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

Summary (6 oral presentations, 6 posters):

1. Sentinel-3 shows a drift in SARM derived GMSL of 1.8 mm/yr. 1.4 mm/yr is coming from a difference between SARM and PLRM data. 0.4 mm/yr is likely due to the PTR problem. Both effects should be corrected for climate studies.

2. There is a need for comprehensive and robust estimate of the uncertainties in sea level from satellite altimetry at a range of temporal and spatial scales

3. There is better understanding of the internal variability in sea level, and the impact of large-scale climate variability on sea level, particularly in the Pacific and the Arctic.

4. New methods are emerging to evaluate and potentially remove natural, internal variability in the satellite altimeter record → These methods should allow for improved estimates of the forced sea level response and help in constraining projections of future sea level

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

Discussion Topics:

Sentinel-3 altimeter stability: What cal/val and instrument processing studies should conducted in advance of Sentinel-6/Jason-CS? Sentinel-3A could be a good testbed for these studies.

- Need to determine the reason for the drift between SARM and PLRM. If the difference between both is not understood before Jason-CS launch then SARM and PLRM Sentinel-6 L2P products will be necessary over several years for the scientific community to investigate and correct the drift.
- For climate studies we need to account also for the PTR deformation. The PTR correction should be able to correct the spurious drift in GMSL → important for certain climate problems such as estimating the Earth energy Imbalance or the closure of the sea level budget
- If corrections are proposed within the coming year they should be evaluated on Sentinel-3 as soon as possible.

How should we advance coastal, hydrology, cryosphere, and ocean altimetry from a climate perspective? Should the OSTST try a joint meeting with other teams (Argo, SWOT, etc.)?

- Most interesting sea level science questions require a cross-disciplinary approach.
- A joint meeting would greatly benefit the satellite altimetry users within the climate science community.
- Suggestion: Larger, combined meeting of science teams once every 2-4 (?) years: OSTST, SWOT, GRACE-FO, ICESat-2, N-SLCT…

Recommendations from Science II: Large scale Ocean Circulation Variability and Change

Many of the contributions are focused on boundary currents

- The lines between **Large Scale and Mesoscale** are no longer distinct: could we integrate the two?

The focus on boundary currents suggests that a better connection between coastal and large scale altimetry communities (and sea-level products) is needed.

Reducing our carbon footprint

- Follow CLIVAR's lead and have periodic webinars between meetings
- Combine or link meetings: OSTST with Coastal altimetry, OSTST with SWOT

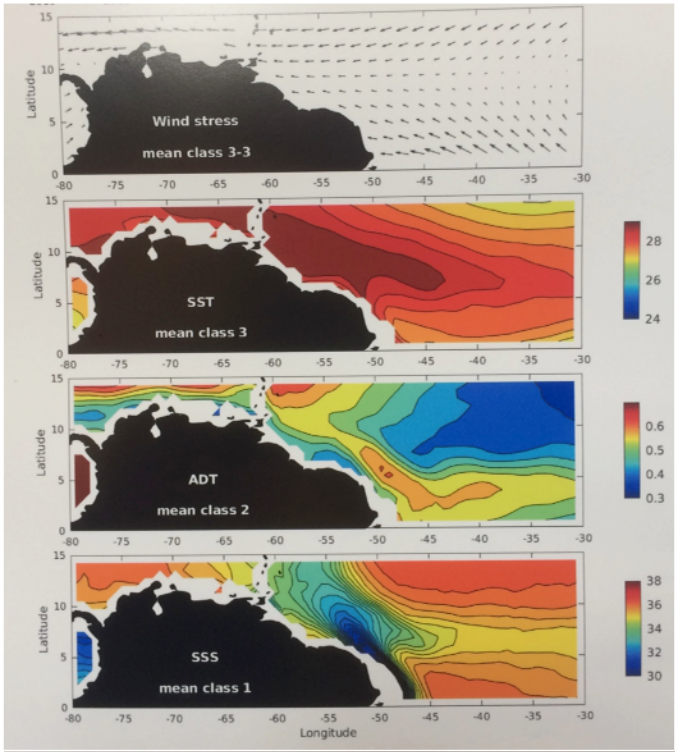
SC02 Large Scale Ocean Circulation Variability and Change

Science highlight: increasing use of machine learning tools

S. Arnault et al

Self Organizing Maps

Hierarchical Ascendant Classification



T. Penduff et al

Convolutional Neural Network

Attenuating chaotic SLA variability in AVISO data

summary

Approaching to mesoscale and smaller mesoscale eddies, nonlinearity becomes more and more important

- Over low latitude west pacific, the < 100day signal can be reproduced by a simplified model with *nonlinear terms (Qiu et al.)*
- Altimeter gridded product resolves the energy removal of resonant linear waves through nonlinear eddy interactions, also shows that the signature of signal propagation characteristics from objective mapping, while the direct 2Dvar mapping result does not show. (Samelson et al., published in JPO.)

Synergistic studies of mesoscale eddies

- Data model comparison, get ready for SWOT
- Lagrangian studies
- ADCP data for small mesoscale studies
- Mesoscale eddy structures are better captured by combining multi-altimeters and drifters (Mulet et al.)
- Data with large spatial and temporal gaps need to be filtered before assimilated, the optimal filtering can be tested using a 3D var. (Jacobs et al.)

Regional modelling

- Regional models cannot capture the remote baroclinic wave energy. This leads to underestimated internal waves in the regional domain and implies that data assimilation based on regional models may need to prescribed baroclinic tides with realistic phase. (Chereskin et al.)

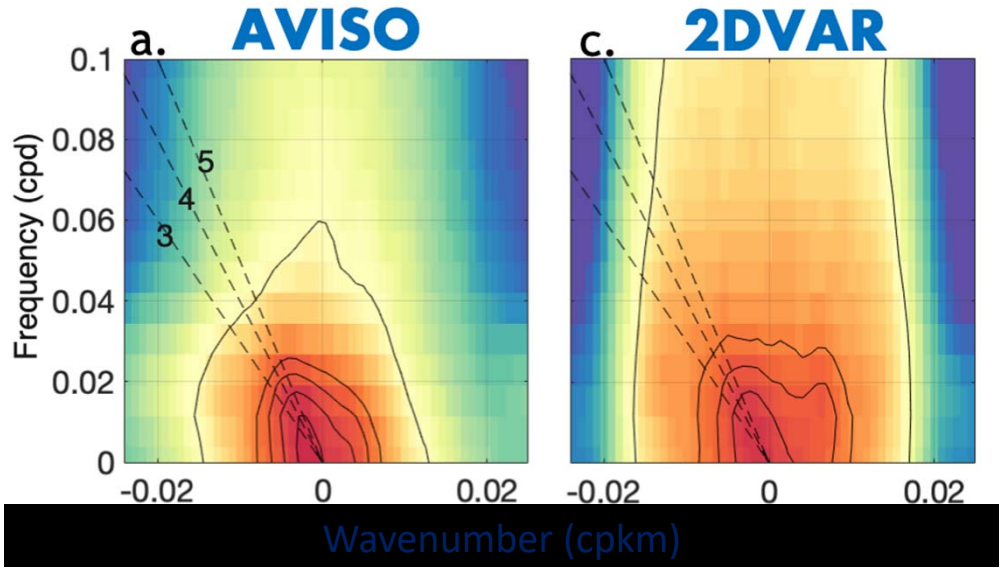
New mapping datasets to compare with Aviso

→New approaches and new inversion schemes

→Different energy content. Is this real?

→ More in-depth validations should be done in the future

From Matt Archer, in Roger Samelson's presentation



SC3 discussion seed questions

- 1. What is the space/time resolution of the current 5+ satellite constellation? Has the along-track resolution been fully utilized in gridded products? A new study came out about the resolution (Ballarotta et al., 2019), 400km equator and 100km high latitude.
- 2. How to ingest SWOT and fine-scale along-track altimetry data into altimetry analysis?
  - How to handle the high-frequency motions of internal tides and waves?
  - How to handle the incoherent sampling of SWOT/fine-scale along track data, in particular its infrequent temporal sampling?
- 3. What are the future innovations in the synergy of satellite data and in-situ observations including data assimilation method and simple statistical and dynamical interpolations.
  - Existing: Simple OI, dynamical interpolation, multi-scale data assimilation (under development), 3dVar, 4dVar
- **4. Session or splinter dedicated to state estimate from altimetry?** Examples: Use SWOT pre-launch field campaign data to test data assimilation? OSSEs with a common nature run?

Science IV: Altimetry for Cryosphere and Hydrology Session

Splinter Group Discussion

Jérôme Bouffard, Karina Nielsen, Sinead Farrell

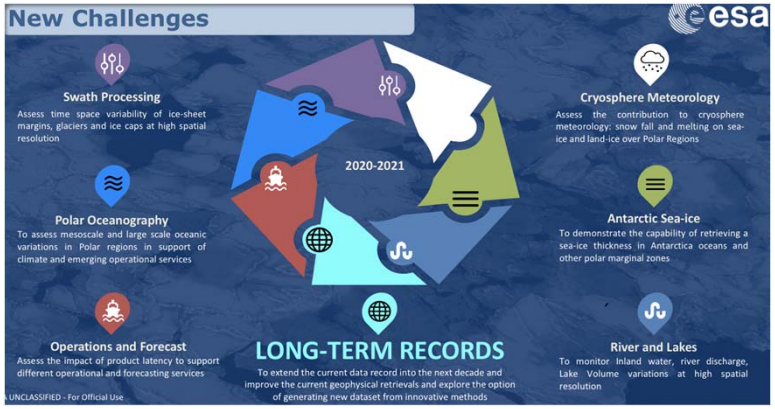
Altimetry for Cryosphere and Hydrology

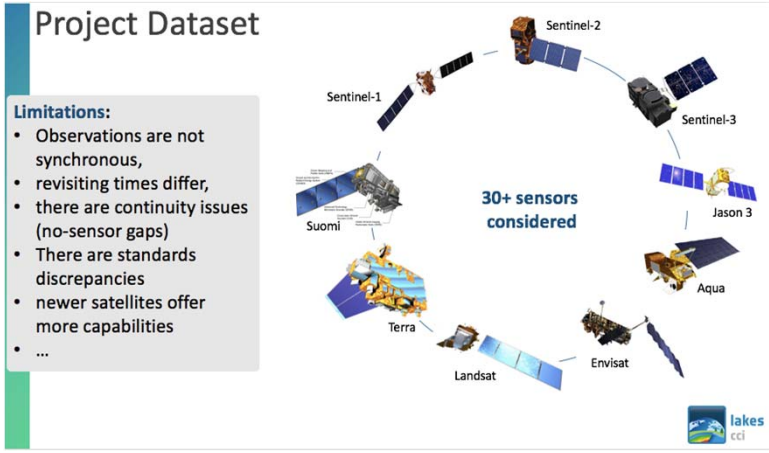
Summary

27 papers total (6 orals, 21 posters)

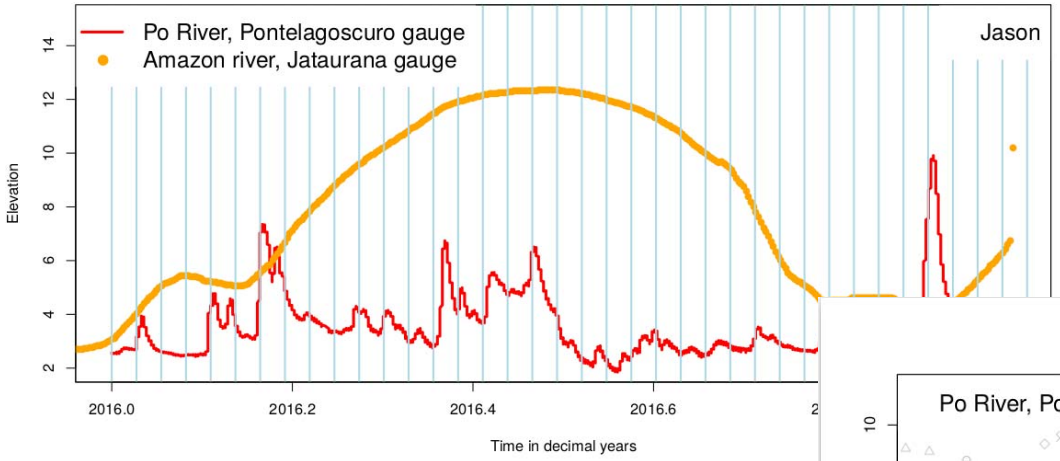
- **Mission Status for ICESat-2; Sentinel-3; CryoSat-2**
- **Updates on River and Lake Monitoring:**

  multi-mission river levels (RIDESAT); ESA Lakes CCI
- **Cryosphere: Updates on advances in land ice elevation change; polar ocean sea level anomaly; sea ice freeboard and thickness; derivations of snow depth on sea ice (AltiKa - CryoSat-2; ICESat-2 – CryoSat-2)**
- **Hydrology: river and lake level monitoring; validations with in situ observations; SWOT virtual discharge and water levels for hydrological modelling; tropical basin monitoring; reservoir monitoring**



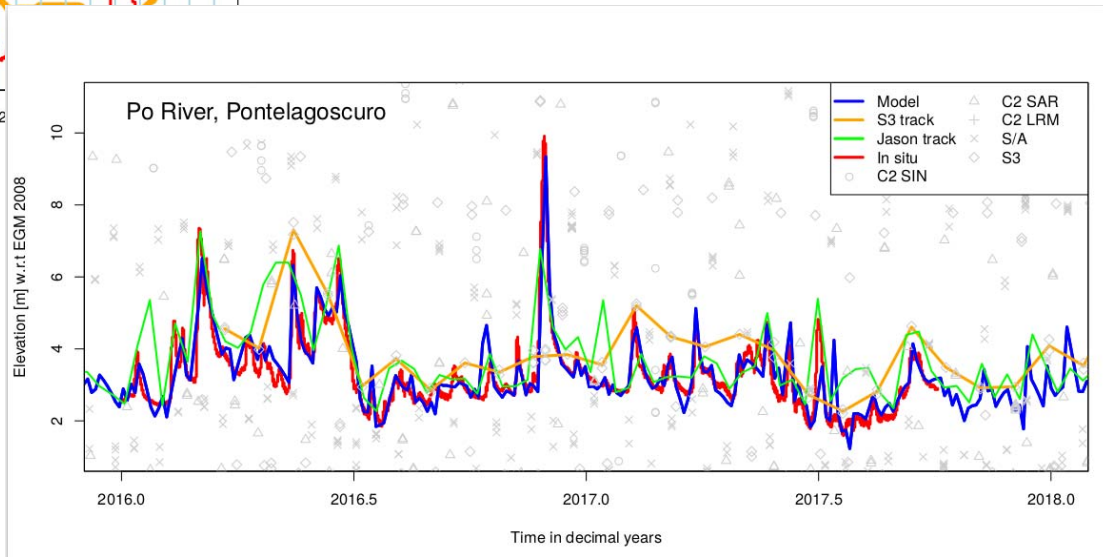


RIDESAT River Level Monitoring



Nielsen, K. et al.

Increased resolution when combining multiple missions rather than relying on one mission alone

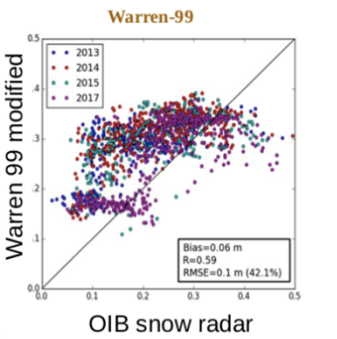


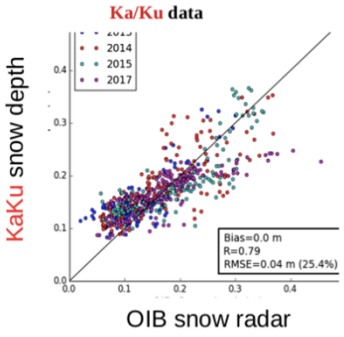
Snow Depth on Sea Ice

Sara Fleury, Florent Garnier
Antoine Laforge, Frédérique Rémy
and Benoit Meyssignac

Snow depth altimetric measurement :Arctic

Validation with Operation Ice Bridge (OIB) airbone data



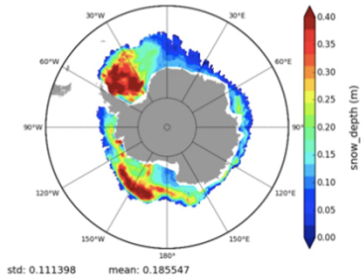


High impact of surface roughness on the range retrieval on both CS-2 and Saral can compensate each other

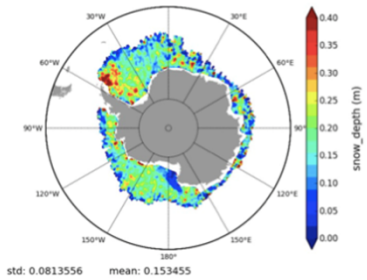
Ka – Ku ≈ penetration depth

Best results from combining AltiKa SARAL LRM footprint with CS-2 pseudo LRM footprint

Snow depth altimetric measurement :Antarctic



2015/06



~ Comparable spatial distributions

- Stronger patterns of depth snow in AMSR data.

- AMSR tend to overestimate (as in Arctic)

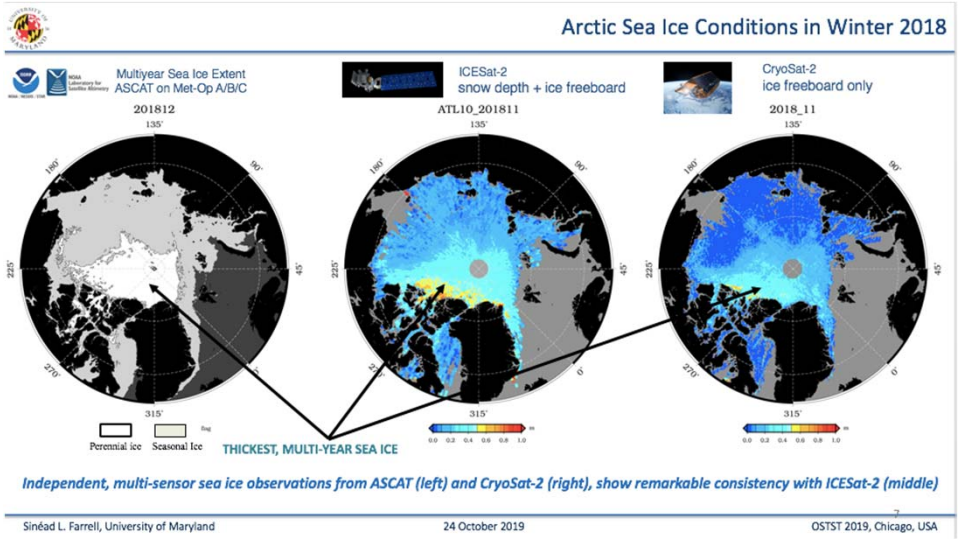
ongoing in the ESA Antarctica+ project

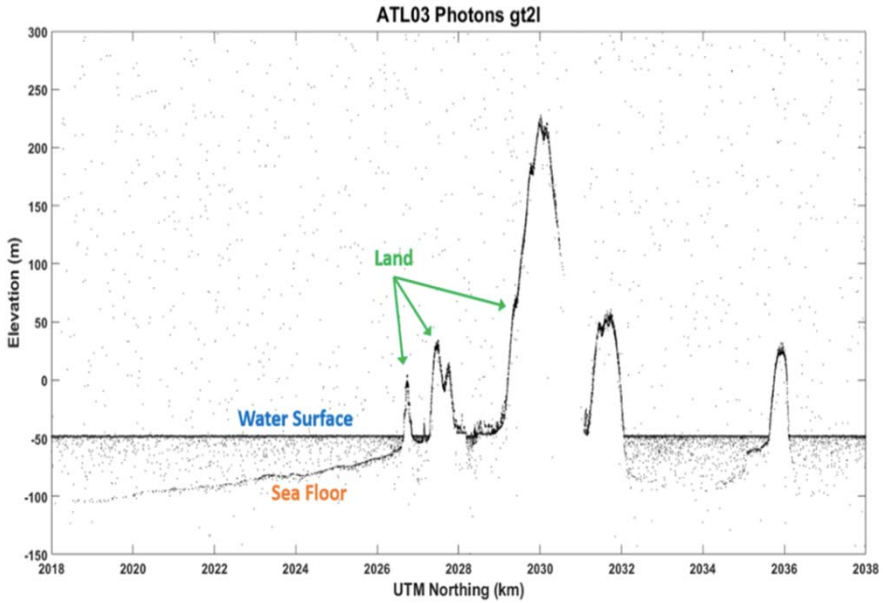
ICESat-2

Sinéad Louise Farrell[1]
K. Duncan[1], E. Buckley[1], J. Kuhn[2], L. Connor[2], E. Leuliette[2]
[1]University of Maryland [2]NOAA Laboratory for Satellite Altimetry

- ICESat-2 data **publicly** available at: **https://nsidc.org/data/icesat-2**

- 14 Oct 2018 to 02 May 2019 currently available at NSIDC, Release 001
- Release 002 of ATLAS data being distributed at NSIDC - October 2019 (LIVE: 4:30 pm EDT 24 Oct!)
  - Reprocessing of Release 001 - fixes to ATBDs (algorithms)
- Data spans: 14 Oct 2018 – 26 June 2019





Unexpected Results!

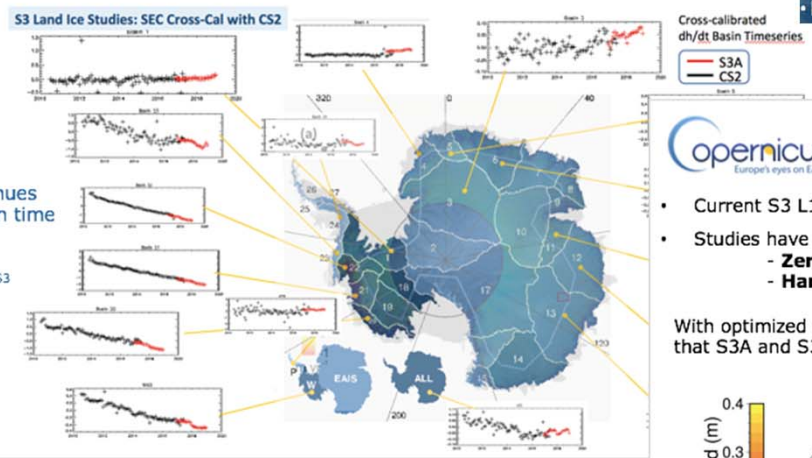
- **Near shore/coastal bathymetry in shallow, clear, shallow waters**
- **ICESat-2 transect over Saint Thomas, U.S. Virgin Islands, shows measurements of land surfaces above and below the water surface**
- **Submerged topography eventually disappears as water depth increases**

Credit: ***Magruder et al., EOS, 2019***

Sentinel-3A/B

S3A & S3B STM LAND Ice Performance

Surface Elevation Change (SEC)
Cross-calibrated elevation time series of Antarctic drainage basins : An essential climate change indicator



S3 successfully continues the CryoSat-2 mission time series!

Except for high latitude due to S3 inclination limitation

European Commission

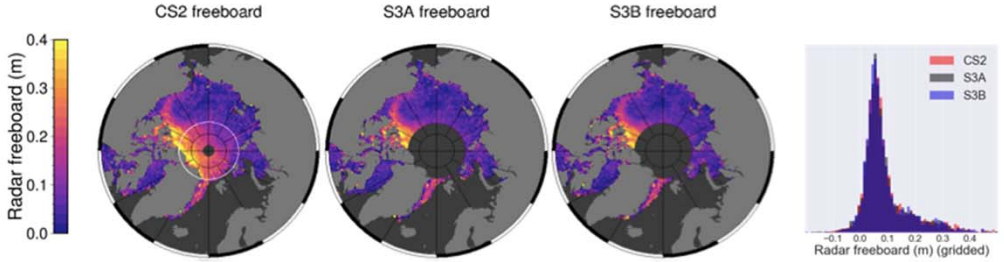
Sentinel-3 LAND Altimetry products & intended evolutions

Pierre Féménias – ESA ESRIN
- S. Labroue, M. Raynal, A. Jouzeau, N. Taburet, L. Amarouche , Jérémie Aublanc – CLS,
- G. Quartly – PML, UK
- A. Muir – MSSL, UK
- M. McMillan – Lancaster University, UK

S3A & S3B STM Sea-Ice Performance

- Current S3 L1 processing is optimized for Ocean surfaces and not Sea Ice
- Studies have shown that essential additional L1 processing is required for optimal sea ice processing:
  - **Zero Padding** (corrects the current under-sampling of specular echoes over sea ice leads)
  - **Hamming weighting** (reduces echo contamination by off nadir leads within the footprint)

With optimized L1 processing for Sea Ice (produced using ESA GPOD service), *Lawrence et al, 2019*, showed that S3A and S3B can match the quality of CryoSat freeboard measurements.



S3 Freeboard (Zero Padding, Hamming Applied) compared with CryoSat Freeboard : *Lawrence et al, 2019*

Isobel L. : "The paper "Extending the Arctic Sea Ice Freeboard and Sea Level Record with the Sentinel-3 Radar Altimeters" has just gone online at https://www.sciencedirect.com/science/article/pii/S0273117719307458"

Altimetry for Cryosphere and Hydrology *Discussion*

How should we prepare for potential polar altimeter gap in mid 2020s?

- Maintain CryoSat-2 and ICESat-2 missions for as long as possible
- Explore the potential for extending polar observations with HY2-A/B/C/D
- **CRISTAL: recommendation to support this mission and avoid gap in observations due to late launch date**

Can we make better use of multi-mission synergies?

- Support orbit alignment between CryoSat-2 and ICESat-2 to improve polar region obs., and global hydrology
- Consistent data processing to generate multi-mission, merged sea ice gridded data product (CMEMS services)
- Coordinated in situ field campaigns for cal/val in polar regions – AltiKa, CryoSat-2, ICESat-2

How should we advance coastal, hydrology, cryosphere, and ocean altimetry?

- Recommendation for at least two sessions, possibly more! 1. polar oceans, sea ice, land ice; 2. inland waters: lakes & rivers
- Better involvement of end users – via thematic sessions & applications sessions (vs. technical sessions)