2025 Ocean Surface Topography Science Team Meeting

Saturday, November 15 2025 - Sunday, November 16 2025

The 2025 Ocean Surface Topography Meeting will occur 15-16 November 2025 in conjunction with the Sentinel-6B launch. It will include, as usual, a variety of science and technical splinters as poster and online sessions. Sentinel-6A Michael Freilich being now the reference mission since April 2022, contributions that support Sentinel-6A Michael Freilich mission are highly encouraged, with focus on the second tandem with Jason-3. High-level science keynotes will be held in-person and online to showcase the science of Sentinel-6. In parallel of the OSTST, a hybrid workshop to discuss the Sentinel-6NG orbit will be held in the morning.

Abstracts Book

Abstract list

Forum only

Coastal Altimetry
Sun, Nov 16 2025, 08:00 - 17:30 - On-line forums for OSTST 2025

08:00 - 18:00: Nearshore wave processes detected using Sentinel-6 MF & SWOT satellite radar altimetry: Dougal Lichtman et al.

Instrument Processing: Propagation, Wind Speed and Sea State Bias
Sun, Nov 16 2025, 08:00 - 17:30 - Nojoqui Falls

08:30 - 18:00: A novel operational Sea State Bias correction for Sentinel-3 Delay/Doppler altimeter measurements incorporating wind directional effect: Ngan Tran et al.

Outreach, Education and Altimetric Data Services
Sun, Nov 16 2025, 08:00 - 17:30 - On-line forums for OSTST 2025

08:00 - 18:00: In situ measurements for SWOT lake water level validation : results from a student project at Lake Guerledan (France): Clémence Chupin et al.

Regional and Global CAL/VAL for Assembling a Climate Data Record
Sun, Nov 16 2025, 08:30 - 17:30 - On-line forums for OSTST 2025

08:00 - 18:00: Jason-3 & Sentinel-6 MF calibration at the Corsica facilities: Pascal Bonnefond et al.
08:00 - 18:00: Extending the Corsica facilities up to SWOT swath: Pascal Bonnefond et al.
08:00 - 18:00: Updated in situ validation results of satellite altimetry from the Bass Strait facility: Christopher Watson et al.

Science I: Understanding and Quantifying Regional and Global Sea Level Budgets
Sun, Nov 16 2025, 08:00 - 17:30 - On-line forums for OSTST 2025

08:00 - 18:00: Evidence of increased deep ocean warming from a sea level budget approach: Anny Cazenave et al.
08:00 - 18:00: Abrupt trend change in the early 2010s observed in sea level variations at the world coastlines, as well as in the global mean sea level and its components.: Lancelot Leclercq et al.

Science II: Large Scale Ocean Circulation Variability and Change
Sun, Nov 16 2025, 08:00 - 17:30 - On-line forums for OSTST 2025

08:00 - 18:00: Drivers of marine heatwaves and their decadal disruption in the southwest Indian Ocean in recent decades: Weiqing Han et al.

Science III: Mesoscale and sub-mesoscale oceanography
Sun, Nov 16 2025, 08:00 - 17:30 - On-line forums for OSTST 2025

08:00 - 18:00: Sub-mesoscale and coastal ocean dynamics in the North Indian Ocean using SWOT and EOS-06/OCM-3 observations: Aditya Chaudhary et al.

Keynote/invited

OSTST Plenary Session
Sun, Nov 16 2025, 08:00 - 17:30 - Nojoqui Falls

15:15 - 15:35: Ocean in Motion: Surface Currents from Space: Sarah Gille
15:35 - 15:55: Sentinel-6B: Continuing Geodesy's Quest to Understand a Warming Earth: Benoit Meyssignac

Oral

Instrument Processing: Propagation, Wind Speed and Sea State Bias
Sun, Nov 16 2025, 08:00 - 17:30 - Grande Beach Room (#208)

14:00 - 14:15: Optimal parameters for mapping alongtrack altimetry: Lilly Jonathan

14:15 - 14:30: Inclusion of the ocean's vertical velocity variance into the sea-state-bias correction: Marcel Kleinherenbrink et al.
14:30 - 14:45: Improved algorithms for the wet tropospheric correction over coastal regions: application to the Sentinel-3 mission: Pedro Aguiar et al.
14:45 - 15:00: Wet troposphere correction derived from water vapor climate data records: Anne Barnoud et al.
15:00 - 15:15: Performances and benefits of a 1D-variational approach to retrieve the wet tropospheric correction: recent achievements for Sentinel-6 and Sentinel-3A and -3B topography missions: Ralf Bennartz et al.
15:15 - 15:30: How has global warming impacted the altimeter wet path delay over the altimetry record?: Telmo Vieira et al.
15:30 - 15:45: Progress on the Wet Path Delay Correction: Historical, Current and Future: Shannon Brown et al.

Workshop on the Sentinel-6 Next Generation's orbit
Sun, Nov 16 2025, 08:30 - 11:00 - Nojoqui Falls

08:30 - 08:40: Opening and scope of the workshop: Detlef Stammer
08:40 - 09:00: The Sentinel-6 Next Generation Copernicus Altimetry Mission: Enhancing Continuity, Performance and Observational Capabilities: Alejandro Egido
09:00 - 09:30: Summary of previous studies and information regarding the reference orbit determination: Loren Carrere
09:30 - 09:50: Summary of the ESA-supported Sentinel-6 Next generation orbital study with Eumetsat and CNES contributions: Michael Ablain et al.
10:05 - 10:15: Cal/Val: Results of past tandem missions: Michael Ablain et al.
10:15 - 10:25: POD performances for Jason-3/Sentinel-3A and lessons learned for Sentinel-6 NG: Frank Lemoine et al.
10:25 - 10:35: Continuity of global and regional mean sea level data record: Noémie Lalau
10:35 - 10:45: Thoughts regarding tides and the reference orbit: Richard Ray
10:45 - 10:55: Continuity in Estimating Ocean Heat Content & Earth's Energy Imbalance: Maria Hakuba et al.
10:55 - 11:00: Conclusions and Final Discussion: Detlef Stammer

Poster

Application development for Operations
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

APO2025_001: A Dynamic Persistent Sea Level Prediction System: Ou Wang et al.
APO2025_002: Moving ocean prediction skill: Gregg Jacobs et al.
APO2025_003: Tactical Overview of the Naval Oceanographic Office's Altimetry Data Fusion Center: Danielle Carpenter et al.
APO2025_004: Satellite altimetry reveals genesis of volcanic tsunami: Y. Tony Song et al.

Coastal Altimetry
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

COA2025_001: A new chapter in satellite altimetry: monitoring small lakes and coastal zones with SWOT HR PIXC data: Ole Baltazar Andersen et al.
COA2025_002: Sentinel-1 Wind Stress Divergence as an Independent Constraint for Sentinel-6 SSH Validation: Rachel Spratt

Instrument Processing: Measurement and Retracking
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

IPM2025_001: Jason-3 Near-Real Time Products Latency and Availability from September 1, 2024 to September 30, 2025: Donald Richardson et al.
IPM2025_002: NOAA's Jason Products and current Jason-3 NOAA Near Realtime Ground Processing System 2025: David Donahue et al.
IPM2025_003: Towards a new era of wave observations from nadir-looking SAR altimeters: Why Sentinel-6 SAR RAW data matter: Ourania Altiparmaki
IPM2025_004: Slope correction for ocean SAR altimetry: Juliette GAMOT et al.
IPM2025_005: Advanced Processing Features for Enhanced Sentinel-6 Products: Mònica Roca-Aparici et al.

Instrument Processing: Propagation, Wind Speed and Sea State Bias
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

IPC2025_001: Advances in Sea Level and Sea State Observations Using Sentinel-6MF SAR Altimetry Data: Christopher Buchhaupt

Outreach, Education and Altimetric Data Services
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

ODS2025_001: Satellite Altimetry Observations Monitoring Changes in Ocean and Surface Water Systems: Applied Science in Support of User Communities: Margaret Srinivasan
ODS2025_002: NASA-SSH: A Suite of New Sea Level Products from NASA: Josh Willis et al.
ODS2025_003: New NASA PO.DAAC altimetry data products: Ian Fenty et al.

Quantifying Errors and Uncertainties in Altimetry data
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

ERR2025_001: Assessment of the TOPEX GMSL stability by analysing the global mean sea level closure using the AVISO L2P-2024 products.: Marie Bouih et al.

Regional and Global CAL/VAL for Assembling a Climate Data Record
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

CVL2025_001: Regional cal/val at multi-locations: Luciana Fenoglio
CVL2025_002: Fiducial Reference Measurements for monitoring satellite altimetry at the ESA Permanent Facility for Altimetry Calibration in Crete and Gavdos: Stelios Mertikas et al.
CVL2025_003: Assessment of Global Mean Sea Level Variations Derived from a Hybrid Altimeter Sea Surface Height Time Series: Brian Beckley et al.
CVL2025_004: Assembling a multi-mission mean sea level time series: Remko Scharroo et al.

Science I: Understanding and Quantifying Regional and Global Sea Level Budgets
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

SC12025_001: Investigating the Mechanisms of Sea Level Change Using 30+ Years of Satellite Altimetry and the ECCO Ocean State Estimate: Ichiro Fukumori et al.
SC12025_002: Improved seasonal prediction skill for U.S. Atlantic Coast and Gulf Coast Using ECCO-based Ocean dynamic Persistence: Tong Lee et al.
SC12025_003: MONITORING SEA LEVEL CHANGE: FROM TOPEX/POSEIDON TO SENTINEL-6 MF AND BEYOND: Robert Steven Nerem
SC12025_004: Sea Level Budgets using over 20 years of GRACE and 30 years of Altimetry data: Ole Baltazar Andersen et al.
SC12025_005: The ESA ARCFRESH and FRESH4BIO Arctic Freshwater projects: Ole Baltazar Andersen et al.

Science II: Large Scale Ocean Circulation Variability and Change
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

SC22025_001: Ensuring Continuity of Florida Current Transport Observations with Satellite Altimetry and Moored Pressure Gauges: Denis Volkov et al.
SC22025_002: Using an Ocean State Estimate and Satellite Altimetry to Improve Sea Level Predictions along the U.S. Gulf Coast: Andrew Delman et al.

Science III: Mesoscale and sub-mesoscale oceanography
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

SC32025_001: Refining knowledge of the California Current System through 4D-Var assimilation of SWOT and nadir altimetry : Sarah Gille et al.
SC32025_002: Capsizing and impact wave detection – Case study of iceberg A-76A: Ole Baltazar Andersen et al.
SC32025_003: Small-scale eddy dynamics on the East Greenland Shelf from SWOT (Fresh4Bio): Ole Baltazar Andersen et al.
SC32025_004: Quantifying and interpreting sources of error when estimating currents from altimetry: Saulo Soares et al.
SC32025_005: A Unified Framework for Next-Generation Sea Surface Height Mapping: Jeffrey J. Early et al.
SC32025_006: Towards Harnessing Machine Learning to Infer Unobserved Variables from Satellite Observations: Jinbo Wang et al.
SC32025_007: Long-term trend in eddy sea surface temperature and height coherence and its implications: Jinbo Wang et al.

Science IV: Altimetry for Cryosphere and Hydrology

Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

SC42025_001: Monitoring the impact of the Kakhovka Dam break in 2023 with SWOT and ICESat-2: Ole Baltazar Andersen et al.
SC42025_002: Investigating Ice Jams in Arctic Rivers with SWOT's High-Resolution Altimetry: Ole Baltazar Andersen et al.

Synergies between Argo, GRACE and Altimetry
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

ARG2025_001: Inferring Ocean Heat Uptake from Satellite Gravimetry and Altimetry: Andrew Delman et al.

The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Sun, Nov 16 2025, 08:30 - 15:00 - Santa Rita Hills or Nojoqui Falls

GEO2025_001: Vertical Land Movement Budget and Its Impact on Coastal Sea-Level: Ole Baltazar Andersen et al.
GEO2025_002: Lake geoid correction grids based on the SWOT Raster product. : Ole Baltazar Andersen et al.
GEO2025_003: Towards the next series of DTU25 mean dynamic topography models: Ole Baltazar Andersen et al.
GEO2025_004: Uncertainty estimation in altimetric derived bathymetry from machine learning models: Ole Baltazar Andersen et al.
GEO2025_005: DTU25 mean sea surface and its uncertainty characteristics : Ole Baltazar Andersen et al.
GEO2025_006: The DTU25GRA SWOT derived global gravity field and evaluation with airborne gravity : Ole Baltazar Andersen

Abstract details

Nearshore wave processes detected using Sentinel-6 MF & SWOT satellite radar altimetry

Dougal Lichtman (National Oceanography Centre, United Kingdom); Paul Bell (National Oceanography Centre, United Kingdom); Chris Banks (National Oceanography Centre, United Kingdom); Christine Gommenginger (National Oceanography Centre, United Kingdom); Jennifer Brown (National Oceanography Centre, United Kingdom); Nieves Valiente (University of Plymouth, United Kingdom)

Session: Coastal Altimetry
Presentation type: Forum only

Abstract:
Nearshore wave breaking is involved in the exchange of heat and gases between water and air, dissipates energy that could erode the shore, and can pose a hazard to coastal users and boats. Wave set up can affect the water level at the coast and add to wave overtopping and flood risk. Currently, it is difficult to measure the spatial distribution of coastal wave breaking and set up, as it requires in situ sensors, such as cameras, water level gauges, marine radar and wave buoys. Satellite sensors offer the potential to map nearshore wave processes on a global scale. Using Penzance a high wave energy bay in SW England, with an array of available coastal monitoring, the added value satellite information can be explored.

Pulse limited radar altimeters can only measure reliably to ~3 km of the coastline. Improved Synthetic Aperture Radar (SAR) altimeter instruments, launched since 2010, can measure within a few km of the shoreline with a resolution of about 350 m. Sentinel-6A Michael Freilich (S6A-MF) follows on from Jason-3 as the current ocean surface topography reference mission. S6A-MF is a SAR altimeter, with a ten day repeat orbit and an along track resolution of ~262 m. It measures water level, significant wave height and wind speed. The orbital track varies by about 1.3 km in the cross-track direction. The track of the S6A-MF passes east of Penzance, nearly perpendicular with the beach, and the footprint of the altimeter covers a wave buoy. This allows the data from S6A-MF to be compared to an in-situ data set of wave heights, which have been flagged for wave breaking as part of the data quality control process.

The SWOT satellite mission provides 2D water surface elevation measurements, for the first time from space. The HR PIXC data product, though designed for rivers and inshore water bodies, is able to detect near shore features in water level at about 30 m spatial resolution. Though care must be taken as SWOT will also detect intertidal and beach areas, mistaking them for water.

Wave breaking can be seen in the variation of significant wave height (SWH) along the propagation paths of wave systems; estimated from SWH (using a water level and depth wave breaking index); and in the backscatter and peakiness of the returned radar signal. These methods can be compared to wave breaking identified in data from the in-situ wave buoy. Wave set up can be seen in the sea surface elevation along track, for SAR altimetry, and as a 2D sea surface elevation map for SWOT.

We show that it is possible to detect wave processes within a few km of the shoreline using satellite altimetry. Here S6A-MF and SWOT HR PIXC data are used to show patterns of wave breaking and reforming in the nearshore and wave set up. This work was carried out as part of the SPLASH project, to understand wave overtopping at the shore, and SWOT-UK, to validate novel 2D altimetry in the coastal zone.
Corresponding author:
Dougal Lichtman (**National Oceanography Centre**, **United Kingdom**), doulich@noc.ac.uk

A novel operational Sea State Bias correction for Sentinel-3 Delay/Doppler altimeter measurements incorporating wind directional effect

Ngan Tran (CLS, France); Laiba Amarouche (CLS, France); Doug Vandemark (UNH, USA); Hui Feng (UNH, USA); Salvatore Dinardo (EUMETSAT, Germany); Bruno Lucas (EUMETSAT, Germany); Carolina Nogueira-Loddo (EUMETSAT, Germany)

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

Abstract:
The Delay/Doppler altimetry technique, also known as SAR altimetry, has opened a new era for satellite altimetry applications since the launch of the CryoSat-2 mission, followed by Sentinel-3A/B and the more recent Sentinel-6A missions. This high-resolution (HR) dataset offers significant advantages over conventional low-resolution (LR) altimetry, including reduced measurement errors and enhanced along-track spatial resolution. However, this technological advancement has also raised questions regarding the differing sensitivities of Delay/Doppler measurements to ocean surface characteristics: such as wave state, wave motion, surface roughness, and currents, compared to conventional data. These evolving effects necessitate adaptations to traditional processing methods to ensure the continuity and quality of satellite sea level observations.
In this study, we address a known issue reported since 2019 concerning HR/LR range biases between ascending and descending orbits, which have been found to correlate with meridional wind patterns. Initially observed in Sentinel-3 data, this phenomenon also affects Sentinel-6 measurements. Several studies have investigated this feature and attributed it to HR data, linking the observed biases to wind-wave-induced Doppler shifts that manifest as apparent horizontal wave motion.
To mitigate this, we developed an empirical correction in the form of a two-dimensional look-up table (LUT), designed as an additional component to the standard two-dimensional Sea State Bias (SSB) correction applied to range data. This correction effectively removes most of the wind-direction-dependent biases observed between the two operational modes, thereby improving the quality of Sentinel-3 SAR altimetry data across the global ocean. Our results demonstrate the value of this correction in ensuring consistent sea level measurements across all nadir altimeter missions. It will be included in the upcoming Marine Baseline Collection 006. This presentation aims to describe this newly developed operational correction and to report its performance evaluation.

Corresponding author:
Ngan Tran (**CLS**, **France**), ntran@groupcls.com

In situ measurements for SWOT lake water level validation : results from a student project at Lake Guerledan (France)

Clémence Chupin (Lab-STICC I ENSTA, IP Paris, Campus de Brest, France); Pierre Bosser (Lab-STICC I ENSTA, IP Paris, Campus de Brest, France); Séverine Enet (ENSTA, IP Paris, Campus de Brest, France); Clémentine Beau (ENSTA, IP Paris, Campus de Brest, France); Scott Bédart (ENSTA, IP Paris, Campus de Brest, France); Zoé Besnard (ENSTA, IP Paris, Campus de Brest, France); Lola Henneuse (ENSTA, IP Paris, Campus de Brest, France); Kim Monoury—Homet (ENSTA, IP Paris, Campus de Brest, France); Siméon Ridel (ENSTA, IP Paris, Campus de Brest, France); Jules Faguet (ENSG / ENSTA, IP Paris, Campus de Brest, France)

Session: Outreach, Education and Altimetric Data Services
Presentation type: Forum only

Abstract:
As part of an engineering student project, we test KaRin's abilities on one of Brittany's largest freshwater bodies: the Guerlédan dam lake. Since 2015, this lake has been the playground for hydrography and robotics students at the École Nationale Supérieure des Techniques Avancées (ENSTA) [5]. This year, six students were responsible for the lake's instrumentation to monitor water levels, to compare the collected data with SWOT observations in the area. The project took place over five months in partnership with Shom (French naval hydrographic and oceanographic service), and included two weeks of field acquisition in October 2024 and February 2025.

The project focused on two main aspects:

1. Lake in-situ instrumentation: design of a measuring scheme to monitor changes in lake level and enable sensors inter-comparison. Several sensors were deployed :
-> Pressure gauges were moored in various locations on the lake over 5 months for long-term water level monitoring. GNSS buoys were deployed at the lake's surface to ensure the sensors' absolute position.
-> A low-cost GNSS & acoustic altimeter system was developed and deployed for spatial water level monitoring.
-> A fixed GNSS antenna was installed for water level measurement using GNSS interferometric reflectometry (GNSS-IR).
-> An EPONIM autonomous radar tide gauge [6] was installed on the top of the dam to allow inter-comparison of all systems.

2. SWOT data analysis: processing and analysis of SWOT HR Raster 100m data [7] in the area (flag, correction parameters, etc.), and spatial and temporal comparison with in-situ data.

All instrumental deployments were successful, and the coupled GNSS & acoustic altimeter system enabled space-based acquisitions on the lake. In-situ sensors provide consistent water level evolution, despite inter-sensor biases in the range 4-10cm, which are still under investigation. SWOT observations could be retrieved on the lake, but an in-depth analysis of the corrections is required to explain the absolute biases observed with in-situ measurements. For future students' surveys, attention will be paid to the air draft of each sensor and its positioning to avoid any possible shifts. Satellite data analysis will be completed by adding Sentinel-3a observations over the lake.

Bibliography
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[5] S. Rohou, "Hydrographes et Roboticiens explorent le lac de Guerlédan". Accessed: May 26, 2025. [Online]. Available: https://guerledan.ensta-bretagne.fr/
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Corresponding author:
Clémence Chupin (**Lab-STICC | ENSTA, IP Paris, Campus de Brest**, **France**), clemence.chupin@ensta.fr

Evidence of increased deep ocean warming from a sea level budget approach

Anny Cazenave (LEGOS-CNES, France); Chunxue Yang (CNR, Italy); Marie Bouih (Magellium, France); Andrea Storto (CNR, Italy); Jianli Chen (Hong Kong Polytechnic University, Hong Kong); William Llovel (IFREMER, France); Karina von Schuckmann (Mercator Ocean International, France); Lancelot Leclercq (LEGOS, France)

Session: Science I: Understanding and Quantifying Regional and Global Sea Level Budgets
Presentation type: Forum only

Abstract:
Assessments of the global mean sea level (GMSL) budget over the satellite altimetry era (since the early 1990s) have concluded that the GMSL budget is closed within data uncertainties until 2016. However, studies have shown that since then, the sea level budget based on Argo data down to 2000 for the thermosteric contribution is no longer closed. Using an ocean reanalysis with no altimetry data assimilation, we show that accounting for deep ocean thermosteric contribution (below 2000 m, not sampled by Argo) allows the GMSL budget to be almost closed since 2016. The deep ocean contribution over 2005-2022 is estimated to 0.4 □ 0.15 mm/yr, i.e., about 10%. to the observed GMSL rise over that period. This finding reveals that deep ocean warming is gaining importance and that ocean heat uptake has now reached several regions below 2000m depth, notably the Northwestern Atlantic Ocean and areas around Antarctica.

Corresponding author:
Anny Cazenave (**LEGOS-CNES**, **France**), anny.cazenave@univ-tlse3.fr

Abrupt trend change in the early 2010s observed in sea level variations at the world coastlines, as well as in the global mean sea level and its components.

Lancelot Leclercq (Université de Toulouse, LEGOS (CNES/CNRS/IRD/UT), France); Julius Oelsmann (Tulane University, US); Habib B. Dieng (Université Assane Seck de Ziguinchor, Sénégal); Anny Cazenave (Université de Toulouse, LEGOS (CNES/CNRS/IRD/UT), France); Marcello Passaro (Technical University of Munich, Germany); Florenc Birol (Université de Toulouse, LEGOS (CNES/CNRS/IRD/UT), France); Svetlana Jevrejeva (National Oceanography Centre, UK); Erwin Bergsma (CNES, France); Rodrigo Abarca-del-Río (University of Concepcion, Chile); Sarah Connors (ESA, UK); Jean-François Legeais (CLS, France)

Session: Science I: Understanding and Quantifying Regional and Global Sea Level Budgets
Presentation type: Forum only

Abstract:
Using coastal sea level data over January 2002 to June 2021 at 1160 virtual coastal stations well distributed along the world coastlines (ESA Climate Change Initiative Coastal Sea Level project), we performed an Empirical Orthogonal Decomposition analysis of the coastal sea level time series globally and regionally. The objective was: (1) identify the main drivers of the coastal sea level variability at interannual time scale, and (2) assess the along-coast coherence of the sea level response to the dominant drivers. Our results confirm the dominant influence of internal climate modes on interannual coastal sea level variations, in particular of ENSO (El Nino Southern Oscillation) along the Pacific coastlines. Besides, our analysis detects an abrupt change in coastal sea level trend between 2008 and 2012, that is also observed in the regional and global mean sea level. Further investigations reveal that such an abrupt change in sea level trend around 2010 is also present in the contributions to the global mean sea level (i.e., in the thermosteric and ocean mass components). Using statistical trend-change detection methods, we indeed report a statistically significant change in trend around 2010/2011, not only in the altimetry-based global mean sea level record but also in the Argo-based and GRACE-based thermosteric and ocean mass time series. In the latter, the change in trend is mostly due to terrestrial water storage. The rate of rise of the global mean sea level increases abruptly from 2.6 ± 0.3 mm/yr over the 2002-2011 decade to 4.1 ± 0.3 mm/yr over 2012-2021. Abrupt trend change (or regime shift) in the early 2010s have been also reported in the literature in several other climate parameters, suggesting this is a global coherent phenomenon. Both internal climate variability and increased radiative forcing are potential drivers of the early 2010s regime shift observed in sea level and other parameters of the climate system.

Corresponding author:
Lancelot Leclercq (**Université de Toulouse, LEGOS (CNES/CNRS/IRD/UT)**, **France**), lancelot.leclercq@univ-tlse3.fr

Drivers of marine heatwaves and their decadal disruption in the southwest Indian Ocean in recent decades

Weiqing Han (The University of Colorado, Afghanistan); William Kamp (ATOC, the University of Colorado, USA)

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

Abstract:
Marine Heatwaves (MHWs) have been extensively studied in many regions of the world's oceans in recent years. In the Southwest Indian Ocean (SWIO), however, studies on MHWs remain limited. Yet, high sea surface temperature (SST) anomalies in the region can influence marine ecosystems, tropical cyclones and regional climate including the Mauritius, Reunion, and Madagascar island nations and the Southeast Africa. Here, we investigate MHW activities in the SWIO since the early 1980s and understand their underlying causes, using a combination of satellite observations, ECCO and other reanalysis datasets, and climate model simulations. While the warming trend has increased the frequency and intensity of MHWs over the past 4 decades (1982-present), we find a distinct inter-decadal variation such that MHWs are essentially absent from 1993 - 2005 but are strong after 2005 and to a lesser extent, before 1993.

For individual MHW events, surface wind anomalies associated with mid-latitude atmospheric intraseasonal Rossby waves weaken the mean wind speed and increase humidity by advecting moist air from the tropics into the SWIO. Both the weakened winds and enhanced humidity reduce latent heat loss, thereby increasing SST and triggering MHW events. On decadal timescales, we show that the Pinatubo volcanic eruption, acting in concert with the Subtropical Indian Ocean Dipole (SIOD), drives the decadal suppression of MHWs during 1993–2005. In contrast, external forcings (natural and anthropogenic) combined with internal climate variability—particularly the SIOD and South Atlantic Multidecadal Variability (SAMV)—induce strong MHW activity in other decades. These results highlight the importance of the interplay between external forcings and internal climate variability across multiple timescales in generating MHWs and shaping their decadal evolution. Accounting for these factors is essential for skillful predictions of MHW activity.
Corresponding author:
Weiqing Han (**The University of Colorado**, **Afghanistan**), whan@colorado.edu

Sub-mesoscale and coastal ocean dynamics in the North Indian Ocean using SWOT and EOS-06/OCM-3 observations

Aditya Chaudhary (Space Applications Centre, ISRO, India); Neeraj Agarwal (Space Applications Centre (ISRO), India); Rashmi Sharma (Space Applications Centre (ISRO), India)

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

Abstract:
High resolution sea level observations from Surface Water and Ocean Topography (SWOT) mission has enabled us to observe the small scale sea level and circulation features that play an important role in dynamics of the ocean. SWOT provides sea level observations at the 2km resolution over the 120 km swath with a middle gap of 20 km. This enables us to derive geostrophic currents over the similar grid. At these smaller scales, there is mix of balanced motions such as mesoscales, submesoscales and unbalanced motions such as internal waves. Circulation features at smaller scales additionally have cyclostrophic components in addition to the pressure gradient and coriolis, which make the geostrophic assumptions invalid. In addition to the small-scale circulation features in the open ocean, sea level observations in the coastal regions is also a focus of SWOT mission. Coastal areas are highly dynamic because of several coastal processes like coastal jets, tidal circulation, high-density gradients, wind generated dynamics, internal waves etc. SWOT observations can help to reveal some of these dynamics.

In this study, we firstly validate the SWOT sea levels observations over the Indian regions through coastal tide gauge observations and argo floats. Validation results show an error of 3-9cm based on multiple tide gauge observations. The coastal observations for the SWOT is also shown to have more valid observations in the 0-8 km coastal band as compared to along-track nadir observations. SWOT show 17% more variability with respect to the standard seal level gridded products. The RMSD between the SWOT and standard seal level gridded products is nearly 3.3 cm; however, there are considerable differences near the coast, where SWOT sea levels depict significantly higher difference (~5cm RMSD). Detailed results will be presented in the meeting.

Secondly, we analyse the covaribility of the chlorophyll form EOS-06/OCM3 and the circulation features derived from the SWOT. A scheme to correct the SWOT circulation for the cyclostrophic features has also proposed. We show several test cases of SWOT and chlorophyll to show the improvements in using the proposed scheme. Detailed results will be presented in the meeting.

Corresponding author:
Aditya Chaudhary (**Space Applications Centre, ISRO**, **India**), aditya.iist@gmail.com

Jason-3 & Sentinel-6 MF calibration at the Corsica facilities

Pascal Bonnefond (Observatoire de Paris - LTE, France); Olivier Laurain (OCA/Geoazur, France); Pierre Exertier (GET, France); Saïd Haouchine (CNES, France); Nicolas Picot (CNES, France)

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

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 25+ 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.
Since April 2022 Sentinel-6 Mickael Freilich replaced Jason-3 as the reference mission. Over the full set of available cycles, results show 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 for Sentinel-6 Mickael Freilich will be also presented: measurements are valid (and accurate) up to the coast (few hundred meters) and the standard deviation of high-rate data (20Hz) is improved by a factor close to two. Updated results using the new set of full-mission reprocessed data (Processing Baseline F08&F09) will be presented.
In preparation of SWOT, an extension of the Reference Surface over the Ajaccio and Senetosa area has been realized during 2 campaigns in 2021 and 2022. Preliminary results of using this extension for SWOT (at least for nadir altimeter) will be also presented (see presentation “Extending the Corsica facilities up to SWOT swath” also presented at the SWOT ST 2025 meeting).

Corresponding author:
Pascal Bonnefond (**Observatoire de Paris - LTE**, **France**), Pascal.Bonnefond@obspm.fr

Extending the Corsica facilities up to SWOT swath

Pascal Bonnefond (Observatoire de Paris - LTE, France); Olivier Laurain (OCA/Geoazur, France); Michel Calzas (DT-INSU, France); Christine Drezen (DT-INSU, France); Lionel Fichen (DT-INSU, France); Gerald Dibarboure (CNES, France); Thierry Guinle (CNES, France); Philippe Schaeffer (CLS, France)

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

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. In anticipation of SWOT, a first phase of extension of the reference surfaces of the Corsica site was carried out in June 2021 (378 nautical miles) and the second in May 2022 (508 nautical miles). The measurements were carried out simultaneously using the instruments developed by DT-INSU as part of FOAM project (CalNaGeo and Cyclopée), which showed very good consistency (a few mm on average and ~20 mm standard deviation). GNSS processing using different software (track, MIT, differential mode / GINS, CNES, iPPP mode) and using the GPS and Galileo constellations jointly or separately have been analyzed. The high degree of consistency, both at processing level and at instrumental level, demonstrates the great maturity acquired thanks to the synergy of the FOAM group. We will present in details, the different phases of processing and preliminary results of the resulting reference surface local (“Mean Sea Surface”) covering the SWOT swath of pass #001 (60km along-track and 50km across-track)
Preliminary Calibration and Validation results of both KaRIn and nadir altimeters will be also presented.

Corresponding author:
Pascal Bonnefond (**Observatoire de Paris - LTE**, **France**), Pascal.Bonnefond@obspm.fr

Updated in situ validation results of satellite altimetry from the Bass Strait facility

Christopher Watson (University of Tasmania, Australia); Benoit Legresy (CSIRO, Australia); Jack Beardsley (Integrated Marine Observing System, Australia); Matt King (University of Tasmania, Australia)

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) continues to provide cycle-by-cycle estimates of absolute altimeter bias for the reference mission, Sentinel-6 Michael Freilich, in addition to Sentinel-3A and Sentinel-3B, each with dedicated comparison points. The facility uses a direct geometric approach to validation that involves maintaining an in situ network of sensors including moored oceanographic instruments, GNSS equipped buoys, a coastal tide gauge and continuously operating GNSS reference stations. The site is well characterised from sustained in situ observations at key off-shore comparison points and coastal locations, in addition to an augmented array of observations that took place over a broader spatial domain in support of the SWOT mission throughout its one-day repeat calibration phase. Here we present updated results for latest products for Sentinel-6 Michael Freilich, and for Jason-3 in its renewed tandem configuration. We conclude highlighting forward plans in place to support validation of the new Sentinel-6B mission.
Corresponding author:
Christopher Watson (**University of Tasmania**, **Australia**), cwatson@utas.edu.au

Ocean in Motion: Surface Currents from Space

Sarah Gille (Scripps Institution of Oceanography, UC San Diego, United States)

Session: OSTST Plenary Session
Presentation type: Keynote/invited

Abstract:
Ocean currents are a critical component of the Earth system. They transport heat, freshwater, and material across the planet, and they exchange energy with surface-level winds. These features make them a key ingredient for forecast systems, both for the maritime environment and for global weather. Operational users require current data to plan ship routes, to determine pathways of ocean debris, and to strategize successful search and rescue operations. Sentinel 6B, together with other satellite altimeters, will provide vital information allowing us to infer time-varying currents by mapping out the ever-changing topography of the ocean surface. Because of the Earth's rotation, large-scale ocean flows are "geostrophic", meaning that water moves around the bumps and dips in the sea surface. Sentinel 6B's sampling will improve our view of major currents, such as the Gulf Stream, as well as helping to expose the evolution of smaller transient eddy-like features.

In the future, we also hope to measure smaller-scale ocean motions to capture the total ocean surface current, using a satellite-based Doppler scatterometer. The combination of Doppler scatterometer measurements and geostrophic currents from altimetry has the potential to transform our understanding of upper-ocean processes, ultimately paving the way for better predictive models to support weather and maritime applications.
Corresponding author:
Sarah Gille (**Scripps Institution of Oceanography, UC San Diego**, **United States**), sgille@ucsd.edu

Sentinel-6B: Continuing Geodesy’s Quest to Understand a Warming Earth

Benoit Meyssignac (LEGOS, France)

Session: OSTST Plenary Session
Presentation type: Keynote/invited

Abstract:
Geodesy—the science of measuring the Earth's shape—has a long-standing tradition of groundbreaking measurements that have resolved major scientific debates and significantly shaped both modern science and the world we live in today. Among geodesy's historic achievements are Eratosthenes' demonstration of Earth's sphericity in the 3rd century BC, as predicted by Pythagoras and Aristotle, and Maupertuis’ confirmation in 1736 of Earth’s oblateness, as predicted by Newton.
More recently, geodesy has reached new heights with the advent of precise radar altimetry in 1993 and space gravimetry in 2002. For the first time, geodesists could not only measure the Earth's static shape, but also monitor dynamic changes—such as sea level rise and water mass redistribution—driven by Earth system processes. After decades of continuous observation, this geodetic system—comprising 14 satellite altimeters, two space gravimetry missions plus millions of in-situ ocean temperature and salinity profiles (from XBT, CTD, and Argo)- has achieved a level of maturity and precision that allows us to estimate sea level variations on a monthly basis, with quasi-global coverage and a long-term stability better than 0.3 mm/year over periods exceeding 20 years. And this precision improves over time as data accumulates, because uncertainty in the observing system decreases due to the temporal decorrelation of errors.
By ensuring the continuity and the accumulation of more high-precision satellite altimetry data, Sentinel-6B will position geodesy at the forefront of a new scientific breakthrough: accurately estimating ocean heat storage, enabling a robust calculation of the global energy budget, and providing critical insight into current global warming. This dataset will offer key information to resolve one of the most pressing scientific debates today—the magnitude of global warming under a doubling of greenhouse gas (GHG) concentrations, a value predicted to range between 2 and 4K by Nobel Prize-winning physicist Syukuro Manabe in 1967.
In this presentation, I will explain how the launch of Sentinel-6B continues geodesy’s legacy of scientific excellence and how the Sentinel-6 series marks a new chapter in the ongoing history of geodesy—and, more broadly, of science itself—by providing critical observations to help answer one the most pressing scientific question of our time: the climate sensitivity to GHG emissions.

Corresponding author:
Benoit Meyssignac (**LEGOS**, **France**), benoit.meyssignac@univ-tlse3.fr

Optimal parameters for mapping alongtrack altimetry

Lilly Jonathan (Planetary Science Institute, United States)

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

Abstract:
The question of generating optimal maps of sea surface height from alongtrack altimetry is examined though both theory and numerical experiments, considering for simplicity only Jason-class altimetry. The framework of Local Polynomial Fitting (LPF) is proposed as a mapping solution with numerous advantages over the more familiar Optimal Interpolation (OI): it requires fewer a priori assumptions; it is easy to keep track of exactly what is being done with the data; its performance and error properties are well understood thanks to a large theoretical literature; it is much faster due to the inverted matrix being orders of magnitude smaller; and finally, since all linear methods are in a sense equivalent, the use of a sufficiently large parameter space in local polynomial fitting would not exclude any possibilities that one might alternately express via OI.

Map fidelity is tested within the context of an Observing System Simulation Experiment, or OSSE, together with a new, general form for the weighting kernel and newly derived error expressions. Minimizing globally-averaged mean square error over thousands of different choices of parameters leads to the identification of an optimal choice. The resulting maps, based on only Jason-class altimetry, rival the standard CMEMS product in quality despite using only a fraction of the data; this suggests the potential for considerably improved maps through a refined mapping algorithm.

The key take-aways are as follows. First, the use of a fit of first or second order (that is, a fit to a plane or a parabolic surface) removes severe artifacts associated with the irregular spacing of the alongtrack data, in line with a well-known theoretical property known as design adaptivity. Second, the optimal radii—ranging from less than 50 km at high latitudes, to about 100 km at low latitudes, to around 180 km at the equator—are considerably smaller than those implied by the CMEMS mapping, suggesting the latter are oversmoothed. Third, weighting function shape is found to play a negligible role in map quality. Finally, further improvements are found to be unlikely because the remaining error is associated with curvature within regions of data gaps from which no information can be recovered.

The results from the OSSE are also compared with best-fit parameters inferred from so-called plug-in estimators, wherein an initial test map is used to deduce an optimal set of mapping parameters based on asymptotic theory. The plug-in estimates are found to be inferior to the OSSE-determined parameters, due primarily to the presence of sudden fall-offs in fit quality just beyond the optimal choices. Thus, while error estimates are of course an important part of the mapping process, OSSE type experiments are invaluable as a way to identify the likely best choice of parameters.

Suggestions are then given as to how these results could be used to improve future data products.
Corresponding author:
Lilly Jonathan (**Planetary Science Institute**, **United States**), jmlilly@psi.edu

Inclusion of the ocean's vertical velocity variance into the sea-state-bias correction

Marcel Kleinherenbrink (Delft University of Technology, Netherlands); Fritjof Ehlers (Delft University of Technology, Netherlands); Florian Schlembach (DGFI, Germany)

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

Abstract:
The sea-state-bias (SSB) correction is one of the largest sources of error in sea-surface-height estimation from nadir altimetry. The SSB is often considered to consist of three contributions: 1) a difference in reflectivity of wave crests and troughs (the electromagnetic bias), 2) non-linear wave shapes (skewness bias) and 3) instrumental and processing effects. Empirical models to correct for the SSB now depend on the significant wave height (SWH) and the normalised radar cross section (NRCS), or its derived level-2 parameter, stress-equivalent wind speed. Despite attempts to improve the model using external data or gradients of retracked parameters, the uncertainty of the SSB correction still lingers around 2 cm. With requirements for upcoming altimeter missions (for example Sentinel-3 Next Generation Topography) being pushed towards this level, an improved correction is required.

Following other works, we agree that the NRCS and SWH are insufficient to describe the complex nature of the ocean surface. The NRCS is closely connected to the mean-square slope, which is primarily driven by short wind waves (<5 m wavelength). The SWH depends primarily on long wind waves and swell, but does not discriminate between both, while they both contribute differently to the electromagnetic and skewness biases. The absence or presence of swell would therefore already introduce problems for the two-parameter model. Additional complexity arises from the presence of surface currents, or near-shore ocean-bottom topography (wave breaking, refraction) and wind-speed variations (wave age). These issues cannot be overcome by traditional processing approaches.

Buchhaupt et al. (2023) already hinted on the connection between the SSB and the ocean's vertical velocity variance. The velocity variance is dominated by medium to long wind waves, while the contribution of swell (if present) is typically in the order of 10%. The addition of the velocity variance parameter is therefore expected to improve the SSB model. Focused SAR processing for nadir altimeters allows to estimate the along-track autocorrelation. The along-track auto-correlation depends on the sea state and is under moderate conditions dominated by the line-of-sight-projected velocity variance of the ocean surface.

In this study, we apply focused SAR processing to Sentinel-6 data at crossovers. We introduce the estimated autocorrelation as a new parameter in the SSB model for the low-resolution sea-surface-height product. The results are compared to the traditional two-parameter models. Some limitations to the suggested methodology are discussed. Further improvements are expected by separating wind-wave and swell parameters based on the analysis of waveform tails.

Corresponding author:
Marcel Kleinherenbrink (**Delft University of Technology**, **Netherlands**), m.kleinherenbrink@tudelft.nl

Improved algorithms for the wet tropospheric correction over coastal regions: application to the Sentinel-3 mission

Pedro Aguiar (FCUP, Portugal); Telmo Vieira (FCUP, Portugal); Clara Lázaro (FCUP, Portugal); M. Joana Fernandes (FCUP, Portugal)

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

Abstract:
Microwave radiometers (MWR) onboard satellite altimetry missions fail to provide accurate wet tropospheric correction (WTC) values over coastal regions. The retrieval errors rapidly increase for decreasing distances to the coastline due to land contamination on the MWR brightness temperatures (TBs) measurements. In this work, improved algorithms for the WTC retrieval over coastal regions are proposed, applied to the Sentinel-3 mission, based on the Sentinel-3 dual-band MWR TBs and complemented with additional parameters to account for surface effects. Methods for mitigating the effects of land contamination on input parameters, MWR TBs and Synthetic Aperture Radar Altimeter (SRAL) backscatter coefficient σ0, at Ku band, are presented. Two approaches were carried out, consisting of the usage of these modified inputs in the open-ocean retrieval algorithm, and, on a second stage, on retrieval algorithms specifically trained on coastal regions. The comparison against the WTC derived from independent coastal Global Navigation Satellite Systems (GNSS) stations shows that the combined strength of coastal retrieval algorithms with modified inputs can lead to a substantial reduction in coastal retrieval errors. The corresponding rms values are 3.1 cm between 5 and 10 km from the coast and 3.3 cm up to 5 km from the coast. For the Sentinel-3 MWR-derived operational WTC retrieval algorithm, these values are 9.2 cm between 5 and 10 km from the coast and 16.2 cm up to 5 km from the coast, which translates to rms error reductions of 6.1 cm and 12.9 cm, respectively.
Corresponding author:
Pedro Aguiar (**FCUP**, **Portugal**), pedro.aguiar@fc.up.pt

Wet troposphere correction derived from water vapor climate data records

Anne Barnoud (Magellium, France); Marie Bouih (Magellium, France); Bruno Picard (Fluctus, France); Benoit Meyssignac (LEGOS, France); Florence Marti (Magellium, France); Michaël Ablain (Magellium, France); Rémy Roca (LEGOS, France)

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

Abstract:
The wet troposphere correction (WTC) from the onboard microwave radiometers on-board the altimetry missions is one of the main sources of uncertainties in the estimate of the global mean sea level rise. Using highly stable water vapor climate data records based on measurements from SSM/I and SSMI/S meteorological space missions, we compute an alternative wet troposphere correction and its associated uncertainty.

Our results show the potential of these climate data records to improve the measurement of the sea level rise from altimetry. First, the uncertainty of the global mean sea level trends can be reduced using these climate data records. Second, the wet troposphere correction derived from water vapor climate data records allows to identify drifts in the WTC estimated from some of the microwave radiometer measurements. In particular, significant drifts have been detected over the first two years of Jason-2 (about 2 mm over 2009-2010) and over the first two years of Jason-3 (about 3 mm over 2016-2018) missions.

We therefore recommend the use of the water vapor climate data records for the validation of the wet troposphere correction of altimetry missions, supporting the need for regularly updated climate data records of water vapor.
Corresponding author:
Anne Barnoud (**Magellium**, **France**), anne.barnoud@magellium.fr

Performances and benefits of a 1D-variational approach to retrieve the wet tropospheric correction: recent achievements for Sentinel-6 and Sentinel-3A and -3B topography missions

Ralf Bennartz (Univ. Vanderbilt, Nashville, TN, USA, United States); Bruno Picard (Fluctus, France); Frank Fell (Informus, Deutschland); Estelle Olibis (EUMETSAT, Deutschland); Remko Scharroo (Eumetsat, Deutschland); Bruno Lucas (Eumetsat, Deutschland); Boyan Bojkov (Eumetsat, Deutschland)

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

Abstract:
Statistical methods are usually used to provide estimates of total column water vapour (TCWV) and wet tropospheric correction (WTC), required to correct altimetry measurements for atmospheric path delays, using brightness temperatures (TB) measured at two or three low frequencies from a passive microwave radiometer (MWR) operated concomitantly with the altimeter. Despite their overall accuracy over oceanic surfaces, uncertainties remain in specific regions of complex atmospheric stratification. Thus, there is a need to further improve the currently used retrieval methods.

Within this context, a one-dimensional variational (1D-Var) method has been developed, assimilating the relevant passive microwave observations to retrieve the WTC and the TCWV over the ice-free global 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, ERA-5 reanalysis, sample products of the latest AIRWAVE TCWV retrieval derived from SLSTR observations, as well as GPS-based high-quality TCWV retrievals from the year 2020.

This validation has allowed to qualify the 1D-var approach as a mature algorithm, capable of retrieving TCWV and WTC at a global performance level comparable to that of the operational product. Moreover, each value of the TCWV and WTC retrieved with the 1D-var method benefits from an associated uncertainty and a self-consistent quality flag greatly facilitating the assessment of the product.

A further step has been taken by applying the same approach to Sentinel-6 mission, based the 3-TB measurements provided by the on-board MWR AMR-C developed by the JPL. We will present the first results of the assessment of the WTC retrieval, illustrating the benefit of the 18.7 GHz channel and comparing the performance of the 1D-var against the operational products.
Corresponding author:
Ralf Bennartz (**Univ. Vanderbilt, Nashville, TN, USA**, **United States**), bennartz@me.com

How has global warming impacted the altimeter wet path delay over the altimetry record?

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

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

Abstract:
Thirty years of satellite radar altimetry allow the monitoring of the changes in sea level at global and regional scales. The accurate determination of these changes depends directly on the wet path delay (WPD) in the altimeter observations, mostly due to the atmospheric water vapor. It is known that the water vapor in the atmosphere increases at an average rate of 7% per 1°C of warming. Building upon this relationship, this study focuses on the impact of global warming on the WPD over the altimetry era (1993-2022). Near surface air temperature (T2m) and total column water vapor (TCWV) data provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) ReAnalysis 5 (ERA5) and the corresponding ERA5-derived WPD have been analyzed.
Results reveal that global land-ocean temperature has increased at an average rate of 0.23°C/decade and, in close association with higher temperatures, TCWV has increased at a rate of 0.37 mm/decade. For the global ocean, these trends are 0.18°C and 0.43 mm per decade, respectively. This shows that, per 1°C of warming, TCWV increases at an average rate of 7% globally and 9% over the global ocean. This global warming over these 30 years was responsible for an average increase in TCWV of 1.3 mm over oceans, which represents an increase in WPD of 8 mm (0.26 cm/decade), equivalent to 1.4 cm (9%) per 1°C of warming.
The good performance of satellite radar altimetry to measure sea level requires regular assessments of all involved components (measurements, orbit, environmental corrections, etc.) both in terms of accuracy and long-term stability. This study shows that the global warming has induced a physical long-term variation in the altimeter wet path delay (0.26 mm/year), which can be misinterpreted as a long-term instability, such as a drift in the correction.
This study also shows that, in spite of the fact that satellite radar altimetry is a remote sensing technique to monitor the planet, the climate change itself is changing the way how this technique is working. This can cause a misleading between physical signals and instrument drifts, requiring a regular monitoring and possibly updates in the altimetry methodologies used to retrieve the WPD of satellite altimeter observations.
Corresponding author:
Telmo Vieira (**University of Porto, Faculty of Sciences**, **Portugal**), telmo.vieira@fc.up.pt

Progress on the Wet Path Delay Correction: Historical, Current and Future

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

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

Abstract:
Here we describe recent updates to the wet tropospheric path delay correction on Jason-2 and Jason-3 that improve the long term stability of the product and reduce uncertainties in the global mean sea level trend. These updates were based on an inter-comparison with SSMI radiometers and independent re-analysis models. While the changes are relatively small, they made improve closure of the sea level budget after 2016.

We will also provide an update on the performance of the Sentinel-6A radiometer in terms of long term stability, which is enabled by the new supplemental calibration system on-board. We will also show new results for the performance in coastal regions that are enabled by the new High Resolution Microwave Radiometer (HRMR).

Finally, we will describe the radiometer currently in development for the CRISTAL mission and discuss new cryospheric applications possible with the combination of sensors on this mission.
Corresponding author:
Shannon Brown (**JPL**, **United States**), shannon.t.brown@jpl.nasa.gov

Opening and scope of the workshop

Detlef Stammer (CEN, Universität Hamburg, Germany)

Session: Workshop on the Sentinel-6 Next Generation's orbit
Presentation type: Oral

Abstract:
The talk will set the stage for the discussion required during this workshop and will define the goals that need to be accomplished before its closing.

Corresponding author:
Detlef Stammer (**CEN, Universität Hamburg**, **Germany**), detlef.stammer@uni-hamburg.de

The Sentinel-6 Next Generation Copernicus Altimetry Mission: Enhancing Continuity, Performance and Observational Capabilities

Alejandro Egido (European Space Agency, Netherlands)

Session: Workshop on the Sentinel-6 Next Generation's orbit
Presentation type: Oral

Abstract:
The European Space Agency (ESA), under directives the EU Council and European Parliament, has the mandate to define "the overall system architecture for the Copernicus space component (CSC) and its evolution on the basis of user requirements, coordinated by the Commission". Following this rationale ESA, in close interaction with the EC, EUMETSAT and Member States, has identified key components of the CSC Long-Term Scenario (LTS).

A pivotal element of the CSC-LTS are the Sentinel-3 Next Generation Topography (S3NG-T) and Sentinel-6 Next Generation (S6NG) missions.

The S6NG mission will guarantee the reference altimetry measurements for the 2035-2055 time frame, providing enhanced continuity of the satellite altimetry geodetic data record for sea surface height, mean sea level, waves and wind speed measurements, created through the reference altimeter missions, starting from TOPEX/Poseidon, Jason-1, Jason-2, Jason-3, and now the current Copernicus Sentinel-6 mission.

The key drivers for the S6NG mission are to provide enhanced continuity responding to evolving user requirements for climate research, (Meyssignac, et al., 2023), while complying with current space debris regulation and programmatic conditions, reflected in the CSC-LTS. New scientific requirements for global and regional mean sea level trend uncertainty have recently been substantiated to address key scientific questions related to climate change such as closing the sea level budget, detecting and attributing the signal in sea level forced by the greenhouse gas emissions and monitoring the Earth's energy imbalance.

This presentation covers the essential requirements, design considerations, and strategic perspectives for the future implementation of the S6NG mission, a recap of the outcomes of the Phase-0 preparatory activities and future plans for the mission.

Meyssignac, B., Ablain, M., Guérou, A., Prandi, P., Barnoud, A., Blazquez, A., Fourest, S., Rousseau, V., Bonnefond, P., Cazenave, A., Chenal, J., Dibarboure, G., Donlon, C., Benveniste, J., Sylvestre-Baron, A., and Vinogradova, N.: How accurate is accurate enough for measuring sea-level rise and variability, Nature Climate Change, 13, 796–803, https://doi.org/10.1038/s41558-023-01735-z, 2023

Corresponding author:
Alejandro Egido (**European Space Agency**, **Netherlands**), alejandro.egido@esa.int

Summary of previous studies and information regarding the reference orbit determination

Loren Carrere (CLS, France)

Session: Workshop on the Sentinel-6 Next Generation's orbit
Presentation type: Oral

Abstract:
The determination of the reference altimeter mission is a complex problem because many conflicting requirements, constraints and issues must be taken into account: the diversity of user requirements, the need to optimise the altimeter system error budget, the adequacy between the signals of interest and the altimeter system capacity, the incentive to minimize mission costs, the need to consider the multi-mission, multi-agency context….
In 2009, in the context of post-EPS (EUMETSAT's follow-on Polar System), a specific study has been conducted by a consortium led by CLS (EUMETSAT funding), to suggest a few optimal orbit candidates for the future reference mission named Jason-CS (now Sentinel-6 mission). At that time, the CEOS (Committee on Earth Observation Satellites, EUMETSAT) recommendations concerned the transition of satellite altimetry into a sustained global system supporting operational oceanography and climate monitoring, which included to maintain continuity of high-accuracy TP/Jason altimetry, maintain continuity with altimeters on at least two complementary high-inclination satellites and extend the capability of altimetry to denser observational coverage…
We propose to present a summary of the 2009 orbits' optimization study including the main objectives, the methodology used and main results concerning tides and high-frequencies and several ocean applications that were considered (mesoscale, climate, hydrology …).
Then we will introduce the new context and the new challenges that must be addressed for the S6NG orbit definition.

Corresponding author:
Loren Carrere (**CLS**, **France**), lcarrere@groupcls.com

Summary of the ESA-supported Sentinel-6 Next generation orbital study with Eumetsat and CNES contributions

Michael Ablain (MAGELLIUM, France); Noémie Lalau (MAGELLIUM, FRANCE); Louis Kern (MAGELLIUM, FRANCE); Thomas Vaujour (MAGELLIUM, FRANCE); Loren Carrere (CLS, France); Pierre Prandi (CLS, France); Antonio Bonaduce (Norway, Norway); Fabio Mangini (Norway, Norway); Detlef Stammer, Prof. Dr. (University of Hamburg, Germany); Emma Woolliams (NPL, UK); Alejandro Egido (ESA/ESTEC, Netherland); Marcel Kleinherenbrink (ESA/ESTEC, Netherland); Robert Cullen (ESA/ESTEC, Netherland); Lionel Zawadzki (CNES, FRANCE); Alexandre Couher (CNES, France); Scharroo Remko (EUMETSAT, Germany)

Session: Workshop on the Sentinel-6 Next Generation's orbit
Presentation type: Oral

Abstract:
The Sentinel-6 mission of the Copernicus Space Component (CSC) provides a satellite aiming at measuring the sea level rise and other key climate variables (e.g. sea state and near surface wind measurements). To ensure continuity and meet evolving user needs, the Sentinel-6 Next Generation (S6NG) mission is being planned (Donlon et al., 2021).
The main goal is to enhance the accuracy and stability of sea level measurements, particularly to support climate research. Meyssignac et al. (2023) described the main science questions to answer and their needs in terms of sea level estimates' accuracy.
A potential change being considered by ESA is lowering the satellite's orbit at 800 km with a higher inclination. The main reason for this potential change is a reduction in the cost of deorbiting the satellite within the five-year timeframe mandated by new EC/ESA Copernicus regulations, this process being fuel-intensive from the current higher altitude. This reduced fuel requirement could even allow for an extension of the mission's operational lifespan to the Copernicus program's standard of 7.5 years, offering programmatic advantages.
However, lowering the orbit would also eliminate the possibility of a tandem phase with the current Sentinel-6 mission. This tandem phase, where both satellites operate simultaneously in similar orbits, is crucial for cross-calibration and data continuity. The loss of this phase could impact the accuracy and consistency of sea level measurements collected by the two missions (Zawadzki and Ablain, 2016). The change of the reference orbit could also impact the sea level stability through different effects impacting the accuracy of the precise orbit determination and the environmental corrections.
The main objective of the orbital study (namely ORBITAS) is therefore to evaluate how a new reference orbit for S6NG will impact the current mean sea level uncertainty budget (Ablain et al., 2019; Guérou et al., 2023; Prandi et al., 2021) and meet the scientific requirements on mean sea level stability established by Meyssignac et al. (2023).
In order to reach the objective, a multi-step approach to analyzing the stability of the sea level data record under various potential future satellite altimetry orbit scenarios will be carried out. The first is the Reference Scenario, which maintains the historical orbit used by previous missions. The second scenario introduces a non-sun synchronous lower orbit. The third scenario relies on non-reference missions (such as Envisat, Cryosat, and Sentinel-3). The core step of the study involves identifying and quantifying several key sources of uncertainty that will impact sea level stability. These include the inter-mission offset uncertainty, uncertainties in precise orbit determination, uncertainties from environmental corrections like ocean tides and atmosphere, and uncertainties with observability of ocean variability due to along-track sampling and poor coverage in areas like the Arctic Ocean. The project's subsequent focus is on generating a Sea Level Rise Stability Uncertainty Budget (SLR-SUB) for all three orbital scenarios at both global and regional scales. From these SLR-SUB, the project will then analyze uncertainties in sea level trends and acceleration over different time periods. This analysis will be extended to ocean heat uptake by combining the absolute sea level record with gravimetry measurements.
The ORBITAS study is supported by ESA, with contributions from Eumetsat for the non-reference missions and from CNES for the POD and environmental corrections.

Corresponding author:
Michael Ablain (**MAGELLIUM**, **France**), michael.ablain@magellium.fr

Cal/Val: Results of past tandem missions

Michael Ablain (Magellium, France); Eric LeulLiette (NOAA, USA)

Session: Workshop on the Sentinel-6 Next Generation's orbit
Presentation type: Oral

Abstract:
Tandem flight phases (hereafter named "tandem phase") have played a key role in verifying and ensuring the consistency of sea level measurements between successive reference missions. The tandem phases have been implemented after the launch of each new reference mission: TP and Jason-1 (2002), Jason-1 and Jason-2 (2008), Jason-2 and Jason-3 (2016), and Jason-3 and S6-MF (2021–2022). During a tandem phase, the two successive reference missions follow each other on an identical ground track at intervals of less than 1 min. Upon completion of each tandem phase, the older reference mission is moved over an alternative orbit to enhance sea level observations (Dibarboure et al., 2012).
During a tandem phase, we can reasonably assume that the ocean and atmosphere at the scales we are interested in do not vary significantly between measurements made by the two altimetry missions. Therefore, by comparing the sea level measurements from the two altimeters, the geophysical and atmospherical effects are canceled out. We can therefore accurately determine the relative errors made by both altimetry missions, which are made up of several effects. The first effect arises from the instrumental differences related to the altimeter characteristics (e.g., altimeter noise, how a radar pulse interacts with the ocean surface; see Dibarboure et al., 2014) and the processing of the altimeter measurements (e.g., algorithm retracking, sea-state bias correction). The second effect stems from differences in the precise orbit determination (POD) (Couhert et al., 2015; Rudenko et al., 2023). The last effect is due to the differences in the mean sea surface (MSS) in areas of strong geoid gradients (Schaeffer et al., 2023) because the two satellites are not exactly on the ground track (±1 km). The systematic instrumental differences are obtained after averaging the short-term time-correlated effects on the relative errors (e.g., instrumental noise, differences in the POD and the MSS) over a period of at least 100 d (CNES, 2008). Tandem phases allowed the precise calibration of the two altimeters, with the detection of systematic instrumental differences of a few millimeters to a few centimeters at different spatial scales from a few hundred kilometers to the global scale (e.g., Dorandeu et al., 2004; Ablain et al., 2010; Cadier et al., 2024). This presentation will showcase relevant results obtained during the past tandem phase, during calibration and validation activities.

Corresponding author:
Michael Ablain (**Magellium**, **France**), michael.ablain@magellium.fr

POD performances for Jason-3/Sentinel-3A and lessons learned for Sentinel-6 NG

Frank Lemoine (NASA, United States); Alexandre Couhert (CNES, France)

Session: Workshop on the Sentinel-6 Next Generation's orbit
Presentation type: Oral

Abstract:
In the past decade the POD groups have demonstrated radial orbit accuracy of less than 10 mm on the key altimetry satellites of Jason-3, the Sentinel-3A/-3B satellites and Sentinel-6 MF. We review briefly the current POD performance especially with respect to radial orbit accuracy, and the long-term stability on global and regional scale. Then based on our ongoing experience, we make some recommendations concerning POD requirements for Sentinel-6NG.
Corresponding author:
Frank Lemoine (**NASA**, **United States**), frank.g.lemoine@nasa.gov

Continuity of global and regional mean sea level data record

Noémie Lalau (Magellium, France)

Session: Workshop on the Sentinel-6 Next Generation's orbit
Presentation type: Oral

Abstract:
The altimetry sea level data record has been continuously calculated using multiple satellite altimetry missions since January 1993. The five successive reference missions, TOPEX/Poseidon (TP), Jason-1, Jason-2, Jason-3, and more recently Sentinel-6 Michael Freilich (S6-MF), have ensured the continuity and stability of the sea level data record. The upcoming launches of the Copernicus Sentinel-6B and Sentinel-6C satellites in the next decade are expected to maintain this continuity and stability. It is crucial to maintain the stability of the sea level data record to effectively monitor the effects of current climate change, including sea level rise and acceleration Meyssignac et al. (2023), oceanic heat uptake, and the Earth's energy imbalance (Hakuba et al., 2021; Marti et al., 2022, 2024).
This continuity has strongly contributed to the stability of the mean sea level at global mean: 0.3 mm/yr within a 90 % confidence level over the last 20 years (update of Guerou et al, 2023), and close to 1 mm/yr at regional mean (update of Prandi et al., 2021).
The most effective method for accurately assessing continuity between successive altimeter missions over the ocean is the tandem flight phase. Tandem phases have been systematically implemented following the launch of new reference altimetry missions, including TP and J1 (2002), J1 and J2 (2008), J2 and J3 (2016), and J3 and S6-MF (2021-2022). These calibration campaigns are essential for maintaining the accuracy and stability of the satellite altimetry record.
Tandem phases allowed the precise calibration of the two altimeters, with the detection of systematic instrumental differences of a few millimeters to a few centimeters at different spatial scales from a few hundred kilometers to the global scale (e.g., Ablain et al., 2010; Cadier et al., 2024; Dorandeu et al., 2004). Specifically, they allowed the accurate estimation of the mean sea level offset between two successive altimetry missions on the order of a few millimeters to a few centimeters (depending on the altimetry missions).
On the global mean, the sea level offset between two successive reference missions is calculated with an accuracy lower than 0.5 mm at a confidence level of 68% (Guérou et al., 2023; Zawadzki and Ablain, 2016). At regional scales of a few hundred km, the uncertainty of the mean sea level offset increases to 2 mm (outcome of the ESA-supported ASELSU project), depending on the area.
With the potential change in the Sentinel-6 Next Generation (S6NG) orbit, the classical tandem phase will not be feasible. One of the objectives of the ESA-supported ORBITAS study is to quantify the impact of the S6NG orbit change on the continuity of global and regional sea level record, considering several orbit change scenarios.

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Corresponding author:
Noémie Lalau (**Magellium**, **France**), noemie.lalau@magellium.fr

Thoughts regarding tides and the reference orbit

Richard Ray (NASA/self, United States)

Session: Workshop on the Sentinel-6 Next Generation's orbit
Presentation type: Oral

Abstract:
Aside from ensuring "good" tidal alias periods for any new orbit, the main concern is what may be lost by giving up the current orbit. Any change will clearly break the current time series at some level. Changing a system capable of monitoring the ocean in the same way over multiple decades is obviously risky, as it possibly disrupts our ability to observe changes in the ocean. Sometimes the ocean's changes are very tiny and challenging to detect with confidence. There is little doubt that the current system is vulnerable to systematic errors, some of them possibly larger than we realize, but a new system has different systematic errors that may be difficult to understand or to account for at the required level.

To be more concrete: We are now beginning to detect tiny changes in the amplitude of the ocean tide which are clearly a manifestation of climate change. The ocean's increasing stratification is evidently changing barotropic-to-baroclinic conversion and this shows up in the energetics of the barotropic tide. The signal is large enough in places like the Yellow Sea that it will be seen in any new (well designed) orbit. In the open ocean, however, systematic errors and measurement errors in current altimetry make the signal difficult to detect, even after 30 years of nearly identical measurements, and any changes in the orbit will compound this difficulty inordinately. I will discuss some details.

Granted, a changing tide is not of great importance to tidal prediction if the tidal changes are indeed tiny. However, these changes are still of importance in their own right as a definite signal of a changing ocean and a changing climate.

Corresponding author:
Richard Ray (**NASA/self**, **United States**), rray54@yahoo.com

Continuity in Estimating Ocean Heat Content & Earth's Energy Imbalance

Maria Hakuba (Jet Propulsion Laboratory, California Institute of Technology, United States); Benoit Meyssignac (LEGOS, Université de Toulouse, CNES, CNRS, IRD, UPS, Toulouse, France, France); Felix Landerer (Jet Propulsion Laboratory, California Institute of Technology , United States); Nathalie Zilberman (Scripps Institution of Oceanography, UC San Diego, United States)

Session: Workshop on the Sentinel-6 Next Generation's orbit
Presentation type: Oral

Abstract:
Earth's energy imbalance (EEI) is a fundamental metric of global Earth system change, quantifying the cumulative impact of natural and anthropogenic radiative forcings and feedback. In principle, the absolute EEI magnitude is the small difference between large incoming and outgoing radiative fluxes at the TOA. But due to calibration and retrieval uncertainties that are one order of magnitude larger than EEI itself, EEI cannot be derived from radiometric observations such as provided by CERES, unless adjustments are made to match the global net radiative flux to independent estimates of long-term planetary heat uptake. The quantification of EEI absolute magnitude is facilitated through heat inventory analysis, where ~90% of heat uptake manifests as an increase in ocean heat content (OHC). Various international groups provide OHC datasets derived from in situ and satellite observations, as well as from reanalyses ingesting many available observations. The most precise EEI time mean, and time variability as compared to CERES, is gained from combining Argo or gravimetric ocean mass data with altimetric sea surface height measurements. Accurate and precise EEI estimates therefore hinge on altimetry precision and it is vital to assess the impact orbit changes of Sentinel-6 Next Generation satellites could pose on EEI estimates.
We will present some of the key challenges the current EEI observing system is faced with, related to looming data gaps and the seamless continuity of both the Earth's Radiation Budget and Ocean Heat Content data records. The GEWEX-EEI community has recommended studies that explore observing system requirements, ways to meet them, critical ancillary information and the impact of data gaps, to help maintain and improve the EEI monitoring system of the future. We provide status updates pertaining to Argo, Deep-Argo, GRACE-C, CERES & Libera, discuss steps taken to investigate continuity risk and implications, and provide first-order requirements for EEI estimation to inform Next Generation Sentinel-6 mission design.
Corresponding author:
Maria Hakuba (**Jet Propulsion Laboratory, California Institute of Technology**, **United States**), maria.z.hakuba@jpl.nasa.gov

Conclusions and Final Discussion

Detlef Stammer (CEN, Universität Hamburg, Germany)

Session: Workshop on the Sentinel-6 Next Generation's orbit
Presentation type: Oral

Abstract:
This talk will summarize the conclusion drawn during the discussion and will discuss the needed additional studies that are required before a recommendation can be made regarding the future orbit choices of the altimetric satellite missions continuing the heritage of the T/P and Jason heritage. The session will consider also the outcomes of a community consultation regarding potential benefits or risks for changing the obit of the important altimetric reference mission for considered applications.
Corresponding author:
Detlef Stammer (**CEN, Universität Hamburg**, **Germany**), detlef.stammer@uni-hamburg.de

A Dynamic Persistent Sea Level Prediction System

Ou Wang (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States); Ian Fenty (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States); Kevin Marlin (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States); Tong Lee (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States); Thomas Huang (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States)

Session: Application development for Operations
Presentation type: Poster
Poster number: APO2025_001

Abstract:
As nuisance flooding in coastal communities becomes more frequent in a warming climate, skillful seasonal prediction of sea-level anomalies (SLAs) is of growing societal importance. Yet state-of-the-art Earth system models often struggle at seasonal lead times due to initialization shocks and model biases. Furthermore, actionable forecasts require low latency and near–real-time updates to support short-fuse operational and policy decisions. Building on a previously demonstrated pilot study, we expand and operationalize a dynamic-persistence approach that leverages the ocean's long memory via adjoint sensitivities to atmospheric forcings within the Estimating the Circulation and Climate of the Ocean (ECCO) state estimation framework, which synthesizes satellite altimetry and other observations with a general circulation model. Seasonal SLAs are forecasted by convolving these sensitivities with climatological atmospheric forcings. We present a prototype cloud-based, near-real-time, low-cost forecasting system that scales this method from a single site to major cities along the contiguous U.S. coastline, with automated workflows for data ingestion and forecast production. This expanded system is designed to deliver actionable, user-relevant guidance for coastal planning and risk management.

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Corresponding author:
Ou Wang (**Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California**, **United States**), ou.wang@jpl.nasa.gov

Moving ocean prediction skill

Gregg Jacobs (University of Southern Mississippi, United States); Joseph D'Addezio (Naval Research Laboratory, United States)

Session: Application development for Operations
Presentation type: Poster
Poster number: APO2025_002

Abstract:
Ocean prediction during the Global Ocean Data Assimilation Experiment (GODAE) set a goal to predict mesoscale eddy circulation. This goal was achieved in no small part by the nadir altimeters from TOPEX / Poseidon through Jason-1. The numerical ocean models were of resolution to represent eddy physics, and the satellite observations roughly resolved the mesoscale features.

Since that time, computational capability has advanced, and numerical ocean models represent much smaller scales. Observing systems from in-situ to satellite have advanced with the demonstration of SWOT. The key difference is that now we experience patch dense data. That is, the locations in which we have high resolution observations change from one day to another. Research has been under way to account for the issues inherent in this situation.

We examine the global and regional prediction enabled by patchy dense data and how the day-to-day variations are taken into account. The process has been demonstrated during the Sub-Mesoscale Dynamics Experiment (S-MODE) and has been implemented into operational ocean prediction systems. A key component is the ability to estimate a global map of scales resolved given the distribution of observations returned on each day. This includes both satellite and in-situ. Thus, when a new in-situ experiment begins and data is returned, the system adapts naturally to make small scale corrections to the ocean prediction system in the local area. When the experiment ends, the system returns to correcting only the larger resolved scales.

The adaptive scale approach changes the scales corrected in prediction system as the SWOT observations change position each day. During the SWOT cal/val period, the adaptive scale approach and the prior standard approach were run side by side for evaluation. Compared to the in situ observations, the adaptive approach reduced steric height error variance by more than 50%. Such evolution in observation application carries forward the ability to adapt to changes in the future.

Corresponding author:
Gregg Jacobs (**University of Southern Mississippi**, **United States**), gregg.jacobs@nrlssc.navy.mil

Tactical Overview of the Naval Oceanographic Office's Altimetry Data Fusion Center

Danielle Carpenter (Naval Oceanographic Office, United States); Alyssa Silvas (Naval Oceanographic Office, United States)

Session: Application development for Operations
Presentation type: Poster
Poster number: APO2025_003

Abstract:
The Remote Sensing Branch of the Ocean Measurements Division in the Oceanographic Department of the Naval Oceanographic Office (NAVOCEANO) is responsible for providing a variety of near-real-time ocean measurements to the US Navy, as well as other government agencies. With developmental assistance from the Naval Research Lab (NRL), numerous sets of satellite data and in-situ observations are processed in house for a variety of customers in a variety of formats. The mission of the Altimetry Data Fusion Center (ADFC) is to provide near real-time altimetry-derived Sea Surface Height Anomaly (SSHa), Marine Wind Speed (MWS), and Significant Wave Height (SWH) for assimilation into operational oceanographic models. ADFC is responsible for providing timely, accurate, and quality-controlled SSHa and wind/wave observations for the assimilation by the Navy's Earth System Prediction Capability (ESPC), Navy Coastal Ocean Model (NCOM), Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS), and Wave Watch 3 (WW3) performed by the Fleet Numerical Meteorology and Oceanography Center (FNMOC). Seven satellites are used in ADFC, the newest being the Surface Water Ocean Topography (SWOT) mission from NASA. Our intent is to show the importance of altimetry in Navy modeling and how it applies to the tactical mission of the fleet.

Corresponding author:
Danielle Carpenter (**Naval Oceanographic Office**, **United States**), danielle.d.carpenter.civ@us.navy.mil

Satellite altimetry reveals genesis of volcanic tsunami

Y. Tony Song (JPL/NASA, United States); Phillip Callahan (JPL, USA); Jean-Damien Desjonqueres (JPL, USA); Severine Fournier (JPL, USA); Josh Willis (JPL, USA)

Session: Application development for Operations
Presentation type: Poster
Poster number: APO2025_004

Abstract:
The 2022 Tonga volcano generated a surprisingly large atmosphere-pressure wave (lamb wave) and a locally damaging tsunami. The tsunami generation is still a puzzle because of the possible complication of seafloor explosion and the volcano eruption-induced atmospheric pressure forcing. This study analyses satellite altimetry observations, assisted by a combined atmospheric wave and oceanic tsunami model, to shed light on the tsunami cause. We found that the AltiKa satellite observed the near-field tsunami, 30 minutes after the eruption, while the S6A and Jason-3 satellites in 30 seconds apart crossed the tsunami through the volcano center, 5 hours after the eruption. We used tsunami travel times to isolate the tsunami signals from ocean dynamic features. The altimetry observations and the model simulation suggest that (1) the tsunami was destructive locally because of the dual effects of the seafloor explosion and the atmospheric pressure forcing, (2) the atmospheric pressure-induced tsunami was responsible for the large-scale disturbance in the Pacific Ocean and beyond, and (3) a large tsunami propagated as far as to the Southern Ocean, suggesting an enhanced southeastward submarine explosion.
Corresponding author:
Y. Tony Song (**JPL/NASA**, **United States**), Tony.Song@jpl.nasa.gov

A new chapter in satellite altimetry: monitoring small lakes and coastal zones with SWOT HR PIXC data

Ole Baltazar Andersen (DTU Space, Denmark); Simon Köhn (DTU Space, Denmark); Karina Nielsen (DTU Space, Denmark)

Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2025_001

Abstract:
The Surface Water and Ocean Topography (SWOT) mission is the first satellite mission to provide 2D spatially distributed elevation measurements with a 21-day orbit. At higher latitudes like Denmark, even the smallest lakes are typically covered by 3.5 different passes within one orbital cycle, resulting in revisit times of ca. 9 days. Small lakes play a vital role in the global freshwater cycle and are thus important to understand, given the rapidly accelerating climate change affecting worldwide freshwater dynamics and increased demand for freshwater from population strain.
Using SWOT's unprecedented abundance of water surface elevation (WSE) measurements, we validate a method of deriving high-accuracy, robust WSE time series from the SWOT HR PIXC 2.0 data on 40 gauged Danish lakes between 0.25 and 40 〖"km" 〗^"2" surface area. Furthermore, we explore the minimum required lake size for SWOT to correctly measure the WSE. With sufficient aggregation of individual point measurements, we find that spatial undulations do not deteriorate the WSE time series accuracy with respect to gauges. We quantify the WSE time-series performance using the summary measures root mean square error (RMSE) and Pearson correlation coefficient (PCC). We find a median RMSE of 5.76cm and PCC of 0.93 using all 40 lakes and 13 months of SWOT data.
Besides the enormous potential to observe even the smallest of lakes, SWOT is the first satellite to bridge the gap between inland water and the ocean effectively. Its 2D elevation measurements show spatial WSE variations in complex coastal areas that can be used to constrain hydrological models and boost flood prevention measures.
Limfjorden is a large fjord/estuary in Denmark, stretching 180 km with a tidal signal of up to 30 cm. It features multiple side arms and encompasses the island Mors. Wind patterns and local land boundaries, such as chokepoints, largely influence the spatial WSE characteristics of Limfjorden. SWOT, for the first time, enables us to observe them. Significant water build-up is especially observable at chokepoints and interfaces with the open ocean under appropriate conditions. WSE levels along two pseudo centerlines (north and south of Mors) are validated using gauge data corresponding to each respective SWOT acquisition time. Our analysis shows that water levels remain consistent and converge to the same value whether traveling north or south of Mors.
Particularly interesting are three SWOT acquisitions before and after the October 2023 Baltic Sea storm, allowing us to investigate its build-up and aftermath. Furthermore, we investigate how SWOT can observe the WSE in Øresund, particularly in and around Copenhagen harbor. We can spatially observe a tide surge passing through Øresund with a WSE gradient of ca. 1.5m. In Copenhagen, we observe an abrupt drop of WSE instead of a gradual decline we can see around the island of Amager, shielding Copenhagen. The abrupt drop is caused by a tide lock installed in the southern part of Copenhagen. We validate the WSE with multiple gauges distributed around Copenhagen.
Harbors in Denmark – and worldwide – are exposed to an ever-increasing flood risk, necessitating mitigation work and better flood and tide modeling. Our examples prove that SWOT can observe small, complex areas with high spatial fidelity, such as harbors. This new data can constrain flood models and facilitate governments and local communities to enact better mitigation measures.

Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

Sentinel-1 Wind Stress Divergence as an Independent Constraint for Sentinel-6 SSH Validation

Rachel Spratt (UCSB, United States)

Session: Coastal Altimetry
Presentation type: Poster
Poster number: COA2025_002

Abstract:
This study is designed to investigate the drivers of vertical transport along the California Current System (CCS) using satellite observations. The CCS exhibits complex Sea Surface Height variability and a density structure influenced by salinity, making it a critical region for understanding wind-driven ocean dynamics.
The goal of this approach is to utilize the OceanSAR-1 foundation model to process Sentinel-1 Wave (WV) mode data. The immediate scope of this work is a test case validation demonstrating the technical feasibility of successfully generating the horizontal divergence of Ekman transport (WE). This WE field, which is derived using Python drivers and geospatial toolkits, is expected to provide an independent observational constraint on wind-driven coastal upwelling and downwelling, showcasing the method from SAR data pre-processing and OceanSAR-1 execution, through the calculation of the high-resolution WE field.
Future work will extend this analysis to a larger dataset. This will entail co-location and comparison of these SAR-derived WE estimates with synchronous, high-accuracy SSH measurements from the Sentinel-6 Level 2P product. This correlation will provide initial evidence of the relationship between instantaneous wind forcing and localized SSH features. Then the S1-derived wind field and a supporting wave model output will be used to independently calculate and compare the Sea State Bias (SSB) against the operational Sentinel-6 corrections. Future comparisons will seek to highlight the synergistic usefulness of multi-sensor integration for diagnosing key physical processes.
Corresponding author:
Rachel Spratt (**UCSB**, **United States**), rachelspratt@gmail.com

Jason-3 Near-Real Time Products Latency and Availability from September 1, 2024 to September 30, 2025

Donald Richardson (ERT Corporation, 6404 Ivy Lane, Suite 650, Greenbelt, MD 20770, United States); David Donahue (NOAA/NESDIS/OSPO/SPSD/SPB, NCWCP 5830 University Research Ct. College Park, MD 20740, United States)

Session: Instrument Processing: Measurement and Retracking
Presentation type: Poster
Poster number: IPM2025_001

Abstract:
The latency of Jason-3 near-real time Operational Geophysical Data Records (OGDR) over the past year is examined using timeliness statistics against the requirement that product distribution be less than 3 hours from data collection. Major gaps in the ODGR production will be addressed, as well as periods of large latencies.

Latency calculations have been automated using the ProPro-005 algorithm as outlined in “ALGORITHMS ABOUT JASON-3 TM DATA AVAILABILITY AND OGDR DATA LATENCY, TP4-J0- NT-86- CNES”, 30-Mar-2011 by C. Juan (CNES) and J. Lillibridge (NOAA).

Corresponding author:
Donald Richardson (**ERT Corporation, 6404 Ivy Lane, Suite 650, Greenbelt, MD 20770**, **United States**), donald.richardson@noaa.gov

NOAA’s Jason Products and current Jason-3 NOAA Near Realtime Ground Processing System 2025

David Donahue (NOAA/NESDIS/OSPO, 5830 University Research Ct., College Park, MD 20740, United States); Donald Richardson (ERT Corporation, 6404 Ivy Lane, Suite 650, Greenbelt, MD 20770, United States); Zhang Yongsheng (NOAA/NESDIS/NCEI, 1315 East West Hwy, Silver Spring, MD 20910, United States)

Session: Instrument Processing: Measurement and Retracking
Presentation type: Poster
Poster number: IPM2025_002

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 (see https://www.ncei.noaa.gov/products/jason-satellite-products for more information). 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.

This poster paper will also outline the current Jason-3 NOAA Near Realtime Ground Processing System located at Suitland MD.

Corresponding author:
David Donahue (**NOAA/NESDIS/OSPO, 5830 University Research Ct., College Park, MD 20740**, **United States**), david.r.donahue@noaa.gov

Towards a new era of wave observations from nadir-looking SAR altimeters: Why Sentinel-6 SAR RAW data matter

Ourania Altiparmaki (TU Delft, Netherlands)

Session: Instrument Processing: Measurement and Retracking
Presentation type: Poster
Poster number: IPM2025_003

Abstract:
The launch of Sentinel-6B and its future successor(s) marks an important step toward enhancing the operational use of satellite altimetry for ocean applications. Beyond their primary mission objectives, Synthetic Aperture Radar (SAR) altimeters onboard these satellites have recently demonstrated an unexpected capability to image long ocean waves generated by storms, known as swells (Altiparmaki et al. 2022). This capability transforms SAR altimeters from purely one-dimensional measurement systems into instruments capable of providing two-dimensional information on ocean wave fields.

Since SAR altimeters were never designed as wave imagers, they cannot resolve the entire wave spectrum, primarily due to cutoff wavelength limitations (Altiparmaki et al. 2024; Kleinherenbrink et al. 2024). Wind waves remain undetectable, while swell retrieval can also be challenging under certain conditions. Along track, Sentinel-6 can resolve swells longer than about 200 m under moderate sea states, with higher velocity variance of wave systems further increasing the cutoff and reducing detectability (Altiparmaki et al. 2024). Across track, the operationally exploitable measurement window is limited to a few kilometers (~3–4 km), within which the ground resolution is relatively low.

Beyond that operational measurement window, the actual footprint (RAW) extends by roughly another 5 km when projected onto the sea surface, providing increased ground resolution. However, this portion is routinely truncated onboard through Range Migration Correction (RMC) processing to efficiently reduce data rate that ground stations can currently support.

Considering that finer ground resolution enables the detection of more distinct swell signatures and with Sentinel-6B's commissioning phase ahead, during which RAW data will be systematically collected over selected calibration and validation zones, this work exploits Sentinel-6A RAW data to demonstrate the benefit of utilizing the full resolution RAW data for swell retrieval (Altiparmaki 2025). Results show improved SAR altimetry swell spectra, with higher signal-to-noise ratio and a clear advantage of RAW over operational (RMC) data in successfully detecting swells traveling close to cross-track. These findings underline the importance of reconsidering the use of RAW acquisitions operationally over the open ocean, and especially in swell-dominated regions, to fully exploit Sentinel-6's potential for tracing the oceanic imprint of extreme events.

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Corresponding author:
Ourania Altiparmaki (**TU Delft**, **Netherlands**), o.altiparmaki@tudelft.nl

Slope correction for ocean SAR altimetry

Juliette GAMOT (Collecte Localisation Satellite, France); Philippe Schaeffer (Collecte Localisation Satellite, France); Marie-Isabelle Pujol (Collecte Localisation Satellite, France); François Bignalet-Cazalet (Centre National d'Etudes Spatiales, France); Emeline Cadier (Collecte Localisation Satellite, France); Thomas Moreau (Collecte Localisation Satellite, France); Claire Maraldi (Centre National d'Etudes Spatiales, France)

Session: Instrument Processing: Measurement and Retracking
Presentation type: Poster
Poster number: IPM2025_004

Abstract:
Since the launch of CryoSat-2 in 2010, Synthetic Aperture Radar (SAR) altimetry has emerged and partially replaced conventional Low-Resolution Mode (LRM) systems. Because SAR altimeters operate differently, geophysical corrections developed for LRM data cannot be directly applied. Among these, the correction for the impact of sea surface slopes on height measurements is particularly important, as it directly influences the accuracy of sea surface height (SSH) and derived oceanographic products.

Building upon the approach previously established for LRM altimeters, this study proposes a dedicated slope correction model tailored for SAR altimetry. The new formulation accounts for the specific geometry of radar footprint of SAR instruments, leading to mission-dependent corrections. To address this, a generic methodology is developed to generate global maps of height correction applicable to any SAR altimeter mission.

The approach is demonstrated using data from the Sentinel-6A mission. The comparison between SAR and LRM sea surface height anomaly (SSHA) measurements reveals systematic biases attributable to surface slope effects. When the proposed correction is applied, these biases are significantly reduced, improving the consistency between Sentinel-6A SAR data and the latest Mean Sea Surface (MSS) model. Quantitatively, the application of the correction decreases the root-mean-square difference between SSHA and the MSS model by up to 1 cm.

By providing a dedicated slope correction for SAR altimetry and a framework for generating mission-specific global correction maps, this work enhances the consistency between SAR and LRM measurements. In the future, this method could help better integrate LRM and SAR altimetry measurements, improving ocean studies and products.

Corresponding author:
Juliette GAMOT (**Collecte Localisation Satellite**, **France**), jgamot@groupcls.com

Advanced Processing Features for Enhanced Sentinel-6 Products

Mònica Roca-Aparici (isardSAT, Andorra); Sergi Hernández-Burgos (isardSAT, Catalonia); Adrián Flores (isardSAT, Catalonia); Gorka Moyano (isardSAT, Catalonia); Pablo Garcia-Arnauld (isardSAT, Catalonia); Adrià Gómez (isardSAT, Catalonia); Roger Almasqué (isardSAT, Catalonia); Ferran Gibert (isardSAT, Catalonia); Albert Garcia-Mondéjar (isardSAT, Catalonia); Salvatore Dinardo (EUMETSAT, Europe); Marco Fornari (ESA (ESTEC), Europe); Alejandro Egido (ESA (ESTEC), Europe); Cristina Martin-Puig (EUMETSAT, Europe); Robert Cullen (ESA(ESTEC), Europe)

Session: Instrument Processing: Measurement and Retracking
Presentation type: Poster
Poster number: IPM2025_005

Abstract:
The Sentinel-6 mission provides high-resolution radar altimetry data that are fundamental for ocean and climate monitoring. To further improve the quality and versatility of S6 products, isardSAT has developed a new set of advanced processing features aimed at improving the overall accuracy and precision, by enhancing focusing performance, calibration accuracy, and processing efficiency. These developments include:

1. Fully-Focussed Capabilities: Implementation of an Omega-K algorithm that coherently averages echoes, frequency based, to improve processing time, and, most importantly, a Fully-Focussed Accelerated BackProjection optimised and implemented for GPU processing, significantly reducing computation time while maintaining full focusing capabilities compared to the Omega-K.

2. To support flexible trade-offs between resolution and noise, an Unfocussed (sub-looked) BackProjection mode has been introduced.

3. Enhanced spectral processing is achieved through a Chirp-Z transform with range walk correction and a configurable posting rate, allowing more precise control of the along-track sampling.

4. A Complex Calibration solution has been developed that ensures improved phase and amplitude instrumental calibration across scientific measurements of different acquisitions.

5. Finally, the development of new methodologies and monitoring tools for external calibration based on passive reflectors, proven to be necessary to meet the drift uncertainty requirements of the future missions.

While some features are already planned for next year's development roadmap, others are shared here to gather community feedback on their potential inclusion in future releases.
This presentation will detail the implementation and validation of these new features, their impact on data quality and processing performance, and how they contribute to the readiness and optimisation of Sentinel-6B products. These advancements represent an important step in ensuring continuity and improvement of the high-precision ocean topography record provided by the Sentinel-6 mission.

Corresponding author:
Mònica Roca-Aparici (**isardSAT**, **Andorra**), Monica.Roca@isardSAT.cat

Advances in Sea Level and Sea State Observations Using Sentinel-6MF SAR Altimetry Data

Christopher Buchhaupt (University of Maryland, United States)

Session: Instrument Processing: Propagation, Wind Speed and Sea State Bias
Presentation type: Poster
Poster number: IPC2025_001

Abstract:
First enabled by CryoSat-2 in 2010, Synthetic Aperture Radar (SAR) altimetry represents a major advancement in ocean remote sensing, providing unprecedented accuracy and resolution in monitoring significant wave height (SWH) and sea surface height. Unlike traditional pulse-limited altimetry, SAR altimetry employs a smaller along-track footprint, allowing precise detection of fine-scale spatial and temporal variations in sea state. This capability is particularly valuable in regions with complex wave behavior, such as coastal zones and high-energy oceanic environments. By offering consistent, global measurements, SAR altimetry enhances our understanding of wave generation, propagation, and interactions with winds and currents. These insights are essential for improving wave climate models, enhancing weather and ocean forecasting, and assessing the impacts of waves on coastal and offshore environments. This poster will provide an overview of the observational capabilities of Sentinel-6MF unfocused SAR altimetry for sea-level and sea-state retrievals and discuss how additional sea state parameters influence the estimation of SWH and sea surface height in current state-of-the-art processing baselines.
Corresponding author:
Christopher Buchhaupt (**University of Maryland**, **United States**), cbuchhau@umd.edu

Satellite Altimetry Observations Monitoring Changes in Ocean and Surface Water Systems: Applied Science in Support of User Communities

Margaret Srinivasan (Caltech Jet Propulsion Laboratory, United States)

Session: Outreach, Education and Altimetric Data Services
Presentation type: Poster
Poster number: ODS2025_001

Abstract:
Ocean altimetry satellite missions have become invaluable for operational agencies, society, and decision-makers by providing consistent, high-resolution measurements of the topography and surface height of both ocean and surface water bodies. Besides the critical research foci of the missions, they can provide significant value in support of critical services such as safeguarding marine operations and navigation, coastal hazard assessment, fisheries, water resources planning, flood management, and disaster response. The data record spans more than 30 years beginning in 1992 with the launch of TOPEX/Poseidon, through the Jason series missions in the early and mid 2000s, Sentinel 6 Michael Freilich (2020), the Surface Water and Ocean Topography (SWOT) mission (2022) and Sentinel 6B scheduled to launch late 2025, enabling tracking of sea level rise and ocean changes, greatly informing climate adaptation strategies.

Collaborations between NASA, the French Space agency, CNES, NOAA, Eumetsat and the European Space Agency (ESA) has ensured open access to the data that underpins resilience planning for vulnerable regions and assets. Engagement within these agencies and with industry has provided practical tools and tailored data products that expand ocean operations and water management efforts.

The continuation of this data record in ESA's Copernicus program and the evolution of satellite technology, as with the SWOT high-resolution wide swath measurements, will continue to transform and expand the broad community of users—from operational agencies to the private sector—and will address current and emerging water challenges for long-term societal benefit. This work presents select Applications demonstrating societal benefit and operational value of the NASA and partners satellite altimeter missions.
Corresponding author:
Margaret Srinivasan (**Caltech Jet Propulsion Laboratory**, **United States**), margaret.srinivasan@jpl.nasa.gov

NASA-SSH: A Suite of New Sea Level Products from NASA

Josh Willis (JPL, United States); Severine Fournier (NASA/JPL, USA); Marlis Kevin (NASA/JPL, USA); Killet Emmy (NASA/JPL, USA); Brian Beckley (NASA/GSFC, USA)

Session: Outreach, Education and Altimetric Data Services
Presentation type: Poster
Poster number: ODS2025_002

Abstract:
Built on the multi-mission altimetry product produced by Beckley et al. at Goddard Space Flight Center (GSFC), the NASA-SSH products provide a series of user-friendly sea level products suitable for scientific and public use. By combining data from TOPEX/Poseidon, all of the Jason-series missions and Sentinel-6 Michael Freilich, the GSFC product carefully levels all satellites to a common reference time period and ensure that consistent processing is applied to all missions.
To produce the NASA-SSH products, an additional level of quality control is performed on the GSFC data products to flag outliers and bad passes. An orbit error correction is computed and applied using a 10-day window of crossovers to reduce any remaining long-wavelength, along-track errors. Finally, the along-track data is smoothed slightly and compiled into user-friendly daily files. This along-track product is perfect for ocean data assimilation and other along-track alimtery data users. These along-track products are then gridded, and used to compute global and regional indicators, that track things like the El Niño Southern Oscillation and global sea level rise.
A new version of the NASA-SSH products (v1.1) will should be released before the end of the 2025 Calendar Year that relies in the highest quality GPS orbits available for all missions, and is expected to significantly improve the accuracy of all products. Future evolutions will include data from high-latitude missions and more sophisticated gridding techniques to produce high-resolution grids.

Corresponding author:
Josh Willis (**JPL**, **United States**), joshua.k.willis@jpl.nasa.gov

New NASA PO.DAAC altimetry data products

Ian Fenty (JPL, United States); Mike Gangl (NASA JPL, USA); Catalina Taglialatela (NASA JPL, USA); Jack McNelis (NASA JPL, USA)

Session: Outreach, Education and Altimetric Data Services
Presentation type: Poster
Poster number: ODS2025_003

Abstract:
NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC) has recently added several new satellite altimetry data products to support scientists. These include an along-track SSH dataset curated from reference missions and an accompanying global gridded product. From the global gridded product four "Indicator" time series data products have also been added: global mean sea level (GMSL), El Nino/Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and Pacific Decadal Oscillation (PDO). Tools and services that support access will be provided as well as links to these new datasets.

Corresponding author:
Ian Fenty (**JPL**, **United States**), Ian.Fenty@jpl.nasa.gov

Assessment of the TOPEX GMSL stability by analysing the global mean sea level closure using the AVISO L2P-2024 products.

Marie Bouih (Magellium, France); Ramiro Ferrari (Magellium, France); Robin Fraudeau (Magellium, France); Michaël Ablain (Magellium, France); Anny Cazenave (LEGOS, France); Benoît Meyssignac (CNRS/LEGOS/CNES, France); Alejandro Blazquez (CNRS/LEGOS/CNES, France); Lionel Zawadzki (CNES, France); Gérald Dibarboure (CNES, France)

Session: Quantifying Errors and Uncertainties in Altimetry data
Presentation type: Poster
Poster number: ERR2025_001

Abstract:
Closing the Sea Level Budget (SLB) at monthly to interannual timescales remains a fundamental objective in oceanography, as it ensures that all major contributions to global mean sea level change are consistently identified and quantified. Beyond its scientific value, the SLB also provides an effective cross-validation framework for key Earth Observation datasets—namely satellite altimetry, gravimetry (GRACE/GRACE-FO), and the Argo network—by testing their mutual consistency and long-term stability.
The SLBC approach has proven particularly useful as a diagnostic tool for assessing instrumental drifts in altimetric missions. Previous studies have demonstrated that residuals of the SLB can reveal subtle biases in the observing system. In particular, Dieng et al. 2017 used SLB residuals to estimate the drift of the TOPEX-A altimeter from L2P DT 2021, in complement to tide gauge analyses, while Barnoud et al., 2023 highlighted a similar radiometer drift signature in Jason-3 wet tropospheric correction data.
In this work supported by CNES (SALP project), we assessed the TOPEX GMSL stability by analysing the global mean sea level closure using the AVISO L2P-2024 products, which incorporates the TOPEX latest GDR-F release. The analysis leverages the most recent version of the SLBC_cci+ dataset, developed within the ESA Climate Change Initiative (CCI+) project. During this project, substantial efforts have been dedicated to improving the estimation and propagation of uncertainties for each SLB component (steric, barystatic, and altimetric terms). These advances now allow us to compute robust and traceable uncertainty estimates on SLB residuals, providing a stronger basis for detecting potential instrumental inconsistencies.
This work thus provides both an independent evaluation of the stability of the TOPEX dataset and a demonstration of how the SLBC framework can serve as a powerful quality assessment tool for long-term altimetric climate data records.

Corresponding author:
Marie Bouih (**Magellium**, **France**), marie.bouih@magellium.fr

Investigating the Mechanisms of Sea Level Change Using 30+ Years of Satellite Altimetry and the ECCO Ocean State Estimate

Ichiro Fukumori (Jet Propulsion Laboratory, United States); Subrahmanyam Bulusu (University of South Carolina, US); Ou Wang (JPL/Caltech, US); Ian Fenty (JPL/Caltech, US)

Session: Science I: Understanding and Quantifying Regional and Global Sea Level Budgets
Presentation type: Poster
Poster number: SC12025_001

Abstract:
We present a new effort to elucidate the origins, pathways, and mechanisms of large-scale oceanic changes in heat, freshwater, and mass that have contributed to more than three decades of observed sea level rise. Although global mean sea level rise is largely attributable to increases in ocean heat content and mass linked to global warming, the expression of these changes across the ocean is heterogeneous and remains incompletely understood. Regional variations are strongly shaped by natural modes of climate variability such as the El Niño–Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), which can at times exceed the magnitude of the global trend. Such regional signals often arise from the redistribution of heat, freshwater, and mass rather than net changes in their global budgets. Identifying the regions and mechanisms through which global warming influences sea level is therefore essential for advancing physical understanding and predictive capability.

Our approach leverages the Estimating the Circulation and Climate of the Ocean (ECCO) ocean general circulation model, which assimilates the complete altimetry record along with a broad suite of other observations. The framework enables interpretation of observed changes in a dynamically consistent manner. Unlike traditional methods that rely on simplified dynamics (e.g., geostrophy) or statistical relationships (e.g., correlation), ECCO provides a comprehensive synthesis of the ocean state constrained by the full governing equations of motion. We will employ ECCO's adjoint model to trace and quantify the drivers of sea level change and use passive tracers to delineate circulation pathways, thereby distinguishing the effects of external forcing from those of internal redistribution. The methodology provides a uniquely powerful means to attribute observed sea level variations to their causal mechanisms.

We illustrate the approach with examples using ECCO Modeling Utilities (EMU), a recently developed, intuitive menu-driven toolkit that enables analysis of ECCO's underlying model without requiring specialized modeling expertise.

Corresponding author:
Ichiro Fukumori (**Jet Propulsion Laboratory**, **United States**), fukumori@jpl.nasa.gov

Improved seasonal prediction skill for U.S. Atlantic Coast and Gulf Coast Using ECCO-based Ocean dynamic Persistence

Tong Lee (JPL, United States); Xue Feng (University of Hawaii, United States); Matthew Widlansky (University of Hawaii, United States); Ou Wang (Jet Propulsion Laboratory, California Institute of Technology, United States); Magdalena Balmaseda (ECMWF, UK); Hao Zuo (ECMWF, UK); Gregory Dusek (NOAA, United States); William Sweet (NOAA, United States); Malte Stuecker (University of Hawaii, United States)

Session: Science I: Understanding and Quantifying Regional and Global Sea Level Budgets
Presentation type: Poster
Poster number: SC12025_002

Abstract:
Seasonal forecast of sea-level variations along the U.S. Atlantic Coast and Gulf Coast using coupled ocean-atmosphere models has limited skill. The reasons include (1) the lack of seasonal predictability of Atlantic atmospheric forcing that drive sea level variations and (2) coupled model forecast drifts that cause a rapid memory loss of the initial ocean state. It raises the question of what predictability the initial state can provide through ocean dynamics without knowledge of future atmospheric forcing. Here, we address this question by performing 12-month hindcasts of the 3-D ocean state using the ECCO (https://ecco-group.org/) global ocean model initialized monthly from ECCO ocean state estimates but forced by climatological atmospheric forcings. Nonseasonal anomalies in the hindcasts reflect dynamic evolution of the initial ocean state without knowledge of future atmospheric forcing, coined as Ocean Dynamic Persistence (ODP). ODP hindcasts of U.S. Atlantic Coast and Gulf Coast generally outperformed the predictions based on the altimetry-based damped persistence (a commonly used statistical prediction method) and the state-of-the-art ECMWF SEAS5 climate forecast system when evaluated against observations. At a lead of 4 months, ODP hindcasts have the highest anomaly correlation coefficients with tide-gauge data at 22 out of 39 coastal locations (mostly south of Cape Hatteras). The sea-level predictability from ODP comes from ocean dynamic memory of the initial states that contain anomalies associated with open-ocean Rossy waves generated by prior atmospheric forcing. The Rossby waves propagate slowly from the open Atlantic Ocean towards the U.S. Atlantic Coast and subsequently transmitted into the Gulf Coast via Coastally Trapped Waves, giving rise to significant se-level predictability along these coasts. The significant predictability offered by ODP underscores the importance of improving coupled models to maximize the predictability offered by initial ocean state. The ODP method is a general approach that is applicable to predictability studies for other phenomena and time scales.

Corresponding author:
Tong Lee (**JPL**, **United States**), tlee@jpl.nasa.gov

MONITORING SEA LEVEL CHANGE: FROM TOPEX/POSEIDON TO SENTINEL-6 MF AND BEYOND

Robert Steven Nerem (University of Colorado, United States)

Session: Science I: Understanding and Quantifying Regional and Global Sea Level Budgets
Presentation type: Poster
Poster number: SC12025_003

Abstract:
Satellite altimetry measurements from 5 separate missions over the last 33 years have provided a critical record of sea level change, even though this wasn't initially the goal. With each new launch, we have expanded our knowledge about sea level change. We now understand how quickly sea level is changing, how this varies regionally, and what the primary causes are. We know the rate of sea level change is increasing, and we can map the observed trajectory of sea level change forward to understand how this trajectory compares to climate model projections of future sea level change. We can also map the regional variations of sea level change and understand how ocean-atmosphere dynamics distributes heat around the global oceans. This fundamental data record will only become more valuable as the time series lengthens. The launch of the SWOT mission in 2022 enriches this record, and it improves the spatial resolution and extends into coastal regions and estuaries. Future research will address how best to combine these data sources.

Corresponding author:
Robert Steven Nerem (**University of Colorado**, **United States**), nerem@colorado.edu

Sea Level Budgets using over 20 years of GRACE and 30 years of Altimetry data

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

Session: Science I: Understanding and Quantifying Regional and Global Sea Level Budgets
Presentation type: Poster
Poster number: SC12025_004

Abstract:
Closing the sea level budget requires reconciling GRACE, GRACE-FO, altimetry, and terrestrial/ice mass contributions. Despite progress, inconsistencies remain (Wang et al., 2022; Barnoud et al., 2022), highlighting uncertainties in Earth's mass dynamics. Building on Ludwigsen et al. (2024), which validated two decades of GRACE with independent land surface mass estimates, we extend the analysis to the 30-year altimetry record to examine transient and long-term drivers of sea level
change. Our results confirm strong agreement between GRACE and ocean mass reconstructions until 2020. Afterward, reconstructions show larger ocean mass increases, mainly due to underestimated precipitation over West Africa in ERA5, a bias confirmed by GRACE land mass data. Correcting for this improves model-observation consistency. Comparative analysis further indicates that discrepancies with steric-corrected altimetry stem largely from ARGO salinity drift and Jason-3 radiometer wet path delay, with smaller contributions from GIA and other biases.

Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

The ESA ARCFRESH and FRESH4BIO Arctic Freshwater projects

Ole Baltazar Andersen (DTU Space, Denmark); Team ARCFRESH (DTU Space, Denmark); Team FRESH4BIO (DTU Space, Denmark)

Session: Science I: Understanding and Quantifying Regional and Global Sea Level Budgets
Presentation type: Poster
Poster number: SC12025_005

Abstract:
The ARCFRESH project is supported by ESA to study how the Arctic freshwater system is undergoing major changes, with implications for ocean circulation, sea level, and ecosystem resilience. However, large-scale and long-term assessments of Arctic freshwater fluxes remain limited due to sparse in situ records and methodological inconsistencies. Here we present results from the ArcFresh project (ESA Cross-ECV), which integrates seven ESA CCI Essential Climate Variables together with the Sea Level Budget X-ECV to provide consistent estimates of freshwater storage and fluxes across the Arctic.
We combine multi-mission satellite altimetry, sea surface salinity, sea ice, glacier and ice sheet mass balance, river discharge, and precipitation–evaporation to estimate pan-Arctic and sub-regional freshwater budgets and fluxes through the major Arctic gateways. Advanced EO-driven methods allow us to extend freshwater flux records over two decades (2003–2022), enabling the study of both long-term trends and extreme events. Rigorous uncertainty propagation ensures that derived fluxes and budgets can be robustly compared across regions and time.
By delivering homogenized, observation-driven estimates of freshwater changes both within the Arctic and across its boundaries, this work advances understanding of how Arctic freshwater dynamics interact with large-scale ocean circulation, with implications for the Atlantic Meridional Overturning Circulation (AMOC), Northern Hemisphere climate, and Arctic marine ecosystem.
The overall aim of ESA Fresh4Bio is to advance the current state of knowledge of the impact of the Arctic freshwater export and Greenland ice discharge on modulating the water column structure and phytoplankton dynamics on the East Greenland Shelf (EGS) Fresh4Bio aims to advance on understanding the effects of freshwater export on the water column structure and, further, on the onset of phytoplankton communities in East Greenland. As one of the first results from the Fresh4Bio project, we present results from a high-resolution (2 km) maps of ocean topography, geostrophic current, and relative vorticity on the East Greenland Shelf from April 2023 to September 2025 by assimilating SWOT and nadir altimetry data in a 1.5-layer quasi-geostrophic

Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

Ensuring Continuity of Florida Current Transport Observations with Satellite Altimetry and Moored Pressure Gauges

Denis Volkov (CIMAS/University of Miami/NOAA-AOML, United States); Ryan Smith (NOAA-AOML, United States); Rigoberto Garcia (CIMAS/University of Miami/NOAA-AOML, United States)

Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Poster
Poster number: SC22025_001

Abstract:
The Florida Current (FC), the upstream segment of the Gulf Stream, plays a central role in both the meridional overturning circulation and the subtropical North Atlantic gyre. A four-decade record of FC volume transport, derived from submarine cable measurements, represents the longest near-continuous climate record of any boundary current. However, this record was interrupted in November 2023 when the cable system failed. While restoration efforts are in progress, alternative approaches are needed to maintain continuity of the observations. In this study, we extend daily FC transport estimates by combining satellite altimetry with pressure gauge measurements from instruments deployed on either side of the current at 27°N. We show that transport estimates based on cross-stream pressure differences provide a viable interim substitute for cable measurements, though they remain constrained by the vertical structure of the flow.

Corresponding author:
Denis Volkov (**CIMAS/University of Miami/NOAA-AOML**, **United States**), dlvolkov@gmail.com

Using an Ocean State Estimate and Satellite Altimetry to Improve Sea Level Predictions along the U.S. Gulf Coast

Andrew Delman (UCLA, United States); Ou Wang (Jet Propulsion Laboratory, California Institute of Technology, USA); Tong Lee (Jet Propulsion Laboratory, California Institute of Technology, USA); Ichiro Fukumori (Jet Propulsion Laboratory, California Institute of Technology, USA); Thomas Frederikse (Planet, Netherlands); Emily Becker (University of Miami, USA); Renee Collini (The Water Institute, USA); Benjamin Kirtman (University of Miami, USA)

Session: Science II: Large Scale Ocean Circulation Variability and Change
Presentation type: Poster
Poster number: SC22025_002

Abstract:
Predictions of regional sea level (SL) variability on subseasonal to decadal timescales have become increasingly relevant for hazard mitigation and coastal planning. Yet physics-driven coupled seasonal prediction and climate models struggle with biases and secular drifts in SL, while data-driven approaches are limited by the spatiotemporal coverage of observations, especially in the subsurface ocean. The Estimating the Circulation and Climate of the Ocean (ECCO) state estimate provides a least-squares fit of the ocean state to altimetry and other satellite and hydrographic observations that is fully consistent with physical conservation laws in the ocean. By assimilating ocean observations while conserving volume/mass, heat, and salt in the ocean interior, the ECCO state estimate avoids spurious drifts and reduces model bias. Furthermore, the adjoint capability of ECCO allows SL reconstructions that attribute SL variations to local and remote forcings at the ocean surface, while enabling synthesis with surface fluxes from seasonal and interannual/decadal prediction models. A case study in the Gulf of Mexico uses ECCO-based SL reconstructions to show that high-frequency monthly SL variability is well explained by wind stress forcing on the Gulf Coast and adjacent Florida Straits, while decadal variability is influenced by forcings as diverse as tropical Atlantic wind stress, Irminger Sea heat fluxes, and Mississippi River discharge. Forcing the adjoint sensitivities with surface fluxes from a seasonal (ECMWF SEAS5) prediction model results in improved subseasonal-to-seasonal SL predictions compared to the existing coupled model predictions; additional improvements are achieved with incorporation of a damped persistence component. Ongoing developments using altimetry and tide gauge data to refine SL predictions for specific coastal sites are discussed.

Corresponding author:
Andrew Delman (**UCLA**, **United States**), andrewdelman@ucla.edu

Refining knowledge of the California Current System through 4D-Var assimilation of SWOT and nadir altimetry

Sarah Gille (Scripps Institution of Oceanography, UC San Diego, United States); Ariane Verdy (Scripps Institution of Oceanography, UC San Diego, United States); Matthew Mazloff (Scripps Institution of Oceanography, UC San Diego, United States); Bruce Cornuelle (Scripps Institution of Oceanography, UC San Diego, United States); Ganesh Gopalakrishnan (Scripps Institution of Oceanography, UC San Diego, United States)

Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32025_001

Abstract:
The California Current System (CCS) is a critically important eastern boundary system, characterized by small-scale eddy features, strong upwelling, and a seasonally reversing surface flow. To refine our understanding of the key physical processes governing this current system, we use 4D Variational Assimilation (4D-Var) to constrain a regional ocean model of the CCS. The modeling-assimilation employs a regional 2-km configuration of the MIT general circulation model (MITgcm) and its adjoint, with a 31-day assimilation window covering May 2023, during the SWOT Cal-Val one-day repeat period. Additional constraints come from the existing constellation of nadir altimeters (including Sentinel 6A and Jason-3), which provide measurements across a greater spatial range than the SWOT Cal-Val data. In situ constraints come from the global ocean observing system, which includes Argo profiles and glider data. The reference (first-guess) model run is initialized using the GLORYS ocean state estimate and forced with ERA5 hourly atmospheric state; those model control (initial temperature and salinity conditions and atmospheric forcings) fields are adjusted iteratively using adjoint model sensitivities to fit the model to available observational constraints. Provided that the initial state is generally consistent with the SWOT observations at large scale, the 4D-Var method can successfully reduce model-data misfits over the month-long assimilation window, despite intrinsic nonlinear variabilities and instabilities in the high-resolution model. Assimilating SWOT, nadir altimetry, and in situ observations improves the model fit to independent (non-assimilated or withheld) observations. The impact of sea surface observations extends to the ocean interior through the dynamical propagation of adjoint sensitivities over 31 days. With this assimilation approach we are able to reproduce small-scale ocean signals, enabling quantification of the role of eddies that are resolved by altimetry.

Corresponding author:
Sarah Gille (**Scripps Institution of Oceanography, UC San Diego**, **United States**), sgille@ucsd.edu

Capsizing and impact wave detection – Case study of iceberg A-76A

Ole Baltazar Andersen (DTU Space, Denmark); Constance Hjort (DTU Space, Denmark)

Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32025_002

Abstract:
The breakup and capsizing of large tabular icebergs contribute to significant oceanic wave events that threaten coastal regions. Despite continuous monitoring near glacier walls, monitoring these processes in open ocean environments has remained challenging due to the unpredictable nature and limited access of the capsizing events. We present a pioneering case study of the London-sized iceberg A-76A, whose final months of fragmentation and capsizing were captured by the SWOT satellite as it approached South Georgia Island in 2023. Our findings highlight SWOT's unique ability to provide two-dimensional, large-scale views of iceberg-induced waves.
We successfully described the waves by their physical characteristics: wavelength (L), wave height (H), and water depth (h). These parameters together define the wave regime, a combination of linearity and dispersiveness, and thus guide the level of complexity required in the wave model. Immediately following the iceberg's impact, waves are expected to be highly
nonlinear due to the extreme nature of the generation mechanism. As they propagate outward, these waves undergo energy loss, and their nonlinearity decreases. Over distance and time, wave trains typically become more regular and linear, with longer wavelengths travelling farther from the origin due to dispersion. We use SWOT to verify the regime of the observed waves. We also use a combination of wavelet transformation and the dispersion relationship to estimate the time that has
passed since the impact. Investigating the relation between the wave's propagation time and regime.
Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

Small-scale eddy dynamics on the East Greenland Shelf from SWOT (Fresh4Bio)

Ole Baltazar Andersen (DTU Space, Denmark); Sara Jensen (DTU Space, Denmark)

Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32025_003

Abstract:
The recently launched Surface Water Ocean and Water Topography (SWOT) mission provides Sea Surface Height (SSH) observations over a 120 km wide swath at 250 meters resolution. This presents a unique opportunity to map small mesoscale and submesoscale ocean dynamics that are not currently resolved by nadir altimetry. This is especially important in the Arctic, where the typical scale of mesoscale motion shrinks to 5-60 km, and where many observational studies are limited by the presence of sea ice and/or clouds. In the Fresh4Bio project, we derive high-resolution (2 km) maps of ocean topography, geostrophic current, and relative vorticity on the East Greenland Shelf from April 2023 to September 2025 by assimilating SWOT and nadir altimetry data in a 1.5-layer quasi-geostrophic model. During the winter period, we applied a sea-ice filter to enhance SWOT spatial-temporal coverage. SWOT provides an efficient way to map fast-evolving small-scale structures and reveal previously unresolved small-scale processes in the marginal ice zone (see figure). The SWOT derived dataset agrees well with Sentinel 2 & 3 derived chlorophyll-a and surface temperature, in the position and structure of fronts and eddies. A case study of a 20-km cold-core eddy with elevated chlorophyll-a, detected simultaneously in SWOT-assimilated maps and optical remote sensing data, demonstrates the potential for coupled physical–biological studies of small eddies in the Arctic. This eddy was unobserved in conventional altimetry from the DUACS multimission maps.

Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

Quantifying and interpreting sources of error when estimating currents from altimetry

Saulo Soares (SIO UCSD, United States); Sarah Gille (SIO UCSD, United States); Teresa Chereskin (SIO UCSD, United States)

Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32025_004

Abstract:
Ocean currents can be readily inferred from satellite sea surface height (SSH) measurements when they are in geostrophic balance. For motions on scales of 200 km, geostrophic balance works well. At scales of 1 km, geostrophy is not expected to explain oceanic motions. For scales between 1 km and 200 km, we still do not know exactly when geostrophic motions predominate and when geostrophy falls short in explaining ocean motions. To address this, we evaluate geostrophic currents derived from nadir altimeters against high-frequency radar (HFR) surface velocity observations off the coast of California. Differences between the two are examined, including their wavenumber spectrum. Results reveal large-scale discrepancies, with root mean square errors around 10 cm/s. Aided by the application of a Helmholtz decomposition and additional filtering of HFR currents, we interpret the misfit in terms of errors in the geostrophic current estimate originating from SSH contamination (e.g. by inaccurate corrections or processes that affect steric height) vs. misfits originating from loss of balance (e.g. cyclogeostrophy or forcing effects). Overall, we find that contamination effects and loss of balance are of similar size. While internal waves in general and residual internal tides in particular contribute significantly to both effects, there are other significant sources of contamination and loss of balance. With the ultimate goal of improving geostrophic current estimates in mind, we seek to better understand and quantify these other sources of error.

Corresponding author:
Saulo Soares (**SIO UCSD**, **United States**), saulo@ucsd.edu

A Unified Framework for Next-Generation Sea Surface Height Mapping

Jeffrey J. Early (NorthWest Research Associates, United States); Cimarron J. Wortham (NorthWest Research Associates, United State); Jonathan M. Lilly (Planetary Science Institute, United States)

Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32025_005

Abstract:
Satellite altimetry underpins much of modern oceanography, yet the community's primary mapped sea surface height dataset is a proprietary, closed source product that is limited by a lack of transparency, excessive smoothing, and inflexibility. We are developing an open-source, algorithm-agnostic mapping framework powered by OceanDB, a backend with efficient spatiotemporal data retrieval, and a new map data compression format to provide fast, versatile access to mapped products at arbitrary locations.

The initial mapping algorithms include Gaussian Process Regression (GPR) with improved, physically based covariance models and Local Polynomial Fitting (LPF) optimized for adaptive, anisotropic smoothing. This unified system will deliver transparent, accurate, and customizable SSH maps with explicit error quantification. In alignment with NASA's long-term priorties, this is being done within the context of Open Science in which every aspect is openly and freely distributed to the community.

Corresponding author:
Jeffrey J. Early (**NorthWest Research Associates**, **United States**), jearly@nwra.com

Towards Harnessing Machine Learning to Infer Unobserved Variables from Satellite Observations

Jinbo Wang (Texas A & M University, United States); Alice Yepremyan (JPL, USA); Edwin Goh (JPL, USA); Ellin Zhao (UCLA, USA)

Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32025_006

Abstract:
The transition from data scarcity to abundance in oceanography began in the late 1980s with the advent of satellite measurements, primarily of sea surface properties. The proliferation of satellites offering unprecedented spatial resolution has since led to an explosion in data volume. Concurrently, rapid advances in data science and machine learning—fueled by modern infrastructure, open-source tools, and improved algorithms—provide viable solutions to the big-data challenges facing the oceanographic community. Here, we present a roadmap for integrating machine learning into satellite data production and highlight several completed projects: generating high-resolution sea surface temperature beneath clouds, filling SWOT nadir gaps in high-resolution SSH, gridding multi-mission sea surface height including SWOT, and developing an ocean surface emulator to advance surface data assimilation.

Corresponding author:
Jinbo Wang (**Texas A & M University**, **United States**), jinbo.wang@tamu.edu

Long-term trend in eddy sea surface temperature and height coherence and its implications

Jinbo Wang (Texas A & M University, United States); Minghai Huang (Texas A & M University, USA); Ping Chang (Texas A & M University, USA); Patrice Klein (Caltech, USA)

Session: Science III: Mesoscale and sub-mesoscale oceanography
Presentation type: Poster
Poster number: SC32025_007

Abstract:
Ocean mesoscale eddies manifest as anomalies in sea surface height (SSHA) and temperature (SSTA), with SSTA reflecting near-surface thermal structure and SSHA integrating density variations throughout the water column; their spatial coherence—quantified by localized SSHA–SSTA spatial correlation—thus serves as a key diagnostic of eddy vertical structure and heat transport. Integrating satellite observations, reanalyses, and a high-resolution climate simulation, we demonstrate that SSHA–SSTA correlation is strongest where large-scale SSH and SST gradients align, as measured by their intersection angle theta, which explains global correlation patterns more effectively than eddy kinetic energy alone. Regions of gradient misalignment (high angle) mark hotspots of non-traditional eddies—warm-core cyclones and cold-core anticyclones—that would drive distinct air–sea fluxes and biogeochemical responses, necessitating their inclusion in climate model parameterizations. A robust global increase in SSHA–SSTA correlation was found over the altimetry era, consistent with rising traditional eddies and declining non-traditional ones amid intensified eddy activity. These findings carry critical implications for quantifying eddy-driven heat transport and for surface quasigeostrophic methods that infer subsurface structure from surface coherence.

Corresponding author:
Jinbo Wang (**Texas A & M University**, **United States**), jinbo.wang@tamu.edu

Monitoring the impact of the Kakhovka Dam break in 2023 with SWOT and ICESat-2

Ole Baltazar Andersen (DTU Space, Denmark); Linda Christoffersen (DTU Space, Denmark)

Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42025_001

Abstract:
In June 2023, the destruction of the Kakhovka Dam, the second largest reservoir in Ukraine by area (2,155 km²) and the largest by water volume (18.19 km³), released unprecedented volumes of water into the downstream river system, causing a floodwave of up to 12 meters and affecting flow conditions for more than 100 km downstream. This sudden hydrological disturbance presents a unique opportunity to assess the capabilities of satellite altimetry for rapid floodwave characterization.
We investigate the information that can be derived about floodwave hydraulics—such as water surface elevation (WSE) and water surface slope (WSS)—from SWOT pixel cloud data. The wave evolves longitudinally downstream, laterally across the floodplain, and even propagates against normal flow into tributaries.
The combination of SWOT's high-density pixel clouds with complementary ICESat-2 river cross-sections enables both longitudinal and transverse characterization of the wave, allowing us to capture not only large-scale water surface gradients but also small-scale distortions induced by obstructions such as islands and bridges. This illustrates the new possibilities within satellite altimetry, as this is the first time it has been possible to observe such extreme events with this level of temporal and spatial resolution.
A prominent example of the effects on tributaries is the Inhulets River, which experiences a floodwave of more than 7 meters that affects WSE for more than 80 km upstream of its confluence with the Dnepr River. The pre-break slope of the Inhulets River is less than 0.1 cm/km. The floodwave steepens the slope to more than 6 cm/km as it propagates upstream, and after 5 days the slope reverses to approximately 1 cm/km as accumulated water drains from the system. After 2–3 weeks the slope returns to pre-break conditions.
To evaluate these observations, we compare them with a simple hydraulic model estimating the floodwave speed (celerity) to be 1.66 m/s (6 km/h) in the downstream direction. The maximum wave slope is modelled to be 14 cm/km, while the SWOT observations show a pre-break slope of 2 cm/km abruptly increasing to 17 cm/km, indicating strong agreement between the model and the observed data.
These findings demonstrate the potential of SWOT to capture rapid hydrodynamic transients in both main channels and tributaries, providing critical insights for future flood hazard assessment.

Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

Investigating Ice Jams in Arctic Rivers with SWOT's High-Resolution Altimetry

Ole Baltazar Andersen (DTU Space, Denmark); Linda Christoffersen (DTU Space, Denmark); Karina Nelsen (DTU Space, Denmark)

Session: Science IV: Altimetry for Cryosphere and Hydrology
Presentation type: Poster
Poster number: SC42025_002

Abstract:
This research examines the effectiveness of the Surface Water and Ocean Topography (SWOT) mission in detecting and characterising ice jams in Arctic rivers, utilising both SWOT altimetry and optical satellite data. Arctic rivers, which remain ice-covered for much of the year, undergo a rapid and complex breakup each spring. This process can lead to the formation of ice jams—accumulations of ice that obstruct river flow—resulting in significant alterations to the river's surface profile and
slope. The primary objective of this study is to evaluate SWOT's capability to observe such events and to contribute to improved monitoring and prediction of associated hydrological changes.
Ice jams typically form during spring breakup when dislodged ice accumulates and blocks the river channel, causing water to back up and potentially raising the upstream water surface elevation by several meters. This can trigger severe flooding and necessitate the evacuation of communities along the riverbanks. Due to the extreme environmental conditions and short-lived nature of ice jams, they have historically been poorly monitored. However, SWOT's high spatial resolution,
wide-swath coverage, and relatively frequent revisit intervals—down to every few days in polar regions—make it uniquely suited for capturing these ephemeral yet high-impact events. The level of detail achievable with SWOT far exceeds that of conventional satellite radar altimetry missions (Biancamaria et al., 2016).
During the calibration and validation (cal/val) phase of the SWOT mission, the satellite captured a ~15 km long ice jam on the Peace River that persisted for several days. Thanks to the daily revisit capability of the cal/val orbit, the ice jam was observed multiple times before its complete breakup. Combined with high-resolution optical imagery from Sentinel-2 (Drusch
et al., 2012) and PlanetScope (Planet Labs PBC, 2025), the SWOT observations enabled a detailed analysis of the temporal evolution of both water surface elevation (WSE) and water surface slope (WSS) upstream of the jam. Comparisons with data from traditional altimetry missions, including Sentinel-3A/B (Seitz et al., 2010) and ICESat-2 (Neumann et al., 2019), reveal that these sensors lack the spatial and temporal resolution necessary to detect the full complexity of ice jam dynamics—highlighting the substantial leap forward that SWOT represents. The transition from a fully ice-covered state to jammed flow and ultimately to an ice-free river contributes valuable insight into the hydrological and cryospheric processes operating in Arctic river systems. These findings underscore the transformative potential of SWOT data for advancing the understanding, monitoring, and prediction of extreme events in cold-region hydrology.

Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

Inferring Ocean Heat Uptake from Satellite Gravimetry and Altimetry

Andrew Delman (UCLA, United States); Maria Hakuba (Jet Propulsion Laboratory, California Institute of Technology, United States); Ian Fenty (Jet Propulsion Laboratory, California Institute of Technology, United States)

Session: Synergies between Argo, GRACE and Altimetry
Presentation type: Poster
Poster number: ARG2025_001

Abstract:
Global ocean heat uptake (OHU) comprises the largest portion of the Earth's energy imbalance, and estimates of its magnitude and variability vary greatly among observational data products and numerical model simulations. Much of the uncertainty in OHU results from data coverage gaps in sparsely-sampled portions of the ocean (especially the deep ocean). Satellites can not observe ocean warming directly, but satellite gravimetry observations (GRACE/GRACE-FO) can be differenced with sea surface height observations from altimetry to directly quantify the steric expansion of the full-depth of the ocean. OHU from ocean heat content (OHC) changes can be inferred from steric height change if the thermal expansion coefficient (α) of the water column is known, but local values of α are dependent on temperature and pressure and thus vary greatly in the ocean. Thus the "effective" α (i.e., the ratio of full-depth steric expansion to vertical-mean temperature change) depends on where heat is being accumulated or removed in the water column.

In order to estimate OHU from satellite-based steric height estimates, this study has assembled multi-product ensembles of OHC and steric height from ocean state estimates and reanalyses, as well as gridded data products based on Argo, expendable bathythermograph (XBT) and other in-situ ocean data sources. Test reconstructions of OHC change using steric height and effective α estimates suggest that most of the global OHC time series can be recovered using regression-derived values of effective α, but the value of effective α varies considerably depending on the product(s) used to estimate it. Regions and time ranges that have particularly high ensemble spreads in OHU/OHC and effective α are identified, and a budget of effective α quantified to determine where and when OHU can most/least effectively be recovered from satellite-derived steric height anomalies.

Corresponding author:
Andrew Delman (**UCLA**, **United States**), andrewdelman@ucla.edu

Vertical Land Movement Budget and Its Impact on Coastal Sea-Level

Ole Baltazar Andersen (DTU Space, Denmark); Carsten Ludwigsen (DTU Space, Denmark); Per Knudsen (DTU Space, Denmark)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Poster
Poster number: GEO2025_001

Abstract:
Elastic vertical land movement (elastic VLM) plays a crucial role in shaping relative sea levels along global coastlines. In Northern Europe, VLM is primarily driven by Glacial Isostatic Adjustment (GIA). However, the rapid melting of Arctic ice is inducing substantial elastic uplift, with both local effects and a long-range footprint extending 1,000–3,000 km from the point of ice loss. When GNSS-based VLM estimates are unavailable, sea-level studies based on tide gauges often rely on GIA-only VLM models to correct for land movement. However, due to present day ice loss, the elastic VLM gains importance. To address this, we develop a global,time-varying elastic VLM model based on detailed estimates of terrestrial and glacial mass changes from glaciers, Antarctica and Greenland. Combined with GIA
modelling, will the elastic VLM model produce a comprehensive VLM estimate, comparable to GNSS-measured rates in a center-of-mass reference frame.
Additionally, far-field elastic effects from Antarctic ice mass loss and terrestrial water storage changes are incorporated to create a complete global vertical deformation map. This dataset can serve as a valuable complement for sea-level studies in regions with sparse or no GNSS coverage

Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

Lake geoid correction grids based on the SWOT Raster product.

Ole Baltazar Andersen (Dr, Denmark); Karina Nielsen (DTU Space, Denmark)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Poster
Poster number: GEO2025_002

Abstract:
It is well known that the geoid signal over large lakes in mountainous regions are not well modeled. This introduces errors in the satellite altimetry-based water level estimates. The Surface Water and Ocean Topography mission (SWOT) launched in December 2022 provides an almost complete spatial coverage which makes it possible to detect spatial signals over e.g. lakes.
Here we apply a state-space model to separate the assumed static signal from a potentially unmodeled geoid signal and the temporal variation in the water level. As data input we use the SWOT 250m raster product. To evaluate how well the spatial and temporal signals are separated we compare the SWOT-based water level time series with time series based on other altimetry data sets.
The procedure is tested for a set of different lakes her under the African rift lakes and lake Titicaca. Here we based the solution on available data at the current time, however the solutions are expected to improve as more data becomes available. The R code is available here https://cavios.r-universe.dev/LakeGeoid.

Corresponding author:
Ole Baltazar Andersen (**Dr**, **Denmark**), oa@space.dtu.dk

Towards the next series of DTU25 mean dynamic topography models

Ole Baltazar Andersen (DTU Space, Denmark); Per Knudsen (DTU Space, Denmark); Nikolai Maximenko (Universiy of Hawaii at Manoa, IPRC, united states); J Hafner (Universiy of Hawaii at Manoa, IPRC, united states)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Poster
Poster number: GEO2025_003

Abstract:
Initially, a new geodetic mean dynamic topography model DTU25MDT is derived using the new DTU24MSS mean sea surface. The DTU24MSS model is similar to the previous DTU21MSS but slope correction has been applied and a few issues at the coasts have been solved. The processing scheme used for deriving the new geodetic MDT is similar to the one used for the previous geodetic DTU22MDT model. However, the filtering was re-evaluated at the western boundary currents to enhance the velocities in those areas.

When deriving the previous combination model DTUUH22MDT it was found that the differences between the combination model and the geodetic model are within 10 cm. Hence, the effects of integrating the drifter velocities on the MDT are of that order of magnitude. Also, the scales appear to be shorter than a few hundreds of kilometres agreeing well with the resolution of the geodetic model. A comparison with other combination models showed larger differences and at longer scales. The differences may be caused by differences in the choice of reference models, processing of drifter data, methodologies for integrating the data, etc. To assess the differences, experiments of integrating the drifter velocities with the geodetic model are carried out with different weighting schemes to assess how much the combination solution is constrained to the geodetic model and how regional biases in the drifter velocities are affecting the solution. Subsequently, the drifter velocities are integrated to enhance the resolution of the geodetic MDT model. The constraints are slightly looser to enhance the details further.

Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

Uncertainty estimation in altimetric derived bathymetry from machine learning models

Ole Baltazar Andersen (DTU Space, Denmark); Bjarke Nilsson (DTU Space, Denmark)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Poster
Poster number: GEO2025_004

Abstract:
With the Surface Water and Ocean Topography (SWOT) mission, we are able to significantly improve our knowledge of ocean geodesy and provide greatly improved marine reference fields. This in turn benefits our ability to derive bathymetric maps in the global oceans.

However, with the introduction of powerful inference and prediction provided by machine learning methods, the careful study of uncertainties in the original data is often lost, or not properly utilized. The black-box framework commonly in machine learning is therefore an obstacle between the end user of the derived products from satellite altimetry, and the original uncertainty in the observations.

Focus on uncertainty estimation for derived products is therefore an important area that would give further insight into the black-box system, as well as provide higher confidence in inference carried out by researchers. We present a study of derived bathymetry from high-resolution satellite altimetry from the SWOT satellite, with associated uncertainty estimation in the global ocean. This provides a look into challenging regions, under sampled areas and helps end-users understand the limits of derived data-products.

Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

DTU25 mean sea surface and its uncertainty characteristics

Ole Baltazar Andersen (DTU Space, Denmark); Bjarke Nilsson (DTU Space, Denmark)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Poster
Poster number: GEO2025_005

Abstract:
During the last 30 years, following the breakthrough that was the TOPEX/Poseidon satellite altimeter, improvements in satellite altimetry have been incremental. We have several generations of satellites to build upon, and with the inclusion of SAR processing, we are reaching the limit of conventional satellite altimetry. With the breakthough that is the Surface Water and Ocean Topography (SWOT) mission, we are able to significantly imrpove our knowledge of ocean geodesy, and provide greatly improved references for oceanography and climate research.

The importance of an accurate mean sea surface reference for global climate science, sea level rise, and coastal impacts has been shown. With the inclusion of two-dimensional satellite altimetry, we go beyond the limitations obtained from nadir looking altimetry. With the 2D data, the longitudinal resolution is substantially improved, and we have seen a substantial improvement, especially in coastal zones, eliminating the majority of coastal contamination causing problems in current models.

With almost two years of SWOT data available, we have near-complete global coverage. Longer wavelengths are already well resolved with the 30 years of conventional altimetry, and utilizing the short-wavelength improvement obtained from SWOT, we can get a combined solution with the best from both sides.

We present the next generation of mean sea surface reference fields, with major improvements in spatial resolution and noise reduction. The inclusion of SWOT data has revealed small-scale oceanographic features previously hidden. The new MSS models will be equipped with an associated uncertainty field and will be of critical importance for geodesy, oceanography, and climate science.

Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

The DTU25GRA SWOT derived global gravity field and evaluation with airborne gravity

Ole Baltazar Andersen (DTU Space, Denmark)

Session: The Geoid, Mean Sea Surfaces and Mean Dynamic Topography
Presentation type: Poster
Poster number: GEO2025_006

Abstract:
The observations from the Surface Water and Ocean Topography (SWOT) satellite have shown to be revolutionary in spatial resolution and precision. With the introduction of wide-swath altimetry sampled at a spacing of 250 m by 250 m, we are able to get reliable and accurate observations in more complex coastal zones than ever before. Traditional gravity fields have always relied on conventional nadir-looking satellite altimetry. Even with the introduction of Synthetic Aperture Radar (SAR) altimeters, the altimetric gravity field was always degraded in the coastal zone due to smoothing and/or extrapolation.
To utilize the high spatial resolution of SWOT, the new DTU25 GRA utilizes the ocean SWOT product (2 km spacing) in the open ocean, but uses the high-sampling of 250 m spacing in the coastal zones globally within the closest 10km.
The airborne gravity data were used for comparison with satellite altimetry-derived gravity models from several sources, including the most recent model DTU25GRA, which includes new high-resolution data from SWOT. We present the results of evaluating the SWOT derived gravity with gravity measured by a strapdown gravimetry campaign using an iMAR iCORUS-01 temperature-stabilized IMU along the south-western coast of Norway conducted in the fall of 2024.
The obtained results are assessed with respect to distance from the coast to quantify the accuracy of satellite altimetry, which has been a challenge for conventional altimetry. We demonstrate how the Inclusion of SWOT data sampled at high resolution (250 meters) results in higher consistency closer to the coast. The findings will be used to determine a distance-based threshold for relative weighting of the different datasets to be used in geoid computations, especially relevant for the computation of the new Scandinavian NKG geoid planned to be released in 2026.

Corresponding author:
Ole Baltazar Andersen (**DTU Space**, **Denmark**), oa@space.dtu.dk

Regional cal/val at multi-locations

Luciana Fenoglio (Chalmers University of Technology, Sweden)

Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2025_001

Abstract:
Innovative remote sensing information merged with in-situ data provide a two-dimensional surface water level which is denser and more accurate than previously. This is possible with the new generation of satellite altimetry since 2016 that includes Delay Doppler, laser and bistatic altimeter techniques.Starting from a local study at the Onsala Space Observatory we show examples where in-situ and space observations are merged for calibration and validation studies.
Corresponding author:
Luciana Fenoglio (**Chalmers University of Technology**, **Sweden**), lucfen@chalmers.se

Fiducial Reference Measurements for monitoring satellite altimetry at the ESA Permanent Facility for Altimetry Calibration in Crete and Gavdos

Stelios Mertikas (Technical University of Crete, Greece); Craig Donlon (European Space Agency, Netherlands); Emma Woolliams (National Physical Laboratory, United Kingdom); Fabrice Collard (Ocean Data Lab, France); Costas Kokolakis (Space Geomatica, Greece); Dimitrios Piretzidis (Space Geomatica, Greece); Achilles Tripolitsiotis (Space Geomatica, Greece); Xenofon Frantzis (Technical University of Crete, Greece)

Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2025_002

Abstract:
The growing number of altimetry satellites, payloads, manufacturers, as well as accelerated developments in measuring techniques and data processing, urgently call for measures to ensure the quality of satellite products for Earth observation. Such sought indicators of quality to be properly working, must be reliable, indisputable, tied and traceable to reference and international standards (e.g., Système international d'Unités). End-users will thus be able to accurately determine whether EO products meet requirements and are suitable for their applications.

At first, each EO mission follows its own in-flight calibration and validation (Cal/Val) to secure quality products. Later after Commissioning, external Cal/Val procedures are pursued with comparisons of satellite observations and products against ground-truth reference measurements. This work describes the way the uncertainty of the reference measurements on ground must be established beyond doubt, and the way external Cal/Val needs to be carried out to properly evaluate the produced satellite observations and products, and thus ensure accurate communication between satellite operators and users. This investigation would be based on the reference measurements made at the ESA Permanent Facility for Altimetry Calibration (ESA-PFAC) in Crete and Gavdos, Greece, where all ESA and world satellite altimeters have been calibrated for almost 20 years. The Cal/Val uncertainties will be established according to the ESA principle for Fiducial Reference Measurements and the guidelines of the Bureau International des Poids et Mesures (BIPM) for determining measurement uncertainty. Integration of Cal/Val results at this facility obtained from diverse instruments, locations, setting, techniques will be also presented. Finally, practical guidelines for achieving FRM-quality ground reference data will be provided, along with plans for expanding the ESA-PFAC Cal/Val services to other, non-altimetry EO missions
Corresponding author:
Stelios Mertikas (**Technical University of Crete**, **Greece**), smertikas@tuc.gr

Assessment of Global Mean Sea Level Variations Derived from a Hybrid Altimeter Sea Surface Height Time Series

Brian Beckley (ERT Inc./NASA GSFC, United States); Frank Lemoine (NASA GSFC, United States); Nikita Zelensky (University of Maryland, United States); Richard Ray (NASA GSFC, United States); Xu Yang (KBR Inc., United States); Gary Mitchum (University of South Florida, United States); Alex Conrad (JPL, United States); Josh Willis (JPL, United States); Severine Fournier (JPL, United States)

Session: Regional and Global CAL/VAL for Assembling a Climate Data Record
Presentation type: Poster
Poster number: CVL2025_003

Abstract:
Providing long-term, global data on global and regional sea level rise is one of the major contributions from satellite altimetry (Abdalla et al., 2021). Therefore, a critical goal is to provide a consistent set of altimeter data records for climate studies, with common geophysical standards. Since the orbit and the International Terrestrial Reference Frame (ITRF) underpin these climate data records, a goal in the Precise Orbit Determination (POD) community has been to provide the highest quality orbits for all altimetry satellites in a consistent reference frame (e.g. Cerri et al., 2010; Lemoine et al., 2010; Couhert et al., 2015; Rudenko et al., 2017). At GSFC we have generated a new time series of precise orbits (GSFC_std2400) for TOPEX/Poseidon, Jason-1,2, & 3, and Sentinel-6a that are based on SLRF2020 and DPOD2020, improved background gravity modelling, improved nonconservative force modelling, and application of the GOT5.6 ocean tide model. In this paper we present altimeter analyses that shows the std2400 and JPL_IGS20 orbits partner very well in forming a hybrid orbit series for Global Mean Sea Level (GMSL) computations. We provide an accuracy assessment of the Sea Surface Height (SSH) time series via tide gauge comparisons, verification phase colinear SSH differences, and ocean mass budget closure analyses.

Corresponding author:
Brian Beckley (**ERT Inc./NASA GSFC**, **United States**), brian.d.beckley@nasa.gov

Assembling a multi-mission mean sea level time series

Remko Scharroo (EUMETSAT, Germany); Estelle Obligis (EUMETSAT, Germany); Bojan Bojkov (EUMETSAT, Germany)

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Abstract:
The era of precise satellite altimetry is generally regarded to start with the launch of TOPEX/Poseidon in 1992. Since then, a continuous series of missions, Jason-1, -2, -3 and Sentinel-6 Michael Freilich have been monitoring global and regional mean sea level from what is called the "altimetry reference orbit" at 1336 km and with a 66° inclination. Many consecutive improvements in satellite instrumentation, satellite design, as well as to the precise orbit determination systems on-board contributed to an increasing accuracy and precision. By flying the successive missions in tandem with a separation of 30 seconds to 30 minutes, it was possible to cross-calibrate those missions to within a few millimeters or better, thus ensuring the long-term stability of the now 33 years record.

Other external factors have also contributed to the continued success of the altimetric sea level record. The ever increasing precision and accuracy of the atmospheric and other geophysical modelling, and the availability and maintenance of a number of tide gauges against which any drift of the altimetric sea level measurements can become evident.

But the most overlooked source of critical validation of the reference missions as well as contributors to the long-term record have been nine other missions that have operated during the same time from a much lower altitude (ERS-1, ERS-2, Envisat, GFO, CryoSat-2, SARAL/AltiKa, Sentinel-3A and -3B, and SWOT), generally in Low Earth high inclination sun-synchronous orbits, conditions that were widely thought to prohibit an accurate retrieval of global mean sea level.

For a proper comparison of the sea level records from all these missions: how do we line up the missions that did not have a tandem?

This is a painstakingly worked out process relying only on being able to determine global means over periods around the 10 days of the reference period and lining those records up.

This poster will demonstrate how this was successfully done to achieve the current 33-year combined global mean sea level record.
Corresponding author:
Remko Scharroo (**EUMETSAT**, **Germany**), remko.scharroo@eumetsat.int