

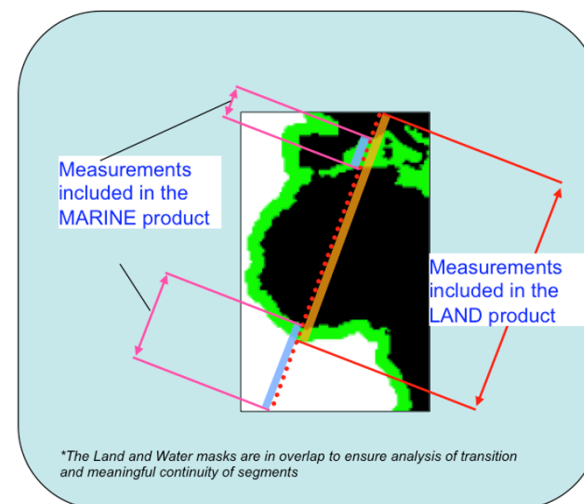
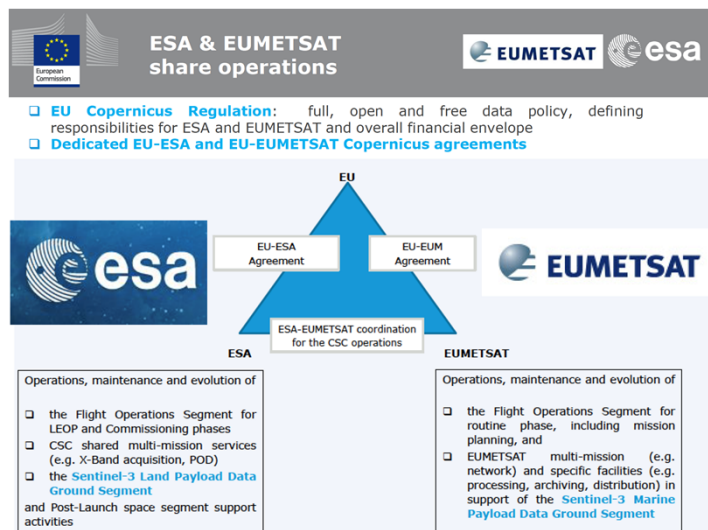
# Sentinel-3 LAND Altimetry products & intended evolutions

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- A. Muir – MSSL, UK

– Lancaster University, UK

## S3 STM – ESA & EUMETSAT shared operations @ BOM



**S-3 STM L2 production organisation**

- ESA is responsible for S3 STM LAND data
- EUMETSAT is responsible for the MARINE data
- L1 processing common to ESA & EUM
- L2 LAND - ESA
- L2 MAR - EUM

- Mask (for the ESA/EUM L2 products partitioning) based on **initial S3 STM SAR mode scenario**, i.e. 300 km SAR mode on coastal areas

## S3 STM Land Mission



“NEW” definition of the ESA S3 STM LAND products:

Cryosphere



Inland Waters



Land Ice

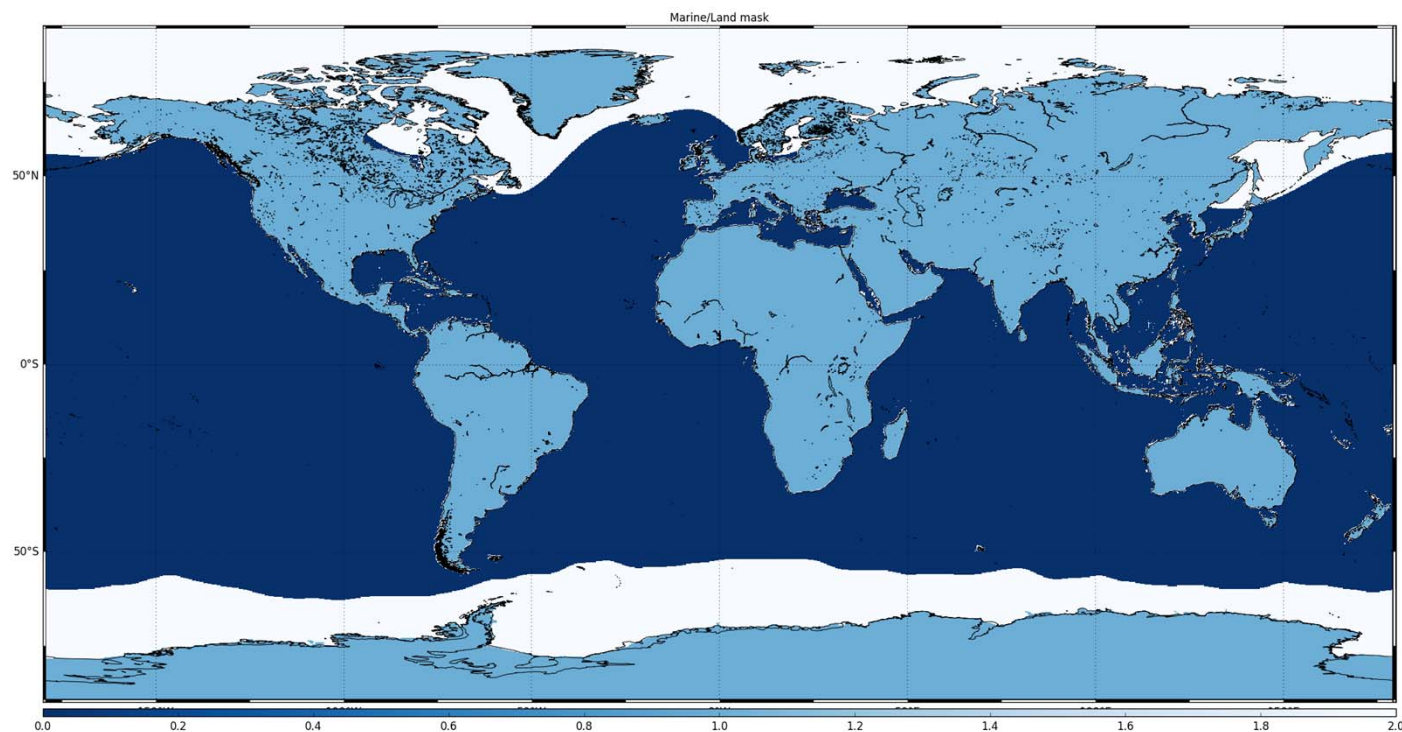


Sea-Ice

- ESA & EUMETSAT recently converged on a better definition of the S3 STM LAND and MARINE products!
- **ESA (LAND PDGS) takes full responsibility for the Inland Waters & Cryosphere**, i.e. land ice and sea-ice (= geophysical products describing the ice e.g. sea-ice thickness, sea-ice extent, sea-ice movement, ... are under ESA responsibility)
- EUMETSAT (**MARINE** PDGS) takes full responsibility for the coastal zone (on top of Open Ocean) and polar zones (geophysical products describing the sea e.g. SSH, SSH is under EUMETSAT responsibility)
- **"Land/Sea" mask update** with a ~20 km overlap along the coast line (Land mask reaching ~10 out in the ocean, ocean mask reaching ~10 km inland)
- **Agreed split** of the Altimetry Level-1 processing chain into different branches



## S3 STM LAND/MARINE Mask



- Marine
- Land
- Common

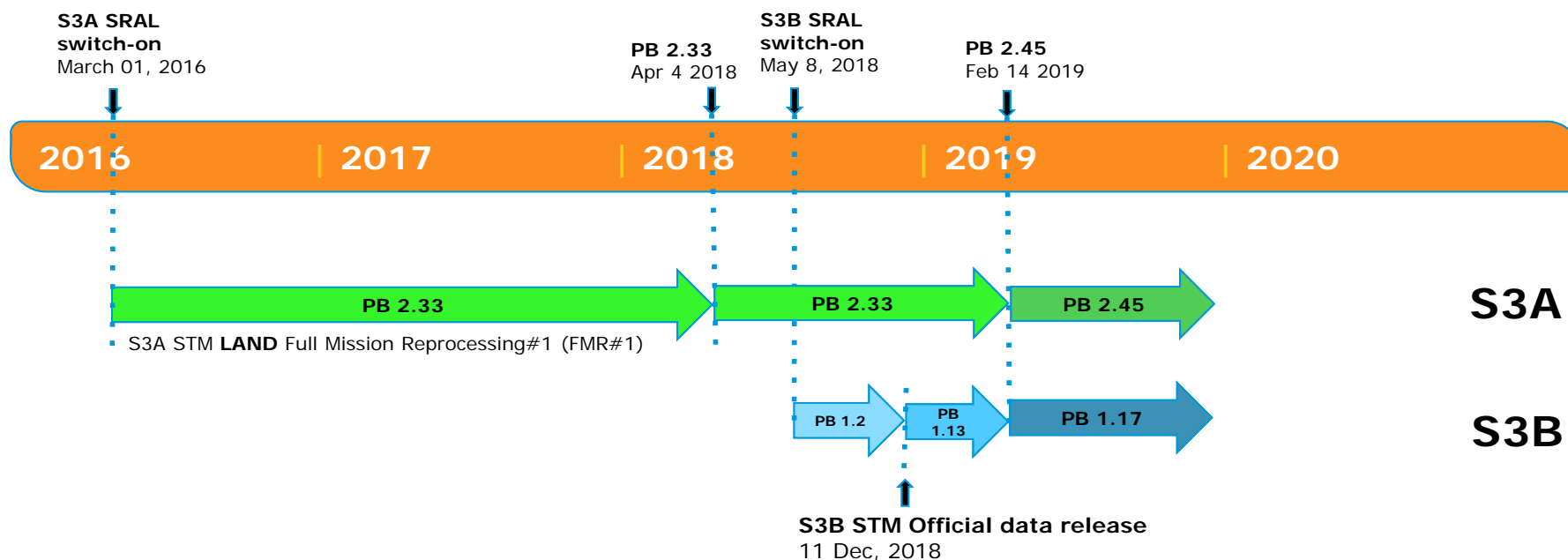
**NEW mask!**



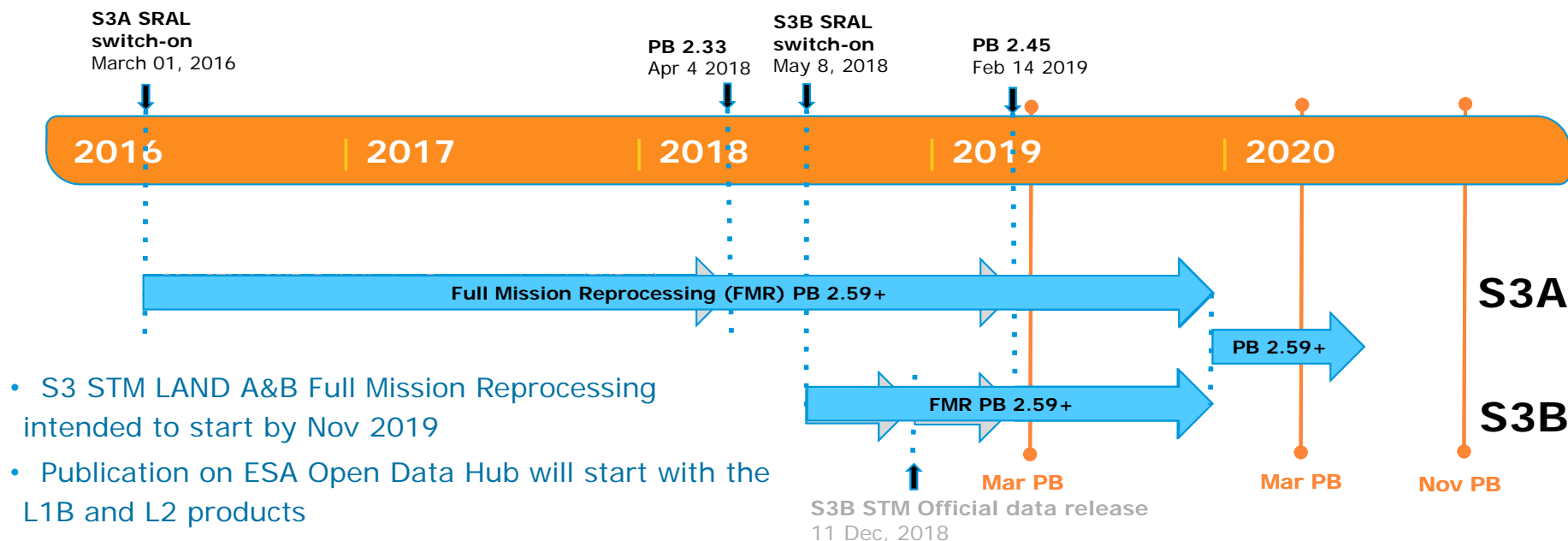
**NO impact on EUM MAR products!**



# S3 STM Land Mission Data Set



## S3 STM Land Mission Data Set



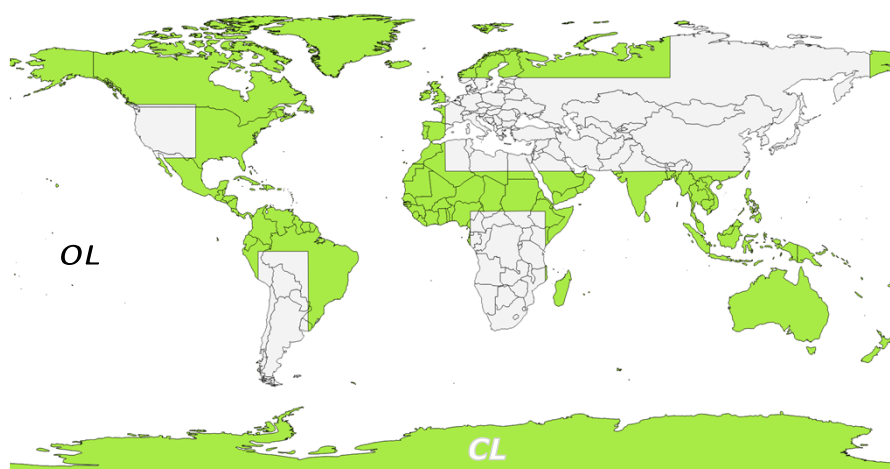
- S3 STM LAND A&B Full Mission Reprocessing intended to start by Nov 2019
- Publication on ESA Open Data Hub will start with the L1B and L2 products
- L1A and L1BS will be published whenever possible
- FMR shall be in line with the new S3 LAND products definition → i.e. **New mask will be applied**

### Improvements:

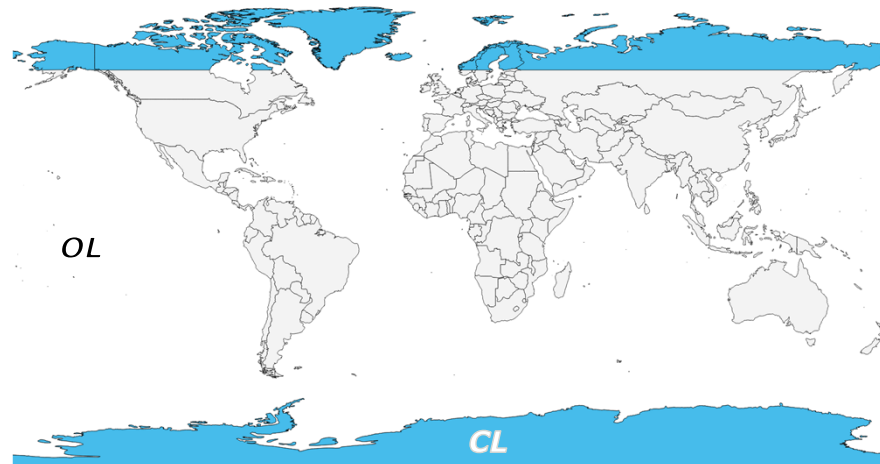
- L2 sea ice freeboard (freeboard\_20\_ku)
- Improvement of Ice concentration parameter
- Improvement of the OCOG retracked parameters in C-band
- New slope model
- DTU2018 MSS
- ...

## S3A & S3B STM - Acquisition mode

### Sentinel-3A



### Sentinel-3B



➔ S3A switch to S3B SRAL Zone Data Base (ZDB) model on 09-March-2019

OLTC = Open Loop Tracking Command

CL = Close Loop



## S3A & S3B STM Inland Waters - Outlook

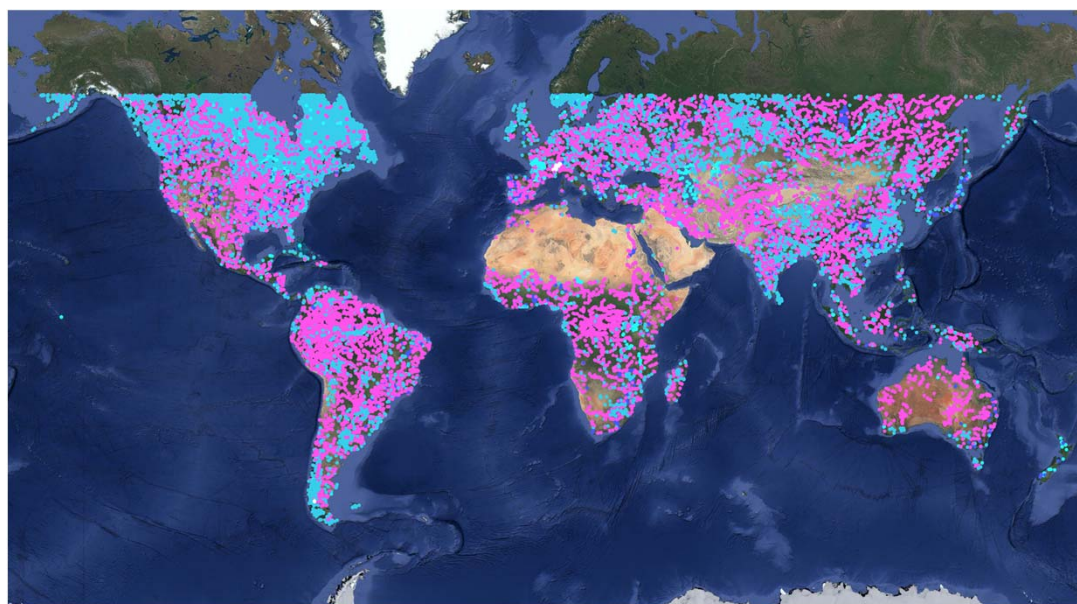
→ Rivers  
→ Lakes & Reservoirs

- S3A → 33.261 Virtual Stations since 9 Mar 2019 (OLTC V5.0)
- S3B → 32.515 Virtual Stations since 24 Nov 2018 (OLTC V2.0)

Both altimeters in OLTC in  $\pm 60^\circ$  Latitudes  
+ CDN1 Range Transponder (Crete)  
+ Svalbard Range Transponder

→ **Plan to extend North!**

Visit and contribute @  
<https://www.altimetry-hydro.eu>

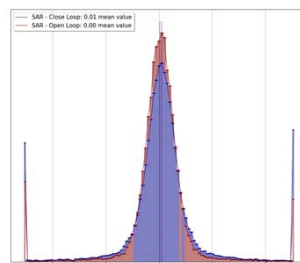


✓ More than 65.000 VS for the S3 constellation !

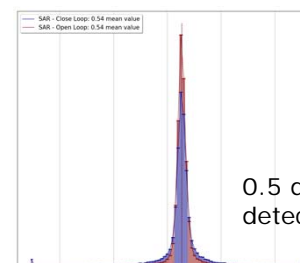
See posters:

- **Altimetry over inland waters: current achievements thanks to the Open-Loop Tracking Command (OLTC) and perspectives for future missions** - Sophie Le Gac (CNES, France)
- **An interactive website for enhancing the Open-Loop Tracking Command (OLTC) of conventional altimeters for inland waters observation** - Sophie Le Gac (CNES, France)

## S3A & S3B STM Inland Waters - Outlook



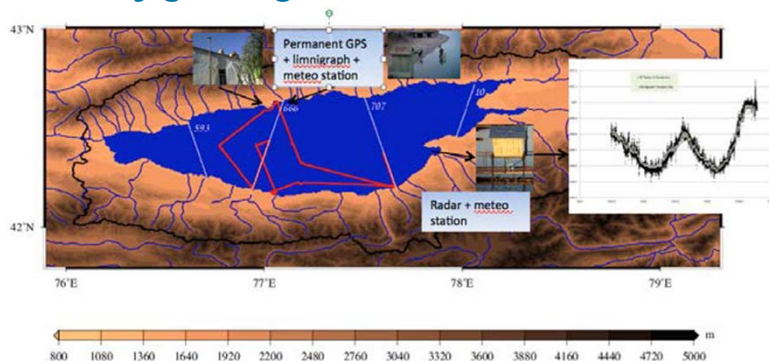
Global WSH differences



Global Sig0 differences

0.5 dB diff detected

→ Very good agreement between both S3A & S3B STM (from the very first S3B day!)

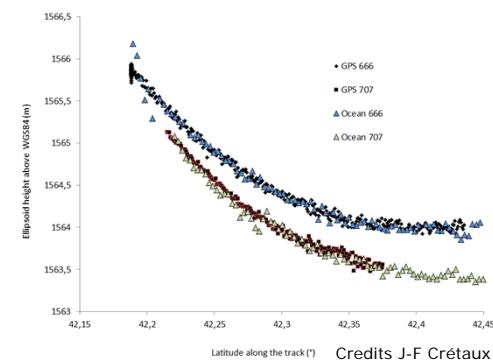


### Ocean retracker

Absolute bias: -14 mm +/-20  
Accuracy: 30 mm

### Ice-1 retracker

Absolute bias: 285 mm +/-20  
Accuracy: 24 mm



→ S3 STM demonstrates capability of performing long term WSH measurement with an **accuracy of 3 cm**

→ This is a **VERY GOOD performance**, fully sufficient for hydrology purpose

→ **Recommendation** from Copernicus Global Land Service and user community for implementation of Zero-Padding and Hamming Window, FF-SAR, all geophysical corrections at 20Hz, ...

# Routine Quality Assessment over 700 lakes

Sentinel 3 - A: Valid / edited / DV - L2 Land water data  
Cycles 48/49



Water surface height  
(orbit – range – corrections – geoid)

Orbit

Retracking derived parameters

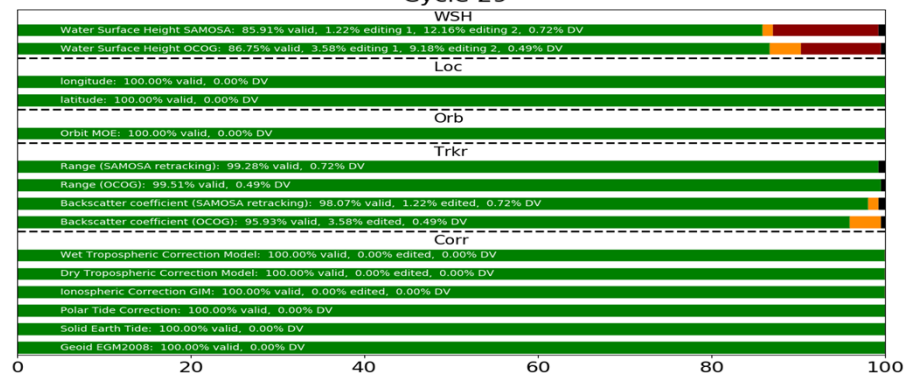
Geophysical corrections

Geoid model

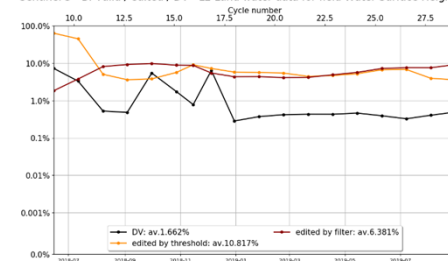
→ Consistency between both mission's percentages of valid measurements

→ Long time consistency (bottom plot)

Sentinel 3 - B: Valid / edited / DV - L2 Land water data  
Cycle 29



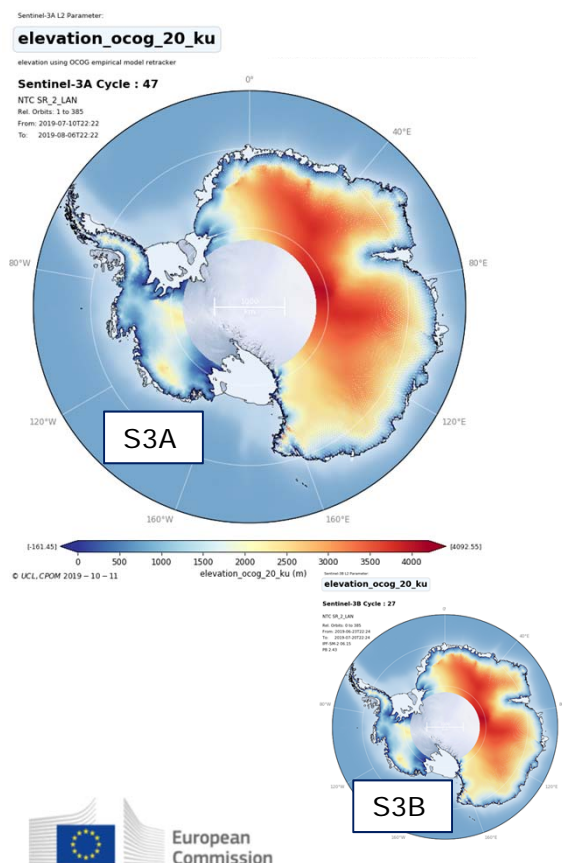
Sentinel 3 - B: Valid / edited / DV - L2 Land water data for field Water Surface Height OCOG



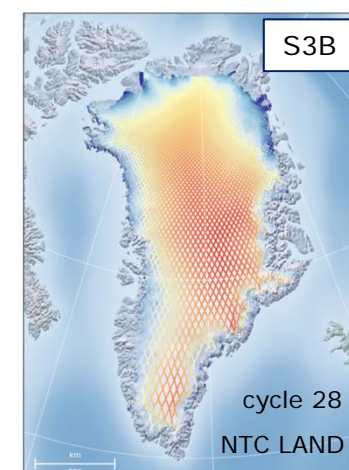
See poster **Performance of the Sentinel-3 STM constellation over Inland Waters** - Nicolas TABURET (CLS, France)



## S3A & S3B STM LAND Ice Performance



- **Excellent S3A and S3B SAR performance** over the majority of the Antarctic and Greenland ice sheets (slopes < 1%)
- **Consistent instrument tracking, accuracy, precision and measurement coverage for both S3A and S3B missions.**



## S3A & S3B STM LAND Ice Performance

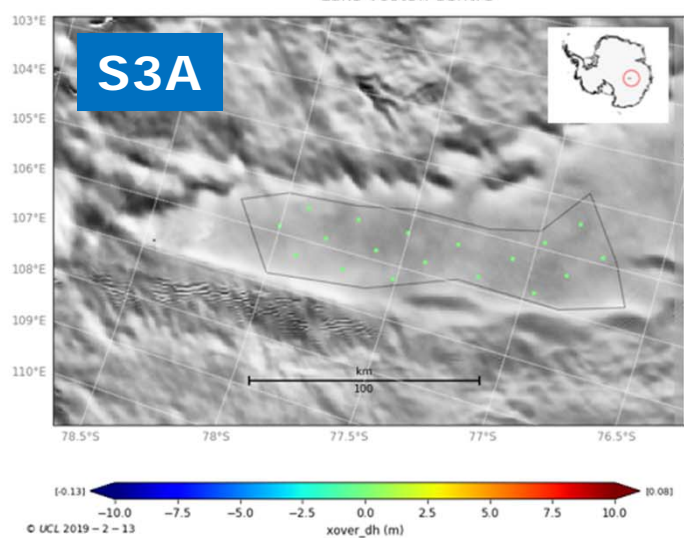
S3A Cycle 39

Elevation difference at Repeat Crossover Locations

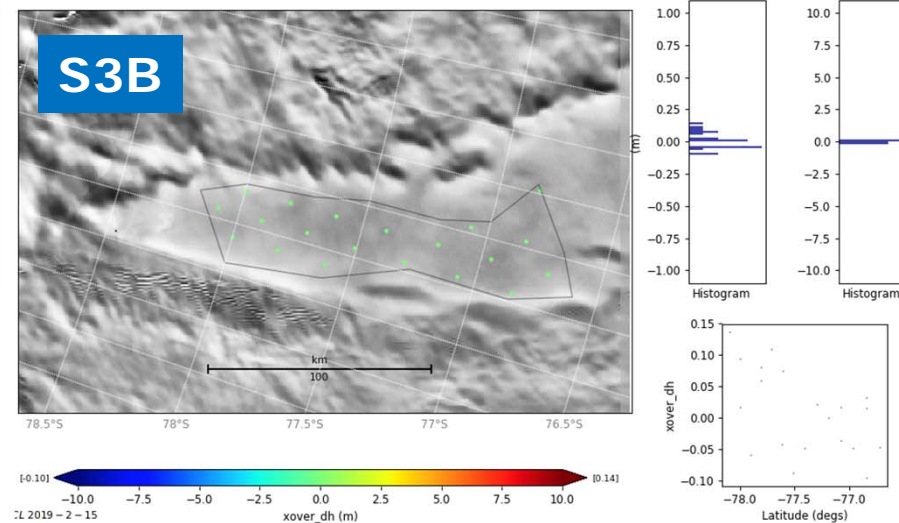
S3B Cycle 20

elevation\_ocog\_20\_ku

Lake Vostok Centre



Stdev = 0.08m



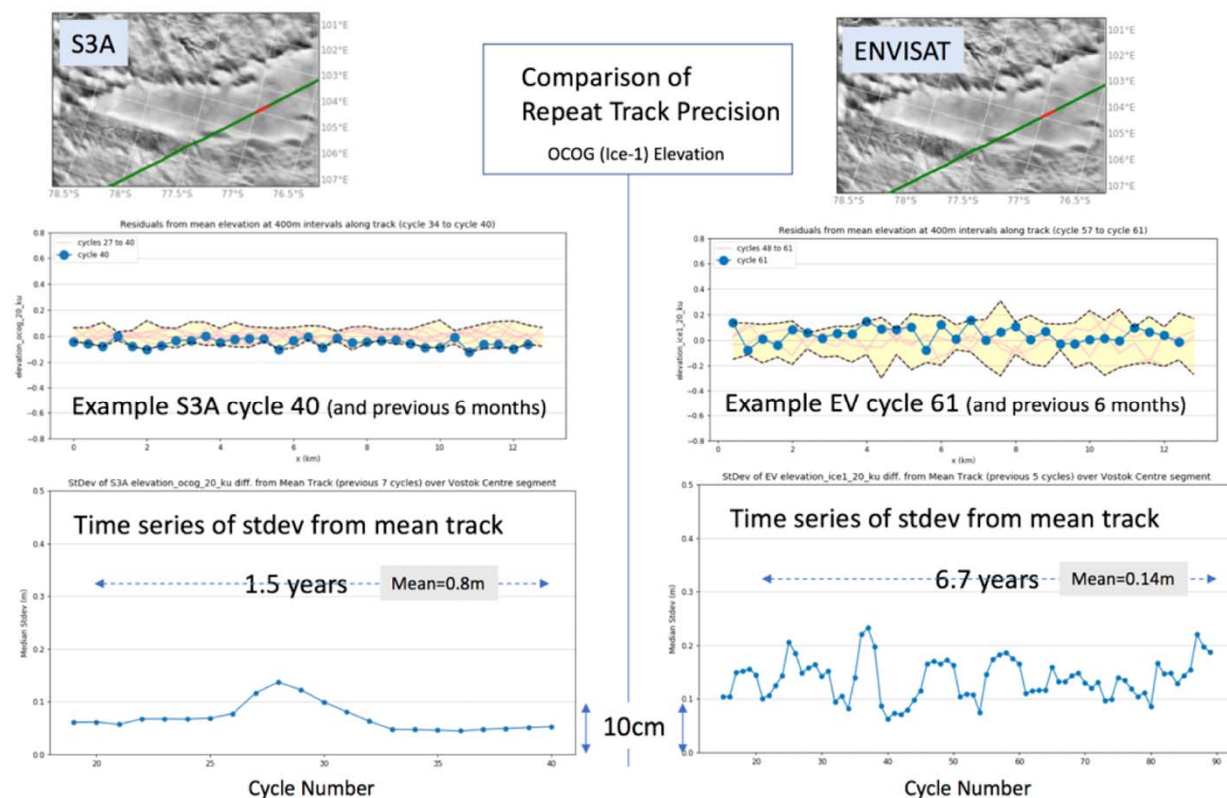
Stdev = 0.07m

Calculated over the center of Lake Vostok (E. Antarctica): low slope, flat surface

→ **Excellent precision** (measurement repeatability) of < 10cm for both S3A and S3B

# S3A & S3B STM LAND Ice Performance

## S3 Land Ice Precision Repeat Track Comparison with ENVISAT



Full mission repeat track study over a test site in Lake Vostok

S3 repeat track precision: 8cm

ENVISAT precision: 14cm

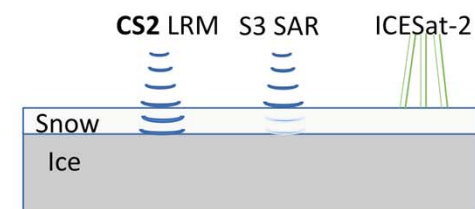
→ S3 has 1.75x better precision than ENVISAT over low slope ice sheet surfaces



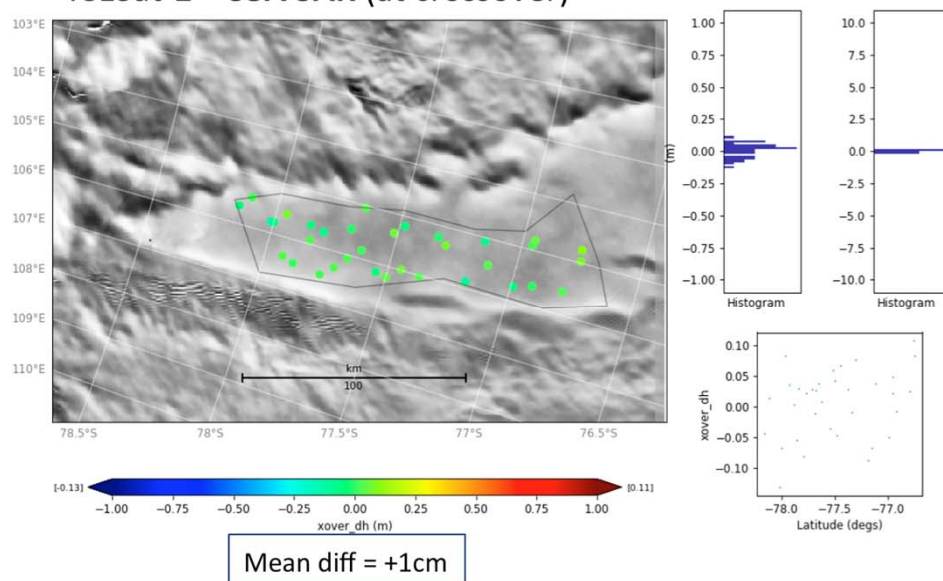
## S3A & S3B STM LAND Ice Performance

### Accuracy vs ICESat-2 & IceBridge

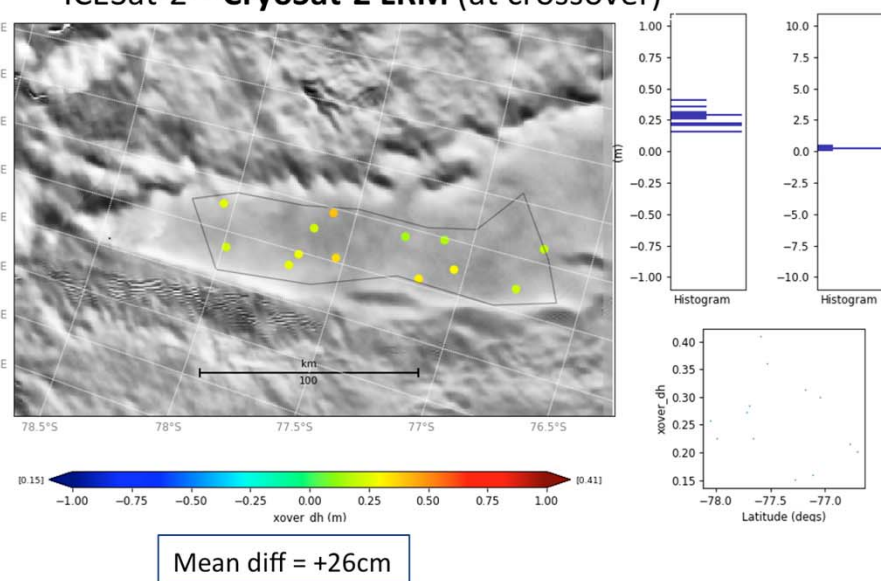
- UCL study of **S3A vs ICESat-2**: 1cm bias
- **S3A vs IceBridge** study in McMillan et al., 2019 : 1cm bias



ICESat-2 – S3A SAR (at crossover)



ICESat-2 – CryoSat-2 LRM (at crossover)

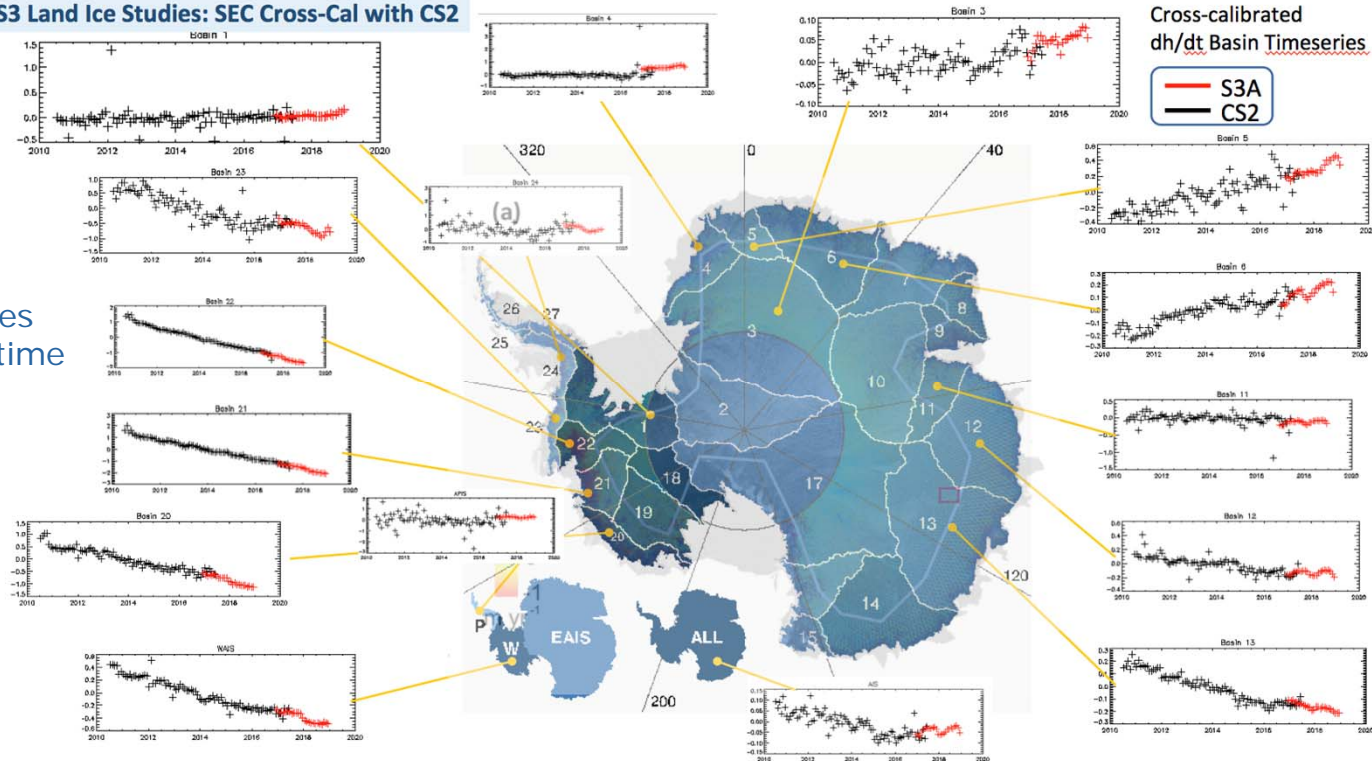


# S3A & S3B STM LAND Ice Performance

## Surface Elevation Change (SEC)

Cross-calibrated elevation time series of Antarctic drainage basins : An essential climate change indicator

### S3 Land Ice Studies: SEC Cross-Cal with CS2

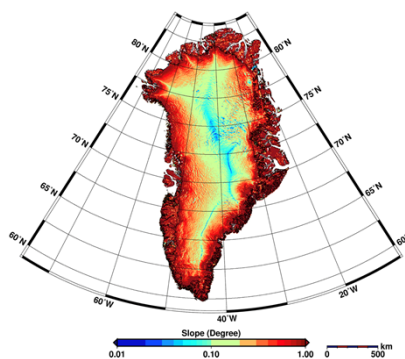
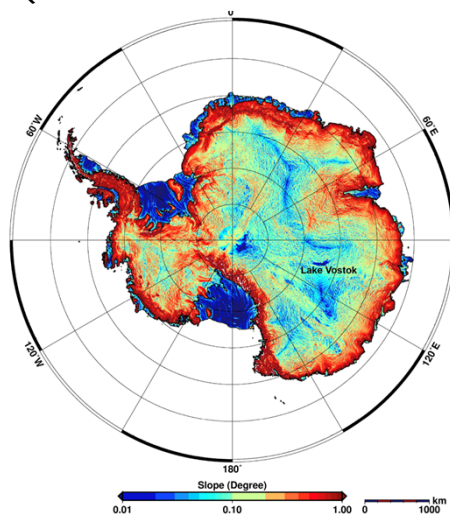


S3 successfully continues the CryoSat-2 mission time series!

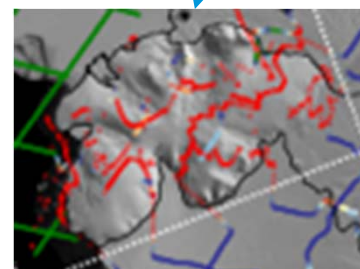
Except for high latitude due to S3 inclination limitation

## S3A & S3B STM LAND Ice Performance

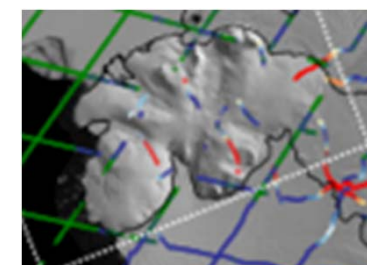
**New Slope Models for Antarctica and Greenland** for reducing slope dependent errors in elevation  
(→ Included in last S3 STM Processing Baseline)



New higher resolution slope model **improves coverage of complex terrain** and 8.24% elevation differences at crossover points < 0.5m



New slope correction



Current slope correction

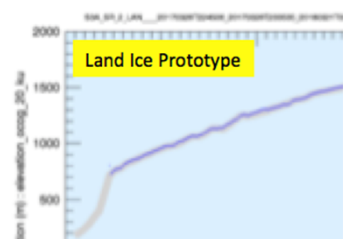
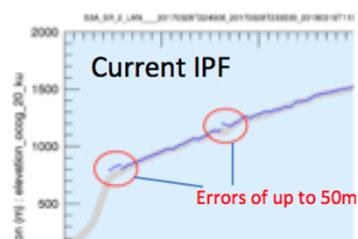
New slope models are derived from Cryosat-2 DEMs  
(*Helm, 2014*)

Current slope models from: RAMP v2 DEM (2001), Bamber DEM (2001)



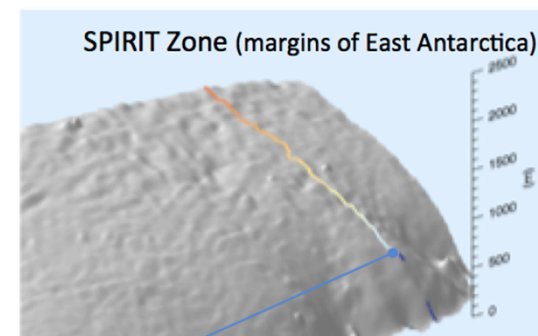
## S3A & S3B STM LAND Ice Performance

- Currently L1 processing is sub-optimal over the ice sheet margins
- Land Ice Prototype L1 processor (centered waveforms) **shows up to 16% better coverage** of ice sheet margin

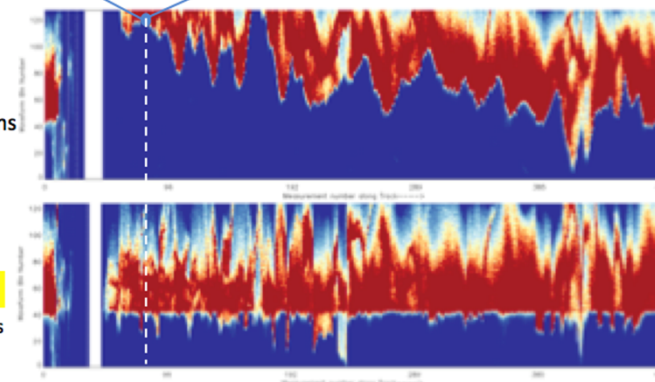


— OCOG Elevation  
 — CS2 DEM

In this area many measurements are lost or incorrect in current L1 processing but retrievable in new L1 prototype.



Current IPF  
 Truncated waveforms



## S3A & S3B STM LAND Ice Performance

Example of Improved Coverage of Critical Areas (with Land Ice L1 Prototype)

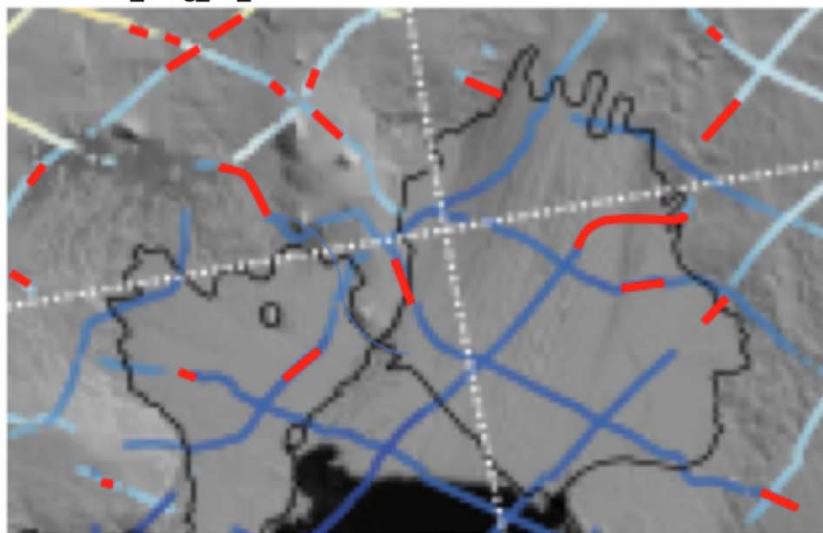
### Pine Island Glacier (a critical area for climate change study)



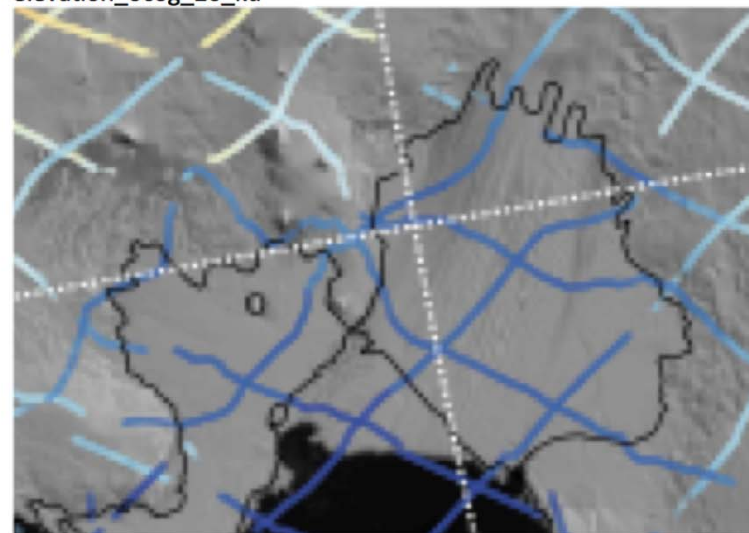
IPF 2.33

Land Ice Prototype

elevation\_ocog\_20\_ku



elevation\_ocog\_20\_ku



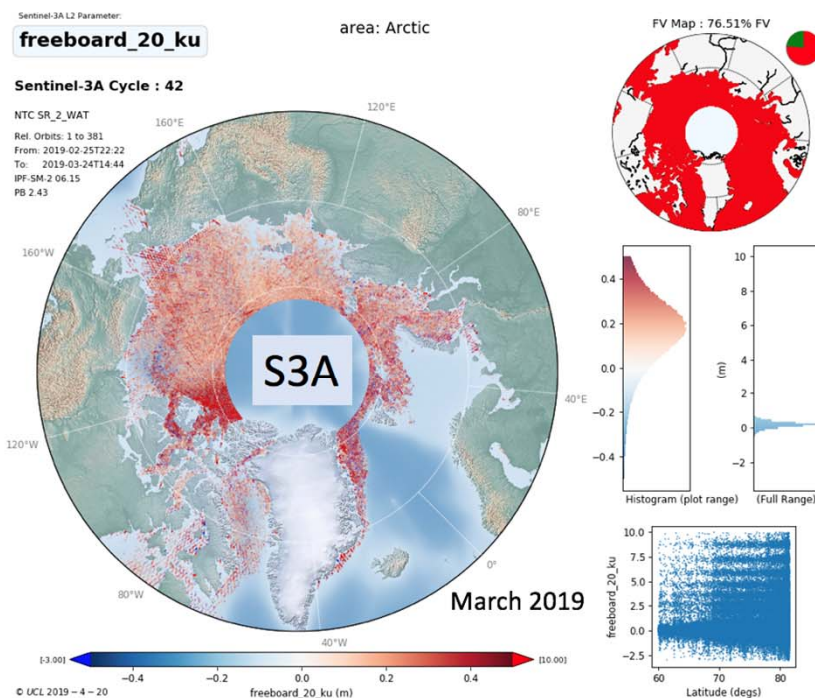
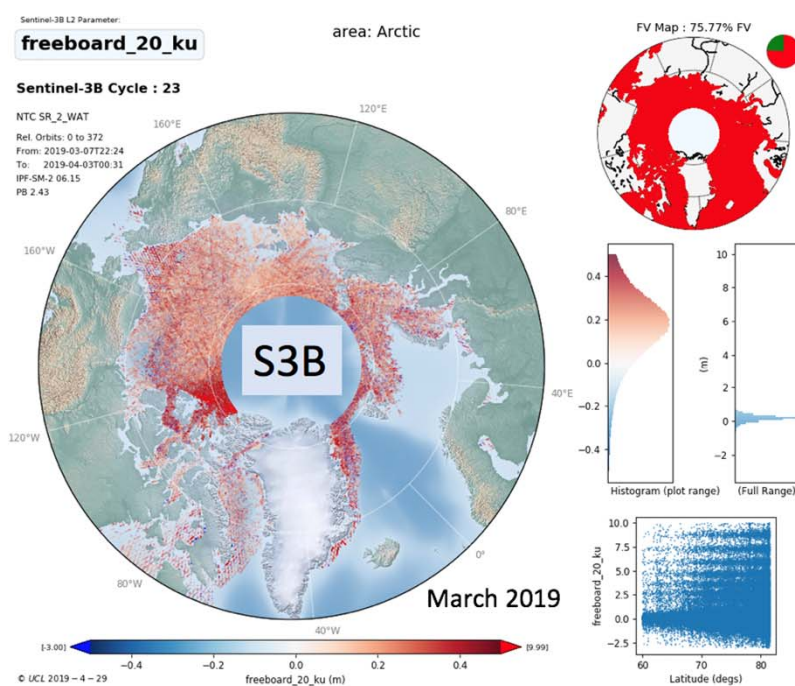
— Bad Quality Elevation Measurements  
(retracker failure, lower echo power)

## S3A & S3B STM LAND Ice Performance

- Before the implementation of the “dedicated L1B Ice surface processing” in the operation S3 STM Instrument Processing Facility (IPF), a reprocessing campaign will be triggered by Q4 2019
- Two years of data starting on 1<sup>st</sup> March 2016 will be reprocessed (running the IPF-like prototype)
- The data period will include the initial period of the S3A mission where OLTC DEM was activated (up to Dec 2016) to test whether the land ice prototype can recover more data over the ice margins in open-loop.
- The data set will be made available via an ftp server (i.e. will not be published on ESA Open Data Hub) to few ESA PI's for validation purpose
- The reprocessing shall be limited to the production of the L1B and L2 Land products

## S3A & S3B STM Sea-Ice Performance

- Since PB2.43 major evolutions (Feb 2019), Sea-Ice freeboard from S3A and S3B are generally consistent with expected results from other missions.
- Final Sea-Ice freeboard measurement quality in all areas will require dedicated L1 sea ice surface processing.
- No significant bias between S3A and S3B.

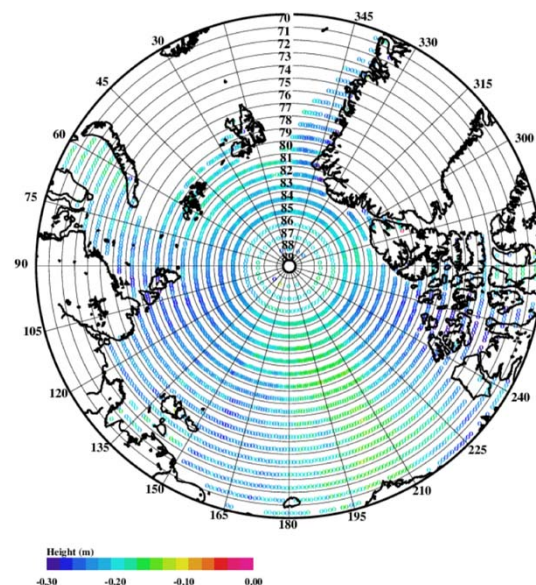
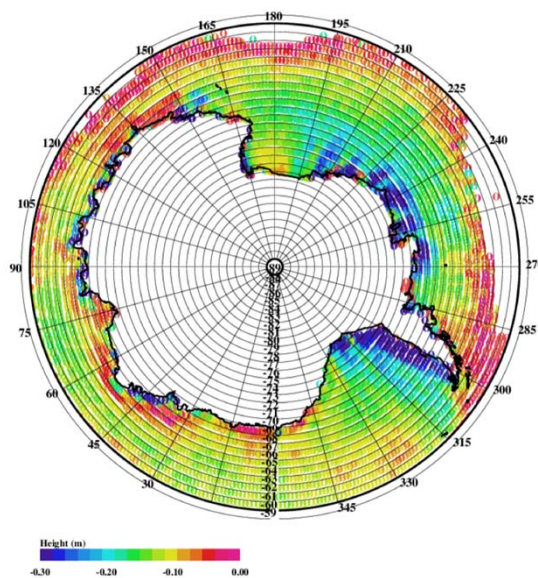


March 2019 Freeboard from S3-B (cycle 23) and S3-A (cycle 42) both show expected results and similar statistics



## S3A & S3B STM Sea-Ice Performance

- Mean Sea Surface (MSS) upgraded from DTU15 to **DTU18** which incorporates a new reprocessing of CryoSat Arctic and Antarctic data sets is expected to improve the accuracy of freeboard measurements.
- **DTU2018 MSS** part of the last S3 STM Processing Baseline (to be deployed) !
  - 8 year mean estimated from > 4 million 20 Hz observations
  - Retracker bias for Gauss Threshold retracker found and corrected.

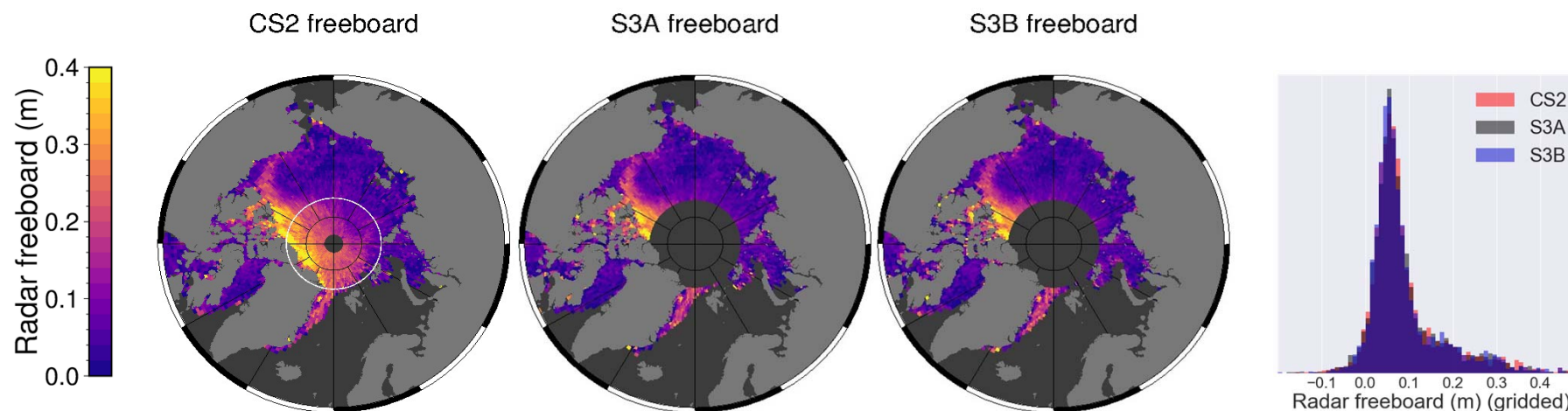




## S3A & S3B STM Sea-Ice Performance

- 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>"

## S3 STM LAND Processing Baseline (PB) evolution

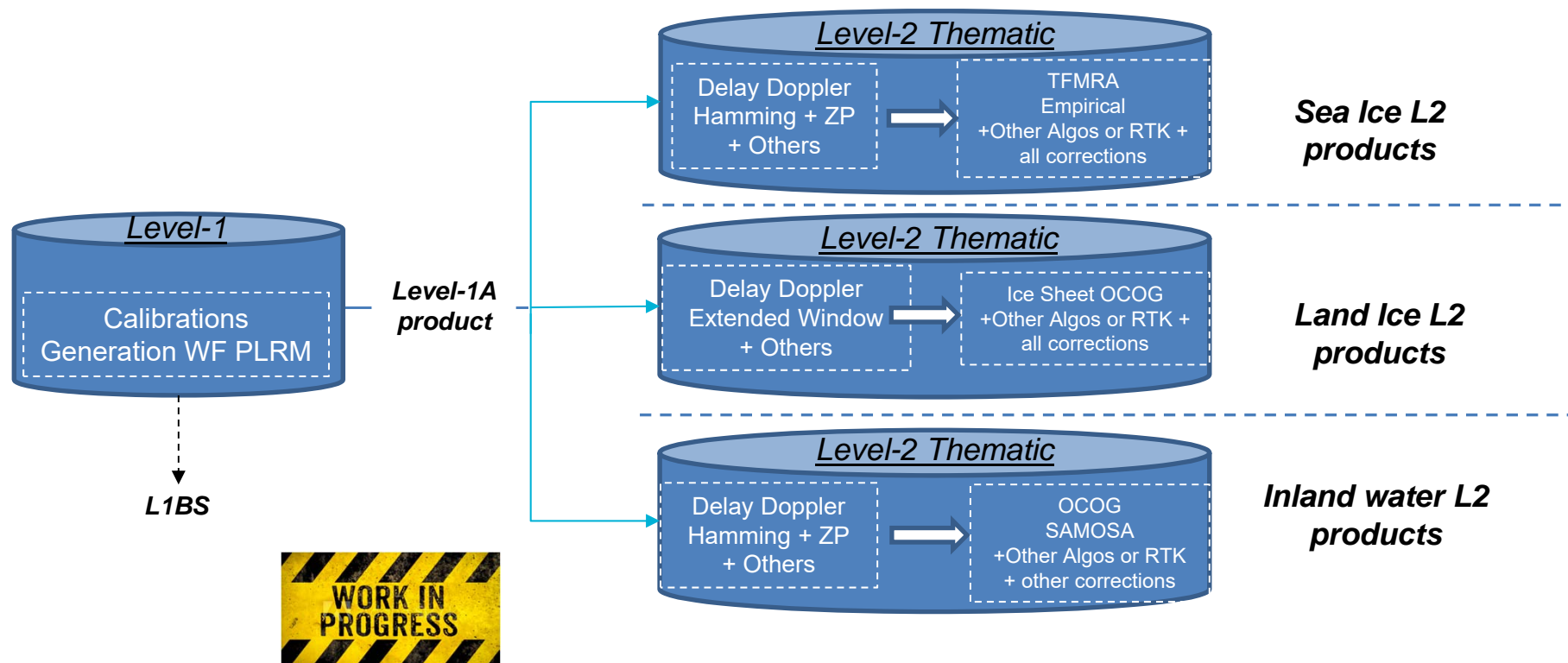
Several recommendations for S3 STM LAND PB evolution:

- **Land ice community** → Include window extension + waveform centring to recover more signal over slopping terrain (Processing "à la CryoSat")
- **Copernicus Land Service & Inland water community** → Improve data quality of rivers and small lakes via the inclusion of Hamming Window and Zero Padding Delay Doppler processing
- **Sea ice community** → Implement Hamming Window and Zero Padding (to cope with the under sampling of the specular echoes over leads and to reduce the echo contamination by off-nadir leads signal)  
→ Be consistent with Cryosat-2 ground processor over sea ice

Given the growing interest of Copernicus Services, Scientists and Altimetry Experts for Doppler Processing, we can expect promising new user requirements, new algorithms in a future (e.g. Fully-Focused SAR - FFSAR processing for inland water purposes).

→ NEW processing scheme will ease evolutions of the PB per surface type

## S3 STM IPF Improved LAND Branches



## S3 STM IPF Improved LAND Branches

### Intended Processing Scheme scenario:

- L0/L1 & L1/L2 data processing will be limited to the S3 STM LAND products coverage

→ Reduced data volume and (re-)processing time

- The new core products list will correspond to:

- L1A
- L1B-S (optional?)
- Each L2 "thematic" products will be a ".nc"
- Land Ice and Sea-Ice products will be processed E2E instead of P2P
- ...





## Conclusions

- The **S3A & S3B STM LAND products** are today fulfilling the **S3 mission requirements** over all surfaces (e.g. Inland Waters, Land ice & Sea-Ice)
- A continuous effort is done to improve the performance of the S3 STM data products and fitness-for-purpose of the S3 STM LAND mission data set
- **A NEW Processing Scheme and Product Format Specifications is being elaborated for the S3 STM LAND products** in order to accommodate the Copernicus Services and users specific recommended evolutions/improvements over ice margins, sea-ice freeboard and inland water surfaces as well as any new future requirements



**Thanks for your attention!**



OSTST – Chicago, US - 21-25 Oct 2019

