Improvement of Sea Surface Height Measurements from ICESat-2 with Applications to Mean Sea Level within Estuaries

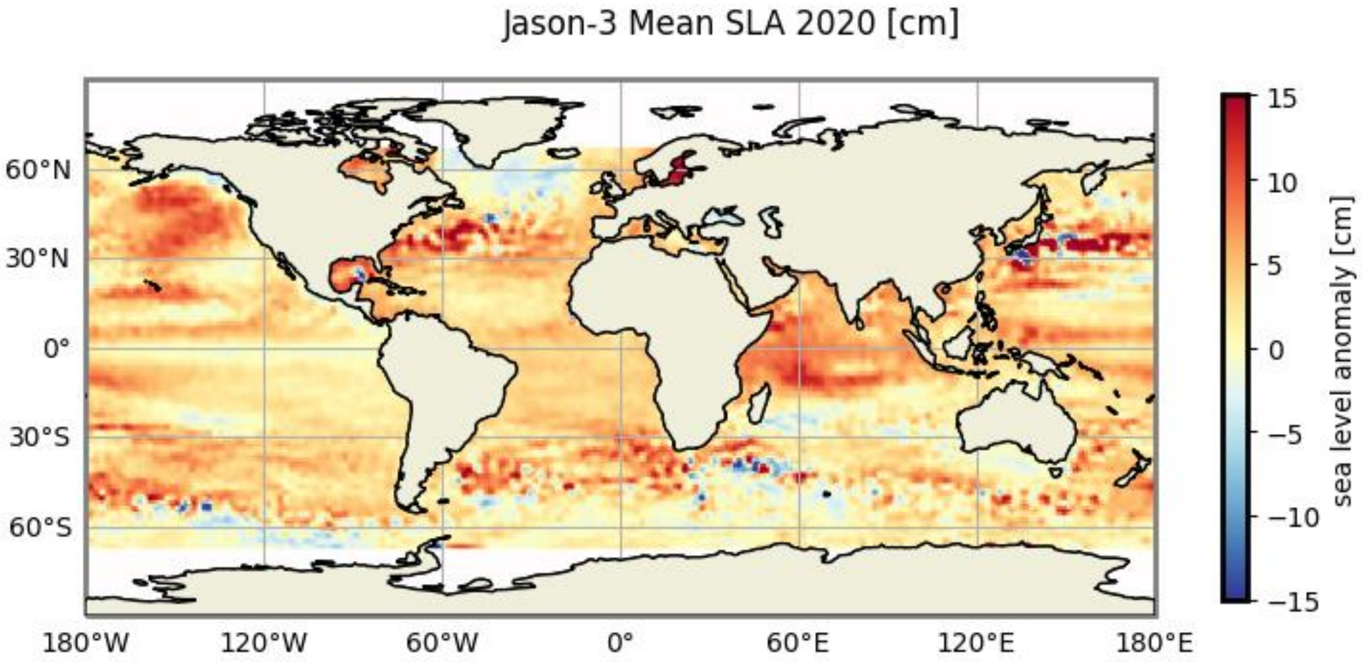
Alexa Putnam[1], Jamie Morison[2] and R. Steven Nerem[1]

1- Colorado Center for Astrodynamics, University of Colorado Boulder

2- Polar Science Center, APL University of Washington

University of Colorado **Boulder**

Measuring Sea Level



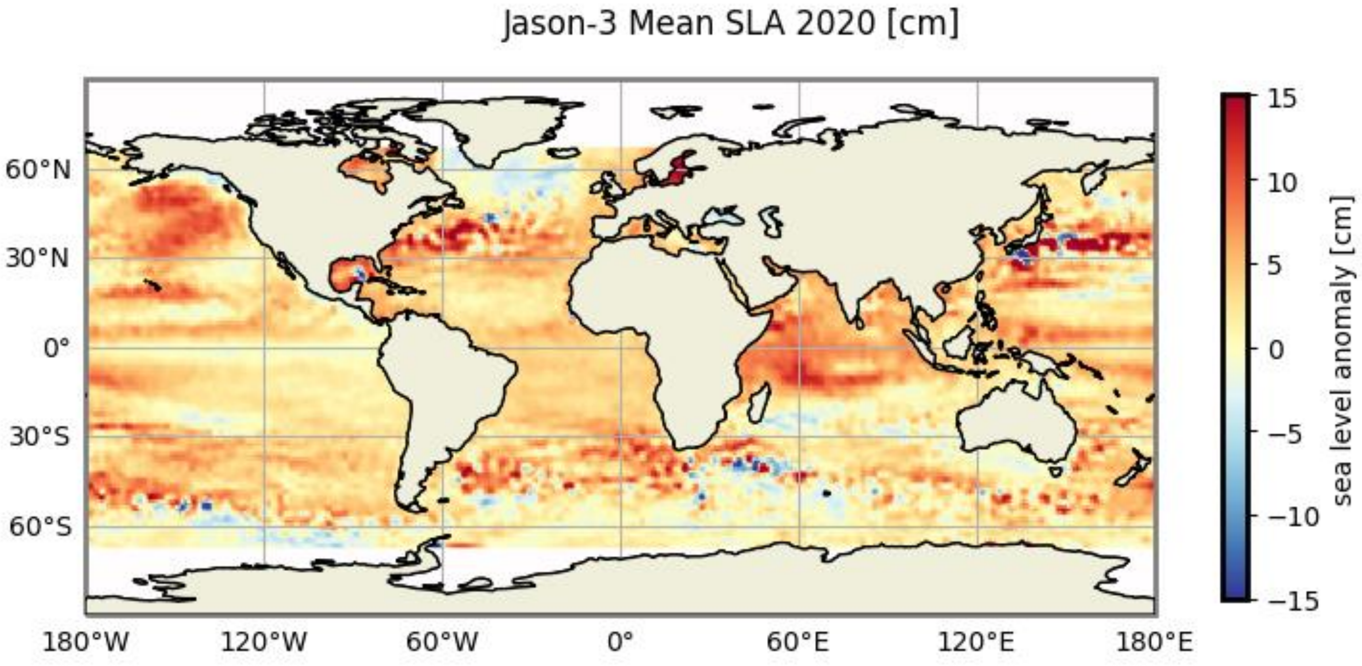
SSH = Altitude – Range
– Sea state bias (SSB)
– Atmospheric delays
– Ocean tide
– Load tide
– Solid earth tide
– Pole tide
– Dynamic atmospheric correction

SLA = SSH – Mean sea surface

↓

Deviations of the sea surface relative to the mean sea surface due to ocean currents and SSH correction errors (Altitude and MSS errors included).

Measuring Sea Level



SSH = Altitude – Range

– Sea state bias (SSB)
– Atmospheric delays
– Ocean tide
– Load tide
– Solid earth tide
– Pole tide
– Dynamic atmospheric correction

SLA = SSH – Mean sea surface

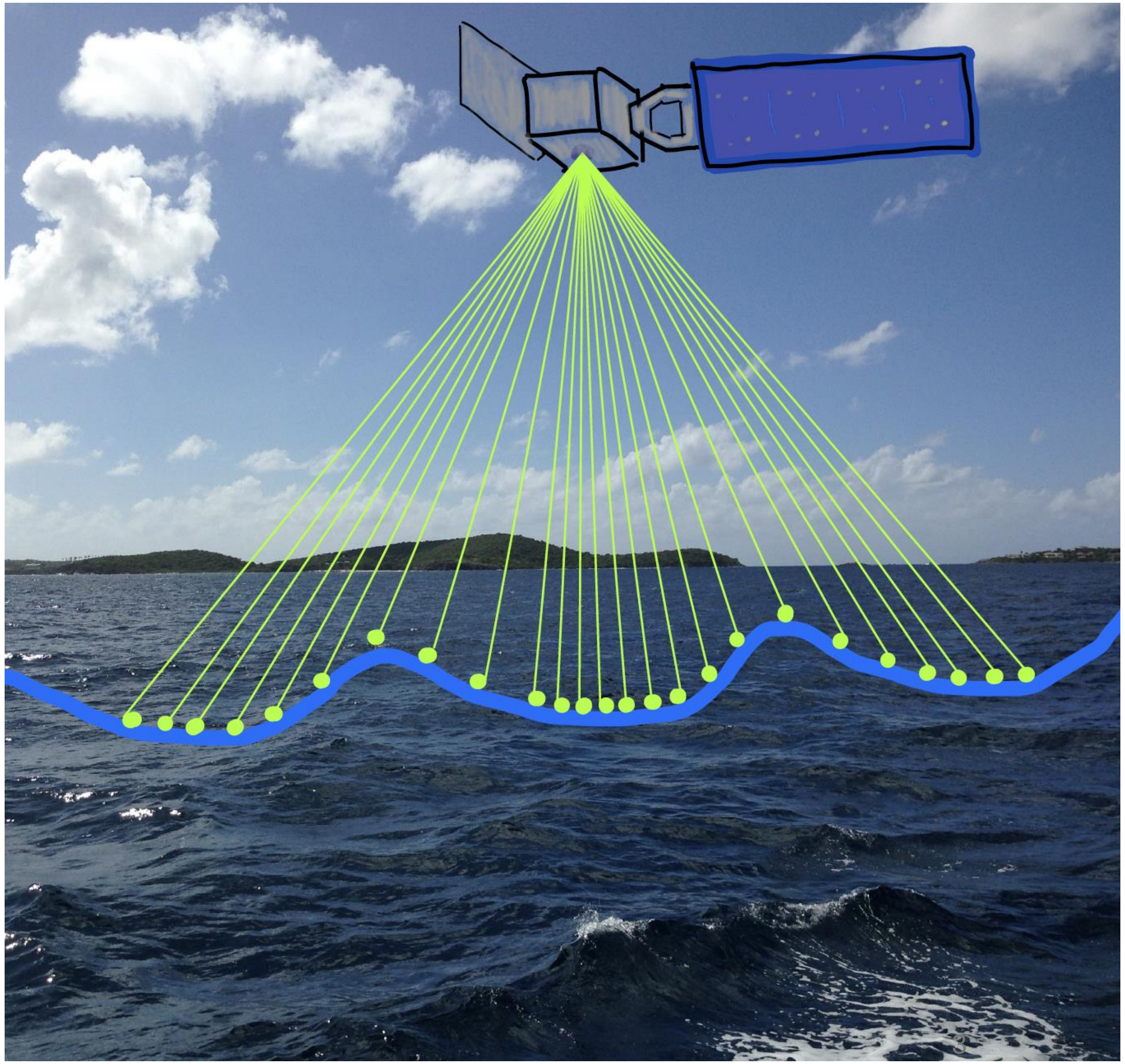
↓

Deviations of the sea surface relative to the mean sea surface due to ocean currents and SSH correction errors (Altitude and MSS errors included).

Sea State Bias (SSB)

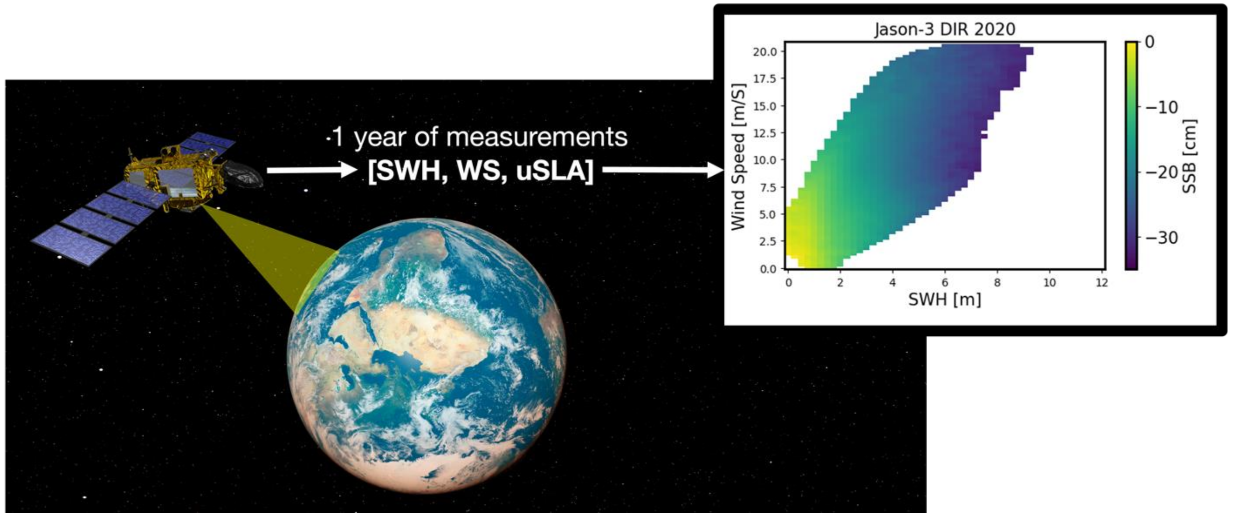
SSB = EM bias + skewness bias + tracker bias

- Electromagnetic (EM) bias: a result of more radiant energy being reflected from wave troughs rather than wave crests.
- Skewness bias: caused by the non-Gaussian distribution of sea surface heights (i.e. difference between the determined median sea surface measured by the retracker and the true sea surface)
- Tracker bias (radar altimetry): errors related to the way the altimeter tracks the returning radar signal.

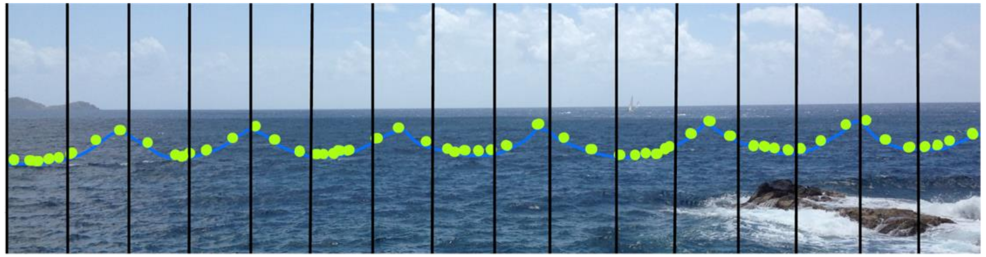


Sea State Bias (SSB)

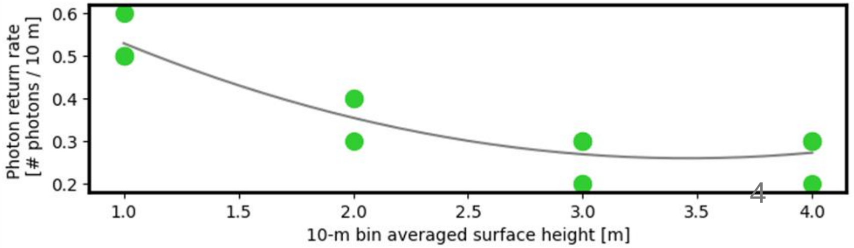
Radar altimetry (RA):
Maps along-track measurements of uSLA (DIR model) or collinear uSLA differences (COL model) into a 2D grid as a function of significant wave height (SWH) and wind speed (WS).
Assumption: DOT is independent of SWH and wind speed.



ICESat-2:
Directly estimates the EM bias as the covariance of height and return rate normalized by the average photon return rate for all 10-m bins within a segment
(i.e. 8000 signal photons or 7 km).

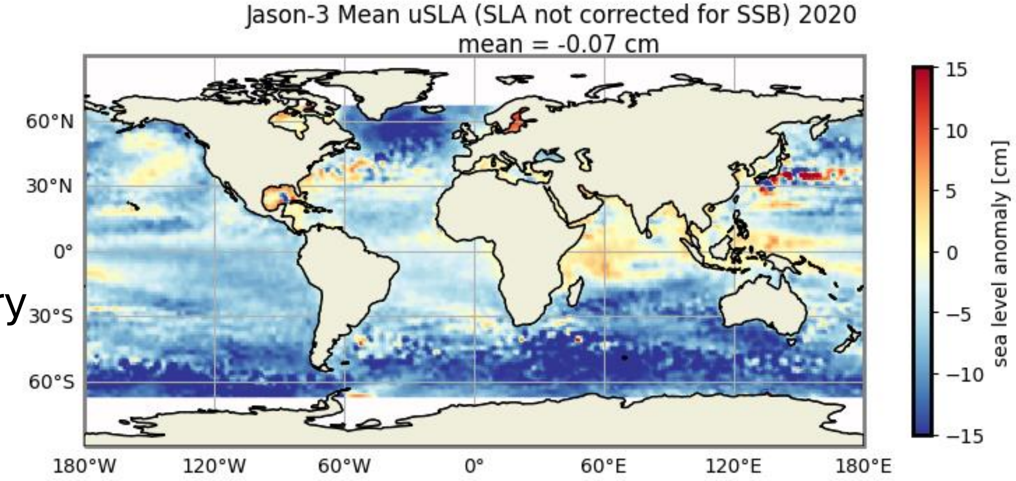


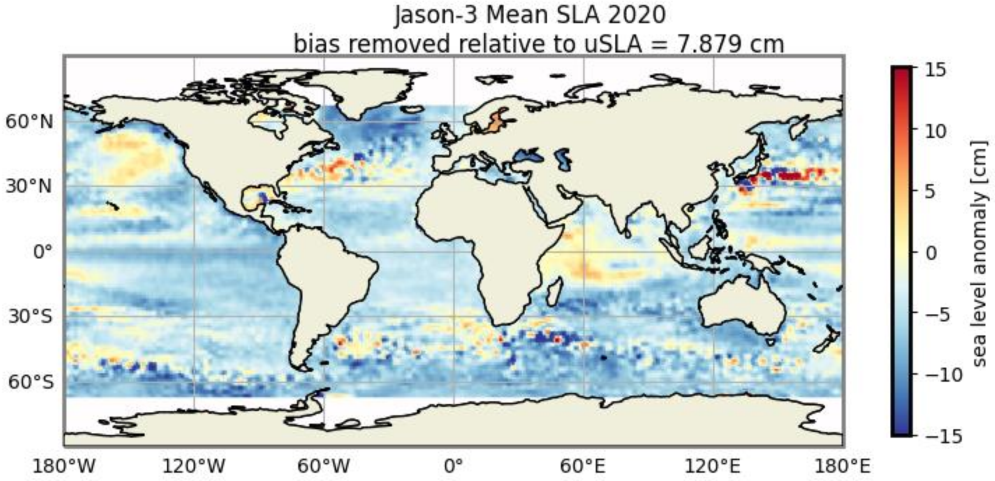
Photons within 10-m segment	5	3	3	2	3	5	3	5	2	2	6	3	4	3	3	4
10-m bin averaged surface height	1	3	4	3	2	1	4	1	4	3	1	4	2	3	3	2



Cryo2ice Symposium 2024

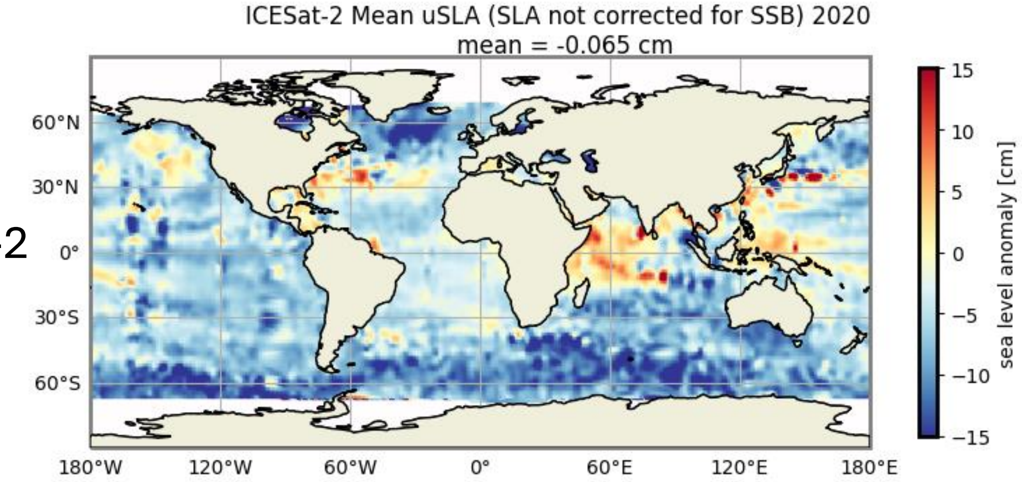
Radar altimetry

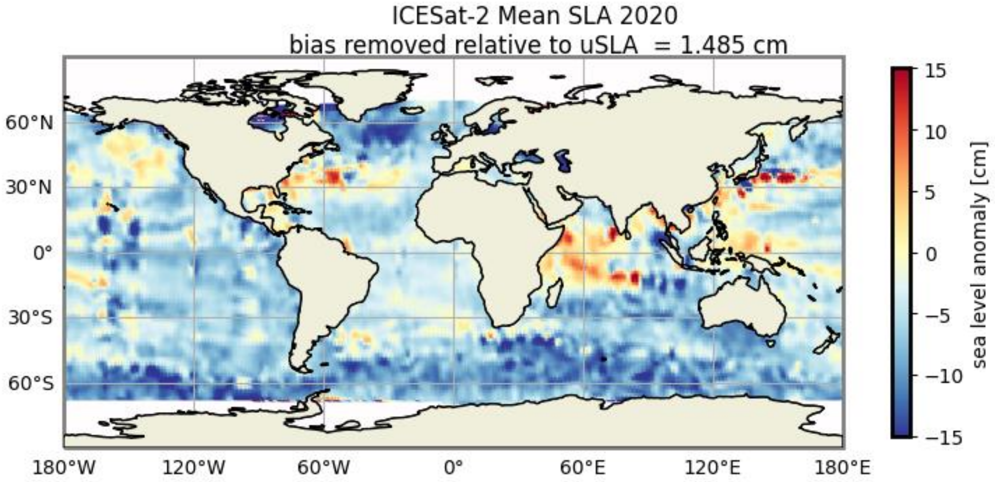




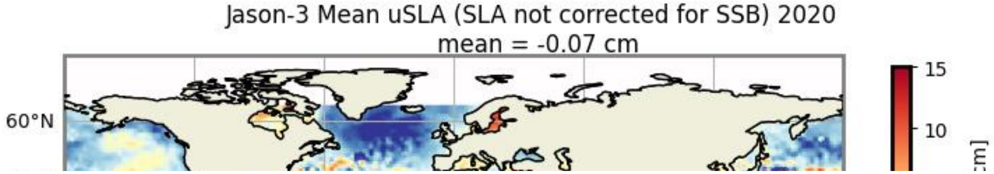
uSLA = A - R - Atm. - Tide - DAC - MSS → Apply SSB correction → SLA = uSLA - SSB

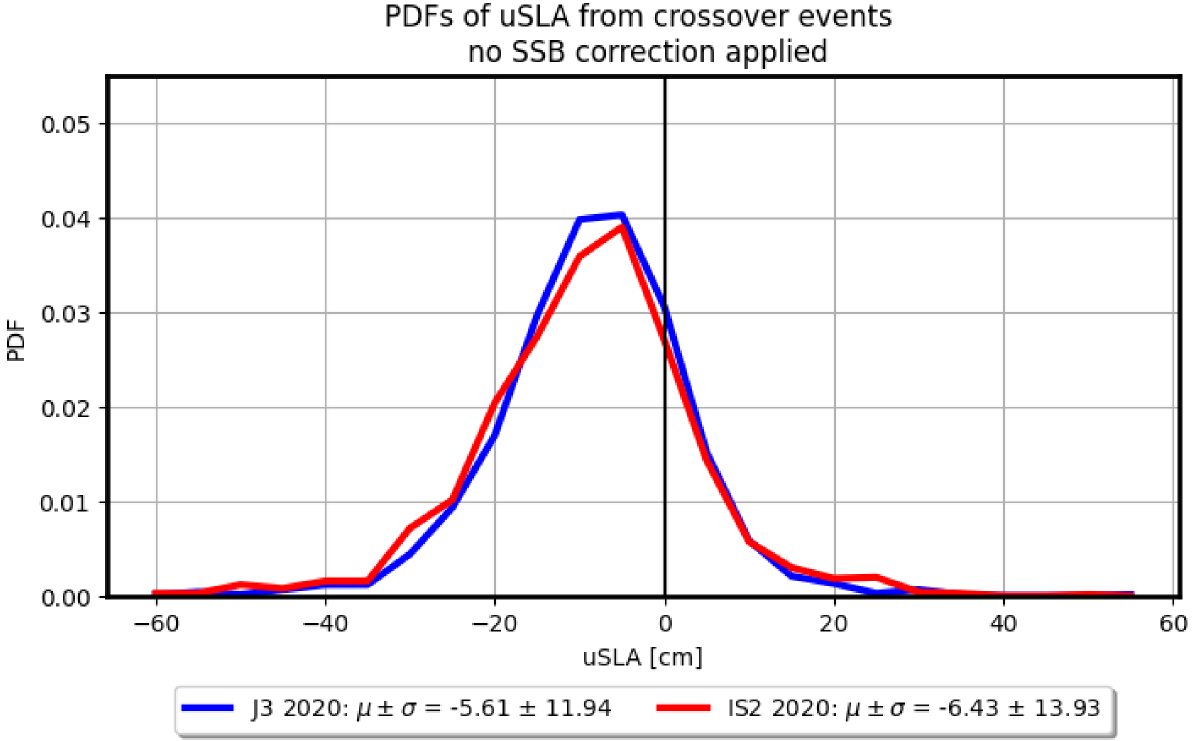
ICESat-2



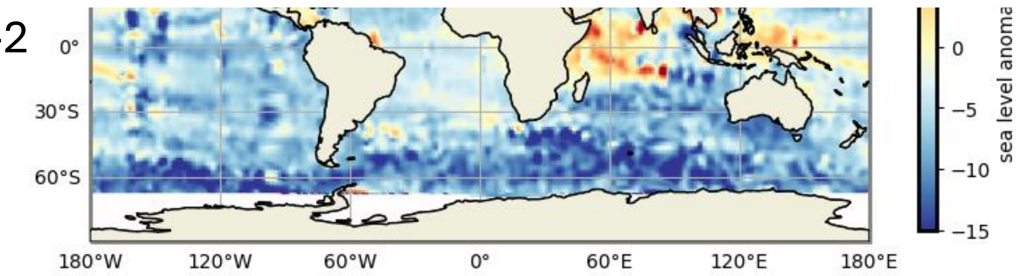


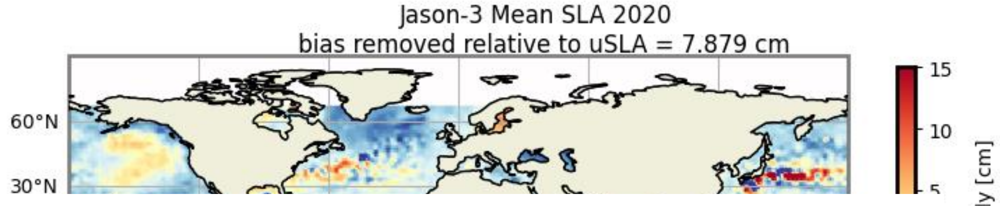
Cryo2ice Symposium 2024

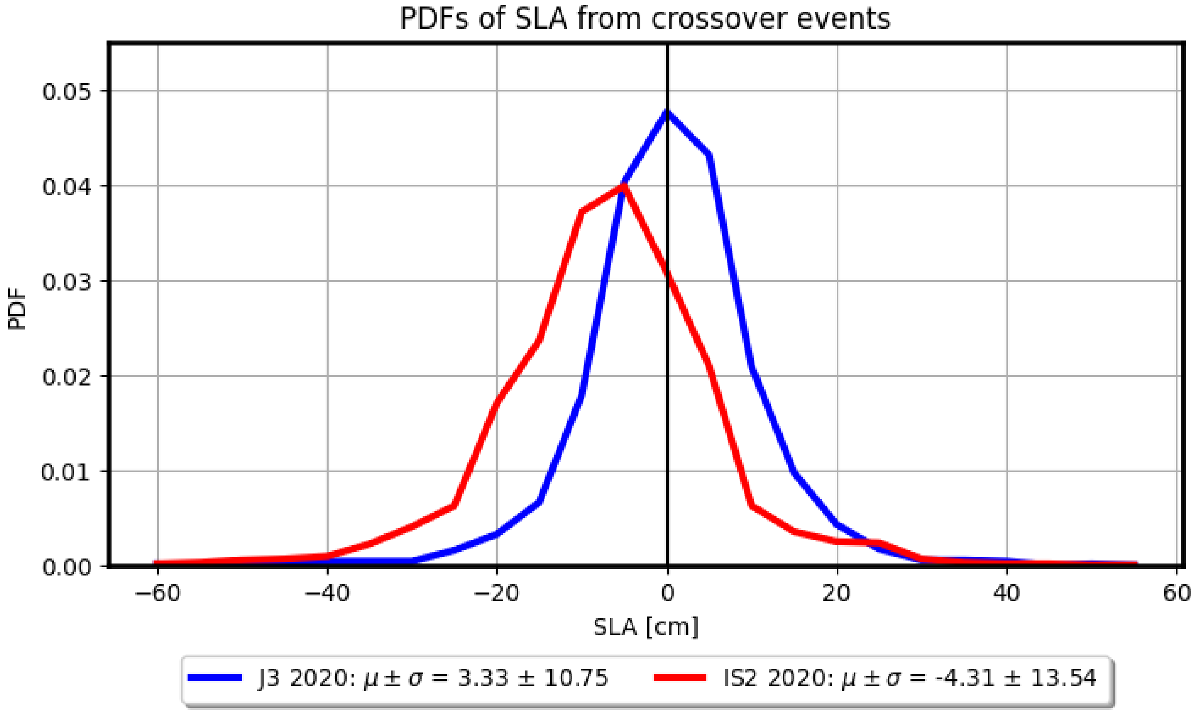


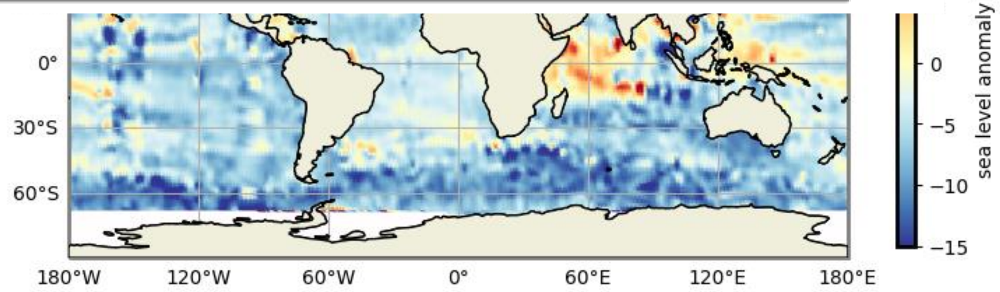


ICESat-2









Summary for SSB Analysis

Radar Altimetry

- Radar SSB models contain uncertainty correlated with SWH and WS because of DOT.

- We've developed a COE model that simultaneously solves for averaged global mean sea surface height to reduce the absorption of DOT signals within the SSB model. This result improves upon the radar SSB solution but not enough to converge on the ICESat-2 solution.

ICESat-2

- ICESat-2 SSB results in both positive and negative values.
  The positive SSB corrections reduce uSLA variability, thereby indicating that it must be correcting for some other sea state-related bias that's not EMB (as we've defined it).

- Radar altimetry trends of positive and negative uSLA with respect to SWH align well with the positive and negative SSB trends with respect to SWH, which is an indication that the true radar SSB might also include both the negative and positive components of the correction.

Conclusion for SSB Analysis

- Thanks to ICESat-2 we've been able to detect an error within radar sea level measurements resulting from the absorption of DOT signal into SSB models (See Morison et al. presentation).

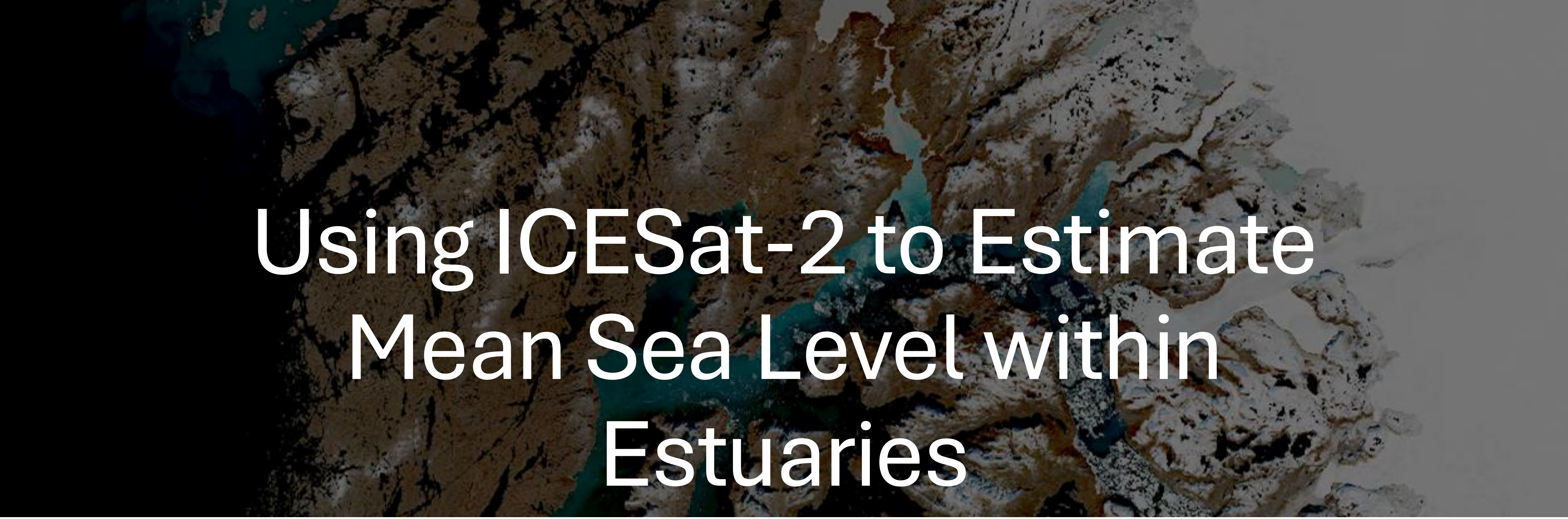
- Radar uSLA and ICESat-2 uSLA show good agreement, thereby indicating that their SSB corrections should be similar.

- The ICESat-2 SSB correction does not just account for EMB. There is another, positive sea state-related bias that is accounted for by the IS2 SSB solution, which we believe is also picked-up with radar altimetry.

<u>Using ICESat-2 we want to answer:</u>

1. What causes the positive SSB correction?

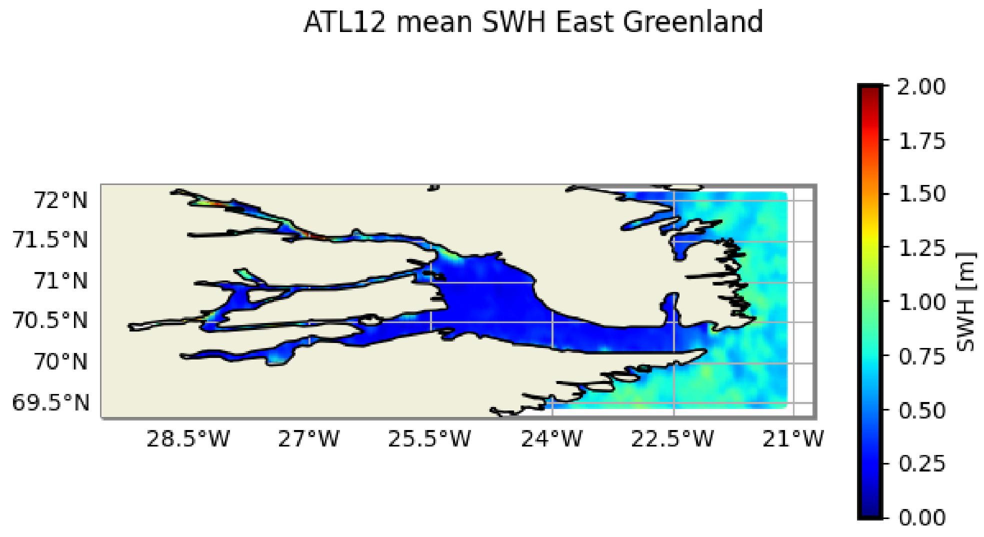
2. How can we improve radar altimetry SSB estimates? And what implications will this have on global MSS models and regional sea level trends?



Using ICESat-2 to Estimate Mean Sea Level within Estuaries

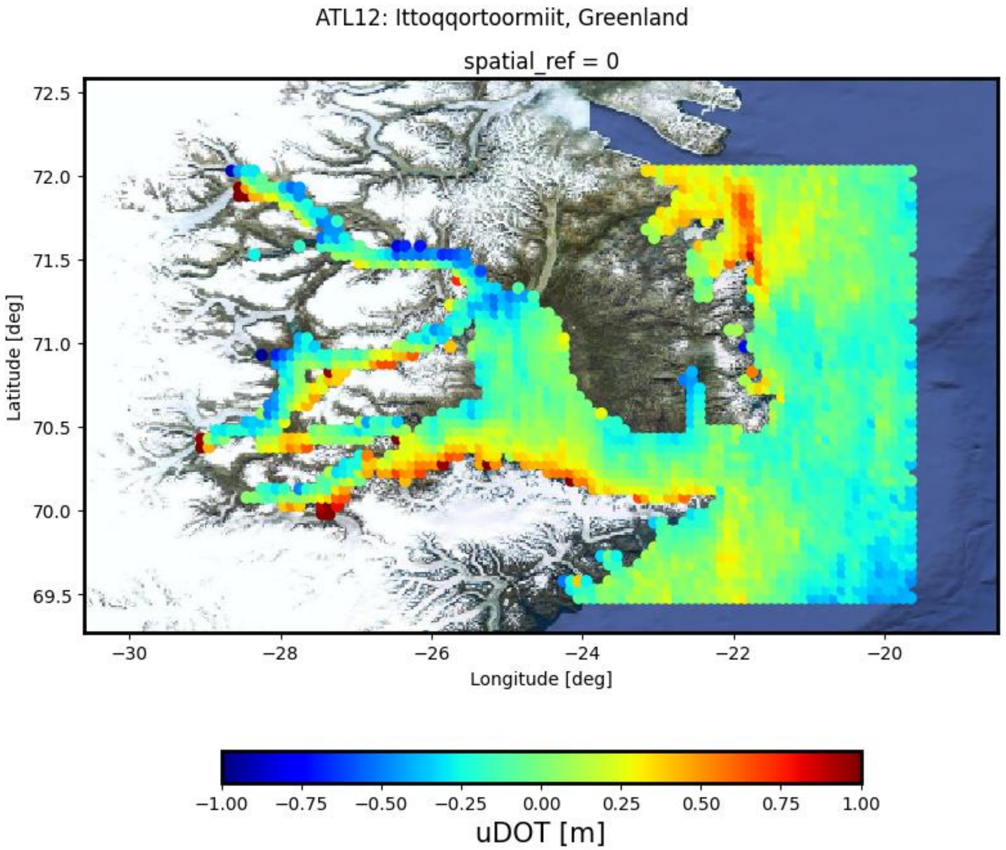
This part of the analysis does not apply the SSB correction because;

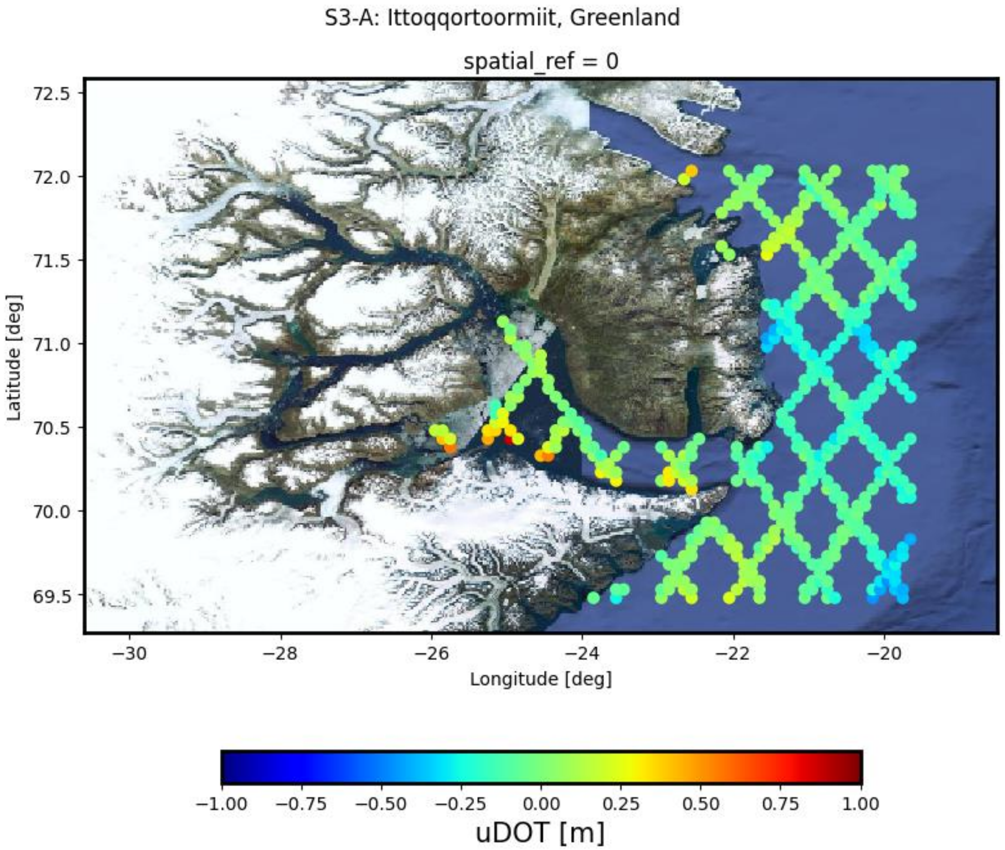
1. ATL13 does not consistently provide an SSB correction.
2. Based on the SSB provided by ICESat-2, the correction is less than 1 cm for SWHs less than 1 m.



ICESat-2 vs. Radar Altimetry

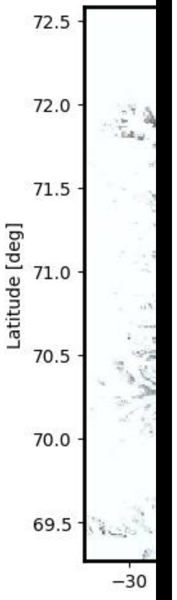
Unlike radar altimetry, ICESat-2's small footprint allows it to measure SSH within narrow passages of water.





ICESat-2 vs. Radar Altimetry

Unlike radar altimetry, ICESat-2's small footprint allows it to measure SSH within narrow passages of water.



Open Access Communication

ICESat-2 for Coastal MSS Determination—Evaluation in the Norwegian Coastal Zone

by Matea Tomić [1,*] and Ole Baltazar Andersen [2]

1 Department of Geomatics, Faculty of Science and Technology (RealTek), Norwegian University of Life Sciences (NMBU), N-1432 Ås, Norway

2 DTU Space, Technical University of Denmark, Elektrovej 328, 2800 Kongens Lyngby, Denmark

* Author to whom correspondence should be addressed.

Remote Sens. **2023**, *15*(16), 3974; https://doi.org/10.3390/rs15163974

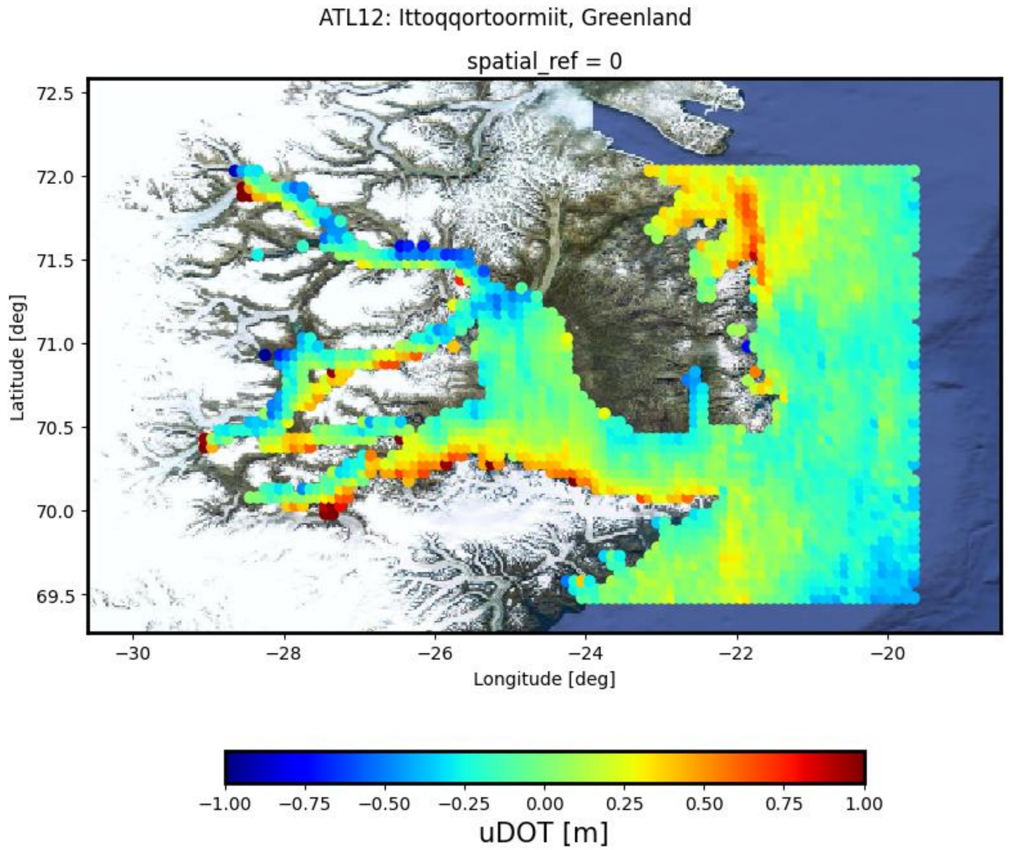
Submission received: 30 June 2023 / Revised: 4 August 2023 / Accepted: 9 August 2023 / Published: 10 August 2023

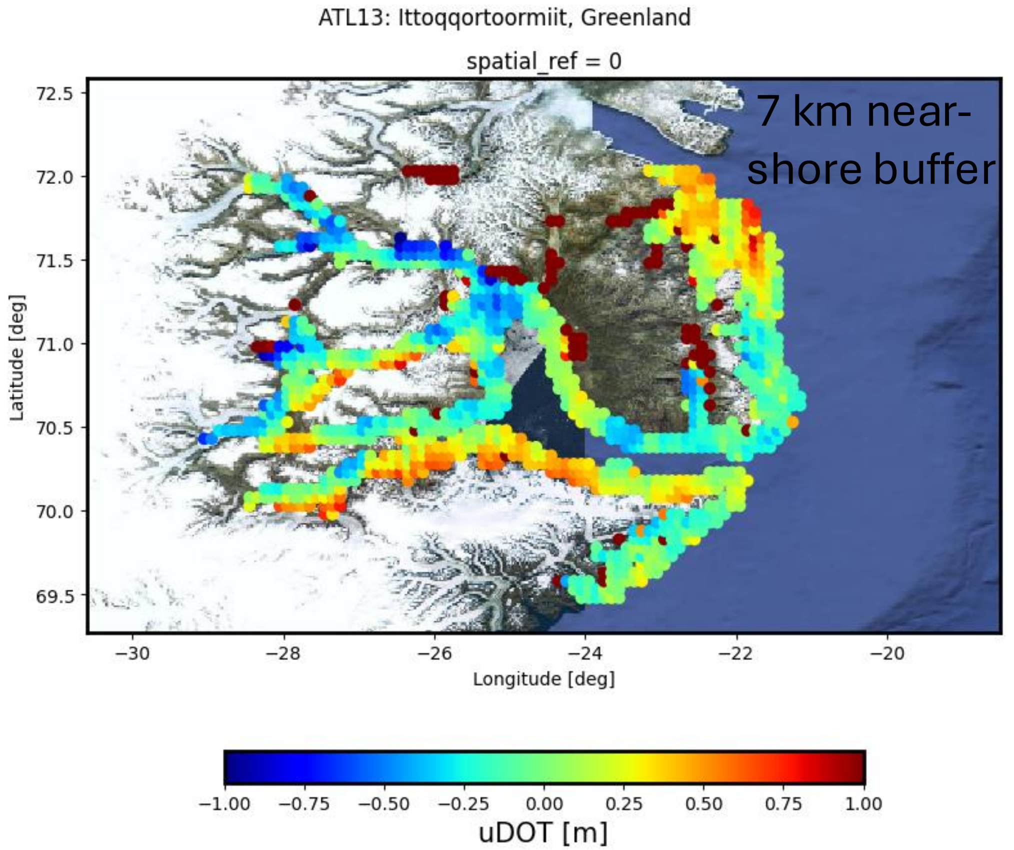
uDOT [m]

uDOT [m]

Cryo2ice Symposium 2024

	ATL12	ATL13
Product	Ocean Elevation	Inland Water Height
Along-track footprint	Every 8000 signal photons → a few 100 m – 7 km depending on the sea state.	Every 100 signal photons (75 for rivers) → 30 m to several hundred meters depending on sea state.





Test locations that range in narrowness

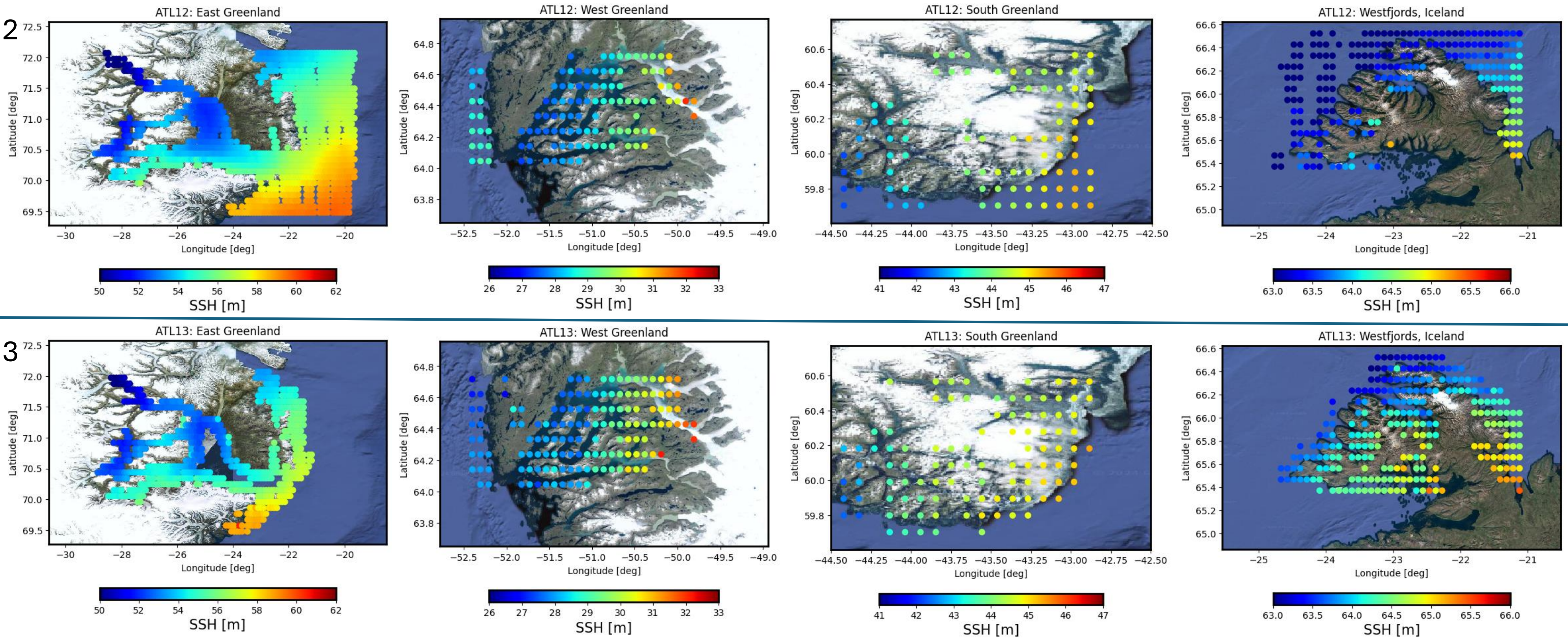
East > West > South > Westfjords

Cryo2ice Symposium 2024

Better coverage by ATL13 as estuaries get narrower

ATL12

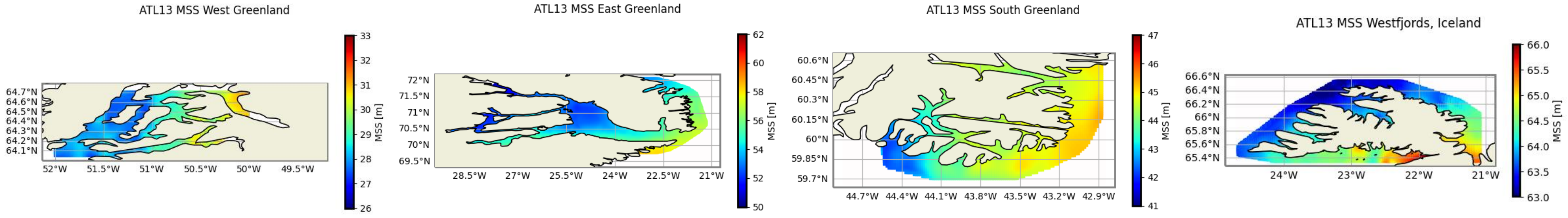
ATL13



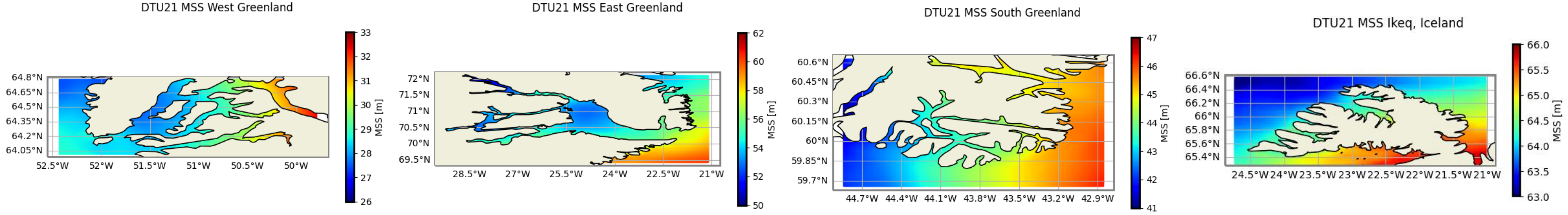
MSS Comparison: ATL13 vs. DTU21

DTU21: 1-minute(1/60º) resolution MSS model from the Technical University of Denmark, which uses multiple satellites over the period of 1993-2012 (Topex/Poseidon ellipsoid but switched to WGS84 reference ellipsoid for this analysis).

ATL13



DTU21



Conclusion for MSS Analysis

- Many estuaries cannot be measured using radar altimetry.

- Narrow estuaries are better covered by the ATL13 Inland Water Height product than the AT12 Ocean Elevation product.

- MSS estimates using only ATL13 sea surface height data are comparable to those from DTU21, but with potential improvements within estuaries.

As a next step we'd like to:

1. Test whether the recently released FES2022 ocean tide or other Arctic tide models can help improve the accuracy of ICESat-2 SSHs within estuaries.

2. Re-compare ATL12 and ATL13 with the upcoming release 7.

3. Provide ICESat-2 MSS for all of Greenland.

Thank You!

Questions?

Alexa.Putnam@Colorado.edu