2022 Ocean Surface Topography Science Team Meeting

Palazzo del Cinema at Lido di Venezia, Venice (Italy)

Monday, October 31 2022 - Friday, November 4 2022

The 2022 Ocean Surface Topography Meeting will occur 31 October - 4 November 2022 (postponement of OSTST 2021) and will include a variety of science and technical splinters. These will include a special splinter on the Sentinel-6 Validation Team (S6VT) feedbacks (chaired by the Project Scientists), a splinter on Coastal Altimetry, and a splinter on CFOSAT. Sentinel-6A Michael Freilich being now the reference mission since April 2022, contributions that support this mission are highly encouraged.

All the presentations will be available through a forum on https://ostst.aviso.altimetry.fr during the full week and at least a week after. This forum will allow people to chat with authors in delayed time. Please note that for people not planning to attend the meeting in person, their presentations will be available also through the same forum (see list of "forum only" contributions pages 3-5).

Abstracts Book

Abstract list

Forum only

Application development for Operations
Wed, Nov 02 2022, 09:00 - 10:30 - On-line forums for OSTST 2022

09:00 - 10:30: Global Water Monitor: Operational Monitoring of Lakes, Wetlands, and River Reaches for Natural Hazards and Regional Security: Martina Ricko et al.
09:00 - 10:30: A new open-source gridded altimetric product: Lilly Jonathan

CFOSAT
Thu, Nov 03 2022, 09:00 - 10:30 - On-line forums for OSTST 2022

09:00 - 10:30: CFOSAT data over sea ice areas: Fanny Girard-Ardhuin et al.
09:00 - 10:30: Ocean wave fields under tropical cyclone conditions as evidenced by SWM/CFOSAT: Eva Le Merle et al.
09:00 - 10:30: A novel sea state classification scheme based on global CFOSAT wind and wave observations: Huimin Li et al.
09:00 - 10:30: Surface Measurements for Oceanographic Satellites: the SUMOS in-situ and airborne campaign : Cédric Tourain et al.

Instrument Processing: Measurement and Retracking
Tue, Nov 01 2022, 09:00 - 12:30 - On-line forums for OSTST 2022

09:00 - 12:30: Performance evaluation of the Amplitude Compensation and Dilation Compensation retracking algorithm: Alba Granados et al.

Instrument Processing: Propagation, Wind Speed and Sea State Bias
Tue, Nov 01 2022, 14:00 - 15:45 - On-line forums for OSTST 2022

14:00 - 15:45: SSB model comparison from different measurement modes: Ngan Tran et al.
14:00 - 15:45: Monitoring Sigma0 in the Sentinel era: Graham Quartly

Precision Orbit Determination
Tue, Nov 01 2022, 09:00 - 12:30 - On-line forums for OSTST 2022

09:00 - 12:30: Sentinel 6 radiation pressure model analysis : Flavien Mercier et al.

Regional and Global CAL/VAL for Assembling a Climate Data Record
Wed, Nov 02 2022, 09:00 - 12:30 - On-line forums for OSTST 2022

09:00 - 12:30: Preliminary results from GNSS processing at the Southern Ocean SOFS site in preparation for SWOT validation: Andrea HAY et al.
09:00 - 12:30: Altimeter validation results from the Bass Strait validation facility, Australia: Benoit LEGRESY et al.
09:00 - 12:30: CWPIES, a shallow water current, waves and pressure inverted echo sounder for higher resolution satellite altimetry calibration and validation.: Benoit LEGRESY et al.
09:00 - 12:30: A Kalman-based approach to simultaneously estimate vertical land motion and altimeter-specific systematic errors using altimeter, tide gauge, and GPS measurements : Mohammad-Hadi Rezvani et al.
09:00 - 12:30: Along track analysis of a GNSS/INS buoy array in the context of Sentinel-6 and future SWOT altimetry validation at the Bass Strait facility: Boye Zhou et al.
09:00 - 12:30: Radar Altimeter in-situ monitoring at the Lake Issyk Kul observatory (Kyrgyzstan): Tilo Schöne et al.

Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Mon, Oct 31 2022, 16:15 - 18:00 - On-line forums for OSTST 2022

16:15 - 18:00: The causes of the sea level trend in the Southwestern Atlantic Continental Shelf: Melina Gisel Rios et al.

Science II: Large Scale Ocean Circulation Variability and Change
Wed, Nov 02 2022, 14:00 - 15:45 - On-line forums for OSTST 2022

14:00 - 15:45: Seasonal Variation in the Effective Depth of Air-Sea Interaction: Jacob Cohen et al.
14:00 - 15:45: Model analysis of barotropic Rossby waves radiated from Tropical Instability Waves: Ted Durland et al.
14:00 - 15:45: Equatorial waves across the Pacific (and Indian and Atlantic): Tom Farrar et al.

14:00 - 15:45: Hydrological cycle of the Mediterranean-Black Sea system: David Garcia-Garcia et al.
14:00 - 15:45: Climate-driven sea level extremes and marine heatwaves in coastal Indonesia: Weiqing Han
14:00 - 15:45: Using coastal altimetry to improve Meridional Overturning Circulation estimates in the South Atlantic: Matthieu Le Henaff et al.
14:00 - 15:45: Indian Ocean Dipole leads to Atlantic Niño: Lei Zhang et al.
14:00 - 15:45: Causal Mechanism of Sea Level Change in the Beaufort Sea: Ichiro Fukumori et al.

Science III: Mesoscale and sub-mesoscale oceanography
Wed, Nov 02 2022, 16:15 - 18:00 - On-line forums for OSTST 2022

16:15 - 18:00: Global mode water detection and its representation in heat transport: Yanxu Chen et al.
16:15 - 18:00: Global assessment of mesoscale eddies with TOEddies; Comparison between multi-datasets and co-location with in-situ measurements: Artemis Ioannou et al.
16:15 - 18:00: Steric height contribution to intraseasonal sea surface height in the Southwestern Atlantic: Laura Ruiz-Etcheverry et al.
16:15 - 18:00: seasonality of the mesoscale sea surface variability from multi-year satellite altimetry: Yao Yu et al.

Science IV: Altimetry for Cryosphere and Hydrology
Thu, Nov 03 2022, 16:15 - 18:00 - On-line forums for OSTST 2022

16:15 - 18:00: Understanding the behavior of altimetric measurements of Laser and Ku-band over sea-ice: Alice Carret et al.
16:15 - 18:00: Nadir altimetry over land: achievements using the Open-Loop Tracking Command (OLTC) and benefits for inland water users: Sophie Le Gac et al.
16:15 - 18:00: Increased variability in Greenland Ice Sheet runoff detected by CryoSat-2 satellite altimetry: Thomas Slater et al.

Sentinel-6 Validation Team (S6VT) feedbacks
Thu, Nov 03 2022, 11:00 - 12:30 - On-line forums for OSTST 2022

11:00 - 12:30: Assessment of Sentinel 6 altimeter data along the Northwest Atlantic shelf : Hui Feng et al.

Tides, internal tides and high-frequency processes
Wed, Nov 02 2022, 14:00 - 15:45 - On-line forums for OSTST 2022

14:00 - 15:45: Frequency dependence of ocean surface kinetic energy and its vertical structure from global high-resolution models and surface drifter observations: Brian Arbic et al.
14:00 - 15:45: TPXO9v2 and TPXO9-atlas-v5: two new global barotropic tide models: Svetlana Erofeeva
14:00 - 15:45: Impact of Remote Internal Waves on Internal Wave Energetics of Regional Model Simulations: Oladeji Siyanbola et al.
14:00 - 15:45: Experiments computing highly-resolved sea level spectra from dual-satellite altimetry: Edward Zaron
14:00 - 15:45: Development of the yearly mode-1 M2 internal tide model in 2019: Zhongxiang Zhao
14:00 - 15:45: Satellite estimates of Mode-1 M2 Internal Tides using non-repeat altimetry missions: Zhongxiang Zhao et al.
14:00 - 15:45: Seasonal variability of internal tides in the global ocean: Harpreet Kaur et al.

Keynote/invited

CFOSAT
Thu, Nov 03 2022, 09:00 - 10:30 - Sala Pasinetti

10:15 - 10:30: On the improvement of ocean/wave coupling with CFOSAT directional wave observations: Lotfi Aouf et al.

Science Keynotes Session
Mon, Oct 31 2022, 14:00 - 15:45 - Sala Grande

14:00 - 14:25: Measuring the Earth energy imbalance from space geodesy to constrain the global energy budget and estimate the climate sensitivity: Jonathan Chenal et al.
14:25 - 14:50: Topographically Trapped Waves around South America with periods between 40 and 130 days in a global ocean reanalysis.: Léa Poli et al.
14:50 - 15:15: 4DVarNN, an end-to-end learning of variational interpolation schemes: current applications on satellite-derived data and on-going developments: Maxime Beauchamp et al.
15:15 - 15:40: Interferometric Swath Radar Altimetry for the study of the Cryosphere: Noel Gourmelen

Oral

Application development for Operations
Wed, Nov 02 2022, 09:00 - 10:30 - Sala Pasinetti

09:00 - 09:15: Estimating upper ocean heat content in the North Atlantic Ocean with the NOAA next-generation enterprise ocean heat content algorithm: Deirdre Byrne et al.
09:15 - 09:30: The 2022 Honga Tonga Tsunami monitored by satellite altimetry and SAR: Yannice Faugere et al.
09:30 - 09:45: Dynamics of the North Pacific “garbage patch” observed with a suite of Lagrangian instruments for ecological applications: Nikolai Maximenko et al.
09:45 - 10:00: 5Hz resolution altimetry wave products for better coastal approach: Annabelle Ollivier et al.
10:00 - 10:15: Towards a global Stokes drift product from SWIM/CFOSAT: Charles Peureux et al.
10:15 - 10:30: Thirty years of iceberg and associated fresh water flux from altimeter: Jean Tournadre et al.

CFOSAT
Thu, Nov 03 2022, 09:00 - 10:30 - Sala Pasinetti

09:00 - 09:15: Small scale wave height variability and wave groups: Marine De Carlo et al.
09:15 - 09:30: Waves Mean Square Slope estimation from CFOSAT/SWIM measurements: Jean-François Poustis et al.
09:30 - 09:45: CFOSAT Sea level and current demonstration products: Yannice Faugere et al.
09:45 - 10:00: Development of a new UAV-based LiDAR altimetry solution for in-situ wave spectrum estimation: Jean-Christophe Poisson et al.
10:00 - 10:15: The cross-analysis of dual-instrument CFOSAT measurements: Towards multiparameter all-angle Ku-band Geophysical Modulation Function: Alexey Mironov et al.

Coastal Altimetry
Wed, Nov 02 2022, 11:00 - 12:30 - Sala Pasinetti

11:00 - 11:15: A new CryoSat-2 regional product for ocean applications: the Cryo-TEMPO Coastal Ocean Thematic Data Product: Francesco Nencioli et al.
11:15 - 11:30: Analysis of Fully Focused and unfocused SAR data in the [0 - 5] km of the coastal strip: Ana Aldarias et al.
11:30 - 11:45: Round Robin Assessment of altimetry algorithms for coastal sea surface height data: Florence Birol et al.
11:45 - 12:00: Coastal Case Study for Leveraging the Potential of Sentinel-6 MF Fully-focused SAR Altimetry for Retracking Significant Wave Height: Florian Schlembach et al.
12:00 - 12:15: Coastal circulation in the Gulf of Cádiz using multi-mission altimetry data: Roberto Mulero-Martinez et al.
12:15 - 12:30: Using satellite altimetry to obtain subsurface ocean temperatures on the Greenland Shelf: Carine van der Boog et al.

Instrument Processing: Measurement and Retracking
Tue, Nov 01 2022, 09:00 - 12:30 - Sala Grande

09:05 - 09:20: A detailed analysis of S3 and S6 fully-focused SAR waveforms: Enabling SAMOSA-based retracking: Frithjof Ehlers et al.
09:20 - 09:35: FFSAR replica removal algorithm for closed-burst data: Samira Amraoui et al.
09:35 - 09:50: 2D SAR Altimetry Retracking – Lessons Learned: Christopher Buchhaupt et al.
09:50 - 10:05: Improving inland water altimetry retracking by incorporating spatial dependency of waveforms: Omid Elmi et al.
10:05 - 10:20: Swell detection from fully-focused SAR altimetry data: Ourania Altiparmaki
10:20 - 10:35: A Significant Wave Height Correction to Account for Vertical Wave Motion Effects in SAR Altimeter Measurements: Alejandro Egido et al.
11:00 - 11:15: On the Benefits of Stack-Masking in Delay-Doppler Altimetry over Non-Homogeneous Surfaces: Pierre Fabry et al.
11:15 - 11:30: Fast-Adaptive: a new, optimal, unbiased, and computationally efficient retracking solution for the analysis of Conventional Altimetry data: Anna Mangilli et al.
11:30 - 11:45: EMD filtering applied to LRM 20 Hz sea level anomaly observations: Francesco Nencioli et al.
11:45 - 12:00: Beyond 20 Hz: Deriving the necessity of increased posting rates from first principles: Frithjof Ehlers et al.
12:00 - 12:15: Towards a homogeneous reprocessing of historical missions: excellent performances of the Adaptive retracker applied to Jason-1 and ENVISAT: Fanny Piras et al.

Instrument Processing: Propagation, Wind Speed and Sea State Bias
Tue, Nov 01 2022, 14:00 - 15:45 - Sala Grande

14:00 - 14:15: AMR-C and HRMR Performance after 1 Year: Shannon Brown et al.
14:15 - 14:30: Benefits of high-frequency observations for the retrieval of the wet tropospheric correction over open ocean: first results based on HRMR Sentinel-6 measurements.: Bruno Picard
14:30 - 14:45: Refined S-6 sea state bias correction models and a multi-frequency EM bias assessment using C-, Ku-, and Ka-band data: Doug Vandemark et al.
14:45 - 15:00: Synergistic use of the Sentinel-3A SRAL/MWR and SLSTR Sensors for the Wet Tropospheric Correction Retrieval: Pedro Aguiar et al.
15:00 - 15:15: Enhanced GPD+ wet tropospheric corrections for the Copernicus Sentinel-3 missions: M. Joana Fernandes et al.
15:15 - 15:30: Performances and benefits of a 1D-variational approach applied to the wet tropospheric correction for the Sentinel 3A and 3B topography missions.: Bruno Picard et al.
15:30 - 15:45: Characterizing Rain Cells as Measured by a Ka-band Nadir Radar Altimeter: First Results and Impact on Future Altimetry Missions: Bruno Picard et al.

OSTST Opening Plenary Session

Mon, Oct 31 2022, 09:00 - 12:45 - Sala Grande

09:05 - 09:30: NASA/CNES/EUMETSAT/NOAA/ESA program status: Nadya Vinogradova-Shiffer et al.
09:30 - 09:45: Jason-3 mission overview: Christophe Ferrier
09:45 - 10:00: SARAL/AltiKa mission overview: Nadège Queruel
10:00 - 10:15: Sentinel-3 mission overview: Bruno Lucas et al.
10:15 - 10:30: Sentinel-6 Michael Freilich mission overview: Julia Figa Saldana et al.
11:00 - 11:15: CFOSAT mission overview: Jean-Michel Lachiver
11:15 - 11:30: SWOT mission status: Lee-Lueng Fu et al.
11:30 - 11:45: Overview and Status of the Copernicus Sentinel-3 Next Generation Topography (S3NG-T) Mission: Pierrik Vuilleumier et al.
11:45 - 12:00: CRISTAL mission status: Paolo Cipollini et al.
12:00 - 12:15: Argo and Sea level science: Present and Future Challenges: Susan E Wijffels
12:20 - 12:35: What do we really mean by emergency? OSTST and IPCC data and results about the global warming.: François Bignalet-Cazalet et al.

Outreach, Education and Altimetric Data Services

Tue, Nov 01 2022, 14:00 - 15:45 - Sala Pasinetti

14:00 - 14:25: Argonautica, ocean and satellites from kindergarten to engineering school: Estelle Raynal et al.
14:25 - 14:40: Citizen science in FloatEco and GO-SEA projects: Nikolai Maximenko et al.
14:40 - 14:55: Altimetry training resources available under EUMETSAT Copernicus Marine Training Service: Vinca Rosmorduc et al.
14:55 - 15:10: CEOS Ocean Variable Enabling Research & Applications for GEO (COVERAGE): A Platform to Simplify and Expand the Accessibility and Synergistic Use of Inter-agency Satellite and in-situ Oceanographic Data: Vardis Tsontos et al.
15:10 - 15:25: Interactive website to visualize and study mesoscale eddies: Jeffrey Early et al.
15:25 - 15:45: Outreach and data services showcases: All All

Precision Orbit Determination

Tue, Nov 01 2022, 09:00 - 12:30 - Sala Pasinetti

09:00 - 09:15: CNES POE-F precise obit performances for the Jason-3 and Sentinel-6 MF missions: Alexandre Couhert et al.
09:15 - 09:30: GSFC Std2006: An updated set of altimeter satellite orbits for TOPEX, the Jason satellites and Sentinel-6A: Frank Lemoine et al.
09:30 - 09:45: GPS-based Precise Orbit Determination of the Sentinel-6 MF and Jason-3 Missions: Shailen Desai et al.
09:45 - 10:00: Sentinel-6 Michael Freilich - Precise Orbit Determination based on Galileo and GPS observations: Francesco Gini et al.
10:00 - 10:15: Sentinel-6 orbit determination at the Copernicus POD Service: Heike Peter et al.
10:15 - 10:30: Cross-calibration of the TRIG and PODRIX GNSS receivers onboard Sentinel-6A: Oliver Montenbruck et al.
11:00 - 11:15: Assessment of GPS Transmitter Antenna Calibration Maps on Precise Orbit Determination of the Sentinel-6 MF Mission : Alex Conrad et al.
11:15 - 11:30: Satellite altimetry POD using GPS satellite quaternions from IGS CNES/CLS ORBEX files: Georgia Katsigianni et al.
11:30 - 11:45: Precise Orbit Determination of DORIS satellites by CNES/CLS IDS Analysis Center in the frame of our contribution to the ITRF2020: Hugues Capdeville et al.
11:45 - 12:00: Systematic errors in Satellite Laser Ranging validations of microwave-based orbit solutions: Daniel Arnold et al.
12:00 - 12:15: On the accuracy of contemporary orbits of altimetry satellites in the radial direction: Sergei Rudenko et al.

12:15 - 12:30: Improved time-variable gravity modelling using monthly COST-G models for precise orbit determination of low Earth orbiting satellites: Adrian Jäggi et al.

Quantifying Errors and Uncertainties in Altimetry data
Thu, Nov 03 2022, 09:00 - 10:30 - Sala Grande

09:00 - 09:15: Leveraging Sentinel-6A interleaved mode to characterize High Resolution error budget over ocean: Emeline Cadier et al.
09:15 - 09:30: Long-term stability of ionospheric GIM corrections in satellite altimetry data sets: Denise Dettmering et al.
09:30 - 09:45: Uncertainties in SSB modeling and impact on MSL: Sébastien Figerou et al.
09:45 - 10:00: Limiting factors of the altimetry observing system to the Global Mean Sea Level monitoring accuracy: Adrien Guerou et al.
10:00 - 10:15: Sea level rise uncertainties: insights from a metrological approach: Emma Woolliams et al.
10:15 - 10:30: Improving long term estimates of global mean sea level, global ocean heat content and Earth's energy imbalance using CDR water vapour data: Anne Barnoud et al.

Regional and Global CAL/VAL for Assembling a Climate Data Record
Wed, Nov 02 2022, 09:00 - 12:30 - Sala Grande

09:00 - 09:15: Absolute calibration results from Bass Strait, Corsica, and Harvest facilities: Pascal Bonnefond et al.
09:15 - 09:30: Performance Characteristics of the CDN1 Transponder Data and Current Results of the ESA Permanent Facility for Altimetry Calibration in West Crete.: Stelios Mertikas et al.
09:30 - 09:45: Potential of the Noumea lagoon as a multi-mission cal/val site for past and future altimetry missions.: Clémence Chupin et al.
09:45 - 10:00: Measuring mean sea level with surface drifting buoys: Shane Elipot et al.
10:00 - 10:15: Possible datum errors at tide gauges detected by satellite altimetry: some case studies: Richard Ray et al.
10:15 - 10:30: Independent and intermission validations of Sentinel-6 Michael Freilich: Eric Leuliette et al.
11:00 - 11:15: Sentinel-6 PDAP products assessment over ocean: François Bignalet-Cazalet et al.
11:15 - 11:30: Jason-3 GDR-F mission performances over ocean: Hélène Roinard et al.
11:30 - 11:45: Sentinel-3 status and performance over ocean: Francesco Nencioli et al.
11:45 - 12:00: Feed-back and contribution after several years of Haiyang-2B data availability: Alexandre Philip et al.
12:00 - 12:15: Calibration and Validation of TOPEX GDR-F Products: Jean-Damien Desjonqueres et al.

Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Mon, Oct 31 2022, 16:15 - 18:00 - Sala Grande

16:15 - 16:30: Non-closure of the global mean sea level budget since 2016: contributions of altimetry and Argo: Anne Barnoud et al.
16:30 - 16:45: An initial investigation of multi-sensor coastal zone altimetry : Brett Buzzanga et al.
16:45 - 17:00: A new network of altimetry-based virtual stations for measuring sea level along the world coastlines : Anny Cazenave et al.
17:00 - 17:15: Assessing the Closure of the Sea Level Budget in the Southwest Pacific Basin Using Deep Argo: Paige Lavin et al.
17:15 - 17:30: Secular and seasonal reconstructing of global and regional sea level change: Carsten Ludwigsen et al.
17:30 - 17:45: Understanding Forced Climate Signals in the 30-year Satellite Altimeter Sea Level Record: R. Steven Nerem et al.
17:45 - 18:00: Influence of Deep-Ocean Warming on Coastal Sea-Level Trends in the Gulf of Mexico: Jacob Steinberg et al.

Science II: Large Scale Ocean Circulation Variability and Change
Wed, Nov 02 2022, 14:00 - 15:45 - Sala Grande

14:00 - 14:15: Benefits of multi-altimeter combination for Arctic sea surface height retrievals: Pierre Prandi et al.
14:15 - 14:30: Heat and salt fluxes in the San Matias Gulf: Nicolás Aubone et al.
14:30 - 14:45: Altimetric Studies of the Oceanic Pathways in the Northeast Pacific Ocean: Ted Strub et al.
14:45 - 15:00: Decadal to Multi-Decadal Circulation Variability in the Western Tropical Pacific Ocean: Bo Qiu et al.
15:00 - 15:15: Lagrangian properties of on-shelf satellite-geostrophy between the North Sea and the North Atlantic: Ezra Eisbrenner et al.
15:15 - 15:30: Toward a probabilistic assessment of the global ocean response to fully-varying river runoffs.: Thierry Penduff et al.

Science III: Mesoscale and sub-mesoscale oceanography

Wed, Nov 02 2022, 16:15 - 18:00 - Sala Grande

16:15 - 16:30: Blending AIS data and altimetric measurements to estimate sea surface currents in the Gulf of Mexico: Clément Le Goff et al.
16:30 - 16:45: Joint estimation of balanced motions and internal tides from future wide-swath altimetry: Florian Le Guillou et al.
16:45 - 17:00: A New Global Mesoscale Eddy Trajectory Atlas Derived from Altimetry : Presentation and Future Evolutions: Cori Pegliasco et al.
17:00 - 17:15: Development of Multiparameter Mesoscale Eddy Products for Operational Use: Heather Roman-Stork et al.
17:15 - 17:30: A Broadband View of the Sea Surface Height Wavenumber Spectrum: Bia Villas Bôas et al.
17:30 - 17:45: Exploitation of high-resolution datasets for sea level studies in the Nordic Seas and Arctic Ocean: Antonio Bonaduce et al.
17:45 - 18:00: Lagrangian analysis of fine-scale (1–100 km) ocean stirring: a preparatory study for the SWOT satellite mission: Robin Rolland et al.

Science IV: Altimetry for Cryosphere and Hydrology

Thu, Nov 03 2022, 16:15 - 18:00 - Sala Grande

16:15 - 16:25: Utilization of SWOT-simulator along with other nadir altimeter observations for estimation of river discharge over Narmada River: Shard Chander et al.
16:25 - 16:35: Dual-band altimetry for polar science and oceanography: the Copernicus CRISTAL mission: Paolo Cipollini et al.
16:35 - 16:45: Towards FRM observations for hydrology and cryosphere Sentinel-3 Cal/Val activities: the St3TART project: Elodie Da Silva et al.
16:45 - 16:55: Understanding Decadal-scale Trends in Altimeter-derived Significant Wave Height in the Bering Sea: Reint Fischer et al.
16:55 - 17:05: Waiting for CRISTAL: evaluation of a snow depth product using Ka/Ku dual-frequency altimetry. Impacts on sea ice thickness estimation.: Sara Fleury et al.
17:05 - 17:15: Water Elevation and Water Extent Measurements With Sentinel-6A Radar Altimeter Fully-Focussed SAR Data: Ferran Gibert et al.
17:15 - 17:25: Reconstructing the spatial and temporal elevation signals on large lakes from ICESat-2: Karina Nielsen et al.
17:25 - 17:35: 30 years of Arctic Ocean Sea Level from Space: Stine Kildegaard Rose

Sentinel-6 Validation Team (S6VT) feedbacks

Thu, Nov 03 2022, 11:00 - 12:30 - Sala Grande

11:00 - 11:15: Sentinel-6 products status: Remko Scharroo et al.
11:15 - 11:45: Cal/Val activities performed by the MPWG: Cristina Martin-Puig et al.
11:45 - 12:05: Highlights from the Sentinel-6 Validation Team: Remko Scharroo et al.

The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

Thu, Nov 03 2022, 11:00 - 12:30 - Sala Pasinetti

11:00 - 11:15: Assessment of marine gravity models of the Mediterranean: Sean Bruinsma et al.
11:15 - 11:30: New CNES CLS 2022 mean sea surface: Philippe Schaeffer et al.
11:30 - 11:45: Rethinking the Modeling of the Mean Sea Surface in the Era of Climate Change: Ole Baltazar Andersen et al.
11:45 - 12:00: The DTUUH22MDT combined mean dynamic topography model: Per Knudsen et al.
12:00 - 12:15: Combining coastal altimetry data with High Frequency radar, drifters and hydrological profiles data to estimate a Mean Dynamic topography on the Mid Atlantic Bight: Solène Jousset et al.

Tides, internal tides and high-frequency processes

Wed, Nov 02 2022, 14:00 - 15:45 - Sala Pasinetti

14:00 - 14:15: POLAR OCEAN TIDES REVISITED: Ole Baltazar Andersen et al.
14:15 - 14:30: ALBATROSS: Improving the bathymetry and ocean tide knowledge in the Southern Ocean with satellite observations: Mathilde Cancet et al.
14:30 - 14:45: Insights from the global EOT20 ocean tide model: Michael Hart-Davis et al.
14:45 - 15:00: Status of GOT5 and associated prediction software: Richard Ray
15:00 - 15:15: A new barotropic tide model for global ocean: FES2022: Loren Carrere et al.
15:15 - 15:30: Toward a community global 1/36° configuration based on NEMO: Perrine Abjean et al.
15:30 - 15:45: Energetics of high frequency Internal Tides in Global HYCOM: Miguel Solano et al.

Poster

Application development for Operations

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

APO2022_001: NOAA's Jason Products: David Donahue et al.
APO2022_002: DUACS DT2021: 28 years of reprocessed sea level altimetry products: Guillaume Taburet et al.
APO2022_003: Altimeter Processing System – 2.0 (ALPS2): Gregg Jacobs et al.
APO2022_004: Integral length scale of ocean surface waves via CFOSAT along-track observation: Yang Gao et al.
APO2022_005: Homogeneous multi-mission 20 Hz sea level anomaly (20 Hz L2P) products available: Sabine Philipps et al.
APO2022_006: Homogeneous multi-mission along-track Sea Level Anomalies, Wave and Wind (Level-2P) : implementation of Sentinel-6A/Jason-CS: Cecile Kocha et al.
APO2022_007: Sentinel-3 Marine Altimetry Centre: Bruno Lucas
APO2022_008: The new daily global mesoscale Blended Ocean Surface Current (BOSC) product: James Carton et al.
APO2022_009: Presentation of the near-real time and delayed time global database of mesoscale ocean eddies detected by TOEddies on altimetry fields and co-located with (BGC-)Argo floats.: Rémi Laxenaire et al.
APO2022_010: A new operational ocean data assimilation and forecasting system of the Japan Meteorological Agency: Hiroaki Asai et al.
APO2022_011: Performances of the new Copernicus Marine Service global ocean monitoring and forecasting real-time high-resolution system: Jean-Michel Lellouche et al.
APO2022_012: Assessment of NRT Wind and Wave Data from Sentinel Altimetry: Saleh Abdalla
APO2022_013: CRISTAL MARINE DATA CENTRE : Cristina Martin-Puig et al.
APO2022_014: Towards 30 years of Arctic sea ice freeboard retrieval using Altimetry: Marion Bocquet et al.

CFOSAT

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

CFO2022_001: A study of SWIM directional wave spectra during rogue wave cases : Alice Dalphinet et al.

Coastal Altimetry

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

COA2022_001: On the use of satellite altimeter-derived wind speed for the evaluation of the Weather Research and Forecasting model : Roberto Mulero-Martinez et al.
COA2022_002: Seasonal and non-seasonal sea surface height variations within the Makassar Strait: Kaoru Ichikawa et al.
COA2022_003: Deep Learning and SAR Altimetry Techniques in Coastal Island Areas: Nick Flokos
COA2022_004: Assessment of global and regional tidal models in coastal regions – a contribution to improve coastal altimetry retrievals: Mathilde Cancet et al.
COA2022_005: New advances in altimetry towards the coast : example of the CTOH sea level products : Fabien Léger et al.
COA2022_006: Coastal Processing from the Copernicus Altimeters: the CORS processor outcomes: Pablo Garcia et al.
COA2022_007: Evaluation of coastal water level products in SAR mode: Luciana Fenoglio et al.
COA2022_008: Circulation variability of the South-Patagonia continental shelf from in-situ and satellite data: Loreley Lago et al.
COA2022_009: Comparison of Cryosat-2 and Sentinel-3 Altimetry with in situ measurements of Sea Level, Significant Wave Height and Wind Speed in the Northern Adriatic and around Venice : Stefano Vignudelli et al.
COA2022_010: Shelf/Deep Ocean Exchanges in the Southern Africa Region: Ricardo Matano et al.
COA2022_011: RiwiSAR-SWH: A data-driven method for estimating significant wave height using Sentinel-3 SAR altimetry: Mohammad J. Tourian et al.
COA2022_012: Portagauge and Satellite Sea level monitoring system for the Southwest Indian Ocean – PASS-SWIO: David Cotton et al.
COA2022_013: Fully Focused SAR Altimetry and Innovative River Level Gauges for Coastal Monitoring – the FFSAR-Coastal Project: David Cotton et al.
COA2022_014: Impact of wind on sea level anomalies on the Patagonian Shelf coherence analysis on different temporal scales: Marie-Christin Juhl et al.
COA2022_015: Analysis of hydrographic data collected by Southern Elephant Seals in the Argentine continental shelf : Melina M Martinez et al.

Instrument Processing: Measurement and Retracking

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

IPM2022_001: Improving SAR Altimeter processing over Inland Water - the ESA HYDROCOASTAL project: David Cotton
IPM2022_002: Improving SAR Altimeter processing over the coastal zone - the ESA HYDROCOASTAL project: David Cotton
IPM2022_003: On-ground processing and performance of the Poseidon-4 altimeter internal calibration: chirp replica and attenuator: Michele Scagliola et al.
IPM2022_004: A star-tracker processor for Sentinel-6: performance and application for radar antenna pitch bias calibration: Gerard Gallardo i Peres et al.

Instrument Processing: Propagation, Wind Speed and Sea State Bias

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

IPC2022_001: Exploitation of the ENA Ground-Based Water Vapour Radiometers in Satellite Altimetry: Bernard Vasconcellos et al.
IPC2022_002: Fundamental data records for altimetry: 20 years of ERS and Envisat Microwave Radiometer reprocessed data: Marie-Laure Frery et al.
IPC2022_003: Integration of SIRGAS-CON data in the estimation of the Wet Tropospheric Correction for Latin America Coastal Altimetry: Anderson Prado et al.
IPC2022_004: Sentinel3 Microwave radiometers : Latest processing improvement, performances and stability assessment of: Marie-Laure Frery et al.
IPC2022_005: Empirical, Nonparametric Estimation of the Sea State Bias using the Interpolation Method: Alexa Putnam et al.

OSTST Opening Plenary Session

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

OPE2022_001: Sentinel-3 Marine Altimetry Mission: Bruno Lucas

Outreach, Education and Altimetric Data Services

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

ODS2022_001: Swot and hydrology from space outreach: Vinca Rosmorduc et al.
ODS2022_002: Accessing Sentinel-6 and Sentinel-3 altimetry data through EUMETSAT big data services: Ben Loveday et al.
ODS2022_003: AVISO+ products and service: what's new?: Laurent Soudarin et al.
ODS2022_004: CTOH studies for extending the range of altimetry applications over the ocean and continental surfaces: Fabien Blarel et al.
ODS2022_005: ODATIS, Ocean Data Information and Services for Easier Access to Data and Analytical Services: Caroline Mercier et al.
ODS2022_006: Cryo2Ice Coincident Data Explorer: Alex Horton et al.
ODS2022_007: Sentinel-3 Topography mission Assessment through Reference Techniques (St3TART) project – Focus on the FRM Data Hub: Elodie Da Silva et al.
ODS2022_008: SAR, SARin, RDSAR and FF-SAR Altimetry Processing on Demand for CryoSat-2, Sentinel-3 and Sentinel-6 at ESA's Altimetry Virtual Lab: Jérôme Benveniste et al.

Precision Orbit Determination

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

POD2022_001: Copernicus POD Service: Overview and status: Jaime Fernández et al.
POD2022_002: Analysis of attitude dependent deficiencies in precise orbit solutions of Jason-3: Cyril Kobel et al.
POD2022_003: POE-F reprocessing of Jason-1 CNES precise orbit solutions: Vincent Debout et al.
POD2022_004: International Combination Service for Time-Variable Gravity Fields (COST-G) – Overview of Current Activities and Future Perspectives: Adrian Jäggi et al.
POD2022_005: Determination of the geocentric gravitational constant to monitor the behavior of the Earth: Marie CHERRIER et al.

Quantifying Errors and Uncertainties in Altimetry data

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

ERR2022_001: In-situ measurements for altimetry cal/val: overview of the H2020 CCVS project: Céline Tison et al.
ERR2022_002: Validation of altimetry by using in situ observations of pressure and acoustic travel time in the Southern Ocean: Jens Schroeter et al.
ERR2022_003: Quality flag and uncertainties of water surface height over Inland waters: Beatriz Calmettes et al.
ERR2022_004: A Trihedral Corner Reflector to Support Radar Altimeters External Calibration: Albert Garcia-Mondejar et al.
ERR2022_005: On the uncertainty associated with detecting global and local mean sea level drifts on Sentinel-3A and Sentinel-3B altimetry missions: Rémi Jugier et al.
ERR2022_006: Propagating uncertainties and error correlation structures through retracking and sea state bias correction: Sajedeh Behnia et al.

Regional and Global CAL/VAL for Assembling a Climate Data Record

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

CVL2022_001: Jason-3 & Sentinel-6 MF calibration at the Corsica facilities: Pascal Bonnefond et al.
CVL2022_002: The Harvest Experiment: Status and New Results from the Sentinel-6 Mission: Bruce Haines et al.
CVL2022_003: Absolute and relative calibration of HY-2B satellite altimeter using the permanent Cal/Val infrastructure in Crete: Stelios Mertikas et al.
CVL2022_004: Regional in situ CalVal of Sentinel-3A&B altimeter range at non-dedicated sites: Mathilde Cancet et al.
CVL2022_005: 12 years of Cryosat-2 range,datation and interferometer calibration with Transponder: Adrián Flores de la Cruz et al.
CVL2022_006: A Dual Band Transponder for Calibrating the Sentinel-6 Mission: Jean-Damien Desjonqueres et al.
CVL2022_007: Challenges for CalVal activities of Copernicus missions: an overview by CCVS project for altimetry: Sylvie Labroue et al.
CVL2022_008: Global cross-calibration of the Jason-3 and Sentinel-6 Michael Freilich missions during their tandem period. : Johan Nilsson et al.
CVL2022_009: Results from Independent Calibration and Validation of Jason-3 on the Interleaved Orbit: Linda Forster et al.
CVL2022_010: Global Ocean Data Quality Assessment of SARAL/AltiKa's GDR-F products : Jettou Ghita et al.
CVL2022_011: Detecting rain cells in SARAL/AltiKa data: results from a supervised learning experiment: Pierre Prandi et al.
CVL2022_012: Evaluation and scientific exploitation of CryoSat ocean products for oceanographic studies: Chris Banks et al.
CVL2022_013: Update on CryoSat-2 long-term ocean data analysis and validation: Marc Naeije et al.
CVL2022_014: Haiyang-2C data assessment, performance and contribution to DUACS Sea Level Anomaly products : Alexandre Philip et al.
CVL2022_015: Assessment of the Sentinel-6 Michael Frielich extension to the TOPEX/Jason Sea Surface Height Climate Data Record referenced to ITRF2020: Brian Beckley et al.
CVL2022_016: Impact of the TopEx/Poseidon GDR-F reprocessing on the Global Mean Sea Level climate data record : Adrien Guerou et al.
CVL2022_017: Assessment over ocean of the last Poseidon1 reprocessing: Hélène Roinard et al.
CVL2022_018: Improved inter-calibration of multi-mission altimeter significant wave heights for climate data record: Guillaume Dodet et al.
CVL2022_019: Jason-3: ALES vs ADAPTIVE vs MLE4, comparing the retracking solutions: Benjamin Flamant et al.
CVL2022_020: Advantages and drawbacks of the filtered solution for dual-frequency ionospheric correction from altimeter: Francesco Nencioli et al.
CVL2022_021: Cal/Val of recent altimeter missions at non-dedicated tide gauge stations in the North Sea: Saskia Esselborn et al.
CVL2022_022: Regional Calval for past and future altimeters : Luciana Fenoglio
CVL2022_023: Sentinel-3 Topography mission Assessment through Reference Techniques (ESA St3TART project) – Focus on SCalSIT: Elodie Da Silva et al.
CVL2022_024: Sentinel-3 Land STM: Land Ice Thematic Products: Sebastian Bjerregaard Simonsen et al.

Science I: Climate data records for understanding the causes of global and regional sea level variability and change

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

SC12022_001: Baltic SEAL: new insights into the mean and variability of the sea level in the Satellite Altimetry era: Marcello Passaro et al.
SC12022_002: Reprocessing of the ERS-1, ERS-2 and ENVISAT missions: performances of the FDR4ALT products: Fanny Piras et al.
SC12022_003: Sea state uncertainty from a triple collocation analysis of observations during the Sentinel-6 Michael Freilich – Jason-3 tandem phase.: Ben Timmermans et al.
SC12022_004: Monitoring the Ocean Heat Content and the Earth Energy imbalance from space altimetry and space gravimetry : Michael Ablain et al.
SC12022_005: Monitoring the local heat content change over the Atlantic Ocean with the space geodetic approach: the 4DATLANTIC-OHC Project: Michael Ablain et al.
SC12022_006: Combining space gravimetry observations with data from satellite altimetry and high resolution visible imagery to resolve mass changes of endorheic basins and exorheic basins: Alejandro Blazquez et al.
SC12022_007: Predicting short and long-term sea level changes using Deep learning: Mads Ehrhorn et al.
SC12022_008: Impact of Greenland freshwater discharge on regional sea level trends in the Arctic ocean: William Llovel et al.
SC12022_009: Meridional Asymmetry in Recent Decadal Sea-Level Trends in the Subtropical Pacific Ocean: Philip Thompson et al.
SC12022_010: Evolution of Regional Sea Level Trends During Satellite Altimeter Era: Benjamin Hamlington et al.
SC12022_011: Estimations of oceanic trends (heat, salt, steric and mass budget) in Mercator Ocean global reanalysis: Romain Bourdalle-Badie et al.
SC12022_012: Fluctuations in deep-ocean heat content and variations of steric sea level observed from Deep Argo floats: Nathalie Zilberman et al.

Science III: Mesoscale and sub-mesoscale oceanography
Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

SC32022_001: Towards improved analysis of short mesoscale sea level signals from satellite altimetry: Yves Quilfen et al.
SC32022_002: Investigating the variability of eddy formation in the eastern subpolar North Atlantic from satellite altimetry: Arunraj Kondetharayil Soman et al.
SC32022_003: Diagnosing ocean eddy salt transport from satellite altimetry and surface salinity data: Oleg Melnichenko et al.
SC32022_004: Improved global sea surface height and currents maps from remote sensing and in situ observations: Maxime Ballarotta et al.
SC32022_005: Characterizing wavenumber spectra in altimetry: An ADCP perspective: Saulo Soares et al.
SC32022_006: Toward Higher resolution Level-3 altimeter products: Marie Isabelle Pujol et al.
SC32022_007: Global spectral characteristics from 1Hz along-track altimetry: Oscar Vergara et al.
SC32022_008: Monitoring the mesoscale eddies interactions with the altimetry constellation: Cori Pegliasco et al.
SC32022_009: Fostering collaborations for designing high level ocean data products : the case for community data challenges.: Sammy Metref et al.
SC32022_010: Studying physical processes in the Southwestern Atlantic to understand BIOlogical productivity & regional ecosystems (SABIO) : Martin Saraceno et al.
SC32022_011: Global pattern of annual cycle of mesoscale sea level anomaly: Nikolai Maximenko et al.
SC32022_012: Role of finescale processes in water exchanges and geostrophic circulation in western and central Baltic Sea: Luciana Fenoglio et al.
SC32022_013: MAGAL Constellation : Arlindo Marques et al.
SC32022_014: Extreme events in three years of ocean physical measurements at the Global Argentine Basin Array of the Ocean Observatory Initiative: Camila Artana et al.
SC32022_015: Assessing the Impact of the Assimilation of SWOT Observations in a Global High-Resolution Analysis and Forecasting System: Mounir Benkiran et al.
SC32022_016: What is the benefit of high-resolution sea level anomaly datasets? A case study in the Bay of Biscay and New Caledonia regions based on Jason2-3, Saral/AltiKA and Sentinel3: Lionel Gourdeau et al.
SC32022_017: Deep learning for accurate SSH reconstruction from altimetry and SST observations: Scott Martin et al.
SC32022_018: Ocean 2D eddy energy fluxes from small mesoscale processes with SWOT: Elisa Carli et al.
SC32022_019: Physically-consistent mapped altimetry products on user-customizable grids: Cimarron Wortham et al.
SC32022_020: High resolution SSH mapping with future satellite mission SWOT: Valentin Bellemin Laponnaz et al.
SC32022_021: Topological analysis of oceanographic time series: Denisse Sciamarella et al.
SC32022_022: Coastal-to-open ocean exchange in the California Current System from new altimetry: Sarah Gille et al.

Science IV: Altimetry for Cryosphere and Hydrology
Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

SC42022_001: Sentinel-3 Altimetry Thematic Data Product for cryosphere & benefits of the Sentinel-3 Validation Team: Clément Lacrouts et al.
SC42022_002: Sentinel-3 Altimetry Thematic Data Product for inland waters & Sentinel-3 Validation Team benefits: Clément Lacrouts et al.
SC42022_003: Towards long term sea ice volume series from altimetry in the Antarctic: garnier florent et al.
SC42022_004: Machine Learning based Classification of Lake ice and Open water from SAR Altimetry waveform parameters : Jaya Sree Mugunthan et al.
SC42022_005: Cryo-TEMPO: A new era of CryoSat-2 Thematic Products over Ice, Ocean and Inland Water: Malcolm McMillan et al.
SC42022_006: CryoSat after 12 years in space: status and future challenges : Jerome Bouffard et al.
SC42022_007: Using deep learning with CryoSat radar altimetry to adjust elevations and map surface penetration: Alex Horton et al.
SC42022_008: Leads Detection with Fully Focused in Antarctica: Sergi Hernández et al.
SC42022_009: CryoTEMPO-EOLIS: Elevation Over Land Ice from Swath processing of CryoSat-2 SARIn mode data: Carolyn Michael et al.
SC42022_010: SWIM: a new potential for sea-ice remote sensing: Charles Peureux et al.
SC42022_011: Automated processing of altimetry-derived river water levels at global scale - Design & first results from a new L3 processor: Nicolas Bercher
SC42022_012: A new approach for the retrieval of lake ice thickness from satellite altimetry missions: Results from the ESA CCI+ Lakes and S6JTEX projects: Anna Mangilli et al.
SC42022_013: Fully-Focussed iceberg detection with Sentinel-6 data and prospects for CRISTAL: Juan Pedro López-Zaragoza et al.
SC42022_014: CRISTAL performance assessment: an end-to-end simulation approach: Albert Garcia-Mondejar et al.
SC42022_015: A first assessment of swath processing for inland water: Alessandro Di Bella et al.
SC42022_016: A novel model-based retracker for sea ice covered regions: Alessandro Di Bella et al.
SC42022_017: Understanding nadir altimetry measurements over continental waters: simulations over rivers and statistical analysis of individual pulses from Sentinel altimetry missions: Sophie Le Gac et al.
SC42022_018: CRISTAL – Copernicus' Next Cryosphere Altimetry Mission: Enrico Mank et al.
SC42022_019: AlTiS Software for generating Time-Series of Water Levels from Radar Altimetry Data: Fabien Blarel et al.
SC42022_020: Merging CryoSat-2 and ICESat-2 Retrievals to Advance Observations of Arctic Sea Ice: Sinead Louise Farrell et al.
SC42022_021: Sea Ice-thickness product iNter-comparison eXerciSe – The ESA SIN'XS project: Elodie Da Silva et al.
SC42022_022: Sentinel-3 for Cryosphere and Hydrology: Ghita Jettou et al.
SC42022_023: Innovative solutions for in-situ Cal/Val of satellite altimetry over inland waters based on UAV and new autonomous micro-gauges: Jean-Christophe Poisson et al.
SC42022_024: Comparing elevation changes observed by CryoSat-2 and ICESat-2 over the Greenland Ice Sheet: Nitin Ravinder et al.
SC42022_025: Sentinel-3 Land STM: New Hydrology Thematic Products performances over Inland Waters: Nicolas Taburet et al.
SC42022_026: Sentinel-3 Land STM: Sea Ice Thematic Products : Sara Fleury et al.
SC42022_027: STREAMRIDE: a satellite-based approach for river discharge estimation: Stefania Camici et al.

Sentinel-6 Validation Team (S6VT) feedbacks
Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

S6VT2022_001: On the assimilation of LR and HR Sentinel-6MF wave data in wave model : Assessement and perspectives: Lotfi Aouf et al.
S6VT2022_002: Sentinel-6 Processing Prototype data release: Claire Maraldi et al.
S6VT2022_003: Sentinel-6-MF Poseidon-4: Main results from the first year and half of mission from the S6PP LRM and HRM Chain: Salvatore Dinardo et al.
S6VT2022_004: Sentinel-6 MF Poseidon-4 Radar Altimeter In-Flight Calibration and Performances Monitoring: Salvatore Dinardo et al.

The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

GEO2022_001: A new method for estimating steric mean sea surface dynamic height in MOVE system combining in-situ profiles and sea level anomalies: Nariaki Hirose et al.
GEO2022_002: An approach for regional coastal sea surface topography for vertical datum transformation using retracked-altimetry, water level gauging and airborne gravity based geoid model: Inseong Jeong et al.
GEO2022_003: A new combined mean dynamic topography model – DTUUH22MDT: Per Knudsen et al.
GEO2022_004: The new CNES-CLS 2022 marine gravity anomaly model: first validation in the Mediterranean: Philippe Schaeffer et al.

Tides, internal tides and high-frequency processes

Tue, Nov 01 2022, 17:15 - 18:15 - Mezzanine

Thu, Nov 03 2022, 14:00 - 15:45 - Mezzanine

TID2022_001: Bathymetry improvement and high-resolution tidal modelling at regional scales: Mathilde Cancet et al.
TID2022_002: Impact of the sea ice friction on ocean tides in the Arctic Ocean, modelling insights at various time and space scales: Mathilde Cancet et al.
TID2022_003: Improved shallow waters tidal estimates using satellite radar altimetry data and numerical modeling.: Henrique Guarneri et al.
TID2022_004: Sentinel-3 SAR Mode altimetry observations of wave breaking dissipation owing to large-amplitude Internal Solitary Waves: effects on SWH and radar backscatter: Adriana M. Santos-Ferreira et al.

Abstract details

The causes of the sea level trend in the Southwestern Atlantic Continental Shelf

Melina Gisel Rios (Dpto. de Física, Universidad Nacional del Sur, Argentina); Laura Agustina Ruiz Etcheverry (CONICET – Universidad de Buenos Aires, Centro de Investigaciones del Mar y la Atmósfera (CIMA). Buenos Aires, Argentina, Argentina)

Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Forum only

Abstract:
In the last decades, several studies have detected a global sea level rise, and it was associated mainly to two factors related to global warming: mass changes due to the transfer of water between continental ice and oceans, and sea-water density changes due to the increasing temperature. However, little is known about these effects in the Southwestern Atlantic Continental Shelf (SWACF). Thus, the objective of this work is to study the role of mass change and density change in the SWACF using 26-year of satellite data and model data. First, we validated the sea level anomaly (SLA) from ORAS5.0 (Ocean Reanalysis System 5) with gridded altimetry data from CMEMS (Copernicus Marine and Environmental Monitoring Service) for the matching period obtaining a significant correlation > 0.6 in the whole SWACF. Then, we computed the steric height due to density changes derived from model temperature and salinity and estimated the mass change has the difference between steric height and SLA. The results were promising since we obtained a correlation > 0.8 between model mass change and GRACE (Gravity Recovery and Climate Experiment) at interannual scales. The analysis of sea level trend in the SWACF and its components revealed that the interannual SLA is increasing about 2.37 mm/yr (ORAS5.0) and 3.37 mm/yr (satellite) and the cause of this rising is mainly explained by the mass change. For completion of this study, we will also analyze GLORYS (Global Ocean Reanalysis and Simulation) reanalysis model and altimetry SLA from ESA-CCI (European Space Agency – Climate Change Iniciative).

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Performance evaluation of the Amplitude Compensation and Dilation Compensation retracking algorithm

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Session: Instrument Processing: Measurement and Retracking
Presentation type: Forum only

Abstract:
Altimetric measurements are key for a variety of areas in geoscience, such as studies on ocean weather, surface wave forecasting, or the assessment of climate change and its impacts. SAR mode altimetric records are used to estimate geophysical parameters over water, such as sea level or wave heights, with high resolution and accuracy required by scientific studies. In addition, strong requirements on the precision are to be met in certain applications. A number of novel theoretical ocean retrackers have been developed to improve the performance of relevant parameters. In this study, an in-house Delay-Doppler (DD) processor for satellite altimetric measurements has been adjusted to include the Amplitude Compensation and Delay Compensation (ACDC) retracking algorithm with the aim to improve the precision of parameter estimates over open ocean. The algorithm exploits intrinsic characteristics of the DD stack deduced from the SAR altimeter analytical model developed in the framework of the SAMOSA project to construct a new ACDC stack. The subsequent multilook operation results in a strong reduction of the speckle noise near the leading edge of the waveform, allowing for an improvement of the precision of the fitted parameters. The performance of the retracking algorithm is assessed by the evaluation of different metrics computed over time series of geophysical parameters retrieved from S3A SAR mode Level-1 products covering an extended spatio-temporal domain.
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Sentinel 6 radiation pressure model analysis

Flavien Mercier (cnes, France); John Moyard (cnes, France); Alexandre Couhert (cnes, France); Robert Cullen (esa, Netherlands)

Session: Precision Orbit Determination
Presentation type: Forum only

Abstract:

The Sentinel. 6 satellite has a new platform, with a very different geometry from the preceding missions like Jason 1,2,3. The main difference is that the solar array panel is now fixed on the satellite body, and the satellite has a fixed attitude in the local orbital frame (with small rotations for geodetical pointing and ground velocity alignment). As a consequence the sun direction relative to the panels has important variations along one orbit. On Jason 3 the illumination of the solar array panels is always close to the normal direction : as a consequence the solar radiation pressure force produced by the panels has a well defined direction independent of the material coefficients. Also, the amplitude does not depend on the balance between the electrical energy production of the array and the material thermally absorbed part. This thermally absorbed part has no impact on the global force, due to a similar re-radiation on both surfaces of the panels.

On Sentinel 6, this property does not hold anymore, and the standard modeling of the panel surfaces (with absorbed, diffuse and specular parts), with correction for the re-radiated part, does not lead to satisfactory results.

Here, we analyze the solar array thermal behavior thanks to in flight information (temperatures variations along the orbit, for different sun orbital angle cases, and energy production of the array). A thermal model is constructed using thermal coefficients adjusted on these flight data (thermal capacity of the panels).

An updated solar radiation pressure model is then constructed.

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SSB model comparison from different measurement modes

Ngan Tran (CLS, France); François Bignalet-Cazalet (CNES, France); Gerald Dibarboure (CNES, France); Claire Maraldi (CNES, France); François Boy (CNES, France); Pierre Féménias (ESA, Italy); Bruno Lucas (EUMETSAT, Germany)

Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Forum only

Abstract:
Since the launch of the Sentinel-3A satellite in February 2016, a new long-term series of Delay-Doppler/SAR altimetry SSH measurements over global ocean has begun with better spatial resolution of the signal in the along-track direction and improved noise reduction through multi-looking. Data from an experimental mode, the so-called LR-RMC mode, are also available from the CNES S3PP prototype with a processing of the S3A data that differs from the classical SAR-mode processing in numerous ways. In-parallel, Jason-3 and now Sentinel-6/MF missions continue the long-term record of SSH measurements started in 1992 by the Topex-Poseidon satellite in the conventional low-resolution mode (LRM). In support of these various high-precision SSH measurements, SSB corrections need to be computed/adapted to each of these specific measurement modes to accurately correct all these range measurements for the sea-state effects because of its empirical nature.
In this poster, we will compare the different SSB solutions to document the range/sea-state relationships from these different measurement modes.

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Monitoring Sigma0 in the Sentinel era

Graham Quartly (Plymouth Marine Laboratory, United Kingdom)

Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Forum only

Abstract:
Over the ocean, an altimeter's sigma0 values are interpreted as a measure of local wind speed due to its effect on surface roughness. However, for climatological studies of possible changes in wind climate it is essential to have confidence in the stability of the calibration of a sensor and also in the relative calibrations of different sensors. Here I review the application of dual-frequency monitoring techniques applied to the Sentinel-3A and 3B altimeters and also to Jason-3 and Sentinel-6MF. The approach relies on the close relationship between scattering at the scales of interest for Ku- and C-band to offer a robust reference. Such an approach provides resilience even where there is an interruption in the series of altimeter satellites.

This technique was developed using the MLE3 estimates from LRM altimetry, but can be applied to MLE4 estimates of (P)LRM altimeters and other estimates from SAR altimeters once an adjustment has been made for these measures sensitivity to perceived mispointing. The peak of the sigma0-sigma0 curves, corresponding to a wind speed of about 6 m/s, is very robust to wave conditions, but significant wave height does have a marked impact on the relationship at very low wind speeds, with a lesser known effect at high wind speeds that is consistent across all the altimeters investigated. A moderate change is also seen to correlate well with sea surface temperature. Thus both wave height and SST may be expected to have an influence in future wind speed algorithms, especially with efforts to study wind changes in a warming climate.

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Global Water Monitor: Operational Monitoring of Lakes, Wetlands, and River Reaches for Natural Hazards and Regional Security

Martina Ricko (KBR at NASA/GSFC, United States); Charon Birkett (NASA/GSFC, United States); Xu Yang (KBR at NASA/GSFC, United States); Curt Reynolds (USDA/FAS, Unites States); Elias Deeb (ERDC/USACE, United States)

Session: Application development for Operations
Presentation type: Forum only

Abstract:
The Global Water Monitor is a NASA funded operational program offering water-related products for lakes, reservoirs, river reaches, and wetland zones. These are being derived from i) the NASA/CNES TOPEX/Jason/Sentinel-6 and ESA/ISRO/CNES ERS/ENVISAT/SARAL/Sentinel-3 series of radar altimeters, ii) the MODIS series of multispectral imagers, and iii) in future, the new ICESat-2/GEDI DEM's. The products will be a combination of water level, surface extent, water storage, and bathymetry. The main stakeholders are the USDA/Foreign Agricultural Service, various Wetland-related organizations, and USACE/NGA.
There is a demand for a global monitoring service that captures the variations in the smallest (1 to 100 km2) reservoirs and water holdings in arid and semi-arid regions. Here, water resources are critical to both agriculture and regional security. Surface water level products across wetland zones are also being requested in respect of inland fisheries and catch potential, and observations of river reaches in gauge-poor regions are required in lieu of spring melt watches and flood hazards.
In addition to meeting operational requirements, recent efforts to create (up to) 25yr timelines has also shown that great care needs to be taken with respect to the merger of results from multiple instrument platforms. Such accuracy is required for the formation of high-quality Earth Data Records and the creation of Long-Term Status Indicators which inform end users of deviations from normal conditions.
Technical advances e.g., the use of Delay-Doppler SAR and the novel FF-SAR technique, are looking to improve along-track spatial resolution and thus attain much smaller lakes and narrower river reaches. The new Sentinel-6 Michael Freilich mission is allowing continuity of the 10-day resolution water level products but with improved surface acquisition (DIODE/DEM mode) and Range determination via optimum waveform retracking and upgraded wet tropospheric corrections. Sentinel-6 is capturing current elevation status accurately and this will help determine current water and energy resources and longer-term trends that might affect regional economic and political instability.
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A new open-source gridded altimetric product

Lilly Jonathan (Planetary Science Institute, United States)

Session: Application development for Operations
Presentation type: Forum only

Abstract:
A beta version of a new gridded altimetric dataset, produced using a refined mapping algorithm and with completely open processing, is presented. This dataset, the Open Source Sea Level Atlas (OSSLA), is for convenience momentarily limited to the use of Jason-class altimeters, yet nevertheless compares very favorably with the CMEMS product despite the use of much more data in the latter.

Error-minimizing parameters are found through an observing system simulation experiment. A synthetic Jason alongtrack dataset is formed from interpolation within hourly surface fields from a yearlong simulation of the Generalized Ocean Layered Model (GOLD) at roughly 1/8 degree resolution. The mapping framework is local polynomial fitting, which involves a fit to a low-order polynomial within some radius and weighted by a tapered kernel. A sweep of thousands of different parameter choices identifies the error-minimizing settings at each latitude relative to the full model fields. These optimal choices are then applied to the actual Jason-class altimeter dataset to yield the OSSLA product.

There are several takeaway messages. First, the fits to a first-order and second-order polynomial perform considerably better than the fit to a zeroth-order polynomial, by removing most of the imprint of the track locations. This is thanks to an important theoretical property of linear and higher-order fits known as “design adaptivity.” Second, the optimal parameters deduced here through the minimization of mean-squared error have half-power points varying from about 40 km at high latitudes to about 180 km at the equator, considerably smaller than the scales used in the optimal interpolation of the CMEMS product. Third, the good performance of this product despite being limited only to the Jason class altimeters suggests that substantial improvements may be gained though refining the mapping algorithm. Finally, remaining mapping errors are seen, unsurprisingly, to be correlated with locations where the sea surface curvature is large while at the same time altimeter tracks are absent; this suggests an upper limit to the mapping-based improvements.

A shortcoming of the OSSLA product is the occasional evidence of long-wavelength errors. These could be removed through additional processing using crossover minimization, which has not yet been applied at this proof-of-concept stage.

Figure: snapshot of SLA gradient magnitude in OSSLA (top) vs. CMEMS (bottom).
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Preliminary results from GNSS processing at the Southern Ocean SOFS site in preparation for SWOT validation

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Forum only

Abstract:
The SWOT satellite altimetry mission represents a paradigm shift from conventional pulse limited altimetry to swath-based measurements. Validation of this new measurement type will be a significant challenge that will require a diverse range of approaches as well geographic spread in site locations (as provided by the 'Adopt-a-Crossover' initiative). Data from the Southern Ocean Flux Station (SOFS) mooring will contribute to this effort, offering in situ sea surface height (SSH) derived geometrically (via Global Navigation Satellite System, GNSS, data) in addition to integrated from sub-surface oceanographic instruments (temperature and salinity through the column). These data will provide a comparison point of interest in a highly dynamic region of the Southern Ocean where the mean significant wave height is ~4 m, and waves are regularly in excess of 10 m.

In this poster, we present preliminary results from GNSS processing of data from the SOFS mooring during periods of differing sea states. We detail the GNSS Precise Point Positioning (PPP) processing approach and investigate the precision and likely biases of the in-situ measurements in comparison with existing altimetry observations. Finally, we discuss the further work required in preparation for the validation of the SWOT mission.

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Altimeter validation results from the Bass Strait validation facility, Australia

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Forum only

Abstract:
The Bass Strait altimeter validation facility (~ 40° 39'S, 145° 36' E) provides cycle-by-cycle estimates of absolute altimeter bias for the Jason-series, Sentinel-3A and Sentinel-3B missions. The facility uses an integrated geometric approach involving a suite of in situ sensors including moored oceanographic sensors, episodically deployed GNSS equipped buoys, a coastal tide gauge and continuously operating GNSS reference stations. This year we present the results for the 4 missions with a focus on Jason-3 GDR-F and the Sentinel-6 1-Hz data. With the advance of fully SAR capable altimetry (Sentinel-6) and in preparation for swath-based interferometric altimetry (SWOT), several enhancements to the Bass Strait facility have been progressed. We detail our ongoing use of 5-beam ADCP instruments for the determination of shallow water SSH, current and wave field information using a pressure inverted echo sounder concept (CWPIES). We review our progress in understanding small but significant systematic errors in SSH derived from GNSS equipped buoys. Together, advances in our in situ instrumentation seek to address an improved determination of along-track SSH (and SSH gradient) for the benefit of validating the next generation of altimeter missions. We present results from these investigations together with latest absolute bias results from the Bass Strait comparison points.

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CWPIES, a shallow water current, waves and pressure inverted echo sounder for higher resolution satellite altimetry calibration and validation.

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Forum only

Abstract:
In view of the developing higher spatial resolution altimetry missions, we have been developing new in situ calibration/validation tools. In order to tackle the challenge of higher resolution radar altimeters, their sensitivity to wave or sea surface height heterogeneity within the footprint, we developed instrumentation to investigate more localised and higher frequency SSH signals. The Bass Strait cal/val area is situated in the South West of the strait and is now equipped for the historical Jason site, but also for Sentinel-3A and Sentinel-3B. The classic method that was used over the past decades included, besides a reference coastal tide gauge and GNSS site, permanent moorings recording bottom pressure, temperature and salinity through the column. The accurate vertical datum of this record is achieved by regular short-term occupation of the mooring sites with GNSS equipped buoys. Recently we added sub-surface kit with bottom mounted 5 beam Acoustic Profilers. These measure current profiles, but also complete wave spectra and Sea Surface Height in addition to the bottom pressure, temperature and salinity.

In this presentation we show the results from the past year where we had 4 of these CWPIES deployed (3 under the Sentinel-6 track with a 10km spacing and one under a Sentinel-3B crossover) from March to October 2021. We compare the measurements to the bottom pressure, seawater density variations and atmospheric pressure. We also compare the measurements to short term GNSS buoy occupations. We find that the acoustic system can track the surface at high frequency with cm accuracy. The drift of the bottom pressure sensor can be monitored. Changes in atmospheric pressure are also recorded by the system thanks to the inverse barometric effect difference between bottom pressure and acoustic surface ranging. We highlight the noise level and reliability of the system and practical use for the future use under Sentinel-6 and SWOT.

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A Kalman-based approach to simultaneously estimate vertical land motion and altimeter-specific systematic errors using altimeter, tide gauge, and GPS measurements

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Forum only

Abstract:
Many studies have sought to combine altimeter (absolute sea level, ASL) and tide gauge (relative sea level, RSL) data to infer systematic errors in altimetry, or vertical land motion (VLM). Regionally correlated errors have not been rigorously addressed, and most studies assume VLM is linear and inferred reliably from non-co-located GPS sites. We develop a Kalman filtering and smoothing approach to simultaneously quantify ongoing variability in VLM as well as regional altimeter-specific systematic errors. We assimilated data from multi-mission altimeters, long-running TGs, and permanent GPS sites, while considering the space-time covariances and time-correlated errors within observational series of tandem and dual crossovers, altimeter minus TG, and GPS heights. We investigated the approach using case study regions including the Baltic Sea, Australia, and South America. We quantified localized variability of VLM trends at TGs, typically ~1.1 mm/yr (but up to ~4.5 mm/yr), that otherwise cannot be inferred from spatially interpolated GPS velocities or predicted GIA rates. We detected small but significant systematic errors in regional altimetry data within a typical range of ~0.5-2.5 mm/yr and evaluated the possibility of their time-variability reaching up to ~3.0 mm/yr over 3.5 years during the mission-specific lifespan. These narrowed the deviation between ASL estimates from TG and ALT records, and reduced the RMSE of their geographical variability by up to ~40%. We further investigated the capabilities of the method to derive time-variable VLM as a result of co- and post-seismic deformation, and ice-mass loss in the Antarctic Peninsula. We discuss the key limitations that arise primarily due to differential oceanographic signals between ALT and TG locations in the presence of complex coastal processes. This approach advances the ALT minus TG technique to estimate localized VLM at TG locations, while simultaneously estimating altimeter-specific systematic errors in a regional context, with potential applicability to other global- and local-scale studies.

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Along track analysis of a GNSS/INS buoy array in the context of Sentinel-6 and future SWOT altimetry validation at the Bass Strait facility

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Forum only

Abstract:
As part of the assessment of Sentinel-6 high-rate (20 Hz) high-resolution data and in preparation for the future swath data from SWOT, various improvements to in situ instrumentation at the Bass Strait validation facility have been explored. An array of six new GNSS/INS equipped Mk-VI buoys have been developed and deployed for an 8-day trial deployment along Sentinel-6 pass 088. Five deployment locations with up to 10 km spacing were used, centred on the historical Jason-series comparison point. Two new buoys and a single buoy of the previous design were deployed within ~200 m of each other at the nominal Jason-series comparison point, allowing for inter-comparison.
Here we investigate the buoy array as a relatively low-cost, flexible, yet high precision method for validation of high-rate and high-resolution altimetry. We investigate differences in oceanic processes and conditions observed by the array, namely tidal effects and significant wave height. We also explore the ability of the buoys to observe the passage of weather systems that create intra-swath variability in the case of the future SWOT mission. We seek to understand the SLA data in Bass Strait from an oceanography perspective – it highlights the tidal resonance in the shallow water area driven by high wind conditions. Under the assumption of geostrophic balance in the deployed area, we compare inferred geostrophic current with in-situ current meter observations in order to better understand the expected performance of the buoy array in future swath-based altimetry validation. We conclude with the comparison of buoy solutions against a single overflight using Sentinel-6 high-rate (20 Hz) high-resolution data for initial assessment of both high-rate high-resolution altimetry product and the quality of the buoy array solutions.

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Radar Altimeter in-situ monitoring at the Lake Issyk Kul observatory (Kyrgyzstan)

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Forum only

Abstract:
Lake Issyk Kul in Kyrgyzstan is a large high-altitude inland lake but ice-free the year around. Due to its E-W extension of ~170km all active radar altimetry missions cross this lake. Since 2016 CAIAG (Kyrgyzstan) and GFZ Potsdam (Germany) installed four GNSS-controlled tide gauges (N, S, E, W) and two climate monitoring stations at Lake Issyk Kul. Tide Gauge data (radar and pressure) is sampled every minute and climate data, such as wind or air pressure, every five minutes. The lake surface is neither influenced by ocean tides nor by inverse barometric effects. Seiches, which occur from time to time, are identifiable by data of the wind sensor at the east coast and the distinct variations of the lake level. The lake is calm except during strong winds detectable from our wind sensors in the East and South. Also surge effects are small.
Starting in 2017 we performed repeated ship-based lake surveys with GNSS/radar and a GNSS buoy for profiling the lake surface along the satellite passages. With the physical connection to the tide gauges, we are able to reconstruct the instantaneous lake profile in the geocentric reference system ITRF2014 for any altimeter passage. For our study we analyzed the 20Hz GDR Level 2 data of Jason-3 (since 2016) and Sentinel-6 (since 2021, STC/NTC both LRM/SAR) for all passages. Along a pass stretching ~60km we tested all retracker available within the product and two additional retracker, developed for land ice applications. We estimated the individual retracker offsets and the internal accuracy. For Sentinel-6 the SAR-OCOG retracker performs best (revision F02 onward) after applying an offset of more than 33cm in respect to the GNSS reference pass. For Jason-3 (Rev.F) the OCOG also performs best with an offset of ~19cm.
Our analyses show the capability of the Lake Issyk Kul observatory for the short-latency monitoring of radar altimetry missions.

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Seasonal Variation in the Effective Depth of Air-Sea Interaction

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Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Forum only

Abstract:
Sea surface temperature (SST) variability is controlled both by ocean processes such as advection, Ekman transport, and mixing, and by surface heat flux driven by atmospheric variations. Quantifying the relative strength of ocean and atmospheric forcing from observations previously has been explored by analyzing local heat budgets. Here, we use an observationally constrained local metric that quantifies the relative influence of ocean and atmospheric forcing from surface observations using a feedback framework. We use monthly satellite observations from 1993-2019 to examine the lagged-correlation relationships between SST, sea surface height (SSH) and surface turbulent heat flux (Q) to define SST-Q and SSH-Q feedbacks, which estimate the strength of atmospheric feedback to SST anomalies and to upper ocean heat content. We then define an effective depth of air-sea interaction (H), which describes the depth of the ocean that participates in the exchange of heat with the atmosphere. We also examine the ratio of the effective depth to the maximum mixed-layer depth (R) to estimate the renewal rate of the mixed-layer heat content from interior ocean processes relative to that from atmospherically driven surface fluxes. We find large values of H and R in regions with strong ocean currents such as the Gulf Stream, the Kuroshio Current, and the Antarctic Circumpolar Current, while interior subtropical regions exhibit small values. We finally study the seasonal dependence of R and find that wintertime R exhibits similar results to the year round R, while in summer, the results are not robust within the midlatitude western boundary currents. This analysis will improve our understanding of the relationship between upper ocean transport processes and surface heat flux variability and enhance our predictive understanding of climate variability.

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Model analysis of barotropic Rossby waves radiated from Tropical Instability Waves

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Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Forum only

Abstract:
An analysis of satellite altimetry shows that sea surface height (SSH) throughout large parts of the North Pacific is significantly coherent with Tropical Instability Waves (TIWs) in the 33-34 day period band (Farrar and Durland, 2021). A qualitative comparison of the coherence gain patterns with the output of a simple barotropic model suggests that much of the observed variability can be attributed to barotropic Rossby waves radiating northward from the TIWs to far reaches of the basin. The SSH variability is patchy on the scale of a few degrees, but in both the observations and in various configurations of the model, this patchiness is organized in a larger ridge-trough-ridge pattern. Based on analyses of a flat-bottom model and the early evolution of a topographic model, Farrar and Durland attributed the ridge-trough-ridge pattern to interference between the short-wave field radiating directly from the TIW region and a long-wave field generated when short waves reflect from the North American coast. This mechanism is robust in the flat-bottom model, and it appears to be important during the early evolution of the topographic model. We show here, however, that by a month or so into the evolution of the topographic model, refraction and partial trapping by bottom topography tends to reduce the amount of wave energy reaching the coast and hence the wave interference due to coastal reflection. Given the annual cycle of the TIWs, the coastal reflection is probably important for brief fractions of the TIW life cycle, but the topographic effects probably play the dominant role in determining the SSH patterns.

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Equatorial waves across the Pacific (and Indian and Atlantic)

Tom Farrar (Woods Hole Oceanographic Institution, France); Ted Durland (Oregon State University, USA)

Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Forum only

Abstract:
Oceanic equatorial waves play a fundamental role in ocean adjustment in the tropics, and can rapidly transmit forcing over planetary scales. Satellite altimetry data contain a wealth of underexploited information on equatorial inertial gravity waves, down to periods of a few days. The long and relatively continuous altimetry record allows us to achieve a high-resolution view of the zonal-wavenumber frequency spectrum of variability in the equatorial Pacific, providing a depiction of the spectrum of SSH variability spanning periods of days to years and Rossby waves to inertia gravity waves. Consistent with previous results, there is clear evidence for equatorial wave vertical and meridional modes resembling linear theory, but the altimetry data reveal some new observational insights. In the Pacific, we find clear evidence for two baroclinic modes and at least seven meridional modes. There has been some doubt as to whether high meridional modes could actually be established, but we find clear evidence for meridional modes up to mode 5 in the inertia-gravity wave spectrum. In the 5th meridional mode, SSH oscillates coherently over a latitudinal range of about 2000 km (10°S to 10°N), but with six sign changes in between. We briefly contrast these results with similar observations in the Atlantic and Indian Oceans—the evidence for discrete vertical-meridional equatorial wave modes is not as strong in these basins, which is consistent with other analyses going back to the 1980s.

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Hydrological cycle of the Mediterranean-Black Sea system

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Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Forum only

Abstract:
The Mediterranean-Black Sea system consists of two semi-enclosed basins connected by the Turkish Straits. In turn, the Mediterranean Sea is connected to the Atlantic Ocean through the narrow Strait of Gibraltar. The hydrological cycle of the system is driven by fresh water exchanges between the atmosphere, continents and oceans, and by salty water mass exchange among the ocean basins. Monitoring such water fluxes, especially its time evolution, is essential to understand the water cycle in the region, which is very sensitive to global climate changes and influences the variability of the Atlantic Meridional Overturning Circulation (AMOC), which in turn affects the global climate. In this study, we have estimated the hydrological cycle of the Mediterranean-Black Sea system from the time-variable gravity observations performed by the Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On satellites, and precipitation and evaporation from ERA5 atmospheric reanalysis data for the period 2002-2020. In the Black Sea, rivers introduce an average water volume of 391 +- 12 km3/year, one third of which escape through the atmosphere and two thirds go to the Mediterranean Sea. In the latter, 1787 +- 23 km3/year are lost via net evaporation. The rivers runoff (502 +- 27 km3/year), and the inflow of Atlantic waters (1020 +- 56 km3/year; 0.0323 +- 0.0018 Sv), finally restore the Mediterranean water budget. The balance is not reached instantaneously, and this delay introduces a seasonal variability in all the fluxes. In particular, the net water flux from the Atlantic Ocean increases up to 2660 +- 111 km3/year in August/September, and reverses to –407 +- 140 km3/year in April/May. On top of the climatology, the mean annual Atlantic water flux varies significantly between 706 and 1262 km3/year.

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Climate-driven sea level extremes and marine heatwaves in coastal Indonesia

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Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Forum only

Abstract:
The low-lying coastal and island regions are vulnerable to sea level rise and extreme events. Compounded by marine heatwaves, sea level extremes have devastating impacts on coastal community and marine ecosystems. As long tide gauge records are sparse, sea level extremes around Indonesia are poorly understood, and the Compound Height-Heat EXtreme events remain unexplored. Here we combine in situ and satellite observations with model simulations, to investigate the long-lasting (>1 month) sea level extremes and C-HHEXs along Indonesian coasts of the Indian Ocean since the 1960s. We find that 90% (80%) of the extreme sea level events, with a maximum monthly sea level anomaly of 0.45m, are concentrated in an 8yr period of 2010-2017, due to anthropogenic global sea level rise and decadal enhancements by wind-driven ocean circulation. Remote and local surface wind anomalies associated with negative phases of the Indian Ocean Dipole (IOD) - enhanced by La Niña for some events – drive individual compound extreme events. By contrast, winds associated with monsoon intraseasonal oscillations force the sea level alone events. The shoaling thermocline in eastern equatorial Indian Ocean under anthropogenic warming favorably precondition the ocean for stronger and more frequent sea level extreme and heatwave compounds, increasing the environmental stress on Indonesia.
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Using coastal altimetry to improve Meridional Overturning Circulation estimates in the South Atlantic

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Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Forum only

Abstract:
Since 2009, the Meridional Overturning Circulation (MOC) in the South Atlantic has been observed with an array of in situ moorings on each side of the basin at 34.5°S, the South Atlantic MOC Basin-wide Array (SAMBA). To date, the component of the meridional transport inshore of the shallowest moorings on either side (about 1300 m depth) has been estimated using a time-mean from an ocean model simulation due to lack of better observations. However, because of their position offshore on the shelf break, the transport that is not directly observed by the SAMBA moorings is expected to be significant. We use along-track coastal altimetry, combined with existing in situ data, to estimate the unobserved inshore component of the MOC transport at 34.5□S. This requires designing a method to estimate the geostrophic transport based on surface altimetry data. The analysis of the vertical ocean structure on each side of the SAMBA array, based on available in situ observations, suggests that the currents are mostly barotropic or equivalent barotropic. This property allows for the estimation of the meridional geostrophic transport offshore of the SAMBA array using along-track altimetry. It is found that the northward transport inshore of SAMBA on the Eastern side of the array and the southward transport on the Western side tend to compensate each other on average. However, the variability of the total inshore component (~4 Sv) is not negligible compared to the ~17 Sv total MOC transport at 34.5°S and should be monitored.
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Indian Ocean Dipole leads to Atlantic Niño

Lei Zhang (University of Colorado Boulder, United States); Weiqing Han (University of Colorado Boulder, United States)

Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Forum only

Abstract:
Atlantic Niño is the Atlantic equivalent of El Niño-Southern Oscillation (ENSO), and it has prominent impacts on regional and global climate. Existing studies suggest that the Atlantic Niño may arise from local atmosphere-ocean interaction and is sometimes triggered by the Atlantic Meridional Mode (AMM), with overall weak ENSO contribution. By analyzing observational datasets and performing numerical model experiments, here we show that the Atlantic Niño can be induced by the Indian Ocean Dipole (IOD). We find that the enhanced rainfall in the western tropical Indian Ocean during positive IOD weakens the easterly trade winds over the tropical Atlantic, causing warm anomalies in the central and eastern equatorial Atlantic basin and therefore triggering the Atlantic Niño. Our finding suggests that the cross-basin impact from the tropical Indian Ocean plays a more important role in affecting interannual climate variability than previously thought.

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Causal Mechanism of Sea Level Change in the Beaufort Sea

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Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Forum only

Abstract:
Over the last two decades, sea-level across the arctic's Beaufort Sea has been rising faster than its global mean by an order of magnitude (Figure a). Beaufort Sea's rapid sea-level rise is mainly a halosteric change (Figure b), reflecting an increase in freshwater content greater than that associated with the Great Salinity Anomaly of the 1970s, raising the possibility of future disruptions in large-scale ocean circulation and climate. Here we provide a new perspective of this Beaufort Sea variation by quantifying its causal mechanism from 1992 to 2017 using a global, data-constrained ocean and sea-ice estimate of the Estimating the Circulation and Climate of the Ocean (ECCO) consortium.

Analysis reveals that the variation is driven by a combination of wind stress and sea-ice (Figure c). Seasonal variation mainly reflects near-surface change due to the annual melting and freezing of sea-ice while interannual change extends deeper and mostly relates to wind-driven Ekman transport. Increasing wind stress and sea-ice melt are, however, equally important for decadal change that dominates the overall variation. Strengthening anticyclonic wind stress surrounding Beaufort Sea intensifies the ocean's lateral Ekman convergence of relatively fresh surface waters. The strengthening stress also enhances convergence of sea-ice and ocean heat that increase the amount of Beaufort Sea's net sea-ice melt (Figure d). The enhanced significance at longer time-scales of sea-ice melt relative to direct wind forcing can be attributed to the ocean's mixing of melt-water being slower than its dynamic adjustment to mechanical perturbations. The spin-up difference implies that, on their own, the sea-ice-melt-driven diabatic change will last much longer than the direct wind-driven kinematic anomaly.

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Frequency dependence of ocean surface kinetic energy and its vertical structure from global high-resolution models and surface drifter observations

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Session: Tides, internal tides and high-frequency processes
Presentation type: Forum only

Abstract:
Surface oceanic kinetic energy is of interest for many reasons, and a greater understanding of the vertical structure of the kinetic energy would aid interpretation of ongoing and proposed remote sensing missions that are focused on velocity. In this work, kinetic energy (KE) at the sea surface (0 m) and 15 m depth in high-resolution global simulations (HYbrid Coordinate Ocean Model; HYCOM, and Massachusetts Institute of Technology general circulation model; MITgcm) is compared with KE from undrogued and drogued drifters, which respectively represent flows at 0 and 15 m. Global maps and zonal averages are computed for four frequency bands—low-frequency (<0.5 cpd), near-inertial, diurnal, and semi-diurnal. In the near-inertial band, MITgcm KE is too low relative to drifters, while HYCOM KE lies closer to observations probably due to more frequently updated atmospheric forcing. In the semi-diurnal band, MITgcm KE is too high, while HYCOM KE lies closer to the drifters due primarily to the inclusion of a parameterized topographic internal wave drag. In both drifter and model results, semi-diurnal spectra display a weak dependence on background low-frequency KE, consistent with mesoscale eddy-induced internal tide non-stationarity. Drifter semi-diurnal spectra are inherently wider than model semi-diurnal spectra, due to Lagrangian sampling of spatially varying fields. Vertical structure is defined here by the ratio of zonally averaged KE in 0 m/15 m model results and undrogued/drogued drifter results. Over most latitudes and most frequency bands, the model ratios track the drifter ratio to within error bars. All of the frequency bands except for the semi-diurnal band display measurable vertical structure. Latitudinal dependence in the vertical structure is greatest in the diurnal and low-frequency bands.
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TPXO9v2 and TPXO9-atlas-v5: two new global barotropic tide models

Svetlana Erofeeva (Oregon State University, United States)

Session: Tides, internal tides and high-frequency processes
Presentation type: Forum only

Abstract:
Two new versions of the TPXO and TPXO-atlas global barotropic tide models were released in October of 2021.

The TPXO9v2 model is an updated version of the previous TPXO9v1 model with 1/6-degree global resolution. The new TPXO9v2 now includes data-assimilative hydrodynamics-based models for the 2Q1, J1, L2, M3, MU2, NU2, OO1 tides, which were previously estimated using inference. While these may be considered minor tides, their sea surface elevations can individually exceed 5 cm in regional domains near the coast, making them important components of altimeter sea level corrections. In addition to using an expanded set of tides in TPXO9v2, this version also contains updated models for the P1 and S1 tides.

The TPXO9-atlas-v5 model is an updated version of the 1/30-degree tidal atlas, which smoothly blends together separate high-resolution coastal models with the TPXO9v2 model offshore. This latest version incorporates new regional solutions around Australia, the Iberian Peninsula and the polar areas, utilizing new data for bottom topography and coastlines. The TPXO9-atlas-v5 model does not yet contain the smaller constituents mentioned above, but continues to use 15 the constituents, M2, S2, N2, K2, 2N2, K1, O1, P1, Q1, Mf, Mm, M4, MN4, MS4, and S1. Among the quantitative differences between this latest TPXO9-atlas-v5 and previous versions, the model explains 3.7% more Cryosat-2 variance in the Arctic and 2.7% more in the Antarctic, compared to TPXO9-atlas-v2.

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Impact of Remote Internal Waves on Internal Wave Energetics of Regional Model Simulations

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Session: Tides, internal tides and high-frequency processes
Presentation type: Forum only

Abstract:
In this study, we demonstrate that remote internal waves are important for the local energetics in regional ocean circulation models. In addition to mesoscale forcing, we force 4-km Regional Ocean Modelling System (ROMS) simulations of the U.S. West Coast with surface tides and internal waves from an 8-km Hybrid Coordinate Ocean Model (HYCOM) simulation. We evaluate the regional model's boundary conditions for reflections, we validate our simulations with observations, and we study internal wave energetics (IWEs).
To control the reflections of internal waves generated in the interior of the domain, we include sponge layers at the open boundaries. We quantify reflection estimates with the help of a discrete Fourier transform (DFT) technique. We use the DFT technique in separating ingoing and outgoing waves at the open boundaries. We find that a sponge width and viscosity of 58 km and 800 m^2/s are optimal for our domain.
We validate our simulations using a 17-years long altimeter dataset and a historic mooring database. To ensure apples to apples comparison, we apply a spatially varying correction factor to obtain stationary equilibrium amplitudes for our one-year simulations. With remote forcing at the open boundaries, the coefficient of determination (R^2) for M2 SSH amplitude increases from 65.5% (for no remote internal tides case) to 85.1% when compared to altimetry. We also obtain approximately 35% increase in root mean square amplitude (RMSA). Across all frequency bands, the velocity and temperature variance captured also increases due to remote internal waves forcing when compared to a historical mooring dataset.
We also show in this study that it may be insufficient to force regional ocean circulation models at their lateral boundaries with only stationary internal tides (ITs). We estimate depth integrated and time mean stationary baroclinic fluxes at the western boundary of our domain to be 34.5% of the total semi-diurnal internal tide fluxes generated from the Hawaiian Island Ridge, i.e., 75.5% is nonstationary. In addition, we find that near-inertial waves (NIWs) constitute a significant portion of the remotely generated internal waves at the open boundaries; for instance, NIWs make up approximately 56% of the total remote baroclinic fluxes at the Northern boundary. We plan to evaluate IWEs in the interior of our domain when the model is forced with stationary, total ITs and total ITs + NIWs at the open boundaries. We also intend to study how seasonal variability in our remote forcing affect our domain's IWEs.

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Experiments computing highly-resolved sea level spectra from dual-satellite altimetry

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Session: Tides, internal tides and high-frequency processes
Presentation type: Forum only

Abstract:
It is well-known that the power spectral density of a random process may be estimated from its autocovariance function. Here I report on efforts to compute the spatially-averaged frequency spectrum and autocovariance of sea level from dual-satellite crossover data. By averaging over all crossover locations, and by using time-lagged sea level differences binned with hourly resolution, combined Jason and Cryosat-2 data yield power spectral density estimates with a Nyquist frequency of 0.5 cycles-per-hour. While the same sea surface is observed by the Jason missions and Cryosat-2, their data are contaminated by independent realizations of measurement noise, so some aspects of the autocovariance are interpreted differently than in conventional time series analysis. Because the crossover locations are not randomly distributed in space and time, there are artifacts related to the aliasing of spatial signals that appear in the frequency domain. Nonetheless, the resulting power spectral estimates clearly exhibit unaliased peaks due to high-frequency sea level above the 1/20-day Nyquist frequency associated with Jason. I will provide examples of these spectral estimates and show how they may be used to learn about non-phase-locked baroclinic tides.

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Development of the yearly mode-1 M2 internal tide model in 2019

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Session: Tides, internal tides and high-frequency processes
Presentation type: Forum only

Abstract:
This work is motivated to study the interannual variations of internal tides using observation-based yearly internal tide models from satellite altimetry. The yearly mode-1 M2 internal tide model in 2019 is constructed using sea surface height (SSH) measurements made by six concurrent altimetry missions: Jason-3, Sentinel-3A, Sentinel-3B, CryoSat-2, Haiyang-2A and SARAL/AltiKa. The model is developed following a three-step procedure consisting of two rounds of plane wave analysis with a spatial bandpass filter in between. Prior mesoscale correction is made on the altimeter data using AVISO gridded mesoscale fields. The model is labeled Y2019, because it represents the one-year-coherent internal tide field in 2019. In contrast, the model developed using altimeter data from 1993–2017 is labeled MY25, because it represents the multi-year-coherent field in 25 years. Thanks to the new mapping technique, model errors in Y2019 are as low as those in MY25. Evaluation using independent altimeter data confirms that Y2019 reduces slightly less variance (~6%) than MY25 does. Further analysis reveals that the altimeter data from five missions (without Jason-3) can yield an internal tide model of almost same quality. Comparing Y2019 and MY25 shows that mode-1 M2 internal tides are subject to significant interannual variability in both amplitude and phase, and their interannual variations are a function of location. For example, along southward internal tides from Amukta Pass (Alaska), the energy flux in Y2019 is two times large and the phase speed in Y2019 is about 1.1% faster. This work demonstrates that internal tides can be observed using yearly concurrent altimetry missions and thus their interannual variations can be quantified. This work confirms that non-repeat (e.g., geodetic, drifting) altimetry missions (phases) can be used to observe internal tides, whose feasibility has been debated in the altimetry community. This mapping technique has been applied successfully to other yearly altimeter datasets.

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Satellite estimates of Mode-1 M2 Internal Tides using non-repeat altimetry missions

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Session: Tides, internal tides and high-frequency processes
Presentation type: Forum only

Abstract:
Previous satellite estimates of internal tides are usually based on 25 years of sea surface height (SSH) data from 1993–2017 measured by exact-repeat (ER) altimetry missions. In this study, new satellite estimates of internal tides are based on eight years of SSH data from 2011–2018 measured mainly by non-repeat (NR) altimetry missions. The two datasets are labeled ER25yr and NR8yr, respectively. NR8yr has advantages over ER25yr in observing internal tides, because of its shorter time coverage and denser ground tracks. For comparison, mode-1 M2 internal tides are mapped from both datasets following the same procedure that consists of two rounds of plane wave analysis with a spatial bandpass filter in between. It is shown that mode-1 M2 internal tides can be mapped from NR8yr in fitting windows as small as 40 km, in contrast to 160-km windows required by ER25yr. The two internal tide models are labeled NR8yr40km and ER25yr160km, respectively. Evaluation using independent satellite altimeter data confirms that NR8yr40km is better than ER25yr160km. Their global energies are 49 and 34 PJ, respectively, indicating that ER25yr160km underestimates the M2 internal tide by 15 PJ (~30%). Further comparisons reveal that the 160-km (versus 40-km) window underestimates the M2 internal tide by 5 PJ (~10%) and the 25-yr (versus 8-yr) time coverage underestimates the M2 internal tide by 10 PJ (~20%). This work confirms that non-repeat (e.g., geodetic, drifting) altimetry missions (phases) can be used to observe internal tides, which offers more orbital choices for one extended altimetry mission.

The effect of window size on internal tide estimation is examined using a high-resolution HYCOM simulation in the same manner. It is confirmed that internal tides are not underestimated by the 40-km fitting window employed in this mapping technique. The effect of time-series duration on internal tide estimation is examined using the six-year-long HYCOM simulation following the same procedure. The investigation is still ongoing. It is expected that our satellite and HYCOM results will provide constraints on the percentage of the incoherent internal tide, which is a function of time-series duration. In addition, the global internal tide dissipation map is computed using the new satellite observation, whose high resolution is a key improvement, because dissipation is derived from flux divergence. The satellite derived dissipation map is compared with the dissipation map derived from the HYCOM simulation reported previously.

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Seasonal variability of internal tides in the global ocean

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Session: Tides, internal tides and high-frequency processes
Presentation type: Forum only

Abstract:
We investigate the seasonal variability of internal tides in the global ocean using a six-year simulation of the Hybrid Coordinate Ocean Model (HYCOM). The non-stationarity of internal tides is caused by the time varying stratification, mesoscale variability, large-scale shifts in amphidromic points, and changes in ice cover. For example, the annual cycle in background flow and stratification modulates the internal tide amplitudes, causing the semidiurnal MA2 and MB2 frequencies. We use six years of steric sea surface height (SSSH) from a realistically forced global HYCOM simulation with a horizontal resolution of 8 km. This data set allows us to explore the global variability in both stationary and non-stationary tides. A least-squares harmonic analysis is used to extract SSSH amplitudes and phases for the M2, K1, O1, and S2 constituents for two-week/month-long time series segments. The amplitude and phase are used to construct the total internal tide for the bi-weekly/monthly time series for each tidal constituent. To compute the stationary internal tide time series, we extract the amplitude and phase of the principal tidal frequency and its annual modulates (e.g., M2, MA2, and MB2) over the entire six-year-long time series. Next, we subtract the stationary time series from the total bi-weekly/monthly time series to obtain the non-stationary bi-weekly/monthly time series for the tidal constituents. We find that the total variance for M2 internal tides for bi-weekly and monthly time series is on average 0.61 cm2 and 0.56 cm2, respectively, for seafloor depths greater than 250 m and a mean amplitude larger than the 50th percentile. Of this total variance, the fraction for bi-weekly/monthly time series due to stationary M2 tides, seasonal stationary tides, and non-stationary tides is 47%/51%, 4%/5%, and 49%/45%, respectively. We observe that the non-stationary fraction is higher for bi-weekly time series when compared to monthly time series. To validate our HYCOM simulation with observations, we also compare seasonal variance in stationary tides with altimetry data. This comparison shows a good agreement. We plan to repeat the same analysis for K1, O1, and S2 constituents. In addition, we also fit annual and semiannual seasonal cycles to the time series of monthly M2 harmonic constants to understand the seasonal variations in total internal tide amplitude. Internal tides generated in the coastal regions, such as Georges Bank, Arabian Sea, and Amazon Shelf, show high seasonal variability.
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Global mode water detection and its representation in heat transport

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Forum only

Abstract:
Mode water, characterized as a thick water mass with homogeneous properties, is a distinctive feature of the upper ocean commonly resulting from surface convection. It thus serves as a heat reservoir and is often referred to as “climate memories” that can modulate sea surface temperatures and ventilate the thermoclines. In this study, we propose a new algorithm applied to the Argo global array to determine the mixed layer depth (MLD) and mode water thickness and volume in a more precise way by taking into account mode water characteristics and how they translate in vertical variations of properties. That is, to look for extreme values of the second derivatives of properties for each single profile and accordingly identify the depths of any sharp gradient change. Thereby, we reconstruct the global mode water pools of renewal near the surface and residence in the ocean interior. The spatial difference between these surface and subsurface pools also suggest possible mechanisms of subduction along isopycnals, which further lead to our understanding of heat content (anomalies) taken up and transported by mode waters. A recent study (Chen et al., 2021) has validated the algorithm by detecting the South Atlantic Subtropical Mode Water, in which a possible route of subduction is also inferred that is closely correlated with anticyclonic Agulhas Rings. Similarly, by co-locating mesoscale eddies derived from satellite altimetry (Laxenaire et al., 2018; 2019; 2020) and mode waters, this study further provides insights into the influence of mesoscale features on heat uptake and transport in a global picture.

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Global assessment of mesoscale eddies with TOEddies; Comparison between multi-datasets and co-location with in-situ measurements

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Forum only

Abstract:
In this study, we investigate mesoscale eddies in the Global Ocean with the help of TOEddies Atlas (Laxenaire et al., 2018). Applied on satellite observations (AVISO/DUACS) of Absolute Dynamic Topography (ADT), TOEddies provides daily information on eddy dynamical characteristics (size,intensity etc.) over a 27 year period (1993-2020) as well as identifies complex eddy-eddy interactions. A statistical description of the mean eddy characteristics, their spatial distributions of eddy occurrences (generation, disappearance and merging/splitting) is firstly provided. Then, a comparative analysis between existing global eddy datasets (Chelton et.al 2011, Tian et.al 2019) is performed. Among the years of observations, several long-lived and coherent mesoscale eddies stand out with lifetimes that exceed 1.5 years. Yet, we find that only a small fraction of them is comparable among datasets while their dynamical characteristics could also substantially differ. Thanks to TOEddies that identifies the multiple merging and splitting events that a single eddy may experience, a complex eddy network is created that reshapes the current view of a unique trajectory associated with one single eddy and allows for an original assessment of the mean eddy pathways. Moreover, eddy detection from altimetry is combined with 20 years of Argo profiling floats in-situ measurements (2000-2020), providing additional information on vertical structure of eddies. An index to identify surface versus subsurface-intensified eddies is used, allowing us to further explore their role in the global ocean circulation as long lasting coherent structures.

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Steric height contribution to intraseasonal sea surface height in the Southwestern Atlantic

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Forum only

Abstract:
The sea level varies at diverse spatial and temporal scales due to several physical processes. The main processes are the steric effect, changes in the density of sea water, and the mass changes (e.g. melting ice). In the Southwestern Atlantic, the sea level associated with the steric effect, known as steric height, dominates the seasonal variability and the spatial variation of sea level trends on the Confluence Brazil-Malvinas and adjacent area. The interannual variability, instead, is important on the mid-latitude of the South Atlantic and negligible over the Southwestern Atlantic continental shelf. Little, however, is known about the intraseasonal sea level variability. Thus, the objective of this work is the understanding of the physical drivers of the sea level variability in the Southwestern Atlantic at temporal scales shorter than seasonal using a combination of high resolution in situ data from CTD attached to elephant seals, altimetry data, and a 3D oceanic model. First, we did quality control of the in situ data and selected the best trajectories of 19 female elephant seals off-shore the continental shelf during spring and early summer of 2018 and 2019. The result shows that 14 trajectories out of 19 are reliable. Then, we compared the reanalysis and analysis forecast from Mercator with gridded altimetry data along the 14 trajectories. The comparison indicated that the performance of the reanalysis model sea level anomaly (SLA) is better than the analysis forecast, obtaining significant correlation coefficients higher than 0.54. With the selected model, the steric height (SHm) was estimated and validated with the in situ steric height (SH). For the SH estimation, we calculated the potential density in each vertical profile of the elephant seals and integrated the anomaly vertically. The preliminary results show that the reanalysis ocean model represents very well the steric height, obtaining 10 cases where the correlation with the SH is higher than 0.5. Finally, we discuss the role of the steric height in the altimetry SLA, finding that its contribution is important when the elephant seals cross an area with mesoscale activity.

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seasonality of the mesoscale sea surface variability from multi-year satellite altimetry

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Forum only

Abstract:
Sea surface slope (SSS) varies in response to a range of physical processes: tides, geostrophic flows, surface and internal waves, etc. We present the sea surface variation in the form of the SSS variability using 30 years of heterogeneous satellite altimetry measurements. We apply band-pass filters to the along-track SSS, and derive the mean and seasonal (annual and bi-annual) components of SSS variability in multiple wavelength sub-bands from 30 to 1000 km. We show the power spectral density of the mean and seasonal SSS variability versus wavenumber, and find that the seasonal components are small (less than 10% in amplitude) compared to the overall mean variability on a global scale. Through correlation analysis, we show evidence that SSS variability with wavelengths less than 30 km is mostly dominated by wave height noise. At longer wavelengths there are real oceanic signals. For example, there are clear signatures of unbalanced flow motions (internal tides/waves) above the mid-Atlantic Ridges and the Amazon outflow. On a global scale, there is higher mesoscale variability (30-100 km) in local wintertime. Some regions, for example the Philippine Sea and the South Equatorial Countercurrents, deviate from this hemispheric-scale pattern. The Northern Hemisphere shows stronger seasonal change than the Southern Hemisphere.

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CFOSAT data over sea ice areas

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Session: CFOSAT
Presentation type: Forum only

Abstract:
Microwave sensors onboard polar orbit satellites are commonly used for sea ice monitoring at high latitude. Since 1992, numerous scatterometers data at C and Ku-bands are available, allowing to build time series of data for sea ice monitoring for both Arctic and Antarctic areas.
Backscatter data enable to discriminate sea ice from open ocean areas, also they can also be used for sea ice type detection (first year from multi-year sea ice in the Arctic), moreover, sea ice displacement maps can be built. These applications were successfully realized using QuikSCAT data at Ku-band and we use CFOSAT CSCAT scatterometer data for this purpose. We will show results over the poles using 2020-2021 et 2021-2022 winters data. Application on sea ice edge/ocean free of ice detection will be shown and examples of multiyear ice detection and sea ice displacement if possible. Comparison with ASCATs scatterometer data at C-band, available at the same period, will be presented, keeping in mind that C and Ku-band data over the pole have different behavior.
First results of the use of CFOSAT SWIM data over the poles will be presented.

Sea ice long-term qualified data are routinely processed at Ifremer/CERSAT and available for the scientific community since 1992 :

- backscatter maps from C and Ku-band scatterometer
- displacement maps with the joint use of radiometer data
- ice edge
- first year/multiyear detection

providing an exceptional basis for analysis and synthesis of long-term variations of the sea ice in the polar areas. They are available through the CERSAT/Ifremer (http://cersat.ifremer.fr) but also they are part of the CMEMS project reanalysis datasets (called « multiyear products ») and the H2020 European project INTAROS system of systems of Arctic data.
These new CFOSAT data are to be added to these data collections.

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Ocean wave fields under tropical cyclone conditions as evidenced by SWM/CFOSAT

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Session: CFOSAT
Presentation type: Forum only

Abstract:
Several studies have shown in the past that the wave fields generated by TCs are asymmetric with higher significant wave height (Hs) in the right front quadrant (with respect to the TC track) (Young, 2006, Kudryavstev et al, 2015). Simulation studies indicate that this asymmetry increases with the TC displacement speed (Kudryavstev et al., 2015, 2021) up to a certain limit. Correlatively, almost in all quadrants of the TC, the shape of the wave spectra at frequencies about the peak look like those for fetch limited conditions (Young, 2006; Hu and Chen, 2011) even when the wave spectra tend to become bi- and tri-modal in direction (Young 2006; Hu and Chen, 2011; Esquivel-Trava et al., 2014; Hwang & Walsh 2018). Young (2006) suggested that in TCs, the nonlinear interactions are the dominant process that controls the shape of the omni-directional spectra even if the wave energy is contained in several wave components with different directions.

The SWIM instrument on-board the CFOSAT mission provides directional ocean wave spectra every 70 km along-track for waves with dominant wavelengths between 70 and 500 m. SWIM provides an extremely interesting data source to further extend the previous analyses carried out with satellite data (only Hs information from altimeter were used), extend those obtained from buoy observations, and assess analytical or modeling studies.

During the conference, we will report on a study carried out by investigating wave parameters estimated from the SWIM instrument in 46 events of the Northern hemisphere in 2019 to 2021. For this study we have classified TCs in three different categories following the suggestion made by Kudryavtsev et al. (2021): slow, medium and fast moving TCs. This has been done by using to the ratio of the maximum wind speed to the translation speed of the TC, provided by the TC data base IBTRACS. Furthermore, the wave parameters estimated from SWIM along its tracks, have been placed in a common reference frame, which takes into account the displacement direction of the cyclone and the distance of the observations with respect to the radius of maximum wind.

Several parameters have been investigated as the significant wave height, the dominant wavelength, the wave age, the frequency spread or peakedness of the omni-directional spectrum, the directional spread, the direction of the dominant waves, the ratio of energy and difference in direction between the first and second partitions. We will show that the assymetry in the fields of several of these parameters depends of the TC class (slow, medium or fast displacement speed). This seems to qualitatively confirm the analytical and numerical approach proposed by Kudryavtsev et al (2021), with however some differences which will be discussed during the conference. With the SWIM data set, we also find that although most regions of the cyclones are characterized by waves not any more forced by the wind, the omni-directional spectra follow adimensional laws which look like those established in the past for fetch-limited situations.

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A novel sea state classification scheme based on global CFOSAT wind and wave observations

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Session: CFOSAT
Presentation type: Forum only

Abstract:
Sea state is recognized as an essential variable in the global climate system, and a complement to other widely used observations including sea surface temperature, sea level, and surface winds. Most previous global sea state investigations have utilized either model outputs or reanalysis data to explore the spatio-temporal characteristics. A main reason for this has been the lack of concurrent wind and wave measurements at global scale. This situation has improved with the launch of the China-France Oceanography SATellite (CFOSAT), which carries a wind scatterometer (SCAT) and a wave spectrometer (SWIM) aboard. In this study, we take advantage of the simultaneous CFOSAT wind and wave observations to develop a new approach for sea state classification. First, global average CFOSAT estimates of wind speed, significant wave height, inverse wave age and mean square slope are found to be consistent with previously reported data. A k-means clustering technique is applied to these measurements to classify sea state conditions into 6 pre-defined clusters in terms of the four-dimensional wind and wave ensemble. Each group has distinct wind and wave features, characterized by differing wind-swell dominance and sea state maturity, etc... The occurrence frequency of these groups across the globe portrays the spatial dominance of different sea state classes. Observed spatial distributions are expected to indicate variability in wave-induced momentum flux. Future efforts shall be devoted to building links between these sea state groups and local air-sea flux characteristics.

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Surface Measurements for Oceanographic Satellites: the SUMOS in-situ and airborne campaign

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Session: CFOSAT
Presentation type: Forum only

Abstract:
As a supporting contribution to the validation of observations by the China-France Oceanography Satellite, CFOSAT, launched on 29 October 2018, the SUMOS campaign was conducted in February and March 2021 by CNES and a number of research teams from the CNRS, Météo-France and Ifremer.
This campaign was mainly oriented for SWIM product assessment. SWIM is an innovative wave scatterometer It is a Ku-band real aperture radar which illuminates the surface sequentially with 6 incidence angles: 0°, 2°, 4°, 6°, 8° and 10°, thanks to its rotating antenna (5.6 rpm), it acquires data in all azimuth orientations. From SWIM measurements are generated, among other: nadir significant wave height and wind speed, wave slope spectra given for 70*90 resolution cells.
The campaign was carried out in the Bay of Biscay between the 15th February and 4th March 2021. It was designed to collect a set of co-located observations of wind, waves and associated parameters (turbulent air-sea fluxes) by both in-situ and remote sensing means. The resulting data will be used to:

- improve CFOSAT/SWIM instrument data inversion methods,
- better identify the performance and limits of the parameters provided by CFOSAT/SWIM,
- advance mission objectives concerning the study of wave hydrodynamics and wind/wave/flux relationships in turbulent conditions.

The campaign also took advantage of the SKIM mission for multiscale monitoring of sea surface kinematics to acquire Ka-band Doppler radar scatterometry data via KaRADOC (an instrument developed by the IETR) to support concepts for future satellite missions using this technique.
Two national experimentation platforms were deployed in and over the Bay of Biscay: F-HTMO, the ATR 42 research aircraft operated by SAFIRE, the French facility for airborne research (Météo-France/CNRS/CNES) and the French Oceanographic research vessel L'Atalante operated by Genavir.
Data were acquired using these two platforms in coordination with CFOSAT passes over the Bay of Biscay. The operation plan included:

1. in-situ measurements of surface waves with 20 drifting buoys (SPOTTER) to measure directional wave spectra and 3 so-called "FLAME" drifting devices to measure wind, and the turbulent fluxes close to the surface; all these systems have been deployed by the L'Atalante ship.
2. measurements taken on board the ship itself using in particular an imaging X-band radar operated by Germany's Helmholtz-Zentrum from Geesthacht. These measurements are used to estimate the directional spectrum of the waves and surface currents. In addition, a stereo video camera and a polarimetric imaging system was deployed by LOPS and collected about 50 hours of measurements to characterize the short and intermediate waves and study their relation with breaking and with remotely sensed parameters
3. airborne radar measurements using the Ku-band Radar for Observation of Surfaces (KuROS) developed and operated by LATMOS, were performed from the ATR 42 research aircraft so as to provide directional wave spectra using the same concept of measurement as used for SWIM.
4. airborne measurements with the KaRADOC radar developed and operated by the IETR, also carried by the ATR 42. These measurements are used in particular to study the concept of acquiring surface current data by applying a pulse-pair method to a Doppler radar signal. KaRADOC was designed as part of the SKIM project proposed by LOPS.

In all, the ATR 42 flew 17 times in perfect coordination with the in-situ measurements carried out on board the L'Atalante and the drifting buoys deployed from the vessel. Of these 17 flights, 13 were synchronized with CFOSAT satellite passes (SUMOS campaign) and the last 4 were used for the SKIM project.
Each flight provided between 3 and 4 hours of data over long distances across the Bay of Biscay. The research vessel was positioned at different points during this period according to the satellite's passes and the constraints of launching and recovering the drifting buoys.
A large set of high-quality data was acquired, and a wide range of weather conditions was observed, enabling campaign objectives to be reached.
The first results of this campaign are very positive. They show very close agreement between measurements from SWIM, the drifting buoys and the MFWAM model. Analysis from the full collocated data set is in progress with in particular studies devoted to the experimental estimation or validation of the Modulation Transfer Function which is used to invert SWIM observations into directional wave spectra.
The data set will be made available to the wider scientific community, including altimetry community, as soon as they become available.
The scientific altimetry community will be able to take advantage of these observations to validate the different products on wave height (SWH) at nadir.

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Assessment of Sentinel 6 altimeter data along the Northwest Atlantic shelf

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Session: Sentinel-6 Validation Team (S6VT) feedbacks
Presentation type: Forum only

Abstract:
A Sentinel-6 mission goal is to maintain data quality closer to the coastline than products from previous conventional altimeter missions such as T/P and Jason-1,2,3. This requires making use of new High Resolution mode (HRM) or SAR mode data to improve the performance in coastal areas, following on from pioneering data from the Sentinel-3 (S3) and Cryosat missions.

This project will build upon ongoing assessments of S3 SAR altimeter data along the US east coast and Nova Scotian Shelf (SS) to examine tandem-phase S-6 and Jason 3 measurements with a specific focus near to the coast. We have already observed clearly measurable improvements using S-3 HR data when compared to Low Resolution Mode (LRM) data. This new S6 Cal/Val work will utilize similar analysis and metrics to evaluate key GDR products including range (i.e. SSH/SSHA), SWH, and Sigma0 (i.e. wind speed). The overall goal is to provide an assessment of S6 altimeter products along the US northeast and SS shelf, with specific objectives being 1) to analyze S6 and Jason-3 data quality (SSH/SSHA, SWH, and Sig0), 2) to quantify noise and bias in key S6 variables via inter-comparison of LRM and HRM (SARM) in reference to J3 LRM data, 3) to assess the accuracy of the altimeter SSH and SSH-derived geostrophic estimates, across the shelves and coastal zones, and 4) to explore coastal applications using S6 HRM data to better identify coastal currents.

As one potential application, a recent study (Feng et al., 2016) showed that interior Gulf of Maine (GoM) subsurface salinity variability was closely tied to change in southwestern Scotian Shelf (SS) inflow derived from SSHA measured by TOPEX/Jason-1, 2 LRM altimeter data. We will revisit this idea that altimetry-based alongshelf geostrophic flow anomalies derived from repeat tracks in J3/S6 and other nearby passes from S- 3 and SARAL/AltiKa along the Southwest SS can serve as a proxy for remote Gulf of Maine forcing. Specifically, we seek to predict water mass change (e.g. salinity) inside the GoM. We will quantify potential improvements gained using HRM SSHA-based currents in comparison with LRM data. In the future, we intend to routinely generate along-shelf current products using along track data from multiple altimeters on the southwest Scotian Shelf and we will investigate the shortest feasible time scales resolved using the suite of satellites.

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Understanding the behavior of altimetric measurements of Laser and Ku-band over sea-ice

Alice Carret (SERCO, France); Antoine Laforge (Mercator, France); Sara Fleury (LEGOS, France); Jérôme Bouffard (ESA, Italy); Alessandro Di Bella (ESA, Italy)

Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Forum only

Abstract:
For more than 10 years, CryoSat-2 (CS2) has been observing and monitoring the polar regions, providing unprecedented spatial and temporal coverage. Satellite altimetry allows the measurement of sea ice thickness, a key variable for understanding sea ice dynamics. Many products developed by the community have already demonstrated the capabilities of CryoSat-2 to estimate sea ice thickness. Nevertheless, several questions remain to better assess the relevance and quality of the measurements according to the ice type. These include the effects of ice roughness in the footprint and Ku frequency penetration levels in the snow cover.

In July 2020, CS2's orbit was raised, as part of the Cryo2Ice project, to have tracks co-located with NASA's high-resolution IceSat-2 altimeter over the Arctic Ocean. These coincident measurements between the Ku-band SAR altimeter for CS2 and the LIDAR altimeter for IceSat-2 provide a unique means of assessing the impact of radar footprints and snow properties in the measurements.

Here we present a methodology for comparing IceSat-2 and CryoSat-2 along coincident trajectories and show the potential of using a dual-sensor approach to understand the measurement. Comparisons between surface roughness estimates and snow products show strong correlations, highlighting the cross-effects of penetration and roughness. We then introduce comparisons with SARAL Ka-band data, which does not penetrate snow, to better understand these effects. We also study the impact of CryoSat-2 waveform processing methods, or retrackers, using various sea ice products proposed by the scientific community.

This ESA-supported study should help prepare the Copernicus CRISTAL mission, which will include a Ka/Ku dual-frequency altimeter for the first time.
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Nadir altimetry over land: achievements using the Open-Loop Tracking Command (OLTC) and benefits for inland water users

Sophie Le Gac (CNES, France); Simon Boitard (NOVELTIS, France); Denis Blumstein (CNES/LEGOS, France); Malik Boussaroque (HydroMatters/LEGOS, France); François Boy (CNES, France); Nicolas Picot (CNES, France); Pierre Féménias (ESA/ESRIN, Italy)

Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Forum only

Abstract:
In times of ever decreasing amount of in-situ data for hydrology, satellite altimetry has become key to provide global and continuous datasets of water surface height. Indeed, studying lakes, reservoirs and rivers water level at global scale is of prime importance for the hydrology community to assess the Earth's global resources of fresh water.
Much progress has been made in the altimeters' capability to acquire quality measurements over inland waters. In particular, the Open-Loop Tracking Command (OLTC) now represents an essential feature of the tracking function. This tracking mode's efficiency has been proven on past missions and it is now stated as operational mode for current Sentinel-3 and Sentinel-6 missions. It has benefited from iterative improvements brought to onboard tables contents repeatedly since 2017.

In 2022, new updates will be performed on the onboard OLTC tables of the Sentinel-3A and Sentinel-3B missions, as well as Sentinel-6A and Jason-3 following their successful Tandem Phase.
The number of hydrological targets used to define the tracking command currently reaches an unprecedented number of targets of almost 100,000 for each Sentinel-3 and about 30,000 for Sentinel-6A. We expect to define a similar number of targets in the interleaved orbit of Jason-3, previously flown by Jason-2, although mostly in Closed-Loop Mode.
These major improvements over the last few years have been made possible by the analysis and merging of the most up-to-date digital elevation models (SRTM, MERIT and ALOS/PalSAR) and water bodies databases (HydroLakes, GRaND v1.3, SWBD, GSW, SWORD). In addition, special effort is put into introducing the most recent reservoir databases. This methodology ensures coherency and consistent standards between all nadir altimetry missions and types of hydrological targets.
Finally, additional efforts have been carried out to define a relevant tracking command outside of hydrological areas, in order to keep track of the continental surface and enabling potential other land applications, while optimizing the OLTC onboard memory.

The OLTC function of nadir altimeters constitutes a great asset for building a valuable and continuous record of the water surface height of worldwide lakes, rivers, reservoirs, wetlands and even a few continental glaciers. This work is essential at institutional and scientific levels, to make the most of current altimeters coverage over land and to prepare for the upcoming calibration and validation of the Surface Water and Ocean Topography (SWOT) mission. In this context, we will show an overview of OLTC achievements and perspectives for future altimetry missions.

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Increased variability in Greenland Ice Sheet runoff detected by CryoSat-2 satellite altimetry

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Forum only

Abstract:
Runoff from the Greenland Ice Sheet has increased over recent decades affecting global sea level, regional ocean circulation, and coastal marine ecosystems. Runoff now accounts for most of Greenland's contemporary mass imbalance, driving a decline in its net surface mass balance as the regional climate has warmed. Although automatic weather stations provide point measurements of surface mass balance components, and satellite observations have been used to monitor trends in the extent of surface melting, regional climate models have been the principal source of ice sheet wide estimates of runoff. To date however, the potential of satellite altimetry to directly monitor ice sheet surface mass balance has yet to be exploited. Here, we explore the feasibility of measuring ice sheet surface mass balance from space by using CryoSat-2 satellite altimetry to produce direct measurements of Greenland's runoff variability, based on seasonal changes in the ice sheet's surface elevation. Between 2011 and 2020, Greenland's ablation zone thinned on average by 1.4 ± 0.4 m each summer and thickened by 0.9 ± 0.4 m each winter. By adjusting for the steady-state divergence of ice, we estimate that runoff was 357 ± 58 Gt/yr on average – in close agreement with regional climate model simulations (root mean square difference of 47 to 60 Gt/yr). As well as being 21 % higher between 2011 and 2020 than over the preceding three decades, runoff is now also 60 % more variable from year-to-year as a consequence of large-scale fluctuations in atmospheric circulation. In total, the ice sheet lost 3571 ± 182 Gt of ice through runoff over the 10-year survey period, with record-breaking losses of 527 ± 56 Gt/yr first in 2012 and then 496 ± 53 Gt/yr in 2019. Because this variability is not captured in global climate model simulations, our satellite record of runoff should help to refine them and improve confidence in their projections.

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Measuring the Earth energy imbalance from space geodesy to constrain the global energy budget and estimate the climate sensitivity

Jonathan Chenal (LEGOS / ENPC, France); BENOIT MEYSSIGNAC (LEGOS / CNES, France); ALEJANDRO BLAZQUEZ (LEGOS / CNES, France); ROBIN GUILLAUME-CASTEL (LEGOS, France)

Session: Science Keynotes Session
Presentation type: Keynote/invited

Abstract:
The energy radiated by the Earth toward space does not compensate the incoming radiation from the Sun leading to a small positive energy imbalance at the top of the atmosphere (0.4–1 Wm–2). This imbalance is coined Earth's Energy Imbalance (EEI). At decadal time scales, it is mostly caused by anthropogenic greenhouse gas emissions and it is driving the current warming of the planet. Combined with surface temperature measurements the EEI measurement informs on the sensitivity of the climate system to GHG emissions (the so-called climate sensitivity). Thus monitoring precisely the EEI is critical to assess the current status of climate change, estimate the climate sensitivity and by this mean evaluate the future evolution of climate. But the monitoring of EEI is challenging as it is two orders of magnitude smaller than the radiation fluxes in and out of the Earth system. Over 90% of the excess of energy that is gained by the Earth in response to the positive EEI accumulates into the ocean in the form of heat such that the monitoring of Ocean Heat Content (OHC) and its long-term change provides a precise estimate of EEI.

Today, global OHC changes can be tracked from space with a combination of the altimetric measurement of sea level change and the gravimetric measurement of ocean mass change. In this talk we review this current space method to estimate global OHC changes and evaluate its relevance to derive EEI estimates on different time scales. We compare its performance with an independent estimate from direct observations of in situ temperature. Then, we use both the space based and in situ based estimates of EEI along with the surface temperature record to derive estimates of the 20th century mean effective climate sensitivity. Accounting for the internal variability (with an explicit representation of the so called "pattern effect") we derive from our observed 20th century effective climate sensitivity an observational constraint on the climate sensitivity of 3.4 [1.5;20.8] K (median, 5-95% CI) with the space geodetic data. With a longer in situ dataset, we obtain a tighter constraint of of 5.4 [2.4;35.6] K.

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Topographically Trapped Waves around South America with periods between 40 and 130 days in a global ocean reanalysis.

Léa Poli (LOCEAN, France); Camila Artana (ICM-CSIC, Spain); Christine Provost (LOCEAN, France)

Session: Science Keynotes Session
Presentation type: Keynote/invited

Abstract:
The South American continental slope hosts a variety of topographic waves. We use a 27 year-long global ocean reanalysis (1/12° spatial resolution) to examine trapped waves around South America at periods ranging from 40 to 130 days. The waves propagate from the Equatorial Pacific to the Tropical Atlantic (22°S) with phase velocities between 1.8 m/s and 7 m/s according to the local background characteristics, such as stratification, slope steepness, latitude, mean flow and shelf width. The Madden-Julian Oscillation (MJO) plays a key role in forcing the trapped waves in two ways i) through an oceanic connection implying equatorial Kelvin waves reaching the western American Coast and ii) through an atmospheric teleconnection enhancing southerly winds in the south-east Pacific. Furthermore, local winds, not necessarily linked with the MJO, modulate and trigger waves in specific locations, such as the Brazil-Malvinas Confluence. Trapped waves impact the along-shore currents: during the positive phase of the waves the near-surface flow is enhanced by about 0.1 m/s.

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4DVarNN, an end-to-end learning of variational interpolation schemes: current applications on satellite-derived data and on-going developments

Maxime Beauchamp (IMT Atlantique, France); Ronan Fablet (IMT Atlantique, France); Quentin Febvre (IMT Atlantique, France); Mohamed Mahmoud Amar (IMT Atlantique, France); Benjamin Carpentier (CLS, France)

Session: Science Keynotes Session
Presentation type: Keynote/invited

Abstract:
The reconstruction of sea surface currents is a key challenge in spatial oceanography. We recently proposed the so-called 4DVarNN algorithm, a generic end-to-end deep learning scheme for inverse problems using a variational formulation. Based on Observing System Simulation Experiment (OSSE) involving high-resolution numerical simulations in the Gulf Stream region, the preliminary applications of the 4DVarNN algorithm using an LSTM-based parametrization of the solver have shown promising results. We propose here to present the recent evolutions of the 4DVarNN framework applied to spatio-temporal interpolations of satellite-derived datasets. First, 4DVarNN embeds a variational formalism which is a natural framework for exploiting multi-tracer synergies (e.g. SSH and SST) in the reconstruction of altimetric fields benefiting from high-resolution satellite products. Using a similar OSSE configuration, we demonstrate how the use of SST may help for the identification of ocean fronts resulting in a better reconstruction of the SSH. Second, the variational formulation also enables to design optimal monitoring and sampling strategies to retrieve the best reconstruction of the submesoscale processes. Last, from an operational perspective, a new version of the code able to deal with datasets scaling up to an ocean basin has been recently distributed. Training the model involves a new strategy based on iterating the entire datasets in small batches. This code is open-source and enables its future use for both design and participation in ocean data challenges.

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Interferometric Swath Radar Altimetry for the study of the Cryosphere

Noel Gourmelen (University of Edinburgh, United Kingdom)

Session: Science Keynotes Session
Presentation type: Keynote/invited

Abstract:
Reference and repeat-observations of land-ice topography is critical to identify causal links between climate and ice trends, generate an accurate record of ice mass balance, and quantify land ice contribution to sea level change. Over the last 30 years, radar altimetry has been instrumental in monitoring ice sheets and their contribution to sea level change. Launched in 2010, the European Space Agency Altimetry mission CryoSat-2 was the first radar altimetry mission with a SAR/Interferometry radar altimeter payload. The aim of this new technology was to gain a better insight into the evolution of the cryosphere, in particular over the steep slopes typically found along ice sheet margins and glaciers where the majority of the mass loss is taking place. CryoSat's revolutionary design features a Synthetic Interferometric Radar Altimeter (SIRAL), with two antennas for interferometry, the corresponding SAR Interferometer (SARIn) mode of operation increases spatial resolution while also increasing the accuracy of the geo-location by resolving the angular origin of off-nadir echoes occurring over sloping terrain.

While the elevation of the Point Of Closest Approach (POCA), or level-2, is the standard product of the CryoSat-2 mission, the Interferometric mode of CryoSat-2 provides the ability to resolve substantially more than just the elevation at the POCA and thus led to a paradigm shift in radar altimetry of land ice. The so-called "swath processing" exploit the fact that over sloping terrain, CryoSat-2 altimeter operates in a manner such that the interferometric phase of the altimeter echoes may be unwrapped to produce a wide swath of elevation measurements across the satellite ground track, well beyond the POCA only. This technique provides the opportunity to increase spatial resolution and to recover elevation over regions where conventional radar altimetry fails; providing an opportunity to monitor land ice trends globally from radar altimetry.

Here I will discuss work done over the last decade to develop and apply swath processing over all components of land ice including the Greenland and Antarctic Ice Sheets, ice shelves, and glaciers worldwide, mapping ice mass balance, sub-glacial lakes, ice shelves melting, and improving the understanding of processes linking ice trends to climate forcing. Finally, I will discuss remaining challenges and the opportunities brought by CRISTAL whose primary mode over land ice will be SARIn and who will have swath processing as a core technology to derive time-dependant ice topography.

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On the improvement of ocean/wave coupling with CFOSAT directional wave observations

Lotfi Aouf (Division Marine et Océanographie Météo-France, France); Stéphane Law-Chune (MOI, France); Danièle Hauser (LATMOS/CNRS, France); Bertrand Chapron (IFREMER, France); Cedric Tourain (CNES, France)

Session: CFOSAT
Presentation type: Keynote/invited

Abstract:
The propagation of waves at the air-sea interface strongly influences surface stress and turbulent mixing in the upper ocean layers. Better estimate of directional properties of sea state should improve the turbulent mixing that deepens the ocean surface boundary layer. The CFOSAT mission provides directional wave spectra that can better scale wind-wave growth and the transition to swell regime. This induces a significant improvement of integrated sea state parameters (Aouf et al. 2021). The objective of this work is on the one hand to assess the impact of wave directionality on ocean circulation, and on the other hand to analyze the dominant wave/ocean coupling term in critical ocean areas where there is high uncertainty on wind forcing such as Southern Ocean and the tropics. To this end several coupled global simulations between the MFWAM wave model and the ocean model NEMO have been implemented globally with a grid resolution of 25 km. The wave model is used with and without assimilation of directional wave spectra and off-nadir wave heights of CFOSAT (SWIM beam 10°). The experiments were carried out over the periods from January to April for the years 2020 and 2021. Firstly, the validation of Significant Wave Height (SWH) from the MFWAM model with independent altimeters data shows significant reduction in bias and scatter index when the assimilation of CFOSAT observations is activated. We have selected the ocean regions where the impact of assimilation is strongest and we examined the impact on ocean wave forcing represented by surface stress, Stokes drift and wave breaking inducing turbulence in the ocean mixed layer. We validated key ocean parameters (current, temperature, elevation, salinity) with in situ observations and satellite data. The results show a significant improvement in surface currents in the Southern Ocean, particularly in the vicinity of the Antarctic Circumpolar Current. We also found an improvement of the surface current in the tropics. Analysis on the oceanic mixing layer indicates a significant impact of the waves. This results in an improvement in the surface temperature in the southern ocean, particularly in the Weddell Sea and between southern Australia and the Antarctic.
Further comments and conclusions will be addressed in the final presentation.

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NASA/CNES/EUMETSAT/NOAA/ESA program status

Nadya Vinogradova-Shiffer (NASA, United States); Annick Sylvestre-Baron (CNES, France); Estelle Obligis (EUMETSAT, Germany); Chris Sisko (NOAA, United States of America); Jérôme Benveniste (ESA-ESRIN, Italy)

Session: OSTST Opening Plenary Session
Presentation type: Oral

Abstract:
Programmatic status from NASA, CNES, EUMETSAT, NOAA and ESA
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Jason-3 mission overview

Christophe Ferrier (CNES, France)

Session: OSTST Opening Plenary Session
Presentation type: Oral

Abstract:
Overview of the Jason-3 mission
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SARAL/AltiKa mission overview

Nadège Queruel (CNES, France)

Session: OSTST Opening Plenary Session
Presentation type: Oral

Abstract:
Overview of the SARAL/AltiKa mission
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Sentinel-3 mission overview

Bruno Lucas (EUMETSAT, Germany); Pierre Femenias (ESRIN/European Space Agency, Italy)

Session: OSTST Opening Plenary Session
Presentation type: Oral

Abstract:
Overview of the Sentinel-3 mission
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Sentinel-6 Michael Freilich mission overview

Julia Figa Saldana (EUMETSAT, France); Pierrik Vuilleumier (ESA/ESTEC, The Netherlands); Parag Vaze (NASA/JPL, Unites States of America); Chris Sisko (NOAA, United States of America); Gilles Tavernier (CNES, France)

Session: OSTST Opening Plenary Session
Presentation type: Oral

Abstract:
Overview of the Sentinel-6 Michael Freilich mission
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CFOSAT mission overview

Jean-Michel Lachiver (CNES, France)

Session: OSTST Opening Plenary Session
Presentation type: Oral

Abstract:
This presentation consists in a status of the CFOSAT mission and will focus in particular on the main events since the previous OSTST meeting.
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SWOT mission status

Lee-Lueng Fu (JPL, United States); Rosemary Morrow (LEGOS, France)

Session: OSTST Opening Plenary Session
Presentation type: Oral

Abstract:
Status of the SWOT mission
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Overview and Status of the Copernicus Sentinel-3 Next Generation Topography (S3NG-T) Mission

Pierrik Vuilleumier (European Space Agency, ESTEC, Netherlands); Craig Donlon (ESTEC/ European Space Agency, Netherlands); Luisella Giulicchi (European Space Agency, ESTEC, Netherlands); Remko Scharroo (EUMETSAT, Germany)

Session: OSTST Opening Plenary Session
Presentation type: Oral

Abstract:
The Sentinel-3 Mission provides an essential satellite altimetry data set for the Copernicus services over the global ocean, coastal zones, sea and land ice and inland waters in support of a large number of end user applications. Four Sentinel-3 satellites (two currently on orbit and two replacements to be launched in the coming years) operating in a sun-synchronous near polar orbit provide an unprecedented and unbroken time series of satellite altimetry measurements from 2016-2035.

Considering the User needs expressed by the European Commission and inputs from an independent Mission Advisory Group are documented in the S3-NG-T Mission Requirements Document. The aim of the Copernicus Next Generation Sentinel-3 Topography (S3NG-T) Mission is to guarantee baseline continuity of existing Copernicus Sentinel-3 nadir-altimeter measurements in the 2030-2050 time-frame while enhancing measurement performance.

The primary objectives of the S3NG-T mission are to:

PRI-OBJ-1. Guarantee continuity of Sentinel-3 topography measurements for the 2030-2050 time frame with performance at least equivalent to Sentinel-3 in-flight performance (‘baseline mission’).

PRI-OBJ-2. Respond to evolving user requirements and improve sampling, coverage and revisit of the Copernicus Next Generation Topography Constellation (S3NG-T and Sentinel-6NG) to ≤ 50 km and ≤ 5 days in support of Copernicus User Needs.

PRI-OBJ-3. Enhance sampling coverage, revisit and performance for Hydrology Water Surface Elevation measurements in support of Copernicus Services.

PRI-OBJ-4. Respond to evolving user requirements and enhance topography Level-2 product measurement performance.

The secondary objectives of the S3NG-T mission are to:

SEC-OBJ-1. Provide directional wave spectrum products that address evolving Copernicus user needs.
SEC-OBJ-2. Provide new products (e.g. sea surface height gradients and river reach averaged gradients, river width and water area. that address evolving Copernicus user needs.

A coordinated constellation of spacecraft is required to provide enhanced continuity to the Sentinel-3 Mission to meet sampling at ≤5 days, ≤ 50 km (25 km wavelength) between 81.5□ north and south of the equator regardless of the satellite technologies employed. Such a constellation requires a reference that allows each mission to be used in synergy with each other to satisfy User needs without bias discrepancies. For the S3NG-T mission, it is assumed that a reference satellite mission (e.g. Copernicus Sentinel-6/NG) will be available in orbit that is designed for this purpose providing a common reference measurement for all S3NG-T satellites and with excellent knowledge of measurement stability. Additional third party altimeter missions may also provide additional data although their launch or access to their data cannot be guaranteed.

Continuity of Sentinel-3 measurements can be guaranteed using a number of different technical solutions with potential enhancements in terms of coverage, sampling, calibration stability, system complexity and size amongst others. The best implementation approach for the S3NG-T mission shall be based on "fitness for purpose to provide enhanced continuity to Sentinel-3 topography measurements" determined by compliance to mission requirements, maturity of technical heritage, technical feasibility/readiness, scientific readiness and maturity, development schedule, risk, cost and programmatic arrangements. Based on the S3NG-T Phase-0 activities and other studies conducted by ESA over the last 5 years the most likely scenarios to implement S3NG-T include the following:

Scenario-1: Replacement of Sentinel-3C and Sentinel-3D using a constellation of 2-n nadir-pointing altimeters.
Scenario-2: Implementation of 2..n swath altimeter including a nadir altimeter.

Scenario-3: A hybrid approach including both nadir pointing altimeter and swath altimeter satellites

This paper will review the current status of the S3NG-T Mission following the completion of Phase-0 studies and on-going Phase A/B1 studies at ESA.

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CRISTAL mission status

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Session: OSTST Opening Plenary Session
Presentation type: Oral

Abstract:
Status of the CRISTAL mission
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Argo and Sea level science: Present and Future Challenges

Susan E Wijffels (Woods Hole Oceanographic Institution and the Argo Steering Team, United States)

Session: OSTST Opening Plenary Session
Presentation type: Oral

Abstract:
Argo's original design was informed by and targeted to complement spaceborne satellite observations, in order to illuminate the subsurface drivers of surface sea level variability and change. This combination has been a powerful observing system combination over the past 20 years. Here, we assess Argo's present and near-term status. We will discuss relevant recent technical challenges Argo has faced and how these have been addressed, including revisiting how Argo deals with and flags sensor drifts. Lastly, we will review progress towards implementation of OneArgo – the new full-depth, multidisciplinary and global array for the future.

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What do we really mean by emergency? OSTST and IPCC data and results about the global warming.

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Session: OSTST Opening Plenary Session
Presentation type: Oral

Abstract:
OSTST community feeds climate community with altimetry data of increasing quality. Number of missions and observations increase, uncertainties are better characterized and historical missions are reprocessed to benefit from recent standards.

Among the users, the IPCC (International Panel on Climate Change) is about to close its sixth assessment cycle, in which the IPCC have produced the Sixth Assessment Report (AR6) with contributions from its three Working Groups, three Special Reports, and a Synthesis Report. In particular, the Working Group I report addresses the most updated physical understanding of the climate system and climate change. Several levels of global warming with an increasing level of casualties and lethality for the terrestrial ecosystem are detailed.

One key feature of this report is the notion of remaining carbon budget, used to describe the total net amount of CO_2 that remains to be released in the future by human activities before reaching a specific global warming level.

In this presentation we consider the IPCC value of remaining carbon budget, and we convert it into remaining emissive years to understand the climate timescale . We analyze typical carbon footprint and deduce some of the most efficient actions that could be taken at individual and collective level.
We open a reflection on the balance between OSTST responsibility to maintain performing science and its responsibility to control its Greenhouse Gazes emissions

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Non-closure of the global mean sea level budget since 2016: contributions of altimetry and Argo

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Oral

Abstract:
The global mean sea level (GMSL) changes result from the sum of the steric and ocean mass global mean changes. Assessing the GMSL budget allows to cross-validate the consistency and stability of the observing systems involved. Many independent studies have shown that the GMSL budget is closed within uncertainties over the 1993-2016 time period. However, the sea level budget appears no longer closed after 2016 when using Jason-3 altimetry, Argo and GRACE/GRACE Follow-On gravimetric data. This non-closure may result from errors in one or several components of the sea level budget (altimetry-based GMSL, Argo-based steric sea level or GRACE-based ocean mass). We have investigated possible sources of errors affecting Jason-3 and Argo data. Concerning altimetry data, comparisons of Jason-3 GMSL time series with other altimetry missions show agreement within 0.4 mm/yr of standard uncertainty over 2016-2020. However, the comparisons of Jason-3 wet tropospheric correction with other altimetry missions and with climate data records show that Jason-3 radiometer is likely to drift. Such drift could be responsible for about 30 % of the non-closure of the budget. Concerning Argo in-situ data, a good agreement is found between all available thermosteric products. However, a decrease in the global mean halosteric sea level is observed since 2016 with strong discrepancies between the different data providers. A halosteric decrease corresponds to a salinity increase which is in contradiction with the global freshening of the oceans. This non-physical behaviour is attributed to uncorrected salinity measurement drifts and is responsible for about 40 % of the budget non-closure. Given that the halosteric component is expected to be negligible in global average, this spurious contribution should be neglected in the budget. The budget closure is significantly improved by taking into account a Jason-3 radiometer drift and assessing the sea level budget using only the thermosteric and ocean mass components. The remaining budget residual trends could be due to potential errors in the other components (i.e. thermosteric component based on Argo in-situ data, global mean ocean mass component based on GRACE and GRACE Follow-On satellite gravimetric data, missing physical contribution) that should be further investigated.

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An initial investigation of multi-sensor coastal zone altimetry

Brett Buzzanga (JPL, United States); Ben Hamlington (JPL, USA)

Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Oral

Abstract:
Satellite altimetry continues to revolutionize ocean science, enabling precise observations of geocentric sea level with near-global coverage. However, altimetry has traditionally been challenged in the coastal zone (within 20 km of land) due to the presence of land in the altimeter and radiometer footprint. As the oceans further encroach on coastal communities, a more detailed understanding of the physical processes impacting sea-level variability as it propagates landward is needed. State-of-the-art satellite altimeters have the potential to observe this coastal data gap and improve our scientific understanding.

Sentinel-6/Michael-Freilich (S6/MF) not only continues the decades-long record of radar altimetry in conventional low-resolution mode, but acquires data high-resolution data simultaneously in synthetic aperture radar mode. While previous ESA missions have shown the potential of high-resolution mode to improve returns at the coast, the data from S6/MF has yet to be fully explored. Complementing these measurements, the laser altimeter onboard the ICESat-2 satellite observes geocentric sea level with a much smaller footprint than radar altimeters (nominally 17 m vs ~300 m for S6/MF). ICESat-2 returns are available very close to the coast, albeit at reduced temporal resolution relative to S6/MF.

Here we use these sensors in conjunction to investigate coastal sea-level trends and variability. We first perform comparisons with temporally overlapping Jason-3 data and in-situ tide gauge observations. Along shorelines of good agreement, we investigate how monthly variability propagates from the open ocean to the coast. Where differences in coastal and open-ocean variability are evident, we perform analysis to disentangle physical drivers, including riverine and atmospheric forcing, and to understand the role of coastal zone morphology. We are specifically interested in the alongshore sea-level gradient. We investigate how the gradient evolves in time, and from the coast to the open ocean. We rely primarily on correlation analysis, but leverage theoretical principles to elucidate our findings.

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A new network of altimetry-based virtual stations for measuring sea level along the world coastlines

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Oral

Abstract:
Until recently, classical radar altimetry could not provide reliable sea level data within 10 km to the coast. However dedicated reprocessing of radar waveforms together with geophysical corrections adapted for the coastal regions now allows to fill this gap at a large number of coastal sites. In the context of the ESA Climate Change Initiative (CCI) Sea Level project, we have recently performed a complete reprocessing of along-track, high resolution (20 Hz, i.e. 300m resolution along-track) altimetry data of the Jason-1, Jason-2 and Jason-3 missions over 2002-2020 along the coastal zones of Northeast Atlantic, Mediterranean Sea, Africa, North Indian Ocean, Southeast Asia, Australia, and America. This reprocessing has provided valid sea level data in the 0-15 km band from the coast. A total of 773 altimetry-based virtual coastal stations (distance <6 km from coast) have been selected for all regions. Sea level anomaly time series, together with associated coastal sea level trends, have been computed over the 2002-2020 time span. In the coastal regions devoid from tide gauges (e.g., African coastlines), these virtual stations offer a unique tool for estimating sea level change close to the coast (typically up to 3 km to the coast, but in many instances up to 1 km or less). Results show that at about 20% of the 773 selected sites, coastal sea level trends are either larger or smaller in the last 4-6 km to the coast compared to open ocean sea level trends. Understanding such a behavior will need further investigation.

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Assessing the Closure of the Sea Level Budget in the Southwest Pacific Basin Using Deep Argo

Paige Lavin (University of Maryland; NOAA/STAR, United States); Gregory Johnson (NOAA/PMEL, United States)

Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Oral

Abstract:
Changes in regional mean sea level can dramatically increase the flooding risk for island and low-lying coastal communities, and can have far larger magnitudes than the trend in global mean sea level. One important tool for understanding sea level variability and ensuring that we are measuring it accurately is the sea level budget (SLB). In this work, we investigate the “closure” of the SLB in the Southwest Pacific Basin by exploring whether the altimeter-based sea level anomaly measurements (from the NOAA/EUMETSAT Radar Altimeter Database System) match the sum of the anomalies in the independently observed steric (from Core and Deep Argo floats) and barystatic (from GRACE/GRACE-FO) sea level components. The Southwest Pacific Basin contains an operational multiyear Deep Argo array (beginning in January 2016) that has not yet been analyzed in this SLB framework. Previous work found it challenging to close the SLB in this region without the higher temporal and spatial coverage of the deep steric term that the Deep Argo floats provide. The Deep Argo float dataset is the most limited of the datasets used here in terms of spatial coverage and resolution (~5° × 5°) so the availability of these data limits where we can calculate the SLB and over what scale. We analyze the SLB within 6° × 6° grid cells that are equivalent in size to four GRACE/GRACE-FO mascons. By comparing the trend in the sea level anomaly to the trends in the barystatic and steric sea level terms, we quantify the impact of the Deep Argo data on the closure of the SLB over each 6° × 6° region for the Southwest Pacific Basin.
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Secular and seasonal reconstructing of global and regional sea level change

Carsten Ludwigsen (DTU Space, Denmark); Andersen Ole (DTU Space, Denmark)

Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Oral

Abstract:
Here we present a global sea level reconstruction from 1992 to 2021. Each mass contribution (Greenland, Antarctica, Glaciers, Terrestrial Water Storage, GIA) to both relative (S) and absolute sea level (N) and vertical land movement (U = N - S) and the halo- and thermosteric contribution is defined monthly in an equal-area grid (r ~ 45km). This allows for reconstructing both secular and seasonal sea level changes at any location of the globe.

Each contributions is defined from the mean of 1000 ensemble calculations. The standard deviation of the ensembles provides the uncertainty.

Globally, the reconstruction fits the global mean sea level (GMSL) observations from altimetry from 1992-2016, with only small monthly misfits (varies between +/- 0.5 cm), while the timeseries GRACE/GRACE-FO agrees with the monthly variations of the sum of the mass contributions (+/- 0.2 cm misfit). After 2016 the trends of Altimetry and the reconstruction begin to deviate with a total disclosure of up to 1.5 cm in 2021, while the mass contribution still aligns with GRACE/FO. Around 2016 we observe that the halosteric sea level contribution is declining, after been around zero from 1992-2015. This indicates a fault in the halosteric calculations possibly related to instrumental problems of the ARGO profiles that results in faulty salinity measurements. Removing the halosteric component removes around 50% of the misclosure, leaving the remaining disclosure unexplained.

Comparisons with altimetry and tide gauges at different locations will be shown at both seasonal and long-term time-scales.

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Understanding Forced Climate Signals in the 30-year Satellite Altimeter Sea Level Record

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Oral

Abstract:
Recent research has shown that the forced response to greenhouse gases and aerosols is beginning to emerge in the 30-year trends of sea level change observed by satellite altimetry. Many of the features in the observed trends can be tied to physical mechanisms in the climate system as it responds to climate change, which we will review. The main question we are trying to answer is what are these trends telling us about future patterns of regional sea level change? To answer this question, we turn to climate models, which allow us to probe the various contributions of greenhouse gases, anthropogenic aerosols, biomass burning, and volcanic eruptions to regional patterns of sea level change. Climate models suggest there will be substantial persistence in the patterns of forced sea level change as we move into the coming decades, but there will likely be subtle differences and accompanying contributions from internal climate variability. We explore various machine learning techniques to understand how to map observed sea level patterns into the future. We will discuss our preliminary results from this effort and our plans for future research.
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Influence of Deep-Ocean Warming on Coastal Sea-Level Trends in the Gulf of Mexico

Jacob Steinberg (Woods Hole Oceanographic Institution, United States); Christopher Piecuch (WHOI, United States); Benjamin Hamlington (NASA JPL, United States); Sloan Coats (University of Hawaii Manoa , United States); Phillip Thompson (University of Hawaii Manoa , United States)

Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Oral

Abstract:
Thirty years of satellite-altimeter measurements show that rates of sea level rise are increasing across much of the global ocean. Such sea-level acceleration is particularly pronounced along the U.S. Gulf of Mexico coastline. Here we use model and observational data to identify the underlying mechanisms responsible for the enhanced rates of coastal sea-level rise in this region. Specifically, we quantify that subsurface warming in the Gulf of Mexico contributes importantly to sea-level rise at the coast. Using the Estimating the Circulation and Climate of the Ocean (ECCO) state estimate, we find changes in ocean bottom pressure are the main contributor to coastal sea-level changes in this region on inter-annual to decadal timescales.These ocean bottom pressure changes reflect both a net mass flux into the Gulf, but more importantly a redistribution of mass within the Gulf, which can be understood as an isostatic ocean response to warming of the Gulf of Mexico below the seasonal mixed layer. The nature of this response is shaped by basin geometry and the depth of warming. This relationship, between ocean bottom pressure at the coast and subsurface warming over the deep Gulf of Mexico, is then tested using observations of ocean bottom pressure from the Gravity Recovery and Climate Experiment (GRACE), coastal relative sea level from tide gauge measurements, sea-surface height from altimetry, and Argo profiles of upper ocean temperature and salinity. Results show that changes in coastal ocean bottom pressure predicted from observed subsurface warming explain a dominant fraction of observed coastal sea-level changes. For example, at St. Petersburg, Florida over the 2008-2017 period, we find subsurface-warming-driven ocean-mass-redistribution effects account for ~50% of the observed coastal sea-level trend — a greater fraction than that due to mass flux into the Gulf. This analysis identifies a physical mechanism by which coastal sea level responds to open-ocean subsurface warming. It motivates future studies of the open-ocean influence on coastal sea level in other regions.

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A detailed analysis of S3 and S6 fully-focused SAR waveforms: Enabling SAMOSA-based retracking

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Session: Instrument Processing: Measurement and Retracking
Presentation type: Oral

Abstract:
S6 fully-focused SAR (FF-SAR) waveforms are noticeably narrower than for S6 unfocused SAR (UF-SAR), which produces a significant bias in the geophysical estimates after applying a SAMOSA-based fitting. We demonstrate that a major part of these shape differences can be explained with the shapes of grating lobes and side lobes in the impulse response function (IRF) of FF-SAR and UF-SAR. With this insight, we can compensate for the differences.

Note that S6 has been designed in such a way that it suppresses the grating lobes in the FF-SAR IRF such that their influence is almost negligible. However, any grating lobes and sidelobes are not perfectly in focus and appear blurred. This was already noticed over a transponder target for CryoSat-2, see Figure 8 in by Guccione et al. (2018). The blurring in range direction occurs, because the applied range cell migration correction (RCMC) corrects only for the range history of the focus point, but not for the range history of targets at the grating lobe or side lobe positions.

We have developed a straightforward technique to minimise the difference between the emulated S6 UF-SAR and S6 FF-SAR waveform shapes, which preserves the full along track resolution. This result is significant, because it enables us to use the same SAMOSA-based retracking model for both UF-SAR and FF-SAR waveforms. This is especially useful for the coastal areas, where the high resolution of FF-SAR has a very high potential.

Our analysis is performed using our multi-mission FF-SAR backprojection algorithm, which allows for fully-focused processing of CryoSat-2, Sentinel-3 and Sentinel-6 MF. UF-SAR waveforms are an “emulated” by-product of the FF-SAR processing, as described in Egido et al. (2017) and Egido et al. (2021). This allows for a fully-consistent comparison of UF-SAR and FF-SAR waveforms at very high posting rates. In fact, all processing settings and input data are identical. It can be demonstrated that our emulated UF-SAR waveforms correspond well to the official L1b product.

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FFSAR replica removal algorithm for closed-burst data

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Session: Instrument Processing: Measurement and Retracking
Presentation type: Oral

Abstract:
The SAR-mode processing in altimetry as it is currently operated in ground segments does not exploit the full capabilities of the SAR system in terms of spatial resolution. The so-called unfocused SAR altimeter (UFSAR) processing performs the coherent summation of pulses over a limited number of successive pulses (64-pulses bursts of a few milliseconds in length) reducing the along-track resolution down to 300 m only. Since recently [2], the concept of coherent summation has been extended to the whole illumination time of the surface (typically more than 2 seconds) allowing to increase the along-track resolution up to the theoretical limit (approximately 0.5 m) and thus improving the SAR-mode capability for imaging reflective surfaces of small size. The benefits of the fully-focused coherent processing have already been demonstrated on various surfaces to differentiate targets of heterogeneous surfaces (like sea-ice, inland-water and coastal) and to achieve the maximum effective number of looks available from SAR altimetry on homogeneous surfaces (like ocean) [2].

The limitations of the FF-SAR in closed-burst mode has already been reported in [2], creating very harmful artificial side lobes in the along-track dimension due to lacunary chronogram. It is extremely challenging to separate real signal from its replicas when they are superimposed, considering that every reflecting focalization point on ground creates its own replicas. Both Sentinel-3 and Cryosat-2 SAR altimetry missions have been designed with a lacunary chronogram, one exception is for the quasi-continuous pulse transmission Sentinel-6 inter-leaved mode. Over heterogeneous targets, replicas interference creates peaks and troughs pattern, with overflow of power outside of the water body boundaries and destruction of power inside the water body boundaries. This clearly jeopardizes confidence in data and its use for large water body detection like lead detection a major goal in SAR altimerty sea-ice application.

At level-2, impact of replicas on the estimated geophysical parameters are not completely understood yet. Even at crossing point between Sentinel-3 and Sentinel-6, it might be tricky to compare the results due to not identical footprint and overflight angle, but also altimeters differences apart from chronogram (like the sampling frequency, deramping/match-filtering and SNR). A new methodology of comparison has been developed and implemented at CLS taking Sentinel-6 data and emulating the sparse closed-burst mode chronogram of Sentinel-3 by removing pulses. Thus on same acquisition points open-burst and closed-burst can be compared each other by isolating only replica effect. More than 700 hydrological targets (including narrow rivers, larger rivers, lakes and dam) have been already processed. First results showed as expected global differences in amplitude but more surprisingly a higher range variability of 1.5cm in closed-burst mode compared to open-burst mode.

Next progress is replica removal, a very important topic if we expect to exploit the full potential of FF-SAR processing with Sentinel-3 and Cryosat-2 data. We propose a deconvolution technique to recover the open-burst radargram using optimization method starting from Wiener filtered first guess [3] and a model that takes into account replicas. A new model of multi-scatterer FF-SAR impulse response function, based on LRM inland-water model approach in [1], has been developed and validated over diverse rivers data acquisition. This model supposes water presence a priori knowledge, which might be relevant for inland-water (by exploiting water surface masks), but turns out to be completely irrelevant for sea-ice lead targets permanently in movement. To tackle this problem, the replica model is first optimized to determine the position and specularity of water presence that fit at best real data. Once the model fixed, deconvolution is validated by comparison of reference Sentinel-6 open-burst geophysical parameters with deconvoluted degraded Sentinel-6 closed-burst data. Different surfaces captured by Sentinel-6 will be deconvoluted including rivers, lakes, leads and open-ocean.

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2D SAR Altimetry Retracking – Lessons Learned

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Session: Instrument Processing: Measurement and Retracking
Presentation type: Oral

Abstract:
For more than ten years, Synthetic Aperture Radar (SAR) altimetry has contributed to a better understanding of sea surface related parameters such as sea surface height (SSH), significant wave height (SWH) and windspeed. However, compared to conventional altimetry (CA) data an inconsistency with respect to SWH estimates is observed. We suggest to solve this issue by introducing an additional geophysical parameter sigmav describing an along-track blurring effect caused by vertical wave particle velocities. As this parameter effects a SAR waveform in a very similar way than SWH it is necessary to use the whole SAR stack as a retracking input. Otherwise, the retracker will not be able to distinguish between SWH and sigmav.

This study shall give an overview about how 2D SAR retracking can be achieved in a – to our best knowledge – correct and efficient manner. We will discuss stack processing choices, starting at Full Bit Rate (FBR) data and retracking choices on the example of CryoSat-2, Sentinel-3A and Sentinel-3B.

The performance of the retrieved geophysical parameters will be visualized in this study with respect to the ERA5 wave model and in-situ-data located in the northeast Atlantic region.

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Improving inland water altimetry retracking by incorporating spatial dependency of waveforms

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Session: Instrument Processing: Measurement and Retracking
Presentation type: Oral

Abstract:
Single-waveform retracking for satellite altimetry applications of inland waters has reached its limits, obtaining decimeter-level accuracy or worse. The existing retracking methods find a retracker offset in a waveform by analyzing the variation in power along with the bin coordinate. This makes the retracking procedure strongly dependent on noise. Moreover, the success of such methods is only guaranteed for certain waveform types requiring cumbersome pre-processing steps, including waveform classification.
In this study, we collect neighboring waveforms into a radargram. The so-called radargram contains, unlike single waveforms, information on spatial variation of backscattered power over water surfaces. The radargram eases the recognition of patterns like retracking gate, off-nadir pattern (e.g., parabola), shoreline, etc. Instead of a retracking gate as a point in the 1D waveform, in a 2D radargram a line (referred to as a retracking line) is to be determined. In fact, by finding a retracker line in a radargram, each radargram can be segmented into two parts: the left and right hand side of the retracking line. This can be interpreted as a binary image segmentation problem in a more straightforward representation, in which spatial constraints are considered.
We formulated this problem using Markov Random Fields (MRF), which explicitly model the interaction between different constraints and auxiliary sources of information in a radargram. In such a formulation, we deal with a Bayesian framework with the goal of finding a specific labeling structure of the image which maximizes the posterior estimation of the MRF (MAP-MRF).
We evaluate our method using Jason-2 satellite altimetry data over 6 lakes in the Mississippi River basin and validate our results against in situ data. Validation shows the benefits of retracking radargrams instead of single-waveforms.

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Swell detection from fully-focused SAR altimetry data

Ourania Altiparmaki (TU Delft, Netherlands)

Session: Instrument Processing: Measurement and Retracking
Presentation type: Oral

Abstract:

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Swells are long-crest waves induced by storms. They can travel thousands of kilometers and impact remote shorelines. They also interact with local wind generated waves and currents. It has been shown that the presence of swell lowers the quality of the geophysical parameters which can be retrieved from the delay/Doppler radar altimeter data. This, in turn, affects the estimation of small-scale ocean dynamics. In addition, the resolution offered by the delay/Doppler processing schemes, which is approximately 300 m spacing in the along-track direction, does not allow to resolve swells. This work presents a method which demonstrates that Synthetic Aperture Radar (SAR) altimeters show potential to retrieve swell-wave spectra from fully-focused SAR altimetry processed data for the first time, and proposes thus, that SAR altimetry can serve as a source for swell monitoring.

We present the first spectral analysis of fully-focused SAR altimetry data with the objective of studying backscatter modulations caused by swell. Swell waves distort the backscatter in altimetry radargrams by means of velocity bunching and range bunching. These swell signatures are visible in the trailing edge of the waveform, where the effective cross-track resolution is a fraction of the swell wavelength. By locally normalizing the backscatter and projecting the waveforms on an along-/cross-track grid, satellite radar altimetry can be exploited to retrieve swell information. The fully-focused SAR spectra are verified using as reference buoy-derived swell-wave spectra of the National Oceanic and Atmospheric Administration's buoy network. Using cases with varying wave characteristics, i.e., wave height, wavelength and direction, we present the observed fully-focused SAR spectra, relate them to what is known from side-looking SAR imaging systems and adapt it to the near-nadir situation. Besides having a vast amount of additional data for swell-wave analysis, fully-focused SAR spectra can also help us to better understand the side-looking SAR spectra.

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A Significant Wave Height Correction to Account for Vertical Wave Motion Effects in SAR Altimeter Measurements

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Session: Instrument Processing: Measurement and Retracking
Presentation type: Oral

Abstract:
In this paper, we propose a correction for the sea state dependent biases observed in the significant wave height (SWH) measurements obtained from high-resolution (HR) data of synthetic aperture radar (SAR) altimeters. Those biases have been linked to the effect of vertical wave motion on the radar signal, which creates a non-negligible Doppler spread that results in a loss of along-track resolution of the SAR altimeter (azimuth smearing). When this effect is not accounted for in the retracking process it results in sea state dependent biases, which can be very significant for high SWH values.

The correction has a form of a look-up table (LUT), that depends on both sea state and mean zero up-crossing period. We calculated the LUT through numerical simulations of the SAR altimeter waveforms at different sea state conditions including the azimuth smearing effect through the SAR altimeter flat sea surface response, and later retracking those waveforms with a model that does not account for the vertical wave motion. To evaluate the LUT correction we use the low-resolution mode (LRM) SWH estimated values, and the mean up-crossing wave period, that we obtain from the Meteo France Wave Advanced Model.

We evaluated the LUT correction using Sentinel-6A/MF HR and LR data and determined that the correction is able to eliminate most of the sea state dependent biases observed between both operation modes. The same results were also observed when the correction is applied to Sentinel-3A/B data, indicating the usefulness of this correction in providing consistent SWH measurements across all altimeter missions.

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On the Benefits of Stack-Masking in Delay-Doppler Altimetry over Non-Homogeneous Surfaces

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Session: Instrument Processing: Measurement and Retracking
Presentation type: Oral

Abstract:
Radar altimetry over non homogeneous surfaces, such as inland waters, coastal zones and sea ice covered waters, requires a dedicated processing chain as of Level-2. The rationale is that calm waters (lakes, leads and some river sections) are specular scatterers while their natural surroundings are made of diffuse scatterers. The resulting echo returns are peaky. In many cases multi-peaks echoes are observed at the SARM / SARINM Stacks (and Waveforms).

Some of these peaks are persistent over many Stack beams and can be considered as “signal” while others are spurious signatures that can be considered as “noise” or “ghost signals” that pop up through the antenna side-lobes. The unwanted signatures shall be filtered out prior to multi-looking otherwise a corrupted waveform will be passed to the retracker and this may cause a non negligible error on the estimated epoch.

Beyond this, the main difficulty for a retracker over non homogeneous surfaces is inherent to the diversity and variety of the scenes. The shape of the waveforms, including the locations, widths and amplitude of the peaks can hardly be modeled as they depend on the unpredictable locations, roughnesses, areas and across track extents of the water surfaces within the altimeter footprint. A similar remark applies to the non-water surfaces which scattering properties depend on their locations within the footprint as well as their shapes, orientations and the type of materials they are made of. This is not really in favour of geophysical retrackers.

In the frame of three ESA contracts (SHAPE, Cryo-SEANICE and HydroCoastAL) ALONG-TRACK has designed and implemented a new empirical retracker called ICCER (Isolate Cleanse Classify - Empirical Retracker) that tackles these specific issues. The algorithm has been discussed in details at the CryoSat 10th Anniversary Science Conference (posters 10 and 158 from the same author). It can be summarized as follows:

- First process the beams individually in order to detect each of its peaks whatever its amplitude.
- Then keep the most powerful peaks and use some slope and roughness criteria to define their respective boundaries (merging the small adjacent peaks in the vicinity of the major ones) so that some continuous blocks of range gates can be isolated as “Pseudo Waveforms”,
- Analyse the whole Stack, looking for the major peaks of energy that are persistent across the beams and identify the “stable beams” for each stable peak,
- Cleanse the Stack by masking off the non stable beams,
- Multi-Look, Classify and Threshold Retrack each Pseudo Waveform.

This robust multi-peaks empirical retracker can be used to densify measurements in SARINM while the first major peak only is needed in SARM altimetry. It can provide multiple classes per waveform. The retracker is also able to process waveforms only.

In this communication we illustrate, over several cases, the benefits of masking the Stacks before multi-looking. We do that by comparing the input and outputs of the ICCER when it processes the Stacks (L1BS products) and when it processes the Waveforms (L1B products), we also compare with other retrackers.

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Fast-Adaptive: a new, optimal, unbiased, and computationally efficient retracking solution for the analysis of Conventional Altimetry data

Anna Mangilli (CLS, France); Salvatore Dinardo (CLS, France); Fanny Piras (CLS, France); Thomas Moreau (CLS, France); Claire Maraldi (CNES, France); Jean-Alexis Daguze (CLS, France); Pierre Thibaut (CLS, France); François Boy (CNES, France); Picot Nicolas (CNES, France)

Session: Instrument Processing: Measurement and Retracking
Presentation type: Oral

Abstract:
The improvement of retracking algorithms aiming at the optimal and efficient estimation of the geophysical parameters is a core activity within the altimetry community. The importance of having an optimal, robust and efficient retracking solution is indeed more and more critical with the increase of the amount of data and the high demanding requirements in terms of data quality and resolution. The accuracy of the retracking solution in retrieving the geophysical parameters has a strong impact on the accuracy of the estimation of Essential Climate Variables as the mean sea level, which is a key issue for trend studies and for the robust assessment of climate change at local and global scales.

Currently, the most used retracking solution implemented in the ground segments for conventional altimetry is the MLE4 retracking algorithm, which is computationally fast but known to be sub-optimal and biased, therefore needing corrections that must be applied to avoid systematic bias in the retrieved parameters. Recently, lots of efforts have been done to improve this solution in terms of estimator, modelling and inclusion of instrumental-related effects (numerical PTR), leading to the development of the Adaptive retracker (Tourain et al 2021, Thibaut et al. OSTST 2017 & 2021) which is now successfully integrated in the ground segment of missions like Jason3 and CFOSAT. The Adaptive retracker is based on a Maximum Likelihood Estimator with the exact formulation of the likelihood function for a Gamma distributed multiplicative noise and provides huge improvements in the parameter estimation with respect to the MLE4 solution. Yet, while being optimal and unbiased, the Adaptive retracker is not numerically efficient as the optimisation of the exact likelihood criterion is done with the Nelder-Mead algorithm that has a very high computational cost. This can be a big issue, preventing for instance this innovative algorithm to be included in “near-real-time” and “real-time” official products.

In this talk we present Fast-Adaptive: a new, optimal, unbiased and computationally efficient retracking approach for the analysis of conventional altimetry (Low Resolution Mode, LRM) data. We will present the formalism, describing the estimator, the optimisation method and the model, which is based on the four parameters “Adaptive-like” model with numerical PTR convolution. We will demonstrate that the proposed retracking solution provides with unbiased and optimal parameter estimation, compatible with the Cramer-Rao bounds, while keeping a low computational cost, comparable to the MLE4 retracker. We will present the validation of the Fast-Adaptive retracker on simulations and we will detail the results of the analysis of representative Sentinel-6 and Jason-3 LRM data sets with the new retracking solution and show the comparison with the existing solutions (MLE4 and Adaptive) on the same data.
The Fast-Adaptive retracker is a new promising and powerful tool for the analysis of LRM data of current and future radar altimetry missions.

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EMD filtering applied to LRM 20 Hz sea level anomaly observations

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Session: Instrument Processing: Measurement and Retracking
Presentation type: Oral

Abstract:
Satellite radar altimetry is used to observe a wide range of spatial scales, ranging from basin scale to small mesoscale (i.e. less than 100 km). The analysis of the small mesoscale with low-resolution altimetry observations is usually based on along-track products, such as the Geophysical Data Record (GDR). Such product have a resolution as small as 300 m (20-Hz rate), although the resolution most commonly used is 6–7 km (1-Hz rate). Unfortunately, the observation of ocean scales smaller than 100 km with LRM products is degraded by the existence of a “hump artefact” visible on sea surface height (SSH) spectra of the 20 Hz product at scales between 3 to 100 km. This hump is due to inhomogeneities in backscatter strength within the LRM disc-shaped footprint, which induce retracking errors which are smoothed along the satellite track. Recent studies have evidenced that the impact of such spectral hump can be mitigated by more restrictive editing algorithm as well as by the use of high-frequency specific corrections, such as the high-frequency adjustment (HFA).

Here, we assess the effectiveness of the Empirical Mode Decomposition filter (EMD) in mitigating the impact of the hump. The EMD filter is a novel filtering method specifically designed for the analysis of non-stationary and non-linear signals. The filter is purely algorithmic (i.e. it lacks a sound mathematical theory) and breaks down the signal into a series of amplitude and frequency modulated zero-mean functions called Intrinsic Moulation Functions (IMF). The main difference with respect to traditional decomposition methods is that these functions are signal-dependent and are estimated via an iterative procedure. Once all IMFs are identified, the filtered signal is reconstructed by summing together only the significant portions (i.e. above a defined noise threshold) of each IMF.

The EMD method has been recently applied for de-noising 1 Hz significant wave height observations showing promising results. Here, we applied an analogous filter to 20 Hz sea level observations from Jason-3. Due to the higher resolution of our dataset, several different parameter configurations were tested (e.g. number of IMFs to include to reconstruct the filtered signal; type of iterative method;…). Our results confirmed that, in its optimal configurations, the filter is extremely efficient at removing the stochastic noise from the signal. However, the filter alone does not reduce the hump artefact observed in the 20 Hz spectra. Overall, the largest mitigation of the 3 to 100 km spectral hump was obtained using the EMD filtering in synergy with the HFA correction.

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Beyond 20 Hz: Deriving the necessity of increased posting rates from first principles

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Session: Instrument Processing: Measurement and Retracking
Presentation type: Oral

Abstract:
Empirical studies have outlined the advantages of 40 Hz and 80 Hz posting rates over 20 Hz in unfocused SAR altimetry (delay/Doppler processing), showing increased precision of sea surface heights and significant wave heights. However, the underlying reasons for this were unknown, as the theoretical Doppler resolution predicts that 20 Hz sampling should suffice.

In our work, we derive the need for posting rates on the order of 60 Hz for all current SAR altimeters from first principles. Hence, our findings are in line with earlier empirical studies that find best performance with 80 Hz in a comparison of 20, 40 and 80 Hz posting rates. The reasons for the increased effective along-track resolution can be fully explained in terms of the observation geometry. We will outline, which orbital parameters and processing settings influence the required posting rate most, and show the limits in which the anticipated along-track resolution of about 300 m is obtained.

Therefore, we hope to settle the ongoing debate in favor of 60 or 80 Hz SAR altimetry data. Our findings will also facilitate the planning of future SAR altimetry missions by making the required posting rates predictable.

Egido, A., Dinardo, S., Ray, C., 2021. The case for increasing the posting rate in delay/Doppler altimeters. Advances in Space Research 2, 930–936.
Dinardo, Salvatore. Techniques and Applications for Satellite SAR Altimetry over Water, Land and Ice. Ph.D. Thesis, Technische Universität, 2020. https://tuprints.ulb.tu-darmstadt.de/11343/.

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Towards a homogeneous reprocessing of historical missions: excellent performances of the Adaptive retracker applied to Jason-1 and ENVISAT

Fanny Piras (CLS, France); Hélène Roinard (CLS, France); Annabelle Ollivier (CLS, France); Anna Mangilli (CLS, France); Claire Maraldi (CNES, France); François Bignalet-Cazalet (CNES, France); Pierre Féménias (ESA, Italy); François Boy (CNES, France)

Session: Instrument Processing: Measurement and Retracking
Presentation type: Oral

Abstract:
During the last years, different teams have devoted huge efforts to improve retracking algorithms for both conventional and Delay Doppler echoes. For LRM measurements, CLS/CNES has developed and successfully validated a solution called "Adaptive Retracker", implementing a new waveform model and a Nelder Mead optimization method with exact likelihood criterion. Compared to the reference MLE4, the Adaptive brings dramatic improvements over all surfaces. It has been presented several times to the OSTST community [Thibaut et al., OSTST 2021, Ollivier et al. OSTST 2019, Thibaut et al., OSTST 2017]
This solution has been implemented as the reference algorithm for nadir echoes in the SWIM ground segment (CFOSAT mission) and in the new reprocessing CNES GDR-F of the Jason-3 mission, with excellent performances as described in [Tourain, 2021] and [Thibaut, 2021], respectively.
In the context of different frameworks, historical missions are now being reprocessed with the Adaptive retracker allowing to have homogeneous long-term time-series processed with this up-to-date algorithm.
Firstly, in the frame of the CNES GDR-F reprocessing, it is planned to reprocess the whole Jason-2 and Jason-1 time series with the Adaptive retracker, allowing to have more than 20 years of Jason data processed with this algorithm. Poseidon-3B (Jason-3 altimeter) is a replica of Poseidon-3 (Jason-2 altimeter), so the Adaptive can be directly applied to Jason-2. It is not the case for Jason-1's altimeter Poseidon-2 that has two important characteristics that needs to be considered in a retracker: First, a compression and decompression algorithm has been applied to Jason-1 echoes, changing their shape and therefore the noise statistics, especially on the trailing edge. Second, Jason-1's platform had pointing issues resulting in numerous periods of strong mispointing. As the Adaptive model is not valid for high mispointing values, and assumes a null mispointing in its current version, the impact of this mispointing must be carefully assessed. Finally, the impact of these two aspects on the neural-network waveform classification must also be analysed as it is used as an input of the Adaptive retracker.
Secondly, in the frame of the ESA project FDR4ALT, aiming at reprocessing ERS-1, ERS-2 and ENVISAT Altimeter and Radiometer datasets based on the best state-of-the-art algorithms and corrections, several Thematic Data Products (TDP) will be provided at the end of the project, including Ocean & Coastal Topography dedicated products, and Ocean Waves dedicated products.
In the frame of this project, the PTR (Point Target Response) arrays were handled in a new way to allow the Adaptive retracker to be applied on ENVISAT with excellent performances with respect to the current reference algorithm MLE3. After a round robin analysis, the Adaptive has therefore been selected to be the only algorithm providing the Sea Level Anomaly (SLA) for the Ocean & Coastal TDP, and the Significant Wave Heigh (SWH) for the Ocean Waves TDP. The full ENVISAT dataset has now been reprocessed with excellent results obtained for the SLA and SWH.

The aim of this talk is to present the methods used to apply the Adaptive retracker on these historical missions in the frame of different projects, and then focus on the excellent performances and results obtained on ENVISAT and Jason-1 compared to the reference algorithms MLE3/MLE4. More specifically, this presentation will address the benefits of this algorithm on historical missions for the SLA and the SWH user communities.
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CNES POE-F precise obit performances for the Jason-3 and Sentinel-6 MF missions

Alexandre Couhert (CNES, France); John Moyard (CNES, France); Flavien Mercier (CNES, France); Sabine Houry (CNES, France); Timothée Braz (CS-SI, France); Vincent Debout (CS-SI, France); Georgia Katsigianni (CLS, France); Eléonore Saquet (CLS, France)

Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
2022 is a successful time for altimetry, with nine currently flying satellites: CryoSat-2 (2010), Saral/AltiKa (2013), Jason-3 (2016), Sentinel-3A (2016), Sentinel-3B (2018), HY-2B (2018), HY-2C (2020), Sentinel-6 MF (2020), HY-2D (2021), all of them being processed with the same CNES POE-F precise orbit standards. This impressive Low Earth Orbit (LEO) constellation is also planned to be complemented by a tenth altimeter mission, the SWOT next-generation satellite in November 2022.
This paper focuses on the two reference missions, Jason-3 & Sentinel-6 MF. and their precise orbit consistency during their tandem phase. To this end, a comparison of the performances of the two orbits will be presented during this important period of validation, with Sentinel-6 MF flying 30 seconds behind its predecessor and following the same ground track. In particular, the operational Sentinel-6 MF CNES POE-F orbit solutions were recently reprocessed following this commissioning period. These new orbits now consider the first Galileo measurements available for an altimeter mission, an improved modeling of the Solar Radiation Pressure (SRP) perturbations, updates on the center of phase positions of the POD instruments, as well as on the parameterization to better account for the residual measurement and dynamic modeling errors.
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GSFC Std2006: An updated set of altimeter satellite orbits for TOPEX, the Jason satellites and Sentinel-6A

Frank Lemoine (NASA GSFC, France); Nikita Zelensky (University of Maryland, U.S.A.); Brian Beckley (KBR, U.S.A.); Xu Yang (KBR, U.S.A.); Douglas Chinn (KBR, U.S.A.)

Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
In support of the OSTST, we have developed a new set of satellite orbits for the reference mission satellites that determine the global change in Mean Sea Level: TOPEX/Poseidon, Jasons 1-3, and Sentinel-6A. The goal was to improve these orbits w.r.t. the previous set of orbits delivered as part of the NASA MEASURES project. The new improved POD standards include an update of the static and time variable gravity model, better modelling of the satellite attitude, improved modeling of the nonconservative forces, use of DORIS data to 7-deg elevation along with an elevation-deweighting model. Other updates include the application of the new model of the linear mean pole used for the development of ITRF2020. We evaluate the improvement over the previous sets of orbits, dpod2014. For Sentinel-6A and Jason-3 we provide an assessment of their orbit quality through POD metrics including analysis of tracking and altimeter crossover data residuals and direct orbit comparisons. We also evaluate the orbits by analysis of the derived sea surface height.
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GPS-based Precise Orbit Determination of the Sentinel-6 MF and Jason-3 Missions

Shailen Desai (Jet Propulsion Laboratory, United States); Alex Conrad (University of Colorado, United States); Bruce Haines (Jet Propulsion Laboratory, United States)

Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
The primary focus of this presentation is results from the radiometric evaluation of the TriG Precise Orbit Determination (POD) Global Positioning System (GPS) receiver onboard the Sentinel-6 Michael Freilich (MF) mission. We assess various tracking metrics, data noise, and precise orbit determination performance, and compare them to those from the Jason-3 IGOR+ GPS receiver. We also present results from the evaluation of our GPS-based POD solutions using independent metrics such as withheld satellite laser ranging data residuals and sea surface height residuals at locations where ascending and descending passes cross (i.e., crossover residuals). We also assess relative performance of our GPS-based Sentinel-6 MF and Jason-3 orbit solutions to the precise orbit ephemeris (POE) that is provided on the science data products. This performance assessment includes both temporal and geographically correlated differences.

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Sentinel-6 Michael Freilich - Precise Orbit Determination based on Galileo and GPS observations

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Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
With global mean sea level rising because of climate change, Copernicus Sentinel-6 is the radar altimetry reference mission to extend the legacy of sea-surface height measurements until at least 2030. The satellite carries a Poseidon-4 radar altimeter and a microwave radiometer. The analysis of the altimeter data relies on highly-accurate knowledge of the orbital position, in particular in the radial component, with errors below 1.5 cm. For this reason, Sentinel-6 carries several instruments, e.g. Laser Retroreflector Array, Doppler Orbitography and Radiopositioning Integrated By Satellite (DORIS) and also a GNSS receiver for generation of data, which allows to perform Precise Orbit Determination (POD) with the highest possible accuracy. Of particular interest for this paper is the GNSS receiver, because it is the first time that a high quality dual frequency Galileo/GPS receiver is flown on-board of a Sentinel satellite.

ESA's Navigation Support Office (NavSO), located at the European Space Operations Centre in Darmstadt, Germany is providing an independent Precise Orbit Determination solution for all Sentinel satellites. As part of this activity, the office has been operationally computing and delivering the POD products, including the Sentine-6 multi-GNSS-based precise orbits since its launch in November 2020.
This presentation will describe the processing techniques adopted at the European Space Agency, with a particular focus on the POD aspects and the related processing of the Galileo and GPS observations. The latest results and their validation will be addressed in this context.

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Sentinel-6 orbit determination at the Copernicus POD Service

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Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
Sentinel-6 Michael Freilich satellite launched in November 2020 is the first satellite carrying a combined GPS and Galileo receiver for precise orbit determination (POD). In addition, it is equipped with a DORIS receiver and a Laser Retro Reflector for Satellite Laser Ranging (SLR). The GNSS-RO (radio occultation) instrument also has a POD antenna. This allows for various cross-comparisons between orbits from the different observation techniques and instruments.
The Copernicus POD Service is a consortium responsible for providing orbit products and auxiliary data files from the Copernicus Sentinel-1, -2, -3, and -6 missions to the corresponding ground segment processing chains at ESA and EUMETSAT. Products and data are also made available to external users through the ESA Copernicus Open Access Hub. For Sentinel-6A, a near real-time orbit product computed based on GNSS data, is delivered to EUMETSAT, the DORIS DIODE aboard acting as backup. The Regular Service Reviews (quarterly and one yearly) also include validation of post-processed Sentinel-6 orbit solutions from various members of the Copernicus POD Quality Working Group (QWG).
Focus of this contribution is on post-processed POD based on the combined GPS/Galileo receiver and validation with SLR done at the Copernicus POD Service. Precise orbits may be derived as single-system or combined solutions. Integer ambiguity resolution is a key technique to obtain highest accuracy orbits. The dynamic modelling of the satellite orbit also benefits from updates and improvements of the satellite macro model.
We present orbit determination results from GPS-only, Galileo-only and combined GPS & Galileo observations with resolved integer ambiguities and using different satellite macro models. Cross-comparison between the different solutions, SLR validation, and comparison to other orbit solutions provided by members of the Copernicus POD QWG are shown and analysed.

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Cross-calibration of the TRIG and PODRIX GNSS receivers onboard Sentinel-6A

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Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
The Sentinel 6A (S6A) satellite ("Michael Freilich") hosts a unique complement of sensors for precise orbit determination (POD). Aside from a Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) and a laser-retroreflector array (LRA) for satellite laser ranging (SLR), the spacecraft is equipped with three Global Navigation Satellite Systems (GNSS) receivers. These include a redundant pair of PODRIX receivers supporting GPS and Galileo tracking as well as a TRIG receiver supporting GPS tracking and radio occultation measurements. All three receivers are connected to high-performance GNSS antennas based on a patch-excited cup (PEC) design with choke rings for enhanced multipath mitigation.

Simultaneous operations of individual receivers or receiver pairs of S6A enables determination of the relative antenna phase centers through ambiguity resolved differential carrier phase observations. The results demonstrate a good consistency of the PODRIX-PODRIX antenna baseline with nominal coordinates provided by the manufacturer, but systematic deviations for the TRIG-PODRIX baselines in all axes. While offsets in boresight direction may be expected due to minor differences in the antenna design and a limited availability of phase pattern calibration data, offsets of 9 mm and 14 mm w.r.t. to the design values may be noted in the direction of the longitudinal and lateral s/c axes, respectively. Other than antenna offset calibrations in single-receiver POD, the calibrations of relative antenna positions is unaffected by nongravitational force modeling uncertainties and can be obtained with good confidence from purely kinematic GNSS measurements.

Concerning baseline inconsistencies in longitudinal, i.e. flight direction, timing offsets in GNSS receivers have earlier been identified as a cause of along-track position errors in GNSS receivers. By way of example, a 1 micro-second error in the latching of carrier phase measurements will cause a 7 mm along-track position error. To disentangle timing errors from geometric antenna position errors, measurements collected in limited phases of a reversed flight orientation were used. These suggest that the antenna baseline in longitudinal (+x) direction matches the design values, leaving a 1.2 micro-second inconsistency between PODRIX and TRIG receivers as the main cause of the apparent along-track baseline error. Independent validation of TRIG and PODRIX POD results through SLR observations suggest that the timing offset can largely be attributed to the TRIG receiver, while the PODRIX timing appears consistent with the SLR data. Dedicated GNSS signal simulator tests are recommended for the preflight validation of the next Sentinel-6B spacecraft to further consolidate these findings and a thorough review of spacecraft design information is encouraged to resolve the baseline inconsistency in cross-track direction.

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Assessment of GPS Transmitter Antenna Calibration Maps on Precise Orbit Determination of the Sentinel-6 MF Mission

Alex Conrad (University of Colorado Boulder, United States); Penina Axelrad (University of Colorado Boulder, United States); Shailen Desai (Jet Propulsion Laboratory, California Institute of Technology, United States); Bruce Haines (Jet Propulsion Laboratory, California Institute of Technology, United States)

Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
The primary focus of this presentation is to evaluate the GPS transmitter antenna calibration maps and impacts on the Precise Orbit Determination (POD) of the Sentinel-6 Michael Freilich (MF) mission using the onboard TriG Global Positioning System (GPS) receiver. We evaluate the Block III residuals using a Block II derived receiver antenna calibration map and Block II POD solution. Residuals are stacked to assess the azimuthal and elevation dependencies in the Block III transmitter frame. Also, the Block II transmitter residuals are stacked to incorporate the azimuthal variability into updated maps. Finally, withheld satellite laser ranging residuals are used to evaluate the differences of incorporating the Block III satellites and updated Block II antenna calibration maps into the Sentinel-6 MF POD solution.

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Satellite altimetry POD using GPS satellite quaternions from IGS CNES/CLS ORBEX files

Georgia Katsigianni (CLS, France); Alexandre Couhert (CNES, France); John Moyard (CNES, France)

Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
In the frame of improving the overall quality of satellite altimetry orbits, the contribution of high-precision GNSS measurements is essential. Nowadays, several altimeter satellites are equipped with GNSS receivers on board: Jason-3, Sentinel-3A/B, HY-2B/C/D, and Sentinel-6 Michael Freilich. Nevertheless, an accurate knowledge of the orientation of the GNSS satellites in space, especially during satellite eclipses, is a key quantity in GNSS data processing. So far, the GNSS satellite attitude is described by mathematical models (i.e. nominal yaw steering (Montenbruck et al.,2015) and auxiliary yaw steering for eclipse season (Kouba,2009) for GPS. Until recently, the International GNSS Service (IGS) proposed the publication and the exchange of GNSS satellite attitude quaternions data in ORBEX format (Loyer et al. 2019). This new information is of great importance for the calculation of carrier phase measurement time series residuals which fluctuate in the case of inaccurate attitude.

In this study we make a comparison between the two ways: a) using the existing mathematical models and b) using satellite attitude quaternions, for GNSS reference orbits. The main interest is to investigate the improvement on satellite altimetry orbits not only during the eclipse periods but also outside of these transient events. GNSS satellite products and ORBEX files are taken from the IGS CNES/CLS analysis center. The Low Earth Orbit(LEO) POD computation is performed using CNES' ZOOM software.

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Kouba, J., 2009. A simplified yaw-attitude model for eclipsing GPS satellites. GPS Solut. 13 (1), 1-12. https://doi.org/10.1007/s10291-008-0092-1

Loyer, S., Banville, S., Geng, J., Strasser, S., 2021. Exchanging satellite attitude quaternions for improved GNSS data processing consistency. Adv. Space Res. 68 (6), 2441-2452. https://doi.org/10.1016/j.asr.2021.04.049

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Precise Orbit Determination of DORIS satellites by CNES/CLS IDS Analysis Center in the frame of our contribution to the ITRF2020

Hugues Capdeville (CLS, France); Jean-Michel Lemoine (CNES, France); Adrien Mezerette (CLS, France)

Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
We have processed all DORIS data available from 1993 to the end of 2020 for our contribution to the ITRF2020 realization. For that, we adopted the last standards and models recommended by IERS and IDS. We now use body and solar array quaternions for Jason-2 and Jason-3 satellites. We have just added the satellite Sentinel-6A to our processing chain.
A Precise Orbit Determination (POD) status for DORIS satellites by taking into account all these improvements will be presented. We will give statistical results such as one per revolution empirical acceleration amplitudes and orbit residuals. We will also give some comparisons to the CNES precise orbit used for altimetry and to GPS-only orbits contributing to the Copernicus POD Quality Working Group of Sentinel. Some external validations of our orbits will be done, such as with independent SLR measurements processing as well as through the use of altimeter crossovers. We will also look at the impact on the DORIS station position estimation.

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Systematic errors in Satellite Laser Ranging validations of microwave-based orbit solutions

Daniel Arnold (Astronomical Institute of the University of Bern, Bern, Switzerland); Alexandre Couhert (Centre National d'Etudes Spatiales, Toulouse, France); Oliver Montenbruck (German Space Operations Center, Deutsches Zentrum für Luft- und Raumfahrt, Wessling, Germany); Cyril Kobel (Astronomical Institute of University of Bern, Bern, Switzerland); Eléonore Saquet (Centre National d'Etudes Spatiales, Toulouse & Collecte Localisation Satellites, Toulouse, France); Heike Peter (PosiTim UG, Seeheim-Jugenheim, Germany); Flavien Mercier (Centre National d'Etudes Spatiales, Toulouse, France); Adrian Jäggi (Astronomical Institute of the University of Bern, Bern, Switzerland)

Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
Satellite Laser Ranging (SLR), i.e., the optical distance measurement to satellites equipped with laser retro-reflectors, has become an invaluable core technique in numerous geodetic applications. SLR measurements to active satellites in Low Earth Orbit (LEO) are up to now mostly used for an independent validation of orbit solutions, usually derived by microwave tracking techniques based on Global Navigation Satellite Systems (GNSS) or Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). This allows for the analysis of systematic orbit errors (e.g., originating from poorly known satellite center of mass locations or sensor offsets) not only in radial direction, but in three dimensions. A high level of radial orbit reliability is key, e.g., to satellite altimetry applications.

For many geodetic applications a mm accuracy and 0.1 mm/year stability is required or at least desired. Unavoidable SLR station biases and coordinate uncertainties are a major error source and obstacle to reach the aforementioned accuracy and stability goals when relying on SLR data. Among the stations of the International Laser Ranging Service (ILRS) there is a large diversity of biases and measurement qualities, and the calibration of these biases for all stations is key to further exploit SLR data for present and future geodetic applications.

It has recently been demonstrated that the analysis of SLR data to active LEO satellites with fixed microwave-derived orbit solutions is a promising means to analyze SLR biases and their stability. For this, a combined analysis of numerous different satellites and a high-quality modeling of gravitational and non-gravitational forces is a prerequisite. Nevertheless, different uncertainties in various dynamical models and offsets remain, potentially affecting also SLR station-related calibration parameters. In this presentation we address the question on how both station- and orbit-related parameters can be simultaneously derived from SLR analyses to active LEO satellites. Based on a consistently produced set of orbit solutions for 9 different LEO missions (Sentinel-3A/B, Sentinel-6A, Swarm-A/B/C, GRACE-FO C/D and Jason-3) we explore different possibilities to compute parameters that reflect corrections to individual orbit solutions, next to station calibration parameters. A special focus is on how to put constraints that are needed to decorrelate the different parameter sets, as well as their impact on the results. These investigations will help to disentangle station- from orbit-related systematic errors, allowing, e.g., a better characterization of the latter in particular in altimetry applications.

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On the accuracy of contemporary orbits of altimetry satellites in the radial direction

Sergei Rudenko (Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM), Germany); Denise Dettmering (DGFI-TUM, Germany); Mathis Bloßfeld (DGFI-TUM, Germany); Julian Zeitlhöfler (DGFI-TUM, Germany); Riva Alkahal (DGFI-TUM, Germany)

Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
Precise orbits of altimetry satellites are a basis for sea surface height estimation, since they provide the reference for the measured distance from a satellite altimeter to a water surface. Various factors affect accuracy of orbits of these satellites, such as type and quality of observations used, proper corrections of measurements, proper modelling of satellite shape, size, optical properties of its surfaces and its orientation in space, accurate modelling of forces acting on a satellite, accurate terrestrial and celestial reference frame realizations and transformation between them, proper modelling of displacements of tracking stations, a proper parameter adjustment algorithm, observation weighting and other factors. Significant progress has been reached in precise orbit determination of altimetry satellites in the latest decades by different orbit determination groups. In this presentation, we investigate the accuracy in the radial direction of contemporary orbits of such altimetry satellites as TOPEX/Poseidon, Jason-1, Jason-2, Jason-3, Sentinel-3A and some others derived in the ITRF2014 realization by various institutions using various types of observations covering totally time span from 1992 until 2021. We investigate single-satellite altimetry crossover differences, radial errors of individual orbit solutions and orbit differences in the radial direction between various orbit solutions for each satellite.

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Improved time-variable gravity modelling using monthly COST-G models for precise orbit determination of low Earth orbiting satellites

Adrian Jäggi (University of Bern, Switzerland); Heike Peter (PosiTim UG, Seeheim-Jugenheim, Germany); Ulrich Meyer (University of Bern, Switzerland)

Session: Precision Orbit Determination
Presentation type: Oral

Abstract:
Accurate time-variable Earth's gravity field information is essential for precise orbit determination (POD) of low Earth orbiters (LEO). In particular the POD of altimeter satellites relies on accurate modelling of the time-variable gravity field. The Combination Service for Time-variable Gravity Fields (COST-G) provides monthly gravity fields based on a combination of GRACE/GRACE-FO derived monthly gravity field solutions from different analysis centers. These monthly solutions are available with a latency of 2-3 months. They serve as base for a deterministic signal model (DSM) of time-variable gravity that enables a few months prediction and therefore application in operational LEO POD. The combined monthly solutions themselves, as well as several variants of the DSM are used for GPS-based POD of Copernicus Sentinel-2, -3 and -6 satellites. The orbit results show a significant improvement when using both, the COST-G monthly and the new DSM gravity field models compared to results using existing long-term static gravity field models, including seasonal and trend estimates, as well. RMS values of the GPS carrier phase residuals and orbit overlaps are significantly reduced. Orbit validation performed by Satellite Laser Ranging (SLR) also show that SLR residuals can be lowered. The DSMs show a similar performance as the monthly gravity fields. In particular they provide more realistic trend estimates in river basins with strong non-seasonal inter-annual variations than the predicted trends of outdated long-term gravity fields. The DSM thus complements the monthly gravity fields as a new COST-G product. It is foreseen to update the COST-G DSM quarterly using a sliding window approach.

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AMR-C and HRMR Performance after 1 Year

Shannon Brown (JPL, United States); Chun Sik Chae (JPL, USA)

Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Oral

Abstract:
The Sentinel-6 Michael Freilich is the newest reference satellite altimetry mission. It includes a radar altimeter, a precision orbit determination suite and a radiometer to measure wet tropospheric path delay. The AMR-C radiometer on Sentinel-6 includes two new innovations compared to the prior Jason-series missions. The first innovation is the inclusion of a secondary calibration system external to the radiometer that is used to stabilize the wet path delay measurement to 0.7mm/yr over 5+ years. The second is a high-frequency radiometer (termed HRMR) with <5km spatial resolution that improves the measurement near land and sea ice boundaries. We will present the performance of the AMR-C and HRMR radiometer systems over the first 1.5 years of in-flight operation. We show that the secondary calibration system provides an unprecedented level of stability and is a new standard for calibration stability for altimeter missions. We also show that the HRMR is providing path delay with < 1cm uncertainty to within 5km from land, a dramatic improvement from prior altimeter missions.
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Benefits of high-frequency observations for the retrieval of the wet tropospheric correction over open ocean: first results based on HRMR Sentinel-6 measurements.

Bruno Picard (Fluctus SAS, France)

Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Oral

Abstract:
Statistical methods are usually used to provide estimations of the wet tropospheric correction (WTC), necessary to correct altimetry measurements for atmospheric path delays, using brightness temperatures measured at two or three low frequencies from a passive microwave radiometer on board the altimeter mission. Despite their overall accuracy over oceanic surfaces, uncertainties still remain in specific regions of complex atmospheric stratification.

Statistical methods are usually used to provide estimations of the wet tropospheric correction (WTC), necessary to correct altimetry measurements for atmospheric path delays, using brightness temperatures measured at two or three low frequencies from a passive microwave radiometer on board the altimeter mission. Despite their overall accuracy over oceanic surfaces, uncertainties still remain in specific regions of complex atmospheric stratification.

It has been demonstrated that high-frequency observations (above 80 GHz) would improve the performances of WTC retrieval over coastal areas and open ocean (Hermozo et al. 2018, 2019). The availability of such channels on-board Sentinel-6 HRMR (89 Hz, 130 GHz, 165 GHz) is a great opportunity to demonstrate those assertions using measurements in coincidence with the historical 3-low frequency channels. Indeed Shannon Brown shown in 2022 the very first results of a coastal algorithm that mitigates the land contamination and provides an accurate correction closer to the coast.

Within this study we will focus on the open ocean area and we will show the first results of the impact of high-frequency channels on the performance of WTC retrieval.
A 3 dense (fully-connected) layers is classically learned over ECMWF analysis and simulated brightness temperatures for each of the 6 channels.
The performances of the 6-channels WTC are compared to the operational product based on the 3-low frequency channels and discussed at global and regional scales based on the variance of SSH at cross-overs metric.
The potential of high frequency channels for the improvement of performances of WTC retrieval under precipitating conditions is also discussed over specific cases.
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Refined S-6 sea state bias correction models and a multi-frequency EM bias assessment using C-, Ku-, and Ka-band data

Doug Vandemark (Univ. of New Hampshire, United States); Hui Feng (Univ. of New Hampshire, US); Ngan Tran (CLS, France); Brian Beckley (NASA-GSFC, US)

Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Oral

Abstract:
This study will report on results from two parallel sea state bias correction model investigations. Ongoing verification of sea level measurements from the Sentinel-6 Michael Freilich mission suggests the possibility of systematic range bias and noise due to the use of preliminary sea state bias correction models based on tandem comparisons with Jason-3 altimeter data. New C- and Ku-band sea state bias models built using Side-B altimeter data from S-6 will be presented including an assessment of revised global range measurement comparison against Jason-3 and against the present S-6 GDRF06 version datasets. One goal of this work is to reduce apparent geographically-correlated error between Jason-3 and S-6 sea level measurements. Part two of this work will use SARAL/AltiKa and Jason altimeter range data to reconsider what these long-term three frequency radar measurements can explain about the underlying physical controls of the altimeter sea state bias. The altimeter data are co-registered with global wave model data to investigate their relative dependence on the expected primary control, long-wave wave steepness, using bulk statistical wave parameters including the significant slope and wave age. The data clearly illustrate that the range bias changes due to steepness decreases as the radar frequency increases, with one operational example being the greater need for ancillary long-wave information when using a C-band altimeter vs. a Ka-band system. We also document a varied impact of the near-surface wind change between the C-, Ku- and Ka-band measurements.

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Synergistic use of the Sentinel-3A SRAL/MWR and SLSTR Sensors for the Wet Tropospheric Correction Retrieval

Pedro Aguiar (DGAOT, Faculty of Sciences, University of Porto, Portugal); Telmo Vieira (DGAOT, Faculty of Sciences, University of Porto, Portugal); Clara Lázaro (DGAOT, Faculty of Sciences, University of Porto, Portugal); M. Joana Fernandes (DGAOT, Faculty of Sciences, University of Porto, Portugal)

Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Oral

Abstract:
The computation of sea surface height measurements from satellite altimetry is nowadays a straightforward procedure, enabling sea level variation studies globally. Amongst the various range corrections that need to be applied to the range measured by the altimeter, the wet tropospheric path delay is still one of the most significant error sources.
The most accurate way to retrieve the corresponding wet tropospheric correction (WTC) is through the measurements of microwave radiometers (MWR) on board altimetry missions, collocated with those from the altimeter. For the altimeter reference missions, three-band MWR have been used, with frequency bands around 18 GHz, 23 GHz and 36 GHz. In the case of the dual-band MWR on board European Space Agency's (ESA) missions, the lack of the lowest frequency channel, which provides mainly information on the surface emissivity and its contribution in the measured MWR brightness temperatures (TB), is currently taken into account by considering additional parameters, namely the altimeter backscatter coefficient, $\sigma 0$, the sea surface temperature (SST), and the atmospheric temperature vertical decrease rate ($\gamma 800$).
Although the altimeter $\sigma 0$ parameter is collocated with the MWR measurements, the SST is currently extracted from external static seasonal tables. Recent studies show that the use of a dynamic SST extracted from Numerical Weather Models (ERA5) improves the WTC retrieval, whereas the $\gamma 800$ parameter provides redundant information.
The Copernicus Sentinel-3 mission payload, besides the Synthetic Aperture Radar Altimeter (SRAL) and MWR sensors, includes the Sea and Land Surface Temperature Radiometer (SLSTR), among other collocated sensors, from which gridded SST observations are derived over ocean, simultaneously with observations from the SRAL and MWR sensors.
In this context, the objective of the present work is the development of a synergistic approach for the ESA Sentinel-3 mission between the SRAL and MWR sensors with the SLSTR instrument. The aim is to derive the SST measurement from the SLSTR sensor for each SRAL observation and assess its impact in the WTC retrieval over open ocean, thus removing the need for the extraction of the SST parameter from external sources.
In a first stage, the SLSTR-derived SST are evaluated against the ERA5 model; their impact in the WTC retrieval is assessed in a second stage. The results show that the use of the SLSTR-derived SST, compared to those from ERA5, has no significant impact on the WTC retrieval over open ocean, both globally and regionally. Thus, for the WTC retrieval, there seems to be no advantage in having collocated SST and altimeter and radiometer observations. Additionally, this study reinforces that the use of dynamic SST leads to a significant improvement over the current Sentinel-3 WTC operational algorithms.
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Enhanced GPD+ wet tropospheric corrections for the Copernicus Sentinel-3 missions

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Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Oral

Abstract:
Amongst its instruments, the Copernicus Sentinel-3 (S3) missions carry the Synthetic Aperture Radar Altimeter (SRAL) for precise sea surface height (SSH) observations and its companion Microwave Radiometer (MWR) for the retrieval of the path delay in the altimeter range caused by the presence of water vapour and cloud liquid water in the atmosphere.
In the scope of an activity sponsored by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), the University of Porto (UPorto) has been developing an improved WTC for the S3 missions. This improvement is accomplished by means of GPD+, Global Navigation Satellite Systems (GNSS)-derived Path Delay Plus, an algorithm developed at UPorto to retrieve enhanced WTC for radar altimeter missions. The requested improvement is particularly relevant over surfaces where the WTC from the on-board MWR is not available or is invalid due to e.g. the presence of land or ice in the large MWR footprint, such as coastal zones, inland waters and high latitudes.
GPD+ is a data combination procedure (Objective Analysis), where valid observations from the on-board radiometer are combined with external measurements from GNSS and imaging radiometers (SI-MWR), to obtain new WTC estimates for all altimeter points for which the Baseline MWR WTC is invalid. In this way, GPD+ preserves the properties of the best available WTC, from the on-board MWR, and further extends this correction to regions and epochs where and when the former is not valid.
To ensure the continuity and consistency of the corrections, all input data used in GPD+ undergo various quality checks and calibration procedures. The various MWR (both the on-board and external SI-MWR) are calibrated against the Special Sensor Microwave Imager/Sounder(SSMI/S), considered a stable radiometric reference.
The corrections have been assessed by comparisons with other WTC sources: radiometers, GNSS and atmospheric models from the European Centre for Medium range Weather Forecasts (ECMWF). The GPD+ WTC validation includes analysis of sea level anomaly (SLA) along-track variance differences and SLA Root Mean Square (RMS) differences at crossovers (mean cycle values, function of latitude and function of distance from coast).
This paper presents the most recent results of the GPD+ WTC for Sentinel-3A and Sentinel-3B, since the start of each mission until April 2021.
The main features of the S3 GPD+ WTC include: are continuous and consistent corrections, valid over all surface types; are calibrated against the SSMI/S dataset, taken as reference; improve data coverage, mostly in coastal and polar regions, and fill existing gaps in the valid MWR observations; are improved WTC both with respect to the Baseline MWR WTC for each satellite and to the ECMWF model-derived WTC.
The operational provision of the corrections is being implemented, with predicted inclusion in the S3 SRAL/MWR Level 2 products starting in mid-2022.

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Performances and benefits of a 1D-variational approach applied to the wet tropospheric correction for the Sentinel 3A and 3B topography missions.

Bruno Picard (Fluctus SAS, France); Ralf Bennartz (Vanderbilt University, US); Frank Fell (Informus, Germany); Estelle Obligis (Eumetsat, Germany)

Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Oral

Abstract:
Statistical methods are usually used to provide estimations of the wet tropospheric correction (WTC), necessary to correct altimetry measurements for atmospheric path delays, using brightness temperatures measured at two or three low frequencies from a passive microwave radiometer on board the altimeter mission. Despite their overall accuracy over oceanic surfaces, uncertainties still remain in specific regions of complex atmospheric stratification.
Thus, there is still a need to improve the methods currently used by taking into account the frequency-dependent information content of the observations and the atmospheric and surface variations in the surroundings of the observations. Within this context, a one-dimensional variational (1D-Var) method has been developed, assimilating the relevant passive microwave observations to retrieve the WTC over ocean.
This physical approach has been applied to the whole Sentinel-3A and Sentinel-3B periods and validated over open ocean against an extensive set of references: the operational product, the GPD+ approach, the AIRWAVE water vapour product derived from SLSTR observations.
The exhaustive validation exercise allows to establish the 1D-var approach as a mature algorithm capable of retrieving the WTC at the level of performance of the operational product. The metric based on the variance of SSH at cross-overs shows that the performance of the 1D-var is even slightly better at global scale, resulting from a more contrasted geographical distribution where the 1D-var or the operational approach performs better, depending on specific geophysical conditions.
Moreover each value of the WTC retrieved with the 1D-var method also benefits from an associated uncertainty and a self-consistent quality flag that greatly facilitates the assessment of the product.

This study has been funded by Eumetsat.

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Characterizing Rain Cells as Measured by a Ka-band Nadir Radar Altimeter: First Results and Impact on Future Altimetry Missions

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Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Oral

Abstract:
The SARAL/AltiKa mission and its Ka-band nadir altimeter offers a unique opportunity to assess the impact of large atmospheric attenuation onto the radar altimeter. The use of Ka-band for the radar altimeter allows a reduction of the spatial resolution from about 15 km with the historical Ku-band instruments to about 4 km. But it also comes with a larger sensitivity to the atmospheric attenuation, especially under rainy conditions.
As the radiometers on-board altimetry mission have a coarser spatial resolution (12 km for MWR on board SARAL/AltiKa), a new approach is proposed here, based on the 40 Hz sigma naught (one point every 175 m), to characterize the impact of rain cells onto the measurements and anticipate the availability of the observations performed by future two-dimensional swath Ka-band altimeters.
The present study uses for the first time directly the timeseries of the Ka-band altimeter backscattering coefficient when previous studies relied on microwave radiometer (MWR) observations or model analyses with coarser resolutions. The Attenuation CElls Characterization ALgorithm (ACECAL) approach combines low-filtering and non-linear fit to retrieve the amplitude of the atmospheric attenuation at Ka-band, the size and the occurrences of rain cells. It not only provides more representative statistics on rain cells (occurrences, amplitude, size), but also describes the internal structure of the cells.

At global scale and for a nadir instrument, the number of observations strongly impacted by the atmospheric attenuation is limited, with a proportion of observations belonging to rain cells lying between 5% and 10%.
Concerning the atmospheric attenuation within the rain cells, the previous studies relied on radiometer observations or model analyses and thus under-estimated the actual amplitude of the atmospheric attenuation caused by rain by a factor four: the global median attenuation under-rainy situation is about 3.5 dB and 10% of the attenuations are larger than 13 dB.
One originality of the method presented here is also to provide robust statistics on the rain cells diameter, their occurrences and geographical distribution. The median is 15 km, 10% of the rain cells have a size larger than 41 km, and the size are also larger at higher latitudes than over the tropics.
This work also demonstrates the capability of Ka-band radar altimeter to provide observations strongly consistent to the measurements provided by missions dedicated to the precipitations, as the precipitation radar on-board the TRMM mission. The retrieval of rain rate and rain cell size but also the characterization of the internal peaks, if they are distributed as secondary products of altimetry missions would certainly benefit to the community, especially if the approach can be generalized to the future two-dimensional swath altimetry missions.

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Argonautica, ocean and satellites from kindergarten to engineering school

Estelle Raynal (CNES, France); Danielle De Staerke (CNES, France); Vinca Rosmorduc (CLS, France)

Session: Outreach, Education and Altimetric Data Services
Presentation type: Oral

Abstract:
Since Fall 2000, the French Space Agency, CNES, has proposed to teachers and their classes, mostly at primary and secondary school levels, to monitor marine animals and buoys using Argos location system. This STEM educational project called "Argonautica", joins both Argos and Jason (and his Argonauts) in its name. It aims to help pupils understand the ocean, its relation to environmental change and the effects on the living world. It also shows them what roles satellites can have in monitoring and understanding these resources. Students and teachers can thus undertake a real scientific investigation with hypothesis, ways to check on them, and analysis of results, with help from scientific partners. It has three different sub-projects, with joint resources for the first two.
With "ArgOcean", students can compare the buoys' tracks with ocean data – from satellites such as the Jason altimeters and others, or from an ocean circulation model. Moreover, classes can build their own buoy, from designing the shell to integrating the electronics or even designing new instruments to measure storms or plastic in the ocean.
ArgoNimaux is the most popular for the youngest, who can choose to track a marine animal week by week, in collaboration with researchers, and also compare their tracks with ocean data. They can see the impact of the ocean variations on marine animals, and learn more about the animals' behaviour, their migrations, foraging trips, etc.
And with the newest branch, ArgoHydro, students can measure in situ data (precipitation, soil moisture, lake and river levels) and correlate them with satellite data (Precipitation, Soil Moisture, water level, …). There also they can design their own buoy, or instrument(s) onboard UAVs, with the added value that they can do the measurements close to their school. ArgoHydro is designed to complement the international Global Learning and Observation to Benefit the Environment (GLOBE) Program. This activity is also held in the frame of the Surface Water and Ocean Topography (SWOT) satellite, developed jointly by NASA and CNES.
Material is available in French, but also in English for the main information on the project and on the data.

Three classes are going to present their projects.
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Citizen science in FloatEco and GO-SEA projects

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Session: Outreach, Education and Altimetric Data Services
Presentation type: Oral

Abstract:
Volunteers and citizen scientists can provide valuable support to scientific studies. In this presentation, we overview collaborations with citizen scientist during FloatEco (floateco.org) and GO-SEA (goseascience.org) projects, funded by NASA, and illustrate how samples and reports, collected by citizen scientists, advanced success of our projects. We also discuss difficulties of such collaborations and importance of careful selection of feasible tasks, development of clear and realistic protocols, initial training and equipping citizen scientists with sufficient tools. Value of citizen science increases as satellite altimetry evolves to resolve smaller spatial scales that play critical roles in climate and ecosystem but are not covered by limited scientific resources.

Collage. Citizen scientists from eXXpedition, The Longest Swim and The Vortex Swim help to deploy and inspect scientific instruments, and collect samples and measurements.

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Altimetry training resources available under EUMETSAT Copernicus Marine Training Service

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Session: Outreach, Education and Altimetric Data Services
Presentation type: Oral

Abstract:
EUMETSAT is responsible for delivering the Level-1 and Level-2 Sentinel-3 and 6 marine and large lake products for Copernicus, and, as such, also plays a key role in promoting data to users and providing training opportunities. The EUMETSAT Copernicus Marine Training Service (CMTS) programme, which started in 2017, is built around an ethos of problem-based learning, with tools for data access and manipulation provided as scaffolding, and an approach that encourages course participants to create and share their achievements (constructivist learning). Courses are offered in both short and long formats, depending on the audience and learning objectives, and adopt a blended approach; mixing asynchronous, synchronous and stand-alone learning modes to accommodate online learning via our Moodle platform (https://training.eumetsat.int/). The aim is to support users in developing the use of Copernicus data for their own research applications, or the requirements of their job roles.

A new phase of the CMTS service is starting January 2022. This new phase will continue to cover all marine aspects of the Sentinel-3 mission and, with the release of data for Sentinel-6 Michael Freilich, will have a renewed focus on altimetry. Consequently, beyond course-based training, it will seek to develop resources that can be used in training by others or for independent learning – such as instructional videos, code repositories, and Massive Open Online Courses. These resources will include new approaches for accessing Copernicus marine data, including those from SRAL and Poseidon-4, via EUMETSATs new data access services. This presentation will give an overview of the existing resources that are available for trainers, alongside details of our plans for future efforts and calls for collaboration.

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CEOS Ocean Variable Enabling Research & Applications for GEO (COVERAGE): A Platform to Simplify and Expand the Accessibility and Synergistic Use of Inter-agency Satellite and in-situ Oceanographic Data

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Session: Outreach, Education and Altimetric Data Services
Presentation type: Oral

Abstract:
There is a broad need, by a growing number of user communities, for synergistic use of increasingly available satellite-derived environmental data, including products from altimetry missions, in support of research and numerous oceanographic applications. However, the potential of such Earth Observations for ocean science and applications for societal benefit has yet to be fully realized. This is largely due to issues encountered by less expert users, who are currently underserved, and which relate to complexities of data access, product selection, and working with large volume, heterogeneous datasets across agency repositories. The CEOS Ocean Variables Enabling Research and Applications for GEO (COVERAGE) initiative aims to address this critical gap. Its seeks to provide improved access to multi-agency, multidisciplinary remote sensing data for the oceans that are better integrated with in-situ and biological observations that pose additional interoperability challenges.

COVERAGE is an international initiative and 3 year pilot project within the Committee on Earth Observation Satellites (CEOS) involving interagency participation. It aligns with programmatic objectives of CEOS and the missions of GEO-MBON (Marine Biodiversity Observation Network), which are to advance and exploit synergies amongst marine observational programs. It focuses on implementing technologies, including cloud-based solutions, to provide an advanced yet accessible data rich, web-based platform for integrated ocean data delivery and access: multi-parameter observations, easily discoverable and usable, organized thematically, available in near real-time, collocated to a common grid and complemented by a set of value-added data services. COVERAGE development is organized around priority application use cases identified by agency partners and user driven. Here we provide an overview of the initiative and the status of the Phase C technical implementation work that builds upon our current prototype. Emphasis is also placed on describing the associated ecosystem thematic demonstration application that focuses on the dynamics of high seas pelagic fish assemblages in relation to the environment in support of emerging high seas area-based management frameworks. Results showing the utility of altimetry data, especially when combined with complementary remote sensing observations from other parameters, in identifying dynamic oceanographic features and biological hotspots of interest are illustrated. International collaborative aspects of the project are discussed with the intent of soliciting community feedback.

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Interactive website to visualize and study mesoscale eddies

Jeffrey Early (NorthWest Research Associates, United States); Brian Curtis (Private database consultant, USA); Jonathan Lilly (Planetary Science Institute, USA); Peter Gaube (University of Washington, USA)

Session: Outreach, Education and Altimetric Data Services
Presentation type: Oral

Abstract:
Over the last several decades satellite altimetry data has enabled researchers to track ocean eddies as they traverse the world oceans. These eddies persist for months and sometimes even years, changing size and shape throughout their lifetimes. Many of these eddies are also observed by other instruments, include surface drifters and profiling floats, among other instruments.

In order to convey the rich qualities of these eddies, we created an online, interactive website to explore the evolution of individual eddies in the world oceans. Users explore the history of tracked eddies in the ocean and study the histories of individual eddies fused with other contemporaneous observations.

This online visualization and exploration tool is backed by datasets used in current research by the co-authors studying the physical structure of these eddies and their interactions with biology. These datasets are normalized in a publicly available relational database which supports the online tools and enable future research projects combining these observations. The goal here is to lower the barrier to entry for research and understanding by scientists, students, educators, and the public at large.
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Outreach and data services showcases

All All (OSTST, France)

Session: Outreach, Education and Altimetric Data Services
Presentation type: Oral

Abstract:
short (1 slide) presentations of outreach and/or data services actions and implementations.
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Estimating upper ocean heat content in the North Atlantic Ocean with the NOAA next-generation enterprise ocean heat content algorithm

Deirdre Byrne (NOAA, United States); Paige Lavin (NOAA, United States); David Trossman (NOAA, United States)

Session: Application development for Operations
Presentation type: Oral

Abstract:
On average, a tropical cyclone (TC) making landfall in the United States causes an estimated $19 billion in damage. The over-ocean intensification of TCs can bring stronger winds and greater rainfall to land areas, making them even more dangerous and costly. This effect was seen in Hurricane Katrina, which went on to cause a record $161 billion in damage. The number of strong - category 4 and 5 - TC landfalls in the US has increased substantially in recent years, with more having occurred in 2017-2021 than in the 54 years preceding that period. One recent example of such a TC is Hurricane Ida, which intensified rapidly from a category 2 to a category 4 storm over the Gulf of Mexico early on 29 August 2021 before arriving on land later the same day. Rapid TC intensification is tied to the heat content of the upper ocean, historically defined as the amount of energy stored in the ocean at sea temperatures of 26°C and above. However, it is clear that additional details of upper ocean stratification are a key factor in the extent to which TCs are able to rapidly intensify.

The NOAA Next Generation Enterprise Ocean Heat Content (NGE OHC), an empirical parameterization, generates depth-resolved ocean profiles to provide daily upper ocean heat content fields and support detailed analysis of the potential for rapid intensification. The method, based on the Geostrophic Empirical Mode, leverages the prevalence and predominance of low mode baroclinic variability in the ocean to directly estimate profiles from altimetry, sea surface temperature, and ancillary parameters. In the North Atlantic, the resultant profiles resolve 94% (92%) of the variance in temperature (salinity) of in situ observations in the upper 1000 dbar. In comparison with the current operational product, the NGE OHC algorithm shows increased accuracy during extreme conditions. In particular, during Hurricane Ida the NGE OHC algorithm decreased the error in estimating the Argo-observed depth of the 26°C isotherm from 31.5 m (legacy product) to 3.25 m. A synopsis of the results from the preliminary product is discussed.

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The 2022 Honga Tonga Tsunami monitored by satellite altimetry and SAR

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Session: Application development for Operations
Presentation type: Oral

Abstract:
The Hunga-Tonga submarine volcano produced a violent explosion on Saturday 15/01/2022 at approximately 04:15 UT (17:15 local time). The explosion generated a tsunami affecting all the Pacific Ocean.
The tsunami has been detected in the multimission (Duacs) operational Sea Level products ingesting the flying altimeters Jason-3, Sentinel-3A, Sentinel-3B provided by Eumetsat, Cryosat-2, Saral, HY-2B provided by Cnes. After a specific processing carried out to remove the natural variability of the ocean, the tsunami signal was detected very clearly in the constellation, notably on HY2B, first to fly over the area 1h30 after the eruption. Comparisons to models show a position mismatch in the NRT predictions, demonstrating the interest of altimetry in tsunami analyses.
The signature of the tsunami was also detected in radar images from the Copernicus Sentinel-1A synthetic aperture radar (SAR) satellite. the peak wavelength of the retrieved waves was estimated allowing us to track them back near the center of the eruption, therefore confirming that they were generated by this event.
This paper describes the tsunami signal as observed by the altimetry constellation and Sentinel1A.

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Dynamics of the North Pacific "garbage patch" observed with a suite of Lagrangian instruments for ecological applications

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Session: Application development for Operations
Presentation type: Oral

Abstract:
The FloatEco (Floating Ecosystem) experiment studies physical and biological processes controlling the neopelagic ecosystem emerging in the eastern subtropical North Pacific as a result of marine debris accumulation in the so-called "garbage patch" area. Here, we present preliminary results of the study of pathways of debris into, from, and inside the area based on the analysis of trajectories and derived dynamical characteristics of drifters of various geometry as well as real debris items tagged with GPS trackers by the Ocean Voyages Institute and also numerous volunteers and partners.

Response of floating objects to the combined effect of Ekman currents, waves, and direct wind force is summarized and used to improve numerical models. The presence in the central part of the garbage patch of debris with a surprisingly broad range of "windages" is explained by the dominance of unorganized currents and winds, inducing strong horizontal mixing and homogenization. Trapped inside this area, objects with different geometry demonstrate signs of frequent interactions, including direct collisions. Such interactions were confirmed during inspections of the FloatEco instruments and they plays a critical role in propagation of species colonizing debris that, in turn, increases the resilience of the debris-based ecosystem to continuous changes of environmental parameters.

We also discuss the Lagrangian connectivity between the pelagic and coastal ecosystems and identify feasible pathways of coastal species into the garbage patch and potential paths of invasion from the garbage patch into the coastal areas.

The improved numerical models are used to describe seasonal and interannual changes in the garbage patch location, shape, and capacity, estimate the total amount of fishing nets in the North Pacific, and to develop practical applications for optimization of cleanup operations.

Figure. Trajectories of FloatEco Lagrangian instruments and streamlines of operational SCUD model. Also, photographs of drifters, float, GPS-tagged fishing nets, and data of cleanup expeditions used in FloatEco analysis.

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5Hz resolution altimetry wave products for better coastal approach

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Session: Application development for Operations
Presentation type: Oral

Abstract:
CMEMS Wave TAC next baseline will be 5Hz resolution wave products, 1km along track, to answer to the users community who wants to get closer to the shore. Therefore, in the Sea State community, the literature usually assumes that altimetry waves at 1Hz is dominated by noise (Ardhuin et al. 2019) and most studies tackle this issue by filtering these data up to 50km at least (Quilfen et al. 2018, Dodet et al. 2020). It is also known that the fading noise has a real impact on correlated errors at these scales (Quartly et al. 2019), with an impact on SLA estimates that can empirically be reduced by methods described in Zaron et al. or Tran et al. 2021.
Is this presentation, we present 5Hz demonstration products, processed from 20Hz data with a particular care to data selection, an essential step for validation purpose (Quartly et al. 2019) and compression.
Their quality over coastal areas is illustrated and demonstrated with respect to the current baseline at 1Hz benchmarked and produced by CCI Sea Sate project (Dodet at al. 2021) and CMEMS operational NRT products.
Their high frequency contain is also deeply analyzed as well as the contamination effects on SLA estimates, mainly in the bump frequency, extensively described in Dibarboure et al 2014.
The results are presented for Jason3, Envisat, LRM missions processed with the innovative adaptive retracking (Tourain et al. 2021), Doppler SAR altimetry observations, (Moreau et al. 2021) and CFOSAT data dedicated to sea state observations (Hauser et al. 2020).
These products are finally proposed to other international teams (for assimilation and/or validation, climate or coastal communities…) via demonstration samples available on Aviso web site.
Give them a try!
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Towards a global Stokes drift product from SWIM/CFOSAT

Charles Peureux (CLS, France); Annabelle Ollivier (CLS, France); Hélène Etienne (CLS, France); Sandrine Mulet (CLS, France); Cédric Tourain (CNES, France); Lotfi Aouf (Météo France, France)

Session: Application development for Operations
Presentation type: Oral

Abstract:
The Stokes drift is the main contribution from ocean surface waves to particles drift in the ocean's upper layer. At the moment, estimates of the Stokes drift at the global scale rely on numerical models, due to the unavailability of such measurements from space.
CFOSAT is a new mission concept, carrying SWIM, a rotating scatterometer, operating both at nadir and off-nadir. It aims at measuring the ocean surface waves slopes spectrum, from which the Stokes drift can be estimated.
Potential for Stokes drift estimation from SWIM is illustrated using statistical diagnostics on SWIM ocean waves spectra. Although the Stokes drift is carried in majority by waves which are not resolved by SWIM, it is shown that an algorithm based on the extrapolation of SWIM waves spectra could be thought of. Such potential combined with the characteristics of SWIM make the effort to design and qualify a Stokes drift product interesting. Such a product would be of particular interest in areas such as the Southern Ocean, where Stokes drift is significant and poorly known, and where the observational conditions are favorable to SWIM (resolved wind sea, favorable wave direction)
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Thirty years of iceberg and associated fresh water flux from altimeter

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Session: Application development for Operations
Presentation type: Oral

Abstract:
Basal melting of floating ice shelves and iceberg calving constitute the two almost equal paths of freshwater flux (FWF) between the Antarctic ice cap and the Southern Ocean. For the Greenland ice cap the figures are quite similar although surface melting also plays a significant role. Basal and surface melt-waters are distributed over the upper few hundred meters of the coastal water column while icebergs drift and melt farther away from land. While the northern hemisphere icebergs are, except for rare exceptions, small (<10km2), in the southern ocean large icebergs (>100km2) act as a reservoir to transport ice far away from the Antarctic coast into the ocean interior, whilst fragmentation acts as a diffusive process. It generates plumes of small icebergs that melt far more efficiently than the larger ones.
Ocean General Circulation Models that include interactive icebergs show that basal ice-shelf and iceberg melting have different effects on the ocean circulation and that icebergs induce significant changes in the modeled ocean circulation and sea-ice conditions around Antarctica or in the northern Atlantic. The transport of ice away from the coast by icebergs and the associated FWF cause these changes. These results highlight the important role that icebergs and their associated FWF play in the climate system. However, there is actually no reliable direct estimates of the iceberg FWF to either validate or constrain the models.
Since 2008 the ALTIBERG project maintains a small iceberg (less than 10km2) database (North and South) using a detection method based on the analysis of satellite altimeter waveforms. The archive of positions, areas, dates of icebergs as well as the monthly mean volume of ice icebergs now covers thirty years (1992-2021). Using classical iceberg's motion and thermodynamics equations constrained by AVISO currents, ODYSSEA SST's and Wave Watch 3 wave heights, the trajectories and melting of all detected ALTIBERG icebergs have been computed for both hemispheres. The resulting trajectories (several hundred thousands) are then used to compute on a regular grid the daily FWF using a calibration method to compensate for the numbers of available atlimeters during the 30 years.
The volume of ice, the probability of presence of icebergs as well as the FWF's temporal and spatial distribution for the 30 years are presented for both hemisphere showing the strong increase of the volume of ice and FWF around Greenland and the complex time and space variability in the southern ocean.
Figure legend: mean daily FWF, mean daily volume of ice , mean icebergs surface and thickness : 1992-2021 period, 50x50km grid.

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Absolute calibration results from Bass Strait, Corsica, and Harvest facilities

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Oral

Abstract:
Bass Strait:
The Bass Strait altimeter validation facility (~ 40° 39'S, 145° 36' E) provides cycle-by-cycle estimates of absolute altimeter bias for the Jason-series, Sentinel-3A and Sentinel-3B missions. The facility uses an integrated geometric approach involving a suite of in situ sensors including moored oceanographic sensors, episodically deployed GNSS equipped buoys, a coastal tide gauge and continuously operating GNSS reference stations. This year we present the results for the 4 missions with a focus on Jason-3 GDR-F and the Sentinel-6 1-Hz data.With the advance of fully SAR capable altimetry (Sentinel-6) and in preparation for swath-based interferometric altimetry (SWOT), several enhancements to the Bass Strait facility have been progressed. We detail our ongoing use of 5-beam ADCP instruments for the determination of shallow water SSH, current and wave field information using a pressure inverted echo sounder concept (CWPIES). We review our progress in understanding small but significant systematic errors in SSH derived from GNSS equipped buoys. Together, advances in our in situ instrumentation seek to address an improved determination of along-track SSH (and SSH gradient) for the benefit of validating the next generation of altimeter missions. We present results from these investigations together with latest absolute bias results from the Bass Strait comparison points.

Harvest:
We describe the latest satellite radar altimeter calibration/validation (CALVAL) results from the Harvest offshore platform and vicinity. Located 10 km off the coast of central California near Point Conception, Harvest has served as the NASA prime verification site for the TOPEX/POSEIDON (T/P) and Jason series of altimeter reference missions for three decades. The T/P repeat ground track was designed to take the satellite directly over Harvest every ten days, enabling the development of a continuous verification record based on direct, overhead passes of the platform. The crucial role of T/P in developing a climate-quality record of sea level and ocean circulation has been inherited by the Jason series of reference missions, which have traced out the same 10-d repeat ground track passing by the platform. With the beginning of the routine operations phase in November 2021, the Sentinel-6 Michael Freilich (S-6 MF) mission will assume the mantle of extending this valuable scientific observation record.With the completion of the year-long S-6 MF commissioning phase, we estimate the sea-surface height (SSH) bias is +13 ± 3 mm (one standard error with N = 29) for the low-resolution mode (LRM) altimeter data. In terms of this bias, the current non-time critical (NTC) and short-time critical (STC) products are indistinguishable, as are the A and B sides of the Poseidon-4 altimeter. The corresponding Jason-3 (J-3) SSH bias is very consistent (+11 ± 2 mm with N = 174). Data from legacy Jason mission also yield slightly positive SSH biases: +6 ± 2 mm (N = 206) and +5 ± 2 mm (N = 249) for J-1 and J-2 respectively. Accounting for systematic errors, none of these SSH bias estimates are statistically different from zero. However, the relative (inter-mission) SSH biases carry greater statistical significance. If the comparison between J-3 and S-6 MF is restricted to common cycles, the result at Harvest indicates the new mission is measuring SSH higher than its predecessor by +5 ± 3 mm (N = 29), in keeping with preliminary results from global analysis. We also provide preliminary results for reprocessed data from the legacy T/P mission, and describe developments from GPS buoy campaigns at Harvest. Results from a 2018-19 tandem GPS buoy campaign suggest RMS accuracies of <2 cm and <1 cm were achieved for absolute and relative SSH respectively. Following this successful campaign, we deployed in October 2020 a GPS buoy to start permanent occupation of the site (with yearly servicing trips). We report early results from this year-long deployment.

Corsica:
Initially developed for monitoring the performance of TOPEX/Poseidon and follow-on Jason legacy satellite altimeters, the Corsica geodetic facilities that are located both at Senetosa Cape and near Ajaccio have been developed to calibrate successive satellite altimeters in an absolute sense. Since 1998, the successful calibration process used to calibrate most of the oceanographic satellite altimeter missions has been regularly updated in terms of in situ instruments, geodetic measurements and methodologies. In this study, we present an assessment of the long-term stability of the in situ instruments in terms of sea level monitoring that include a careful monitoring of the geodetic datum. Based on this 20+ years series of sea level measurements, we present a review of the derived absolute Sea Surface Height (SSH) biases for the following altimetric missions based on the most recent reprocessing of their data: TOPEX/Poseidon and Jason-1/2/3, Envisat and ERS-2, CryoSat-2, SARAL/AltiKa and Sentinel-3A&B. For the longest time series the standard error of the absolute SSH biases is

now at a few millimeters level which is fundamental to maintain the high level of confidence that scientists have in the global mean sea level rise.
Launch in November 2020, Sentinel-6 Mickael Freilich flew in tandem with Jason-3 during its first year of mission. We will present in detail the analysis of this tandem phase. Preliminary results shows that the absolute SSH bias for both missions are very close at the few mm level for the LRM mode and both very close to 0. Improvement thanks to SAR will be also presented: measurements are valid (and accurate) up to the coast (few hundred meters); on the whole set of cycles, the standard deviation of 20Hz data is improved by a factor close to two: 33 mm compared to 56 mm with LRM (69 mm for Jason-3).
In preparation of SWOT, an extension of the "geoid" over the Ajaccio and Senetosa area has been realised during 2 campaigns in 2021 and 2022. Prelimininary results will be also presented.
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Performance Characteristics of the CDN1 Transponder Data and Current Results of the ESA Permanent Facility for Altimetry Calibration in West Crete.

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Oral

Abstract:
A microwave range transponder has been operating at the CDN1 Cal/Val site on the mountains of Crete for about 6 years to calibrate international satellite radar altimeters at the Ku-band. This CDN1 transponder is part of the European Space Agency Permanent Facility for Altimetry Calibration (PFAC), and has been producing continuously as of 2015 a time series of range biases for Sentinel-3A, Sentinel-3B, Sentinel-6A, Jason-2, Jason-3 and CryoSat-2. A second range and sigma-0 transponder at a crossover location of Sentinel-6 "Michael Freilich" on the island of Gavdos is also operational as of 11-Oct-2021. This work presents a thorough examination of the transponder Cal/Val responses in an effort to understand and determine which factors are responsible for the observed changes in the Cal/Val results. Fourteen uncontrolled and three controlled sources of variations have been investigated.
The latest calibration results for the Jason-3, the Copernicus Sentinel-3A and -3B, Sentinel-6A and the HY-2B radar altimeters will be described based on four sea-surface and two transponder Cal/Val sites of the PFAC in west Crete, Greece. Absolute biases for Jason-3, Sentinel-6A, Sentinel-3A, Sentinel-3B and HY-2B will be given using various techniques, infrastructure and settings.

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Potential of the Noumea lagoon as a multi-mission cal/val site for past and future altimetry missions.

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Oral

Abstract:
At the interface between New-Caledonia and the Pacific Ocean, the Noumea Lagoon is an example of a dynamically complex coastal zone, that challenges the present and future altimetry mission. In this area, the SSH evolution is still an unresolved issue as sea level from altimetry and coastal tide gauge, and vertical land movements from GNSS, do not provide consistent information on long term trends (Aucan et al. 2017; Martínez-Asensio et al. 2019). This could be explained by multiple reasons, such as errors in the determination of GNSS Vertical Land Movements (VLM) due to mismodelled discontinuity (Ballu et al. 2019), a local elevation of the water body (setup) linked to waves and wind or the limitation of the altimetry data processing.

We addressed this question through the GEOCEAN-NC 2019 oceanographic campaign. During 3 weeks, we deployed various instruments in the lagoon, with a particular interest for the intersection zone of 3 altimetry tracks (1 Jason track and 2 Sentinel-3a tracks). To obtain in-situ sea level variations over the entire altimeter period at this particular location, we virtually transfered the Noumea tide gauge using observations from a GNSS buoy (2 days) and a bottom pressure sensor (1 year). In the same time, we analysed the 20Hz along-track data from Jason and Sentinel-3a GDRs according to the standards used on other historical cal/val sites. For that, we determined the optimal GDRs correction parameters, and integrated geoid gradients from the XGM2019 model, validated thanks to the CalNaGeo GNSS carpet measurements.

These two SSH time series (i.e. in-situ and altimetry) allow us to compute the altimeter biases over the entire Jason (1/2/3) and Sentinel-3a period. We show that the resulting altimeter biases are less than 10 cm for both Jason and Sentinel, with inter-mission biases consistent with other cal/val sites. With our 3 weeks field campaign, we have developed a relevant methodology to reanalyse 20 years of altimetry observations, and demonstrate the opportunities offer by the Noumea site to develop cal/val activities, for past, current and future missions. In this respect, several experiments are planned in 2023 to take advantage of the SWOT calibration phase 1-D repeat orbit.

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Measuring mean sea level with surface drifting buoys

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Oral

Abstract:
The overarching idea of this project is to establish a new ocean observing system for monitoring global and regional mean sea level (MSL) changes. This system will consist of a global array of thousands of water-following drifting buoys, or drifters, tracked by a Global Navigation Satellite System (GNSS) which will continuously provide the geographical positions and the height of the sea surface along the buoys' trajectories. The Lagrangian sea surface height data collected in this way, averaged over regional basins and the global ocean, will provide daily estimates of regional and global mean sea levels. This new system will be independent, resilient, sustainable, and hopefully relatively economical. Additionally, the new system could provide opportunities for developing globally-distributed, local and regional calibration and validation efforts for satellite altimetry missions. Importantly, by providing high-frequency and regional and global estimates, this new system will have the capability to bridge the observational gap between the existing altimeter satellite system and the tide gauge observing system. Using the example of the historical trajectories of the drifters of the NOAA Global Drifter Program (GDP), we have recently demonstrated (see Elipot, 2020) that with the current configuration of the GDP array, global-mean sea-level decadal linear trend estimates with an uncertainty less than 0.3 mm per year could be achieved with daily random error of 1.6 m or less in the vertical direction for each individual drifter daily estimate. Can this target accuracy be reached with existing technologies?

In order to answer this question, we are conducting a pilot project that consists in deploying three drifters in a moored configuration, at two coastal locations, in La Jolla, CA and Virginia Key, FL, both collocated with NOAA tide gauges providing reference sea level measurements. The first drifter, acting as a control, is a standard (build to print) version of Surface Velocity Program (SVP) drifter from the Scripps Institute of Oceanography Lagrangian Drifter Laboratory. It is equipped with a standard precision single-frequency GPS chipset (u-blox) and antenna. The second drifter is also a standard SVP unit, but supports internal recording of the raw, high-rate (1-Hz) GPS tracking observations for post processing. Providing a gold standard of positioning data, the third drifter is additionally equipped with a geodetic-grade GPS chipset (Septentrio AsteRx) continuously recording dual-frequency tracking data from Global Navigation Satellite Systems (GNSS). This drifter is also equipped with an inertial measurement unit to continuously measure the platform attitude.

To characterize the performance, the raw full-rate (1-Hz) observations from the two enhanced SVP drifters will first be processed using the JPL GipsyX software in order to obtain the best achievable sea-level estimates for each case. These observations will be sequentially decimated and reprocessed in various solution strategies to understand the trade-offs between data sampling and battery capacity on one hand, and achievable sea-level estimate accuracy on the other hand. Ultimately, we will use the results of this pilot project to suggest, from a cost-analysis point of view, a pathway to deliver the envisioned new global mean sea-level observing system as an added value to the NOAA Global Drifter Program.
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Possible datum errors at tide gauges detected by satellite altimetry: some case studies

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Oral

Abstract:
The OSTST is accustomed to using tide gauge data for validation of satellite altimetry, and even, when the need arises, for calibration of altimetry (e.g., when determining the TOPEX Side-A to Side-B bias). Here we turn the problem around -- we use altimetry to find possible cases of datum errors in about a dozen tide gauges, all of them high-quality stations, most located on small islands. We estimate datum errors by solving simultaneously for implied linear vertical land motion (VLM) at the tide gauge, plus one or more discontinuous jumps. This is done using daily mean tide-gauge sea levels and two complementary altimeter gridded datasets: Aviso/CMEMS data and MEaSUREs data. The gauge data must be adjusted for long-period tides, the pole tide, and dynamic ocean loading (consistent with that used in altimetry processing). The estimated errors/jumps in all cases are fairly small, usually only a few cm; the largest found is about 10 cm. Analysis of implied VLM provides perhaps the most convincing evidence that the detected tide-gauge errors are real: the VLM for the periods before and after detected jumps, as well as the VLM for the whole (adjusted) time series, should show improved consistency. The adjusted VLM should also show better consistency with VLM measured with nearby GNSS instruments, although this is sometimes ambiguous owing to differences between multiple GNSS stations, their distances from the tide gauge, and uncertainties in GNSS rates due to equipment changes or errors. For the dozen or so cases we have discovered, we are revisiting tide-gauge instrumentation and associated documentation for evidence of the suggested errors. As of this writing, we have resolved one case, at Rodrigues, where a jump during October 2013 has been traced to a site visit during which cables to two water-level calibration sensors were inadvertently reversed. The sensors are separated by 43 mm, and reversing them adjusts measured sea level by that amount. The altimeter-based tide-gauge offset had previously been estimated at 32 ± 6 mm (one sigma), which is consistent within a 95% confidence interval of the offset from the cable reversal. This datum error at Rodrigues has now been corrected in the public data archives of the UH Sea Level Center. This use of altimetry to identify tide gauge errors, combined with independent information to correct the errors, obviously then benefits altimetry thanks to the improved validation datasets.

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Independent and intermission validations of Sentinel-6 Michael Freilich

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Oral

Abstract:
After a successful 12-month commissioning, the Sentinel-6 Michael Freilich (S6MF) mission, entered routine operations on 29 November 2021. Sentinel-6 was designed to operate in two altimeter modes, Low-Rate (LR) and High-Rate (HR), which increased the complexity of the commissioning compared to its predecessor missions in the TOPEX/Jason series. Calibration/validation of both LR and HR products are essential to NOAA users of sea level, wave heights, and wind speeds, and for a wide range of applications from marine wave and wind hazard warnings, hurricane intensity forecasting, coast inundation, marine debris mitigation, and fisheries management.

As S6MF assumes the role of reference mission in the altimetry constellation, we summarize independent and intermission cal/val results. From a global tide gauge network, we assess system stability and from available buoys we evaluate near-real time wind and waves. Using the Radar Altimeter Database System, we also summarize intermission differences.

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Sentinel-6 PDAP products assessment over ocean

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Oral

Abstract:
Launched on 21 November 2020, Sentinel-6 Michael Freilich is a Copernicus satellite designed to ensure the continuity to the mean sea level climate time series measured by the TOPEX/Poseidon and Jason satellites since 1992. The main payload carried on-board Sentinel-6 is the Poseidon-4 (POS4) dual frequency radar altimeter. POS4 uses an approximate9 kHz Pulse Repetition Frequency, and an innovative interleaved chronogram allowing for the optimization of the number of measurements acquired. Thanks to the interleaved design, POS4 offers for the first time the possibility to downlink simultaneous: Low Resolution (LR) data aiming at extending the legacy of the mean sea level record, and High Resolution (HR) or Synthetic Aperture Radar (SAR) data that significantly improves the along-track spatial resolution and reduces measurement noise. The on-board Range Migration Correction (RMC) algorithm , another innovation of POS4, allows reducing the HR data volume by half, in turn it facilitates the downlink of both LR and HR data all over the Globe.

In this presentation we focus on the altimetry products from baseline F06, both the NRT/STC/NTC data disseminated by the EUMETSAT PDAP ground segment, as well as the full mission reprocessed data of the same baseline produced by EUMETSAT. All the NRT/STC/NTC timeliness products are assessed, and particular attention is given to the quality assessment of the NTC and reprocessed products. Both LR and HR performances are addressed. Moreover, POS4 instrument performances from the PDAP Long Term Monitoring are briefly summarized.

For all latencies, LR requirements are fulfilled and data products show good continuity with Jason-3. GMSL inter-mission bias is well characterised after about 12 months, and GMSL continuity with Jason-3 is illustrated, although a longer time series is needed to fully demonstrate this. It is also shown that HR requirements are met for all latencies, except for SWH that are overestimated at high wave heights due vertical wave velocity impacts (a known issue in SAR altimetry) even after the number of looks was reduced in baseline F06. HR RMC is also assessed and presents performances very similar to the HR RAW data performances over open ocean, and in coastal regions.

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Jason-3 GDR-F mission performances over ocean

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Oral

Abstract:
TOPEX/Poseidon, Jason-1, Jason-2, and then Jason-3 have allowed to build a high-precision ocean altimetry data record on historical ground track and will be followed by Sentinel-6-MF as the reference mission.
Long-term monitoring of the Jason altimetric system is routinely performed at CLS, as part of the CNES SALP (Système d'Altimétrie et Localisation Précise) project. The main objective of this activity is to provide an estimation of these missions' performances for oceanic applications such as mesoscale or climate studies. As TOPEX/Jason/Sentinel-6 are the reference missions used in operational applications or for delayed time studies and especially for monitoring of the Global Mean Sea Level, we pay special attention to the long-term stability of their Global Mean Sea Level (GMSL). The Jason-3 GDR-F data have been provided to users since cycle 171 (2020, September), and data reprocessing in standard "F" was performed during 2021 over the past. This reprocessing campaign has a twofold objective: improve the quality of the products and share common standards with Sentinel-6/Jason-CS, as Sentinel-6 datasets have followed standard "F" from its launch (in 2020, November) onwards.
A precise knowledge of Jason-3 data quality and errors is a key activity to ensure a reliable service to scientists involved in climate change studies as well as operational oceanography. The monitoring of all altimeter and radiometer parameters is routinely performed to detect jumps or drifts. After six years in orbit as a precise altimeter mission, we will give in this presentation an updated with standard "F" overview of Jason-3 data coverage and data quality concerning altimeter and radiometer parameters, but also the performance of delayed and real time products (GDR, IGDR, OGDR) at mono-mission crossovers and along-track. We will also focus on the way the reprocessing impacts Jason-3 dataset and these performances.
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Sentinel-3 status and performance over ocean

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Oral

Abstract:
The Copernicus Sentinel-3A mission was successfully launched in February 2016. It is a multi-instrument mission to measure surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. To reach the data coverage required by the Copernicus service, its twin Sentinel-3B was launched on 25th of April 2018. After 5 months in a tandem flight configuration (Sentinel-3B 30 seconds ahead of Sentinel-3A), Sentinel-3B was moved to its final orbit, the same as Sentinel-3A but shifted by 140°.

To assess and monitor the overall performance of the Sentinel-3 mission ESA and EUMETSAT have defined the Mission Performance Framework. Within this framework, the Sentinel-3 Mission Performance Centre (S3-MPC) is the component in charge of the performance of the Optical Mission and of the Surface Topography Mission (STM). For the STM, the S3-MPC has been in charge of several activities:

- Calibration and characterisation of the performance of Sentinel-3 altimeter (SRAL) and microwave radiometer (MWR)
- Validation of the ground processing and final products
- Assessment of the overall mission performance
- Support for the continuous improvement of the S-3 STM performance

Here, we provide an overview of the latest assessment of the STM Sentinel-3A and 3B Level 2 mission performance over the ocean. The analysis will focus on different geophysical parameters (e.g. topography, wind and waves). Mission performance will be assessed through mono-mission diagnostics (e.g. cross-over analysis) as well as through comparison with other altimeters and models.

Our results evidence that both Sentinel STM performance over the ocean are nominal with estimated errors well within the mission requirements for all physical parameters (i.e. sea level anomaly, significant wave height and sigma naught). Observations are consistent with other altimetry missions (e.g. Jason-3 and Saral-Altika) in terms of both global spatial distribution and temporal evolution. Drifts in the global long-term trends of seal level anomaly previously reported for Sentinel-3A and Sentinel-3B compared to Jason-3 have been addressed: sources of the errors have been identified and solutions to correct them proposed for both Sentinel STMs. Analyses on the residual small errors have also been performed to characterize their spatial patterns and identify potential correlations with other geophysical or instrument parameters.

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Feed-back and contribution after several years of Haiyang-2B data availability

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Oral

Abstract:
The Haiyang-2B (H2B) mission has been launched in October 2018 by the Chinese Agency NSOAS (National Satellite Ocean Application Service). H2B is the second unit of the Haiyang-2 altimetry Program which also features HY2C (launched in September 2020) and HY2D (launched in May 2021) as well as the upcoming units E to H in the future. These satellites are dedicated to monitor the dynamic ocean environment and they bring a significant contribution to the sampling capability of the CEOS Ocean Surface Topography Virtual Constellation.

For almost 2 years, H2B has used to produce several operational products such as Sea Level Anomaly (SLA) Level-2P/3/4 [1][2][3][4] funded by CNES (Centre National d'Etudes Spatiales) and Wind and Waves (W&W) products L2P/L3/L4 [4] supported by CNES, and CMEMS (Copernicus Marine Environment Monitoring Service) funding. Preliminary results shown good data quality and benefits to used H2B on SLA and W&W products [4].

After several years of data availability, we will present the feedback on H2B data quality. We will explain the choices made related to SLA standards and post-processing for L2P products. Furthermore, the contribution and performance of H2B in L3 SLA products will be discussed. To conclude, we will evoke recommendations for L2 data improvement for future missions.

[1] Lievin et al. OSTST conference 2020

[2] Kocha et al., 2021 : « Reprocessing of a sea level L2P-multi-mission dataset covering 28 years", Aviso news letter 18

[3] Kocha et al. EUMETSAT conference 2021

[4] Philip et al. OSTST conference 2020
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Calibration and Validation of TOPEX GDR-F Products

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Oral

Abstract:
The original TOPEX Geophysical Data Record products were affected by altimeter instrument degradation and drifts in the radiometer path delay correction during the time of the mission. In addition, the standards for the models used to derive the sea-level time series are now considered obsolete. As a major upgrade, new so-called GDR-F products have been generated that benefit from significant improvements. In particular, the GDR-F products apply numerical retracking of the altimeter data, the end-of-mission radiometer calibration, and GDR-F standards for the auxiliary corrections. We present a summary of the evolutions applied to this product, and results from the calibration and validation of the product.

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A new CryoSat-2 regional product for ocean applications: the Cryo-TEMPO Coastal Ocean Thematic Data Product

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Session: Coastal Altimetry
Presentation type: Oral

Abstract:
Although the primary focus of CryoSat-2 is the cryosphere, the mission has provided over a decade of key altimetry observations across a diverse range of scientific domains (e.g. Bathymetry, Polar Oceanography, Coastal Ocean and Inland Waters). Due to its Interferometric Synthetic Aperture Radar (SARIn) altimeter, CryoSat-2 was a precursor of the development of Delay Doppler processing (the so called “SAR mode”) for ocean applications. Compared to traditional nadir altimeters, SARIn SAR mode observations are characterized by a much smaller footprint, and hence higher along-track resolution (~300-400 m instead of ~5-7 km), as well as reduced noise level. Over the oceans, these characteristics enable major advancements especially in coastal regions: the higher resolution allows a more detailed representation of the smaller structures (<100 km), while the smaller footprint improves data coverage and precision closer to the coast. Despite these advantages, CryoSat-2 ocean observations remain somehow underutilized in the oceanography community.

The overarching aim of the Cryo-TEMPO project is to develop agile, robust and state-of-the-art CryoSat-2 Products, which are dedicated to specific Thematic Areas, and which are accessible to a broad range of scientific and service users. The coastal ocean is one of the five thematic areas included in the project. The first goal of the Cryo-TEMPO Coastal Ocean Thematic Data Product (TDP) is to maximize the potential of CryoSat-2 observations over the ocean by implementing an ocean-specific processing chain based on the best performing methods and algorithms for coastal applications (and currently not implemented for the production of the official CryoSat-2 ocean products). These methods include, among others: the SAMOSA+ retracker, high-frequency adjustment (HFA) correction, iterative data editing, dedicated sea state bias (SSB) correction and regional mean dynamic topography (MDT). A second goal of Cryo-TEMPO is to expand the user base of its products beyond the traditional altimetry experts by providing an easy-to-use dataset. Thus, the Cryo-TEMPO Coastal Ocean TDP contains only few parameters (i.e. SLA, filtered SLA, flags) compared to traditional level 2 products. Furthermore, each variable is distributed with an associated transparent and traceable uncertainty.

The Cryo-TEMPO Coastal Ocean TDP is currently based on SAR and low resolution mode (LRM) CryoSat-2 observations over the Mediterranean region (-6.4 E to 36.5 E longitude; 30 N to 46 N latitude). Input data to generate the dataset are the official CryoSat-2 GOP baseline-C level1-b products. The Coastal Ocean TDP spans from the beginning of the mission (April 2010) to present, with new CryoSat-2 observations processed and added to the database on a monthly basis. The first version of the product (as well as monthly visualisations of the main variables) is currently available at the Cryo-TEMPO web portal (http://www.cpom.ucl.ac.uk/cryotempo/index.php?theme=coastaloceans). The data will be distributed and freely accessible via the ESA Cryosat science server (https://earth.esa.int/eogateway/missions/cryosat/data). Each year, the methods and algorithms used in the processing chain will be updated and optimized following altimetry expert and user feedbacks and the full Cryo-TEMPO Coastal Ocean TDP reprocessed.

The current version of the product has been compared to the official GOP baseline-C products. Our results show that the Cryo-TEMPO Coastal Ocean TDP is characterized by lower variance (especially in the LRM regions of the domain), indicating improved accuracy of the product. The largest impacts in the product are from the SSB and HFA corrections as well as from the iterative editing. Our analysis included also comparisons with in-situ observations. These include tide gauges sea-level records from the western part of the Mediterranean basin and surface velocities from the SOCIB HF-radar located in the Balearic Sea. Comparison between the Coastal Ocean TDS and tide gauges SLA indicates a good consistency between the two. Correlations are in line with those previously reported for Sentinel-3A and Jason-3 (although with larger root mean square error). Comparison between satellite-based across-track geostrophic currents and those from HF radar also shows good consistency. Furthermore, the errors between the two are smaller than previously reported in the same region from an analogous comparison using Saral-Altika altimeter observations, instead.

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Analysis of Fully Focused and unfocused SAR data in the [0 - 5] km of the coastal strip

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Session: Coastal Altimetry
Presentation type: Oral

Abstract:
One of the most novel concepts in coastal altimetry is the Fully Focused SAR (FF SAR) processing. FF SAR introduces improvements in terms of along-track resolution in high Pulse Repetition Frequency (PRF) radar altimeters. The processing is similar to the SAR altimetry, but the along-track resolution up to the theoretical limit equal to half the antenna length (~0.5 m). This is in contrast to the ~300 m unfocused SAR along-track resolution given in coastal altimeter products (Egido and Smith 2017). The FF SAR footprint is pulse-limited across-track and SAR focused along-track. The main drawback of FF SAR is its high computational effort, but some works have been done to reduce the computation time without losing accuracy (Guccione et al., 2018).
The performance of Sentinel-3 FF SAR products in the Gulf of Cadiz (Spain) was analysed and compared with unfocused SAR, in terms of accuracy and precision. The analysis was done in the 0-5 km coastal band, being zero the point where the track intersect with the coast. Two FF SAR algorithms still in development were used: (i) FF SAR Back Projection (BP) (S3 prototype version of Kleinherenbrink et al., 2020); and (ii) FF SAR Omega-Kappa (WK) (Guccione et al., 2018). Four retracking algorithms were used to estimate the retracked range: Threshold retracker (Davis 1993), SAMOSA (Ray et al., 2015), SAMOSA+ (Dinardo et al., 2018) and ALES+ SAR (Passaro et al., 2020). Two tracks from Sentinel-3A and two from Sentinel-3B were processed in the study area according to the availability of in-situ measurements. The analysis was done in the period 2016-2019 for the six datasets.
The products accuracy was obtained by comparing time series of Sea Level Anomaly (SLA) at 80 Hz with those obtained from a radar tide gauge. The statistic used was the standard deviation of the difference (sdd). Also, an analysis of the Percentage of Cycles High Correlated (PCHC) was done. This analysis is done before the outlier detection so the results can be used to compare directly the different dataset. To evaluate the precision: (1) the SLA differences between consecutive measures along-track were calculated for each cycle, (2) the noise over a single cycle was obtained using the average of these differences, (3) the track precision was determined averaging the noise of all the cycles. These differences were considered a good estimation of noise, since SLA is not expected to change significantly in 85 m, which is the distance between consecutive measurements at 80 Hz.
The products still under testing but preliminary results show percentages of PCHC higher in FF SAR than unfocused SAR. The accuracy in FF SAR and unfocused SAR is quite similar. Values of sdd between 5 and 10 cm were obtained in most of the datasets and tracks. Although it should be noted that lower values of sdd were obtained at 1-2 km of the coast in FF SAR. Moreover, preliminary results in terms of along-track precision show lower noise in FF SAR than in unfocused SAR. Differences between FF SAR algorithms and retrackers are analysed too. Some improvements are observed retracking with ALES+ SAR retracker.
In addition, the across-track surface current velocities, derived from the different SLA retrievals, are compared with high-frequency radar (HFR) data, in order to assess the potential of the different algorithms and retrackers for their use in coastal oceanography applications in the Gulf of Cadiz.

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Round Robin Assessment of altimetry algorithms for coastal sea surface height data

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Session: Coastal Altimetry
Presentation type: Oral

Abstract:
Multidecadal efforts have made possible the current record of ocean sea surface height variations, 30-year long, provided by high-precision altimeter satellites. These observations have greatly improved our knowledge of the open ocean and are now an essential component of many operational marine systems and climate studies. It is not the case in the coastal ocean, where satellite altimetry encounters different issues that make it more difficult to derive accurate geophysical data. However, monitoring coastal sea level changes at global scale is now a critical need that the too rare in-situ data cannot fulfill. This has motivated many efforts to bring the sea level retrieval by satellite altimetry as close as possible to the shore. The result of these efforts is now the availability of many new algorithms for retracking radar altimeter data, correcting sea surface heights and finally deriving sea level variations.

The main objective of this study, initiated and funded by the French space agency (CNES), is to objectively define the best set of altimetry algorithms for computing sea level anomalies (SLA) in coastal zones. We focus on Low Resolution Mode altimetry and aim for the creation of long-term time series spanning different missions. For the different processing components (retrackers, geophysical corrections, and auxiliary parameters, for a total of 21 algorithms), the relative quality of the different solutions is assessed with clearly defined metrics for variability, data availability, and impact on SLA as a function of distance to the nearest coast. The analysis is made at both global and regional scales for 3 specific zones: the Mediterranean Sea, the North East Atlantic and the East Australian coasts. In the regions considered, a comparison against available tide gauge data is also performed. This methodology is applied to Jason-2 and Jason-3 missions, and we determine which algorithms are the most limiting, and how results vary from one mission to the other.

The set of best performing algorithms near the coast will finally be presented, with the criteria used for the selection. This set will constitute the baseline algorithms for the generation of a new Level-3 SLA product.

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Coastal Case Study for Leveraging the Potential of Sentinel-6 MF Fully-focused SAR Altimetry for Retracking Significant Wave Height

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Session: Coastal Altimetry
Presentation type: Oral

Abstract:
Estimating significant wave height (SWH) from satellite altimetry in the coastal zone has been a great challenge so far. The received radar echoes exhibit large interference from strongly reflective targets such as mud banks, sheltered bays, ships etc. Fully-focused SAR (FF-SAR) processing exhibits a theoretical along-track resolution of less than half a metre. This unfolds great potential for a manifold of coastal applications.

We have developed a Sentinel-6 Michael Freilich (S6-MF) FF-SAR processor and fit the zero-Doppler beam of the SAMOSA2 waveform model. In order to account for coastal interference, we apply the CORALv2 coastal retracker to estimate the SWH.

For validation of our processing and retracking strategy, we have selected five coastal S6-MF crossings along the coast of the Dutch Wadden See as well as the Eastern and Western Scheldt to analyse the characteristics of the processed signals. The analysis is performed with regard to different crossing angles of the actual satellite track with the coastal shoreline and local features that induce spurious signals within the processed signals. We present an assessment of different processing approaches to exploit FF-SAR processing for improving the SWH estimates in the close vicinity of the shoreline and put them into comparison with UF-SAR-processed signals.

The assessment is accompanied by a statistical analysis that was adopted from the European Space Agency Sea State CCI project. Several metrics are assessed such as outliers, intrinsic noise, a correlation analysis with a high-resolution wave model, and number of valid points. The latter is based on the quality flag, which is an output of the retracker and represents a crucial indicator on how many useful measurements are estimated. The results are compared against the official delay-Doppler-processed products and serve as a valuable reference of validation.

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Coastal circulation in the Gulf of Cádiz using multi-mission altimetry data

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Session: Coastal Altimetry
Presentation type: Oral

Abstract:
Understanding and monitoring coastal currents and sea-level variability play a key role in the management of coastal areas and activities of high socio-economic and environmental impact developed in the coastal fringe, all of them affected by the current climate change scenario. In this context, one of the main challenges of coastal altimetry is to achieve observations of the sea surface close to land. In coastal zones, altimetry signals are affected by the presence of land within the footprint of the instrument. Besides, derived oceanographic parameters, such as surface current velocities, are partially controlled by local agents, as small-scale wind variability and abrupt bathymetry. The former issue is partially solved by advances in new retracking processing, which allow obtaining accurate measurements up to 3 km from land. The second point must be addressed by the development of local corrections. In this work, surface geostrophic current velocities derived from CryoSat-2 and Sentinel-3A/B altimetry data have been successfully corrected with a wind correction derived from a high-resolution wind speed data from the Weather Research and Forecasting model (WRF). The total surface currents have been used to study the coastal circulation of the Gulf of Cádiz (southwestern Iberian Peninsula), from January to December, 2020. Total surface velocities were previously validated with high-frequency (HF) radar in the study area, obtaining solid statistical scores (correlations up to 0.95 and root mean square errors lower than 10 cm/s), up to 3 km from the coastline. The results and methodology presented state the need of understanding local agents for exploiting altimetric data for coastal oceanographic purposes. Besides, it shows the possibilities of using altimetric data in any coastal location where no other observing systems are available.

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Using satellite altimetry to obtain subsurface ocean temperatures on the Greenland Shelf

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Session: Coastal Altimetry
Presentation type: Oral

Abstract:
We present a novel application of satellite altimetry to monitor ocean temperatures on the continental shelf around the Greenland Ice Sheet with the goal of better understanding past and better predicting future sea-level rise. Mass loss from the Greenland Ice Sheet is now responsible for about 20% of the total annual increase in global mean sea-level, a dramatic increase from the 1970’s, 80’s and 90’s when the mass balance of the ice sheet was in a state of near equilibrium. About half of present-day ice sheet mass loss is due to enhanced surface runoff while the other half is due to glacier dynamics, mainly enhanced ice discharge by Greenland’s more than 200 marine-terminating glaciers. Recent work has linked the interannual variability of Greenland’s marine terminating glaciers to subsurface ocean temperature variability, specifically the temperatures of the relatively dense, warm and salty waters of subtropical origin (Atlantic Water) that control the intensity of submarine melt occurring along the ocean/glacier interface. Our preliminary analysis of satellite altimetry data in combination with a multi-year record of in-situ ocean data in the vicinity of Jakobshavn Glacier in Central West Greenland suggests that satellite altimetry data can indeed be used to infer Atlantic Water temperatures on Greenland’s continental shelf. In particular, the thermal expansion set by interannual subsurface temperature variations induce sea-level variations of several centimeters, a signal which can be observed in an adequately-processed near-coastal multi-instrument satellite altimetry dataset. Prospects and requirements for employing satellite altimetry to monitor ocean temperatures in different sectors around Greenland will also be discussed.

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Benefits of multi-altimeter combination for Arctic sea surface height retrievals

Pierre Prandi (CLS, France); Pierre Veillard (CLS, France); Yannice Faugère (CLS, France); Gérald Dibarboure (CNES, France)

Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Oral

Abstract:
We present a new Arctic sea level dataset (https://doi.org/10.24400/527896/a01-2020.001) based on the optimal interpolation of three satellite radar altimetry missions.
A dedicated processing is applied on measurements from SARAL/AltiKa, CryoSat-2 and Sentinel-3A to identify radar echoes coming from leads in the ice covered regions of the Arctic Ocean. After a data editing and application of instrumental, environmental and geophysical corrections tailored for the Arctic Ocean, these echoes are combined with open ocean echoes through an optimal interpolation scheme to map sea surface anomalies. The resulting gridded sea level anomaly fields provide an unprecedented resolution for this type of products:
the final gridded fields cover all latitudes north of 50°N, on a 25 km EASE2 grid, with one grid every three days over four years from July 2016 to June 2020.
We benefit from the use of an adaptive retracker on SARAL/AltiKa. This retracking algorithm is able to process both specular (leads) and brownian (open ocean) echoes with one phyisical model. Using this retracker on SARAL/AltiKa removes the need to estimate an empirical bias between open ocean an ice covered areas. Therefore SARAL/AltiKa measurements provide a consistent baseline for the cross-calibation of CryoSat-2 and Sentinel-3A, for which leads are retracked using an empirical algorithm (TFMRA).
When compared to independent tide gauge data available in the basin, the combined product exhibits a much better performance and temporal resolution than any of our single mission dataset. This dataset has already been used to document new Atlantic water pathways north of Svalbard (https://doi.org/10.1029/2020JC016825).
Processing details and validation results are documented in Prandi et al., 2021 (https://doi.org/10.5194/essd-2021-123).
This product, supported by CNES, is a prototype for the future generation of regional Arctic CMEMS-SLTAC products that will generate both gridded sea level anomaly fields and cross calibrated along track products for data assimilation.
Future evolutions of this regional Arctic Ocean product will benefit from the inclusion of upcoming satellite radar altimetry missions such Sentinel-3 C&D, and CRISTAL.
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Heat and salt fluxes in the San Matias Gulf

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Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Oral

Abstract:
The San Matías Gulf (GSM) is a semi-closed basin of about 150 km in meridional extension and 100 km in zonal extension, the largest of the so-called north Patagonian gulfs in Argentina, centered at 41° 30' S. Here, we studied the climatological oceanic flow of heat and salt through the mouth of the GSM with the use of a high-resolution baroclinic regional numerical model (CROCO). Because of an excess of evaporation over precipitation all year-round and maximum solar radiation during summer, fresh and cold shelf water that enters the gulf in summer by its south edge of the mouse keeps recirculating in a cyclonic gyre to be advected along the north end of the gulf during autumn with a higher content of salt and heat. We also correlate the surface velocities from our model with those infer from satellite altimetry and with current meters arranged in four moorings along the gulf mouth. The barotropic structure found in the zonal currents that feed the gulf its a key feature to build, with the help of altimetry data and other satellite measures, a long term time series of oceanic heat and salt flux across the gulf mouth. The circulation system, as well as the heat and salt fluxes that exchange the gulf with the continental shelf, have a significant ecological impact, including local fisheries, and therefore influence the well-being of the population that depends directly or indirectly on said ecosystems. The modelling and in situ mooring efforts are part of the SABIO EUMSTAT-CNES project.

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Altimetric Studies of the Oceanic Pathways in the Northeast Pacific Ocean

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Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Oral

Abstract:
Our research addresses a long-standing question in Eastern Boundary Upwelling Systems (EBUS): Over what distances are water parcels and passive species carried along the coast or onshore/offshore by the normal seasonal progression of currents or by anomalous events? A well-discussed example is the varying presence and absence of warm-water and cold-water zooplankton species in the northern region of the California Current System (CCS) during both seasonal variability and ENSO extremes. Observations of changes in water properties and species have been used to hypothesize transports from tropical or subarctic domains, but there have been few efforts to quantify realistic transport distances. Numerical circulation models have been used in a few regions to estimate Lagrangian trajectories, but to verify these hypothesized and modeled transports, Lagrangian trajectories based on observations are needed. We are using time series of mapped geostrophic velocities, derived from 28+ years of satellite altimeter observations, to calculate geostrophic Lagrangian trajectories of passive water parcels in the upper ocean around and within the California Current System, during normal seasonal cycles and anomalous climate events (ENSO extremes, marine heat waves, etc.). The geostrophic trajectories represent approximate movements beneath the Ekman layer. To include the wind-driven effects and the deeper currents, we employ results of a high-resolution numerical ocean circulation model to calculate 3-D tracer and water parcel trajectories, complementing the altimeter analysis. We also calculate trajectories using two data sets that combine geostrophic and Ekman components. In this presentation we show examples of the trajectories calculated from the various fields, addressing the question of transports between the northern and southern CCS during seasonal cycles and interannual events.

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Decadal to Multi-Decadal Circulation Variability in the Western Tropical Pacific Ocean

Bo Qiu (University of Hawaii, United States); Shuiming Chen (University of Hawaii, United States)

Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Oral

Abstract:
Available satellite altimeter sea surface height (SSH) data from the past 28 years are used to investigate the decadal-to-multi-decadal ocean changes in the Western Tropical Pacific Ocean (WTPO). As represented by the North Equatorial Current (NEC) bifurcation off the Philippine coast, the low-frequency WTPO circulation variability is well captured by the altimeter-derived SSH data and which, in turn, can be quantified favorably by the wind-forced linear vorticity dynamics. Using the long-term ERA5 reanalysis wind stress data, we extend the wind-forced SSH record back to the 1950s. Over the past seven decades, the SSH-inferred circulation variability in the WTPO has lengthened from biennial in the 1970s, to interannual in the 1980s-1990s, to decadal in the recent two decades. Much of this period lengthening in the WTPO variability is caused by similar lengthening in the wind forcing field as a result of multi-decadal transitions from dominance by the Eastern Pacific-type of ENSO variability to that by the Central Pacific-type of ENSO variability.

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Lagrangian properties of on-shelf satellite-geostrophy between the North Sea and the North Atlantic

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Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Oral

Abstract:
Ocean observations on a global scale and with reasonable time resolution are expensive, as a result global ocean observations are sparse. An exception are satellite observations, which cover nearly the entire ocean surface. Unfortunately, the surface is the only part of the ocean which can be directly observed using remote sensing, nonetheless, the value of these observations is undeniable. Utilizing the temporal and spatial consistency, we explore within a Lagrangian framework the possibilities of geostrophic currents as they are derived from satellite observations. We focus on shelf seas, an ocean system that can be considered a weakness of exactly this particular observational product. Nonetheless, our main interest lies exactly in the shelf seas which connect the eastern North Atlantic, an important climate component, to the North Sea, an important economic region. Shelf seas in general, including those mentioned, are driven by both the state of the local atmosphere and furthermore the adjacent major oceans. Unfortunately, the restriction to surface observations makes it difficult to directly identify processes which drive change on shelf seas. Moreover, the ocean processes become more complex where major ocean currents hit shallower waters, making it especially difficult to observe. Satellite altimetry, regardless of the constraints, always yields a projection of the underlying ocean dynamics onto the surface, which we capitalize on by treating the observed currents as a tracer of the underlying dynamics. Doing so, we avoid the main issues of currents from satellite-altimetry, an unidentifiable error in both strength and direction for one, and on top general ignorance regarding the vertical extent. Aiming to identify the responses of the shelf seas between the eastern North Atlantic and the North Sea to both atmospheric and oceanic climate indices, we track virtual particles. We show seasonal and decadal variability of the Lagrangian properties in the shelf seas and furthermore show that satellite-geostrophy can be used to approximate in particular the subpolar gyre index, the dominant principal component of sea surface height in the central subpolar gyre. Finally, probing the limits of satellite-geostrophy we show that across the shelf, physical tracers like temperature and salinity cannot be followed assuming advection by these theoretical current pathways originating from satellite observations.

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Toward a probabilistic assessment of the global ocean response to fully-varying river runoffs.

Thierry Penduff (CNRS - IGE, France); Stephanie Leroux (DATLAS, France); William Llovel (CNRS - LOPS, France); Jean-Marc Molines (CNRS - IGE, France); Jerome Vialard (IRD - LOCEAN, France); Matthieu Lengaigne (IRD - MARBEC, France); Soumaia Tajouri (LOPS, France); Florian Sevellec (CNRS - LOPS, France); Julien Jouanno (IRD - LEGOS, France); Fabrice Papa (IRD - LEGOS, France); Clement de Boyer Montegut (IFREMER - LOPS, France)

Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Oral

Abstract:
The main goal of the IMHOTEP OST-ST project is to investigate the response of the global ocean to fully-varying freshwater discharges from rivers and from the Greenland ice sheet between 1980 and 2018. This response concerns sea surface salinity (SSS), regional sea surface height (SSH) and its manometric/steric components, heat and freshwater contents, water mass properties, regional to basin-scale circulation, etc. We are currently analyzing satellite/in-situ observations and the outputs from a recent series of NEMO-based global ocean/sea-ice/iceberg 1/4° simulations where runoffs are individually set to climatological and fully-variable in various source regions.

The JRA55 fully-variable atmospheric forcing is applied in all simulations without any SSS relaxation, which is replaced by a precipitation correction term that lets salinity free to evolve. Daily river discharge forcing data were derived from the ISBA-CTRIP hydrological reanalysis, and monthly (solid and liquid) freshwater discharges from Greenland are derived from satellite altimetry data (SAR mode) combined with regional climate simulations (Mouginot et al., 2019). Special attention was dedicated to the bathymetry and the partitionning between solid and liquid discharges all around Greenland, in order to realistically feed icebergs and freshwater plumes.

This presentation is focused on the interannual variability and 40-year trends of SSS in response to fluctuating runoffs at global scale, based on 5 simulations and a comparison to an ESA L4 product merging SMOS, Aquarius and SMAP SSS data (Boutin et al., 2021). Results show that the simulated SSS interannual variability compares well with observations. River runoffs directly force interannual SSS variability which can reach 0.5 to 0.75 g/kg in specific regions (Amazon plume, Siberian coast, Maritime Continent, China river mouths, etc) and about 0.2 g/kg along many coasts, with substantial penetration into the open ocean in several regions. Substantial (positive or negative) 40-year trends in the runoffs of key rivers also have a direct impact on regional SSS trends, which exhibit substantial freshening trends off Siberian coasts and throughout the Maritime Continent, and salinization off the equatorial African west coast in particular.

These first results also suggest that SSS interannual variability is primarily driven by atmospheric and runoff fluctuations; this is quite different for the interannual variability of SSH and of many other oceanic climate indices, which are strongly impacted by chaotic intrinsic variability (CIV) in addition to the former two external drivers. Assessing the interannual response of these latter oceanic fields to fluctuating runoffs thus require an attenuation of this low-frequency CIV, which in turn requires ensemble ocean simulations with slightly different initial states (as done during the OCCIPUT project, https://meom-group.github.io/projects/occiput/). The IMHOTEP project team will perform in 2022 two 10-member ensembles of global ocean/sea-ice 1/4° simulations driven by the same JRA55 forcing, one ensemble with climatological and one without interannually-varying runoffs: comparing the fluctuations of ensemble means of key variables will allow a more complete analysis of the multivariate and multi-scale response of the ocean to fluctuating runoffs, regardless of CIV. These analyses will provide direct insight for the interpretation of signals observed by satellite and in situ platforms, and their attribution to distinct drivers.

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POLAR OCEAN TIDES REVISITED

Ole Baltazar Andersen (Professor, Denmark); Stine Kildegaard Rose (DTU Space, Denmark)

Session: Tides, internal tides and high-frequency processes
Presentation type: Oral

Abstract:
Polar oceans have generally been harder to determine from satellite altimetry because the regions outside the 66 parallel has traditionally only been surveyed from satellites in sun-synchronous orbits. With Cryosat-2 this has changed. However, the satellite poses a number of challenges to tidal analysis because of its long ground track repeat period (368 days) and its diverse measurement modes, low-rate mode (LRM) over the ocean and synthetic aperture radar interferometric mode (SARin) over ice surfaces and parts of the ocean.
Within the ESA CP40 project the SAMOSA+ physical retracker were developed to process the Cryosat-2 data across measurement modes. Being a physical retracker it enables determination of the sea state bias and hence provides more stable sea level estimates compared with traditional empirical retrackers used previously for the Polar Ocean. Nearly 10 years of Cryosat-2 data have been analysed for residual ocean tides to the FES2014 ocean tide model in the Arctic Ocean and Antarctic Ocean using the response formalism. We use data from the 28.94 days favorable near monthly repeat pattern as this has favorable alias period for most major constituents. Using this information we, the long wavelength corrections to the major astronomical constituents M2, S2, K2, N2, K1, O1, P1, and Q1 tides have been mapped for both the ocean and floating ice shelves domains. In addition, several smaller third, fourth and sixth diurnal tides have been determined. Some of these small compound/over tides does show small but consistent signal across regions like the Weddell sea (South Atlantic) and in the Baffin Bay between Greenland and Canada.

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ALBATROSS: Improving the bathymetry and ocean tide knowledge in the Southern Ocean with satellite observations

Mathilde Cancet (NOVELTIS, France); Ole Andersen (DTU Space, Denmark); Michel Tsamados (University College London, United Kingdom); Geir Moholdt (Norwegian Polar Institute, Norway); Florent Lyard (LEGOS/OMP/CNRS, France); Marco Restano (SERCO/ESA, Italy); Jérôme Benveniste (ESA/ESRIN, Italy)

Session: Tides, internal tides and high-frequency processes
Presentation type: Oral

Abstract:
The knowledge about bathymetry and ocean tides is at the crossroads of many scientific fields, especially in the Polar regions, as it has significant impact on ocean circulation modelling and the understanding of the coupled dynamical response of the ocean, sea ice and ice shelves system, the quality and accuracy of sea surface height and sea ice parameter estimates from satellite altimetry, or the understanding of ice-shelf dynamics, among others. In isolated regions such as the Southern Ocean, where very few in-situ campaigns are possible, satellite observations bring invaluable information, either directly, with the physical parameters that are measured, or indirectly, considering the strong links between particular characteristics of the parameters and the ocean processes.
The ALBATROSS project (ALtimetry for BAthymetry and Tide Retrievals for the Southern Ocean, Sea ice and ice Shelves), led by NOVELTIS in collaboration with DTU Space, NPI and UCL, is one of the activities funded by the European Space Agency in the frame of the Polar Science Cluster, with the objective to foster collaborative research and interdisciplinary networking actions.
ALBATROSS is a 2-year project that started in mid-2021 with several objectives: first, to improve the knowledge on bathymetry around Antarctica, considering decade-long most recently reprocessed CryoSat-2 datasets, innovative information on bathymetry gradient location through the analysis of sea ice surface roughness characteristics, and the compilation of the best available datasets in ice-shelf regions; second, to improve the knowledge on ocean tides in the Southern Ocean through the implementation of a high-resolution hydrodynamic model based on the most advanced developments in terms of ocean tide modelling, and data assimilation of observations, including satellite-altimetry derived tidal retrievals from the most recent and relevant satellite altimetry products to fill the gap between the 66°S-limited coverage of the Topex-Jason suite missions and the Antarctica coast.
This paper presents the most recent results obtained within the ALBATROSS project.

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Insights from the global EOT20 ocean tide model

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Session: Tides, internal tides and high-frequency processes
Presentation type: Oral

Abstract:
The recently developed and published EOT20 model provides global estimations of ocean tides from multi-mission satellite altimetry using residual tidal analysis. Utilising advances in coastal altimetry, such as the use of the ALES retracker, FES2014 as an updated reference tide model and improved coastal line representation, EOT20 attempts to provide improved estimations of ocean tides in the coastal region. The model provides the amplitude and phase of seventeen tidal constituents on a global 0.125-degree grid. The resultant model is compared to in-situ observations obtained from tide gauges taken from the updated TICON dataset and ocean bottom pressure sensor data as well as through gridded sea level variance analysis of satellite altimetry data.

EOT20 showed a reduction in root-mean-square (RMS) error for the eight major tidal constituents compared to the predecessor, EOT11a, with a major reduction in error compared to tide gauges seen in the coastal region. When compared to other global ocean tide models, EOT20 remains consistent with other models in the open ocean and shelf regions with the largest improvements being seen in the coastal region particularly in the M2 tidal constituent.

Overall, when used as the ocean tide correction EOT20 shows a reduction in gridded sea-level variance compared to both EOT11a and FES2014. This was particularly seen in the coastal regions, where a reduction in sea-level variance was seen closer to the coast when using EOT20 as the tidal correction. In this presentation, the developed EOT20 model as well as the validation of the model will be presented and discussed.

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Status of GOT5 and associated prediction software

Richard Ray (NASA/GSFC, United States)

Session: Tides, internal tides and high-frequency processes
Presentation type: Oral

Abstract:
New empirical tide solutions have been computed for the global ocean, following methods going back to Schrama & Ray (1994). Global high-resolution assimilation methods have markedly advanced over the past decade, and it is now difficult for purely empirical methods to improve models such as FES2014 and TPXO.9 -- at least until several years of SWOT data are available. Nevertheless, some improvements are obtained in polar regions and for minor tides such as J1 (which in FES2014 was a purely hydrodynamic model without data assimilation).

There may be some interest in the tide prediction software package associated with GOT5, which is a complete rewrite of earlier software with enhanced capabilities. For one, the package can handle netCDF formats (as in FES2014), native OTIS binary, and the older GOT4 ascii format. It can even handle (as sledgehammer to as pin) a simple list of harmonic constants for a single location. Options at initialization can turn nodal modulations on or off. Also on option, minor constituents can be inferred or not, using either piecewise linear admittance functions or Munk-Cartwright Fourier functions. For inference, the software keeps track automatically of which tides need to be inferred and which are input. Constituents can be identified with a standard Darwinian name, or with a numerical 7-digit (extended) Doodson number which completely defines a tidal argument. The latter can thus handle any obscure compound tide of any order. Although written in Fortran-2008, some other languages (e.g., Julia) can call the software directly.

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A new barotropic tide model for global ocean: FES2022

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Session: Tides, internal tides and high-frequency processes
Presentation type: Oral

Abstract:
Thanks to its current accuracy and maturity, altimetry is considered as a fully operational observing system dedicated to various applications such as climate studies. Altimeter measurements are corrected from several geophysical parameters in order to isolate the oceanic variability and the tide correction is one of the most critical. The accuracy of tidal models has been much improved for last 25 years leading to centimetric accuracy in the open ocean. The last release of the global tidal model, referenced as FES2014b was distributed since mid-2016.

The underlying unstructured mesh resolution of FES2014b was increased in areas of interest like shallow waters and on the slope of the continental shelves, and the error of the pure hydrodynamic ocean solution has been divided by a factor of 2 compared to previous version (FES2004). Still, some significant errors remain in some regions, due to the omission of compound tides and bathymetric errors (in shelf/coastal seas), seasonal sea ice effects and lack of available data for assimilation (in the high latitudes).

To address the reduction of these errors and facing the new challenges of the tide correction for HR altimetry, in particular the forthcoming SWOT mission, a new global tide model FES2022 has been developed, focusing particularly on shallow waters and high latitudes.
This new tidal solution uses higher spatial resolution in coastal areas, extending systematically the model mesh to the narrowest coastal systems (fjords, estuaries, …), and the model bathymetry has been upgraded in many places thanks to an international collaboration effort. The hydrodynamic modelling benefits also from further improvements which allows producing very accurate hydrodynamic simulations. The use of the most recent altimeter standards and high inclination altimeters like Cryosat-2, Saral/AltiKa and even Sentinel-3, also allowed retrieving some tide observations in the highest latitudes to help improving the polar tides modelling. Preliminary results show a great improvement of the FES2022 hydrodynamic solution compared to FES2014's one. The assimilation procedure is on-going and a specific loading tide solution will also be produced in the coming months. Some validation results of the new FES2022 global tidal solution are presented here.
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Toward a community global 1/36° configuration based on NEMO

Perrine Abjean (Mercator Ocean International, France); Clément Bricaud (Mercator Ocean International, France); Jérome Chanut (Mercator Ocean International, France); Romain Bourdalle-Badie (Mercator Ocean International, France); Gilles Garric (Mercator Ocean International, France); Théo Brivoal (Mercator Ocean International, France)

Session: Tides, internal tides and high-frequency processes
Presentation type: Oral

Abstract:
In the framework of the Copernicus Marine Environment Monitoring Service, Mercator Ocean International operates a global high-resolution forecasting systems at the resolution of 1/12°. Increasing resolution appears necessary to improve the quality of service and to satisfy the users' requests in the operational application (Le Traon, 2019). Resolving scales below 100 kilometers, and in particular sub mesoscale processes (1-50 km), appears to be essential to better represent the circulation in the open ocean (Chassignet, 2017), and, in particular to improve the large-scale representations thanks to a more explicit energy transfers between finer and larger scales (Fox-Kemper Baylor, 2019). A deeper understanding of their various contributions (geostrophic flows, tidal motions, waves, inertial currents) and their role in the global ocean kinetic energy budget will improve the knowledge of these energy transfers between different scales.

With the multiplication of observing platforms and the enhancement of their accuracy, the time and space resolution of observations have been improved. The description of finer scales has since been significantly improved. It is now estimated that the present and future observation platforms will be able to deliver data at scales finer that 50 km. SWOT (https://swot.jpl.nasa.gov/science.html) will allow observing scales until 15 to 30 km whereas actual altimeters are limited to 150 km (Morrow 2019). These new missions could also provide ocean currents at a resolution from 70 km at high latitude to 250 km at the equator. However, the current status of numerical models routinely operated for analysis and forecasts, are not adapted for digesting measurements coming from such new generations of sensors.

In 2019, it has been decided to go towards higher resolution and develop a new global sub mesoscale-permitting model. Benefiting from the context of the European H2020 IMMERSE project, a new 1/36° global configuration (resolution of 3 km at the equator and 1km close to the pole), based on the NEMO 4 OGCM has been developed. Thanks to the resolution increase, this model can resolve the Rossby radius in almost all open oceans areas at global scale quite everywhere and to span a large part of the internal wave spectrum. This model is driven at the surface by the 1H ECMWF IFS system. Tidal forcing with 5 components (K1, O1, S2, M2, N2) and atmospheric pressure forcing have been activated.

First, based on a hierarchy of simulations at 1/4°, 1/12° and 1/36° and with/without explicit tide representation, we propose a first evaluation of the benefits due to the resolution increase and tidal forcing. Circulation, energy, tidal representation and mixing of the experiments are compared to each other's.

A long multi-year experiment performed with the global 1/36° configuration is in preparation and will be described. 3D hourly outputs will be stored and data will be available through cloud facilities. This experiment is also planned to be used in OSSE framework (Observing System Simulation Experiment).
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Energetics of high frequency Internal Tides in Global HYCOM

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Session: Tides, internal tides and high-frequency processes
Presentation type: Oral

Abstract:
This study aims to quantify the energetics of internal tides in 4-km global Hybrid Coordinate Ocean Model (HYCOM) simulations, including the energy cascade from the primary tidal to higher frequencies and their evolution along internal tide “beams”. The ocean model is run in a forward (non-data-assimilative) mode, forced by realistic atmospheric fields and tidal forcing (M2, S2, K1, O1, N2). Velocity and density fields are band-passed into tidal (D1+D2) and supertidal frequency bands before computing the baroclinic energy budget. Globally, supertidal motions are confined to low latitudes (±30^o), where on average they account for roughly 10% of the total tidal energy. The geographic distribution of supertidal kinetic energy shows a high correlation with the advective flux, a measure of nonlinear wave energy, and good qualitative agreement with observed instances of solitary nonlinear internal waves (Jackson et al. 2012), which are characterized by higher frequencies and wavenumbers. To understand how internal tides evolve along their propagation path and interact with ocean currents, the energetics along the main internal tide beams at the Amazon Shelf and Mascarene Ridge are analyzed in detail. In the Amazon, energy is converted to baroclinic tides at the shelf break at the primary tidal frequencies. The associated pressure fluxes decay over a 1000km distance due to dissipation and energy transfers to higher harmonic pressure and advective fluxes. The supertidal fluxes peak 400km away from the generation site and then remain steady. A high-resolution simulation using the nonhydrostatic Massachusetts Institute of Technology general circulation model (MITgcm) at the Mascarane ridge shows that the horizontal grid resolution in HYCOM is insufficient to resolve subgrid scale solitons impeding an accurate energy cascade to smaller wavelengths, essentially “trapping” energy at frequencies lower than those observed in the MITgcm energy spectrum, which show a series of bulges at frequencies higher than 24cpd. However, in agreement with HYCOM, the energy in the supertidal band increases in proportion to the total tidal energy and is found to be about 50% in MITgcm and about 20% in HYCOM, suggesting that energy at higher frequencies (due to solitons) is underestimated in HYCOM.

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Blending AIS data and altimetric measurements to estimate sea surface currents in the Gulf of Mexico

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Oral

Abstract:
The maritime traffic around the Loop current of the Gulf of Mexico is large enough to help retrieving the oceanic surface current. Using Automatic Identification System (AIS) data streams for the period 2019-2020, a distance-weighted least-squares approach [Le Goff et al 2021] is used to estimate ocean surface currents at a depth corresponding to the mean draught of the commercial vessels (about 7m).

The calculated gridded data product has spatial resolution of 0.125º × 0.125º and daily temporal resolution. These estimations provide a valuable resource to investigate the ageostrophic processes that altimeter-based data are not sufficient to resolve. However, the limited coverage of the AIS Data (limited to the main maritime routes), prevents studies from reaching regional basins and thus limits potential applications of the collected data at larger scales where altimetry data is sufficient. As such, synergy between AIS-derived sea surface currents and altimetry data needs to be considered to increase the accuracy of sea surface currents in the Gulf of Mexico.

The merging is done through the Multiscale Inversion for Ocean Surface Topography (MIOST) [Ubelmann et al., 2020] variational tool to retrieve both geostrophic and ageostrophic current. This tool allows the decomposition of the signal into different components representing different time and space scales (i.e., mesoscale to large-scale) and different physical signals (i.e., geostrophic, internal waves, near-inertial oscillations, Ekman current…).

The resulting improved ocean surface current estimates will be compared to the intensity of surface currents estimated from the AOML drifters. Comparisons with high-resolution Sea Surface Temperature (SST) images from infrared instruments will be focused on the eddy separation events for the Gulf of Mexico loop current and on the associated eddy paths. Identification of warm rings with an eddy tracking algorithm (e.g., AMEDA [Le Vu et al 2018]) will allow the determination of the characteristics and life cycle of these eddies.

[Le Goff et al 2021] : Le Goff, C., Boussidi, B., Mironov, A., Guichoux, Y., Zhen, Y., Tandeo, P., et al. (2021). Monitoring the greater Agulhas Current with AIS data information. Journal of Geophysical Research: Oceans, 126, e2021JC017228. https://doi.org/10.1029/2021JC017228

[Ubelmann et al 2021]: Ubelmann, C., Dibarboure, G., Gaultier, L., Ponte, A., Ardhuin, F., Ballarotta, M., & Faugère, Y. (2021). Reconstructing ocean surface current combining altimetry and future spaceborne Doppler data. Journal of Geophysical Research: Oceans, 126, e2020JC016560. https://doi.org/10.1029/2020JC016560

[Le Vu et al 2018]: Le Vu, B., Stegner, A., & Arsouze, T. (2018). Angular Momentum Eddy Detection and tracking Algorithm (AMEDA) and its application to coastal eddy formation. Journal of Atmospheric and Oceanic Technology, 35(4), 739-762.

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Joint estimation of balanced motions and internal tides from future wide-swath altimetry

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Oral

Abstract:
For more than 25 years, altimetry has allowed the study of near-global sea surface height (SSH) at scales longer than 150 km and drastically transformed our understanding of mesoscale processes in the oceans. But the scales resolved by nadir (along-track) altimetry are limited by the 100-300 km spacing between one dimensional satellite ground tracks. Even by merging several nadir measurements, the space time resolution of the resulting 2D SSH maps does not allow to conveniently characterize and study small mesoscale (<150km) motions. Still, recent studies, based on numerical models, have highlighted the impacts of short-mesoscale and submesoscale processes on ocean dynamics.

The Surface Water and Ocean Topography (SWOT) mission is expected to provide Sea Surface Height (SSH) measurements resolving scales of a few tens of kilometers. Over a large fraction of the globe, the SSH signal at scales <100km is essentially a superposition of a component due to balanced motions (BMs) and another component due to internal tides (ITs). These two classes of motions are associated with different dynamical processes and therefore impact the ocean kinetic energy budget differently. To make the best use of the future SWOT SSH observations, BMs and ITs will need to be separated. However, the main difficulty to separate the signals lies in the strong interactions between BMs and ITs, generating non-stationary ITs that cannot be estimated by conventional statistical methods.

In that context, we introduce a dynamical method that process altimetric observations to simultaneously estimate the SSH signatures of BMs and ITs on two-dimensional regular grids. The method, based on original data assimilation techniques, uses simple dynamical model, each specific to the mapping of one component: a quasi-geostrophic model for BMs, and a linear shallow-water model for ITs. A particular effort is made to perform the inversions in well-chosen reduced-order basis.

The algorithm is tested with Observation System Simulation Experiments (OSSE), where the true state of the ocean is provided by the MITgcm global LLC4320 simulation. We focus on a realistic observational scenario in the California Current System during the SWOT's fast sampling phase. The proposed algorithm is able to map and separate a large amount of the variance of BMs and ITs. Importantly, in addition to the reconstruction of stationary ITs, the algorithm estimates the amplitude and phase of nonstationary ITs, which is very encouraging for the process of future SWOT data.
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A New Global Mesoscale Eddy Trajectory Atlas Derived from Altimetry : Presentation and Future Evolutions

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Oral

Abstract:
Mesoscale eddies are ubiquitous in the ocean. When they rotate faster than they travel, they can trap water into their cores and transport it along their paths, redistributing heat, salt, chemical and biological components from their generation to their dissipation areas.
The new versions of the global Mesoscale Eddy Trajectory Atlas (META) 3.2 Delayed Time all-satellites and two-satellites are produced by SSALTO/DUACS and distributed by AVISO+ (https://aviso.altimetry.fr) with support from CNES. Significant changes from the historical 2.0 version previously distributed and regularly updated were made to provide an improved representation of the mesoscale eddies, illustrated here.
The META3.2 detection scheme is based on the Py-Eddy-Tracker algorithm (Mason et al., 2014, https://github.com/AntSimi/py-eddy-tracker), applied on Absolute Dynamic Topography (ADT, DUACS DT2021 reprocessing) maps filtered to remove large-scale patterns. ADT-detection better represents quasi-stationary and recurrent structures than sea level anomaly based detection. The amplitude threshold is reduced to 0.4 cm, increasing the number of small eddies, in particular during the growing and decay phases of the trajectories, or close to coasts and islands. Only one local extremum is tolerated within an eddy contour, with a better agreement with ocean color data tan the multiple-extrema structures authorized before. The tracking scheme is based on the contours' overlap (following Pegliasco et al., 2015) instead of the research of eddy candidates in a restricted area, reducing the wrong temporal associations. To provide maximal information, META3.1exp products make available the structures detected only one day, the trajectories lasting less than 10 days and the trajectories lasting at least 10 days in different files. The products also include new information such as the mesoscale eddy shapes with the eddy edges and the contour associated with the maximum averaged-speed, and the eddy speed profiles from the center to the edge. Thus, META3.2 products allow easier collocation of data for transdisciplinary research. A future evolution of the product is to include the eddies' interactions (merging and splitting events) with a network representation (META-Networks). This evolution will be discussed with the users to best meet their needs.

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Development of Multiparameter Mesoscale Eddy Products for Operational Use

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Oral

Abstract:
Mesoscale eddies play a major role in upper ocean circulation and dynamics and have a significant impact on biophysical and biogeochemical processes. In the California Current System, cross-shelf transport, nutrient cycling, and biological productivity are all heavily influenced by mesoscale eddy activity. Using near-real time (NRT) satellite observations from NOAA daily gridded sea level anomalies from the Radar Altimeter Database System (RADS), geostrophic currents, and eddy kinetic energy, NOAA Geo-Polar Blended Sea Surface Temperature Analysis, NASA's Soil Moisture Active Passive (SMAP) version 5.0 sea surface salinity processed by JPL, and NOAA/CoastWatch NRT VIIRS multi-sensor chlorophyll DINEOF gap-filled analysis, these eddies can be operationally tracked and characterized in order to monitor related processes. Here multiparameter mesoscale eddy tracking is applied to the California Current System in order to analyze the impact of these eddies on nutrient pumping and biogeochemical processes in the region. An additional observational Multiparameter Eddy Significance Index (MESI) is introduced for biophysical and biogeochemical analysis and demonstrates how this multiparameter mesoscale eddy tracking methodology can be used to monitor upper ocean processes, primary productivity, and ocean acidification. The correlation between MESI and the observed variability in near-surface nutrients is shown to be in excess of 85% in the research area. This eddy tracking includes twenty observational and calculated tracked variables spanning 2018-2021 with features that allow for advanced monitoring and analysis of mesoscale eddies. Multiparameter mesoscale eddy tracking is a candidate product for CoastWatch with broad oceanographic applications for both operational and research fields.

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A Broadband View of the Sea Surface Height Wavenumber Spectrum

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Oral

Abstract:
The variability of sea surface height (SSH) is controlled by processes that span a broad range of spatial and temporal scales. At mesoscales and large submesoscales (300--15 km), the SSH spectrum is expected to be consistent with quasi-geostrophic (QG) turbulence theory and to be characterized by a quasi-linear spectral slope, with variance decaying toward higher wavenumbers. In contrast, at scales ranging from hundreds of meters to a few meters, SSH variability is dominated by surface gravity waves, with a spectrum characterized by one or more peaks at the wavenumber of the dominant waves. Because there is a clear scale separation between QG turbulence and surface wave dynamics, these two spectral bands have traditionally been explored independently. The Surface Water and Ocean Topography (SWOT) mission will for the first time resolve the 2D variability of SSH on scales at which some of these processes overlap; thus, there is a need to better understand the contribution of different physics to the SSH variability and consider the SSH spectrum as a continuum.

Here, we use measurements from airborne lidar altimetry to present a broadband view of the SSH wavenumber spectrum over scales ranging from hundreds of kilometers to a few meters, based on observations collected during a field campaign conducted off the California coast. The structure of the spectrum is discussed in light of the multiple processes that contribute to the SSH variability, such as geostrophically balanced motions, internal waves, infra-gravity waves, and surface waves. Additionally, we leverage the detailed knowledge of the 2-dimensional surface wave field measured by the airborne scanning lidar to assess the effects of different SSH averaging and sampling strategies during distinct surface wave and wind conditions.

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Exploitation of high-resolution datasets for sea level studies in the Nordic Seas and Arctic Ocean

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Oral

Abstract:
The inter-annual changes of the Arctic Ocean features are well-known proxies of the global climate change, affecting the global climate through specific processes (e.g. dense water formation, meridional heat redistribution). The ocean circulation at high latitudes has significantly changed during recent decades, with an enormous impact on the socio-economic activities of the Nordic populations. Monitoring the Arctic environment is however non-trivial: the Arctic observing network is notably lacking the capability to provide a full picture of the changing ocean due to technological and economical limitations to sample the seawater beneath the ice or in the marginal ice zones. This leads to the obvious need of optimizing the exploitation of data from space-borne sensors. Among these, altimetric radars measuring the sea level at millimetric precision have revolutionized our knowledge of the oceanic circulation, for more than 2 decades, at a large spectrum of scales ranging from the mesoscale activity to the slowly varying basin-wide dynamics. Technological solutions are continuously needed and pursued to enhance the spatial resolution of the altimetric signal and enable the solution of the mesoscale dynamics, either in the design of the altimeter itself (e.g. wide-swath altimeters) or in the combined use of altimeter data from multiple bands. Newly reprocessed along-track measurements of Sentinel-3A, CryoSat-2, and SARAL/AltiKa altimetry missions (AVISO/TAPAS), optimized for the Arctic Ocean (retracking) and sampled at 5 Hz, have been recently produced in the framework of CNES AltiDoppler project. This study is devoted to the exploitation of such satellite altimetry data in high-latitude regions. We investigate the benefits of the reprocessed altimetry dataset at 5 Hz with augmented signal resolution in the context of ocean and sea-ice coupled short-range forecasts. In particular, we compare the effectiveness of this dataset to improve the mesoscale details of the forecasts in comparison to the conventional altimetry sampling dataset and to the altimetry-blind experiments, in order to assess the added value of the enhanced altimetry reprocessing in Nordic Seas. This comparison can motivate the assimilation of the high-resolution altimetry data in ocean re-analysis for the Arctic.

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Lagrangian analysis of fine-scale (1–100 km) ocean stirring: a preparatory study for the SWOT satellite mission

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Oral

Abstract:
Ocean fine scales (1–100 km, days to weeks) play a key role in pelagic ecosystems, the energy cascade, and biogeochemical cycles. Fine scales are largely studied with Lagrangian diagnostics derived from nadir altimetry data. However, these diagnostics are limited by the spatiotemporal resolution of nadir altimetry products. The new SWOT (Surface Water and Ocean Topography) satellite mission, planned for launch in the fall 2022, will enhance the spatial resolution of altimetry products by one order of magnitude. In this work, we study the fine-scale transport properties not resolved by nadir altimetry and that will be observable by SWOT. Two Lagrangian diagnostics are computed on geostrophic velocity maps derived from sea surface height outputs from a model at two resolution: maps at 1/20° representative of SWOT observations, and maps at 1/4° representative of products provided by nadir altimetry. Results show that the stirring is underestimated in the nadir-like data set by a factor of 2 to 3 on average, and follow the underestimation of the strain rate. Retention patterns by eddies also differ between 1/20° maps (SWOT) and 1/4° maps (nadir). A new class of eddy, not found in 1/4° maps, is highlighted. Implications for marine ecosystems, biogeochemical cycles and the ocean dynamic are discussed as well as opportunities for in-situ experiments during the SWOT satellite mission.

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Small scale wave height variability and wave groups

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Session: CFOSAT
Presentation type: Oral

Abstract:
Recent altimeter retracking (e.g. Tourain et al. 2021) and filtering methods (Quilfen et al. 2019) have considerably reduced the noise level in estimates of the significant wave height, allowing to study smaller scale processes. Previous studies on the along-track variations of wave heights have shown that wave-current interactions may explain most of the variability at scales 20 to 100 km (Ardhuin et al. 2017, Quilfen and Chapron 2019). Here we take advantage of the very low noise level of SWIM nadir beam to explore scales under 10 km, looking at the accuracy of wave height measurements in storms.

From theory, we expect that part of the short-scale variability of the estimated Hs is related to wave groups which give random variations in wave height at scales of a few kilometers, depending on the sea state. Theory on signal envelopes links the spatial distribution of wave heights to the convolution of the wave spectrum (Rice 1944).

Here we use the fact that ocean waves spectra are routinely measured by CFOSAT's SWIM instrument to evaluate the theoretical contribution of wave groups to the wave height variability at scales under 10 km using the CFOSAT L2 products. For large period swells, the 500m wavelength cut-off of the L2 spectra hinders the theoretical estimate of Hs variability. In this study, this issue is overcome by looking at model spectra and comparing with L2S products. Wave groups are expected to have a bigger impact for narrow wave spectra.

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Waves Mean Square Slope estimation from CFOSAT/SWIM measurements

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Session: CFOSAT
Presentation type: Oral

Abstract:
Launched in 2018, the CFOSAT mission provides information at global scale about the sea-state and waves main characteristics such as height, wavelength and direction. This information is derived from the normalized cross-section of the ocean surface radar backscattered signal measured by the on-board SWIM instrument. However, waves main characteristics are not sufficient to accurately describe the sea-state and extra parameters should be considered such as waves mean square slope (mss).

It is well documented that the surface waves slope distribution, hence the mss, can be related to the normalized cross-section. In this work, it is assumed that the waves slope distribution is almost Gaussian and a two parameters Student law is fitted to the SWIM measurements. The inversion of these two parameters gives an information about the mss and the deviation of the slope distribution from the Gaussian distribution. The results on the mss will be compared to results derived from optical models and the differences will be discussed.

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CFOSAT Sea level and current demonstration products

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Session: CFOSAT
Presentation type: Oral

Abstract:
Although CFOSAT is dedicated to wind and wave characterization the Ku altimeter on board has the capacity of providing and Sea level measurements, relevant to enrich the DUACS (Data Unification and Altimeter Combination System) Sea Level Anomaly products for the benefit of the Copernicus Marine Service users. With an orbit reaching 82° latitude, it could in particular help to compensate the loss of current nadir missions at low and high latitudes.
The short and long wavelength errors of CFOSAT Sea Level Anomaly were investigated and specific procedures, based on a multimission approach, were implemented in order to correct from the poor orbit accuracy. Once homogenized to the other missions, the CFOSAT provide an interesting set of Sea Level, with a good quality at mesoscale. Across track geostrophic current were derived providing an unprecedented global colocation of wave spectra and currents. Based on these studies, a Level3 demonstration product were produced and will be available on Aviso.

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Development of a new UAV-based LiDAR altimetry solution for in-situ wave spectrum estimation

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Session: CFOSAT
Presentation type: Oral

Abstract:
For two years now, the development of a UAV-based (Unmanned Aerial Vehicle) LiDAR altimetry system (the vorteX.io VTX-1 light altimeter) has demonstrated its capability to perform water surface height measurements with centimeter accuracy on various inland water bodies (lakes, rivers and estuaries). This unique, new type of lightweight altimeter has been developed specifically for measuring water surfaces. It is based on a LiDAR with 8 beams emitted in the near infrared uniformly distributed over an aperture of 16° perpendicular to the along-track direction of the UAV. Thus, depending on the surface roughness, 8 surface height measurements are acquired simultaneously.

The main objective of the study is the development of a new calibration/validation solution for satellite altimetry systems based on the use of LiDAR onboard UAVs to measure wave/swell spectra over the ocean. In this framework we combine LiDAR acquisitions in the open sea and inversion processing on these measurements in order to extract the sea surface state parameters. We take advantage of the UAV's deployment capabilities and the combination of LiDAR and optical measurements from the vorteX.io light altimeter to develop a new, relevant and flexible calibration solution of radar altimeters but also with the goal of the calibration of the SWIM radar scatterometer measurements onboard CFOSAT.

In this framework, we first simulate LiDAR measurements of sea surface height based on the CNES simulator RADARSPY. Then, after defining a specific flight plan, we developed an algorithm performing the estimation of the directional wave spectrum through the sea surface height measurements acquired by the lightweight altimeter. Then a field campaign has been realized close to Saint-Jean-de-Luz (South of France) where drone flights were performed over sea above a wave buoy from the French network CANDHIS. After the data processing of the actual drone measurements, the estimated directional wave spectrum were computed and compared to the one estimated from the CANDHIS. We present in this study the results of the simulations, the developed directional wave spectrum estimator, the drone flight over ocean and the comparisons with the CANDHIS buoy and the final results.

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The cross-analysis of dual-instrument CFOSAT measurements: Towards multiparameter all-angle Ku-band Geophysical Modulation Function

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Session: CFOSAT
Presentation type: Oral

Abstract:
Alexey Mironov, , Jean-Francois Piolle, Bertrand Chapron

The CFOSAT satellite operates two Ku-band rotating radars: the nadir/near-nadir Ku-band wave scatterometer (SWIM) and the dual-polarization, moderate incidence angle, Ku-band wind scatterometer (SCAT). This unique instrumental configuration provides regular global collocated measurements of radar backscatter to retrieve sea surface state parameters, including significant wave height, directional wave spectrum, and wind vector. Two sensors also give the opportunity to improve the quality of the retrieved parameters by combining both data sources. This approach can be applied for the improvement of SCAT wind retrievals using SWIM observations, and vice-versa, SWIM wave spectrum measurements could be interpreted better with the use of additional SCAT information. Observations for different incidence angles have a different sensibility to sea surface parameters: short and long waves, surface currents, surface temperature, etc. Thus, the joint use of CFOSAT instruments requires a common unified description of multi-angle radar backscatter properties (σ0) as a function of a wide set of environmental parameters.
The IFREMER Wave and Wind Operational Center (IWWOC) provides CFOSAT nadir/near-nadir and moderate angle measurements together with model data with SWISCA S Level 2 product. In the present work, an alternative multi-parameter Ku-band Geophysical Model Function (GMF) was derived from this extensive dataset of radar and collocated model output in the common 25 km reference grid. The traditional set of GMF variables (wind vector, incidence angle, polarization, ….) was extended with various additional geophysical parameters: significant wave height, sea surface current vector, sea surface temperature, ice concentration, precipitation rate. The obtained GMF reproduces the main features of NSCAT-4 GMF for moderate incidence angles and TRMM/GPM GMF for near-nadir observations. However, the real backscattering properties of SWIM and SCAT are quite different from commonly used Ku-band GMFs due to various reasons like radar antenna design, swath patterns and noise signal distortions. These instrument-specific features are clearly distinguished as well.
The high volume of available data enables precise studies on the particular impact of different isolated geophysical variables on the backscattering coefficient value. As well, the total observational dataset could be regressed with the use of the neural network (NN) approach. In this case, the machine learning strategy should be adapted specifically to reduce possible biasing due to unequally distributed geophysical input variables. The resulting NN GMF could be considered as the approximation of the Ku-band radar cross-section as a function of a multi-parameter environment. In addition to wind/wave inversion tasks, it can serve as a robust platform for rapid signal calibration and re-adjustment during mission exploitation.
We anticipate the implementation of the demonstrated results and resulting model to extend the existing SCAT data processing with collocated SWIM nadir/near-nadir observations and additional NWP variables. As well, to improve existing SWIM nadir/near-nadir measurement interpretation.

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Leveraging Sentinel-6A interleaved mode to characterize High Resolution error budget over ocean

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Oral

Abstract:
The Copernicus Sentinel-6A mission was successfully launched on the 21st November 2020. This mission is taking the responsibility to extend the global sea level record on the reference low inclination orbit started in 1992 with TOPEX/Poseidon mission and continued by the Jason series. This new Copernicus constellation (Sentinel-6B launch expected in 2026) will ensure the continuity of this unique high-precision coverage of altimetry data in support to climate change monitoring, research, and forecasting, as well as operational oceanography applications.

In the frame of the CNES/EUMETSAT commissioning activities, Sentinel-6A LR (LRM) and HR (SAR) data from PDAP have been fully validated thanks to the tandem flight with Jason-3. Both LR datasets are in line allowing a smooth transition between Jason-3 and Sentinel-6A as a reference mission. Thanks to Poseidon-4 altimeter on board Sentinel-6A and its interleaved mode, co-located LR and HR measurements are provided, allowing a precise estimation of the performances between the modes by direct comparison.

In this presentation, we focus on the assessment of Sentinel-6A HR data over ocean. We aim at listing the known small limitations and draw a first error budget of Sentinel-6A HR data, with the objective to identify potential processing improvements.

The assessment has been compared to Sentinel-3A SAR performances and its remaining small errors (Raynal et al 0STST 2019 and Cadier et al OSTST 2020). Analyses show some similarities, in term of swell dependencies or wind impact, but also some different behaviours: it has been shown that the impact of ocean vertical velocity is more important on Sentinel-6A HR than on Sentinel-3.
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Long-term stability of ionospheric GIM corrections in satellite altimetry data sets

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Oral

Abstract:
High-accurate and long-term stable ionospheric delay corrections for satellite altimetry measurements are essential for reliable estimation of sea surface heights and global mean sea level (GMSL) trends. For most missions and applications, these corrections are directly computed from dual-frequency observations of the satellite altimeter. However, for single-frequency missions (such as SARAL or Cryosat-2) as well as for coastal and inland applications, external information is required. Usually, this is taken from GNSS-based Global Ionospheric Maps (GIM) as available from different analysis centers of the International GNSS Service (IGS). These corrections are also available in most altimeter data sets (e.g. Jason Geophysical Data Records, GDR).

When using GIM information for correcting altimeter measurements for ionospheric delay, the different orbit heights of GNSS satellites and altimetry satellites require an adaption of the GIM corrections to account for the free electrons in the topside ionosphere and the plasmasphere (i.e. between about 800 to 1300 km and 20.200 km). This scaling can be done using electron models, as well as by empirical estimated scaling coefficients. This contribution investigates the impact of different ionospheric corrections and scaling approaches on altimetry-derived GMSL estimates. This is done based on open-ocean data of the Jason missions, for which dual-frequency corrections as well as GIM corrections are available in the GDR data sets. It will be shown that the widely used scaling approach based on the International Reference Ionosphere (IRI95) is not able to accurately scale the GIM models, since it disregards all information above 1400 km height. The impact of neglecting the plasmaspheric part of the atmosphere strongly correlates with the 11-year solar cycle and manifests itself as a trend error in GMSL. For the Jason period (2002 to 2021) a trend difference of 0.17 mm/year is shown, which is even larger for smaller periods (e.g. 1.0 mm/year for Jason-1 lifetime). The application of an additional constant scaling factor of 0.886 will reduce the trend differences to below 0.05 mm/year.

The Sentinel-6 MF observation period is still too short for reliable trend investigations. However, a similar impact is to be expected if the same scaling approach has been applied to the GIM data. First results for this missions will also be shown.

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Uncertainties in SSB modeling and impact on MSL

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Oral

Abstract:
Current operational SSB corrections are derived empirically and built up as look-up tables that describe the SSB amplitude as a 2D function of the SWH and the wind speed parameters, both directly measured by altimeters. Different aspects of the empirical determination have been improved through the years: statistical methods for the SSB modeling, ways to extract the SSB signals from the SSH data, and improvement in the sea state description to better describe in-turn the SSB behaviors, but no much work has focused on the documentation of its uncertainties. It's the aim of this presentation.
This characterization will serve 3 different purposes:
- Choice of an optimum SSB solution to use in ground segment for flying missions to get accurate SSH data. Often a 1-year based solution is used after launch to update the SSH measurements, but is 1-year period an optimum value or is it necessary to cumulate more data to get a more stable SSB solution due to inter-annual variations?
- Optimization of the reprocessing workload requested for SSB computation during reprocessing phase for past missions. Often also a 1-year based SSB solution is computed within reprocessing exercise to improve/homogenize the SSH derivation with the latest GDR standards and the SSB correction applied but as said before some inter-annual variations can perturbate the representativeness of the dataset, such as El-Nino events for instance. The "best" solution might be to derive a SSB table from the entire mission but because of the work burden of the reprocessing of all the dataset, this is not the most common option. A compromise could be found and propose to the Agencies.
- Documenting the contribution of the sea state bias (SSB) and associated dual-frequency ionospheric corrections to the global sea level uncertainty budget by providing not only the uncertainty level of this source of error in SSH data but also how it propagates to the sea level rise estimate.
This study will assess the variability and stability of SSB solutions through ensemble mean and the provision of the spread of the ensemble members can be used to estimate uncertainty. Some recommendation in term of optimum configuration (period length, choice of ensemble members by more robust averaging methods, selection of 'normal' years, …) to mitigate errors on sea level rise monitoring and the impact of the SSB table choice in the MSL uncertainty budget will be provided.

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Limiting factors of the altimetry observing system to the Global Mean Sea Level monitoring accuracy

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Oral

Abstract:
The satellite altimetry observing system has proved since 1992 and the TopEx/Poseidon mission its capacity to monitor the sea level rise induced by climate change over the globe. On the basis of this accurate monitoring of sea level, space agencies developed climate data records that are now commonly used by scientists to study climate change and by stakeholders to support their decisions on climate change adaptation and mitigation strategies. For science users as for stakeholders it is essential to quantify the exact stability and accuracy of the altimetry-based climate indicators as they are at the basis of their analysis and assessments.

In this context, we will present the latest released of the Global Mean Sea Level (GMSL) climate data record produced by the French space agency CNES and distributed on the AVISO+ website. This data record is based on reprocessed along-track data, so-called L2P21 data, of the reference missions TopEx-Poseidon, Jason-1/-2 and -3. It is delivered with an estimate of the associated uncertainties following the method developed in Ablain et al. (2019). Based on an updated version of the uncertainty budget of TopEx and Jasons altimetry missions, presented in Guerou et al. (2022, submitted), we will demonstrate that we achieve stability performances of ± 0.3 mm/yr at the 5-95% confidence level for the GMSL trend over the full data record and ± 0.06 mm/yr^2 (5-95% C.L) for the GMSL acceleration. In addition we will present the relative contribution of each uncertainty budget contributor (i.e., the altimeter, the radiometer, the orbit determination, the geophysical corrections) to the total GMSL uncertainty. Thanks to such analysis, we will identify the current limiting factors to the GMSL monitoring stability and accuracy and suggest key topics of investigations to help the altimetry community to improve the GMSL accuracy in the future.

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Sea level rise uncertainties: insights from a metrological approach

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Oral

Abstract:
The altimetry data record (1993-2022) has enabled the global mean sea level (GMSL) rise to be quantified. Not only is the sea level rising, but it is accelerating (Dieng et al., 2017; Nerem et al., 2018; Ablain et al. 2019) and understanding this acceleration is necessary both to support society's response to climate change and to inform climate research on the sea level budget, greenhouse gas forcing and the Earth energy imbalance. Here we describe work on quantifying the uncertainty on the sea level climate data record, and identifying the uncertainty needed to provide new answers to the climate research questions.

Work by Ablain et al. (2019) and updated in Guérou et al. (2022) at a global scale, has quantified GMSL rise as +3.3 mm/yr (90% confidence uncertainties 0.3 mm/yr) over 1993-2021. Its acceleration has been quantified at 0.12 ± 0.05 mm/yr². At local scales, (Prandi et al. 2021), the sea level is rising almost everywhere over the globe, at rates ranging between 0 and 6 mm/yr, with uncertainties ranging from 0.8 to 1.2 mm/yr depending on the location. The local sea level accelerations are ranging between -1 mm/yr² and +1 mm/yr² with uncertainties between 0.057 and 0.12 mm/yr² (Prandi et al., 2021).

Here we present more recent work refining these uncertainty estimates through a metrological approach that propagates uncertainties, and error covariance structures, through the full processing chain of the altimeter measurement from the raw waveform to GMSL, using methods described in Mittaz et al. (2019). We review the assumptions in the derivation of the retracking model from the radar equation, consider error correlation structures in the corrections, and provide fresh consideration of the error covariance matrix, building on the earlier research.

The work was developed in the ASELSU project funded by ESA. The project has also reviewed the climate science research questions to understand the need for improved altimeter observations. There are three major science questions that require accuracies greater than those currently achieved. These questions are the closure of the sea level budget, the detection and attribution of the signal in sea level that is forced by greenhouse gas emissions (GHG) and the estimate of the Earth energy imbalance (EEI).

Dieng et al. 2017: https://doi.org/10.1002/joc.4996.
Nerem et al. 2018: https://doi.org/10.1073/pnas.1717312115
Ablain et al 2019: https://doi.org/10.5194/essd-2019-10
Guérou et al. 2022: https://doi.org/10.5194/egusphere-2022-330
Prandi et al. 2021: https://doi.org/10.1038/s41597-020-00786-7
Mittaz et al. 2019: https://doi.org/10.1088/1681-7575/ab1705

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Improving long term estimates of global mean sea level, global ocean heat content and Earth's energy imbalance using CDR water vapour data

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Oral

Abstract:
The Earth's energy imbalance (EEI) quantifies the excess of radiative energy received from the sun compared to the infrared energy radiated by the Earth. The EEI has recently been estimated from global ocean heat content (GOHC) based on satellite altimetry and satellite gravimetric data with a typical accuracy of 0.2 W.m-2 (with a 90% confidence level) on decadal time scales which is not sufficient to monitor and understand the climate variability due to large volcanic eruptions, to the recent hiatus or to anthropogenic activities. The wet tropospheric correction (WTC) used to compute the altimetric-based sea level data is derived from the microwave radiometers (MWR) on board the altimetry missions. It is identified as a major source of error in the global mean sea level (GMSL) rise (Ablain et al., 2019), affecting the GOHC and EEI estimates derived from satellite geodetic data. In this study, we show that the MWR-derived WTC from altimetry missions is responsible for about 15 % of the EEI trend uncertainty variance.

Motivated by the recent emergence of high long-term stability of climate data records (CDR) of water vapour outlined by the GEWEX water vapour assessment (Schröder et al., 2016), we also investigate the feasibility and advantages of using these data to estimate a more stable WTC for altimetric-based sea level data, hence to improve our knowledge on the GMSL, GOHC and EEI. To compute the WTC from CDR water vapour data, we use a polynomial formula whose coefficients and associated uncertainties are determined using ECMWF ERA5 reanalysis data. Then, we use CDR water vapour data provided by HOAPS and REMSS to compute a new WTC along the L2P altimetric tracks. With an empirical approach, we estimate that the CDR-derived WTC trend has an uncertainty of 0.05 mm/yr whatever the dataset and the period considered. Over 2016/2020, the comparison of MWR-based with CDR-based WTC shows a likely drift of the Jason-3 MWR of the order of 0.5 mm.yr-1 that would tend to overestimate the GMSL trend, the GOHC trend and the EEI mean. Over 08/2002-08/2016, the EEI mean so far estimated to 0.748 ± 0.129 W.m^{-2} with the usual radiometer WTC is now estimated to 0.829 ± 0.122 W.m^{-2} using REMSS CDR water vapour data (standard uncertainties). This corresponds to a trend increase of 11 % and a relative uncertainty variance reduction of 12 %. This study suggests that a new WTC combining high-frequencies from the radiometer and low-frequencies from the CDR data could help improve the long term estimates of the EEI. However, a better characterisation of the water vapour uncertainties is needed to estimate more accurately the uncertainty of the CDR-derived WTC and its impact on the GMSL, GOHC and EEI time series.

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Sentinel-6 products status

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Session: Sentinel-6 Validation Team (S6VT) feedbacks
Presentation type: Oral

Abstract:
Since the launch of Sentinel-6 Michael Freilich on 21 November 2020, the products coming from the operational ground segment have been carefully monitored to ensure the best performance. Although the ground segment was more ready for purpose than could have been expected during the pandemic, it was of course expected that some anomalies would occur in a brand new ground segment. Anomalies, biases, and misconfigurations were efficiently dealt with, although this quite often hampered the consistency of the products. This was expected, and EUMETSAT took care to inform the early users --- members of the Sentinel-6 Validation Team (S6VT) --- of any changes affecting the products, also letting them in to outputs of the validation platform where changes were first introduced.

The commissioning phase was set up in various stages, first focussing on the low-resolution (LR) near-realtime (NRT) and short-time critical (STC) products, and then later expanding to the high-resolution (HR) and non time critical (NTC) products. Through several meetings with the S6VT, recommendations were made to stagger the release of the data to the general public, noting their compliance to the performance requirements with some caveats.

Meanwhile, a switch from the nominal (Side A) to the redundant (Side B) of the altimeter was also planned and executed. This build in an actual full redundancy, knowing that Side A have been fully characterised and cross-calibrated, so at it stands ready to be reverted to in case of failure or severe degradation of the now operational Side B.

At the end of the commissioning data from the entire mission was reprocessed with the then operational processors and configuration so that a consistent data set was obtained, further allowing a thorough cross-calibration and providing all the data to all users, including during the earlier commissioning period.

But the status of the processors is not frozen, as the state of the art is continuously evolving, and for the best performance of the mission, the processors need to go with it. This includes changes that already became operational since late September:
- Addition of the 3 high-frequency HRMR channels in the computation of the wet tropospheric correction, improving coastal retrievals
- Use of the around-the-orbit ECHO Cal for the calibration of range and power, reducing the influence of temperature variations on retrievals

This presentation summarises the status of the data processing and reprocessing activities.

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Cal/Val activities performed by the MPWG

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Session: Sentinel-6 Validation Team (S6VT) feedbacks
Presentation type: Oral

Abstract:
The Mission Performance Working Group is a body composed of experts from EUMETSAT, NASA, ESA, NOAA and CNES. The group meets on a regular basis, and it is aiming at monitoring the Sentinel-6MF overall altimetry mission performance. The group assesses on mission and payload performance budgets, data products quality, algorithm development, new processor verification and validation performance, calibration and validation planning, as well as provides scientific support to the reprocessing calibration and validation, key mission instrument meetings and mission performance meetings. The MPWG activities are similar to those done by the MSEs as per previous Jason mission.

In this presentation, the MPWG will share with the OSTST the latest calibration and validation findings including any mission scientific challenges. Moreover, we will present the scientific plans for Sentinel-6MF evolutions, and provide an estimated timeline for these evolutions to be available to the Sentinel-6MF user community.
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Highlights from the Sentinel-6 Validation Team

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Session: Sentinel-6 Validation Team (S6VT) feedbacks
Presentation type: Oral

Abstract:
The Sentinel-6 Validation Team (S6VT) is a collection for about 100 scientists from about 40 institutions who were given early access to the data from the Sentinel-6 Michael Freihlich mission during its commissioning phase in turn for their support in analysing the performance of the instruments and allow them to exploit the unique capabilities of Sentinel-6.

Three virtual workshops were held post-launch:
- May 2021: Focussing on the low-resolution (LR) near-realtime (NRT) and short-time critical (STC) data, although the high-resolution (HR) data was already been made available to the S6VT. This ended with the endorsement to provide the LR altimeter and AMR-C data of NRT and STC timeliness to all users.
- November 2021: Focussing on the HR and NTC data quality. This concluded with the endorsement to provide all data to all users.
- July 2022: Focussing on the cross-calibration and quality of the full-mission reprocessed data. This concluded with the endorsement to release this data to all users.

This presentation highlights some of the key points from the workshops: data analyses and exciting applications.
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Assessment of marine gravity models of the Mediterranean

Sean Bruinsma (CNES, France); Franck Reinquin (CNES, France); Philippe Schaeffer (CLS, France)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Oral

Abstract:
Marine gravity data collected with gravimeters on ships, while not available for large parts of the Mediterranean, is used in the assessment of altimeter-inferred gravity anomalies, such as the known DTU and UCSD models as well as our first model of the Mediterranean. The marine gravity data we used was compiled and calibrated for the GEOMED2 project. The aim of that project, which started in 2014, was the calculation of high-resolution geoids of the Mediterranean using different methodologies. One interesting and surprising result of the project was that the ship gravity data, even the data from the sixties and seventies after calibration, is more accurate than DTU15 or UCSD v24 and is therefore suitable for model assessment.
In this analysis, we compared the different altimeter-inferred gravity anomaly models between themselves, and to the ship gravity anomaly data.

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New CNES CLS 2022 mean sea surface

Philippe Schaeffer (CLS, France); Isabelle Pujol (CLS, France); Pierre Veillard (CLS, France); Yannice Faugere (CLS, France); Dagneaux Quentin (CELAD, France); Gerald Dibarboure (CNES, France); Nicolas Picot (CNES, France)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Oral

Abstract:
A new Mean Sea Surface model, the CNES_CLS_2021 MSS, has been determined. It is based on the integration of more than 27 years of altimetric data, using more than 10 altimeters from the historical Topex/Poseidon to the in-flight Sentienl-3A/B missions, including ERM and geodetic/drifting orbits. As the previous 2015 version this new MSS is focused on the fallowing points of improvement which remains a permanent challenge:

- the correction of ocean variability, especially for wavelengths lover than 200 km.
- the accuracy of altimetric data and therefore of the MSS near the coast.
- a most accurate mapping of the finest topographic structures until wavelengths shorter than 10 km.

A particular attention was also paid to the Arctic area by combining traditional SSH with leads.
We therefore propose a synthesis of analyzes of these different aspects in order to quantify the improvements of this new MSS compared to other existing MSS.

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Rethinking the Modeling of the Mean Sea Surface in the Era of Climate Change

Ole Baltazar Andersen (Professor, Denmark); Steve Nerem (Professor, USA)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Oral

Abstract:
Since the beginning of the precision satellite altimeter era in the early 1990s, efforts have been focused on computing the mean height of the ocean surface for use in various geodetic and oceanographic studies. With 30 years of satellite measurements now available, it is time to rethink the modeling of the mean sea surface (MSS) in the era of climate change.
There are linear changes in the height of the ocean surface due to melting ice and increasing ocean heat content that will not average to zero when computing the mean height [Fasullo and Nerem, 2018; Hamlington et al., 2020]. Today, there are places in the ocean that are 15 cm higher than they were 30 years ago, and today the average error is around 5 cm for conventional MSS models.

We propose that linear sea level changes be used in a new definition of the MSS correction which is tied to a particular date in time. For example, one definition could be:
$MSS(\phi,\lambda,t)= MSS(\phi,\lambda,2003.0)+\dot{(MSS)}(\phi,\lambda)(t-2003.0)$

Where $MSS(\phi,\lambda,2003.0)$ is the height of the sea surface in 2003.0 and the epoch used for the most common MSS models, e.g., the DTU and CLS MSS models. $\dot{(MSS)}(\phi,\lambda)$ is the linear rate of change of the sea surface height averaged over 30 years.
Linear changes will not average to zero over time and thus can build up to cause large errors in the conventional definition of the MSS. If one is unconcerned with the trends, then the $MSS(\phi,\lambda,2003.0)$ can be used in the same manner as for conventional MSS models. It's also possible to consider including the acceleration of sea surface height, but these are small [Nerem et al., 2018] and a longer time series is needed before a stable map of the accelerations can be computed [Hamlington et al., 2020].
The linear rate of change $\dot{(MSS)}(\phi,\lambda)$ will of course change in the future as more data are added, but testing shows that it remain reasonably stable over a decade or so, and can be updated when new MSS models are produced. There is considerable evidence that the 30-year trend patterns in sea surface height are driven by the "forced response" of Greenhouse gases and aerosols, and these patterns will be reasonably persistent as we move forward in time [Fasullo and Nerem, 2018].

We will present the testing of a new mean sea surface correction and find the performance to be significant for recent satellites like Jason-3 and Sentinel 3 and 6. It reduces the mean offset for these recent satellites wrt with respect to conventional satellites, but it also performs significantly better in reducing the spatial variability. With stability of the trend. We believe, that the MSS correction will be significant for the upcoming SWOT mission, as the MSS correction can be considered into the near future as sea level has changed considerably over the last 30 years.

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The DTUUH22MDT combined mean dynamic topography model

Per Knudsen (DTU Space, Denmark); Ole Andersen (DTU Space, Denmark); Nikolai Maximenko (University of Hawaii at Manoa, IPRC, Honolulu, USA); Jan Hafner (University of Hawaii at Manoa, IPRC, Honolulu, USA)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Oral

Abstract:
Initially, a new geodetic mean dynamic topography model DTU22MDT is derived using the new DTU21MSS mean sea surface. The DTU21MSS model has been derived by including re-tracked CRYOSAT-2 altimetry also, hence, increasing its resolution. Some issues in the Polar regions have been solved too. The geoid model was derived within the ESA supported Optimal Geoid for Modelling Ocean Circulation (OGMOC) project. It was based on the GOCO05C setup, though the newer DTU15GRA altimetric surface gravity was used in the combination. The OGMOC geoid model was optimized to avoid striations and orange skin like features. Subsequently the model had been augmented using the EIGEN-6C4 coefficients to d/o 2160.
The processing scheme used for deriving the new geodetic MDT is similar to the one used for the previous geodetic DTU MDT models. The filtering was re-evaluated by adjusting the quasi-gaussian filter width to optimize the fit to drifter velocities. Subsequently, the drifter velocities are integrated to enhance the resolution of the MDT model. Weights and constraints are introduced in the inversion and tuned to obtain a smooth model with enhanced details. A special concern is devoted to the coastal areas to optimize the extrapolation towards the coast line. The presentation will focus on the coastal zone when assessing the methodology, the data and the final model DTUUH22MDT.

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Combining coastal altimetry data with High Frequency radar, drifters and hydrological profiles data to estimate a Mean Dynamic topography on the Mid Atlantic Bight

Solène Jousset (CLS, France); Sandrine Mulet (CLS, France); John Wilkin (Rutgers University, USA); Eric Greiner (CLS, France); Gérald Dibarboure (CNES, France); Nicolas Picot (CNES, France)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Oral

Abstract:
The Mean Dynamic Topography (MDT) is a key reference surface for altimetry. It is needed for the calculation of the ocean absolute dynamic topography, and under the geostrophic approximation, the estimation of surface currents. The MDT is the missing component for the optimal assimilation of altimeter data into operational ocean system. However, in coastal areas, where in-situ measurements are sparse, mainly on the shelf, the global MDT solutions are often less accurate than in the open ocean. Considering the availability of long time-series of high-quality HF-Radar velocity measurements in the Mid Atlantic Bight, the main objective is to include these data to calculate an improved MDT is this area.

The prerequisites for the computation of this new Mean Dynamic Topography are to remove the non-geostrophic signal from the HF radar measured velocities. The first step is thus to pre-process these data. We used average currents from December 2006 through November 2016, estimated from HF radars and processed by Rutgers University (https://tds.marine.rutgers.edu/thredds/cool/codar/cat_totals.html ; Roarty et al, 2021). Then the mean wind-driven currents modelized as in Mulet et al (2021), were removed. Besides, the first guess MDT computed from altimetry and gravimetry was improved by using a dedicated filter along the coast. Finally, the improved MDT was estimated from the first guess MDT and the processed in-situ data (HF-radars, drifters and T/S profiles) through a multivariate objective analysis.

This new regional MDT defines better currents near the coast. In particular, the MDT shows more organized across-shelf gradient following the shelf-break, and a more continuous mean flow on the shelf.

Mulet, Sandrine, Marie-Hélène Rio, Hélène Etienne, Camilia Artana, Mathilde Cancet, Gérald Dibarboure, Hui Feng, et al. « The New CNES-CLS18 Global Mean Dynamic Topography ». Ocean Science 17, nº 3 (17 juin 2021): 789-808. https://doi.org/10.5194/os-17-789-2021.
Roarty, Hugh, Scott Glenn, Joseph Brodie, Laura Nazzaro, Michael Smith, Ethan Handel, Josh Kohut, et al. « Annual and Seasonal Surface Circulation Over the Mid-Atlantic Bight Continental Shelf Derived From a Decade of High Frequency Radar Observations ». Journal of Geophysical Research: Oceans 125, nº 11 (2020): e2020JC016368. https://doi.org/10.1029/2020JC016368.

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Utilization of SWOT-simulator along with other nadir altimeter observations for estimation of river discharge over Narmada River

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Oral

Abstract:
SWOT mission is expected to be the first satellite to provide high-resolution global surface water elevation maps. These radar interferograms over water surfaces would enable a wide range of research opportunities especially in the field of land hydrology. In this work, satellite observations (river level, width) along with an integrated hydrological modelling scheme is utilized to estimate the river discharge over the Narmada site that we are aiming to establish as a calibration site for the upcoming SWOT mission. In the first step, the Virtual stations (VS) were selected over the SWOT and Sentinel-3A/3B orbit along with the available CWC gauge stations, for the estimation of river discharges. Water level time series was generated using Sentinel-3 radar altimeter data after correcting geophysical range corrections like dry tropospheric correction, wet tropospheric correction, ionosphere correction for the period 2016-2020. Virtual Station near Hoshangabad was selected for calibration of the derived discharges based upon the availability of nearby CWC measured level/discharge information (nearly 5 km apart); the present gauge also falls within a km of proposed SWOT nadir track. The retrieved water levels over the VS were found to be fluctuating between 281.76 meter to 287.97 meter. The in-situ field trip was carried out in synchronous with altimeter overpass on 8 February 2020. Acoustic Doppler current profiler (ADCP) and DGPS profiles were taken during the experimentation. The estimated river width and discharge was found to be 510.29 m and 107.75 m3/s respectively. SWOT hydrology simulator along with RiverObs and prior reach database SWORD-v5 was used for testing the module for estimation of water surface elevation profiles. The input for the simulator like water level and river width shape files were generated using existing Sentinel-3 altimeter data and Landsat-8 optical dataset respectively. The inundated areas within a stretch of nearly 10 km was found to be fluctuating between 404 to 575 Ha during the period 2014-2020, where the maximum extent was taken from the wetbnd layer from national Wetland inventory and assessment (NWIA) dataset. The derived surface water elevation, river width and slope information were used for estimating the river discharge at the desired location using rating curve information. CWC in-situ dataset was also used for deriving the water stage-discharge relationship and calibrating the model. WRF Hydrological modelling was also set up over the basin for estimation of river discharge over targeted locations of altimeter tracks and CWC stations. The derived river discharge will provide a valuable dataset for numerical ocean models and a better understanding of the hydrological cycle over the Indian region.

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Dual-band altimetry for polar science and oceanography: the Copernicus CRISTAL mission

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Oral

Abstract:
Within the expansion of the Copernicus Sentinel Constellation, the Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) mission is being developed as a key contribution to Europe's planned response to the need for monitoring of the polar regions. This need has clearly been identified by an EC-led user consultation process and by the Global Climate Observing System (GCOS). GCOS has recommended continuation of satellite synthetic-aperture radar (SAR) altimeter missions, like the altimeters on board CryoSat-2 and Sentinel-3. CRISTAL will fly to 88° latitude ensuring an almost complete coverage of the Arctic Ocean, as well as of the Antarctic ice sheet (like CryoSat-2, which is currently in its extended mission phase). CRISTAL will feature a dual Ku/Ka band SAR altimeter with interferometric capability on the Ku channel, the first instrument of this kind in space and expected to enable unprecedented measurements.

While the primary objectives of CRISTAL (i.e. measure and monitor variability of sea ice thickness and its snow depth, and measure and monitor the surface elevation and changes of polar glaciers and ice sheets) target mainly cryosphere science, this mission, exactly like CryoSat-2 is also expected to contribute significantly to oceanography. CRISTAL will allow observations of global ocean topography up to the polar seas, therefore contributing to global observations of mean sea level, mesoscale and sub-mesoscale currents, wind speed, and significant wave height. This information serves as critical input to operational oceanography and marine forecasting services so it feeds directly into Copernicus' Marine and Climate Change Services.

In this presentation we will illustrate the advanced technical characteristics of CRISTAL, give an update on its development status (currently in Phase B2) and discuss how this mission extends the heritage of CryoSat-2 over the cryosphere, the oceans and inland waters. We will finally discuss how the dual-band capability is expected to enable new investigations in the marginal ice zone, in the coastal zone and on surface roughness-related effects, like the sea state bias.

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Towards FRM observations for hydrology and cryosphere Sentinel-3 Cal/Val activities: the St3TART project

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Oral

Abstract:
The Copernicus Sentinel-3 Surface Topography Mission (STM), based on a constellation of two satellites, provides extremely valuable surface elevation information over inland waters, sea ice and land ice, thanks to its SAR altimeter which retrieves high-resolution along-track elevation measurements, and to its orbit that covers high-latitude polar regions. To ensure that these measurements can be used with confidence, and to maximize the return on investment of the Copernicus Sentinel-3 STM, adequate validation of the geophysical retrieval methods, processing algorithms and corrections must be performed, considering independent observations as Reference Measurements.

St3TART is an EU and ESA funded project led by NOVELTIS with a consortium of 17 European partners (CNES, DTU, NPI, vorteX.io, LEGOS, Hydro Matters, CLS, LOCEAN, IGE, SERTIT, GIS, CNR-IRPI, NPL, DT/INSU, IRD, M2C, SYRTE). It aims to generalize the concept of Fiducial Reference Measurements (FRM) for the Copernicus Sentinel-3 STM and to collect and distribute FRM data for the validation of the satellite mission over inland waters, sea ice and land ice. The provision of FRM will serve the validation activities of the ESA S3 Land Altimetry products, currently performed by the Sentinel-3 Mission Performance Centre, with the support of the Sentinel-3 Validation Team, for the sake of performance assessment and fitness-for-purpose of the Sentinel-3 STM Land core products. Those products cover inland waters, land-ice and sea-ice areas.

The objective of the St3TART project is not only to collect existing data or measure new observations during field campaigns, but to ensure that these observations meet the criteria of FRM standards and can be used in an operational way for the validation of the Sentinel-3 Land topography mission. Within the project, field campaigns are means to provide operational observations for the validation of the Sentinel-3 data.

In addition of the definition and consolidation of methods and protocols for the validation of the Sentinel-3 Altimetry Land products with FRM measurements, a roadmap will be drawn for the operational provision of FRM for the Sentinel-3 validation, considering the most relevant and cost-effective methods to be maintained, supported as far as possible or implemented. This will include guidelines for SI traceability, definition of the FRM measurement procedures, processing methods, and uncertainty budgets estimation. Several FRM campaigns have already been executed in sea ice covered region (Greenland) and on hydrological sites (on Garonne, Rhine and Po rivers), based on the first recommendations gathered in this roadmap.

A platform is under development to publicly disseminate the FRM data and measurements gathered within the St3TART project in order to facilitate the validation of the Sentinel-3 STM Land data products, with fully characterized and documented FRM processing and measurements. The St3TART project also supports the community with the development of SCalSIT, a tool intended to help identifying in-situ Cal/Val sites over Inland Water Surfaces.

We will present the main objectives, tools and outcomes of the project.

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Understanding Decadal-scale Trends in Altimeter-derived Significant Wave Height in the Bering Sea

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Oral

Abstract:
The winter conditions of the surface ocean at high latitudes are characterized by stormy seas that pose challenges to coastal communities, fisheries and shipping. Here we investigate conditions in the Bering Sea in winter over the past 20 years using altimeter-derived significant wave height (SWH). Using observations from the Jason-1, -2 and -3 satellites as well as from ERS-2, Envisat, CryoSat-2,SARAL/AltiKa, Sentinel-3A and -3B, we have found that the prevalence of very-high and phenomenal sea state conditions in the Bering Sea have increased. These are sea state conditions with SWH > 9 m, generated by storm-force to hurricane-force winds.

Have winter conditions in the Bering Sea become stormier due to a retreating sea ice cover? We hypothesize that the clear decrease in sea ice extent increases the chance of extreme SWH by increasing ocean fetch and decreasing the dampening effects of sea ice on wave energy. To test this hypothesis, we analyze the spatial and temporal relationships between SWH, sea level pressure systems and surface winds. Atmospheric data are from ERA5 reanalysis. The temporal variability of the atmospheric forcing is investigated by tracking low pressure systems over the Bering Sea and comparing their frequency to the increasing frequency of observed SWH. The role of sea ice variability during the study period is also studied by comparing the spatial trends of sea ice extent to the location of extreme SWH events. This analysis is based on the NOAA/NSIDC Climate Data Record sea ice products. Under similar atmospheric conditions we expect the prevalence of stormy seas to increase for lower sea ice concentrations.

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Waiting for CRISTAL: evaluation of a snow depth product using Ka/Ku dual-frequency altimetry. Impacts on sea ice thickness estimation.

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Oral

Abstract:
Snow on the sea ice is an element that is still very poorly known and poorly observed. However, it plays an important role in climate change due to its albedo, and in the dynamics of the sea ice due to its insulating properties. This lack of knowledge is also one of the main factors limiting the measurement of sea ice thickness by altimetry.
A method to measure this snow depth was first proposed in [Guerreiro et al. 2016]. It is based on the comparison of two altimetry frequencies, the Ku frequency on board CryoSat-2, and the Ka frequency from Saral. Indeed, these frequencies have different snow penetration properties. This observation was one of the reasons for adding a second frequency to the Copernicus CRISTAL polar altimeter project.
Following this study, an Altimetric Snow Depth (ASD) product was developed in the Arctic as part of the ESA CryoSeaNice project. In the framework of the ESA CS+AO project, an equivalent snow depth product has also been computed in Antarctica.
The first objective of this presentation is to show the relevance of this approach and the contribution of these data to the measurement of sea ice thickness.
To do so, the ASD data are compared with different datasets from different sources: space data obtained with the AMSR-2 passive radiometer, model data and in-situ data.
The AMSR-2 data are currently the only other snow depth observations that provide monthly estimates of snow depth on the polar ice pack. The first version (Meier et al, 2018) available on the NSIDC website (https://nsidc.org/data/AU_SI12/versions/1) has the disadvantage that it only covers first-year ice. The Bremen AMSR-2 v1.0 product (Rostosky et al, 2018) is calculated on multi-year ice but only for the months of March and April (during the Operation Ice Bridge campaigns). Only the NSIDC product covers the Southern Hemisphere, but this is complete because in this region the pack ice is mostly first-year ice.
Furthermore, in the Arctic, we will compare the ASD data with the Warren99 modified climatology (Arctic only), the PIOMAS model, the NESOSIM model (Arctic only) and the CMEMS LIM-3 sea ice model. The performance of these snow depth solutions will be evaluated by comparison with: 1) several Operation Ice Bridge (OIB) airborne campaigns, 2) the 2017 ESA-CRYOsat Validation Experiment (CryoVex) campaign that includes the KAREN Ka-band airborne altimeter, and 3) Beaufort Gyre Exploration Project (BGEP) data. Finally, the impact of different snow depth solutions on sea ice thickness estimates will be presented.
Finally, the important potential of these results for the monitoring of sea ice evolution by the future Copernicus CRISTAL mission will be discussed.
Acknowledgements: This work was supported by the ESA CryoSeaNICE project, the ESA CryoSat+ Antarctica project and the CNES TOSCA CASSIS project.

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Water Elevation and Water Extent Measurements With Sentinel-6A Radar Altimeter Fully-Focussed SAR Data

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Oral

Abstract:
The Sentinel-6A satellite, launched in November 2020, carries the first radar altimeter operating in open burst with a PRF high enough (~9kHz) to perform the focussing of the whole target observation echoes in a fully coherent way with practically negligible impact from along-track replicas. Furthermore, such a feature allows to improve the along-track resolution down to the theoretical limit around 0.5 m when processing the data with a Fully-Focussed SAR (FFSAR) algorithm. This resolution increment actually represents a revolutionary step with respect to the ~300 m along-track resolution provided by current operational processors based on Unfocussed SAR algorithms, commonly used in previous radar altimeters with a closed burst chronogram, such as CryoSat-2 and Sentinel-3. In this contribution, we explore new applications over inland water surfaces derived from such new Sentinel-6 FFSAR products. Indeed, the FFSAR Ground Prototype Processor (GPP), developed by isardSAT and based on the backprojection algorithm [1], has been used to process data over different types of inland water targets with the following objectives: (1) validate range measurements with in-situ water height data in case of nadir targets and (2) monitor water extent for off-nadir targets located within certain observation constraints. In this contribution we present results for both activities. First, we provide statistics of long-term monitoring of a series of reservoirs, which have reported global biases and standard deviations well below 10 cm. Secondly, we present a methodology to estimate water extent of small targets located on unambiguous across-track targets. We have analysed targets that present strong seasonal variability in terms of area, and validated the method by comparing water extent measurements derived from Sentinel-6 with the ones derived from optical, SAR imagery and in-situ observations. The overall work is part of the VALERIA (Validating Algorithms Levels 1A and 2 in Ebre RIver Area) project developed within the Sentinel-6 Validation Team using data from the satellite commissioning phase.

[1] Egido, Alejandro and Walter H. F. Smith. “Fully Focused SAR Altimetry: Theory and Applications.” IEEE Transactions on Geoscience and Remote Sensing 55 (2017): 392-406.

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Reconstructing the spatial and temporal elevation signals on large lakes from ICESat-2

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Oral

Abstract:
Satellite altimetry is now a well-established method to measure water level changes in lakes and rivers to understand climate change, for water resource management, and security.

The water level in lakes can generally be estimated with a relative RMSE of 10-20 cm when compared to in situ data. Contrary to what we expect, the RMSE is sometimes higher for larger lakes, not because of a poorer performance of the altimeters but due to a spatial signal in the elevation relative to the vertical reference potentially from un-modeled geoid signals, wind, or other static fields. Hence, when reconstructing the water level time series over large lakes, tracks crossing at different locations, are affected by a different contribution in elevation. This is especially problematic for geodetic missions like CryoSat-2 and SARAL/AltiKa, but also if more than one track is applied for the repeat missions.

To reduce the error due to a spatially distributed elevation signal on large lakes we suggest setting up a model where the spatial and temporal signal is estimated simultaneously. This is done in a state-space model where the spatial part is modeled via a Gaussian Markov Random Field and the temporal part is modeled via a random walk. To separate the spatial and temporal signals require a good coverage in space and time which is achieved with ICESat-2. A further advantage of ICESat-2 is the high precision that enables us to detect smaller variations.

Hence, we can use the highly precise ICESat-2 data to construct correction grids to account for the spatially distributed elevation signal. Such grids can be used to correct the other missions like CryoSat-2 and Sentinel-2 to improve the reconstructed water level time series.

We show examples from the lakes Tanganyika, Lake Malawi, Titicaca, Baikal, Issykul, and others. We also demonstrate how the reconstructed water level time series based on other missions like CryoSat-2 and Sentinel-3 is improved when using the ICESat-2 based correction grids.

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30 years of Arctic Ocean Sea Level from Space

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Oral

Abstract:
The Arctic is warming more than twice the speed of low- and mid-latitudes which are causing dramatic changes in the region. Sea ice is declining more rapidly, resulting in more open ocean which enhances ocean waves and wind conditions and changes the upper ocean layers. The river outflow into the Arctic Ocean is increasing and contributes to changing the Arctic Ocean. The changing temperature and salinity results in changing sea level which is best observed Pan-Arctic by satellite altimetry. Namely, in the later 10 years, satellite altimetry has improved making it possible to observe climate change in more detail.

We present a complete 30-year time series of the Arctic Ocean sea level from ERS-1 (1991) to CryoSat-2 (2021). We look at the extremely dynamic environment and focus on the dramatic changes in the latest 10 years compared to the 30 years of altimetric measurements. This will be done through case studies from the Beaufort Gyre region, the Russian Shelf area, and by studying the general ocean circulation.

The Arctic sea-level record is part of the ESA CCI Sea level initiative and has been updated with a new and better CryoSat processing using ESA G-POD SARvatore Data Repository. The sea-level record is validated against tide gauges, and compared to the ESA CryoTempo Polar Ocean Theme.
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Sentinel-3 Marine Altimetry Mission

Bruno Lucas (EUMETSAT, Germany)

Session: OSTST Opening Plenary Session
Presentation type: Poster
Poster number: OPE2022_001

Abstract:
Sentinel-3 is part of a series of Sentinel satellites responsible for taking care of a continuous 'health check' of the Earth planet under the umbrella of the Copernicus program. The Copernicus program will launch four Sentinel-3 satellites (from A to D) to achieve this goal from 2016 to 2030s. EUMETSAT's ground segment is responsible for the processing of the Sentinel-3 altimetry data in the marine environment: open ocean, coastal zones and sea level into the sea ice leads.

Since 2016 Sentinel-3A's SRAL, Synthetic Aperture Radar Altimeter, has been successfully contributing to the continuity of the sea level climate data record. Sentinel-3B launched in 2018 completes the currently operational mission.
Besides the Sea Level, also the Wave Height, Wind Speed are retrieved.
To further improve the quality of the datasets the processing baseline has considerably evolved during the years of the mission.
The Marine datasets besides being made available to the general public, are operationally used by the Copernicus services: CMEMS (Copernicus Marine Environment Monitoring Service) and C3S (Copernicus Climate Change Service).

This presentation will provide an overview of the latest evolutions of the Sentinel-3 SRAL/MWR processing, the relations between Sentinel-3A and -3B processing, and the strategy that EUMETSAT has adopted to provide the consistent long-term data set while continuing to evolve and improve the processing algorithms and standards. The latest reprocessing "BC 004" is the baseline for a quality analysis of the Sentinel-3 Marine Centre data in a multi-mission setting. To this goal this presentation aims at: providing multi-mission time series (Sentinel-3A, Sentinel-3B, Jason-3 and Sentinel-6) of the main climate records (sea level, significant wave height, wind speed and wet troposphere path delays) in ocean surfaces; quantifying cross-overs (mono- and multi- mission); as well as provide a 5-year global assessment of SAR mode versus Pseudo-LRM. The roadmap with the upcoming baseline "BC005" will shown with its relevant impacts for sea level measurements.

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Baltic SEAL: new insights into the mean and variability of the sea level in the Satellite Altimetry era

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_001

Abstract:
For sea level studies, coastal adaptation, and planning for future sea level scenarios, regional responses require regionally-tailored sea level information. Global sea level products from satellite altimeters are now available through the European Space Agency's (ESA) Climate Change Initiative. However, these global datasets are not entirely appropriate for supporting regional actions. For the Baltic Sea region, complications such as coastal complexity and sea-ice restrain our ability to exploit altimetry data opportunities.

This presentation highlights the opportunities offered by such regionalised advances, through an examination by the ESA-funded Baltic SEAL project (http://balticseal.eu/). We present the challenges faced, and solutions implemented, to develop new dedicated along-track and gridded sea level datasets for Baltic Sea stakeholders, spanning the years 1995-2019. Advances in waveform classification and altimetry echo-fitting, expansion of echo-fitting to a wide range of altimetry missions, and multi-mission cross calibration, enabled all mission data to be integrated into a final gridded product.

This gridded product provides new insights into the Baltic Sea's mean sea level and its variability to be gathered. A Mean Sea Surface dataset was developed, in addition to an analysis of sea level trends in the region (using both tide gauge and altimetry data). The Baltic SEAL absolute sea level trend at the coast better aligns with information from the in-situ stations, when compared to current global products. A pronounced sea level trend gradient which increases towards the North-East was found. A proportion of the SL trend gradient can be directly linked to enhanced southerly wind forcing and associated Ekman transport towards the Bothnian Bay. The spatial and temporal density of the data allows for a robust comparison between the sea level time series and relevant climate indices such as the North Atlantic Oscillation, with implications for regionalising global climate change impacts. These investigations highlight the potential of regionalised products for the Baltic Sea region, and beyond, to study regional sea level variability.

Figure Caption: Panel a: correlation of the NAO index with SLA from gridded altimetry. Panel b: normalised time series of NAO index (green) and SLA difference between Bay of Bothnia (northernmost sub-basin) and south-west sub-basins (orange). Each point represents the time average of the quantities of the winter months December, January and February.

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Reprocessing of the ERS-1, ERS-2 and ENVISAT missions: performances of the FDR4ALT products

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_002

Abstract:
In the framework of the European Long Term Data Preservation Program (LTDP+), which aims at generating innovative Earth system data records named Fundamental Data Records (FDR) and Thematic Data Records (TDP), similar to level 2+ geophysical products, ESA/ESRIN has launched two years ago a reprocessing activity of the ERS-1, ERS-2 and ENVISAT altimeter and radiometer dataset. A large consortium of thematic experts has been formed to perform these activities which are 1) to define new tailored end-user products including the long, harmonized record of uncertainty-quantified observations, 2) to define the most appropriate and state-of-the-art level 1 and level 2 processing, 3) to reprocess the whole times series according to the upgraded ground processing and, 4) to validate the different products and provide them to a large community of users focused on the observation of the atmosphere, ocean topography, ocean waves, coastal, hydrology, sea ice, ice sheet regions. This activity will result in the production of 8 different datasets for each mission, each of them addressing a different need. The project kicked off in September 2019 and the first phase of definition and pre-validation is now completed. The production phase began in early 2022 and is expected to be finalized at the end of 2022. Results already show major improvements compared to the current ESA ERS and Envisat Altimetry products, on all surfaces.
The objective of this talk is first to remind the OSTST members of this initiative, to explain the main guidelines, constraints, and status of the project and then to present the excellent performances of the FDR4ALT products. In particular, the presentation will show how the different communities (over global ocean, coastal, inland waters, sea ice, land ice, waves and atmosphere) will be able to benefit from this reprocessing to improve their long-term climate analysis.

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Sea state uncertainty from a triple collocation analysis of observations during the Sentinel-6 Michael Freilich – Jason-3 tandem phase.

Ben Timmermans (National Oceanography Centre, United Kingdom); Christine Gommenginger (National Oceanography Centre, United Kingdom); Chris Banks (National Oceanography Centre, United Kingdom)

Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_003

Abstract:
Accurate knowledge and understanding of the sea state and its variability is crucial to numerous oceanic and coastal engineering applications. Owing to increased numbers of concurrent satellite missions, both the duration of record and frequency of observations of the sea state have motivated substantial research effort directed at both oceanic and coastal sea state variability. However, owing to a sparsity of high quality in situ long term records, uncertainty in sea state observations remains problematic. The Sentinel-6 Michael Freilich mission adds to the continuing satellite record and in particular, the Sentinel-6 MF – Jason-3 tandem phase offers a valuable opportunity to examine uncertainty in sea state observations. Together with in situ data from moored buoys, the three data sets provide collocated observations of significant wave height that can be used for a triple collocation analysis spanning 12 months. Results from the initial phase of the analysis are presented for some specific cases.

Further, the 12 month tandem phase potentially offers relatively abundant collocated data that permits analyses of the relative uncertainty contributions conditional upon sea state. In particular we start by examining swell dominated regions and propose a methodology based upon exploiting recent multivariate sea state observations from Sentinel-1 imaging SAR, recently produced by the European Space Agency Sea State Climate Change Initiative (CCI). Traditionally, in the absence of global in situ or remote observations, a reanalysis product could be employed to identify swell events. However, these new high quality sea state observations, that include swell wave height and wave period, facilitate a multivariate intercomparison with reanalysis data. Preliminary intercomparison has already suggested discrepancy in wave period. We summarize some recent results and describe how this approach directs the geographic focus of the Sentinel-6 MF – Jason-3 tandem phase triple collocation study.

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Monitoring the Ocean Heat Content and the Earth Energy imbalance from space altimetry and space gravimetry

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_004

Abstract:
The Earth energy imbalance (EEI) at the top of the atmosphere is responsible for the accumulation of energy in the climate system. While necessary to better understand the Earth's warming climate, measuring the EEI is challenging as it is a globally integrated variable whose variations are small (0.5-1 W.m−2) compared to the amount of energy entering and leaving the climate system (~ 340 W.m-2). Accuracies better than 0.1 W.m−2 are needed to evaluate the temporal variations of the EEI at decadal and longer time-scales, characteristic of the response to anthropogenic and natural forcing.
Since the ocean absorbs about 90% of the excess energy stored by the Earth system, estimating the ocean heat content (OHC) provides an accurate proxy of the EEI. Here, the OHC is estimated at global scale based on the combination of space altimetry and space gravimetry measurements. Changes in the EEI are derived with realistic estimates of its uncertainty. The mean EEI value is estimated at +0.74±0.22 W m-2 (90% confidence level) between August 2002 and August 2016 and this value is increasing at a rate of 0.02 ± 0.05 W.m-2 (90% confidence level). Comparisons against independent estimates based on Argo data and on CERES measurements show good agreement within the error bars of the global mean and the time variations in EEI. On the other hand, discrepancies are also detected at inter-annual scales indicating that the current accuracy of EEI needs further improvement at these time scales. Estimates of the regional OHC change are also provided preliminarily and will be improved in the following months with a focus on the Atlantic Ocean. In particular, the role of the halosteric effects will be further investigated and the resulting product will be assessed against hydrographic data.
The space geodetic OHC-EEI product is freely available at https://doi.org/10.24400/527896/a01-2020.003.

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Monitoring the local heat content change over the Atlantic Ocean with the space geodetic approach: the 4DATLANTIC-OHC Project

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_005

Abstract:
Given the major role of the Atlantic Ocean in the climate system, it is essential to characterize the temporal and spatial variations of its heat content. The 4DATLANTIC-OHC Project (https://eo4society.esa.int/projects/4datlantic-ohc/) aims at developing and testing space geodetic methods to estimate the local ocean heat content (OHC) changes over the Atlantic Ocean from satellite altimetry and gravimetry. The strategy developed in the frame of the ESA MOHeaCAN Project (https://eo4society.esa.int/projects/moheacan/) is pursued and refined at local scales both for the data generation and the uncertainty estimate. At two test sites, OHC derived from in situ data (RAPID and OVIDE-AR7W) are used to evaluate the accuracy and reliability of the new space geodetic based OHC change. The Atlantic OHC product will be used to better understand the complexity of the Earth's climate system. In particular, the project aims at better understanding the role played by the Atlantic Meridional Overturning Circulation (AMOC) in regional and global climate change, and the variability of the Meridional Heat transport in the North Atlantic. In addition, improving our knowledge on the Atlantic OHC change will help to better assess the global ocean heat uptake and thus estimate the Earth's energy imbalance more accurately as the oceans absorb about 90% of the excess energy stored by the Earth system.
The objectives of the 4DATLANTIC-OHC Project will be presented. The scientific requirements and data used to generate the OHC change products over the Atlantic Ocean and the first results in terms of development will be detailed. At a later stage, early adopters are expected to assess the OHC products strengths and limitations for the implementation of new solutions for Society. The project started in June 2021 for a 2-year duration.
Visit https://www.4datlantic-ohc.org to follow the main steps of the project.

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Combining space gravimetry observations with data from satellite altimetry and high resolution visible imagery to resolve mass changes of endorheic basins and exorheic basins

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_006

Abstract:
Continuous monitoring of the Global Terrestrial Water Storage changes (TWS) is challenging because of the large surface of continents and the variety of storage compartments (WCRP, 2018). The only observing system which provides global TWS mass change estimates so far is space gravimetry. Unfortunately, most storage compartments (lakes, groundwater, glaciers...) are too small to be resolved given the current spatial resolution of gravimetry missions. This intrinsic property makes gravimetry-based TWS changes estimates difficult to attribute and to interpret at individual basin scale. In this context, combining gravimetry-based TWS estimates with other sources of information with higher spatial resolution is a promising strategy.

In this study, we combine gravimetry data with independent observations from satellite altimetry and high resolution visible imagery to derive refined estimates of the TWS changes in hydrological basins containing lakes and glaciers. The combination consists in including independent observations of glacier (Hugonnet et al., 2021) and lake (Cretaux et al., 2016) mass changes in the conversion process from gravity L2 data to water mass changes data. The combination is done for all regions of the world on a monthly basis. This approach allows to split properly glacier and TWS changes at interannual to decadal time scales, and derive glacier-free estimates of TWS in the endorheic basins and the exorheic basins. We find that for the period from 2002 to 2020, the total TWS trend of 0.23±0.25 mm SLE/yr is mainly due to a mass loss in endorheic basins TWS of 0.20±0.12 mm SLE/yr. Over the same period, exorheic basins present a non-significative trend of 0.03±0.14 mm SLE/yr. On the contrary, the interannual variability in the TWS change of 4 mm SLE is mainly due to the exorheic basins TWS change.

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Predicting short and long-term sea level changes using Deep learning

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_007

Abstract:
Predicting short- and long-term sea-level changes is a critical task with deep implications for both the safety and job-security of a large part of the world's population.

The satellite altimetry data record is now nearly 30 years and we may begin to consider employing it in a deep learning (DL)---and, by definition, data-hungry---context, a somewhat unexplored territory until now.
Because DL is capable of capturing non-linear processes, it seems well-suited for climate- and weather-influenced data, although the requirement of large (or, rather, diverse) datasets has hampered its use in altimetry settings.
Furthermore, explainability of DL models has been an issue, as has the computing requirements in the past, and most machine learning models do not output uncertainties in their predictions.
Global Mean Sea Level (GMSL) largely changes linearly with time (3 mm/year) but this global average exhibits large geographical variations and covers a suite of regional non-linear signals changing in both space and time and improving the mapping and understanding of these regional signals will enhance our ability to project sea level changes into the future.

Today, though, datasets have approached a suitable size, model explainability is solved by permutation importance and SHAP values, computing is cheap enough and through several methods we are able to include information on uncertainties as well, handled by either appropriate loss functions, meta-learners or Bayesian methods.

Thus the time has come to employ 30 years of satellite altimetry data to improve our predictive power in sea-level changes. This project focuses on the above problems in both global and regional settings.
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Impact of Greenland freshwater discharge on regional sea level trends in the Arctic ocean

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_008

Abstract:
Satellite altimetry has revealed the sea surface signature of a wide range of processes and scales, from tides to multidecadal trends. While ocean warming and continental ice melt are the main drivers of global mean sea level changes, regional sea level variability also responds to fluctuations in salinity, ocean circulation, air-sea fluxes. Temperature has been identified as the main driver of regional sea level trends, but less attention has been paid to salinity impacts mainly because of the lack of historical in situ data. Recent improvements have been made in estimating continental freshwater discharges especially from Greenland and rivers, and in particular their interannual variability. Thus, it is now possible to investigate the impacts of fully-varying freshwater discharges on regional sea level and ocean circulation/dynamics. Realistic, fully-variable freshwater discharges data have been implemented in a global 1/4° ocean/sea-ice/icebergs general circulation model based on NEMO. Global sensitivity runs have been produced over 1980-2018 using 2 sources of freshwater runoffs: (i) solid/liquid discharges from Greenland, (ii) river runoffs. These 2 sources are independently set to climatological or fully variable forcings in successive simulations. In this presentation, we will present recent results (from the IMHOTEP OST/ST project) on Greenland freshwater discharge on regional sea level trends. We find that Greenland discharge may impact regional sea level trends in the Beaufort gyre over 1998-2011 with values larger than 10 mm/yr. We find that the halosteric contribution drives these trend differences located in the the upper 300m. Salinity budgets will be investigated to understand the sources and origin of such a freshening and whether the Greenland is directly responsible for such regional sea level changes.

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Meridional Asymmetry in Recent Decadal Sea-Level Trends in the Subtropical Pacific Ocean

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_009

Abstract:
Recent sea surface height (SSH) trends in the South Pacific are substantially greater than trends in the North Pacific. Here, we use the Estimating the Climate and Circulation of the Ocean Version 4 Release 4 ocean state estimate and the Ocean Reanalysis System 5 to identify the forcing and mechanisms underlying that meridional asymmetry during 2005–2015. Thermosteric contributions dominate the spatial structure in Pacific SSH trends, but contributions from local surface heat fluxes are small. Wind stress trends drive a spin-up of the South Pacific subtropical gyre and a northward shift of the North Pacific subtropical gyre. A reduced gravity model forced with reanalysis winds qualitatively reproduces the meridional seesaw in sea level, suggesting that asymmetric trends in subtropical wind stress drive a cross-equatorial heat transport. A reversal in forcing associated with this process could impact near-term rates of coastal sea-level change, particularly in Pacific Island communities.
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Evolution of Regional Sea Level Trends During Satellite Altimeter Era

Benjamin Hamlington (NASA Jet Propulsion Laboratory, United States); Se-Hyeon Cheon (NASA Jet Propulsion Laboratory, United States); Christopher Piecuch (Woods Hole Oceanographic Institute, United States); Philip Thompson (University of Hawaii at Manoa, United States)

Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_010

Abstract:
Since 1993, satellite altimeters have measured sea level with high accuracy. In contrast to tide gauges, altimeters have provided continuous observations of sea level with near-global coverage. These measurements have led to accurate estimates of the rate of global mean sea level (GMSL) rise and a clear indication of the regional deviations from this rate. Recent studies have found a statistically significant increase in the rate of GMSL rise and there are indications that the anthropogenic, or forced, pattern of sea-level rise is emerging from the internal variability. Building off of this and considering the consistent acceleration on global scales since 1970 discussed in a number of recent studies, the satellite altimetry data provides an opportunity to assess the near-term trajectory of sea-level rise. Here, we discuss the evolution of the altimeter-measured regional sea-level trends in recent years and determine the extent to which current trends are informative of the longer-term trajectory of sea-level rise. Comparisons are also made to model-based projections from recent consensus reports, demonstrating how satellite altimeter observations can be used in tandem with models to improve our assessment of future sea-level change.

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Estimations of oceanic trends (heat, salt, steric and mass budget) in Mercator Ocean global reanalysis

Romain Bourdalle-Badie (mercator ocean, France); Jean-Michel Lellouche (mercator ocean, France); Gilles Garric (mercator ocean, France); Eric Greiner (CLS, France); Mathieu Hamon (mercator ocean, France); Giovanni Ruggiero (mercator ocean, France); Olivier Le Galloudec (mercator ocean, France); Marie Drévillon (mercator ocean, France)

Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_011

Abstract:
Over the past years, Mercator Ocean International (MOI) has been regularly developing and upgrading its global ocean physical reanalysis through improvements in the ocean model, assimilation scheme and assimilated data sets. In the framework of Copernicus Marine Service (CMS), MOI developed a global eddy-resolving physical reanalysis GLORYS12v1 at 1/12° (Lellouche et al. 2021) and participated to the global multi-reanalysis product GREP at ¼° resolution (Storto et al. 2018). MOI global reanalyses are coupled physical ocean and sea ice systems covering the 1993-present altimetry period. Oceanic observations are assimilated using a reduced-order Kalman filter. Along track altimeter Sea Level Anomaly, satellite sea surface temperature and sea ice concentration, and in situ temperature and salinity vertical profiles are jointly assimilated. All the essential oceanic physical variables from these reanalyses are available with free access through the CMS data portal (https://marine.copernicus.eu/).
Current MOI reanalyses, and particularly GLORYS12v1, have shown their reliability to correctly reproduce the main expected climatic interannual variability signals for ocean and sea ice, the general circulation, and the inter-basins exchanges. Nevertheless, GLORYS12v1 shows an unexpected marked warming trend together with an underestimation of the global mean sea level rise (Lellouche et al. 2021).
In this presentation we show how, through a better balance between the mass entering the system and the steric signal, we plan to tackle the latter issue in the next MOI reanalysis. Considering that NEMO ocean model is not able to reproduce the steric effect (Boussinesq approximation), and that the global mass can be estimated thanks to gravimetry measurements (GRACE), we propose to constrain the global mass toward satellite estimation and to diagnose the global steric elevation from the reanalysis system. Advantages and weaknesses of this method are first discussed. Then, results obtained from experiments performed with a global ¼° resolution are presented with a focus on different components of sea level trend (mass, steric, thermosteric, halosteric) at global and local scale and for different ocean layers. Comparisons with observed data supplement this study.

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Fluctuations in deep-ocean heat content and variations of steric sea level observed from Deep Argo floats

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Session: Science I: Climate data records for understanding the causes of global and regional sea level variability and change
Presentation type: Poster
Poster number: SC12022_012

Abstract:
The Deep Argo array consists of 200 active autonomous floats deployed in deep (> 2000 m) ocean basins that measure temperature and salinity every 10 days between the surface and seafloor. This new dataset is available on the Global Telecommunication System and Argo Global Data Assembly Centers in near real time and after delayed mode quality control. Regional pilot arrays have demonstrated Deep Argo's ability to quantify changes in the amount of heat stored in the deep ocean, where and how it is distributed, and fluctuations in water mass characteristics with accuracies approaching repeat hydrographic data. Recent analyses using Deep Argo profiles reveal an acceleration of Antarctic Bottom Water warming in the Southwest Pacific Basin using historical data from the 1990s–2010s and deep Argo data from 2014–2018, steady warming of this water mass in the Brazil Basin from the 1980s–2000s through 2019–2020, and similar warming rates in the Argentine Basin between the 1970s–1990s and 2020–2021. There is no discernible warming trend within the Lower North Atlantic Deep Water in the Brazil Basin over the past few decades, but a cooling trend is observed in the Irminger Sea between 2016–2021 that interrupted the warming phase prevailing since the late 1990s. Preliminary results based on Deep Argo profiles collected between 2014-2022 in the North Atlantic Ocean will be reported describing the thermosteric and halosteric components of sea level variations, and showing comparisons of steric sea level estimates from satellite measurements (satellite altimetry minus space gravimetry) with Deep Argo data. Performances and development of float and sensor technology, and deployment plans and envisioned expansions of the Deep Argo mission will be outlined.

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Improving SAR Altimeter processing over Inland Water - the ESA HYDROCOASTAL project

David Cotton (Satellite Oceanographic Consultants Ltd, United Kingdom)

Session: Instrument Processing: Measurement and Retracking
Presentation type: Poster
Poster number: IPM2022_001

Abstract:
Introduction
HYDROCOASTAL is a two year project funded by ESA, with the objective to maximise exploitation of SAR and SARin altimeter measurements in the coastal zone and inland waters, by evaluating and implementing new approaches to process SAR and SARin data from CryoSat-2, and SAR altimeter data from Sentinel-3A and Sentinel-3B. Optical data from Sentinel-2 MSI and Sentinel-3 OLCI instruments will also be used in generating River Discharge products.
New SAR and SARin processing algorithms for the coastal zone and inland waters will be developed and implemented and evaluated through an initial Test Data Set for selected regions. From the results of this evaluation a processing scheme will be implemented to generate global coastal zone and river discharge data sets.
A series of case studies will assess these products in terms of their scientific impacts.
All the produced data sets will be available on request to external researchers, and full descriptions of the processing algorithms will be provided

Objectives
The scientific objectives of HYDROCOASTAL are to enhance our understanding of interactions between the inland water and coastal zone, between the coastal zone and the open ocean, and the small scale processes that govern these interactions. Also the project aims to improve our capability to characterize the variation at different time scales of inland water storage, exchanges with the ocean and the impact on regional sea-level changes

The technical objectives are to develop and evaluate new SAR and SARin altimetry processing techniques in support of the scientific objectives, including stack processing, and filtering, and retracking. Also an improved Wet Troposphere Correction will be developed and evaluated.

Presentation
The presentation will describe the different SAR altimeter processing algorithms that are being evaluated in the first phase of the project, and present results from the evaluation of the initial test data set. It will focus particularly on the performance of the new algorithms over inland water.

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Improving SAR Altimeter processing over the coastal zone - the ESA HYDROCOASTAL project

David Cotton (Satellite Oceanographic Consultants Ltd, United Kingdom)

Session: Instrument Processing: Measurement and Retracking
Presentation type: Poster
Poster number: IPM2022_002

Abstract:
Introduction
HYDROCOASTAL is a two year project funded by ESA, with the objective to maximise exploitation of SAR and SARin altimeter measurements in the coastal zone and inland waters, by evaluating and implementing new approaches to process SAR and SARin data from CryoSat-2, and SAR altimeter data from Sentinel-3A and Sentinel-3B. Optical data from Sentinel-2 MSI and Sentinel-3 OLCI instruments will also be used in generating River Discharge products.
New SAR and SARin processing algorithms for the coastal zone and inland waters will be developed and implemented and evaluated through an initial Test Data Set for selected regions. From the results of this evaluation a processing scheme will be implemented to generate global coastal zone and river discharge data sets.
A series of case studies will assess these products in terms of their scientific impacts.
All the produced data sets will be available on request to external researchers, and full descriptions of the processing algorithms will be provided

Objectives
The scientific objectives of HYDROCOASTAL are to enhance our understanding of interactions between the inland water and coastal zone, between the coastal zone and the open ocean, and the small scale processes that govern these interactions. Also the project aims to improve our capability to characterize the variation at different time scales of inland water storage, exchanges with the ocean and the impact on regional sea-level changes

The technical objectives are to develop and evaluate new SAR and SARin altimetry processing techniques in support of the scientific objectives, including stack processing, and filtering, and retracking. Also an improved Wet Troposphere Correction will be developed and evaluated.

Presentation
The presentation will describe the different SAR altimeter processing algorithms that are being evaluated in the first phase of the project, and present results from the evaluation of the initial test data set focusing on performance at the coast.

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On-ground processing and performance of the Poseidon-4 altimeter internal calibration: chirp replica and attenuator

Michele Scagliola (Aresys, Italy); Lisa Recchia (Aresys, Italy); Alessio Izzo (Aresys, Italy); Andrea Recchia (Aresys, Italy); Marco Fornari (RHEA for ESA, the Netherlands); Robert Cullen (ESA, the Netherlands); Luisella Giulicchi (ESA, the Netherlands)

Session: Instrument Processing: Measurement and Retracking
Presentation type: Poster
Poster number: IPM2022_003

Abstract:
The main payload of Sentinel-6 Michael Freilich is a dual-band (Ku and C) pulse-width limited radar altimeter, called Poseidon-4, that transmits pulses at a high pulse repetition frequency thus making the received echoes phase coherent and suitable for azimuth processing. Among the different unique characteristic of Poseidon-4, it is worth recalling that digital pulse range compression is performed on-board to transform the received chirp using a matched filter. Thus, a proper calibration approach has been developed, including both an internal and external calibration.
In particular, this abstract presents the long-term monitoring of the internal calibration data for chirp replica and for attenuator that are processed on ground by ad-hoc tools provisioned by Aresys to ESA:
• CAL1 INSTR: This mode measures the internal instrument transfer function in Ku band and in C band. The results of these measures can be taken into account at Digital compression level in the chirp replica(f) to optimize the impulse response of the instrument.
• CAL ATT: Since amplification gain control knowledge directly impacts the σ0 measurements, an attenuation calibration is included in the design. This measures the top of the range impulse response within the full attenuation dynamic range that is then matched to a corresponding value on ground.

The performance of Poseidon-4 altimeter is here presented by analysis of the long-term monitoring of the on-ground processed data from CAL1 INSTR and CAL ATT calibration sequences commanded on board. The analysis of such calibration data allows to verify that the instrument has reached the requirements and that it is maintaining the key performance over its life. Moreover, in-depth analysis of the calibration data revealed how the instrument depends on its temperature and on the orbit of the satellite.

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A star-tracker processor for Sentinel-6: performance and application for radar antenna pitch bias calibration

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Session: Instrument Processing: Measurement and Retracking
Presentation type: Poster
Poster number: IPM2022_004

Abstract:
Radar altimeter processors require knowledge of platform and radar antenna attitude to provide accurate range and datation measurements. Although the attitude solution generated at real-time by the on-board computer may be accurate enough for ground applications, it is actually of interest to reprocess the star-trackers raw measurements on-ground with consolidated orbit data for validation purposes. Additionally, having more than one star-tracker on-board allows to derive independent Roll-Pitch-Yaw attitude estimates as observed from each star-tracker, what is of interest to identify and characterise eventual mechanical distortions between the star-trackers and the platform, such as thermo-elastic distortion due to the long-term variable thermal loads. In this contribution we present the star-tracker processor that has been implemented by isardSAT for the Sentinel-6 mission as part of the ESA Sentinel-6 Poseidon-4 (P4) L1 Ground Prototype Processor (GPP) to address the points raised before. We describe and discuss the overall performance of the star-tracker processor implemented. Then, we provide a comparison of the pitch measured by the star-trackers with an independent estimate provided by the P4 L1 GPP, allowing to determine the residual bias in pitch between the star-trackers measurements and the actual radar antenna pointing. Finally, we present a thermal analysis addressing how this residual bias evolves during the long-term thermal variation of the spacecraft.

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Copernicus POD Service: Overview and status

Jaime Fernández (GMV AD., Spain); Marc Fernández (GMV AD., Spain); Heike Peter (PosiTim UG, Germany); Pierre Féménias (ESA/ESRIN, Italy)

Session: Precision Orbit Determination
Presentation type: Poster
Poster number: POD2022_001

Abstract:
The Copernicus Precise Orbit Determination (CPOD) Service delivers, as part of the Ground Segment of the Copernicus Sentinel-1, -2, -3, and -6 missions, orbital products and auxiliary data files for their use in the corresponding Payload Data Ground Segment (PDGS) processing chains at ESA and Eumetsat and to external users through the ESA Copernicus Open Access Hub.
In this contribution focus is given to the altimeter satellites Sentinel-3A, -3B, and Sentinel-6 Michael Freilich for which the CPOD Service is responsible for near real-time orbit products. Contrary to the Jason-1,-2, and -3 satellites, the GNSS POD NRT orbits (ROE) computed by the CPOD Service are used and DORIS DIODE aboard is the backup. For the Sentinel-3 satellites also a short-time critical and non-time critical orbit product is delivered as backup to the CNES (Centre National d'Etudes Spatiales) orbit products.
The CPOD Service is supported by the CPOD Quality Working Group (QWG), composed by leading experts on GNSS and Low Earth Orbit (LEO) POD. Independent orbit solutions are provided from these members to support quarterly and yearly Regular Service Reviews. These reviews guarantee a continuous and independent quality control of the orbital products generated operationally by the CPOD Service. In addition, the CPOD QWG regularly meets to discuss recent developments and enhancements in the field of LEO POD and the applicability to the service operations.
In the frame of the Regular Service Reviews non-time critical orbits from the three altimeter satellites are compared to CNES and other orbit solutions from members of the Copernicus POD Quality Working Group (QWG). Satellite Laser Ranging measurements are used to independently validate the orbits.
Overview and status of the Copernicus POD Service is presented in terms of organisation, design, operations and performance in particular related to Sentinel-3 and Sentinel-6 satellites.

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Analysis of attitude dependent deficiencies in precise orbit solutions of Jason-3

Cyril Kobel (AIUB, Switzerland); Daniel Arnold (AIUB, Switzerland); Adrian Jäggi (AIUB, Switzerland)

Session: Precision Orbit Determination
Presentation type: Poster
Poster number: POD2022_002

Abstract:
Analysis of attitude dependent deficiencies in precise orbit solutions of Jason-3

C.Kobel, D.Arnold, A.Jäggi

The Jason-3 satellites' mission is to supply data for scientific, commercial, and practical applications to sea level rise, sea surface temperature, ocean temperature circulation, and climate change. The surface height is determined by radar altimetry measurements. To interpret these measurements, a precise orbit determination (POD) is required. The goal of this study is to identify (and remove) existing deficits in the Jason-3 POD process to further improve the high accuracy of the resulting orbit solutions. One of the characteristics of Jason-3 is that the satellite regularly changes its attitude, depending on the elevation of the Sun above the orbital plane. The LEO is either in a yaw-steering or in a fixed-yaw attitude mode, with the x-axis of the satellite-body-fixed frame pointing in the flight or anti-flight direction. Previous analyses have shown that different systematic errors in the resulting orbits are present, depending on the attitude mode in which the satellite is operating. These systematics are further analyzed in this study.
We use two different satellite geodesy techniques: the Global Positioning System (GPS) as one of the most important techniques for POD, and Satellite Laser Ranging (SLR) for LEO orbit validation by highly precise distance measurements from ground stations to the LEO retroreflector arrays. On the one hand, GPS observations are used for the POD of Jason-3, on the other hand, to derive potential corrections for the phase center offsets (PCO) of the LEO receiver antenna used in the POD process. The different attitude modes allow the estimation of corrections in all three components of the antenna frame, which is not possible for many LEOs which are operated in a fixed-yaw attitude mode. First results show that in the radial direction, which is of central importance for altimetry satellites, different corrections will be estimated when comparing the two fixed-yaw attitude modes. Using SLR, as an independent technique, allows for estimation of offsets in the orbit frame as well as in the satellite-body-fixed frame. Validity and sensitivity tests of the SLR analysis will be performed, e.g., by introducing artificial offsets and checking the capability of recovering them from the SLR analysis. By comparing the offset estimations from the two different techniques (GPS and SLR), it may be possible to get a better understanding of the presence and magnitude of systematics orbit errors for the different attitude modes.

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POE-F reprocessing of Jason-1 CNES precise orbit solutions

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Session: Precision Orbit Determination
Presentation type: Poster
Poster number: POD2022_003

Abstract:
The CNES POD team reprocessed and made available Jason-1 precise orbits in the last POE-F standards over the full decadal mission (January 2002 – June 2013). Jason-1 CNES orbit solutions are now consistent with those off the other past and present satellites of the altimeter constellation, all available in the POE-F standards. We present the processing evolutions on the early GPS+DORIS and then DORIS-only period after the loss of the GPS receivers. Also, we provide some details on how Jason-1 POE-F orbit solutions differ from the more recent missions. In particular, the lower quality of the POD instruments which requires to give a higher relative weight to dynamic modeling over the available measurements.

The orbital performance has been evaluated using independent laser range observations. We exhibit an improvement with respect to the previous POE-E standards on the GPS+DORIS period, as well as on the DORIS-only period, benefiting from a different constraining strategy for the empirical accelerations.

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International Combination Service for Time-Variable Gravity Fields (COST-G) – Overview of Current Activities and Future Perspectives

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Session: Precision Orbit Determination
Presentation type: Poster
Poster number: POD2022_004

Abstract:
The International Combination Service for Time-variable Gravity Fields (COST-G) is a Product Center of IAG's International Gravity Field Service (IGFS). COST-G provides consolidated monthly global gravity fields in terms of spherical harmonic coefficients and thereof derived grids of surface mass changes by combining existing solutions or normal equations from COST-G analysis centers (ACs) and partner analysis centers (PCs). The COST-G ACs adopt different analysis methods but apply agreed-upon consistent processing standards to deliver time-variable gravity field models from GRACE/GRACE-FO low-low satellite-to-satellite tracking (ll-SST) and from Swarm GPS high-low satellite-to-satellite tracking (hl-SST). The poster presents the organizational structure of COST-G and results from the first releases of combined monthly GRACE and GRACE-FO solutions. In addition, the perspectives from the provision of deterministic signal models (DSM), allowing for a few months prediction and therefore application in operational precise orbit determination activities of low Earth satellites, are discussed.

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Determination of the geocentric gravitational constant to monitor the behavior of the Earth

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Session: Precision Orbit Determination
Presentation type: Poster
Poster number: POD2022_005

Abstract:
For the past fifty years, geodetic satellites have contributed to the measurement of numerous geophysical parameters. They thus enabled us to improve our knowledge on several Earth's physical parameters and behaviors, through their refined observation. In particular, the geocentric gravitational coefficient is a key contributor to Satellite Laser Ranging (SLR) validation of the stringent accuracy requirement on the radial positioning of altimeter satellites, defining sea level relative to the Earth's center of mass. Indeed, SLR range biases estimated for the upcoming ITRF2020, derived from Medium Earth Orbit (MEO) Lageos and Etalon satellites, may not be applicable for Low Earth Orbit (LEO) altimeter satellites given the relatively large uncertainty of 2.0 ppb in the geocentric gravitational constant.
The purpose of this paper is to reassess the value of the Earth's GM from SLR measurements. This constant is defined by the product of the Earth's universal gravitational constant G and its mass M. The analysis is based on its simultaneous estimation with laser station and satellite biases, taking the most of eight well-chosen geodetic satellites. At first we focused on two specific spherical geodetic satellites, said to be without signature effects, Blits and Larets. We were able to revise estimates of the GM constant using CNES' ZOOM precise orbit determination software. Additionally, by combining MEO and LEO satellites, a consistent value of GM has been reassessed, being GM = 398600.4419 ± 0.0002 km3/sec² (TT-compatible). This value is higher than the reference value estimated previously in 1992. Also, some problems related to the design and center-of-mass corrections of the targets used have been raised and would need to be further investigated.

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Exploitation of the ENA Ground-Based Water Vapour Radiometers in Satellite Altimetry

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Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Poster
Poster number: IPC2022_001

Abstract:
Satellite altimetry has become a standard tool for many Earth Observation studies applied to sea, glaciers, rivers, inland waters and lakes, in order to measure the height of a water body above a reference ellipsoid. The signal emitted by the altimeter sensor is highly dependent on the wet tropospheric correction (WTC), due to its interaction with water vapour suspended in this atmospheric layer. Since water vapour does not behave as a well-mixed gas, its prediction becomes a delicate task. Therefore, microwave radiometers are on board the altimeter satellites in order to determine the WTC very accurately over open-ocean. Despite the ability of this passive sensor to produce collocated measurements with the altimeter, other sources of WTC are needed in locations where observations are invalidated due to the presence of non-ocean surfaces in its footprint, such as in coastal areas and high latitudes.
This study aims to investigate ground-based radiometers (MWRGB) as a reliable source of water vapour measurements for deducing the WTC of altimetric observations. For this purpose, the WTC from the MWRGB is assessed by comparison with other four external WTC sources: (1) microwave radiometers on board (MWROB) altimetry missions such as Sentinel-3 A and B, SARAL/AltiKa, and Jason-3; (2) Global Navigation Satellite Systems (GNSS); (3) radiosonde (RS); and (4) ECMWF (European Centre for Medium-Range Weather Forecasts) - ERA5 atmospheric model. The first three comparisons can be collocated or not while the latter is collocated through spatial and temporal interpolation. Among all the comparisons, the only one that is not independent is the comparison with radiosonde, since the information provided by this source is also introduced in the MWRGB retrieval algorithms.
MWRGB from one observatory of the Atmospheric Radiation Measurements (ARM) user facility have been used in this study, which is the ENA (Eastern North Atlantic). In addition, retrievals from two ARM algorithms were used in order to evaluate which one best suits the needs of Satellite Altimetry – NN or MWRRETV2.
For the ENA observatory, collocated comparisons, or up to 40 km, show RMS of WTC differences in the range 1.02 cm - 1.41 cm. The collocated comparison with ERA5 show RMS of 1.09 cm - 1.19 while the comparison with GNSS, which is non-collocated at only 51 m, shows a higher value of 1.41 cm. Furthermore, the comparisons with MWROB up to 40 km present an RMS in the range of 1.02 cm - 1.30 cm. For the comparison with RS, which is non-collocated at 89 km, an RMS of nearly 2.37 cm is found, which may be explained by the large distance between the two datasets, close to the limit of the WTC spatial correlation scale.
The intra-algorithm assessment showed that in general the NN and MWRRETV2 algorithms have great similarity in their results, with a variation of RMS of WTC differences in the range of 0 – 2.8 mm. Therefore, for the needs of Satellite Altimetry up to 40 km, the NN algorithm proves to be a reliable source for deducing WTC, due to the near real-time latency of its retrieved data.
At last, two neural network algorithms were tuned to estimate the WTC directly from MWRGB brightness temperatures (TB) observations, which are: (WTCGB_2TB) using 2 inputs - TB from both the 23.8 and 30 GHz bands; and (WTCGB_3TB), using 3 inputs – the former two TB with further inclusion of the TB from the 90 GHz band. Thus, the training dataset consisted of 100,000 samples which refer to 1 year of observations, 3 or 2 TB as inputs, and model-interpolated WTC for the same instants as output. An independent assessment for the WTC values retrieved from both algorithms was carried out against GNSS data. WTCGB_2TB presented an RMS of 1.42 cm while the WTCGB_3TB obtained a better performance of 1.34 cm. Furthermore, the comparison with the NN algorithm, for the same period, showed an RMS of 1.41 cm, which was higher than the result found for the WTCGB_3TB.
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Fundamental data records for altimetry: 20 years of ERS and Envisat Microwave Radiometer reprocessed data

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Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Poster
Poster number: IPC2022_002

Abstract:
In the framework of the European Long Term Data Preservation Program (LTDP+) which aims to generate innovative Earth system data records named Fundamental Data Records (basically level 1 altimeter and radiometer data) and Thematic Data Records (basically level 2+ geophysical products), ESA/ESRIN has launched a reprocessing activity of ERS-1, ERS-2 and ENVISAT altimeter and radiometer datasets. A large consortium of thematic experts has been formed to take in charge these activities which are 1) to define products including the long, harmonized record of uncertainty-quantified observations, 2) to define the most appropriate level 1 and level 2 processing, 3) to reprocess the whole times series according to the predefined processing and, 4) to validate the different products and provide them to large communities of users focused on the observation of the atmosphere, ocean, coastal, hydrology, sea ice, ice sheet regions.

The level 1 processing of microwave data have been thoroughly reviewed for the three missions. Errors in the processing have been corrected when sufficient information could be found, and radiometric corrections were updated to the latest standards. Uncertainties along the radiometric transfer model are identified and most of them will be evaluated. The aim is to provide the uncertainty for each measurement provided in the Fundamental Data Record. Following previous reprocessing efforts, intercalibration of the three microwave radiometers is achieved with diagnosis such as vicarious calibration over ocean or Amazon Forest. In addition to these harmonized brightness temperatures, a bias-corrected version of the brightness temperatures will be also part of the FDR.

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Integration of SIRGAS-CON data in the estimation of the Wet Tropospheric Correction for Latin America Coastal Altimetry

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Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Poster
Poster number: IPC2022_003

Abstract:
Satellite Altimetry is one of the main techniques for observing the oceans on a global scale and has contributed to the knowledge of the Mean Sea Level (MSL) and its variations. The main measurement of altimetric satellites is the distance between the satellite and the ocean surface (Range), which is incorrect owing to errors caused by the interaction of the signal with the atmosphere and the sea surface, requiring corrections to account for these effects. The troposphere is responsible for most of these errors, caused by its dry and wet components. The Dry Tropospheric Correction (DTC) is mainly due to atmospheric gases and pressure, being already well established and modeled with high accuracy. Oppositely, the Wet Tropospheric Correction (WTC), caused mainly due to the water vapor present in the troposphere, is much more variable in space and time than the DTC, therefore, more difficult to model.
The altimetric satellites are equipped with instruments called Microwave Radiometers (MWR), which measure the amount of water vapour under the satellite path, providing information for the estimation of the WTC. The MWR works well in the open ocean, the surface for which the instrument has been designed, and for which the retrieval algorithms are often tuned, but it fails in coastal zones and inland waters, due to the presence of land in the MWR footprint, and also in areas where ocean ice and heavy rain occur.
In view to recover the WTC in these regions, the GNSS (Global Navigation Satellite System) derived Path Delay Plus (GPD+) method, developed by the University of Porto, uses Zenith Tropospheric Delays (ZTD) from GNSS global and regional networks' stations combined with other sources of information, such as valid on-board MWR measurements, Scanning Image Microwave Radiometers (SI-MWR) and Numeric Weather Models (NWM) from the European Center for Medium-Range Weather Forecasts (ECMWF), to estimate this correction with high accuracy all over the planet.
The International GNSS Service (IGS) network, used by GPD+, has GNSS stations spread across the globe, but the coverage is not dense enough, with regions where there are few or no stations. Regional networks are used in order to increase the number of stations and the amount of information. GPD+ currently uses the regional networks EUREF Permanent Network (EPN) and SuomiNet, both located in the northern hemisphere. In order to densify the existing GNSS dataset used in GPD+, it is necessary to add new stations, mainly in the southern hemisphere, in regions such as South America, Africa and Oceania.
This work aims to exploit the Latin America and Caribbean SIRGAS-CON network and its potential for densification of the GPD+ input dataset in this region. The accuracy and stability of the WTC derived from SIRGAS-CON ZTD were analyzed, by comparison with WTC from IGS ZTD and ERA5 NWM, and the stations that meet GPD+ requirements were selected for the WTC computation by the algorithm.
The WTC computed by GPD+ with and without data from SIRGAS-CON stations were compared with the GNSS-derived WTC, by means of a non-independent and non-collocated comparison at altimetry points from CryoSat-2, Sentinel-3A and Sentinel-3B, in the Latin America and Caribbean regions. The results show that the RMS of the WTC differences for the solution with SIRGAS-CON stations is lower than the solution without SIRGAS-CON stations, for the three satellites, mainly in coastal zones, reaching up 2 mm, which indicates an improvement in the algorithm performance after the addition of the new network.
An independent evaluation with data from radiosondes is currently in progress. It is expected that the results of this second evaluation are in line with the results obtained so far, confirming the positive impact of the SIRGAS-CON ZTD in the estimations of the GPD+ WTC in the densified regions.

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Sentinel3 Microwave radiometers : Latest processing improvement, performances and stability assessment of

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Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Poster
Poster number: IPC2022_004

Abstract:
Sentinel-3B was launched the 25 April 2018, two years after Sentinel-3A. The two radiometers are identical in design. The pair of satellite will increase coverage and data delivery for Copernicus service. For routine operation, Sentinel-3 configuration is such that both satellites will fly with a 140° separation.

The two-channels microwave radiometer (23.8 and 36.5 GHz) on board the two missions is similar to the Envisat and ERS MWR sensors. It is combined to the altimeter in order to correct the altimeter range for the excess path delay (WTC for wet tropospheric correction) resulting from the presence of water vapor in the troposphere.

An ascending/descending signal is observed on comparison to simulations for Sentinel-3A and B, indicating a design root cause. The more probable root cause seems to be the OLCI wall close to the MWR. A correction for that signal has been developed and implemented. Latest algorithms developed for Sentinel-3 MWRs will be presented.

The wet tropospheric correction (WTC) is a major source of uncertainty in altimetry budget error, due to its large spatial and temporal variability. It also contributes significantly to the uncertainty in the long term mean sea level trend. In order to better quantify the WTC trend, it is important to focus on the detection of potential instrumental drifts. The long-term stability of each radiometer will be assessed using different methods.

First, vicarious calibrations are statistical selections of coldest and hottest temperatures over the ocean and the Amazon forest respectively. They are commonly used for the in-flight calibration during commissioning phase, but also for long-term monitoring. Second, the double difference accounts for frequency, Earth Incidence Angle, and orbital differences between platforms. Finally, conclusions can be drawn on the stability of the WTC.
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Empirical, Nonparametric Estimation of the Sea State Bias using the Interpolation Method

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Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Poster
Poster number: IPC2022_005

Abstract:
An alternative approach to empirical, non-parametric sea state bias (SSB) modeling was developed with intention of providing a simple, transparent and efficient means to derive both a raw and smoothed SSB solution. This alternative approach, referred to as the interpolation method, maintains the flexibility to generate 2-D or 3-D models using either direct or difference measurements of the sea level anomaly uncorrected for SSB (uSLA). The interpolation method was further used to introduce a combined, or joint (JNT), SSB solution using a weighted combination of collinear and crossover uSLA measurements. The raw and smoothed SSB solutions derived using the interpolation method are obtained over three steps, with a supplemental fourth step that consists of estimating a model-dependent dual-frequency ionosphere calibration bias to correct for a relative range+SSB error.

We have generated SSB models for Topex/Poseidon and Jason-1 through -3 using the interpolation method. By applying the same SSB modeling method that includes a dual-frequency ionosphere calibration bias to four sequential satellites, we explore the potential benefits to the long-term sea level time series.

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Swot and hydrology from space outreach

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Session: Outreach, Education and Altimetric Data Services
Presentation type: Poster
Poster number: ODS2022_001

Abstract:
Last year we published on Aviso web site series of slides presenting Swot and hydrology from space for University and engineering schools. The "product" series was missing and have been added this year, using the mock-up data made available.

In 2021, the focus has been people going to present in schools (primary, middle and high schools). New series have been developed and will be published again on Aviso, with also links with the ArgoHydro educational project, part of Argonautica.
Moreover, some "real life" applications have been listed, for developing a porfolio for a wide variety of audience.

We are more than ever keen on having feedbacks, whether you've been using the slides (how? -- example uses would be interesting), have had a look at them and did not find what you needed (what was missing?), etc.

Demo could be organized.
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Accessing Sentinel-6 and Sentinel-3 altimetry data through EUMETSAT big data services

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Session: Outreach, Education and Altimetric Data Services
Presentation type: Poster
Poster number: ODS2022_002

Abstract:
As the size and complexity of the Earth observation data catalogue grows, the ways in which we interface with it must adapt to accommodate the needs of end users, both research-focussed and operational. Consequently, since 2020 EUMETSAT have introduced a suite of new data services to improve the ability of users to view, access and customise the Earth observation data catalogue they provide. These services, which are now operational, offer both GUI- and API- based services and allow fine grained control over how users interact both with products, and the collections they reside in. They include, i) the new implementation of the EUMETView online mapping service (OMS), ii) the EUMETSAT Data Store for data browsing, searching, downloading and subscription, and iii) the Data Tailor Web Service and standalone tool for online and local customisation of products.

From early 2022, these services will also support the dissemination of the EUMETSAT Copernicus Marine Data Stream, including the Level-1 and Level-2 altimetry products from both the Sentinel-3 and Sentinel-6 missions at both near real-time and non-time-critical latency.

Here, we give an overview of the capability of these data services, with examples of how to use them via web interfaces and, in an automated fashion via APIs. These examples will focus on interaction with the Copernicus marine products provided by EUMETSAT. In addition, we will outline the tools and resources that are available to assist users in incorporating these services into their workflows and applications. These include online user guides, python libraries and command line approaches to facilitate data access, and a suite of self-paced training resources and courses. This poster presentation will include demonstrations of the services, information on plans and schedules for the inclusion of future data streams, and the opportunity for new and experienced users to ask questions and give feedback.

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AVISO+ products and service: what's new?

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Session: Outreach, Education and Altimetric Data Services
Presentation type: Poster
Poster number: ODS2022_003

Abstract:
Aviso (Archiving, Validation and Interpretation of Satellite Oceanographic data) is a service set up by CNES to process, archive and distribute data and products from altimetry satellite missions. Its portal AVISO+ (www.aviso.altimetry.fr) is the entry point for 10000 registered users to freely access more than 40 products from CNES and CTOH not only for ocean-oriented applications but also for hydrology, coastal, ice applications. In addition, the website proposes information (handbooks, use case, outreach material, . . .) to discover the products and their use.
This presentation gives an overview of available products and services. We also present here all the recent novelties, and those to come.
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CTOH studies for extending the range of altimetry applications over the ocean and continental surfaces

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Session: Outreach, Education and Altimetric Data Services
Presentation type: Poster
Poster number: ODS2022_004

Abstract:
The Center for Topography of the Oceans and Hydrosphere (CTOH) is a French Observation Service created in 1989 and dedicated to satellite altimetry studies. It focuses on the development and promotion of new processing approaches of the altimetric data for emerging research domains (coastal ocean, oceanic sub-mesoscale phenomenons, continental surface water, sea ice, polar caps). It works in close relationship with space agencies (mainly CNES and ESA) at different levels for satellite altimetry missions: preparation of new missions, definition of the user's needs, CAL/VAL studies, signal analysis & data reprocessing, development of thematic products, teaching and outreach.
In terms of data distribution, the CTOH maintains a global GDR data base for almost all altimetry missions since Topex/Poseidon. All the products are made homogeneous (addition of the most recent parameters / corrections for the old missions) and provided in netcdf format. A new version of ERS-2 data, reprocessed by the CTOH for hydrological applications is also available (it includes ICE-1 and ICE-2 retrackers). Both 1Hz and 10/20/40Hz data are available globally. For some products, the CTOH database contains also L1 products (waveforms).
In addition, the CTOH develops new altimetry products:

- Fine-resolution ocean products: position of the main Southern Ocean polar fronts and global climatology of near-inertial current characteristics.
- Coastal products : X-TRACK along-track SLA time series and tidal harmonic constants, reprocessed with a software designed for coastal altimetry, but also the recent high-resolution (20-Hz) X-TRACK/ALES sea level product, now reaching a distance of 3-4 km from the coast on average (see Leger et al., OSTST 2022). These products are distributed by AVISO+ and by ESA, respectively.
- Continental hydrology products : including Topex/Poseidon reprocessed by the CASH project and water level maps developed for 5 rivers: the Amazon, Orenoque, Gange-Bramhapoutre, Congo and Mekong.

It also contributes to the development of sea-ice products distributed by AVISO+ (Arctic Sea Ice Thickness and Snow depth monthly maps over sea ice) and to the "Hydroweb" data base for monitoring river and lake levels.

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ODATIS, Ocean Data Information and Services for Easier Access to Data and Analytical Services

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Session: Outreach, Education and Altimetric Data Services
Presentation type: Poster
Poster number: ODS2022_005

Abstract:
The ODATIS Ocean Cluster (Ocean Data Information and Services) is the entry point to access all the French Ocean observation data, from in situ and remote sensing measurements. It federates, at the national level, data management activities and scientific expertise in oceanography, in various disciplines such as physics, chemistry, biology, from the open ocean to the coastline and estuaries, from the surface to the depths.
The ODATIS ocean data and services cluster is a component of the Data Terra research infrastructure along with other national data centers : AERIS - atmosphere, THEIA – continental surfaces and FORM@TER – solid earth. ODATIS relies on a decision-making and executive structure whose members belong to 6 partner institutions: CNRS, CNES, Ifremer, IRD, Shom and Universités Marines. The cluster is structured around 9 data centers and services (CDS) which offer guaranteed services in data management: 2 dedicated to satellite data (including AVISO+), the others to in situ data.
The main task of the ODATIS Ocean Cluster is to facilitate/promote the discovery and use of data, to develop derived products, to make available software, tools and services intended primarily for the French scientific community working in the area of ocean research. Some ODATIS services examples:
- The ODATIS Scientific Expertise Consortia (CES) promote and enhance innovative processing methods and innovative products for spatial, airborne or in situ observation of the ocean and its interfaces with the atmosphere, the continent and the ocean floor. The Scientific Expertise Consortia federate scientific stakeholders at national and even international level, ensure the production of value-added product prototypes, or the operation of these prototypes to produce specific data on ocean issues (coastal or offshore), and finally disseminate, share data through exhaustive and qualified database of national data.
- The Technical Workshops train data managers and users to good practices (FAIR principles, data warehouses) and to the handling/visualization of the cluster's data and products. Practical works are organized, adapting to the level of participants coming from several scientific communities (biology, physics) on Virtual Research Environment (VRE), with examples of handling large volumes of data.
- A support service for campaigns at sea is provided for ODATIS by CNES with the support of CLS. This make available satellite data delivery according to objectives and technical constraints of the campaign. Through the ODATIS Ocean pole, and several weeks/months before being at sea, the campaign team can consider several solutions: delivery of satellite ephemeris (repetitive orbits), real time data of predefined variables, analyses and interpretations, downloadable onboard with an optimized format, and/or delivery of delayed-time satellite data (reprocessed data) after the actual period of the campaign at sea. These data files can incorporate specific processing enhancements for the area of interest, or better spatial resolution.

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Cryo2Ice Coincident Data Explorer

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Session: Outreach, Education and Altimetric Data Services
Presentation type: Poster
Poster number: ODS2022_006

Abstract:
CRYO2ICE is a campaign that increased the ground track intersection of the CryoSat-2 and ICESat-2 satellites over short time intervals. The orbit change of CryoSat-2 is an enabling step for applications that require co-incident data, such as measuring snow depth and capturing the temporal variation. In addition to aligning the satellites, an efficient data access layer to identify coincident CryoSat-2 and ICESat-2 data measurements is required.

The Cryo2Ice Coincident Data Explorer enables users to visualise the spatial intersections for a given time window and download the ESA and NASA data products. The website's unique temporal separation time functionality allows users to select intersects that are close in time (e.g. 3 hours) up to a 28 day separation, providing useful application for Sea Ice, Land Ice and the Ocean. The intuitive and reactive interface enables users to choose the area of interest by specifying a bounding box or drawing a polygon. Easy to use download scripts allow users to download only their intersecting data, saving a large amount of both download time and data preparation time. The provided KML file allows users to save the visualisation component of their results and view it at a later time. The robust implementation makes it possible to run large queries in batch mode and receive the results via email.

The website provides access to CryoSat-2 LRM, SAR and SARIn mode data and ICESat-2 ATL06, ATL07, ATL10, and ATL12 products. Combined datasets for CryoSat-2, linking the LRM, SAR, and SARIn L2 products, and for ICESat-2, linking the ATL06 and ATL07 products, allow users to view and intersect these products at the same time. Predicted ground track data is available, allowing users to view and plan for future CryoSat-2 and ICESat-2 satellite passes and intersections. The portal additionally provides access to CryoTEMPO-EOLIS Point and Gridded products.

Airborne missions such as Operation IceBridge data sets are available, with the CryoVex data and its following campaigns coming in the future.

The website allows intersections to be computed between any pair of available datasets from different missions, as long as they coincide in time. One could intersect the ICESat-2 ATL07 product with CryoSat-2 SAR mode data, or go outside of the CRYO2ICE scope and intersect airborne Operation IceBridge data with EOLIS Point Product's swath elevation. Each dataset available on the website can also be queried in single mode, allowing users to view the data independently rather than searching for intersections.

This poster will detail the Cryo2Ice Coincident Data Explorer and gather feedback for additional features, capabilities and datasets. A new combined CryoSat-2 and ICESat-2 product, created to make coincident data even easier to use and download, will also be presented.
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Sentinel-3 Topography mission Assessment through Reference Techniques (St3TART) project – Focus on the FRM Data Hub

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Session: Outreach, Education and Altimetric Data Services
Presentation type: Poster
Poster number: ODS2022_007

Abstract:
The Copernicus Sentinel-3 Surface Topography Mission (STM) provides extremely valuable surface elevation information over inland waters, sea ice and land ice, thanks to its SAR altimeter which retrieves high-resolution along-track elevation measurements, and to its orbit that covers high-latitude polar regions. To ensure that these measurements can be used with confidence, and to maximize the return on investment of the Copernicus Sentinel-3 STM, adequate validation of the geophysical retrieval methods, processing algorithms and corrections must be performed, considering independent observations as Reference Measurements.
St3TART is an EU and ESA funded project led by NOVELTIS with a consortium of 17 European partners (CNES, DTU, NPI, vorteX.io, LEGOS, Hydro Matters, CLS, LOCEAN, IGE, SERTIT, GIS, CNR-IRPI, NPL, DT/INSU, IRD, M2C, SYRTE). It aims to generalize the concept of Fiducial Reference Measurements (FRM) for the Copernicus Sentinel-3 STM and to collect and distribute FRM data for the validation of the satellite mission over inland waters, sea ice and land ice. The provision of FRM will serve the validation activities of the ESA S3 Land Altimetry products, currently performed by the Sentinel-3 Mission Performance Centre, with the support of the Sentinel-3 Validation Team, for the sake of performance assessment and fitness-for-purpose of the Sentinel-3 STM Land core products. Those products cover inland waters, land-ice and sea-ice areas.
The objective of the St3TART project is not only to collect existing data or measure new observations during field campaigns, but to ensure that these observations meet the criteria of FRM standards and can be used in an operational way for the validation of the Sentinel-3 Land topography mission.
The FRM Data Hub will provide a centralized access to these FRM measurements. It aims to federate the Cal/Val community in sharing these reference observations in a free and accessible manner, with fully characterized and documented FRM processing and measurements.
The poster will present the architecture of the tool, its interface, the first available datasets and the format specification.

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SAR, SARin, RDSAR and FF-SAR Altimetry Processing on Demand for CryoSat-2, Sentinel-3 and Sentinel-6 at ESA's Altimetry Virtual Lab

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Session: Outreach, Education and Altimetric Data Services
Presentation type: Poster
Poster number: ODS2022_008

Abstract:
The scope of this presentation is to provide an update on the ESA radar altimetry services portfolio for the exploitation of CryoSat-2 (CS-2) and Sentinel-3 (S-3) data from L1A (FBR) data products up to SAR/SARin L2 geophysical data products. At present, the following on-line & on-demand services compose the portfolio:

- The ESA-ESRIN SARvatore (SAR Versatile Altimetric TOolkit for Research & Exploitation) for CS-2 and S-3 services. These processor prototypes allow the users to customize the processing at L1b & L2 by setting a list of configurable options, including those not available in the operational processing chains (e.g. SAMOSA+ and ALES+ SAR retrackers).

- The TUDaBo SAR-RDSAR (TU Darmstadt – U Bonn SAR-Reduced SAR) for CS-2 and S-3 service. It allows users to generate reduced SAR, unfocused SAR & LRMC data. Several configurable L1b & L2 processing options and retrackers (BMLE3, SINC2, TALES, SINCS, SINCS OV) are available.

- The TU München ALES+ SAR for CS-2 and S-3 service. It allows users to process official L1b data and produces L2 products by applying the empirical ALES+ SAR subwaveform retracker, including a dedicated SSB solution.

- The Aresys FF-SAR (Fully-Focused SAR) for CS-2 & Sentinel-3 services. They provide the capability to produce L1b products with several configurable options and with the possibility of appending the ALES+ FFSAR output to the L1b products. In the future, the service will be extended to process Sentinel-6 data.

All output data products are generated in standard netCDF format, and are therefore also compatible with the multi-mission "Broadview Radar Altimetry Toolbox" (BRAT, http://www.altimetry.info).

The SARvatore services have been migrated from the ESA G-POD (https://gpod.eo.esa.int/) to the Altimetry Virtual Lab, a community space for simplified services access and knowledge-sharing. Services are currently hosted on EarthConsole (https://earthconsole.eu), a powerful EO data processing platform now also on the ESA Network of Resources. This enables SARvatore services to remain open for worldwide scientific applications (info at altimetry.info@esa.int, brochure at: https://earthconsole.eu/knowledge-base-2/brochures/).

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NOAA’s Jason Products

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_001

Abstract:
The interagency Jason-3 Mission measures sea surface height, wind speed, and significant wave height to help track global sea level rise, ocean currents, and upper ocean heat content. Four partner agencies share mission responsibilities: the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL), the Centre National d’Etudes Spatiales (CNES), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). NOAA’s roles include satellite command and control, operational data processing, operational data distribution, and archive of data and processing software. NOAA’s Environmental Satellite Processing Center (ESPC) generates Jason-3 Operational Geophysical Data Record (OGDR) products. ESPC distributes OGDRs in near real time (within 3-5 hours of observation) in NetCDF format via their Data Distribution Server, and in BUFR format via the World Meteorological Organization (WMO) gateway. All Jason-3 mission data are archived by NOAA’s National Centers for Environmental Information (NCEI) using its Comprehensive Large Array-data Stewardship System (CLASS). The OGDRs, CNES-derived interim Geophysical Data Records (IGDRs), and the final science-quality Geophysical Data Records (GDRs), all in NetCDF, are made available by traditional FTP as well as through modern interoperable data services. Jason-3 geophysical data record products are used for ocean nowcasting and forecasting, assimilation into global and region models, hazard monitoring, and hurricane intensification forecasts. Additional product details and data access information are available at https://www.ncei.noaa.gov/products/jason-satellite-products.

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DUACS DT2021: 28 years of reprocessed sea level altimetry products

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_002

Abstract:
For more than 23 years, the multisatellite DUACS system has been providing high quality multi-mission altimetry Sea Level products for oceanographic applications, climate forecasting centers, geophysics and biology communities. They consist in directly usable and easy to manipulate Level 3 (along-track cross-calibrated Sea Level Anomaly SLA) and Level 4 (multiple sensors merged gridded gap-free) products. Global and regional datasets (Arctic Ocean, European Seas ...) are available.

A full reprocessing of these products is carried out almost every 3 years, based on the state-of-the-art Level 2 to Level 4 algorithms. In Decembre 2021, a new version will be available within the Copernicus Marine Environment and Monitoring Service (CMEMS) and the Copernicus Climate Change Service (C3S) covering 28 years of altimetric data (i.e. almost a century of cumulated data using 24 altimetric missions). This version benefits from major improvements associated with new altimeter and mapping standards.

Here, we report the first results of this DUACS DT2021 multi-mission reprocessing. We first describe the main steps of the altimeter production system. Then, we discuss the characteristics and limits of the different products (C3S, CMEMS) in order to help the ocean and climate communities on their optimal use for validation, assimilation activities and other scientific studies. Several comparisons with independent datasets (along-track, drifters, tide gauges) show that a significant improvement has been achieved at mesoscale with this new version: almost 20% of SLA error reduction at wavelengths [65, 500km] and around 10% of geostrophic currents error reduction compared to the previous version (DT2018). At decadal time scale, the trend of the global mean sea level has been estimated to 3.4 +/- 0.4 mm/yr. (90% Confidence Interval), in line with other estimates and previous reprocessing DUACS-DT2018. New altimeter corrections are also available for the users (internal waves, correction for the Topex-A instrumental drift, flag ice).

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Altimeter Processing System – 2.0 (ALPS2)

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_003

Abstract:
The Altimeter Processing System (ALPS) is the software run operationally at the Naval Oceanographic Office that daily processes satellite sea surface height observations into the form used for ocean predictions, hurricane heat content, and many other applications. This system has processed data since TOPEX/Poseidon with continued updates and advances for new satellites and sensors, quality control, and error estimation and removal. The system has undergone a complete rewrite and transition to operations in 2021 now processing Jason-3, CryoSat-2, AltiKa, Sentinel-3A, Sentinel-3B, and Sentinel-6A MF / Jason-CS. The accuracy measured in crossover RMS error is significantly better than the prior version. Output data will be provided in NetCDF formats with one file for each revolution of data. This will allow timely sea surface height, wave height, and wind speed. Legacy formats will be provided with a one year overlap.

An additional advancement is the ability to process swath observations as will be expected from the Surface Water / Ocean Topography (SWOT) satellite. Many quality control and error estimation processes translate to the swath observations, and additional estimation processes have been implemented. These include removal of estimated errors using the cross-track direction shape and filtering in the along-track direction based on the power spectral density estimation of the SWOT simulator. Evaluation of these error estimates so far shows that the energy content in simulations from realistic ocean models is larger than the expected errors represented in the SWOT simulator.

The SWOT simulator has been employed on regional and global model simulations. The results provided in the expected SWOT NetCDF format have been tested in ALPS2 for processing. The example in the figure below shows 10 days of data from the SWOT simulator sampling the operational Global Ocean Forecast System sea surface height. The simulator used all SWOT noise sources, and the simulator estimates of roll and phase error have been removed within the ALPS processing. This is the result of processing the simulated SWOT data through ALPS2. While the present ALPS2 is capable of processing SWOT now, we will be continuing to test the processing and assimilation of results into ocean forecasts systems up to the SWOT launch time. The ALPS2 system will be used during the SWOT cal/val with real time ocean prediction systems in the cal/val area for assimilation and demonstration of performance. The intent is to begin operational SWOT processing at NAVOCEANO at the end of the SWOT cal/val period.

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Integral length scale of ocean surface waves via CFOSAT along-track observation

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_004

Abstract:
The integral length scale of a turbulent velocity is treated as the characteristic scale of the largest scale of motions in the turbulent flow. It is a key parameter in turbulent theory and numerical simulations. The ocean surface waves show complex turbulence-like dynamics. In this work, the integral length scale of ocean surface waves provided by the China France Oceanography Satellite (CFOSAT) is examined. The results show that the integral length scales possess evident spatial and temporal variations, with a mean value around 100 km. More precisely, the integral length scales are larger in mid-latitudes as compared to the ones in tropical regions; the scales observed in the Southern Hemisphere are larger than those in the Northern Hemisphere. For the seasonal differences, larger scales are found in winter than in summer. In addition, the differences are larger in the Northern Hemisphere than the ones in the Southern Hemisphere due to the continents. The results presented in this work may be applicable to oceanic models, and also extend our understanding of ocean surface turbulent motions.

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Homogeneous multi-mission 20 Hz sea level anomaly (20 Hz L2P) products available

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_005

Abstract:
Since the launch of TOPEX/Poseidon and ERS-1 in the early 90's more than 10 other Altimetry missions were launched and operated by different agencies. The level 2 data (destinated to expert users) are distributed using different file formats (binary, netcdf) and contain different geophysical standards used to compute the sea level anomaly. Some datasets evolve rapidly and are regularly reprocessed, whereas other datasets, especially from finished missions are seldom reprocessed or not at all (and therefore do not profit from new standards).

In the frame of the SALP (Service d'Altimétrie et de Localisation Précise) project supported by CNES (Centre National d'Etudes Spatiales) and of the Sentinel-3 Marine Altimetry L2P-L3 Service (operated under an EUMETSAT contract in the frame of the Copernicus Programme funded by the European Union) level 2P 1 Hz data are available to users for all the altimeter missions (TOPEX/Poseidon, Jason-1/2/3, ERS-1/2, Envisat, Saral/AltiKa, Sentinel-3A/B, GFO, Cryosat-2, HY-2A) in delayed time on AVISO+ (https://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/along-track-sea-level-anomalies-l2p.html), as well as in near-real-time and short-time-critical for Sentinel-3A, Sentinel-3B and soon Sentinel-6A.

Since 2021 level 2P 20 Hz data are also available on AVISO+ for Sentinel-3A, Sentinel-3B and Jason-3 for near-real-time and short-time-critical timeliness. Other missions (HY-2B and Sentinel-6A) will be added in 2022. Hereafter the value-added sea level anomaly L2P products are presented. They are easy to use (netcdf format) homogenous along-track mono-mission products, providing as much as possible the same updated corrections and models for the altimeter missions, in order to facilitate inter-mission comparisons. The products contain the sea level anomaly as well as all the corrections used to compute it. The sea level anomaly is provided with a validity flag, enabling users to discard data with spurious measurements. Furthermore an inter-mission bias is applied to have consistent time series since TOPEX/Poseidon.

The L2P 20 Hz products are the input products of the future L3 5Hz sea level DUACS products (see abstract MI. Pujol "Toward Higher resolution Level-3 altimeter products").

The L2P 20 Hz service and its products will be presented in detail.

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Homogeneous multi-mission along-track Sea Level Anomalies, Wave and Wind (Level-2P) : implementation of Sentinel-6A/Jason-CS

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_006

Abstract:
L2P products were reprocessed in 2021 [1][2][3]. They are easy to use homogenous along-track mono-mission products, providing as much as possible the same updated corrections and models for the altimeter missions, in order to facilitate inter-mission comparisons. The products contain the sea level anomaly as well as all the corrections used to compute it, wind and wave. A validity flag, enable users to discard data with spurious measurements. The sea level anomaly level 2P products are, among other uses, the input data for level 3 products and for the Global Mean Sea Level computation (an inter-mission bias is applied in order to have consistent time series since TOPEX/Poseidon).

We present here the implementation of the new Copernicus mission Sentinel-6A/Jason-CS, an international partnership between the U.S. and Europe. On the Jason orbit, Sentinel-6A/Jason-CS will ensure continuity of sea level observations into a fourth decade.

In the frame of the SALP [4] project supported by CNES [5] and of the Sentinel Marine Altimetry L2P-L3 Service [6] level 2P data of sea level anomalies product and wind/wave product are available to users in delayed time on AVISO+ (https://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/along-track-sea-level-anomalies-l2p.html) for all the altimeter missions : TOPEX/Poseidon, Jason-1/2/3, ERS-1/2, Envisat, Saral/AltiKa, Sentinel-3A/B, GFO, Cryosat-2, HY-2A, HY-2B and soon Sentinel-6A/Jason-CS.

[1] Lievin et al. OSTST conference 2020
[2] Kocha et al., 2021 : « Reprocessing of a sea level L2P-multi-mission dataset covering 28 years”, Aviso news letter 18
[3] Kocha et al. EUMETSAT conference 2021
[4] Service d’Altimétrie et de Localisation Précise
[5] Centre National d’Etudes Spatiales
[6] in cooperation agreement with EUMETSAT in the frame of the Copernicus Programme funded by the European Union

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Sentinel-3 Marine Altimetry Centre

Bruno Lucas (EUMETSAT, Germany)

Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_007

Abstract:
EUMETSAT is responsible for the Ocean and Coastal products of Sentinel-3 mission, on behalf of Copernicus. The poster will show the current status of the Marine Centre in terms of data production/quality of altimetry data for Sentinel-3.
Details on the Key Performance Indicators of the data production will be shown, taking into account the completeness and the timelines. Details on the data production, such as Orbit usage statistics, will also be shown. The latest events of the spacecraft and also Marine ground segment will be reported.
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The new daily global mesoscale Blended Ocean Surface Current (BOSC) product

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_008

Abstract:
We describe design of the new 1/6° (mesoscale) resolution daily global Blended Ocean Surface Current (BOSC) product (analysis depths: 20 cm and 15m). This quasi-realtime data-informed product will eventually be available through NOAA CoastWatch for applications ranging from climate and weather analysis and forecasting to fisheries, marine debris, and coastal engineering. Looking forward, BOSC is designed to complement velocity observations from future Doppler satellite scatterometry.

BOSC currents are constructed by summing gradient currents derived from the 1/4° resolution daily NOAA gridded multi-satellite sea level anomaly, with near-surface Stokes/Ekman currents derived from NOAA surface stresses and surface wave statistics, filled in with ice drift observations at high latitude. Satellite-derived SST constrains the mixed layer temperature equation to improve representation of meso-scales as well as coastal and tropical currents. Global Drifter Program drifter paths are used to constrain the time-mean currents at 15m depth. In addition to summarizing the theory and error analysis we show comparisons to two other widely used surface current products and to independent velocity observations for a two-year focus period: 2019-2020. Fig. 1 (upper panel) shows 15m BOSC currents in the Kuroshio/Kuroshio outflow region of the Northwest Pacific during the first month of our focus period.

Fig. 1 legend
Currents at 15m depth in the Kuroshio region of the western North Pacific, averaged during January 2019. Colors show speed while black arrows show vector velocity. Upper panel shows BOSC. Lower panel shows Globcurrent (www.globcurrent.org).

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Presentation of the near-real time and delayed time global database of mesoscale ocean eddies detected by TOEddies on altimetry fields and co-located with (BGC-)Argo floats.

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_009

Abstract:
Following the first description of the concept of mesoscale ocean eddy networks and its implementation in the TOEddies algorithm (Laxenaire et al., 2018), this tool, when applied to Absolute Dynamic Topography satellite observations has, in a particularly effective way, helped our team and partners to highlight complex behaviors of these ocean structures. TOEddies has been applied to near-real-time altimetric fields for operational support to target eddies (e.g., the Curent Ring of Northern Brazil during EURC4A-OA; Stephen et al., 2021) and to monitor their sampling by autonomous devices (e.g., Bio-Argo 6903095 launched into a cyclone during cruise SO282). When applied to delayed-time fields, the characteristics of the eddies, and thus their networks, have been used to highlight complex eddy behaviors as they propagate through the ocean (e.g., the Agulhas rings connecting the Mozambique Channel and the Zapiola gyre; Laxenaire et al., 2018). The full power of this formidable database was achieved when these data were collocated with automatic devices sampling the vertical column. For example, by colocating them with Argo float data and vertical sampling from science cruises, we have shown the subduction of the Agulhas rings (Laxenaire et al., 2019, 2020), the importance of eddies on the assessment of meridional transport during a Go-Ship transect (Manta et al, 2021), their direct impact on the overall distribution of mode waters in the South Atlantic (Chen et al., 2021), and the offshore transport achieved by eddies of eastern upwelling origin in the Atlantic (Ioannou et al., submitted). Furthermore, through their colocalization with the BGC-Argo database, different impacts of eddies on the role of deep chlorophyll maxima in global primary production have been suggested (Corned et al., 2021). These excellent results, which proved the great value of this database, highlighted the need to share it with the wider community. We are therefore implementing a database, both in delayed and near-real time, of eddies detected by TOEddies collocated with (BGC-)Argo floats associated with a toolkit to use them (both in Matlab and Python). In this poster, we demonstrate the capabilities of these datasets by selecting results we have obtained thanks to them over the past four years.

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A new operational ocean data assimilation and forecasting system of the Japan Meteorological Agency

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_010

Abstract:
The Japan Meteorological Agency (JMA) had been operating the Western North Pacific Ocean Data Assimilation System (MOVE/MRI.COM-WNP: hereafter referred to as the "old system") since March 2008 in order to monitor and forecast ocean conditions in the North Pacific Ocean and the seas around Japan. The old system consisted of the Western North Pacific Model (WNP: horizontal resolution of about 10 km) and the North Pacific Model (NP: horizontal resolution of about 50 km), and used the three-dimensional variational method (3DVAR) for data assimilation. The old system was capable of resolving medium-scale eddies in the seas around Japan and major ocean currents such as the Kuroshio Current, but its horizontal resolution was too coarse to represent coastal bathymetry, and it did not include tidal processes or the effects of sea-level rise and fall due to atmospheric pressure, making it difficult to represent coastal sea state changes (rapid sea-level rise, abnormal tide).
Therefore, the JMA has newly developed MOVE/MRI.COM-JPN (MOVE-JPN), which covers the seas around Japan with a horizontal resolution of 2 km, as a system capable of monitoring and forecasting such coastal phenomena, and started its actual operation in October 2020. MOVE-JPN consists of an analysis system that assimilates ocean observation data and simulates the latest ocean state, and a prediction system that initializes higher-resolution models using pre-computed analysis and forecasts the future ocean state as boundary conditions. The analysis system consists of a global three-dimensional variational system (G3-3DVAR) and a North Pacific four-dimensional variational system (NPR-4DVAR). Boundary conditions of the NPR model are given by the global analysis model through 1-way offline nesting. The prediction system is composed of GLB, NP, and JPN models and is initialized by the incremental analysis updates (IAU) scheme. The JPN model is 1-way nested to the 2-way nested set of the GLB and NP models, all of which explicitly represent tidal motion. The new system is expected to contribute to ocean state information put on the JMA web site, and to be used to support maritime traffic, fisheries, oil spills, and other activities such as searching for ships and aircraft in distress.
JMA has a plan to introduce Sentinel-3A/B and HY-2B altimeter sea level anomaly (SLA) data to MOVE–JPN, which is now using Jason-3, SARAL and Cryosat-2 along-track SLA data from CMEMS. SLA is assimilated after exclusion of two nonsteric components, namely the global ocean mass change and the sea level variations due to the barotropic response to atmospheric forcing. In the presentation, we will show the results of the impact of assimilating additional SLA data(Sentinel-3A/B, HY-2B).

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Performances of the new Copernicus Marine Service global ocean monitoring and forecasting real-time high-resolution system

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_011

Abstract:
Since October 2016, and in the framework of Copernicus Marine Service, Mercator Ocean International delivers in real-time daily services (weekly analyses and daily 10-day forecasts) with a global 1/12° high resolution (eddy-resolving) system (Lellouche et al., 2018). Oceanic observations are assimilated in the model using a reduced-order Kalman filter method. Along track altimeter Sea Level Anomaly (SLA), satellite sea surface temperature (SST) and sea ice concentration, and in situ temperature and salinity vertical profiles are jointly assimilated to estimate the initial conditions for numerical ocean forecasting. A 3D-VAR scheme is also used to better control the slowly evolving large-scale biases in temperature and salinity.
A major release of this analysis and forecasting system will be available at the end of 2022 with the following changes and updates:
- A new version of NEMO ocean and sea ice models (new numerical schemes, coherent bulk formulation with the atmospheric forcing, multi-categories sea ice model);
- Higher spatial and temporal resolution (1/10° - 1 hour) atmospheric forcing from IFS ECMWF analyses and forecasts;
- A new assimilated SST observation (assimilation of L3 ODYSSEA SST high resolution product instead of L4 OSTIA gridded product);
- A new Mean Dynamic Topography for SLA assimilation;
- A different parametrization of the model error covariance with a new anomalies base deduced from the Mercator Ocean reanalysis at 1/12° (Lellouche et al., 2021);
- A 4D extension of the data assimilation scheme allowing a better spatiotemporal continuity of mesoscale structures;
- The assimilation of “super-observations” to filter out noisy data and scales that the model does not resolve;
- The use of satellite-based monthly estimates of the Global Mean Sea Level to better constrain the ocean mass and the steric height.

This presentation will show how some identified weaknesses present in the previous system have been improved. It will also highlight the new system’s performance in terms of analysis and forecast skills, of representation of mesoscale activity, of mass/steric distribution and of representation of the equatorial dynamics. The new system is very close to SLA observations with a forecast RMS difference below 5 cm (best analysis is around 4 cm). The description of the ocean water masses is also very accurate and departure from in situ temperature and salinity observations are generally below 0.3 °C and 0.05 PSU. In addition, a global comparison with independent (not assimilated) velocity measurements shows that the location of the main currents is accurately represented.

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Assessment of NRT Wind and Wave Data from Sentinel Altimetry

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_012

Abstract:
EU Copernicus Sentinel-3A was launched more than 6 years ago. It was accompanied by its sibling Sentinel-3B two years later and by Sentinel-6A less than two years ago. It is now timely to evaluate NRT Sentinel wind and wave products and their value to ECMWF either for validation or for data assimilation.

Sentinel wind and wave data are verified against ECMWF Integrated Forecast System (IFS) model products, buoy measurements and measurements done by other radar altimeters. Self-consistency checks are also carried out. The quality of the data, its geographical distribution and temporal evolution will be presented.

Results from various wave data assimilation experiments involving data from various altimetry missions includeing Sentinel-3 and Sentinel-6 will be demonstrated.

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CRISTAL MARINE DATA CENTRE

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Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_013

Abstract:
Copernicus is a component of the European Union Space Programme. It looks at our planet and its environment for the benefit of all European citizens. It offers information services that draw from satellite Earth Observation and in-situ (non-space) data. EUMETSAT is responsible for the continued operation and exploitation of the existing Copernicus Sentinel-3 and -6 ocean-monitoring missions, the up-coming Sentinel-4 and -5 atmosphere monitoring missions and future missions designed to monitor carbon dioxide and the climate.

Within the expansion of the Copernicus Sentinel Constellation, ESA is developing the Copernicus polaR Ice and Snow Topography Altimeter (CRISTAL)), planned for launch in 2027. CRISTAL's secondary objective is to contribute to the observation of global ocean topography as a continuum up to the polar seas in terms of . This will contribute to the observation system for global observation of mean sea level, mesoscale and sub-mesoscale currents, wind speed and significant wave height. Information from this mission serves as critical input to operational oceanography and marine forecasting services as well as ice thickness retrieval in the polar oceans. In this mission, EUMETSAT is entrusted to operate the marine data centre generating operational global ocean products.

This presentation will present EUMETSAT plans towards the development and definition of CRISTAL marine data centre. We will present the work plan for the next years, the envisioned products for this data centre, as well as all science activities planned to ensure that CRISTAL products are operational for the ocean surface topography community.

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Towards 30 years of Arctic sea ice freeboard retrieval using Altimetry

Marion Bocquet (LEGOS, France); Sara Fleury (LEGOS, France); Thomas Moreau (CLS, France); Florent Garnier (LEGOS, France); Frédérique Rémy (LEGOS, France)

Session: Application development for Operations
Presentation type: Poster
Poster number: APO2022_014

Abstract:
Sea ice thickness is an important variable for sea ice monitoring and climate projections. Although observations of ice extent and concentration have been available since late 1978, the same is not true for ice thickness. Because of the high interannual variability of the ice pack, climate trends in thickness and volume can only be observed over long time series. The earliest measurements of sea ice thickness (as multi-year averages for ERS-1 and ERS-2) were published in 2003 (Laxon al 2003) (but these results have never been replicated). Today, the longest series go back to the winter of 2002/2003 (the beginning of the Envisat mission). The main difficulty in going back in time is linked to the difference in altimeter generation and processing. The launch of the first SAR altimeter aboard CryoSat-2 made it possible to obtain the first consistent measurements of freeboards measurements, thanks to its small footprint (about 5km2). Prior to CryoSat-2, space altimeters were in low-resolution mode (LRM), with a footprint of the order of 150km2 overlapping heterogeneous surface types. To improve Envisat measurements, different calibration methodologies relative to CryoSat-2 have been proposed taking advantage of the common flight period (2010-2012) (Guerreiro al 2017, Paul al 2018, Tilling al 2019, etc.).We propose in this study a more general and robust method based on a neural network taking into account the state of the ice, from its surface roughness to its type. In order to extend the coverage to the beginning of the polar altimeter era (1993), we extended this method to ERS measurements by taking advantage of the common period with Envisat. Therefore, the measurements are successively corrected with reference to the most accurate CryoSat-2measurements, offering a homogeneous series over nearly 30 years. If ERS thickness measurements have not been reproduced, it is also because of the pulse-blurring effect due to instabilities of the tracker board, which must be corrected. The methodology used in the study to overcome this, is the interpretation of the N.Peacock (2004) approach. We are finally able to provide a radar freeboard product for the Arctic between 50°N and82.5°N over almost 30 winters (up to 88°N for Cryosat-2). The freeboard product is given with corresponding uncertainties using a Monte Carlo methodology to propagate all emission uncertainties through the neural network. The time series is finally compared to numerous in situ datasets, airborne measurements, or other products from other types of altimeters such as the ICE-Sat missions. Unless it is complicated to give precise conclusions due to the lack of long and homogeneous time series of snow depth, the comparisons show good consistency between field data and altimetry data.

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Jason-3 & Sentinel-6 MF calibration at the Corsica facilities

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_001

Abstract:
Initially developed for monitoring the performance of TOPEX/Poseidon and follow-on Jason legacy satellite altimeters, the Corsica geodetic facilities that are located both at Senetosa Cape and near Ajaccio have been developed to calibrate successive satellite altimeters in an absolute sense. Since 1998, the successful calibration process used to calibrate most of the oceanographic satellite altimeter missions has been regularly updated in terms of in situ instruments, geodetic measurements and methodologies. In this study, we present an assessment of the long-term stability of the in situ instruments in terms of sea level monitoring that include a careful monitoring of the geodetic datum. Based on this 20+ years series of sea level measurements, we present a review of the derived absolute Sea Surface Height (SSH) biases for the following altimetric missions based on the most recent reprocessing of their data: TOPEX/Poseidon and Jason-1/2/3, Envisat and ERS-2, CryoSat-2, SARAL/AltiKa and Sentinel-3A&B. For the longest time series the standard error of the absolute SSH biases is now at a few millimeters level which is fundamental to maintain the high level of confidence that scientists have in the global mean sea level rise.
Launch in November 2020, Sentinel-6 Mickael Freilich flew in tandem with Jason-3 during its first year of mission. We will present in detail the analysis of this tandem phase. Preliminary results shows that the absolute SSH bias for both missions are very close at the few mm level for the LRM mode and both very close to 0. Improvement thanks to SAR will be also presented: measurements are valid (and accurate) up to the coast (few hundred meters); on the whole set of cycles, the standard deviation of 20Hz data is improved by a factor close to two: 33 mm compared to 56 mm with LRM (69 mm for Jason-3).
In preparation of SWOT, an extension of the "geoid" over the Ajaccio and Senetosa area has been realised during 2 campaigns in 2021 and 2022. Prelimininary results will be also presented.
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The Harvest Experiment: Status and New Results from the Sentinel-6 Mission

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_002

Abstract:
We describe the latest satellite radar altimeter calibration/validation (CALVAL) results from the Harvest offshore platform and vicinity. Located 10 km off the coast of central California near Point Conception, Harvest has served as the NASA prime verification site for the TOPEX/POSEIDON (T/P) and Jason series of altimeter reference missions for three decades. The T/P repeat ground track was designed to take the satellite directly over Harvest every ten days, enabling the development of a continuous verification record based on direct, overhead passes of the platform. The crucial role of T/P in developing a climate-quality record of sea level and ocean circulation has been inherited by the Jason series of reference missions, which have traced out the same 10-d repeat ground track passing by the platform. With the beginning of the routine operations phase in November 2021, the Sentinel-6 Michael Freilich (S-6 MF) mission will assume the mantle of extending this valuable scientific observation record.

With the completion of the year-long S-6 MF commissioning phase, we estimate the sea-surface height (SSH) bias is +13 ± 3 mm (one standard error with N = 29) for the low-resolution mode (LRM) altimeter data. In terms of this bias, the current non-time critical (NTC) and short-time critical (STC) products are indistinguishable, as are the A and B sides of the Poseidon-4 altimeter. The corresponding Jason-3 (J-3) SSH bias is very consistent (+11 ± 2 mm with N = 174). Data from legacy Jason mission also yield slightly positive SSH biases: +6 ± 2 mm (N = 206) and +5 ± 2 mm (N = 249) for J-1 and J-2 respectively. Accounting for systematic errors, none of these SSH bias estimates are statistically different from zero. However, the relative (inter-mission) SSH biases carry greater statistical significance. If the comparison between J-3 and S-6 MF is restricted to common cycles, the result at Harvest indicates the new mission is measuring SSH higher than its predecessor by +5 ± 3 mm (N = 29), in keeping with preliminary results from global analysis.

We also provide preliminary results for reprocessed data from the legacy T/P mission, and describe developments from GPS buoy campaigns at Harvest. Results from a 2018–19 tandem GPS buoy campaign suggest RMS accuracies of <2 cm and <1 cm were achieved for absolute and relative SSH respectively. Following this successful campaign, we deployed in October 2020 a GPS buoy to start permanent occupation of the site (with yearly servicing trips). We report early results from this year-long deployment.

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Absolute and relative calibration of HY-2B satellite altimeter using the permanent Cal/Val infrastructure in Crete

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_003

Abstract:
The HaiYang-2B (HY-2B) altimeter satellite has been launched by the Chinese National Satellite Ocean Application Service (NSOAS) on 24 October 2018, to monitor the marine dynamic environment. In this work, HY-2B observations have been assessed by the Permanent Facility for Altimetry Calibration in Crete, Greece and in the context of the Dragon research initiative of ESA. This action supports Earth observation research activities between European and Chinese institutes.
At first, a preliminary analysis of the HY-2B Geophysical Data Records revealed minor inconsistencies between the 1-Hz and 20-Hz products, as in the Net Instrument Correction and the Ku-band range. These have been reported to and immediately corrected by NSOAS, resulting in a consistent release of the HY-2B data.
Two years of altimetric observations of HY-2B have been calibrated using two sea-surface Cal/Val sites in Crete. Results will be given for two Cal/Val sites: the CRS1 site in the south west tip of Crete, where the descending Pass No. 66 is calibrated, and the RDK1 site in the central south Crete used for the calibration of its ascending pass No. 161. In addition, relative calibration of HY-2B has also been carried out around Crete with reference to Jason-3, Sentinel-3A and Sentinel-3B. Finally, an assessment of the HY-2B's microwave radiometer has been performed by comparing radiometric tropospheric delays with tropospheric delays derived by the ECMWF model and the permanent GNSS stations in Crete.

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Regional in situ CalVal of Sentinel-3A&B altimeter range at non-dedicated sites

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_004

Abstract:
In situ calibration ensures regular and long-term control of the altimeter sea surface height (SSH) time series through comparisons with independent records. Usually, in situ calibration of altimeter SSH is undertaken at specific CalVal sites through the direct comparison of the altimeter data with in situ data.

However, Noveltis has developed a regional CalVal technique, which aims at increasing the number and the repeatability of the altimeter bias assessments by determining the altimeter bias both on overflying passes and on satellite passes located far away from the calibration site. In principle this extends the single site approach to a wider regional scale, thus reinforcing the link between the local and the global CalVal analyses.

The regional method was initially developed at the Corsican calibration sites of Senetosa and Ajaccio. It was then successfully implemented at the Californian site of Harvest and at the Australian site of Bass Strait, in close collaboration with JPL and the University of Tasmania, respectively. The method was used to compute the altimeter biases of Jason-1, Jason-2, Envisat and SARAL/AltiKa at all these sites, which provided the first Envisat and SARAL/AltiKa absolute bias estimates at non-dedicated sites using the same method. These various studies demonstrated the high consistency of the regional approach with the analyses of the global CalVal teams and the work of the local in situ CalVal teams.

The method has been used in the frame of the ESA MPC-S3 project to monitor the Sentinel-3 mission at the three calibration sites (Corsica, Harvest and Bass Strait). We present the results obtained for the Sentinel-3A and Sentinel-3B satellites, the regional CalVal approach being of particular interest for the latter, as it does not pass close to any of the considered calibration sites and classical direct comparisons with the in-situ data cannot be performed. In general, the regional technique shows high potential for the monitoring of any altimetry missions.

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12 years of Cryosat-2 range,datation and interferometer calibration with Transponder

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_005

Abstract:
The CryoSat-2 mission is designed to determine fluctuations in the mass of the Earth's land and the marine ice fields. Its primary payload is a radar altimeter that operates in different modes optimised depending on the kind of surface: Low resolution mode (LRM), SAR mode (SAR) and SAR interferometric mode (SARIn). This instrument is named SIRAL: SAR Interferometric Radar Altimeter.

Transponders are commonly used to calibrate absolute range from conventional altimeter waveforms because of its characteristic point target radar reflection. The waveforms corresponding to the transponder distinguish themselves from the other waveforms resulting from natural targets, in power and shape.

ESA has deployed a transponder available for the CryoSat-2 project (a refurbished ESA transponder developed for the ERS-1 altimeter calibration). It is deployed at the KSAT Svalbard station: SvalSAT. Another transponder was deployed in Greece Technical University of Crete for the Sentinel-3 calibration, and later moved to West Crete in a permanent position. A new transponder is located in Gavdos, in another island close to Crete, and was deployed during the Commissioning phase of Sentinel-6.

We are using these transponders to calibrate SIRAL's range, datation, and interferometric baseline (or angle of arrival) to meet the mission requirements. In these calibrations, we are using three different types of data: raw Full Bit Rate data, stack beams before they are multi-looked (stack data) in the Level 1B processor, and the Level 1B data itself.

Ideally the comparison between (a) the theoretical value provided by the well-known target, and (b) the measurement by the instrument to be calibrated provides us with the error that the instrument is introducing when performing its measurement. When this error can be assumed to be constant regardless the conditions, it will provide the bias of the instrument. And if measurements can be repeated after a certain period of time, an indication of the instrument drift can also be provided.

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A Dual Band Transponder for Calibrating the Sentinel-6 Mission

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_006

Abstract:
Sentinel-6 mission has been launched in November 2020. It is the first altimetry mission with explicit requirements for the accuracy of Global Mean Sea Level drift. In support of this goal, JPL has developed a transponder that allows for an accurate monitoring of the altimeter.
This transponder is the first instrument of its kind to operate in both the Ku and C bands. It will therefore allow for a full calibration of range and power of both altimeter channels.
We present a summary of the instrument design and characteristics along with results from the flyovers during the tandem phase with Jason-3.

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Challenges for CalVal activities of Copernicus missions: an overview by CCVS project for altimetry

Sylvie Labroue (CLS, France); Céine Tison (CNES, France); Franceso Nencioli (CLS, France); Matthias Raynal (CNES, France); Jérémie Aublanc (CLS, France); Nicolas Taburet (CLS, France); Adrien Guérou (CLS, France); Marie Laure Denneulin (CLS, France); Thierry Guinle (CNES, France); François Bignalet Cazalet (CNES, France); Sébastien Clerc (ACRI-ST, France)

Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_007

Abstract:
The objective of the H2020 project "Copernicus Cal/Val Solution (CCVS)" (https://ccvs.eu/) is to define a holistic Cal/Val strategy for all ongoing and upcoming Copernicus Sentinel missions. The 2 years CCVS project aims at proposing long-term solutions to address currently existing constraints in the Cal/Val domain and exploit existing synergies between the missions and situ data.
The CCVS innovation comes from that four different domains are being addressed within the same project: the optical imagery, the SAR imagery, the atmospheric sounding and the altimetry, with different skills gathered in each field. For each domain, an exhaustive review of existing mission requirements and CalVal means in place have been carried out: on board calibration approach, inter-satellite approach, vicarious method, use of models, in-situ measurements, campaigns, and distribution portals. The second phase of the project is addressing the identification of potential gaps and will propose recommendations and solutions whenever possible to fill these gaps and finally improve the overall CalVal process.
We will present an overview of the main project achievements for the altimetry domain, addressing the different surfaces (ocean, inland waters and cryosphere) and associated variables for Sentinel-3, Sentinel-6 and upcoming CRISTAL missions. We will focus on the main outcomes of the mission requirements analysis, on the exchanges with the Copernicus services and on the gaps and recommendations identified in the CalVal methods. The ongoing work on the usage of ground-based measurements to support CalVal activities is specifically addressed in a separate dedicated abstract on CCVS project presented by C. Tison.

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Global cross-calibration of the Jason-3 and Sentinel-6 Michael Freilich missions during their tandem period.

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_008

Abstract:
The Sentinel-6 Michael Freilich mission was launched from Vandenberg Air Force Base on November 21 2020. It is designed to provide high-precision measurements of ocean surface topography and to provide the scientific community with continuity of record of global sea level rise. The main payload is the Poseidon-4 nadir radar altimeter transmitting on both C and Ku-band in interleaved mode. This mode allows the altimeter to continuously operate in both SAR and LRM mode, allowing for higher resolution retrieval of ocean topography and backward combability with the long-term historical record. Sentinel-6 was launched into exactly the same ground track as its predecessor, Jason-3, just 30 seconds apart, providing an opportunity to cross-calibrate near-coincident measurements, in both space and time, from the two missions.

Here, we present results from the cross calibration of measurements from the Sentinel-6 and Jason-3 missions, with a primary focus on the NTC and GDR-F products, respectively. In particular, we focus on measurements from the altimeter (both Ku- and C-band) and radiometer, including range, significant wave height, backscatter, and wet troposphere delay. We also consider both LRM and SAR measurements from Sentinel-6.

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Results from Independent Calibration and Validation of Jason-3 on the Interleaved Orbit

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_009

Abstract:
The Jason-3 spacecraft has been collecting sea level measurements along the historical groundtrack from February 2016 to April 2022 (cycle 227). Following the decision to have Sentinel-6 take over as new reference mission, Jason-3 has been moved to the Interleaved Orbit. As of April 25th, 2022 (cycle 300), the Jason-3 mission has resumed operations and now complements the Sentinel-6 data for an optimal time and space coverage.
We present a summary of calibration and validation results highlighting that the Jason-3 mission on the Interleaved Orbit continues to provide altimetry products of high value for oceanographic applications at the mesoscale level and for climate studies. The analysis is based on the GDR-F products and includes comparing the performance using JPL’s orbit determination based on GPSP data only.

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Global Ocean Data Quality Assessment of SARAL/AltiKa‘s GDR-F products

Jettou Ghita (CLS, France); Manon Rousseau (ALTEN, France); Nadege Queruel (CNES, France); Françoise Bignalet-Cazalet (CNES, France); Nicolas Picot (CNES, France); Pierre Prandi (CLS, France)

Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_010

Abstract:
The SARAL mission was successfully launched on February 25th 2013. Its Ka-band altimeter and dual frequency radiometer have been delivering high quality sea surface topography measurements since. On July 4th, 2016 an orbit maneuver was performed to move the spacecraft to a new orbit where the satellite altitude is no longer maintained, starting the so-called drifting phase. Following the loss of the platform’s reaction wheels on September 13th 2014 and star tracker on February 3rd 2019, the pointing accuracy is degraded from 2019 onwards.

We present the current mission performance status of the SARAL/AltiKa mission over ocean, based on the analysis of the latest GDR version data (GDR-F) and for different temporal and spatial scales: long term evolution, mesoscales, coastal areas, high latitudes...

The main objective of this study is to assess quality of the SARAL/AltiKa's product over the whole series. Several Cal/Val metrics are presented to document data availability and overall mission performance. Comparisons with the previous GDR-T data version are used to highlight the benefits of the new GDR-F standard. Cross-comparisons with other altimetry missions (e.g. Jason-2, Jason-3) show the still excellent performance of SARAL/AltiKa.

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Detecting rain cells in SARAL/AltiKa data: results from a supervised learning experiment

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_011

Abstract:
Operating in Ka band, SARAL/AltiKa is more sensitive to liquid water in the atmosphere which can drastically attenuate the signal even for moderate events (eg light rain) and impact the retrieval of geophysical parameters. This turned out not to pose any problem regarding data availability thanks to the instrument's link budget margins. The operational products come with a rain flag based on the pre-launch work of Tournardre et al. (2009), which was finely tuned during the cal/val phase of the mission (Tournadre et al., 2015).

This rain flagging algorithm is based on the detection of along-track short scale coherent variations of the off nadir angle derived from the trailing edge slope of the waveforms. This algorithm is efficient at detecting rain events, sigma blooms but is also sensitive to other perturbations of the waveform (true mispointing events for example).

In this analysis we try to train machine learning/artifical intelligence classifiers to detect rain events in SARAL/AltiKa data. We tested a range of supersived learning methods on a database of colocations between SARAL/AltiKa and rain rates derived from SSMI-S F16, F17 and WindSat.
This was done first on 1Hz data with a range of algorithms (K-Nearest Neighbors, Random Forests) and input features (altimeter parameters, radiometer parameters).
On 40Hz data, more complex architectures (Convolutionnal Neural Nets) were tested on waveforms alone and on waveforms plus other parameters (eg brightness temperatures).

Results show that both at 1 and 40 Hz we are able to train efficient detectors of rain events, even when waveforms are the only input available. Removing measurements that are detected as 'rainy' provides similar mission performance improvements compared to the current rain flag (measured at cross overs or through SLA PSD estimation) while removing less measurements.

While this work remains preliminary, this class of methods could be useful the editing of current and future altimetry missions.
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Evaluation and scientific exploitation of CryoSat ocean products for oceanographic studies

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_012

Abstract:
CryoSat's ability to operate in different operating modes over water surfaces led to the first in-orbit evidence of the value of SAR-mode altimetry for oceanography, with the mission continuing to provide high-quality data and information not just over ice but also over the open ocean, polar waters and coastal regions. After ten years in orbit, CryoSat routinely delivers a number of oceanographic products for global ocean applications. A dedicated operational CryoSat ocean processor (COP) has existed since April 2014 generating data products available in near real time (FDM/NOP), within ~3 days (IOP) and a geophysical ocean product (GOP) available within a month. An improved processing baseline was introduced in late 2017 and the same processing chain has now been applied to provide consistent ocean data products from the start of the mission.
Within the ESA funded CryOcean-QCV project, the National Oceanography Centre (NOC) in the UK is responsible for routine quality control and validation of CryoSat Ocean Products. Activities include the production of daily and monthly reports containing global assessments and quality control of sea surface height anomaly (SSHA), significant wave height (SWH), backscatter coefficient (Sigma0) and wind speed, as well as a suite of validation protocols involving in situ data, model output and data from other satellite altimetry missions. This presentation will review some of the metrics and results obtained for CryoSat Ocean Products for SSHA, SWH and wind speed when assessed against data from tide gauges, wind and wave buoys, WaveWatch III wave model output, HF radar surface current data and comparisons with Jason-2 and Jason-3. Example metrics include SSHA along-track power spectra and the characterisation of offsets and variability regionally and in different sea states.
In this presentation, we demonstrate the quality and scientific value of the CryoSat data in the open ocean where the altimeter operates mainly in conventional low-resolution-mode (LRM) but also over selected ocean regions where CryoSat operates in SAR-mode.
Finally, scientific exploitation of the CryoSat data for oceanographic studies will be illustrated, focusing on CryoSat sea surface height anomalies. We will present examples of the benefits of CryoSat ocean products for oceanographic studies based on a dedicated Level 3 gridded product, featuring investigations of propagating ocean features (e.g. Rossby-type wave propagation, signals from El Niño and Southern Oscillation) and global/regional sea level trends.

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Update on CryoSat-2 long-term ocean data analysis and validation

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_013

Abstract:
ESA's Earth Explorer CryoSat-2 precisely measures the changes in the thickness of marine ice floating on the polar oceans and variations in the thickness of the vast ice sheets that overlie Greenland and Antarctica. The data delivered by the CryoSat-2 mission completes the picture to determine and understand the ice role in the Earth system in general and climate change in particular. For this, the quality of the satellite orbit, the measurements of the altimeter, and all required corrections have to meet the highest performance; not only over the ice caps and sea-ice surface but also over the oceans. As Cryosat-2 ocean products continuously evolve they need to be quality controlled and thoroughly validated via science-oriented diagnostics based on multi-platform in situ data, models and other (altimeter) satellite missions. The rationale for this is based on the new CryoSat-2 scientific roadmap, which specifically addresses the key technical and scientific challenges related to the long-term monitoring of sea-level and ocean circulation changes in the context of Global Warming. This also involves opportunities for synergy with missions like ICESAT-2 and the upcoming Copernicus CRISTAL mission.

In this context, the objective of our research is the long-term monitoring of the level-2 CryoSat-2 Geophysical Ocean Product (GOP), by evaluating the stability of the measurement system and identifying potential biases, trends and drifts over the ocean, through calibration and comparisons with concurrent ocean altimeter data, supported by the Radar Altimeter Database System (RADS). Independently, we also address this by comparing the GOP geophysical parameters with external models and in situ measurements such as the ones from selected sets of tide gauges. The very precise determination of the orbital height is part of the research activity but dealt with in a separate paper.

For our activity we persistently monitor, analyze and identify systematic errors in the observations, estimated (trends in) biases in range, significant wave height, backscatter, wind speed and sea state bias, and timing biases. An important finding is that GOP CryoSat-2 Baseline C data seem to have a range bias of -2.82 cm and no apparent drift w.r.t. altimeter (Jason) reference missions (< 0.1 mm/yr). The comparison with tide gauges is based on monthly averaged sea level from the PSMSL archive, for which we conclude that GOP data has a correlation of better than 0.84 with a selected set of 185 PSMSL tide gauges, a mean standard deviation better than 5.8 cm, and an average drift of -0.19 mm/yr, which translates to an overall drift of +0.11 mm/yr when taking a global GIA correction of +0.3 mm/yr into account. We conclude that Cryosat-2 GOP represents a (long-term) stable measurement.

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Haiyang-2C data assessment, performance and contribution to DUACS Sea Level Anomaly products

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_014

Abstract:
The Haiyang-2C (H2C) mission has been launched in September 2020 by the Chinese Agency NSOAS (National Satellite Ocean Application Service). H2C is the third unit of the Haiyang-2 altimetry Program which also features HY2B (launched in October 2018) and HY2D (launched in May 2021) as well as the upcoming units E to H in the future. These satellites are dedicated to monitor the dynamic ocean environment and they bring a significant contribution to the sampling capability of the CEOS Ocean Surface Topography Virtual Constellation.

In order to assimilate H2C data into Sea Level Anomaly (SLA) Level-2P/3/4 [1][2][3][4] funded by CNES (Centre National d'Etudes Spatiales) and Wind and Waves (W&W) products L2P/L3/L4 [4] supported by CNES, and CMEMS (Copernicus Marine Environment Monitoring Service) funding, we performed a global HY2C data assessment. We obtained excellent data quality results that are shown here. We will also discuss about performance and contribution of H2C to DUACS (Data Unification and Altimeter Combination System) products into future assimilation.

[1] Lievin et al. OSTST conference 2020

[2] Kocha et al., 2021 : "Reprocessing of a sea level L2P-multi-mission dataset covering 28 years", Aviso news letter 18

[3] Kocha et al. EUMETSAT conference 2021

[4] Philip et al. OSTST conference 2020

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Assessment of the Sentinel-6 Michael Frielich extension to the TOPEX/Jason Sea Surface Height Climate Data Record referenced to ITRF2020

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_015

Abstract:
The recent launch of Sentinel-6 Michael Freilich offers the possibility of continuing global mean sea level (GMSL) monitoring well into the current decade. In this presentation we report Sentinel-6/Jason-3 inter-mission bias estimates based on direct sea surface height (SSH) collinear differences of near coincident measurements during the verification phase, and with comparisons to a global network of tide gauges. In an effort to provide a more consistent SSH time series and seamless transition to Sentinel-6, we have generated orbits for the entire time span based on the revised ITRF2020 terrestrial reference frame. We report the efficacy of correction algorithm revisions leading to the development of the NASA MEaSURE’s V6.0 sea surface height Climate Data Record (MEaSUREs - Integrated Multi-Mission Ocean Altimeter Data for Climate Research (MEaSUREs-SSH) | PO.DAAC / JPL / NASA).
We provide an assessment of recent improvements to the accuracy of the 30+ year sea surface height time series, describe continuing calibration/validation activities, and evaluate the subsequent impact on current global mean sea level estimates, and the accounting of the ocean mass budget.

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Impact of the TopEx/Poseidon GDR-F reprocessing on the Global Mean Sea Level climate data record

Adrien Guerou (CLS, France); Anne Barnoud (Magellium, France); Michaël Ablain (Magellium, France); Hélène Roinard (CLS, France); François Bignalet-Cazalet (CNES, France); Gérald Dibarboure (CNES, France); Nicolas Picot (CNES, France)

Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_016

Abstract:
The Global Mean Sea Level (GMSL) climate data record is monitored since 1992 thanks to the reference altimetry missions TopEx/Poseïdon, Jason-1/-2 /-3 and now Sentinel-6A MF. The first and historical mission TopEx/Poseïdon has been shown to be affected by an instrumental degradation of its side-A altimeter (Beckley et aL, 2018) from the middle of 1995 until the change to the side-B in February 1999. The instrumental degradation strongly affects the GMSL long-term stability (Watson et al., 2015; Dieng et al., 2017; Ablain et al., 2018) by about 1 mm/yr over all the TopEx-A period. Based on comparisons with tide gauges or on a sea level budget closure (SLBC) approach, empirical corrections of the TopEx-A GMSL drift were proposed (summarized in WCRP 2018). Applying an empirical correction significantly impacts the GMSL rise estimate over the first altimetry decade and allows the detection of a significant GMSL acceleration over the full data records (0.12±0.06 mm/yr^2). However, improving TopEx-A Geophysical Data Record (GDR) products would be preferable to the application of an empirical correction that is based on external data and subject to significant uncertainty.

A major update of the TopEx/Poseïdon GDR (i.e., GDR-F) has recently been generated by the JPL/CNES teams. It includes major improvements such as the use of numerical retracking of the altimeter instruments, consideration of the radiometer calibrations over the full lifetime of the mission, as well as improved geophysical corrections standards.

In this context, we will present the reference GMSL climate data record using the reprocessed TopEx/Poseidon GDR-F data products. A focus will be made on the estimation of the side-A/side-B GMSL offset determination, as well as its related uncertainties, a key contributor to the GMSL trend uncertainty at the beginning of the climate data record. Thanks to a combined comparison to tide-gauges and estimation of the SLBC, we will concentrate our presentation on the external validation of the major improvements on the TopEx side-A stability. Based on the estimation of each methods' uncertainties, we will quantify the confidence level at which the TopEx side-A drift is reduced in the GDR-F data. Such analyses will also allow us to revisit the altimetry error budget at the time of the TopEx mission and improve the overall GMSL uncertainties.

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Assessment over ocean of the last Poseidon1 reprocessing

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_017

Abstract:
On August 10 1992, the TopEx/Poseidon satellite was successfully launched into orbit by an Ariane 42P rocket from the French Guiana launch site. For the next 13½ years, the two radar altimeters on board the platform, the NASA Altimeter (ALT) and SSALT (or Poseidon-1), successfully collected valuable oceanographic data. Since both altimeters operated at the same frequency and used the same antenna, a sharing plan of the antenna was established which allowed operation of the ALT 90% of the time with the remaining 10% devoted to Poseidon-1 operation.

The Poseidon-1 reprocessing activity that was performed during the last years by CNES/CLS teams. It included the reprocessing of all internal calibration sequences, the retracking of the waveforms and the update of the instrumental corrections. Poseidon-1 proved to have an excellent instrumental stability making it valuable to contribute to the TOPEX-A drift on going analysis. In addition to being useful for the Global Mean Sea Level determination, this reprocessing also offered the possibility to enrich the long-term altimetry records with homogenized data set.
The objective of this presentation consists in giving an overview of Poseidon-1 data quality and assessing the performance of products at mono-mission crossovers and along-track. Comparisons to TOPEX GDR-F preliminary dataset are also presented.

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Improved inter-calibration of multi-mission altimeter significant wave heights for climate data record

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_018

Abstract:
With 30 years of uninterrupted observations and more than 15 successful missions, satellite altimetry is a mature technology for investigating sea state variability at decadal timescales with global coverage. However, deriving robust long-term statistics from multi-mission products requires careful processing of each mission product in order to ensure inter-mission consistency and long-term stability. Over the last three years, the ESA Sea State Climate Change Initiative has been performing a full reprocessing of the SGDR products from Jason-1, ENVISAT, Jason-2, Cryosat-2, SARAL, and Sentinel-3A. This reprocessing benefits from recently developed waveform retrackers, consistent data editing and inter-calibration methods and an adaptive denoising approach designed for the analysis of non-stationary and non-linear signals. In this study, we present the method to calibrate the Jason-2 reference data against in situ observations and inter-calibrate the other missions using comparisons with this reference at crossover ground points. The validation of the results uses in situ observations, model results from ERA-5 reanalysis and WW3-IFREMER hindcast, and cross-comparisons of independent missions . A particular focus is given on the coastal zone and on low and extreme sea state data in order to discuss the performance of this new altimeter product with respect to standard products provided by the space agencies.

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Jason-3: ALES vs ADAPTIVE vs MLE4, comparing the retracking solutions

Benjamin Flamant (CLS, France); Matthias Raynal (CNES, France)

Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_019

Abstract:
The official retracking solution for Jason-3 products is the MLE4 retracking. However, recent improvement using ALES (TUM/ESA) and ADAPTIVE (CNES/CLS) retracking solutions may change this reference. While the ALES retracker was specifically developed for coastal use, the ADAPTIVE retracker aims at incorporating the true instrumental PTR rather than a model.
In this context, this study was conducted, mostly over Jason-3 1Hz data, to compare these retracking solutions in plain ocean as well as coastal areas.

For this study, we built a dataset over 117 cycles from the official Jason-3 GDR product on which we interpolated the official ALES+ product distributed in the TUM ALES website. The comparison was mainly performed on the SLA products, investigating firstly the availability of the data and secondly its quality.

Concerning the availability of the data, there is an equivalent number of measures for both ALES and ADAPTIVE retrackers. In coastal areas (3-10 kms to the coastline), there is a data availability increase of 25% for the ADAPTIVE retracker and 16% for ALES with respect to MLE4. The main difference remains in the necessity to perform the calval editing steps over the ALES data to exclude all erroneous measures, while the ADAPTIVE retracker is way more restrictive in its retracking method.

When focusing on data quality, although the noise from a spectral analysis on the SLA product shows a slight improvement for ALES data, the 20Hz noise (deduced from the range std) shows a larger noise for ALES data than both ADAPTIVE and MLE4. While the spectrum result is confirmed in plain ocean (reduction of 1mm STD on the high frequency part of the SLA), the opposite is observed in coastal areas (<15km).

This analysis, completed by other calval diagnostics, will identify the respective strengths and limitations of the three retracking solutions for altimetric studies for both coastal and open ocean use.
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Advantages and drawbacks of the filtered solution for dual-frequency ionospheric correction from altimeter

Francesco Nencioli (CLS, France); Helene Roinard (CLS, France); Francois Bignalet-Cazalet (CNES, France); Gerald Dibarboure (CNES, France); Nicolas Picot (CNES, France)

Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_020

Abstract:
The ionosphere is the part of Earth's upper atmosphere ionized by solar radiation. The resulting electron activity plays an important role in delaying the propagation of the altimeter pulses, accounting for errors of more than 10 cm in the evaluation of the distance between the satellite and the ocean surface. Such induced delay must therefore be corrected to obtain reliable altimetry observations.

To measure this ionosphere-induced delay, satellite altimeters use observations from two signals emitted at the same time at two different frequencies (e.g. these correspond to the wavebands–Ku and –C in the case of the Jason and Sentinel-3 missions). Because of the frequency difference, the two signals are differently delayed as they cross the ionosphere. The ionospheric correction can thus be estimated as a function of the difference in delay between the two signals (hence the term "dual-frequency ionospheric correction") after the Sea State Bias (SSB) corrections are applied. Since it includes measurements errors from two different frequency bands, as well as errors associated with the choice of the SSB correction algorithm applied, the ionospheric correction is inherently noisy. Furthermore, since it is directly proportional to the ionospheric total electron content (TEC) which is primarily controlled by solar radiation, the correction is characterized by large spatial and temporal variability. Such low frequency variability is primarily controlled by three main factors:
- Solar activity
- Local time
- Latitudinal location

While applying the raw ionospheric correction improves SLA observations when the correction values are large, it becomes ineffective (if not even detrimental) when the values are small due to the small signal to noise ratio. Since the instrumental noise primarily controls the high-frequency variability, it is required to low-pass filter the ionospheric correction to improve the overall quality of the final SLA products.

Here, we describe the iterative filtering approach used for the production of Sentinel-3 and Jason-3 GDR-F altimetry products. The filter was designed to achieve two goals:
- Base the correction on as many dual-band ionospheric observations as possible
- Improve the correction where altimetric observations are discontinuous or isolated

To achieve the first goal, the selection of the ionospheric observations used for the correction is independent from the quality of sea level observations. However, while this maximizes the number of observations selected, at the same time increases the number of potential outliers. The iterative filtering applies a median and a Lanczos filter in sequence, in order to progressively reduce the number of outliers in the ionospheric observations used to compute the final filtered correction. To achieve the second goal, since the filtered correction has long spatial correlation scales, a spline interpolation is applied to fill gaps in the interpolated correction up to few hundreds km.

The advantages of such approach were assessed by comparing the resulting sea level anomaly fields with those obtained using the unfiltered ionospheric correction. Our results show that the SLA variance reduction from the iterative filtered ionospheric correction is always larger than that from the raw correction, regardless of the values of the correction. Thus, the iterative filtered correction outperforms the raw correction over all ocean regions and for any level of solar activity:

• Within the tropics and/or during years of strong solar activity (i.e. high correction value conditions),when the raw correction already reduces the variance of SLA observations, the iterative correction further improves them.

• At low latitudes and/or during years of weak solar activity (i.e. low correction value conditions), when the raw correction introduces additional variance to SLA observations, the iterative filtered correction can still improve (or at least not degrade) them.

Due to the use of the Lanczos filtering and Spline interpolation, the iterative filtered correction increases the number of valid correction values in the open ocean regions impacted by intense rain events. On the other hand,

the number of edited values is substantially increased along the continental coast-lines and the Antarctic ice margins.

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Cal/Val of recent altimeter missions at non-dedicated tide gauge stations in the North Sea

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_021

Abstract:
Consistent calibration and monitoring is a basic prerequisite for providing reliable time series of global and regional sea level variations from altimetry. The precision of sea level measurements and regional biases for eight altimeter missions (Jason-1/2/3, Sentinel-6MF, Envisat, Saral, Sentinel-3A/B) is assessed at eleven GNSS-controlled tide gauge stations in the German Bight (SE North Sea) for the period 2002 to 2021. The gauges are operated operationally by the German Waterway and Shipping Administration (WSV) and The German Federal Institute of Hydrology (BfG) and are partly located in open water, partly at the coast close to mudflats. The altimetry is extracted at virtual stations with distances from 2 to 24 km from the gauges. The processing is optimized for the region and adjusted for the comparison with instantaneous tide gauges readings. An empirical correction is applied to account for mean height gradients and slight differences of the tidal dynamics between gauge and altimetry. It improves the agreement between the two data sets considerably by 15-75%. The precision of the altimeters is depending on location and mission and is shown to be at least 1.8 to 3.7 cm based on an assumed precision of 2 cm for the gauges. The accuracy of the regional mission biases is strongly dependent on the knowledge of the sea surface height difference between the measurement locations. The most consistent biases are obtained based on the CLS2011 model with mission dependent accuracies from 1.3 to 3.4 cm. Hence, operational GNSS-controlled tide gauges, e.g. by WSV and BfG might complement the calibration and monitoring activities at dedicated Cal/Val stations.

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Regional Calval for past and future altimeters

Luciana Fenoglio (University of Bonn, Germany)

Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_022

Abstract:
Since 10 years the available network of in-situ stations in the German Bight and in Eastern Baltic has been used for the validation of altimeter mission data in the coastal zone. Calibration was attempted as well. Similarly, in-situ stations in inland water have been used for the validation of SAR altimeters in the Rhine river.
CALVAL activities have been conducted based on dedicated in-situ observations, statistics, cross comparisons between models, different algorithms and external satellite data.
Today network developments and new requirements for calibration and validation of future missions suggest a further and also new use of these facilities.
Plans are presented together with results obtained using actual satellite missions.

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Sentinel-3 Topography mission Assessment through Reference Techniques (ESA St3TART project) – Focus on SCalSIT

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_023

Abstract:
The Copernicus Sentinel-3 Surface Topography Mission (STM), based on a constellation of two satellites, provides extremely valuable surface elevation information over inland waters, sea ice and land ice, thanks to its SAR altimeter which retrieves high-resolution along-track elevation measurements, and to its orbit that covers high-latitude polar regions. To ensure that these measurements can be used with confidence, and to maximize the return on investment of the Copernicus Sentinel-3 STM, adequate validation of the geophysical retrieval methods, processing algorithms and corrections must be performed, considering independent observations as Reference Measurements.
St3TART is an EU and ESA funded project led by NOVELTIS with a consortium of 17 European partners (CNES, DTU, NPI, vorteX.io, LEGOS, Hydro Matters, CLS, LOCEAN, IGE, SERTIT, GIS, CNR-IRPI, NPL, DT/INSU, IRD, M2C, SYRTE). It aims to generalize the concept of Fiducial Reference Measurements (FRM) for the Copernicus Sentinel-3 STM and to collect and distribute FRM data for the validation of the satellite mission over inland waters, sea ice and land ice. The provision of FRM will serve the validation activities of the ESA S3 Land Altimetry products, currently performed by the Sentinel-3 Mission Performance Centre, with the support of the Sentinel-3 Validation Team, for the sake of performance assessment and fitness-for-purpose of the Sentinel-3 STM Land core products. Those products cover inland waters, land-ice and sea-ice areas.
The objective of the St3TART project is not only to collect existing data or measure new observations during field campaigns, but to ensure that these observations meet the criteria of FRM standards and can be used in an operational way for the validation of the Sentinel-3 Land topography mission. Within the project, field campaigns are means to provide operational observations for the validation of the Sentinel-3 data.
One of the tasks of the project is the development of a Super Cal/Val Site Identifier Tool (SCalSIT). This tool will support the Cal/Val community and scientists in identifying potential in-situ Cal/Val sites over Inland Water Surfaces, by an appropriate cross-processing of the satellite orbits versus water mask ground data. The tool is configurable, to take into account a specific geographic area, a list of satellite orbits (theorical or user orbit products), a land water mask, the percentage of surface water occurrence, a buffer around the satellite tracks, and the minimum number of passes over a crossover. The output vector files can be in KML, CSV or GeoJSON formats.
It has been developed for the needs of the Sentinel-3 Surface Topography Mission constellation, but its generic implementation makes it compatible with other missions such as CryoSat-2, Sentinel-6 or SWOT.
The SCalSIT software is an open-source software, developed as a QGIS plugin, which makes it very easy to use and platform-independent, and it can also be used via a Command Line Interface.
The poster will present the main characteristics of the tool and an example of outputs.

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Sentinel-3 Land STM: Land Ice Thematic Products

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Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2022_024

Abstract:
Sentinel-3 is an Earth observation satellite series developed by the European Space Agency as part of the Copernicus Programme. It currently consists of 2 satellites: Sentinel-3A and Sentinel-3B, launched respectively on 16 February 2016 and 25 April 2018. Among the on-board instruments, the satellites carry a radar altimeter to provide operational topography measurements of the Earth's surface. Over land ice, the main objective of the Sentinel-3 constellation is to provide accurate measurements of the polar ice sheets topography, to support ice sheet mass balance studies. Compared to previous missions embarking on conventional pulse limited altimeters, Sentinel-3 is measuring the surface topography with an enhanced spatial resolution, thanks to the on-board SAR Radar ALtimeter (SRAL), exploiting the delay-Doppler capabilities.
To further improve the performances of the Sentinel-3 Altimetry LAND products, ESA and the Sentinel-3 LAND Mission Performance Cluster (MPC) recently developed specialized delay-Doppler and Level-2 processing chains over (1) Inland Waters, (2) Sea-Ice, and (3) Land Ice areas. The objective is to provide new dedicated "thematic products" to the users for the three surfaces mentioned. Over land ice delay-Doppler processing with an extended window has been implemented to enhance the coverage of the ice sheet margins. The operational production of these thematic products will start by Fall 2022.
To ensure the mission's requirements are met, the Sentinel-3 MPC is also in charge of the qualification and the monitoring of the instrument, and core product performances. In this poster, the Land Ice ESLs (Expert Support Laboratories) of the MPC presents a first performance assessment of the Land Ice thematic products. The analyses include comparisons to Operation IceBridge airborne data and other sensors such as ICESat-2 and CryoSat-2. The quality step-up provided by the Land Ice thematic products, and highlighted in this poster, is a first and major milestone. From now on, the Sentinel-3 Land Thematic Products will independently evolve to better meet and fulfil the requirements of the Land Ice community. A Full Mission Reprocessing (FMR) is planned early for 2023, to produce fully homogeneous S3A and S3B Land Ice thematic datasets.
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On the use of satellite altimeter-derived wind speed for the evaluation of the Weather Research and Forecasting model

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_001

Abstract:
Surface wind is an essential variable for the study of ocean dynamics. It is one of the main agents responsible for driving ocean surface currents since it is directly related to the generation of mechanisms such as Ekman's currents. The role of the surface winds is especially relevant in complex coastal areas such as the Gulf of Cadiz (southwestern of the Iberian Peninsula), where the wind field is highly variable in the spatio-temporal domain. Therefore, improving weather models to accurately simulate the wind speed in complex areas is needed for the study of both the ocean and the associated climate variability. Unlike in-situ data from weather stations and buoys, which allow the evaluation of the temporal evolution of the model's simulations, wind speed from satellite altimetry enable the analysis of the spatial variability of the wind speed along the satellite track over the ocean. This work presents the capabilities of wind speed (WS) retrievals from the altimeters on-board satellites Sentinel-3A/B (S3A/B) for the spatial validation of WS outputs from the Weather Research and Forecasting (WRF) model over the complex coastal area of the Gulf of Cádiz (GoC). In order to assess the applicability of the altimetry data for this purpose, comparisons between three different WS data sources over the GoC area were evaluated: in-situ measurements, S3A/B altimetry data at 20 Hz of posting rate and the WRF model output. Outputs from the WRF model over the area were evaluated with in-situ data, with satisfactory results (WS bias < 0.75 m/s) over the different locations. The spatial variability of the WS derived from the WRF model was compared with the along-track altimetryderived WS. The analysis was carried out under different wind synoptic conditions. Qualitative and quantitative results (average RMSE < 1.0 m/s) proved the agreement between both data sets under low/high wind regimes, proving that the spatial coverage of satellite altimetry enables the spatial validation of high-resolution numerical weather prediction models in water-covered surfaces, including coastal areas. This work aims to fostering the use of altimetry data for improving the knowledge of the wind speed and sea surface circulation over complex areas where the availability of in-situ measurements is limited or inexistent. We have shown how the spatial coverage of satellite altimetry enables the spatial validation of high-resolution NWP models in any water-covered surface of the world, including coastal areas, a feature that sets altimetry apart from any other data source.

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Seasonal and non-seasonal sea surface height variations within the Makassar Strait

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_002

Abstract:
Variations of sea level difference over the Makassar Strait drive changes of currents in the strait, a major part of the Indonesian throughflow, but sea surface height (SSH) variations within the strait have not been fully studied. By applying a coastal retracker to Jason-2 waveform data, we determine local SSH variations at 1 deg-S within the strait from June 2008 to September 2016. For long-term variations, the local SSH varies with the same phase with a Pacific side of the large-scale sea level difference, but seasonal local SSH variations are rather independent. Comparing with the local SSH in the strait, SSH variations in the Celebes Sea to the north of the strait are smaller and nearly sinusoidal, which suggests presence of local dynamics within the strait that dominate local asymmetric seasonal SSH changes, such as convergence of weakened wind-driven flows over a shallow area near the southern boundary of the strait. Both long-term and seasonal SSH variations are not in phase with sea surface temperature (SST) variations, implying steric height changes are negligible. However, for residual component, phases of SSH and SST variations agree in some periods, suggesting presence of baroclinic response, such as internal Kelvin waves.

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Deep Learning and SAR Altimetry Techniques in Coastal Island Areas

Nick Flokos (National Technical Univesity of Athens, Greece)

Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_003

Abstract:
Synthetic Aperture Radar (SAR) Altimetry has made a remarkable progress over the past years. Advances in data processing, combined with technological progress such as the advent of new Altimetry satellites (Sentinel 3A,3B,6, SWOT etc.) increased the accuracy of the retrieved geophysical parameters (i.e., Sea Level Anomaly, Significant Wave Height and Wind Speed) in coastal zones within several hundred meters from the coastline.
The improvement in the estimation of the geophysical parameters using SAR Altimetry has been reported by many researchers. The improved accuracy is obtained through the development of new SAR Altimetry retracking algorithms in several research and development projects (i.e., SAR Altimetry Mode Studies and Applications-SAMOSA). Similar to Low Resolution Mode (LRM) Altimetry, the requirement of specialised retrackers for SAR waveforms is vital in improving the estimated ocean parameters. The waveform retracking is a postprocessing protocol to convert waveforms into scientific parameters of power amplitude (related to wind speed), range (related to sea level), and slope of leading edge (related to SWH) that characterise the observed scene (Idris et al., 2021).
However, several issues remain open. Close to the coastline, SAR altimeter simultaneously views scattering surfaces of both water and land producing complicated waveform patterns therefore a huge range of waveform shapes is observed. This complexity poses a real challenge to today’s approach to retrack waveform.
This work aims to present results from an in-house developed Deep Learning algorithm, in order to retrack waveforms by learning complicated patterns in coastal areas. Initially various steps of data preparations have to be conducted to receive the waveforms leading edge position:

1. Normalisation of the waveforms
2. Labelling of the waveforms
3. The training, developing and testing data sets

The use of a Convolutional Neural Networks will be introduced. With CNNs the use of waveforms images will be feasible, therefore the algorithm will be able to process more waveforms of a satellite track and provide more information instead of taking into account one waveform or a single part of it.
Because we are working with time series, it is beneficial to know the previous assumed leading edge position for the current case. By using Recurrent Neural Networks (RNN), it is possible to give the information of the assumed actual leading edge position to the next following waveform analysis. However, of course, it is also feasible to combine the CNN and RNN (Mattes, 2019).

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Assessment of global and regional tidal models in coastal regions – a contribution to improve coastal altimetry retrievals

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_004

Abstract:
Because of the repeat period of the satellite altimetry missions (from 10 days for the Topex/Jason suite to more than one year for CryoSat-2), the high-frequency ocean tidal signals are aliased in the altimeter sea surface height measurements at periods that correspond to other ocean dynamics processes. To access the ocean circulation dynamics with the centimetric accuracy expected by the users, it is thus necessary to accurately remove the ocean tide signals from the altimeter measurements.
With amplitudes ranging from several centimetres to several metres, the ocean tide correction is one of the largest corrections to the altimetry sea surface heights on the shelves and in coastal regions. To remove this signal, global tidal models are used, such as FES2004, GOT4.10 and FES2014. However, these models still show large errors on the continental shelves. In some regions, the errors can reach tens of centimetres, as the amplitude of the tidal signals is large and more complex to model due to non-linear interactions between the tidal waves and the shallow bathymetry. With new and future satellite altimetry techniques (SAR, wide-swath) that enable to reach ever more coastal areas, and to resolve the ocean dynamics at ever finer scales, the need for accurate coastal tidal model solutions is salient.
Today, specific efforts are made to improve the tidal models in the coastal regions, thanks to high-resolution modelling and to the use of coastal observations (from altimetry and tide gauges) to constrain the models. Various models are thus available, at global and regional scales. These models are not always provided in the altimetry products, but they could be of high interest to locally improve the coastal altimetry sea surface height retrievals.
In the frame of the HYDROCOASTAL project funded by the European Space Agency, NOVELTIS performed an inventory of the available and most recent global and regional tidal models that could potentially be used as corrections for coastal altimetry data. The performance of these models was compared with a specific focus on coastal and continental-shelf regions where the tidal corrections are particularly critical for coastal altimetry observations. Finally, some recommendations were made about the models that perform best depending on the regions.

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New advances in altimetry towards the coast : example of the CTOH sea level products

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_005

Abstract:
Through different projects, the Center for Topographic studies for the Ocean and Hydrosphere (CTOH) contributes largely to advances in coastal altimetry and to its use in coastal applications. It has developed the X-TRACK software dedicated to the reprocessing of coastal altimetry data. X-TRACK is now a mature sea level product distributed worldwide by AVISO+ (https://www.aviso.altimetry.fr), cited in many scientific publications. It consists in long time-series of SLA from most altimetry missions, processed homogeneously, but also as long-track empirical tidal constants. The latter provides independent synoptic data on the coastal ocean for tidal studies, validation of tidal models or assimilation into tidal models.

In order to continue provide the most complete sea level datasets to coastal users, the CNES L2P Product (https://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/along-track-sea-level-anomalies-l2p.html) will now be integrated into the X-TRACK processing chain: 12 altimetry missions, covering the 1992-2021 time period.

The CTOH contributes also, trought the high performance of X-TRACK software, to the development of new coastal sea level products specifically designed for climate studies, in close collaboration with ESA, TUM, CLS, NOC and SKYMAT. As part of the ESA Climate Change Initiative project, the Adaptive Leading Edge Subwaveform (ALES) Retracker (Passaro et al., 2014) and the X-TRACK software (Birol et al., 2017), previously validated and successfully applied to coastal sea level research, have been combined for the first time, in order to reprocess 18 years of sea level anomaly data (Jan. 2002 to Jan 2020) at a high frequency level (20 Hz) based on Jason missions. This new coastal sea level product called X-TRACK/ALES (https://climate.esa.int/en/projects/sea-level/data/) significantly extends the spatial coverage of sea level altimetry data in the coastal direction, now reaching a distance of 1.2-4 km from the coast on average (Birol et al., 2021). This is an unprecedented coastal coverage for any long-term altimetry data set, and then a significant contribution to the coastal research community. In addition, a new network of virtual altimetry-based stations in coastal areas of the world has also been derived from this dataset, providing new information on sea level change in the world coastal zones (see Cazenave et al., OSTST 2022).

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Coastal Processing from the Copernicus Altimeters: the CORS processor outcomes

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_006

Abstract:
The Copernicus constellation has today 3 altimeters in flight, the two Sentinel-3, A & B, and the most recent altimetric mission Sentinel-6, as a continuation of a long historical series. All of them are operating the new standard Synthetic Aperture Radar mode, enabling for the first time an enhanced resolution sea surface monitoring over the global Ocean (CryoSat-2 was operating in SAR / SARin only over dedicated areas).
Coastal zones are crucial for the human development, and the characterisation of the ocean processes near to the coast is a must. The sea level rise is one of the most pressing climate change impacts, and although it is driven by global ocean forcing, refining this variable, along with sub-mesoscale ocean dynamics in the last 10 km to the coast, is still a challenge in the altimetry field.
Dedicated processing evolutions are needed for these areas when using altimetry data to derive the geophysical retrievals Sea Surface Height (SSH) and Significant Wave Height (SWH). The contribution of undesired targets is to be addressed and the retracking process is to be adapted. This has been the goal of this study, developed over the recent years, refining the processing steps of an algorithm that has been designed, implemented, and validated over a variety of complex coastal topography areas and different sea states.
The validation outcomes give a consistent SSH noise reduction of around 50% over different validation areas, such as the Mediterranean Sea. In the other hand, Power Spectral Density (PSD) studies show a better (denoised) SWH PSD over the full range of wavelengths from the largest (real geophysical signal) to the smallest scales (measurements noise). The SSH median bias between the ocean and coastal isardSAT retracking outputs is about 5 mm, while the SWH median bias is about 10 cm.
SAR mode data from the 3 Copernicus altimeters is used for this investigation. The coastal processing is focussed at filtering out as much as possible the sea surface signal contamination, with the minimum degradation of the sea surface scientific information. This specific processing comes from the idea explained at (Garcia et al.,2018, https://doi.org/10.1016/j.asr.2018.03.015) using CryoSat-2 SARin data, adapted to Copernicus altimeters SAR data.
isardSAT has developed this study as ESA Expert Support Laboratory within the Sentinel-3A Mission Performance Centre team and within the CORS (Coastal Ocean Retracking for Sentinels) project as contribution to the Sentinel-6 Validation Team.

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Evaluation of coastal water level products in SAR mode

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_007

Abstract:
Coastal zones, estuaries and inland waters are among the environments most affected by anthropogenic impact and climate change and are multi-risk due to coastline retreat, flooding and pollution. Accurate knowledge of water height is of major importance to analyze and understand causes and drivers of changes and to plan protection measures. Satellite delay doppler altimetry (DDA) provides improved results compared to conventional altimetry (CA). Goal of this study is the evaluation of the state of art and enhanced dedicated coastal and inland retrackers to understand their limitation, plan improved processing and new missions.

The project HYDROCOASTAL brings together coastal and inland water zone measurements by SAR altimeter. Several retrackers, dedicated to one or both zones are applied in the processing of CryoSat-2 and Sentinel-3A/B altimeter data.
The University of Bonn contributes to the Hydrocoastal Project with the enhanced retracking and validation efforts. The Spatio-Temporal Altimeter Retracker for SAR altimetry (STARS) is an enhancement of the STAR retracker for low resolution mode (LRM) and uses the functional waveform model Signal model Involving Numerical Convolution for SAR (SINCS) to retrack the Delay Doppler waveforms.
The geophysical parameters estimated by retracking are evaluated in each region from all available retrackers. At Uni-Bonn the validation activities focus on the German Bight and Baltic Sea coastal region and include the Elbe estuary. The goal is to carry out a characterization of the product performance with estimation of the data accuracy. A cross-validation analysis of the new SAR products is performed against other altimeter products, model data and insitu data. The study area has been used for the validation of radar altimeter data in open ocean and near the shore in previous work.
The study presents and discusses the validation results based on the validation matrix which has been agreed with the project partners. The resulting statistics is compared in few cases with the statistics output from the in-house validation strategy matrix.
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Circulation variability of the South-Patagonia continental shelf from in-situ and satellite data

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_008

Abstract:
The Patagonia continental shelf is a vast region within the Southwestern Atlantic Ocean that is known for its high primary production rates and, consequently, for the wide biological diversity present there. To better understand the biological patterns observed, it is necessary to deepen the knowledge of the physical processes that they are exposed to. In this study, we analyze two direct velocity observations of up to 18 months, measured over the South-Patagonia continental shelf, located along 44.7□S at the 90 and 110 m isobaths, respectively, in addition to altimetry satellite data. Results show that the barotropic circulation dominates the dynamics at both sites, with a mean flow towards the west-northwestin the inner shelf and to the north in the outer shelf. The variability of the meridional barotropic velocity in the inner shelf is dominated by the local meridional wind stress. The in-situ barotropic velocity in the outer shelf presented a mean value of 7 cm s-1 and a range between -10 and 30 cm s-1 and is partially influenced by the meridional wind stress. We hypothesize this mooring is embedded in a transition area, partially affected by the shelf dynamics and partially affected by the slope regime. The SLA from the L4 gridded product developed by AVISO allowed the analysis of the forcing of the circulation variability of the outer shelf measurements. In particular, we found a seasonal signal in the meridional barotropic velocity that is in agreement with a SLA zonal gradient between the middle shelf and the slope region. Through the thermosteric effect, this SLA zonal gradient is generated by the differential heating in austral summer of the shelf waters, with depths lower than 200 m, and the slope waters, with depths higher than 1000 m and subject to the relatively cold Malvinas current. We also detected an intra-seasonal signal in the outer shelf meridional velocity that is also present in the SLA of the region.

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Comparison of Cryosat-2 and Sentinel-3 Altimetry with in situ measurements of Sea Level, Significant Wave Height and Wind Speed in the Northern Adriatic and around Venice

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_009

Abstract:
Coastal altimetry is an important observational resource for a better understanding of coastal oceanographic processes and their dynamic connection between the inland and open ocean. During the last decade significant improvements have been achieved in using satellite radar altimetry near coasts. Advances in processing and new/improved corrections permitted to obtain accurate sea level estimations within few kilometers from the coast. The retrieval of waves and winds in the coastal zone is as yet not as mature as sea level measurements.

The advent of SAR altimetry now permits to achieve higher spatial resolution and better precision than before. However, there is a need to assess the quality and the accuracy of these new data sets in order to gain the proper confidence in their operational usage. HYDROCOASTAL, a project funded by ESA, aims at maximizing exploitation of SAR measurements in the coastal zone and inland waters, by evaluating and implementing new approaches to process SAR data from the CryoSat-2 Sentinel-3 European satellites.

The Northern Adriatic Sea and the area around Venice is a perfect site to test modern altimetry applied to coastal studies in virtue of the favourable location of altimetric tracks as well as the availability of long-term in-situ observations from a number of instruments including tide gauges, wave and wind recorders, that offer clear advantages for comparison purposes.

The aim of this work is the presentation of comparison results of CryoSat-2 and Sentinel-3 data processed with GPOD, in preparation of exploiting HYDROCOASTAL re-processed datasets of sea level, wave amplitude and wind speed in support of regional monitoring.

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Shelf/Deep Ocean Exchanges in the Southern Africa Region

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_010

Abstract:
We use the model and altimeter data to characterize the circulation and shelf/deep-ocean interactions over the Agulhas Bank and the Southern Benguela Upwelling Region. The dynamical mechanisms controlling the shelf circulation as well as the shelf/deep-ocean interactions are identified with a suite of process-oriented experiments. Local winds and the sporadic transit of Natal Pulses, which are meanders generated by the transit of Agulhas eddies, are the main drivers of the shelf circulation and shelf/open ocean exchanges. Local winds control the inner shelf circulation and Agulhas eddies the outer shelf. Model analysis reveals a quite energetic water mass exchange between the Agulhas Current and the Agulhas Bank as well as between the Agulhas Bank and the Southern Benguela Upwelling region. We present evidence that shelf/open ocean interactions not only play a fundamental role on the shelf circulation but also on the water mass structure of the open ocean because these interaction lead to an enhanced vertical mixing of Agulhas Current waters. We estimate that the water mass exchanges associated with shelf/open-ocean interactions along the Agulhas Bank are of the same order of magnitude than the Indian/Atlantic interocean exchange.

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RiwiSAR-SWH: A data-driven method for estimating significant wave height using Sentinel-3 SAR altimetry

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_011

Abstract:
More than 600 million people (about 10% of the world's population) live in coastal areas that are less than 10 m above sea level. Despite the urgent need to monitor coastal waters, in-situ measuring stations including wave buoys around the world do not provide sufficient insight into coastal water level variations, and in particular, they cannot provide sufficient information on one of the essential properties of water surfaces, namely the Significant Wave Height (SWH). Satellite altimetry plays an increasingly important role, especially after operating in Synthetic Aperture Radar (SAR) mode. However, due to the complexity of the coastal water surfaces, the performance of the satellite altimeters over the coastal area falls behind the open ocean surfaces. In addition, the well-known direct relationship between waveform rise time and SWH does not hold for SAR waveforms due to a different processing scheme. This study proposes a data-driven method to determine SWH using the Sentinel-3 data for both oceanic and coastal zones. For this purpose, we propose a method based on the rise time and the width of a waveform, called RiwiSAR-SWH (rise time width model for SAR-SWH), which is free from the complexity of the SAR physical model and estimates SWH over the coastal area and open ocean in a relatively straightforward manner. We have employed our method over different regions in the coastal zone of the North Sea. The results are validated against in-situ buoy data and compared with SWH estimates from SAMOSA+, SAMOSA++ and the Sentinel-3 Ocean retracker. The validation shows that the proposed method can determine SWH with accuracy ranging from 0.25 m to 0.91 m for different locations in the North Sea. Moreover, we obtain reliable SWH to within 1 km from the coast, which is an improvement of more than 40% compared to existing methodologies.

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Portagauge and Satellite Sea level monitoring system for the Southwest Indian Ocean – PASS-SWIO

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_012

Abstract:
Madagascar currently has very limited tidal prediction capability (based primarily on model data) and no national sea level monitoring capability. There is only one functioning tide gauge station, whilst an earlier tide gauge, in the cyclone-prone north of the island, was swept away several years ago.
Working closely with its Madagascar partners, the Direction Générale de la Météorologie (DGM), PASS-SWIO aims to establish a sea level monitoring system for Madagascar based on the deployment of a low-cost relocatable tide gauge (Portagauge).
Financial limitations make it impractical for Madagascar to install multiple tide gauge stations at all points of interest along their extensive coastlines, nor can they be maintained on the multi-decadal timescales that are required to derive robust estimates of long-term sea level trends. Yet, tidal information is vital for the safety of communities, infrastructure and commerce, and since short-term hazards can be exacerbated by long-term increases in sea level, knowledge of longer-term changes is also essential.
Fortunately, longer-term sea level variability, including the trends associated with Climate Change, can be derived from satellite altimetry data, but these 'absolute' sea level measurements are calculated relative to an ellipsoidal reference frame and require both correction for vertical land motion as well as 'ground-truthing' to some known fixed point on land if they are to be meaningful for planning and mitigation purposes. Such vertical land motion is traditionally measured by GNSS receivers via the detection of positioning and timing information from a constellation of navigational satellites. The recent GNSS-IR technique exploiting the signal-to-noise ratio, allows sea level to be inferred relative to the same geodetic reference frame as satellite altimetry. The co-location of GNSS receivers with conventional tide gauge sensors (which measure relative to some fixed point on land), thus allows short-term tide gauge and GNSS-IR measurements to be connected to satellite altimetry, which can then substitute for long-term observations from tide gauge data.
The NOC Portagauge is a low-cost system which uses GNSS interferometric reflectometry (GNSS-IR) technology alongside a conventional radar gauge. As part of the PASS-SWIO project a Portagauge will be deployed at Toamasina port on the NE coast of Madagascar, for a minimum period of 6 months.
DGM will be trained to maintain and operate the Portagauge, and to carry out processing and analysis of Portagauge, tide gauge and satellite altimeter data (Jason-2, Jason-3, Sentinel-3A and 3B). They will cross validate portagauge data against satellite data and generate an analysis of tidal and non-tidal sea-level characteristics for the Madagascar coastal region, including seasonal signals, inter-annual variability and trends.
Finally, the PASS-SWIO team will work with agencies and key users in Madagascar to define a road map to establish a long-term, sustainable, national sea-level monitoring system for the country. It will be important to ensure that the planned capacity development meets key requirements, complements existing capability and will be sustainable, considering resource requirements.
The end goal of the project is to provide a model for a sea level monitoring system for developing island states and coastal nations, based on low-cost tide gauges and satellite data.
The presentation will provide an overview of the project and present initial results from analysis of satellite altimeter data in the Madagascar region.
PASS-SWIO is funded by ESA under the EO Science for Society Programme – Open Call.

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Fully Focused SAR Altimetry and Innovative River Level Gauges for Coastal Monitoring – the FFSAR-Coastal Project

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_013

Abstract:
Introduction
The recently developed technique of "fully focused" processing of SAR altimeter data provides opportunities for exciting new applications, as it provides hitherto unachievable along-track resolution of up to (and in some cases less than) tens of metres.
The objective of the FFSAR-Coastal Project is to apply the SMAP Fully Focused SAR (FFSAR) altimetry processor on Sentinel-3A and Sentinel 3B data and evaluate the potential of FFSAR altimeter data to make a significant new contribution to coastal and estuarine monitoring systems.
Two different environments are being considered:
• The Severn Estuary and river: A highly dynamic mixed tidal estuary environment, the confluence between a river and its estuary experiencing large tidal range and strong tidal currents.
• The lower Rhone Delta and Camargue: A low lying, flat river delta and wetland environment, susceptible to inundation and rising water levels.
By studying these two very different environments, the potential applicability and benefits offered by FF SAR altimeter data in other coastal, estuarine and delta locations will be demonstrated.
Innovative in situ lidar water level gauges, provided by vortex.io will be used for validation.

FFSAR-Coastal is funded by ESA under the EO Science for Society Programme – Open Call.

Presentation
The presentation will provide an overview of the FFSAR Coastal project and present early results.

There are two main elements to the project.

DTU Space are using the SMAP (Standalone Multi-Mission Altimetry Processor), developed by CLS, and applying it to Sentinel 3A and 3B altimeter data for two regions with very different characteristics: the Severn estuary in the UK, and the Rhône delta in France. The objective is to evaluate how well FFSAR altimeter data can resolve fine scale features in these two different environments. Initial results will be used to identify the optimum processing choices, which will then be applied to generate time series of data for selected tracks. These data will be validated against in-situ data and models, to quantify the performance against other data sources. Further analysis will then investigate the capability of FFSAR altimeter data to capture small scale physical signals (surface gradients, currents, roughness signatures) in highly tidal regions and to detect and measure tidal asymmetry/gradients across estuaries not seen with conventional altimetry
For the Rhône delta the analysis will focus on the ability of FFSAR data to accurately map different low lying channels and filaments.

The second element is the deployment of innovative river level "micro-gauges" (vorteX.io microstations) to provide ground truth data, and to test these as a flexible and low-cost option for satellite validation and river monitoring. Two micro-gauges will be installed in each of the selected regions, as close as possible to the Sentinel 3A and 3B ground tracks, and drone campaigns with an embedded LiDAR altimeter will be carried out to provide high resolution sea level measurements, synchronised to satellite overpasses, to provide a water level profile between the micro-gauge location and the satellite ground track.

The project is also engaging with local user groups to identify key gaps in the existing monitoring systems, and to develop recommendations on how FFSAR altimeter data can best be used as part of
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Impact of wind on sea level anomalies on the Patagonian Shelf coherence analysis on different temporal scales

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_014

Abstract:
Sea level anomaly (SLA) differ in strength and variability not only depending on the region, but also with temporal scales. The drivers of SLA behave analogous and can be found e.g. at the low-frequencies by atmospheric pressure pattern as well as on the high-frequency end by tides, wind and waves. In the study area, the Patagonian continental shelf, SLA show higher variability in low periods from days to weeks on the shelf, driven by tides, wind, fresh water discharge. Previous studies showed that seasonal SLA correlate well with wind forcing as well as with River discharge in vicinity of large river runoffs as the Rio de la Plata. However, so far, little is known about wind forcing contributing to SLA over the entire shelf on higher frequencies.

This contribution consists of a comprehensive analysis of altimetry-based SLA from Copernicus provided in daily resolution on a 0.25° x 0.25° grid in order to investigate wind-driven impacts on different temporal scales. Additional dataset are used for validation and comparison, namely SLA from Reanalysis ORAS5, tide gauge data from GESLA-3, and satellite-based wind data from Copernicus. In order to guarantee a fair comparison, consistent handling of ocean tides and atmospheric effects is ensured by an adding or removal of DAC (Dynamic Atmosphere Correction) as well as removal of tides.

This coherence study shows that areas of the Patagonian shelf are influenced by along- and across shore wind in different frequency bands, which are partly connected to prevailing wind regimes and local features. On larger spatial scales, the shelf can be divided into two shelf regimes, which show different dynamics, based on dominating currents as the Malvinas and Brazil current and prevailing wind regimes. For both, different coherences are reached. Comparison with tide-filtered tide gauge data confirms the altimetry results and adds insights into the wind dependency of SLA close to the coast. A comparison of altimetry-based SLA with simulated SLA from Reanalysis is further used to highlight different behavior of observations and models, as found for the (sub-)mesoscale frequencies and for regions of higher tidal impact.

This presentation will demonstrate that in addition to the existing studies about the seasonal cycle, SLA on higher frequency show significant agreement with wind forcing, which can further be associated with certain wind directions. Furthermore, it will be shown that certain pattern in high and low coherence are linked to an impact of major currents, fresh water discharge and cross shelf ocean mass transport.

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Analysis of hydrographic data collected by Southern Elephant Seals in the Argentine continental shelf

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Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2022_015

Abstract:
Within the OSTST SABIO project, in situ data obtained from CTD (Conductivity, Temperature and Depth) sensors attached on 6 elephant seals (Mirounga Leonina) during the period between the 17th and 31st of October 2019 are analyzed . First, data quality is assessed through the comparison with Satellite Sea Surface Temperature Multi-scale Ultra-high Resolution (SST MUR). The sub-surface (15 m depth) in situ data collected correlates very well (r=0.9) with the SST-MUR, suggesting that the in situ data are of high-quality. The elephant seals did zonal trajectories from Peninsula Valdés to the shelf break and did an average of 88 dives per day from the sea surface to the bottom of the sea and covered, on average, a distance of 117 km over the continental shelf. The high spatio-temporal resolution of the in situ data set allows to describe a clear flag pattern in the sections: T and S gradients were-up to 0.06 deg C/km and 0.03 UPS/km respectively along the trajectories. Superposition of the trajectories on top of the SST-MUR data helped to understand that such flag pattern is due to the fact that the animals crossed frontal regions several times.
The analysis of the temperature and salinity along the trajectories also allowed us to identify two regions: north of 42°S and south of 42°S. In the northern region, the temperature is 1°C warmer and 0.5 saltier than in the southern region. This feature was also observed in the Temperature-Salinity (TS) diagrams. Moreover, four water masses were identified from the TS diagrams: Malvinas Water, Low Salinity Coastal Water, Mid-Shelf Water and Water with High Salinity from Gulf of San Matias. Additionally, we show that the maximum depth reached by the elephant seals can be used to evaluate the quality of bathymetry datasets. Finally, taking advantage of the in situ T and S vertical profiles, the potential density change was calculated, the so-called steric effect, and compared with the value estimated by a reanalysis model. The comparison between both data sets is quite good (correlation r=0.83).

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Bathymetry improvement and high-resolution tidal modelling at regional scales

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Session: Tides, internal tides and high-frequency processes
Presentation type: Poster
Poster number: TID2022_001

Abstract:
Coastal processes (tidal currents, storm surges, waves) are highly dependent on bathymetry and directly impact offshore and coastal activities and studies. Many studies and applications lie on a growing modelling effort of the ocean and the limited accuracy of bathymetry, especially on the continental shelves, contributes to degrade the numerical model performance despite significant use of in-situ and satellite measurements assimilation. In particular, the tidal models are very sensitive to the bathymetry accuracy on the shelves, where the ocean tides show the largest amplitudes and are strongly non-linear.
The increase in the grid resolution, combined with local model tuning, is one of the means to improve the tidal model performance in the coastal regions and large improvements have been achieved thanks to this approach. However, increasing the resolution of the model grid implies consistent bathymetry quality and accuracy, which is today the main limiting factor to accurate high-resolution tidal modelling.
In particular, this has a direct impact on the quality of the altimetry sea surface heights as the tide correction is one of the largest corrections on the shelves, ranging from several centimetres to several metres. It is of prime importance for the current and future satellite altimetry missions that already or will enable to retrieve high-resolution coastal observations of the sea surface height, such as Sentinel-3, Sentinel-6/Jason-CS and SWOT.
Various sources of bathymetry data exist but many regions remain poorly known because of too sparse measurements, data access limitation or large temporal variability of the seabed dynamics. In this context, CNES recently funded a project that aimed to improve the bathymetry and the tides in the North-East Atlantic Ocean, the Mediterranean Sea, the Arctic Ocean and around Australia.
The work was divided in several steps: 1) an inventory of the existing bathymetry datasets in the regions of interest; 2) the integration of the collected datasets into a reference global bathymetry dataset; 3) the evaluation of this new bathymetry dataset through the implementation of a regional hydrodynamic tidal model configuration; 4) the assimilation of tidal observations into the hydrodynamic model and the production of high resolution regional tidal atlases.
This paper presents the performance of these four new regional tidal models that pave the way for the implementation of the new global tidal model, FES2022.

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Impact of the sea ice friction on ocean tides in the Arctic Ocean, modelling insights at various time and space scales

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Session: Tides, internal tides and high-frequency processes
Presentation type: Poster
Poster number: TID2022_002

Abstract:
The ocean tides are one of the major contributors to the energy dissipation in the Arctic Ocean. In particular, barotropic tides are very sensitive to friction processes, and thus to the presence of sea ice in the Polar regions. However, the interaction between the tides and the ice cover (both sea ice and grounded ice) is poorly known and still not well modelled, although the friction between the ice and the water due to the tide motions is an important source of energy dissipation and has a direct impact on the ice melting. The variations of tidal elevation due to the seasonal sea-ice cover friction can reach several centimeters in semi-enclosed basins and on the Siberian continental shelf. These interactions are often simply ignored in tidal models, or considered through relatively simple combinations with the bottom friction.
In the frame of the Arktalas project funded by the European Space Agency, we have investigated this aspect by performing a sensitivity analysis of a regional pan-Arctic ocean tide hydrodynamic model to the friction under the sea ice cover, in order to generate more realistic simulations. Different periods of time, at the decadal scale, were considered to analyze the impact of the long-term reduction of the sea ice cover on the ocean tides in the region, and at the global scale. Tide gauge and satellite altimetry observations were specifically processed to retrieve the tidal harmonic constituents over different periods and different sea ice conditions, to assess the model simulations.
Improving the knowledge on the interaction between the tides and the sea ice cover, and thus the performance of the tidal models in the Polar regions, is of particular interest to improve the satellite altimetry observation retrievals at high latitudes, as the tidal signals remain a major contributor to the error budget of the satellite altimetry observations in the Arctic Ocean, but also to generate more realistic simulations with ocean circulation models, and thus contribute to scientific investigations on the changes in the Arctic Ocean.

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Improved shallow waters tidal estimates using satellite radar altimetry data and numerical modeling.

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Session: Tides, internal tides and high-frequency processes
Presentation type: Poster
Poster number: TID2022_003

Abstract:
Satellite observations can help in the retrieval of constituents in shallow waters. Noise contamination, however, makes smaller constituents irretrievable and large sources of error. Throughout shallow areas, the constituent's relevancy changes. For example, near an amphidromic point where M2 relevance drops, so does the potential of satellite contribution for improving its accuracy. Moreover, shallow waters are generally influenced by many constituents (>100). Accurately retrieving all these constituents with satellite radar altimeter data alone is not possible. Series length requirements imposed by the Rayleigh criteria to separate constituents are still unavailable.
Removing unwanted signals from satellite observations improves least-squares-based harmonic estimates, given an inversion matrix with the same condition number. This variance reduction is the core of the remove compute restore approach commonly used. First, residual harmonic sets are computed with the difference between observations and model background estimates through conventional or weighted least-squares. Then, the residual harmonics are added to the background model estimates.
Here we implemented a method that extends the typical approach by including model background estimate and error covariance in the least-squares step. This inclusion helps to weigh between constituents well represented in the model and those that must be updated.
To test the method, we designed a semi-synthetic experiment. First, we used tide gauge data to generate a satellite equivalent dataset and compared estimations between the two methods listed above and the model estimate. Next, we applied the method to compute tidal estimates along satellite radar altimeter tracks (T/P Jason) in the 2D Dutch Coastal Shelf Model (DCSMv6) domain.
Results from the synthetic experiment show that the second method produces consistently better estimates reducing RSS consistently through temporal cross-validation. In addition, it provides an effective way of keeping as many constituents estimates as the model series can resolve, adding the benefits of satellite observations. Finally, results from the North Sea implementation show the new estimates increase the variance reduction of satellite residuals across the whole domain relative to background tidal estimates. The range of improvements varies between 0 and 3cm, which is significant given already very accurate model background estimates. The benefited areas include the English Channel, the Irish Sea, the English North-Sea Coast, the Bay of Biscay, the German Bight, and the North Atlantic region close to the upper boundary of the model domain.

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Sentinel-3 SAR Mode altimetry observations of wave breaking dissipation owing to large-amplitude Internal Solitary Waves: effects on SWH and radar backscatter

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Session: Tides, internal tides and high-frequency processes
Presentation type: Poster
Poster number: TID2022_004

Abstract:
Wave breaking is a common phenomenon when there is high to medium wind speeds over the ocean. But the wave breaking can have various sources, being the wind only one of them. For instance, wave breaking occurs near inhomogeneous unsteady currents, when waves propagate into an opposing current steepen, shorten and may break; or more simply, as waves shoal over shallow bathymetry. Wave breaking limits the height of surface waves, mixes the ocean surface, generates currents, and enhances air-sea fluxes of heat, mass and momentum through the generation of turbulence, the entrainment of air and the creation of spray and aerosols (Melville, 2018). In this work, we study the wave breaking caused by large amplitude and nonlinear Internal Solitary Waves (ISWs). Internal Waves play an important role in determining the near-surface sea temperature structure and the air–sea exchange processes, being therefore important for understanding the evolution of the climate system. In the presence of strong ISW-Surface Wave interaction, breaking surface waves are known to occur and hence, it is expected that wave energy dissipates and the wave energy spectrum is altered. Furthermore, it has been recently shown that ISWs are successfully detected by using satellite altimetry.
Here, we select two different regions of the ocean, namely the tropical Atlantic Ocean off the Amazon shelf and the Banda Sea in the Indian Ocean, where there are scenes of Sentinel-3 OLCI (Ocean Land Colour Instrument) acquired simultaneously with along-track SAR mode altimeter, which included signatures of large amplitude ISWs. New data of unfocused SAR (UF-SAR) and fully-focused SAR (FF-SAR) modes is analysed. It has been observed a strong decrease in normalized radar cross section (NRCS) over the rough part of the ISWs, and a small increase in the smooth part relatively to the unperturbed ocean background (Santos-Ferreira et al., 2018). Moreover, we demonstrate that the Significant Wave Height (SWH) parameter is significantly attenuated, after the passage of an ISW, considering length scales of about 10 km before and after the ISW crest (i.e. in 20 km length scales). It is suggested that the cause of this SWH attenuation is related to the wave breaking associated with the ISWs, characterized by surface wave energy dissipation, turbulence effects and air emulsion. Furthermore, Sentinel-2 images are analysed and provide insights admittedly into this same phenomenon: white-capping of two different kinds are reported, the first being a traditional radiance increase at all (visible) wavelengths extended in time scales of tens of seconds, and a second kind associated to quick transient “flashes” of enhanced radiance depicted in different coloured pixels in RGB composite images, with typical time scales of one second or less. Fraction of modulation of breaking waves in the presence of internal waves are presented.

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Towards improved analysis of short mesoscale sea level signals from satellite altimetry

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_001

Abstract:
Satellite altimeters routinely supply sea surface height (SSH) measurements, which are key observations for monitoring ocean dynamics. However, below a wavelength of about 70 km, along-track altimeter measurements are often characterized by a dramatic drop in signal-to-noise ratio, making it very challenging to fully exploit the available altimeter observations to precisely analyze small mesoscale variations in SSH. Although various approaches have been proposed and applied to identify and filter noise from measurements, no distinct methodology has emerged for systematic application in operational products. To best address this unresolved issue, the Copernicus Marine Environment Monitoring Service (CMEMS) actually provides simple band-pass filtered data to mitigate noise contamination of along-track SSH signals. More innovative and suitable noise filtering methods are thus left to users seeking to unveil small-scale altimeter signals. As demonstrated here, a fully data-driven approach is developed and applied successfully to provide robust estimates of noise-free Sea Level Anomaly (SLA) signals. The method combines Empirical Mode Decomposition (EMD), to help analyze non-stationary and non-linear processes, and an adaptive noise filtering technique inspired by Discrete Wavelet Transform (DWT) decompositions. It is found to best resolve the distribution of SLA variability in the 30-120 km mesoscale wavelength band. A practical uncertainty variable is attached to the denoised SLA estimates that accounts for errors related to the local signal-to-noise ratio, but also for uncertainties in the denoising process, which assumes that the SLA variability results in part from a stochastic process. For the available period, measurements from the Jason-3, Sentinel-3 and Saral/AltiKa missions are processed and analyzed, and their energy spectral and seasonal distributions characterized in the small mesoscale domain. In anticipation of the upcoming SWOT (Surface Water and Ocean Topography) mission data, the SASSA data set (Satellite Altimeter Short-scale Signals Analysis, Quilfen and Piolle, 2021) of denoised SLA measurements for three reference altimeter missions already yields valuable opportunities to evaluate global small mesoscale kinetic energy distributions. Results are also presented to analyze the variability of SLA, SWH, and Sigma0 in the 70-10 km range from the Sentinel-3 20Hz PEACHI experimental products.

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Investigating the variability of eddy formation in the eastern subpolar North Atlantic from satellite altimetry

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_002

Abstract:
Abstract:

Mesoscale processes contribute nearly 50% of the meridional heat transport variability in the eastern subpolar North Atlantic (Zhao et al. 2018). In this project, we study the variability in the generation of coherent anticyclonic addies in the Iceland Basin of the eastern Subpolar North Atlantic using satellite altimetry. For this, we employ two automatic eddy detection schemes to track eddies (Faghmous et al. 2015 and Chelton et al. 2011) FA15 and CH11 respectively using Sea Level Anomaly data. We compare the two schemes to understand the difference between them in terms of detection of eddies, calculation of size, life, and strength of eddies. We also look at how effective/different these products are in identifying the eddies and how do they behave with different satellite products (multi-satellite or two satellite products). We found that the number of anticyclonic eddies detected by CH11 differs by nearly 200 with FA15 for the period between 1993-2019, with a notable interannual variation. However, both products captured a low-frequency variability in the generation of anticyclonic eddies. The mean characteristics of eddies detected by both products were similar. The results also point out that the type of satellite dataset determines the outcome of the same analysis.

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Diagnosing ocean eddy salt transport from satellite altimetry and surface salinity data

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_003

Abstract:
Satellite sea level anomaly (SLA) and sea surface salinity (SSS) data are used to characterize and quantify the contribution of mesoscale eddies to the ocean transport of salt. Given relatively large errors in satellite SSS retrievals, we evaluate the eddy transport of salt using two methods. The first method is based on the so-called eddy composite analysis. Because of the averaging over a large number of eddies in a given geographic area, composite eddies result in quite small standard errors, producing robust estimates of the associated transport of salt. The second method estimates the eddy transport of salt in a traditional way by computing pointwise covariances between eddy-induced velocity and SSS fluctuations. Comparing between the two methods, we find that the estimates of the eddy salt transport agree very well globally, emphasizing the physical mechanism responsible for the eddy transport of salt (eddy advection) and validating the assumption that the eddy transport is mainly due to large mesoscale eddies, observed by satellite altimetry.

Our analysis confirms that the eddy transport of salt (or, equivalently, freshwater) is an essential component of the marine hydrological cycle. The regions of major eddy transport of salt identified in our study occur in the tropical belt, across the equatorward limbs of the subtropical gyres, and across the Antarctic Circumpolar Current (ACC). The eddy salt transport is poleward across the ACC with the largest transport taking place in the Indian Ocean sector. The eddy salt transport is divergent in the subtropical gyres (eddies pump salt out of the gyres) and convergent in the tropics. The eddy salt transport in the sub-polar gyres is substantially smaller than the eddy salt transport in the tropics and subtropics. We also note that the zonal component of the eddy salt transport is quite significant, particularly over the western and eastern boundaries of the gyres and in the near-equatorial belt, where strong zonal gradients of SSS exist. Overall, our study demonstrates that the possibility to characterize and quantify the eddy transport of salt in the ocean surface layer can rely on the combined use of satellite observations of SLA and SSS.

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Improved global sea surface height and currents maps from remote sensing and in situ observations

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_004

Abstract:
We present a new gridded sea surface height (SSH) and current dataset produced by combining observations from nadir altimeters and drifting buoys. This product is based on a multiscale/multivariate mapping approach, which aims to improve the resolution of operational products provided by Copernicus services and offers the possibility to study mesoscale circulations, equatorial wave dynamics and Arctic Sea level variability. The dataset covers the entire global ocean and spans from 2016-01-15 to 2020-06-30. The multi-scale approach decomposes the observed signal into different physical contributions. In the present study, we simultaneously estimate the mesoscale ocean circulations as well as part of the equatorial wave dynamics (e.g., tropical instability and Poincaré waves). The multivariate approach is able to exploit the geostrophic signature resulting from the synergy of altimetry and drifter observations. In addition, sea level observations of Arctic leads are also used in the merging to improve the SSH in this poorly mapped region. A quality assessment of this new product is proposed against the product distributed in the Copernicus Marine Service. We show that the multi-scale mapping approach offers promising perspectives for surface ocean circulation reconstructions. The geostrophic circulation is better mapped in the new product. The mapping errors are significantly reduced in regions of high variability and in the equatorial band. The drifters help to refine the mapping in the in regions of intense dynamics where the temporal sampling must be accurate enough to properly map the rapid mesoscale dynamics. The effective resolution of this new product is hence between 5% and 10% finer than the Copernicus product.
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Characterizing wavenumber spectra in altimetry: An ADCP perspective

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_005

Abstract:
New satellite altimeters bring new capabilities to resolve small-scale variability and near-surface signatures of surface eddies and inertia-gravity waves (IGWs). We use underway Acoustic Doppler Current Profiler (ADCP) velocity measurements in combination with altimetry to probe the dynamics of this high-wavenumber ocean variability and to explore the interactions between geostrophic eddies and unbalanced IGWs. ADCP data allow us to diagnose the ratio of rotational (geostrophic) to divergent (unbalanced) submesoscale energy. We examine distinctions between tropics and mid-latitudes, and evaluate seasonal variations in high-wavenumber variability of the upper ocean, and we examine the role of eddies compared with IGWs. Results from ADCP data show that submesoscale rotational energy decreases with increasing depth nearly everywhere, while submesoscale divergence energy shows weak vertical dependence, but tends to peak near the stratification maximum. In the regions where IGWs appear to dominate the submesoscale, the rotational-to-divergence ratio more often is higher than predicted by the Garrett-Munk spectrum, except around the thermocline in the southeast tropical Pacific. Under the isotropy assumption, the rotational energy levels at wavelengths of 15-100 km imply O(10-1) or less eddy Rossby numbers almost everywhere and at all depths and seasons. These findings provide a framework for interpreting altimeter small-scale altimeter observations.

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Toward Higher resolution Level-3 altimeter products

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_006

Abstract:
In 1998, first Level3 along-track, user friendly altimeter products have been developed with support from CNES and delivered to the users on AVISO+. The Level3 processing includes a homogenization of the SLA for the different altimeters (i.e. reduction of the global and regional biases), allowing the users to directly use the products without any pre-processing. They are widely used for different applications, including assimilation in numerical models. Since 2008, such products are generated and disseminated by the Copernicus Marine Service (CMEMS; previously MyOcean during its demonstration phase).
Since few years, efforts are done in order to improve the altimeter measurement in open ocean and coastal area. While the observation of the small mesoscale signal remains a challenge for the conventional altimeter measurement, new techniques and processing allow to significantly reduce the measurement errors and noises. Additionally, with the future altimeter missions as the large swath SWOT mission, the altimeter processing will face a new challenge be able to accurately process the signal at finer spatial scales.
A new generation of along-track products is under development with support from CNES (DUACS-RD project) and ESA (EO4SIBS project). They are derived from high resolution (20Hz) altimeter measurement and are specifically processed in order to solve finer scales up than the conventional 1Hz product and better sample the coastal areas. They merge recent developments that enable to optimize the Sentinel3 SAR altimeter processing (Boy 2017, Moreau,2018) and the Jason/Altika noise level (Zaron 2016, Tran 2019) and allow us to better exploit the fine-scale content of the altimetric missions. They also take into account improvements that are also done in geophysical corrections estimation (e.g. internal tide model [Zaron 2018]) and local Mean Sea Surface Estimation (e.g. Dibarboure et Pujol, 2019). Experimental datasets over European Seas and Black Sea, with a nearly 1km (5Hz) sampling, are already available on AVISO+ (https://www.aviso.altimetry.fr/duacs), CMEMS (https://marine.copernicus.eu/) and EO4SIBS (http://www.eo4sibs.uliege.be/). They can be tested by users. We will present these experimental 5Hz products. All the joint developments will be eventually integrated in CMEMS as part of the European regional product.
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Global spectral characteristics from 1Hz along-track altimetry

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_007

Abstract:
We use three years of Sea Surface Height (SSH) observations over the World Ocean to analyze its spectral characteristics: spectral slope and noise levels. Our analyses are based on previous works that focused on the spectral slope characterization through a linear regression over a geographically dependent wavelength range, corresponding to the mesoscale wavelength range. In our current analysis, we adopt a methodology that allows for the characterization of the spectral slope by optimal fit of a linear function, considering the statistical uncertainty of the observed spectra. This is particularly important in the wavelength range of the instrumental noise (15-30 km wavelength): the noise level influence the spectral shape over the geophysical spatial scales. The observed values of spectral slope are within the range of previous works however we observe a higher spatial variability in regions where the eddy kinetic energy varies sharply, with spectral slope values that drop significantly in low energy regions. Noise level distribution is also within the range of previous results, although we observe higher values in the mid latitudes (10 to 15%) and intertropical band. In addition, our current approach allows us to analyze (when present) the break in the mesoscale spectral slope that occurs at wavelengths shorter than 100 km, partly due to the internal tides and their energy cascade to smaller scales, but also other dynamical signal and instrumental errors. Preliminary results on this topic are also presented.
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Monitoring the mesoscale eddies interactions with the altimetry constellation

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_008

Abstract:
Mesoscale eddies are ubiquitous structures in the ocean. As mesoscale eddies can trap and transport water within their cores over long distances, they have been investigated globally since the availability of altimetry maps. Mesoscale eddies are first detected in the sea surface, and then tracked in time and space. Several methods of detection and tracking have been developed, most of them propose to describe the evolution of mesoscale eddies with an association in individual trajectories, with a beginning and an end. Few methods are able to take into account the interactions between trajectories, and when merging and splitting events are recorded, it is necessary to change the semantics and the metrics to describe the behaviour of mesoscale eddies. Here we present a new mesoscale eddies dataset, where the structures are gathered in networks. Eddies are detected on daily absolute topography maps with the Py-Eddy-Tracker algorithm (PET, Mason et al., 2014, https://github.com/AntSimi/py-eddy-tracker). Following Pegliasco et al. (2015), successive eddies with overlapping contours are associated in the same network if the overlap ratio, defined as the intersection of their area divided by the union of their areas, is more than 5 %. Within networks, segments represent the temporal evolution of individual eddies and nodes between segments correspond to merging or splitting events. Segments are what was previously called trajectories, but the individuality (no interactions) is not assumed. During merging and splitting events, more than two eddies present an overlap. The highest overlap ratio is used to determine which segment stops in a merging event and which segment starts in a splitting event. We developed simple functions to manipulate and visualize this new type of dataset.
To assess the networks' coherence, we use a lagrangian perspective. A coherence level is obtained by advecting for 14 days particles injected within the eddy's contours of maximum averaged speed, both backward and forward in time, with the surface currents derived from absolute dynamic topography. At the end of the advection, the number of particles still within the eddy's contours is normalized by the initial number of particles. A coherence level is associated to each segment and each interaction and can be used for selection by the users. The META-Networks (Mesoscale Eddy Trajectories Atlas – Networks) can be used for any interdisciplinary research topic, for example by coupling the mesoscale eddies' contours with in situ data, or describe the displacement of tracers along eddies' paths, at a regional or global scale.

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Fostering collaborations for designing high level ocean data products : the case for community data challenges.

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_009

Abstract:
Algorithms using trainable components, data assimilation and other inverse techniques are becoming unavoidable tools for designing high-level data products leveraging oceanic observations for a wide range of applications. These fast and promising advances are speeding up the pace of technological and scientific progress in our field. However, because of the variety of approaches, sometimes emanating from different communities and scattered research groups, keeping track of progress is becoming more difficult. This is why fostering community-driven, intercomparison frameworks would be of great benefit for creating the next-generation high level ocean data products and to the oceanographic community in general.
Our project BOOST-SWOT (“Building Of Ocean Surface Topography maps with SWOT”) has led to a number of methodological developments for sea surface height cartography and for the preprocessing of the SWOT ocean data. This includes: inverse techniques for filtering SWOT observational noise, algorithms for mapping SSH with data assimilation techniques applied to simple dynamical models, and approaches for optimally accounting for high-frequency internal wave dynamics in mapping algorithms. In order to assess the potential and the limitations of the above algorithms, we have implemented a series of collaborative data challenges that have been shared across different research groups. These collaborative data challenges have been implemented on the basis of observational data, state-of-the-art numerical model simulations and evaluation metrics. They are meant to provide well-posed benchmarks for intercomparing inversion methods for the mapping of altimeter data.
In this presentation, we will take a look back at the BOOST-SWOT results and at the benefits and issues raised during the challenges. On the basis of the BOOST-SWOT experience, we will try to describe what are, from our perspective, the key elements for a fruitful collaboration across different research groups through open data challenges: easy to access open source codes and data, co-designed evaluation metrics and blind evaluation references. We will conclude on what could be the first steps towards developing and maintaining systematic collaboration frameworks for our community in the future.

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Studying physical processes in the Southwestern Atlantic to understand BIOlogical productivity & regional ecosystems (SABIO)

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_010

Abstract:
The main objective of the OSTST SABIO project is to improve our understanding of the physical processes in the Southwestern Atlantic that impact the biological productivity and the regional ecosystems using satellite altimetry, in-situ and model output data. The objective is motived by the following questions: (Q1) What are the main physical drivers of the large biological activity observed over the Patagonian shelf and slope? (Q2) Does the Malvinas Current (MC) acts more as a blender or as a barrier between open ocean and shelf waters? (Q3) How the different trophic levels (phytoplankton, intermediate trophic levels, elephant seal prey) are structured within the water column according to the oceanographic conditions associated with the foraging habitat (Patagonian shelf, Patagonian upper slope, and oceanic water beyond the MC) targeted by southern elephant seals? The data necessary to answer these questions are obtained through two on-going field experiments. The first experiment collects in-situ physical (temperature, pressure, salinity, currents) data thanks to four fixed moorings that have been deployed in the Patagonian shelf in September 2021. The second experiment is measuring physical (temperature, pressure, salinity, wind) and biological (light and acceleration that are used as a proxy of phytoplankton and prey catch attempt rates) variables at the same time through eleven elephant seals that have been instrumented in Peninsula Valdez (Argentina) in October 2021 and are sampling the Southwestern Atlantic. Taking advantage of the in-situ dataset that are being collected, the project also proposes to answer the following two questions that are complementary to the main objective indicated above: (Q4) What is the contribution of the steric height effect to sea level variability in the Southwestern Atlantic at intra-seasonal scales? (Q5) What are the state-space topologies of the dynamical systems that characterize the Southwestern Atlantic?

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Global pattern of annual cycle of mesoscale sea level anomaly

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_011

Abstract:
Analysis of historical data of mesoscale sea level anomaly reveals robust global pattern of its annual cycle (Figure). Outside of the tropics, the annual signal is initiated on the eastern boundaries of all oceans and propagates westward consistently with the dynamics of Rossby waves. Locations of 30% of documented mesoscale eddies (both cyclonic and anticyclonic) are consistent with the phase of the annual signal. This suggests that, contrary to the stochastic turbulent concept, formation and propagation of eddies may be anchored to such basin-wide phenomena as Rossby waves, beta-plumes and striations.
Our finding will help to better understand the dynamic of mesoscale eddies and relation of their statistics to large-scale, time-mean or low-frequency ocean phenomena and to improve predictions of seasonal variability of sea level, both globally and locally.

Figure. Month of maximum SLA in daily climatology, high-pass filtered with 5-degrees longitude-latitude filter.

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Role of finescale processes in water exchanges and geostrophic circulation in western and central Baltic Sea

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_012

Abstract:
Sub-mesoscale features in the North Sea-Baltic Sea transition zone correspond to upwelling events and water transport. The transport is mainly driven by sea level differences and the flow by barotropic pressure gradient. The Gotland basin in the central Baltic basin is dominated by the Gotland gyro with mean cyclonic basin scale circulation of radius 25-35 km.
We analyse the pre-SWOT status with concurrent SAR altimetry, ocean models, gridded altimeter products for SLA and MDT and SWOT simulations performed with the JPL Ocean Simulator. We also compare to in situ permanent stations records and previous campaign data. At these small scales, ocean dynamics evolve rapidly and the combination of altimetric SSH with other satellite or in situ data of different space-time coverage is a challenge.
This study is part of the « Adopt-a-crossover » initiative, in preparation to the SWOT Ocean Fast-sampling phase. In situ campaign experiments are planned. The in-situ data will contribute to initial validation of SWOT, and are expected to provide an intercomparison of physical and bio-physical fine-scale ocean processes.
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MAGAL Constellation

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_013

Abstract:
The concept of a small radar altimeter constellation has already been proposed but not yet implemented due to technological limitations or high costs associated with the operation of such a constellation. Yet, some oceanic processes are still poorly studied and understood due to the lack of adequate sampling of the ocean by past and current satellite altimetry missions. With the increase in popularity of the CubeSat concept and the current availability of low-cost and high-performance components, improving the space-time resolution of satellite altimetry with a constellation of small satellites becomes a possible scenario.
The MAGAL Constellation is a future constellation of small satellites carrying radar altimeters that aims to improve the understanding of ocean circulation variability in local, regional, and global scales through improving the spatiotemporal resolution of sea surface topography measurements. By operating as a collective unit, the measurements provided by MAGAL are expected to augment those from the current large satellite radar altimeters. Hence, the framework should be collaborative, to better tackle the gaps of the reference programs, improving the collective data products with an enhanced data set over the open ocean, while also targeting the coastal processes.
Four main use cases have been selected, for which the sampling of the ocean with higher spatial and temporal resolutions is required: better characterization of the mesoscale variability at local and regional scales to support operational oceanography; eddy detection and tracking; monitoring of marine debris pathways, and the monitoring of the water level of inland water bodies.
To achieve these goals, six CubeSat, no larger than 24U, are being considered which, to reduce the launch cost, are all launched simultaneously into the same orbital plane. The orbital characteristics of the constellation have been selected to provide full coverage of the Earth's surface with a 5-day repetition cycle and distance between adjacent tracks of ~88 km at the Equator. The altitude must be higher than 500 km, to reduce the effect of atmospheric drag, and less than 600 km, due to the restrictions imposed by altimeter and power budget. A sun-synchronous orbit with 97.4° inclination has been selected for repeatability. The separation of the satellites in the orbital plane, as well as orbit corrections, are to be provided by the thruster system.
The MAGAL platform will be miniaturized and manufactured in series, minimizing production, operational and launching costs. The design process will take advantage of the new Space 4.0 industry to integrate readily COTS subsystems (navigation, tracking, cooling and propulsion). Profiting from its low cost, replacement of end-of-life satellites (~3 years) can be accommodated in the same or complementary orbital planes. However, the altimeter payload state-of-the-art demands the development of a new era of small, lower power consuming altimeters.
The radar altimeter will operate at a frequency of 13 GHz, with a Frequency Modulated Continuous Wave (FMCW) architecture. The FMCW architecture was selected as it has a lower power consumption (20 W consumption for 1 W transmission RF power) than traditional pulsed radar altimeters. For this radar altimeter to work correctly, with an adequate observation footprint, the antenna must be at least 1.5 m diameter deployable dish antenna. The signal will then be received and treated using digital signal processing using a FPGA approach.

A Data Analysis Center (DAC) will also be developed based on cloud-based services, surpassing security issues. The DAC will be responsible for storage of acquired data, and processing of those data, including overlay of different layers from multiple sources (e.g. meteorology), in the back-end side, producing scientific and commercial information. A front-end layer will be responsible for displaying processed data in various graphical interfaces, allowing overlaid correlations between data and layers.

The project MAGAL Constellation (Nr. 033688) is co-financed by the European Regional Development Fund through COMPETE 2020, LISBOA 2020 and by FCT under the UT Austin-Portugal interface program, and will consider the insights from the European Union agenda for sustainable development, addressing as many fields of action as possible, and adding value alongside the underlying technology development. Besides providing an integrated approach, bringing together the sea’s economy and its sustainable growth into the future, the MAGAL project will contribute to the knowledge advancement in these fields.
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Extreme events in three years of ocean physical measurements at the Global Argentine Basin Array of the Ocean Observatory Initiative

Camila Artana (CSIC ICM, Spain); Christine Provost (LOCEAN, France)

Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_014

Abstract:
We analyzed physical parameters gathered by a mooring array at mesoscale spatial sampling deployed in Argentine Basin within the Ocean Observatory Initiative, a National Science Foundation Major Research Facility. The array was maintained at 42°S 42°W, a historically sparsely sampled region with small ocean variability, during 34 months from March 2015 to January 2018. The data documented four extreme oceanic events in 2016, a year that stands out with the highest level of eddy kinetic energy in the 29-year-long satellite altimetry record at the mooring site. The four events were anticyclonic structures, a meander of the Subtropical Front and three intense anticyclonic eddies with swirl velocities of the order of 0.4 m/s. Satellite altimetry provided complementary information on the size, origin and fate of the structures. The three anticyclonic eddies (named A1, A2' and A2") showed distinct characteristics. A1 was a large, 300 km-diameter, bottom-reaching eddy. In contrast, A2' and A2" were smaller with a size close to the Rossby radius (40 km) and a vertical extension of 2500 m. They were attenuated in the satellite altimetry maps. The high-frequency mooring data indicated the presence of near-inertial waves trapped at depth within the anticyclones and provided evidence of favorable conditions for the potential development of mixing well below the mixed layer.
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Assessing the Impact of the Assimilation of SWOT Observations in a Global High-Resolution Analysis and Forecasting System

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_015

Abstract:
A first attempt was made to quantify the impact of the assimilation of Surface Water Ocean Topography (SWOT) swath altimeter data in a global 1/12° high resolution analysis and forecasting system through a series of Observing System Simulation Experiments (OSSEs). The impact of assimilating data from SWOT and three nadir altimeters was quantified by estimating analysis and forecast error variances for sea surface height (SSH). Wave-number spectra and coherence analyses of SSH errors were also computed. SWOT data will significantly improve the quality of ocean analyses and forecasts. Adding SWOT observations to those of three nadir altimeters globally reduces the variance of SSH and surface velocities in analyses and forecasts by about 30 and 20%, respectively. Improvements are greater in high-latitude regions where space/time coverage of SWOT is much denser. The combination of SWOT data with data from three nadir altimeters provides a better resolution of wavelengths between 50 and 200 km with a more than 40% improvement outside tropical regions with respect to data from three nadir altimeters alone. The study has also highlighted that the impact of using SWOT data is likely to be very different depending on geographical areas. Constraining smaller spatial scales (wavelengths below 100 km) remains challenging as they are also associated with small time scales. Although this is only a first step, the study has demonstrated that SWOT data could be readily assimilated in a global high-resolution analysis and forecasting system with a positive impact at all latitudes and outstanding performances.
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What is the benefit of high-resolution sea level anomaly datasets? A case study in the Bay of Biscay and New Caledonia regions based on Jason2-3, Saral/AltiKA and Sentinel3

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_016

Abstract:
Wavelength spectral analysis of alongtrack altimetric data helps to characterize the seasonal and spatial variability of the sea level anomaly (SLA) signal. It allows us to infer the nature of the surface dynamics (balanced vs unbalanced motion, internal waves). For such analyses, low resolution mode data sets (1 Hz, 6-7 km sampling) are classically used. At this stage there is a strong gap in terms of effective resolution between the 1 Hz along track products (40-70 km resolution) and what is expected from the data of the future SWOT mission. However, the finest spatial sampling is 20 Hz for Jason, and 40 Hz for SARAL/AltiKa. For these products, the main limitation to observe small mesoscale is the existence of a spectral “hump” and a larger noise level due to surface waves and other surface inhomogeneities within the radar footprint. The new concept of SAR mode altimeter as used in Sentinel 3 provides better precision and resolution capabilities.
In the prospect of the SWOT mission, this paper focuses on high resolution (HR) datasets from the recent satellite missions based on regional analysis including Jason-2/3, SARAL/AltiKa, and Sentinel-3. At the present time, there is no HR-SLA datasets for all these missions and over the global ocean that are easily usable. In this poster we review different methods and options in the data processing to get HR-SLA. The ability of the different datasets and processing to provide information on the dynamics is illustrated in two contrasted regions: the Bay of Biscay located in the mid-latitudes NE Atlantic and the subtropical region south of New Caledonia in the tropics. The benefit of HR data is evident for scales up to 100 km. It illustrates both the gain brought by the Ka-band of Saral and the SAR mode of S3A over the Ku band of Jason and the benefit of the long time series of Jason data for the studies of internal tides. We emphasize the need to take into account the anisotropy and the very local nature of the ocean dynamics properties in order to assess regional dynamics.

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Deep learning for accurate SSH reconstruction from altimetry and SST observations

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_017

Abstract:
Two-dimensional sea surface height (SSH) reconstructions from satellite altimetry are widely used in studies of upper ocean dynamics. Nonetheless, accurate SSH reconstruction is challenging since observations are only made along widely spaced one-dimensional tracks, leaving large observational gaps. The widely used SSALTO/DUACS product implements optimal interpolation (OI) to reconstruct the SSH field from the along-track altimetry. However, OI introduces significant errors in regions of high eddy kinetic energy, where the dynamical timescales become comparable to the satellite return times. Improvements will likely be achieved if the interpolation procedure succeeds in accounting for the non-linear multi-scale dynamics of mesoscale ocean turbulence and its interactions with the evolving mean flow.

Recent studies across many disciplines demonstrate that Deep learning (DL) neural networks can reveal complex non-linear dependencies in large datasets, and we have adapted this approach to satellite altimetry. Here, we present an improved SSH reconstruction using a DL framework that is based on a convolutional long short-term memory architecture. In addition to satellite altimetry, we also utilised sea surface temperature (SST) observations to achieve a significantly lower SSH reconstruction error than existing interpolation methods. Tested on independent altimeter observations for a region of the Gulf Stream with an energetic mesoscale eddy field, our high-resolution reconstruction (7km grid) has about a 30% improvement in root-mean-square error relative to SSALTO/DUACS. While already providing a more accurate and higher-resolution SSH product, our DL framework could be improved in many ways, including using different types of existing ocean datasets and wide-swath observations from the upcoming NASA SWOT and ODYSEA missions.

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Ocean 2D eddy energy fluxes from small mesoscale processes with SWOT

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_018

Abstract:
Ocean mesoscale eddies are the most energetic component of the ocean dynamics, important for the horizontal fluxes of energy, momentum, and tracers such as heat, carbon and nutrients. Today, observations of smaller scales are limited, and we might be missing 75% of the mesoscale eddies at high latitudes. The future SWOT SAR-interferometry wide-swath altimeter mission aims to provide 2D swath observations of ocean surface topography to characterize the ocean mesoscale and submesoscale circulation from the large scale down to around 15 km wavelength. This research focuses on the understanding of this smaller mesoscale field in the Southern Ocean, with a focus on the Agulhas current. Our main aim is to investigate whether small-scale eddy fluxes reinforce or compensate for the large mesoscale fluxes that we can observe today, and where and when this is occurring. The study of mesoscale eddies and their interaction with the larger scale structures is achieved using various eddy diagnostics: the eddy kinetic energy (eke), strain rate, barotropic energy transfer, anisotropy of eddy variability, and energy flux between scales with a coarse graining approach. We compare the dynamics in key regions of the Agulhas boundary current, the Agulhas Retroflection and Cape Cauldron region, and the meandering Agulhas Current Extension. First, the dataset generated with the hourly MITgcm LLC4320 on a native grid at 1/48-degree is used. A comparison is made with today's observability using reconstructed DUACS maps, based on the optimal interpolation of the along-track sampling of the MITgcm at a coarser 1/10-degree resolution. For the observability with SWOT, diagnostics are finally computed on the simulated SWOT swaths, taking a sea surface height (ssh) based on the 1/48° MITgcm simulation and the SWOT ocean simulator, with and without the SWOT errors. The observable scales for these different diagnostics, and error reduction techniques for SWOT, will be discussed.

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Physically-consistent mapped altimetry products on user-customizable grids

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_019

Abstract:
Mapped sea surface height (SSH) anomaly products from satellite altimetry are already an integral part of modern oceanography, widely used in both scientific and operational contexts. However, we note three significant limitations of the present mapped products and distribution system. 1) The correlation function imposed by the most common mapped products is physically unrealistic and inconsistent with the underlying along-track observations. This correlation function, originally proposed in 1985, has good statistical properties in general but artificially steepens spectral slopes in mapped SSH products, essentially throwing away information about small scales. 2) Effective resolution, errors and uncertainties in mapped products are often misunderstood by oceanographers, leading to mis-application of altimetry products. 3) Scientists often require the SSH field on a custom grid, and either apply additional interpolation or improvise their own mapping procedures.

We attempt to address these three issues. Our approach is based on standard Gaussian process regression methods with a carefully chosen parametric covariance function that is consistent with observations. Covariance parameters (space and time decorrelation scales, spectral slopes, and propagation speeds) are estimated by Maximum Likelihood Estimation, and will be presented as part of the mapped data product. This presentation will primarily focus on the third issue. We introduce an open-source, reproducible tool that allows statistical SSH mapping on custom grids. The final distributed products are fully open source and flexible to meet the needs of scientists. The data are not constrained to a fixed grid, but will be provided in functional form, reproducing the interpolation and its error estimate at any point in time.

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High resolution SSH mapping with future satellite mission SWOT

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_020

Abstract:
Sea Surface Height (SSH) information is available all over the world thanks to satellite altimetry measurements. Data processing and mapping algorithms produce sea level products that are part of ocean monitoring variables. In order to provide this information to marine environment actors, Copernicus Marine Service Program (CMEMS) created an operational ocean mapping algorithm called Data Unification and Altimeter Combination System (DUACS). This processing system uses data provided by currently flying altimeters (Sentinel, Jason, SaRal...) and supplies two types of SSH products : L3 (along-track) and L4 (gridded map). Next generation altimeter satellite SWOT will be launched late 2022 and will embark a new sensor based on Ka band. It will display high resolution SSH measurements on both side of its track across two swaths of 50 km. This is a major breakthrough because existing altimeters can only measure SSH along their tracks by pointing at nadir. All scientists and engineers of DUACS are hoping for new mission SWOT to improve the quality of L3 and L4 products. In that sense, this study focuses on the improvement in resolution of L4 gridded products thanks to SWOT satellite. In order to answer that question, 3 OSSEs were carried out in order to evaluate the performances of 3 different kinds of SSH observation systems : a) 3 Nadirs, b) 1 SWOT and c) 3 Nadirs + 1 SWOT. By comparing OSSEs one another it will be possible to assess both the performances of SWOT compared to 3 nadirs satellites and the benefit when SWOT is added to a 3 nadirs constellation. Results show that SWOT has a higher spatial resolution than 3 Nadirs at high latitudes, which is due to its high spatial sampling. At mid latitudes, SWOT enables to detect smaller structures only in low variability zones. Within energetic western boundary currents such as Gulf Stream or Kuroshio, 3 Nadirs constellation has a better temporal sampling and provides higher spatial and temporal resolution. In order to confirm these diagnosis, eddy detection algorithms were launched on SSH recontructed maps. Results show that detected eddies density is correlated with higher spatial resolution zones. The OSSE computing 3 Nadirs + SWOT data shows that the benefit of SWOT is unequal over the globe. It improves the spatial resolution everywhere, with limited effect in Western boundary currents and along the Equator. Yet, temporal resolution can get worse when SWOT is added, especially in zones where barotropic current is poorly evaluated.

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Topological analysis of oceanographic time series

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_021

Abstract:
Topological tools from nonlinear dynamics are used to assess enduring near-surface Lagrangian aspects of the Malvinas Current. The procedure, known as BraMAH (Branched Manifold Analysis through Homologies) is a finite-dimensional and finite-time technique that enables distinguishing and classifying the different nonlinear processes at work in time series datasets (Charó et al, 2021, 2020, 2019, Sciamarella & Mindlin, 2001, 1999). Consistent results are obtained comparing datasets generated with simplified models proposed to understand chaotic advection in the ocean (Rypina et al, 2007; Koshel et al, 2006), with satellite-tracked drifter trajectories and trajectories computed from a multiyear record of velocities derived from satellite altimetry data (Beron-Vera et al, 2020). A family of topologically distinct dynamics is observed in the weakly communicating flow regions that were previously detected using metric -i.e. non topological- tools. This is the first time that the time-varying distributions of single-topology regions are obtained from altimetry data; each region being identified with a particular class of finite-time dynamics.

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Coastal-to-open ocean exchange in the California Current System from new altimetry

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Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32022_022

Abstract:
In the California Current System, exchanges between the coast and open ocean are modulated by small-scale transient eddy features. We assess the observability of these features using altimeter data from Sentinel 6/Jason-CS along with other high-resolution altimeter data from Jason-3, AltiKa, and Sentinel-3. We compare SAR-mode altimetry with Ku and C-band altimeter data from the high-resolution retracked altimeter data released as part of the ALES product. These observations are evaluated in the context of shipboard in situ observations from shipboard acoustic Doppler current profiler measurements and from the on-board thermosalinograph and with high-frequency radar measurements. A summer 2020 research cruise collected underway CTD observations along multiple transects across an eddy, providing a useful measure of sea surface height compared with in situ steric height. Altimeter data are used to assess the scales of variability that dominate cross-shelf exchange and the mechanisms responsible for coastal-to-open ocean exchange.

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A study of SWIM directional wave spectra during rogue wave cases

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Session: CFOSAT
Presentation type: Poster
Poster number: CFO2022_001

Abstract:
The transition from wind waves to swell is accompanied by strong non-linear interactions between several wave components and also kinematic effect in presence of strong surface currents. This can lead to dangerous seas and appearance of rogue waves which need to be better forecasted for the marine safety and ship navigation. Since 2019 the SWIM instrument onboard the CFOSAT satellite mission has shown its high capacity to observe the wave directional properties for wavelength ranges from wind-wave to swell (e.g dominant wavelength between 70 and 500 m). Further directional and frequency spreading computed from SWIM wave spectra are key parameters for setting a rogue wave indicator, particularly in crossing seas conditions (Le Merle et al. 2021).
The goal of this work consists in studying cases of rogue waves and investigating whether the probability of occurrence of rogue waves is related to the specific shape of the directional wave spectra obtained with the SWIM instrument.
The wave observation of rogue or abnormal waves has been considered from the buoys of the in-situ Thematic Assembly Center network of Copernicus Marine Service (CMEMS). Only the buoy observing maximum wave height (Hmax) and with peak period greater than 8 seconds have been used. The unstable character of dangerous seas is described by the observed ratio of Hmax and Significant Wave Height (Hmax/SWH). The crossovers of buoys and CFOSAT tracks has been selected during 2020 and 2021.
Firstly, we discussed an interesting event which indicates a rogue wave case occurring during a mature and powerful storm in western Australia during the austral winter. During this event the Hmax reaches 18 meters and SWH of 8 meters is recorded. The wave spectrum from SWIM indicates a superposition of mixed sea condition with an established long wind sea that has been generated by 35 knots steady winds, and a powerful swell. Moreover, other cases of more calm sea state but with abnormal Hmax will be briefly presented. The wave spectra associated with normal sea will also be used to define possible specific features of the spectra associated with abnormal Hmax. We have examined the relationship between the SWIM spectra and the buoys observations, particularly by using extreme indicators such as 2D Benjamin and Feir instability (BFI2D) and kurtosis.

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In-situ measurements for altimetry cal/val: overview of the H2020 CCVS project

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Poster
Poster number: ERR2022_001

Abstract:
The objective of the H2020 project “Copernicus Cal/Val Solution (CCVS)” (https://ccvs.eu/) is to define a holistic Cal/Val strategy for all ongoing and upcoming Copernicus Sentinel missions. CCVS will identify gaps and propose long-term solutions to address currently existing constraints in the Cal/Val domain and exploit existing synergies between the missions. The project started end of 2020 for two years.
An exhaustive review of all CAL/VAL aspects has been made to identify the major gaps. In this presentation, we will focus on the in-situ data and campaigns for altimetry topics.
First, the main results of the survey on the in-situ measurements available for the altimetry CAL/VAL will be presented. Secondly, the gap analysis will be performed.
In-situ measurements and campaigns are used to better characterize some errors of the instruments and, mostly, to qualify the level 2 products. The ground algorithms are improved by comparing their results with these measurements. They also play an important part for climate monitoring. For this topic, the determination of the systematic and random uncertainties is a key issue. These measurements enable also to prepare for future missions.
The in-situ networks, used for Cal/Val of altimetry sensors, are of three main kinds:
• In-situ facilities deployed specially to qualify the altimetry products, deployed under satellite tracks, mainly with multi-missions' coverage (for instance, tide gauges or GNSS-based instruments for Sea Surface Height),
• In-situ facilities deployed specially to characterize instrumental error sources (for instance, transponders for altimeters),
• In-situ facilities dedicated to other purposes and used as opportunities (this is the case for many networks).
Some campaigns are deployed to prepare future missions or to better characterize surfaces with few observations (ice sheet, hydrology).

FIDUCIAL REFERENCE MEASUREMENTS SITES
Several key sites have been identified around the world. They are located on cross-overs of altimetry mission tracks and often overflown by more than two different missions. Most of them are designed for ocean variables (Corsica, Crete for Europe) but there are also hydrological ones such as the Parintins (Brazil) site over the Amazon river and the Issykkul site (Kirghizstan) which has been used for over 15 years. These sites can be qualified as “FRM sites for altimetry”. Note that an ESA project, FRM4ALT, covers the CRETE site.
These sites are hosted by different organizations (Universities, Research Labs, etc.) and receive funding from national agencies, space agencies or European entities. They often rely on national partnerships to support in-situ equipment (one country provides the equipment; another country hosts them). The processing is performed by the entities in charge of the sites but collaborative efforts have been made over many years to homogenize the processing systems into a standard system (e.g. considering geodetic corrections etc) even though realized at best effort.

ACTIVE MEASUREMENTS: SIGNALS SENT TO THE SATELLITES
A few sites use active ground sensors or reflection signals pointing at the satellite to calibrate some physical measurements. In the altimetry field, we can identify the following:
• The ILRS (laser reflectometry) network which provides very accurate measurements on satellite orbits, a great validation for the POD solutions.
• Radar transponders designed especially for the altimeters.
The transponders have very specific design adapted to each altimeter. Located at the nadir below the satellite, they re-emit the altimeter waveforms once received. Its own calibration remains difficult but it is operational for several missions (JA3, S3, S6-MF) and ESA aims at having a new location to complement the CRETE site.

OPPORTUNITY NETWORKS
At large scale, the Cal/Val of altimetry missions rely mainly on “opportunity networks” where in-situ data which are not collected for space purposes become key data for Cal/Val activities (e.g. buoy networks).

The in-situ networks are often gathered in “networks of networks”. Countries aggregate their in-situ facilities, often under the UN aegis. The data are open access but the processing may depend on each country, as well as the design of the sensors and the calibration process. Some national entities gather the available data and use their own harmonized process (for instance, the CMEMS in-situ TAC for all oceanic observations or the NDBC for buoys). Some confusion can result from the same original measurements being accessible via several routes and with different processing pathways.

The presentation will detail the main networks we are using for altimetry CAL/VAL. Our objective is to underline the gaps but also the assets to propose the best CAL/VAL solutions for the Copernicus system.

This project has received funding from the European Union’s Horizon 2020 research and innovation program under the grant agreement

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Validation of altimetry by using in situ observations of pressure and acoustic travel time in the Southern Ocean

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Poster
Poster number: ERR2022_002

Abstract:
In large parts of the Southern Ocean stratification and dynamics are relatively uniform and allow the application of the "Gravest Empirical Mode" (GEM) concept. Among other characteristics, the concept describes how variations of heat content are linearly related to those of salt content and steric height. The slope of the function depends on the local stratification. Furthermore heat content variations are a function of vertical acoustic travel time. This leads to the conclusion that measuring ocean bottom pressure (OBP) and vertical travel time with pressure inverted echo sounders (PIES) allows us to calculate sea surface height anomalies. The concept has been developed during the Sub-Antarctic Flux and Dynamics Experiment (SAFDE) experiment south of Australia (Sun et al., 2001). Its validity has been confirmed south of Africa (Behnisch et al., 2013).
In previous studies GEM was primarily applied by using altimetry and learn about the stratification of the ocean. Here we turn the question around and try to use in situ observations to predict and explain altimetry using GEM. An array of 13 PIES deployed south of Africa was used to generate oceanic sea surface height variability estimates. These are compared to multi satellite altimetry analysis produced by AVISO, and along track estimates from the Radar Altimetry Database (RADS). We present variances, correlations and patterns of variability of the measured signals and their differences.

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Quality flag and uncertainties of water surface height over Inland waters

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Poster
Poster number: ERR2022_003

Abstract:
Inland waters are essential for environmental, societal and economic services such as transport, drinking water, agriculture or power generation. But inland waters are also one of the most affected resources by climate change and human populations growth.
Altimetry, which has been used since 1992 for oceanography, has also proven to be a useful tool to estimate inland water surfaces such a rivers and lakes, which are considered Essential Climate Variables (ECVs). the heterogeneity of the targets size, surfaces roughness etc… and the surrounding environment near the water targets make the interpretation of the measurements more complex. In addition, the availability of a measurement must be complemented by the confidence that it can be attributed to the estimation of the water surface height and providing the uncertainty associated with this measurement will be useful for assimilations and downstream products.
The aim of this presentation is to describe the use of a waveform classification method, based on neural network algorithms, on level 2 data in order to identify reliable measurements on water body targets. This classification can be used as a metric for data quality and is therefore incorporated in the data processing to define a quality flag in the inland product. The quality flag is being implemented in two ESA projects using data for the reprocessing of several missions data: FDR4ALTwith data from ENVISAT, ERS-2 and ERS-1 missions and CryoTempo with data from Cryosat2. Secondly, it aims at the presenting the methodology for estimating the uncertainty on the estimated water level.

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A Trihedral Corner Reflector to Support Radar Altimeters External Calibration

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Poster
Poster number: ERR2022_004

Abstract:
Radar altimeters require periodic external calibration to monitor the instrument drifts that are not covered by the internal calibration paths. These activities are normally performed by acquiring data over active transponders and analysing the performances. European radar altimeters such as CryoSat-2, Sentinel-3 A/B and Sentinel-6A rely on transponders on Svalbard and Crete to monitor their stability, while usage of passive reflectors for radar altimeter calibration has been not feasible as the required size for the corners was to big to achieve acceptable signal-to-clutter ratios (SCR).

Nevertheless, recent developments in radar altimeter SAR-based algorithms allow now to obtain high resolution data in the along-track dimension by recombining all the echoed pulses within the illumination time in a coherent way. These new algorithms, known as Fully-Focussed SAR (FFSAR) algorithms, increase the SCR while drastically reducing the along-track resolution from the current ~300 m obtained with Unfocussed SAR (UFSAR) processing to sub-meter scale.

Being aware that such improvement in resolution represents a new opportunity for passive reflectors, a trihedral corner reflector was designed and installed by isardSAT in one summit of the Montsec ridge in the Pyrenees in April 2021, about four kilometers from cross over between Sentinel-6A and Sentinel-3B. Successful acquisition of the Sentinel 6A have been performed since July 2021. Sentinel-3B is expected to include the corner reflector in the list of calibration targets in the following OLTC update.

We present the Sentinel-6A and Sentinel 3B range, datation and sigma0 results using Corner Reflector. Along-track and across-track resolutions are also computed to monitor the stability of the PTR instrument behaviour. Preliminary Sentinel-6 results have confirmed the corner reflector feasibility as the performances obtained present similar accuracy and precision as the ones from transponders.

Corner reflectors could play a role in future calibration of radar altimeters, especially due to their ease of installation, maintenance and long term stability.

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On the uncertainty associated with detecting global and local mean sea level drifts on Sentinel-3A and Sentinel-3B altimetry missions

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Poster
Poster number: ERR2022_005

Abstract:
An instrumental drift in the Point Target Response (PTR) parameters has been detected on the Copernicus Sentinel-3A (S3A) altimetry mission. It could have an impact on sea level rise of a few tenths of mm yr−1. In order to accurately evaluate this drift, a method for detecting global and local mean sea level relative drifts between two altimetry missions is implemented. Associated uncertainties are also accurately calculated thanks to a detailed error budget analysis. A drift on both S3A and S3B GMSL is detected with values significantly higher than expected. For S3A, the relative GMSL drift detected is 1.0 mm yr−1 with Jason-3 and 1.3 mm yr−1 with SARAL/AltiKa. For S3B, the relative GMSL drift detected is −2.2 mm yr−1 with SARAL/AltiKa and −3.4 mm yr−1 with Jason-3. The drift detected at global level does not show detectable regional variations above the uncertainty level of the proposed method. The investigations led by the altimeter experts can now explain the origin of this drift for S3A, while it is still under investigation for S3B. The ability of the implemented method to detect a sea level drift with respect to the length of the common period is also analysed. We find that the maximum detectable sea-level drift over a 5 years period is 0.3 mm yr−1 at the global scale, and 1.5 mm yr−1 at local scales (2400 km). However, these levels of uncertainty do not meet the sea-level stability requirements for climate change studies.
Preprint available at https://os.copernicus.org/preprints/os-2021-106/
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Propagating uncertainties and error correlation structures through retracking and sea state bias correction

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Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Poster
Poster number: ERR2022_006

Abstract:
What is the uncertainty budget in deriving Global Mean Sea Level (GMSL) from satellite altimetry? This is one of the questions to be addressed within the framework of the ESA-funded project Assessment Sea Level rise Stability Uncertainty, ASeLSU. ASeLSU is approaching this question in a metrological manner which entails a full breakdown of all sources of uncertainties arising from the altimeter and assessment of error correlation structures to quantify the uncertainty budget.

From acquiring the radar backscatter to forming a waveform and estimating the GMSL, many processing steps are involved, which makes the uncertainty analysis intricate. This is especially true considering that components such as the altimetric range and sea state bias correction are not derived independently. Four primary parameters – epoch, sigma-0, significant wave-height, and mis-pointing angle – are derived from the most common retracking used MLE4 (Amarouche et al., 2004). Two of these parameters, sigma-0 and significant wave-height, are used to estimate the wind speed, which in turn is used with significant wave-height (again) to determine the sea state bias correction.

In this study, we performed simulations using simplified retracker algorithms to understand the extent of possible error correlations between the different quantities derived from retracking, and to propagate those through to sea state bias and the ionosphere correction.

Amarouche et al., 2004: https://doi.org/10.1080/01490410490465210

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On the assimilation of LR and HR Sentinel-6MF wave data in wave model : Assessement and perspectives

Lotfi Aouf (Division Marine et Océanographie Météo-France, France); Alice Dalphinet (Meteo France, France)

Session: Sentinel-6 Validation Team (S6VT) feedbacks
Presentation type: Poster
Poster number: S6VT2022_001

Abstract:
To keep the reliability of wave parameters from Copernicus Marine Services (CMEMS) at a good level, it is important to update the assimilation system in wave model with new altimeter mission such as Sentinel-6MF (S6MF). This work consists in assessing the impact of using Significant Wave Height (SWH) from S6MF in global and regional operational wave model MFWAM. We implemented long period assimilation experiment of low resolution SWH from S6MF latest level 2 processing for both SAR and LRM modes. The validation of model output have been performed in comparison with independent wave data from altimeters and buoys. The results shows significant improvement of scatter index of SWH in average by ~15 %. We also remarked a better performance for the assimilation of retrieved SWH from SAR mode compared to the ones provided by LRM (MLE3) in different ocean basins namely, high and mid latitudes and the tropics.
The most striking result concerns the capacity of S6MF to correct efficiently high SWH exceeding 15 m such as ones observed in severe storms at the Southern Ocean.
In this work we also examined the impact of high resolution SWH (20Hz) from S6MF. To this end we implement a robust filtering to remove corrupted data particularly in coastal areas. Assimilation runs have been performed for regional (Iberian-Biscay-ireland) high resolution configuration of the model MFWAM with a grid size of 2 km. The assimilation scheme has been adapted in terms of correlation length in the optimal interpolation scheme.
We perfomed a comparison between the assimilation of HR SWH from S6MF and the assimilation of 5Hz SWH provided by CFOSAT. The validation of the results have conducted with coastal buoys network provided by CMEMS in situ TAC. Further we investigated the use of directional wave spectra from CFOSAT in order to analyse the quality of HR SWH depending on long swell conditions.
More comments and conclusions will be summarized in the final presentation.

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Sentinel-6 Processing Prototype data release

Claire Maraldi (CNES, France); Salvatore Dinardo (CLS, France); Emeline Cadier (CLS, France); Adrien Guérou (CLS, France); Thomas Moreau (CLS, France); François Boy (CNES, France); François Bignalet-Cazalet (CNES, France); Nicolas Picot (CNES, France); Cristina Martin-Puig (EUMETSAT, Germany)

Session: Sentinel-6 Validation Team (S6VT) feedbacks
Presentation type: Poster
Poster number: S6VT2022_002

Abstract:
Launched on 21 November 2020, Sentinel-6 Michael Freilich is a Copernicus satellite designed to ensure the continuity to the mean sea level climate time series measured by the TOPEX/Poseidon and Jason satellites since 1992. The main payload instrument carried on-board Sentinel-6 is the Poseidon-4 (POS4) dual frequency radar altimeter. POS4 uses a 9 kHz Pulse Repetition Frequency and an innovative interleaved chronogram which allows the optimization of the number of measurements acquired. Like this interleaved mode enables the acquisition of two modes in parallel: a Low Resolution Mode (LR) which aims in extending the legacy of the mean sea level record, and a High Resolution Mode (HR) or Synthetic Aperture Radar Mode (SAR) that significantly improves the along-track spatial resolution and reduces measurement noise. Downlink of both LR and HR data is enabled thanks to the on-board Range Migration Correction (RMC) algorithm which allows HR data volume reduction.

Developed in the frame of the CNES/CLS R&D activities, the Sentinel-6 Processing Prototype (S6PP) allows implementation and validation of innovative algorithms for S-6 MF for both LR and HR data processing. Among these recent developments, some have been endorsed for future implementation in the PDAP operational ground segment. In particular, future PDAP versions will benefit from the implementation of the so-called numerical retracking in both LR and HR, aiming at taking account for any instrumental evolution. Also HR data processing will include correction for range walk effect which affects both SWH estimations and Sea Level Anomaly long term estimations, and for vertical wave velocity effects via HR LUT computed and provided by NOAA.

In this presentation we present the data quality of an S6PP expertise dataset in order to prepare users for the future PDAP evolutions. It consists in a one year dataset processed with S6PP, from PDAP L1B LR and L1A HR products, and including the PDAP geophysical corrections. Both LR and HR data are assessed, and particular attention is given to the GMSL continuity with Jason-3.

The dataset can be downloaded by the users on the AVISO website.

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Sentinel-6-MF Poseidon-4: Main results from the first year and half of mission from the S6PP LRM and HRM Chain

Salvatore Dinardo (CLS, France); Emeline Cadier (CLS, France); Thomas Moreau (CLS, France); Claire Maraldi (CNES, France); Francois Boy (CNES, France); Adrien Guerou (CLS, France); Nicolas PICOT (CNES, France)

Session: Sentinel-6 Validation Team (S6VT) feedbacks
Presentation type: Poster
Poster number: S6VT2022_003

Abstract:
Sentinel-6 is an Earth Observation satellite constellation part of the EU Copernicus Programme developed by ESA, operated by EUMETSAT in collaboration with NASA, NOAA and CNES. The first satellite of the Sentinel-6 constellation (Sentinel-6 Michael Freilich, S-6 MF in short) has been launched on 21 November 2020.
The S6-MF satellite embarks as main scientific payload the sensor Poseidon-4 (POS4) which is a dual frequency redundant radar altimeter. It represents a significant breakthrough with respect to its predecessors Jason-class altimeters thanks to its digital architecture based on an on-board digital matched-filtering.
In the frame of the exploitation of the S6 MF altimetry mission, CNES has contracted CLS for the development of the Sentinel-6 Processing Prototype (S6PP). S6PP is a multi-chain (LRM, UF-SAR, FF-SAR, Pulse-Pair, Transponder) processor in which the novel algorithms developed in the CNES/CLS R&D activities are implemented and validated in support to the different thematic applications and in view of promoting them for a possible implementation in operational ground segment.
The present work covers in particular the main results over open ocean for the main altimetric geophysical measurements the LRM (Low Resolution Mode) and High Resolution Mode (HRM, also known as UF-SAR) chains of S6PP in terms of precision, accuracy and spectral content in Ku band.
Given the POS4 sensitivity to in orbit temperature variations, the instrument drift and the requirement to measure the GMSL (Global Mean Sea Level) in seamless continuity with Jason-3, the mandate for S6PP was to process the S6-MF with minimum possible level of approximations along the processing chain.
Hence, for this purpose, novel algorithms have been developed and implemented inside the S6PP LRM chain, as:
o LRM Physics-Based Waveform (frequency-domain) Model [REF6] with possibility to set in input the ocean skewness coefficient (as 0.1 per Jason heritage)
o Numerical LRM Retracking based on In-Flight PTR or on Theoretical PTR (sinc**2)
o Possibility to retrack the LRM waveform built on board (LRM I2Q2) or the one built on ground from HRM RAW/RMC L1A data products

and also inside the S6PP HRM chain, as:
o Beam-Forming carried-out by Chirp-Zeta Transform (CZT) in the approximate beam-steering configuration in order to correct for the range-walk effect [REF1] with only a limited increment of CPU time (10%)
o Possibility to use different multi-look number in building the waveform in order to be less impacted by the ocean surface motion effect as orbital wave velocity [REF2]
o Posting Rate of the SAR waveforms at the standard 20 Hz or higher [REF3, REF4, REF5]
o SAR Physics-Based (frequency-domain) Waveform Model [REF6] with possibility to set in input the ocean skewness coefficient (as 0.1 per Jason heritage)
o Numerical SAR Retracking based on In-Flight PTR or on Theoretical PTR
o Delay-Doppler Map ambiguities natively modelled in the SAR waveform Model [RE7]

The input data products are from STC latency for the HRM chain and NTC for the LRM chain; however, the orbits have been updated for both chains using the JPL ones.
Furthermore, it was decided in LRM mode to retrack the LRM waveform built on board (LRM I2Q2) at full PRF.
The ionospheric and wet tropospheric correction will be the one from Jason-3 in order to have a homogeneous set of geophysical corrections for the whole mission time.
The entire first year of S-6 MF data (from beginning of the Tandem Phase) have been processed in the afore-said baselines for the LRM and HRM data flavors and the GMSL in both the modes will be derived and compared to Jason-3 in order to verify the continuity between the two missions in LRM and HRM.
Finally, the LRM data will be processed with and without the In-Flight PTR in order to assess the impact of the In-Flight PTR shape evolution in term of sea level stability, considering the strong aging reported by S6 MF POS4 altimeter.
The In-Flight PTR will be the one built from the ECHO-CAL calibration data.
Instead, the HRM data will be processed with a beam-forming based on CZT (with a range walk correction) and with a beam-forming based on Fast Fourier Transform (i.e. no range walk) in order to assess the impact of the

range walk effect on the S6-MF sea level stability. The impact of the ocean topography skewness in HRM will be also addressed and even estimated for the first time from the HRM data in order to confirm the heritage average value of 0.1

The reference dataset for the spectral analysis and stability validation will be Jason-3 dataset.

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[REF2] https://doi.org/10.3390/jmse8060447
[REF3] https://www.aviso.altimetry.fr/fileadmin/documents/OSTST/2013/posters/Dinardo_coastal.pdf
[REF4] https://doi.org/10.1016/j.asr.2020.03.014
[REF5] https://doi.org/10.1016/j.asr.2020.09.037
[REF6] https://doi.org/10.1016/j.asr.2017.11.039
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Sentinel-6 MF Poseidon-4 Radar Altimeter In-Flight Calibration and Performances Monitoring

Salvatore Dinardo (CLS, France); Claire Maraldi (CNES, France); Jean-Alexis Daguze (CLS, France); Samira Amraoui (CLS, France); Francois Boy (CNES, France); Thomas Moreau (CLS, France); Nicolas Picot (CNES, France)

Session: Sentinel-6 Validation Team (S6VT) feedbacks
Presentation type: Poster
Poster number: S6VT2022_004

Abstract:
Poseidon-4 is a dual frequency redundant radar altimeter, embarked on board of European Commission Copernicus Programme Sentinel-6 MF satellite, which represents a significant breakthrough with respect to its predecessors Jason-class altimeters thanks to its digital architecture (based on an on-board digital matched-filtering) and to novel internal calibrations modes.
In this work, we assess Poseidon-4 main instrumental improvements and performances, with the presentation of the more important outcomes from the In-Flight internal calibration modes and from an external calibration analysis over a transponder.
The instrumental performances of the radar altimeter, as verified from its internal calibrations, are excellent: Poseidon-4 delivers a range/azimuth instrument impulse response with the highest quality and fidelity in the age of space-borne radar altimetry and its thermal noise response is almost at level of random noise, and this both for its nominal and redundant side.
A significant power decay of the level of the transmitted power in Ku Band has been detected both for the nominal and redundant side, which will not lead anyhow to a violation of the mission requirement of the minimum signal-to-noise ratio over ocean at the end of the expected satellite life (5.5 years).
The novel CAL1 ECHO-CAL calibration mode allows to characterize very precisely the sensitivity of the instrument impulse response to the in-orbit temperature variations: this has been estimated to be of +0.3 mm for the range and of +0.01 dB for the power in Ku Band. Furthermore, the novel CAL1 INSTR mode successfully allows the monitoring of the transmitted chirp and, in case, to update the chirp replica used on-board for the pulse compression in order to recover for any significant degradation in the impulse response quality during the course of the mission life.
The PTR sidelobes in Ku Band do not evolve in a perfect symmetrical manner between the left-hand side and right-hand side but some deviations have been registered for side-A (0.5 mm and 0.025 dB after 10 months). The impact of these dis-symmetries on the range measurement stability will be analyzed in a separate work (S6PP science results, abstract submitted in the same session).
The external calibration by transponder analysis highlights a very small end-to-end range bias and a time-tag bias.
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A new method for estimating steric mean sea surface dynamic height in MOVE system combining in-situ profiles and sea level anomalies

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Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Poster
Poster number: GEO2022_001

Abstract:
A new estimation method for the mean sea surface dynamic height (MSDH) is applied for a variational ocean data assimilation system developed in the Meteorological Research Institute, Japan Meteorological Agency (MOVE system). MOVE system constrains temperature and salinity as state variables (Fujii and Kamachi, 2003) with assimilating in-situ profiles, sea surface temperature, and sea level anomalies (SLAs). For the calculation of the cost function associated with the SLAs, a MSDH is necessary to refer to the model sea surface dynamic height (SDH). A conventional MSDH in the MOVE system is produced by assimilating temperature and salinity from the in-situ profiles during 1993-2012 on the climatology of World Ocean Atlas without numerical simulations. However, it significantly depends on the density of the observations. For instance, it is difficult to conduct in-situ observations in winter in the Sea of Okhotsk, where sea ice covers sea surface. In addition, the number of the observation in the 1990s, before the deployment of the Argo floats, was sparse compared to the 2000s, after the deployment of the Argo floats. A new MSDH proposed here is estimated by subtracting the observed SDH, which is calculated by using in-situ profiles, from the SLAs. It can reduce seasonal dependency of the in-situ observations and extent the period of SLA data from 1993 to the latest. The MSDH used in the MOVE system consist of a steric component while the observed SLAs includes both steric and non-steric components. The non-steric variations derived from the barotropic response to atmospheric forcing and the global ocean mass change must be corrected, and the correction was conducted based on the method in Hirose et al. (2019). The steric MSDH values on each in-situ profile referenced 2000 m depth are gridded on the eddy-resolving model for the North Pacific Ocean. The new MSDH shows a similar spatial pattern against the conventional MSDH and has a bias of 0.5 cm averaged over the whole domain, indicating that the new approach basically worked well. In the south of Japan, however, the significant differences between the new and conventional MSDHs, which are larger than 10 cm, were obtained corresponding to the shift of the mean Kuroshio axis. We will present an impact of the new MSDH on the MOVE system in the presentation.

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An approach for regional coastal sea surface topography for vertical datum transformation using retracked-altimetry, water level gauging and airborne gravity based geoid model

Inseong Jeong (NOAA, United States); Stephen White (NOAA, United States)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Poster
Poster number: GEO2022_002

Abstract:
Altimetry based ocean surface topography is crucial for deriving global/regional ocean surface current via geostrophy. To this end, many global/regional MSS (mean sea surface) or MDT (mean dynamic topography) models have been developed, primarily in a geodetic sense, sea surface topography is a direct representation of vertical separation between sea surface and a reference equipotential surface (i.e. geoid surface). Therefore, sea surface topography is another crucial input for vertical datum transformation such as transforming ellipsoid height to MHW (mean high water) tidal datum. NOAA's VDatum is a comprehensive suite of tools for performing vertical transformations among a variety of tidal, orthometric and ellipsoidal vertical datums (https://vdatum.noaa.gov), allowing to convert geospatial data from different horizontal/vertical references into a common system. Generating a topography of sea surface for datum transformation (or datum TSS) is different in many ways from developing the existing MDT models for deriving ocean current. The main objective is to better model a vertical separation of sea surface itself from the reference geoid surface, not only producing accurate sea surface slope/gradient, which is necessary for estimating ocean current, also placing an emphasis on nearshore estuary and riverine upstream areas where vertical datum transformations are frequently applied for coastal hazard planning purposes. Therefore we propose an approach to create a regional datum TSS for VDatum by integrating i) retracked altimetry SSH (sea surface height) data with custom geophysical corrections and vertical offset adjustment referenced to NOAA's water level gauges; ii) GNSS campaigned water level gauge input to merge with altimetry SSH; iii) airborne gravity based geoid model (xGeoid20B model from NOAA's National Geodetic Survey) that provides enhanced coastal gravity signal and helps reduce errors coming from nearshore SSH.

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A new combined mean dynamic topography model – DTUUH22MDT

Per Knudsen (DTU Space, Denmark); Ole Andersen (DTU Space, Denmark); Nikolai Maximenko (University of Hawaii at Manoa, IPRC, Honolulu, USA); Jan Hafner (University of Hawaii at Manoa, IPRC, Honolulu, USA)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Poster
Poster number: GEO2022_003

Abstract:
Initially, a new geodetic mean dynamic topography model DTU22MDT is derived using the new DTU21MSS mean sea surface. The DTU21MSS model has been derived by including re-tracked CRYOSAT-2 altimetry also, hence, increasing its resolution. Some issues in the Polar regions have been solved too. The geoid model was derived within the ESA supported Optimal Geoid for Modelling Ocean Circulation (OGMOC) project. It was based on the GOCO05C setup, though the newer DTU15GRA altimetric surface gravity was used in the combination. The OGMOC geoid model was optimized to avoid striations and orange skin like features. Subsequently the model had been augmented using the EIGEN-6C4 coefficients to d/o 2160.
The processing scheme used for deriving the new geodetic MDT is similar to the one used for the previous geodetic DTU MDT models. The filtering was re-evaluated by adjusting the quasi-gaussian filter width to optimize the fit to drifter velocities. Subsequently, the drifter velocities are integrated to enhance the resolution of the MDT model. Weights and constraints are introduced in the inversion and tuned to obtain a smooth model with enhanced details. A special concern is devoted to the coastal areas to optimize the extrapolation towards the coast line. The presentation will focus on the coastal zone when assessing the methodology, the data and the final model DTUUH22MDT.
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The new CNES-CLS 2022 marine gravity anomaly model: first validation in the Mediterranean

Philippe Schaeffer (CLS, France); Sean Bruinsma (CNES, France); Franck Reinquin (CNES, France)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Poster
Poster number: GEO2022_004

Abstract:
A new model of marine free-air gravity anomalies has been determined. It is based on the same data set used in the CNES CLS 2022 Mean Sea Surface determination. Particular attention was paid to the shortest wavelengths of less than 30 km. Furthermore, data sampling at 1 Hz (~7km) along track is not sufficient in this context. It is necessary to focus this new determination on the use of high-resolution data that are provided by a new generation of altimeters such as the Cryosat-2 (20 Hz) and SARAL (40 Hz) missions in the geodetic/drifting phase. However, at this rate, observations are too noisy and need application of a dedicated optimal filter.
We will present a validation of this new model based on a comparison with existing models, which were also derived from altimetry data.

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Sentinel-3 Altimetry Thematic Data Product for cryosphere & benefits of the Sentinel-3 Validation Team

Clément Lacrouts (ACRI-ST, Italy); Pierre Féménias (ESA/ESRIN, Italy); Stefano Vignudelli (CNR, Italy); Ghita Jettou (CLS, France); Matthias Raynal (CLS, France); Laïba Amarouche (CLS, France); Alan Muir (UCL, UK); Malcolm McMillan (University of Lancaster, UK)

Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_001

Abstract:
With the launch of Sentinel-3A (2016) and Sentinel-3B (2018), the Copernicus programme has a constellation of two SAR altimeters, which provides an operational access to inland Water Surface Height (WSH) data (i.e., lakes and rivers), with outstanding product performance and data coverage.
To further improve the performance of the Sentinel-3 Altimetry LAND products, ESA is developing dedicated and specialized Level-1 and Level-2 processing chains for all S3 Altimetry Land surfaces, i.e., over Inland Waters and Cryosphere. The so-called Thematic Instrument Processing Facilities (T-IPF) are developed by ESA for the processing of (1) Inland Waters, (2) Sea-Ice, and (3) Land Ice areas.
The new T-IPFs are currently under development with an intended deployment by Q4 2021. The T-IPF's will include specific evolutions, with in particular the implementation of Hamming and Zero Padding to the Delay Doppler processing for inland water surfaces. These evolutions will improve water level accuracy in the Level-2 Inland Water data product. The coverage of the respective Thematic Data Products will be limited to the respective thematic area, defined by S3 land thematic mask.
The Sentinel-3 Validation Team (S3VT) is an international team of leading scientists and engineers – regularly meeting every year – that works in the assessment and the Cal/Val of the Sentinel-3 data products, through field experiments and comparisons. In this frame, all valuable and relevant activities made over inland waters are presented and discussed. The benefits for experts interested in joining the Sentinel-3 Validation Team community will be explained, as well as the procedures to become a member of this dynamic community. Proposals of new validation activities are very welcome and can be submitted.

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Sentinel-3 Altimetry Thematic Data Product for inland waters & Sentinel-3 Validation Team benefits

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_002

Abstract:
With the launch of Sentinel-3A (2016) and Sentinel-3B (2018), the Copernicus programme has a constellation of two SAR altimeters, which provides an operational access to inland Water Surface Height (WSH) data (i.e., lakes and rivers), with outstanding product performance and data coverage.
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Towards long term sea ice volume series from altimetry in the Antarctic

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_003

Abstract:
The main difficulties to retrieve sea ice thickness and volume in the southern ocean come from the lack of in-situ observation and knowledge related to sea ice properties. For instance, whereas in-situ observations in the Arctic have enabled to construct snow depth climatologies (e.g the Warren climatology), there are no equivalent snow depth data in the Austral. By consequence, except for a few studies such as Zwally et al, 2008, Kurtz and Markus, 2012 and more recently Kacimi and kwok, 2020, mainly based on based on ICESat's data, no valid sea ice thickness estimations have yet been drawn apart from an experimental ESA-SICCI product (available on the CCI Data Portal, http://cci.esa.int/data), but it does not currently extend beyond the 2016 winter.

In this context, the objective of this presentation is to review the recent developments on sea ice volume estimations in the southern ocean conducted in the framework of an ESA Living Planet Fellowship and the ESA CSAO+ project.
We will first present and compare two radar freeboard solutions calculated from the CryoSat-2 data. The first solution is based on the commonly used TFMRA50 retracker and the second solution has been derived from altimetric ranges calculated on the GPOD platform with the SAMOSA+ physical retracker. Then, we will describe the methodology used to recalibrate the Envisat Low Resolution Mode (LRM) on CryoSat-2 Synthetic Aperture radar (SAR) mode in order to provide homogeneous freeboard estimations.
In a second part, we will evaluate the recent altimetric snow depth product (ASD) computed from the difference of radar penetration between the SARAL/AltiKa Ka-band and the CryoSat-2/SIRAL ku-band radar frequencies (Garnier et al, 2021).
The ASD data will be used to compute the first 100 % altimetric SIT estimation that should also mimic the future CRISTAL mission datasets. This estimation will be compare with the ESA-SICCI product that considers the AMSR passive radiometer snow depth data. In addition, first elements of validation are presented by comparison with some Upward Looking Sonar data (ULS, Behrendt et al, 2013), transects measurements during the Sea Ice Mass Balance in the Antarctic, (SIMBA, Lewis, 2011) and the ICESat's data.
Finally, we will present and analyse tendencies of 2003-2020 sea ice volume time series in the Antarctic.

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Machine Learning based Classification of Lake ice and Open water from SAR Altimetry waveform parameters

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_004

Abstract:

Lakes cover a significant fraction of the landscape in many northern countries and play a key role in regulating weather and climate. Lakes also have a significant impact on northern communities since the presence (or absence), extent and thickness of lake ice affect transportation (ice roads), food availability, recreational activities, and tourism in wintertime. The recent decline in in-situ observations of lake ice phenology (i.e., freeze-up and break-up dates, and ice cover duration) and lake ice thickness makes remote sensing technology a viable means for monitoring lake ice conditions. Although satellite altimetry has been used in various cryospheric studies, little work has been conducted on lake ice compared to sea ice, for example. This study was conducted at Great Slave Lake, Northwest Territories, Canada, using Sentinel-3A/B SRAL Level 2 data from June 2018 to December 2020. Reflections of radar altimeter echoes differ with properties/conditions of the target and the resulting radar returns contain information about the target surface. Hence, we explored information provided by waveforms to discriminate between open water and lake ice based on machine learning. To characterize the waveforms, five waveform parameters were extracted: Leading Edge Width (LEW), Offset Center of Gravity (OCOG) Width, Pulse Peakiness (PP), backscatter coefficient, and the maximum value of the echo power. Random Forest (RF) and Support Vector Machine (SVM) classifiers were selected to perform along-track classification of open water and lake ice. Class labelling was performed manually via visual interpretation of Sentinel-3 SRAL Level 2 waveforms, Sentinel 2 MultiSpectral Instrument (MSI) Level 1C data, and MODIS Aqua/Terra Level 1B data. Through our proposed method, we reached the highest accuracy of 91.89% (SVM) and 89.58% (RF) during the freeze-up period (November-December). Comparatively, classification performance was lower during the break-up period (late April-early June) reaching an overall accuracy of 77.19% (SVM) and 77.32% (RF). The backscatter coefficient and OCOG Width were found to be the two parameters of most importance for discriminating between ice and open water. Analysis of early results suggests that higher classification accuracies may be achieved by subdividing open water and ice into two more classes to represent leads and melting ice. In addition, pseudo LRM data from Sentinel-3 are currently being analysed and compared to results obtained with SAR data. These new results will also be presented.

Keywords: SAR altimetry, lake ice, classification, waveform, machine learning

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Cryo-TEMPO: A new era of CryoSat-2 Thematic Products over Ice, Ocean and Inland Water

Malcolm McMillan (Lancaster Univeristy, United Kingdom); The Cryo-TEMPO consortium (Lancaster University, UK); Jerome Bouffard (ESA, Italy); Alessandro di Bella (ESA, Italy)

Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_005

Abstract:
After more than 11 years in orbit, CryoSat-2 has provided a decade of measurements with which to monitor and understand our changing planet. With its unique orbit and payload, not only has CryoSat-2 far exceeded its primary mission objectives over both land and sea ice, but it has also delivered scientific and methodological advances across a diverse range of applications. To date, many of these advances have been made by altimetry experts, using the standard Level-2 or lower-level products distributed by ESA's ground segment. Typically, higher-level products have been limited to gridded datasets, where the native 20 Hz measurements have been averaged in space and time. Following consultations with the wider community, it has become increasingly clear that there is significant untapped value that can be realised by expanding the user-base beyond the traditional altimeter expert. Crucially, this requires simplified, agile and state-of-the-art thematic products, that deliver an easy-to-use dataset whilst maintaining the native along-track sampling of the original Level-2 products. Thus, ESA has embarked on a new path towards developing CryoSat-2 Thematic Products, which aim to rapidly expand the existing user base and thereby drive further innovation and exploitation.

Here, we present the latest results from Cryo-TEMPO, a 3-year ESA-funded study that began in October 2020 with the goal of delivering a new era of innovative CryoSat-2 Thematic Products over five domains; land ice, sea ice, polar ocean, coastal ocean and inland water. The over-arching objectives of Cryo-TEMPO are (1) to implement dedicated, state-of-the-art processing algorithms over each thematic domain, (2) to develop agile, adaptable processing workflows, that are capable of rapid evolution and processing at high cadence, (3) to create products that are driven by, and aligned with, user needs; thereby opening up the data to new communities of non-altimetry experts, and (4) to deliver transparent and traceable uncertainties associated with each thematic parameter. In this presentation we shall provide an overview of the project, a review of the first generation of these thematic products, and a look forward to the evolutions that are being implemented within the second phase of the study.

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CryoSat after 12 years in space: status and future challenges

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_006

Abstract:
CryoSat-2 was launched twelve years ago and was the first European mission dedicated to the cryosphere, with the objectives to monitor precise changes in the thickness of polar ice sheets and floating sea ice. For that, the satellite carries the first Synthetic Aperture Interferometric Altimeter (SIRAL) which still remains one of the most innovative altimeters in space although newer versions are boarded on different satellite missions.
Going beyond its ice monitoring objectives, CryoSat-2 has also demonstrated to provide a valuable source of observations over multiple surfaces. Numerous CryoSat-based studies have been carried in order to optimize processing algorithms for hydrology, geodesy and ocean applications. A major step forward has consisted to transpose these innovations into an operational framework by generating new thematic products so-called “Cryo-TEMPO”.
The mission has been recently extended until the end of 2025 with the scope to achieve new important goals, to extend the synergy with ICESat-2 and its unequalled data set and to secure a unique long-term climate record as long as possible. This will be possible thanks to well established international with many important worldwide institutions and agencies.
Scope of this paper is to describe the current mission status, show its main achievements and provide programmatic highlights for the extended period 2023-2025. In particular we will provide an overview of recent product evolutions and new science results which also pave the way for the development of the CRISTAL Sentinel Expansion mission.

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Using deep learning with CryoSat radar altimetry to adjust elevations and map surface penetration

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_007

Abstract:
Over the past 30 years, altimetry has revolutionised our ability to monitor surface conditions, quantify changes of the world's ice masses and its impact on sea level, water availability, and glacial risks. With two high resolution altimeters currently active – the interferometric radar altimeter CryoSat-2 and the laser altimeter IceSat-2 – the present period offers a unique opportunity to co-exploit the observations made by the two sensors and improve the monitoring of ice height and trends.

Recent advances in swath altimetry processing, using the interferometric synthetic aperture radar (SARIn) mode of CryoSat-2, have enabled improved spatial resolution of surface elevation. Meanwhile, IceSat-2 provides enhanced resolution compared to the previous generation thanks to its six laser beams. However, Radar and laser altimeters have different intrinsic properties and behaviours. Joining and interpreting their measurements requires careful consideration of factors such as differences in electromagnetic interaction with the surface, impact of weather, and footprint size.

Here we use a Deep Neural Network to combine elevation measurements acquired by ESA's CryoSat-2, SARIn waveform parameters, NASA's Operation Ice Bridge, IceSat-2, and surface conditions over the Greenland Ice Sheet. We explore the difference between radar and laser altimetry and its relationship with surface condition, the impact of penetration of radar waves into snow and firn, and the respective measurement uncertainties.

While neural networks have been increasingly utilised in a wide variety of academic and commercial applications, their use for correcting elevation bias within the cryosphere is novel. The modelled elevation correction will be used to generate time-dependent Digital Elevation Models. Finally, we explore the potential to map ice, snow and firn surface conditions based on the relative differences between laser and radar instruments.

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Leads Detection with Fully Focused in Antarctica

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_008

Abstract:
Leads between ice floes are key elements to determine the sea surface height in sea ice scenarios since they provide a sea-level reference for the freeboard height measurements. Satellite-based techniques for lead-detection have traditionally required conventional delay-Doppler processing (DDP), where all echoes of a burst are coherently combined within the burst but then incoherently averaged with the other bursts received during the illumination time. DDP has a typical spatial resolution of 300m along-track, which in practice limits the type (orientation, width) of leads that can be detected. Fully-Focused SAR processing technique (Egido & Smith 2017) allows reductions of spatial resolution down to approximately 0.5m by coherently integrating all the echoes received within the illumination time, yielding significant improvements in terms of lead detection among other applications.
Future satellite altimeters such as Sentinel-6 and eventually the Copenicus polaR Ice and Snow Topography Altimeter (CRISTAL) mission will be operated at open bursts (or interleaved) and will provide fully-focused SAR echoes with high spatial resolution and unambiguous along-track backscattered echoes.
Currently flying altimeters such as CryoSat-2 and Sentinel-3 are not optimized for fully-focused SAR processing due to their close burst operation. They can still be used for lead detection using FFSAR applied together with additional steps to mitigate the ambiguities caused by not sampling the surface uniformly. They are expected to be particularly useful for the detection of small-sized leads down to ~10m in scenarios with leads properly separated some hundreds of meters.
In this contribution we present the current status of the fully-focused SAR analysis over Antarctica sea ice, combining data from current altimetry missions and validating it with satellite images. This work is part of our contribution to the "CryoSat+ Antarctica: Improved Sea Ice Thickness and Ocean Observations" project.
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CryoTEMPO-EOLIS: Elevation Over Land Ice from Swath processing of CryoSat-2 SARIn mode data

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_009

Abstract:
Land-ice is declining globally, raising sea levels worldwide and impacting glacial risks and access to fresh-water in high-mountain glaciers regions. CryoSat-2's primary mission objectives are to monitor the changes affecting the world's sea-ice and large ice sheets to quantify thickness, mass trends and contribution to sea-level change. In practice, CryoSat's revolutionary interferometric design has allowed several technical breakthroughs and led to the application of radar altimetry to environments that were previously unforeseen. One such breakthrough is Swath processing of CryoSat's SARIn mode making full exploitation of the information contained in CryoSat's waveforms and leading to one to two orders of magnitude more measurements than the conventional so-called Point-Of-Closest-Approach (POCA) technique.

Following on from the early demonstration of the technique and of its potential impact, the CryoSat ThEMatic PrOducts - SWATH Cryo-TEMPO" project aims to consolidate the research and development undertaken during the CryoSat+ CryoTop / CryoTop evolution / CS2 Mountain Glaciers ESA projects into operational products. The purpose of the thematic products is to make the data available to the wider scientific community in a form that does not require a detailed understanding of the sensor used and extensive post-processing. The first such product CryoTEMPO-EOLIS (Elevation Over Land Ice from Swath) consists of two distinct products; (1) a product containing point cloud of elevations with an associated uncertainty; and (2) a gridded product containing a spatial reduction of the point product onto a uniform grid of time-dependent elevation at 2km spatial posting and monthly temporal resolution, also with an associated uncertainty.

In phase one of the project, these two products were released over the Greenland and Antarctic ice sheets. As part of phase two, CryoTEMPO-EOLIS point products were generated over land ice outside of the two largest ice sheets covering glaciers in Arctic Canada, Iceland, Svalbard, Alaska, Russian Arctic, Southern Andes, High Mountain Asia, Greenland Periphery and Antarctic Periphery. Gridded products were also produced over the Vatnajökull and Austfonna ice caps in Iceland and Svalbard respectively. These new gridded products contain a pixel level uncertainty value, allowing the user to refine the pixels used based on the magnitude of uncertainty. This dataset will further the ability of the community to analyse and understand trends across land ice globally.

The poster will summarise the approach, provide an overview of the uncertainty and gridding methodologies, and show example use cases. The purpose of the presentation is to stimulate discussion and exchange ideas in the community about further useful products for user analysis and monitoring of climate change.

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SWIM: a new potential for sea-ice remote sensing

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_010

Abstract:
CFOSAT is a new mission concept carrying SWIM, a scatterometer in Ku-band, aimed at measuring ocean waves spectra worldwide. It carries 6 low incidence rotating beams: one at nadir, and the 5 others at 2, 4, 6, 8 and 10 degrees incidence. These characteristics make CFOSAT a good intermediate between altimeters and classical scatterometers operating at higher incidence angles.

At nadir, sea-ice reflects more energy than over open water, implying peaky waveforms, that are not well processed using classical retraking algorithms. An adaptative retracking algorithm is applied to CFOSAT nadir data, which provides a so-called pseudo mss parameter over sea-ice, that directly relatesto its surface roughness.

Off nadir, sea-ice reflects less energy than open water and exhibits a convex response with incidence. To our knowledge, apart from very specific studies, these characteristics had never been performed in the past to discriminate sea-ice from open water. A bayesian sea-ice flagging algorithm is developped, that is based on the prior knowledge of the average behavior of NRCS over sea-ice and open water, the so-called Geophysical Model Functions. Comparison with SSMI sea-ice concentration data shows better performances than the existing flag based on forecasts, and shows promising potential for more specific sea-ice characterization.

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Automated processing of altimetry-derived river water levels at global scale - Design & first results from a new L3 processor

Nicolas Bercher (QINAO SAS - AltiHydroLab.Fr, France)

Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_011

Abstract:
In the present paper, we introduce the design and applications of a new L3 ("L2-to-L3") processor dedicated to the monitoring of river water level. The processor is tailored for the basin to global scale processing of most of the past 30 years of altimetry data.

The main motivation behind this new design is to develop concepts, processing methodologies and tools that are meant to stand for long, to be perennial. Experience has proved that some early design assumptions led to limited processing capabilities. And the resulting tools are usually not able to deal with the changes induced by the permanent evolution of the Satellite Altimetry techniques and characteristics. This is particularly significant, but not limited to, in respect to the space-time distribution of the data acquisitions, the Altimeter measurement modes and the actual location of the water bodies.

The long term capabilities of Inland Water processing chains has often been considered as a second order problem, sometimes relegating it to later times, sometimes by choice or for sake of simplicity, sometimes by mistake. However, the amount of accumulated Altimetry data, which is about 30 years nowadays, coupled to the recent (Sentinel-6) and the forthcoming missions (SWOT, Sentinel-9/CRISTAL, etc.), urgely deserves flexible processing schemes able to deal with these evolutions.

The L3 processor developed by AltiHydroLab.fr focuses on offering as much flexibility as possible. For example, it is designed to be able to track water bodies that do change their shape in time; To exploit data from repeat orbit satellites that may drift at times (e.g., SARAL/Altika) or simply change their orbit (Jasons' interleaved orbits, geodetic orbital phases, etc.); To produce river water level estimates from non-repeat, or long-repeat, orbit missions (CryoSat-2).

For example, it has been estimated (by the author) that Jason-3 overflies about 60,000 different water body sections during each 10-days cycle, this number is about 200,000 for SARAL/AltiKa (35-days cycle), and 160,000 for Sentinel-3 satellite (27-days cycle). Such big numbers make it virtually impossible to maintain a decent catalogue of Virtual Stations alive for decades.

Huge catalogues of virtual stations are hard to maintain in the long run because things are slowly changing, moving, etc. As decades are passing by, the integration of the slow geomorphological changes makes the systems outdated.

Among the auxiliary datasets exploited by the L3 processor is the SWORD database (SWOT A priori River Database), initially designed for the SWOT mission and which is gaining more and more attention into the Altimetry/Inland Water community. This allows to project the data onto a common hydrographic reference. In particular, water level data outputted by the L3 processor are systematically linked to the relevant SWORD nodes so that the data are ready to be used by third parties who also make use of the SWORD database routinely in their frameworks.

The main applications of the presented L3 processor are real time monitoring of river water levels, retrospective analysis based on archives reprocessing and to feed river discharge models able to assimilate space-time distributed measurements.

In complement, the processor also include a data reading tool that allow the users to standardise their Altimetry input data (variable names, data shapes, etc.) so that the processor can is purely format-agnostic. In between, the reading and the processing stages, lives a powerful mini-language that makes it easy to express automatised/recurrent computations that are also format-agnostic.

The work in this paper is funded by personal funds from the author and in the frame of the ESA HYDROCOASTAL project.
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A new approach for the retrieval of lake ice thickness from satellite altimetry missions: Results from the ESA CCI+ Lakes and S6JTEX projects

Anna Mangilli (CLS, France); Pierre Thibaut (CLS, France); Claude Duguay (University of Waterloo and H2O Geomatics, Canada); Justin Murfitt (University of Waterloo, Canada)

Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_012

Abstract:
Lake ice thickness (LIT) is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS). LIT is a sensitive indicator of weather and climate conditions through its dependency on changes in air temperature and on-ice snow depth. The monitoring of seasonal variations and trends in ice thickness is not only important from a climate change perspective, but it is also relevant for the operation of winter ice roads that northern communities rely on. Yet, field measurements tend to be sparse in both space and time, and many northern countries have seen an erosion of in situ observational networks over the last three decades. Therefore, there is a pressing need to develop retrieval algorithms from satellite remote sensing to provide consistent, broad-scale and regular monitoring of LIT at northern high latitudes in the face of climate change.

This talk presents a novel, physically-based retracking approach for the estimation of LIT by using conventional low-resolution mode (LRM) and synthetic aperture radar (SAR) Ku-band radar altimetry data. Details will be provided about the formalism of the LRM and SAR LIT retracking methods and assessment of retrieved ice thickness using thermodynamical simulations and in-situ data. Results will focus on LIT estimation obtained using Jason-2, Jason-3, and Sentinel-6 data over Great Slave Lake (Canada) for different winter seasons. Finally, the talk will highlight how these methods significantly improve the accuracy of the LIT estimations, paving the way towards regular and robust LIT monitoring with current and future LRM and SAR altimetry missions.

The LRM_LIT algorithm has been developed in the framework of the European Space Agency's Climate Change Initiative (CCI+) Lakes project and is currently being implemented for the production of LIT time series from LRM data for Phase 2 of the project starting in June 2022. These data will be publicly available to the scientific community through a dedicated data platform, following the project schedule (2022-2025). The SAR_LIT algorithm is being developed within the ESA S6JTEX project that aims at enhancing the scientific return of the tandem phase between the Jason-3 and Sentinel-6 reference missions, allowing for continuity of observations across 30 years of conventional altimetry (from Topex or ERS in 1992) and SAR altimetry data, started with Cryosat-2 and now Sentinel-3 or Sentinel-6 missions.

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Fully-Focussed iceberg detection with Sentinel-6 data and prospects for CRISTAL

Juan Pedro López-Zaragoza (isardSAT SL., Spain); Albert Garcia-Mondéjar (isardSAT SL., Spain); Ferran Gibert (isardSAT SL., Spain); Sergi Hernández (isardSAT SL., Spain)

Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_013

Abstract:
Sentinel-6 is an operational oceanography programme consisting on two satellites that will map the sea surface levels with great precision. Sentinel-6 includes two identical satellites with the first launched on November 21, 2020 (Sentinel-6 Michael Freilich) and the second scheduled for launch in 2025 (satellite B). Following its launch, the Sentinel-6 Validation Team (S6VT) has carried out validation activities with Sentinel-6 Michael Freilich data for more than a year to ensure the best possible outcome of the mission.

Thanks to the transmission pattern of Sentinel-6 Poseidon-4 (continuous transmission at 9kHz PRF, Open Burst mode), the data can be processed using Fully-Focussed SAR techniques, which enables a much better along track resolution and also better scene focussing. This is highly beneficial over sea ice areas, where the coherence of the scene is kept during the illumination time and very detailed features, such as small leads and icebergs, can be precisely acquired.

This work will show how we can use Sentinel-6 Poseidon-4 radar altimeter data over sea ice waters to detect the presence of small icebergs and extract useful parameters from them. Furthermore, we will show the improvement obtained in resolution when analysing the data using Fully-Focussed techniques over conventional unfocussed SAR processing.

Nevertheless, carrying a single radar antenna (as it happens in the Sentinel-6 Poseidon-4 radar altimeter) severely reduces the number of parameters we can extract from the detected icebergs using this technique, as well as not allowing us to locate them with precision.

The future Copernicus Polar Ice and Snow Topography Altimeter mission (CRISTAL), with an expected launch on 2027, will carry on-board as its main payload the IRIS altimeter. Amongst other improvements with respect to previous missions, a key feature from the IRIS altimeter will be the use of 2 antennas in the Ku band allowing the determination of the across track location using the SAR interferometric (SARIn) information. The use of an interferometric mode greatly improves the information we can extract from the small icebergs detected, as well as to locate them with great precision with respect to the satellite track.

To finalise this work, we will show which are the future prospects regarding iceberg detection for CRISTAL, and how it will allow us to combine the Fully Focussed analysis techniques used during the S6VT activities with the SARIn mode to maximise the information and resolution we can obtain detecting icebergs.

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CRISTAL performance assessment: an end-to-end simulation approach

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_014

Abstract:
The Copernicus Polar Ice and Snow Topography Altimeter(CRISTAL) mission, planned to be launched in 2027 will incorporate a dual Ku/Ka-band interferometric altimeter with specific transmission pulse sequences designed to enhance the performances over sea and land ice. The open burst mode will enable the generation of Fully Focussed products over sea ice with snow depth retrievals derived from the Ku/Ka range differences instead of taking them from external auxiliary data. In the same way, as in CryoSat-2, the closed burst interferometric mode over land ice will allow the generation of swath elevations for the full Greenland and Antarctica, improving the current coverage of the CryoSat-2swath products that are only produced in the ice margins.

At this stage of the mission design, phase B2/C/D, the expected performances need to be evaluated against the requirements to verify the effectiveness of the mission configuration and assess its compliance.

In this framework, an end-to-end validation environment has been designed. It is composed of the System and InstrumentSimulator (SIS), the Ground Processor Prototype (GPP), and the Performance assessment tool (PAT).

Following the validation plan defined during the first stage of the project, the SIS will be in charge of generating datasets for the different scenarios that are foreseen to be of interest for the mission performance assessment (e.g. point targets, sea ice with different snow properties, ice sheet with small slope and uniform snow and ice characteristics, glaciers with different size, slope, and orientations, ocean tracks with different SWH and wind conditions, river and lakes for specific size and geometry).

The GPP will process the simulated data using different processing chains to ensure compliance with the functional and performance requirements. It is composed among others of Level1 Calibration chains, Level1 Low Rate chains(LR-RMC, LR Over-Sampled, and the conventional LR), Level1Delay Doppler chain, Level1 Fully Focussed chain, Level2retrackers module (compilation of different retrackers tailored for the different thematic surfaces), Level2Geophysical corrections and retrievals (translating the information from the retrackers into sea ice, land ice, ocean and inland waters measurements).

The PAT is in charge of closing the end-to-end chain: it will cross-check each of the geophysical parameters generated by the GPP against the corresponding requirement, starting from the knowledge of the simulated parameters, assessing and validating the end to end performance chain.

This presentation will give an overview of the expected performances of the CRISTAL mission based on the end-to-end validation activity carried out in this project.

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A first assessment of swath processing for inland water

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_015

Abstract:
With an along-track resolution of around 300 m, ESA CryoSat-2 (CS2) brought along a whole new range of monitoring possibilities of inland water bodies. The introduction of Synthetic Aperture Radar (SAR) altimetry enabled the study of rivers and lakes that were not visible with conventional Low Resolution Mode (LRM) altimeters. However, the 300 m resolution is still a challenge for the smallest water bodies, for which sometimes none or only a single observation is available.
Over some selected water bodies, the CS2 altimeter operates in SAR Interferometric (SARIn) mode, using both the antennas on board. The phase difference between the two returns can be used to locate the across-track origin of the echo. While, traditionally, retracking methods are used to retrieve a single surface height estimate from waveforms over inland water bodies, in this study, we apply a swath approach where multiple peaks of single SARIn waveforms are retracked and geolocated across track using the phase difference information.
We show that this method can be used to retrieve a large number of valid water level estimates (WLE) for each SARIn waveform, even from water bodies that are not immediately located at the satellite nadir. We investigate the potential of this technique over rivers and lakes by looking at the increase in spatial coverage as well as at the impact on the precision of the measurements when compared with conventional nadir altimetry and in-situ hydrometric data.
Increasing the number of WLE is of great importance especially for small water bodies, where the number of available valid measurements from altimeters is generally very limited. The results presented in this work are additionally relevant for the future Copernicus Polar Ice and Snow Topography Altimeter mission (CRISTAL), which will also fly an interferometric altimeter.

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A novel model-based retracker for sea ice covered regions

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_016

Abstract:
This abstract focuses on the description and the preliminary validation of a model-based retracker for sea ice covered regions. Retracking is carried out by fitting an adaptation of the semianalytical model described in [1] to altimeter power waveforms acquired over Arctic sea ice to retrieve values of surface elevation, backscattering efficiency, surface roughness, snow depth and a normalized multilooked peak power. Curve fitting is performed using the Levenberg–Marquardt algorithm which fits the specific model function—i.e. the objective function—to the altimeter power waveform. The potential advantages of such a model-based approach would be, e.g., to account for the elevation bias introduced by threshold retrackers over sea ice and leads, caused by varying surface roughness and by the empirical choice of retracking thresholds.
Preliminary validation of the retracker is performed by comparing CryoSat along-track elevations with those obtained by the SAMOSA+ retracker. Additionally, freeboard estimates from the semianalytical reracker are compared with Operation IceBridge data collected during CryoSat underflights in the Arctic. In order to assess the potential advantage of a joint retracking of sea ice freeboard and snow depth, we investigate differences in freeboard estimates from the semianalytical retracker computed in three different ways: by not applying the snow model, by considering a constant value of snow depth along specific CryoSat tracks, and by attempting to directly retrack the snow depth.

[1] Recchia, L., Scagliola, M., Giudici, D. & Kuschnerus, M. An Accurate Semianalytical Waveform Model for Mispointed SAR Interferometric Altimeters. IEEE Geoscience and Remote Sensing Letters 14, 1537–1541 (2017).

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Understanding nadir altimetry measurements over continental waters: simulations over rivers and statistical analysis of individual pulses from Sentinel altimetry missions

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_017

Abstract:
Over the last few years, satellite radar altimetry measurements have become more and more numerous over inland waters, thanks to improvements in the tracking function as well as enhanced measurement modes (from pulse-limited low resolution mode to high resolution synthetic aperture radar). This higher quality and abundance of measurements also raises the question of their processing: from historical retracking algorithms (e.g. the Offset Centre Of Gravity - OCOG retracking) to most recent innovative ones (e.g. Fully-Focused SAR). In particular, it is of common knowledge in the hydrology community that current ground segments using the OCOG algorithm provide, on frequent occasions, biased water surface height estimates and is not reliable at global scale. The need for more reliable and robust processing methods is therefore one of the biggest challenges for radar altimetry over land.
The main challenge is that contrary to ocean altimetry, the radar signal over inland waters is highly variable both in space and time, as it depends on the nature and size of the water body observed (lakes, rivers, flood plains, etc.) as well as on surface conditions.
In this study, we focus specifically on rivers where various types of waveforms can be acquired: sinc²-like peak (the most frequent ones), asymmetric peak, multiple peaks, distorted Brown-like waveform. We address the representativeness of the signal's specularity, as it has been documented in the literature that the radar backscattered signal over rivers is often highly specular and can be modeled as a squared cardinal sine function. We use two parallel approaches: simulation of radar signals over a specular surface, and analysis of real data acquired by current Sentinel-3 and Sentinel-6 Ku-Band missions over rivers.
In the theoretical approach, we use simulations of various specular surfaces and analyze both the amplitude and phase behaviors. It is interesting to analyze the relative impact of the observing system configuration (e.g. radar bandwidth, altitude, sampling) and the nature of the surface (e.g. geometry of the observed scene, backscatter coefficient) on the simulated radar signal.
In the data analysis approach, we use a unique dataset of one hundred rivers worldwide to perform a statistical analysis of the specular nature of the signal and other characteristics in function of the scene configuration. River width is one but not the only parameter impacting the measured signal.
With this study, we aim at understanding the most significant factors controlling the measured radar signal over rivers in order to build a robust and universal processing algorithm capable of providing reliable water surface height estimates to inland waters users.
In the perspective of the Surface Water and Ocean Topography (SWOT) mission, nadir altimetry more than ever stands as an important asset for calibration and validation of this mission as well as for the design of future altimetry missions such as the Copernicus Sentinel-3 Next Generation: Topography mission, which will necessarily address the question of processing performance over inland waters.
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CRISTAL – Copernicus’ Next Cryosphere Altimetry Mission

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_018

Abstract:
The Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) mission is planned to be launched in 2027 and will carry the first Ku/Ka band interferometric altimeter (IRIS) for enhanced sea ice thickness measurement and overlying snow depth retrieval. It utilizes a high PRF open burst mode allowing for fully focussed SAR processing with along-track resolutions below 10 m. It will also have the capability to detect icebergs. CRISTAL will also measure ice sheet and glacier elevations as well as open ocean, coastal areas and hydrological targets with dedicated closed burst modes similarly to CryoSat-2 and Sentinel-3. The IRIS digital receiver architecture inherited from Sentinel-6/Poseidon-4 will provide superior accuracy with an even increased RF bandwidth of 500 MHz resulting in a range resolution of 0.3 m.

The IRIS altimeter is accompanied by a high resolution microwave radiometer for wet tropospheric correction and snow/ice classification, a multi-constellation, multi-frequency GNSS receiver (PODRIX) and a laser retroreflector array (LRA) for precise orbit determination, plus an USO assembly providing the ultra-stable master clock for the altimeter. There is also the option for accommodating a Payload of Opportunity.

The mission status is currently at the end of phase B2 with the System PDR in March 2022 confirming the expected performances.
The presentation will give an overview of the instrument and satellite implementation aspects relevant for achieving the mission and an overview of the predicted performances based on the PDR status.

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AlTiS Software for generating Time-Series of Water Levels from Radar Altimetry Data

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_019

Abstract:
AlTiS (Altimetry Time Series) is a software to visualize and process radar altimetry data. It was developed to analyse radar altimetry data over small areas like river, lakes and wetlands, located in the altimetry groundtracks. Its major goal is the creation of time-series of water levels from the height derive from the altimeter measurement but it can also be used to generate time series of any altimetry-based parameters (e.g., corrections applied to the range, backscattering coefficients, or brithness temperatures).
Through a Graphical User Interface (GUI), without any skills in data processing, the user can handle altimetry data in order to :

- Display several parameters of altimetric measurement like surface height, altimetric range, atmospheric corrections applied to the range to take into account the propagation delay of the electromagnetic wave through the earth atmosphere (ionospheric correction and wet and dry tropospheric corrections) and also to display some characteristic parameters of the waveform like the backscatter coefficient, and peakiness.
- Graphically select altimetric measurements to remove outliers and easily done owing to Landsat background image.
- Generate water height time series from the valid altimetry data previously selected

AlTiS accepts CTOH altimetry products (Level 2 GDR supplied by the CTOH). CTOH GDR data have been specifically conditioned to optimize the data size by making a geographical selection and includes the right altimetry parameters for hydrological studies.
AlTiS can process several altimetric data products from followed missions : Jason-1/2/3, ERS-2, ENVISAT, SARAL, Sentinel-3A/B, and soon, Sentinel-6/Jason-CS and the nadir altimeter onboard SWOT. They are supplied for free through a web request form on the CTOH website (http://ctoh.legos.obs-mip.fr/applications/land_surfaces/altimetric_data/altis).
AlTiS is mainly employed for hydrological applications and can be used for training courses on radar altimetry at bachelor or master levels. It is also a very convenient tool to analyse the radar altimetry data contained in the GDR over any type of land surfaces.

AlTiS is a software developed by CTOH as part of its activities as a National Observation Service. AlTiS is a free software and it is released as an open source under the CeCill License. Altis is working under python3 environment and tested for GNU/Linux, Windows 10.
AlTiS is available on GitLab : https://gitlab.com/ctoh/altis

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Merging CryoSat-2 and ICESat-2 Retrievals to Advance Observations of Arctic Sea Ice

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_020

Abstract:
The Arctic Ocean experiences enhanced sensitivity to global temperature increases due to the positive sea-ice ocean albedo feedback. This has resulted in an acceleration of warming in the Arctic region since 2000, where temperatures are now rising at rates 2-3 times the global average. In turn this warming has contributed to the continued downward trend in sea ice extent over the last three decades and recent evidence suggests that this decline can impact mid-latitude weather.

Here we discuss exploiting satellite laser and radar altimeter (LaRA) observations of the ice cover to better constrain the evolution of snow depth on sea ice. Snow on Arctic sea ice has a long correlation length-scale (order kilometers) since snow accumulation on the sea ice cover, and its redistribution, are associated with synoptic events. Thus, obtaining direct estimates of snow on sea ice is also useful for constraining the precipitation over the Arctic Ocean in winter. In addition, knowledge of the seasonal evolution of snow depth on sea ice provides important insights about changes in marine mammal habitat.

In August 2020, as part of the ESA Cryo2Ice program, the semi-major axis of the CryoSat-2 orbit was raised by ~900 m providing periodic synchronicity in the longitude of both the ICESat-2 and CryoSat-2 satellites, every 19th CryoSat-2 revolution and 20th ICESat-2 revolution. Here we exploit the Cryo2Ice orbit resonance to perform cross-calibration of sea ice and lead heights at two electromagnetic frequencies. Using Cryo2Ice data we estimate the seasonal evolution of snow depth on sea ice. To do this we exploit the difference in radar and laser penetration depths into the snow pack. Typically, in dry snow conditions, the laser return from ICESat-2 originates from the air/snow interface, while the return from CryoSat-2 is from the snow/ice interface. We combine freeboard measurements retrieved from different scattering horizons to directly estimate the snow depth. Focusing on the last three winter periods (2018-2021) we demonstrate remarkable consistency between the two independent estimates of sea ice freeboard and we discuss the evolution of snow on sea ice throughout the winter season. Our results demonstrate the relationship between snow depth and ice type/age, wherein deeper snow is seen to accumulate over multi-year ice, in line with previous studies. Ultimately this work will lead to improved estimates of sea ice thickness from satellite techniques, since all current ice thickness retrieval techniques (from both altimeters, passive microwave, and infrared methods) require an estimate of snow depth as an auxiliary input parameter.

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Sea Ice-thickness product iNter-comparison eXerciSe – The ESA SIN'XS project

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_021

Abstract:
The SIN'XS project, led by NOVELTIS in collaboration with AWI, LEGOS and UCL, is a three-year activity (May 2022 – May 2025) funded by ESA in the frame of the Polar Science Cluster, with the objective to foster collaborative research and interdisciplinary networking actions.
In light of rapid changes of the Arctic and Antarctic sea ice cover, continued and improved observations, understanding, and predictions of its thickness are particularly important for a range of fields from climate studies to offshore operations in ice. Systematic and accurate ice thickness observations are now available from several satellite missions.
However, they differ in used processing algorithms and assumptions, temporal and spatial coverage and resolution, and applicability to stakeholder needs like modelling and assimilation, numerical weather prediction, and ship routing. These differences between products have so far complicated the consistent use of the various data products, and there is little consensus about Arctic and Antarctic Sea ice volume variability and change.
The Sea Ice-thickness product iNter-comparison eXerciSe (SIN'XS) will identify some of these gaps by carrying out in-depth intercomparisons of a wide range of satellite ice thickness products from altimetry and other methods, in close collaboration with an international community of scientific and operational sea ice experts, and in partnership with the WMO Global Cryosphere Watch (GCW).
It will develop joint protocols for the intercomparison of ice thickness products and their validation, using established approaches from the GEO/CEOS Quality Assurance framework for Earth Observation (QA4EO) and by further developing a framework for Fiducial Reference Measurements (FRMs).
SIN'XS will develop an online system to engage the community with data submission and to support scientific analysis and impact assessment of the data sets and intercomparisons.
In this poster, we will present the main objectives, the tools and the first outcomes of the project.

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Sentinel-3 for Cryosphere and Hydrology

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_022

Abstract:
Sentinel-3 is an Earth observation satellite series developed by the European Space Agency as part of the Copernicus Programme. It is designed as a constellation of two identical polar orbiting satellites, for the provision of long-term operational marine and land monitoring services. The constellation currently comprises 2 satellites: Sentinel-3A and Sentinel-3B, launched respectively on 16 February 2016 and 25 April 2018. Among the on-board instruments, the satellites carry a radar altimeter to provide operational topography measurements of the Earth's surface. Besides measuring the sea surface height, the mission primary objectives also include the measurement of the surface topography over inland waters, sea-ice, and land ice.
Compared to previous missions embarking conventional pulse-limited altimeters, Sentinel-3 is sampling the Earth's surface with an enhanced spatial resolution, thanks to the on-board SAR Radar ALtimeter (SRAL), exploiting the delay-Doppler capabilities. To further improve the performances of the Sentinel-3 Altimetry LAND products, ESA and the MPC has developed the so-called Thematic IPFs, which are dedicated delay-Doppler and Level-2 processing chains for (1) Inland Waters, (2) Sea-Ice, and (3) Land Ice areas. The objective is to provide dedicated "thematic products" specially tuned for Cryosphere and Hydrology areas.
In this talk, the Mission Performance Cluster, in charge of qualification and the monitoring of the core products performances, will present the main changes in ground segment processors, and a first assessment of the thematic products. The quality step-up provided by these thematic products will be highlighted, using comparisons with reference missions in these areas such as CryoSat-2, ICESat-2, and comparisons with in-situ datasets.
From now on, the Sentinel-3 Land Thematic Products will continuously and independently evolve to better meet the requirements of the Cryosphere and Hydrology user community. A Full Mission Reprocessing (FMR) is planned early 2023, to produce fully homogeneous S3A and S3B Thematic datasets.

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Innovative solutions for in-situ Cal/Val of satellite altimetry over inland waters based on UAV and new autonomous micro-gauges

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_023

Abstract:
The first radar altimetry missions were dedicated to the open ocean. However, continental water surfaces (enclosed seas, lakes, rivers, flooding areas...) can also be measured by satellite altimetry. For many years now, satellite altimetry is increasingly used to monitor inland waters all over the globe, and even more with the advent of delay doppler radar altimeter embedded on the Copernicus Sentinel-3 and Sentinel6-MF missions, and the future SWOT mission based on interferometric radar imagery. For these instruments, new algorithms are currently being developed to support improved data processing over hydrological surfaces in order to achieve significant accuracy improvements. There is therefore an increasing need for new in-situ systems to provide reference data for large-scale Calibration/Validation (Cal/Val) activities over inland water.

In this context, vorteX.io designed a lightweight remote sensing instrument, inherited from the specifications of radar altimeters on board altimetric satellites, capable of providing water height measurements with centimeter-level accuracy and at high frequency. Mounted on a flying drone, the system combines a LiDAR system and a camera in a single payload to provide centimetre-level water surface height measurements, orthophotos, water surface mask and water surface velocity throughout the drone flight. The vorteX.io system is the result of a review of existing in-situ systems used for Cal/Val of satellite altimetry in hydrology or operational monitoring of water heights (often to anticipate potential river floods or to monitor reservoir volumes). As the lightweight altimeter is inspired from satellite altimetry, water level measurements are directly comparable to satellite altimeter data. Thanks to the UAV capability, water measurements can be performed on long distances along rivers, and at the same location and time as the satellite pass. New hydrological variables are planned to be added in the next future (water surface temperature, river discharge, turbidity, …).

The drone-embedded lightweight altimeter has been successfully used during several measurement campaigns for the French space agency (CNES) as part of the Cal/Val of Sentinel-3A, Sentinel-3B, and Sentinel-6 missions. This innovative instrument is being considered as one of the means of the in-situ validation of the future SWOT mission for hydrology. We present here the results of the measurements performed by the vorteX.io VTX-1 altimeter in different hydrological contexts in France in 2020 and 2022.

In addition, vorteX.io offers an innovative and intelligent service for monitoring hydrological surfaces, using easy-to-install and fixed remote sensing in-situ instruments, based on compact light-weight altimeter also inspired from satellite technology: the micro-stations. Micro-Stations directly address the needs of in-situ measurements (Fiducial Reference Measurements) for Cal/Val activities over inland water bodies. Indeed, the vorteX.io micro-station is able to automatically wake up and perform measurements at the exact moment of the satellite overflight thanks to satellite ephemerides. With this feature, there is no time delay between in-situ measurements and the satellite overflight. Water heights are provided with respect to the ellipsoid or local geoid. All geophysical corrections required can be applied on the fly. Different hydrological variables are measured (water surface height, the associated uncertainty, water surface speed) and new others are planned to be added in the next future (water surface temperature, turbidity, …). The vorteX.io solution has already been used in various CNES and ESA projects and will be implemented in the ESA St3TART project and will be used for Cal/Val activities of the future SWOT mission on the Garonne River.

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Comparing elevation changes observed by CryoSat-2 and ICESat-2 over the Greenland Ice Sheet

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_024

Abstract:
Satellite altimeters have continuously observed surface elevation changes across the Greenland Ice Sheet surface for the past three decades. Improvements made in processing these observations and in the development of new sensors during this time, have culminated in high resolution instruments, which are able to provide new insights into the physical processes and changes that the Greenland Ice Sheet experiences as the climate warms.

Here, we compare elevation changes and trends in elevation change observed over the Greenland Ice Sheet, by the CryoSat-2 and ICESat-2 satellite altimeters, between October 2018 and March 2022. We quantify the agreement between estimates from the two altimeter missions across the entire Greenland Ice Sheet and within its' principal drainage basins. In addition, we assess seasonal variations in elevation observed by both instruments, largely driven by snowfall accumulation in the winter and surface melting in the summer. Significant changes in these processes have been observed across Greenland as the climate has warmed in the recent decades; comparing the elevation changes observed by the radar and laser instruments on-board CryoSat-2 and ICESat-2, respectively, has the potential to improve our understanding of these surfaces processes due to the differences in how these two frequencies interact with the physical properties of near-surface snowpack. We also assess elevation differences within the predominantly dry ice sheet interior in order to improve understanding of the differences in penetration depth of the different wavelengths of the two signals. As an example, in Northwest Greenland, we estimated the trends in elevation change to be -25.93 cm/yr and 20.86 cm/yr from CryoSat-2 and ICESat-2, respectively. We process the satellite radar and laser altimetry data over grids of different spatial resolution in order to statistically identify the optimum spatial and temporal sampling for each mission. Our assessment provides a detailed, multi-year comparison of radar and laser altimeter observations across the entire Greenland Ice Sheet, allowing us to examine the suitability of combining these datasets or where appropriate, computing a correction for surface depth penetration, providing a basis for improved estimates of ice sheet mass balance from satellite altimetry. Our Ice Sheet wide comparison here is an advancement on previous comparisons of radar and laser altimetry, which were based on surveys from airborne laser altimetry like NASA's Operation IceBridge, thus limiting the spatial extent to the margins of the Greenland Ice Sheet, where majority of the surveys were carried out.

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Sentinel-3 Land STM: New Hydrology Thematic Products performances over Inland Waters

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_025

Abstract:
Sentinel-3 is an Earth observation satellite series developed by the European Space Agency as part of the Copernicus Programme. It currently consists of 2 satellites: Sentinel-3A and Sentinel-3B, launched respectively on 16 February 2016 and 25 April 2018. Among the on-board instruments, the satellites carry a radar altimeter to provide operational topography measurements of the Earth's surface. Over Inland waters, the main objective of the Sentinel-3 constellation is to provide accurate measurements of the water surface height, to support the monitoring of freshwater stocks. Compared to previous missions embarking conventional pulse limited altimeters, Sentinel-3 is measuring the surface topography with an enhanced spatial resolution, thanks to the on-board SAR Radar ALtimeter (SRAL), exploiting the delay-Doppler capabilities.
To further improve the performances of the Sentinel-3 Altimetry LAND products, ESA and the Sentinel-3 Mission Performance Cluster (MPC) recently developed specialized delay-Doppler and Level-2 processing chains over (1) Inland Waters, (2) Sea-Ice, and (3) Land Ice areas. The objective is to provide new dedicated "thematic products" to the users for the three surfaces mentioned. Over hydrology the T-IPF will including new algorithms, in particular the hamming window and the zero-padding processing. Thanks to the hamming window, the waveforms measured over specular surfaces are cleaned from spurious energy spread by the azimuth impulse response. The zero-padding provides a better sampling of the radar waveforms, notably valuable in case of specular energy returns. The operational production of these thematic products will start by Fall 2022.
To ensure the missions requirements are met, the Sentinel-3 MPC is also in charge of the qualification and the monitoring of the instrument, and core products performances. In this poster, the Hydrology ESLs (Expert Support Laboratories) of the MPC provide a first performance assessment of the Hydrology thematic products and comparisons with the previous PDGS products. The analyses include comparisons with InSitu datasets, benefiting from the contribution of the St3TART project, and provide an estimate of the Water Surface Height accuracy. Inter satellite comparisons are also in the scope of the studies and Water Surface Height estimates consistency in between Sentinel-3 and ICESat-2 will complement this analysis. The quality step-up provided by the Hydrology thematic products, and highlighted in this poster, is a first and major milestone. From now on, the Sentinel-3 Land Thematic Products will independently evolve, to better meet and fulfil the requirements from the Copernicus Services and the scientific Hydrology community. A Full Mission Reprocessing (FMR) is planned early 2023, to produce fully homogeneous S3A and S3B Hydrology thematic datasets.

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Sentinel-3 Land STM: Sea Ice Thematic Products

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_026

Abstract:
Sentinel-3 is an Earth observation satellite series developed by the European Space Agency as part of the Copernicus Programme. It currently consists of 2 satellites: Sentinel-3A and Sentinel-3B, launched respectively on 16 February 2016 and 25 April 2018. Among the on-board instruments, the satellites carry a radar altimeter to provide operational topography measurements of the Earth's surface. Over sea-ice, the main objective of the Sentinel-3 constellation is to provide accurate measurements of the sea-ice sea surface height and the sea-ice radar freeboard. Compared to previous missions embarking conventional pulse limited altimeters, Sentinel-3 is measuring the surface topography with an enhanced spatial resolution, thanks to the on-board SAR Radar ALtimeter (SRAL), exploiting the delay-Doppler capabilities.

To further improve the performances of the Sentinel-3 Altimetry products, ESA and the Sentinel-3 LAND Mission Performance Cluster (MPC) recently developed specialized delay-Doppler and Level-2 processing chains over (1) Inland Waters, (2) Sea-Ice, and (3) Land Ice areas. The objective is to provide new dedicated "thematic products" to the users for the three surfaces mentioned. Over sea-ice the T-IPF will include new algorithms, in particular the hamming window and the zero-padding processing. Thanks to the hamming window, the waveforms measured over specular surfaces are cleaned from spurious energy spread by the azimuth impulse response. The zero-padding provides a better sampling of the radar waveforms, notably valuable in case of specular energy returns. The operational production of these thematic products will start by Fall 2022.

To ensure the missions requirements are met, the Sentinel-3 LAND MPC is also in charge of the qualification and the monitoring of the instrument, and core products performances. In this poster, the Sea Ice the Expert Support Laboratories (ESL) of the MPC present a first performance assessment of the Sea Ice thematic products. The analyses include exhaustive inter-comparison with CryoSat-2, showing that the two missions provide similar estimated freeboard measurements. The quality step-up provided by the Sea Ice thematic products, and highlighted in this poster, is a first and major milestone. From now on, the Sentinel-3 Land Thematic Products will independently evolve, to better meet and fulfil the requirements of the Sea Ice community. A Full Mission Reprocessing (FMR) is planned early 2023, to produce fully homogeneous S3A and S3B Sea Ice thematic datasets. A Full Mission Reprocessing (FMR) is planned early 2023, to produce fully homogeneous S3A and S3B Sea Ice thematic datasets.

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STREAMRIDE: a satellite-based approach for river discharge estimation

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Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42022_027

Abstract:
River discharge monitoring is crucial for many activities ranging from the management of water resources to flood risk mitigation. Due to the limitations of the in situ stations (e.g., low station density, incomplete temporal coverage as well as delays in data access), the river discharge is not always continuously monitored in time and in space. This prompted researchers and space agencies, among others, in developing new methods based on satellite observations for the river discharge estimation.

In the last year, ESA has funded the SaTellite based Runoff Evaluation And Mapping and River Discharge Estimation (STREAMRIDE) project, which proposes the combination of two innovative and complementary approaches, STREAM and RIDESAT, that use almost exclusively satellite data for estimating river discharge. In particular, precipitation, soil moisture and terrestrial water storage observations are used within a simple and conceptual parsimonious approach (STREAM) to estimate runoff, whereas altimeter and Near InfraRed (NIR) sensors are jointly exploited to derive river discharge within RIDESAT.

By modelling different processes that act at the basin or at local scale, the combination of STREAM and RIDESAT is able to provide less than 3-day temporal resolution river discharge estimates in many large rivers of the world (e.g., Mississippi, Amazon, Danube, Po), where the single approaches fail. Indeed, even if both the approaches demonstrated high capability to estimate accurate river discharge at multiple cross sections, they are not optimal under certain conditions such as in presence of densely vegetated and mountainous areas or in non-natural basins with high anthropogenic impact (i.e., in basin where the flow is regulated by the presence of dams, reservoirs or floodplains along the river; or in highly irrigated areas). Here, we present some new advancements of both STREAM and RIDESAT approaches which help to overcome the limitations encountered. In particular, specific modules (e.g., reservoir or irrigation modules for STREAM approach) as well as improvements in the retrieval algorithm (e.g., to take in account the contribution of the river sediment load and vegetation for RIDESAT algorithm) were implemented. Furthermore, in order to exploit the complementarity of the two approaches, the two river discharge estimates were also integrated within a simple data integration framework and evaluated over sites located on the Amazon and Mississippi river basins. Results demonstrated the added-value of a complementary river discharge estimate with respect to a stand-alone estimate.

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