Ocean Surface Topography Science Team (OSTST) Meeting, Chicago, October 2019

# Sea Level Anomaly from a Multi-Altimeter Combination in the Ice-Covered Southern Ocean

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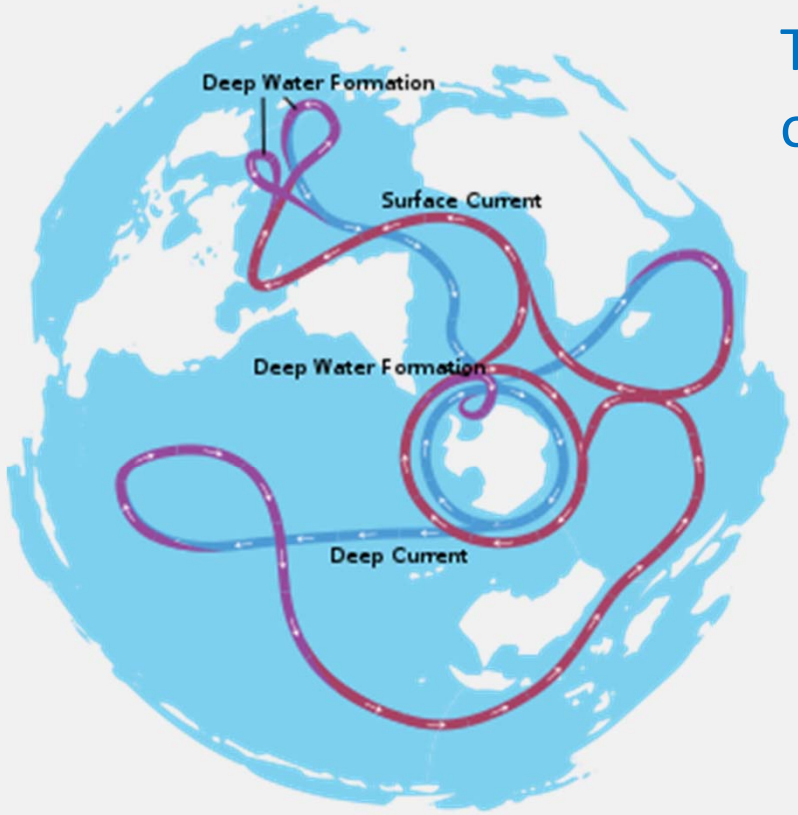
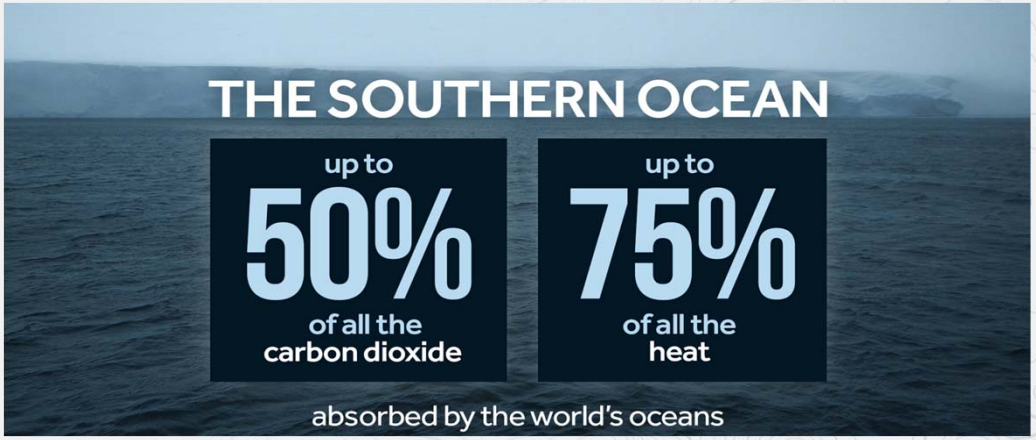
# INTRODUCTION

# Introduction

## The Southern Ocean: A Central point of the global Climate.

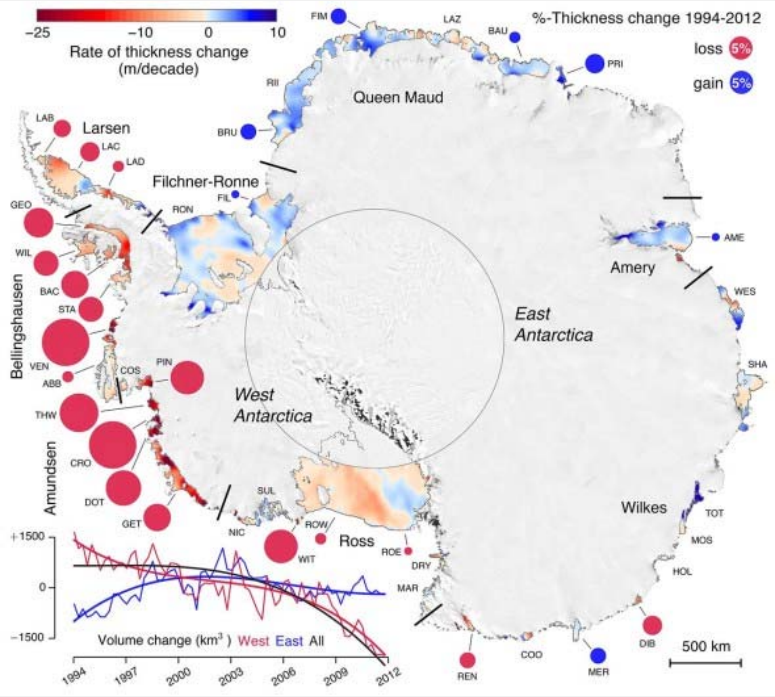


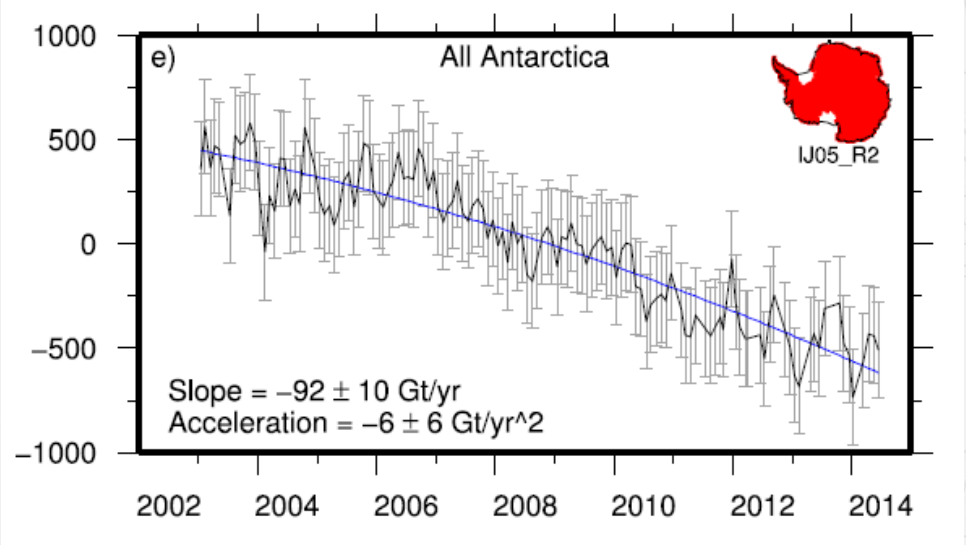

- Linking 3 main oceanic basins
- Meridional Overturning Circulation



# Introduction

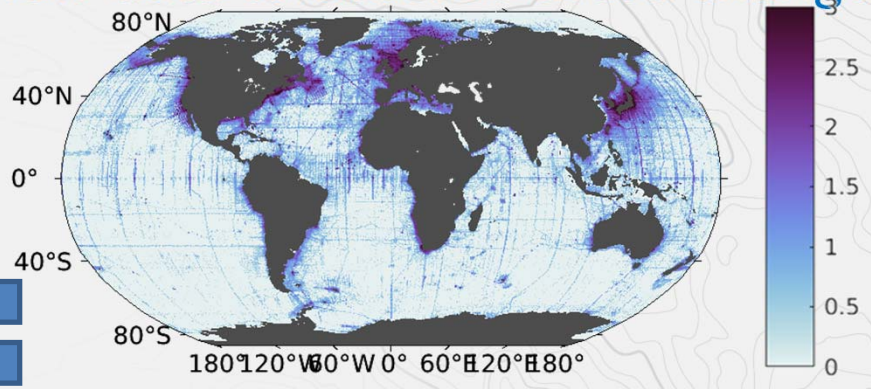
## Great changes over the past few years



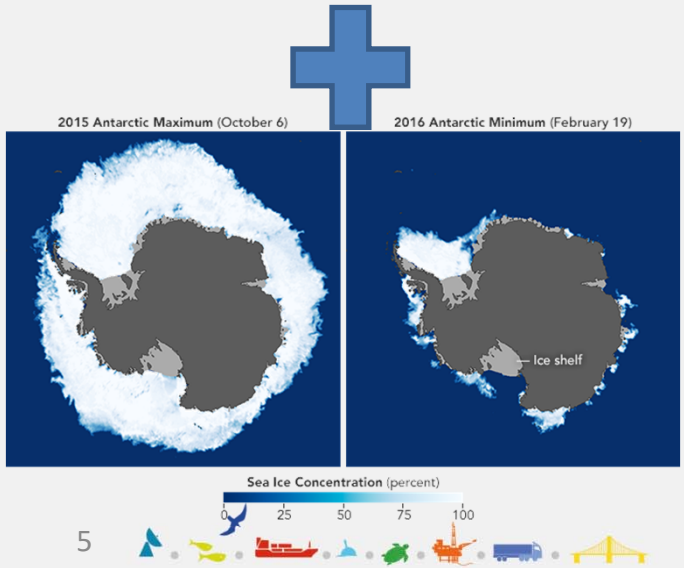



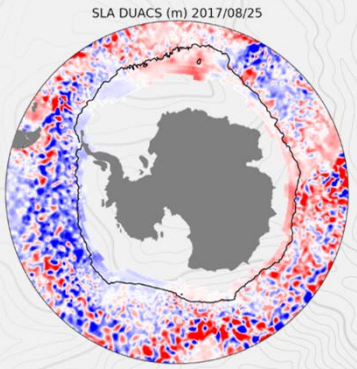
# Introduction

## Very few data to observe these changes




LOG10 number of ship data in the global ocean



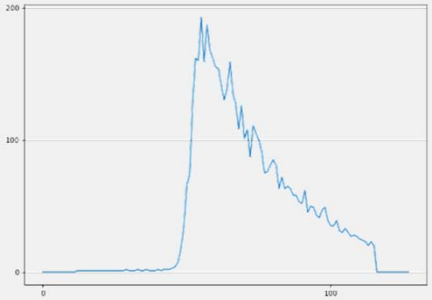



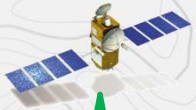

DUACS SLA map (from satellite altimetry)

# MAJOR CHALLENGES

# Altimetry for sea level retrieval in sea ice zones (1)

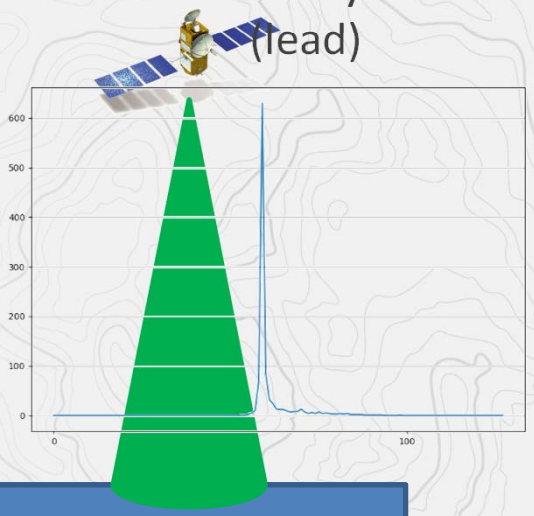
- Brownian Echo (Open Ocean)



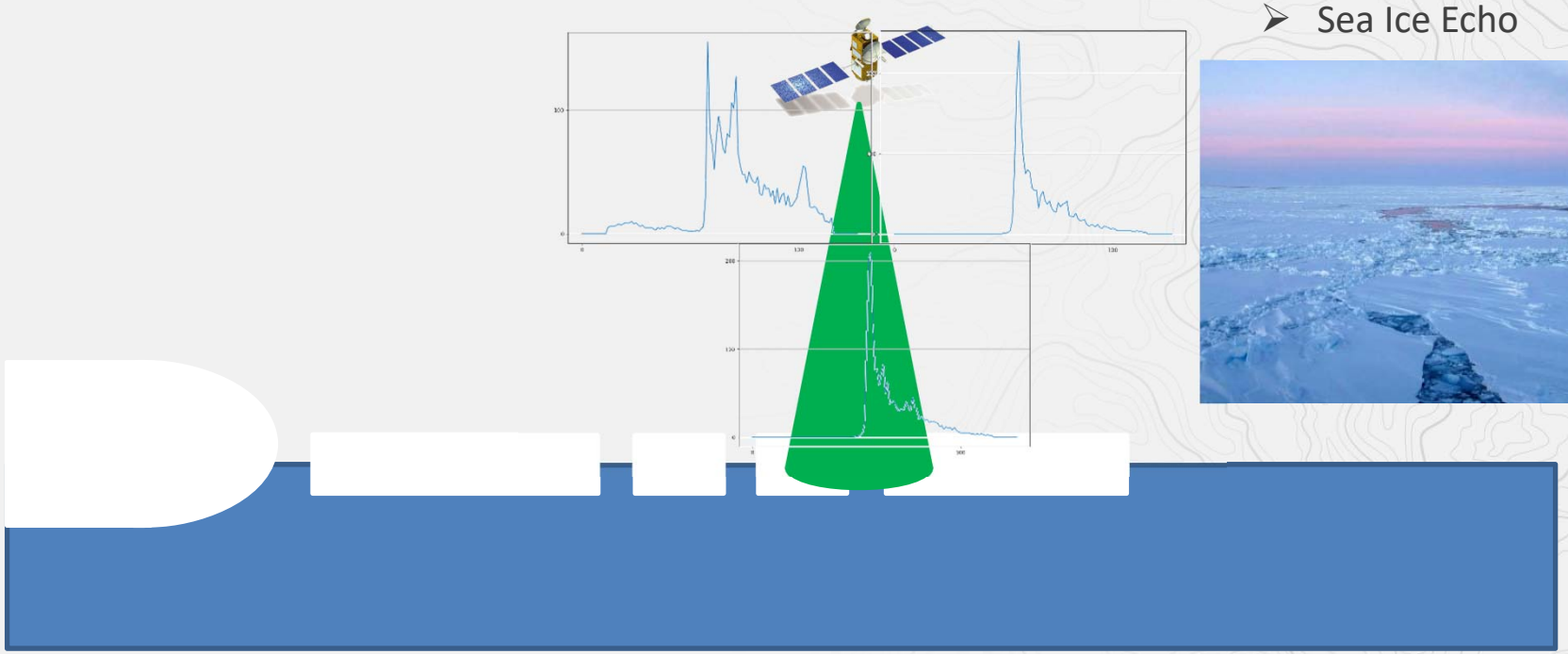


# Altimetry for sea level retrieval in sea ice zones (1)

- Peaky echo (lead)




# Altimetry for sea level retrieval in sea ice zones (1)



- Sea Ice Echo

# Merging multiple altimeter missions







Low Resolution Mode (LRM)

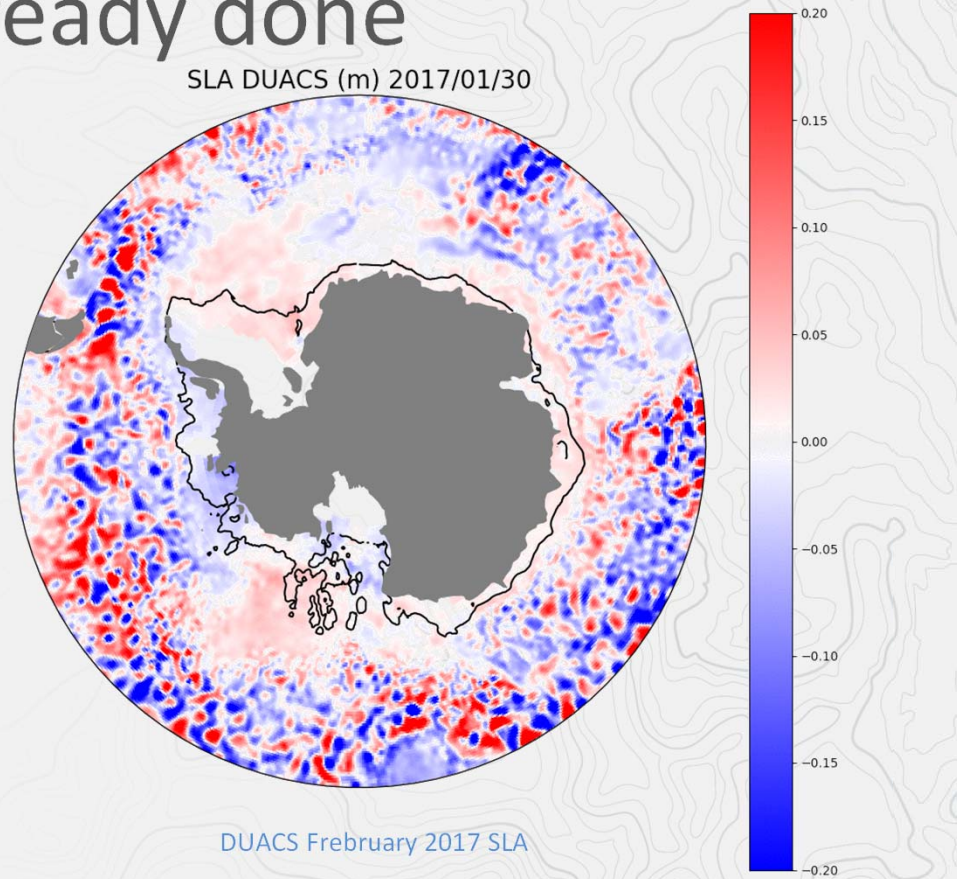
Synthetic Aperture Radar (SAR)

# NEW PRODUCT CHARACTERISTICS

# What is already done

## DUACS SLA product:

- Multi-mission global SLA product
- 1Hz along track resolution
- No data in sea ice zones




DUACS Frebruary 2017 SLA

3% Sea Ice Concentration

# What is already done

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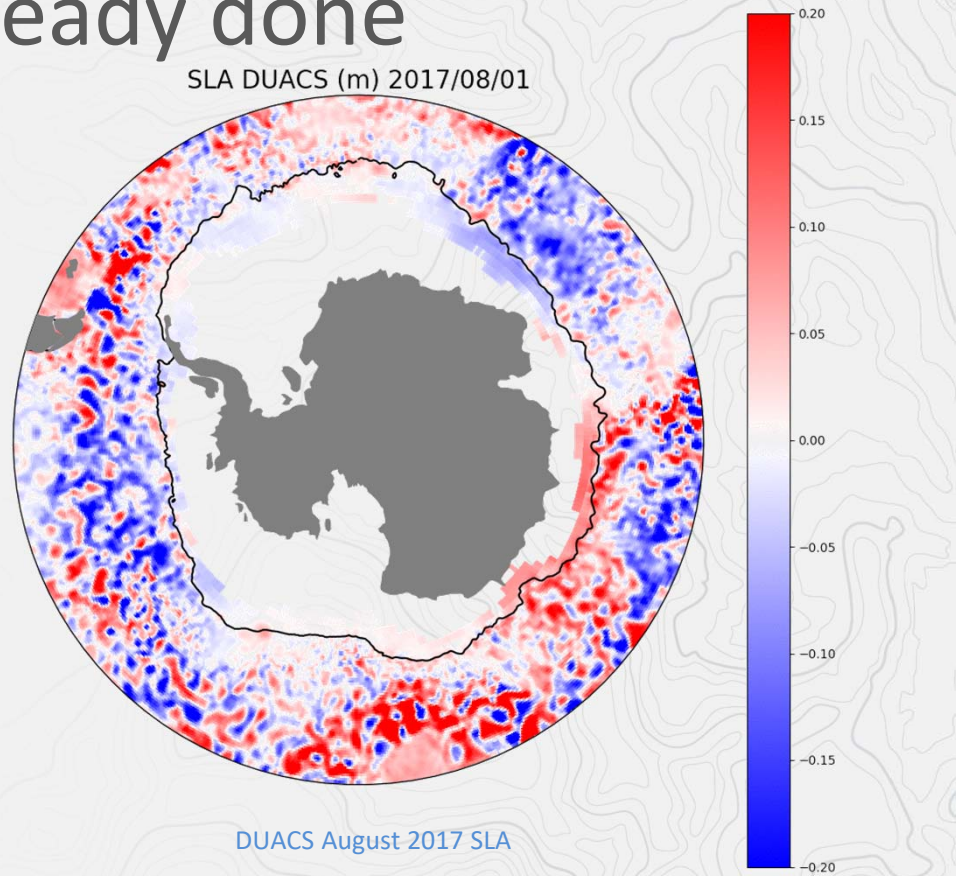


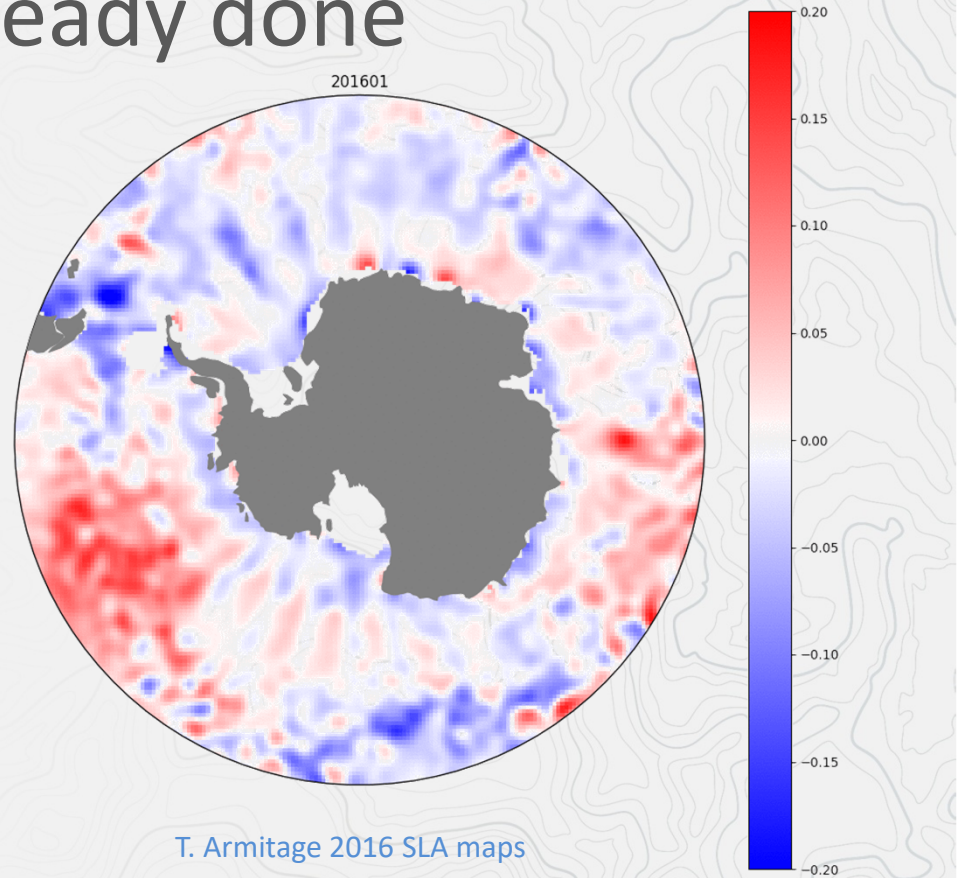

DUACS August 2017 SLA

3% Sea Ice Concentration

# What is already done

## T. Armitage (2018) SLA:

- Cryosat-2 monthly SLA map spanning 2012-2016 from 20Hz along track data
- 50km grid
- Data in sea ice zones for the first time
- Sometimes unphysical patterns created by Cryosat-2 Orbit

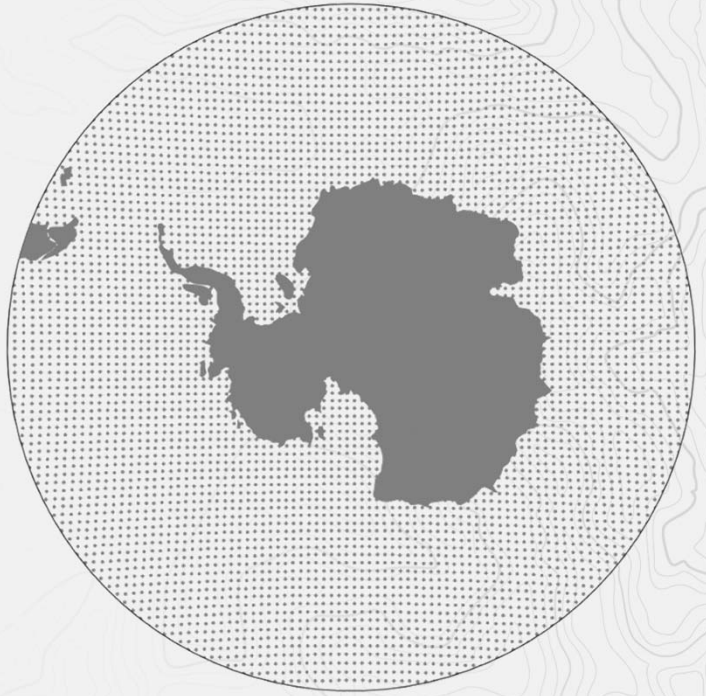



T. Armitage 2016 SLA maps

# What we want to make

## Southern Ocean SLA Product

- Sea level anomaly daily product on an 25km grid, for the 2002-2018 time period.
- Using of high resolution altimeter data (20/40 Hz), filtered and sampled to 1Hz in open ocean
- Continuity between ocean and leads.
- Multi-mission



EASE2 Grid 100 km resolution

# Why we think it will work

- Multi-mission processing shows great improvements in resolution compared to single-mission products.
  - *Up to 5 satellites currently sampling the Southern Ocean !*
- Adaptive retracking for LRM missions allows continuity between sea ice zones and open ocean.

| SAR Altimeter | LRM Altimeter |
|---|---|

| | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sentinel-3A | | | | | | | | | | | | | | | | | |
| Jason-3 | | | | | | | | | | | | | | | | In progress | |
| AltiKa | | | | | | | | | | | | | | | | | |
| Cryosat-2 (Ocean) | | | | | | | | | | | | | | In progress | | | |
| Cryosat-2 (Sea Ice) | | | | | | | | | | | | | | | | | |
| Jason-2 | | | | | | | | | | In progress | | | | | | | |
| Envisat | | | | | | | | | | | | | | | | | |

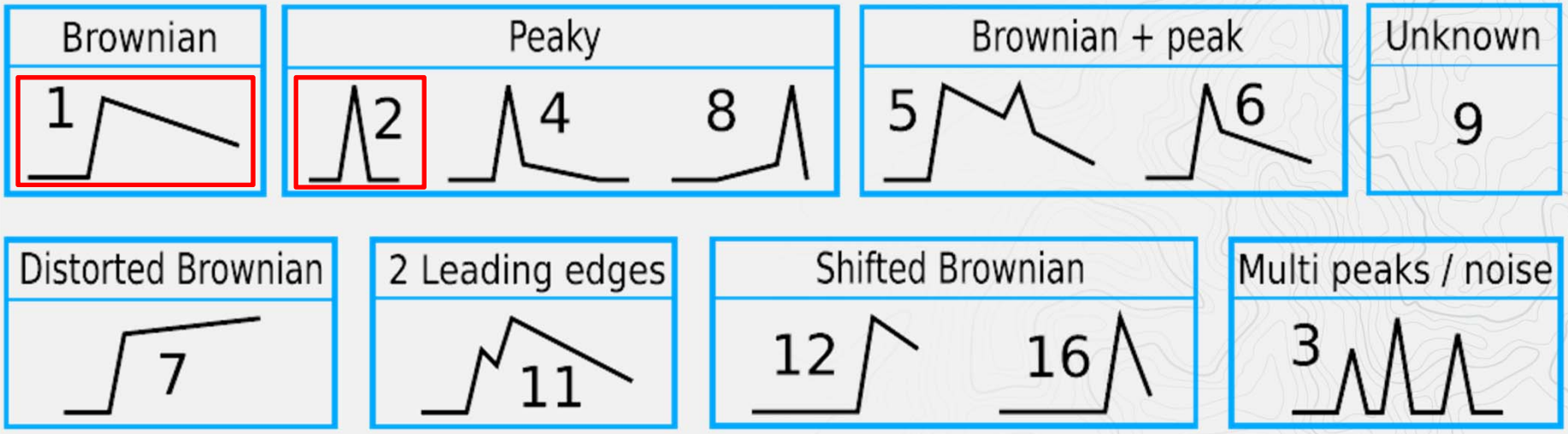
# DATA PROCESSING

# Data Sources

- Envisat: RA2MWR Reprocessing v3 products
- AltiKa: S-GDR Official Product
- Cryosat-2 (SAR): PDGS ICE Baseline C
- Sentinel-3A: CNES S3PP (Processing Prototype)

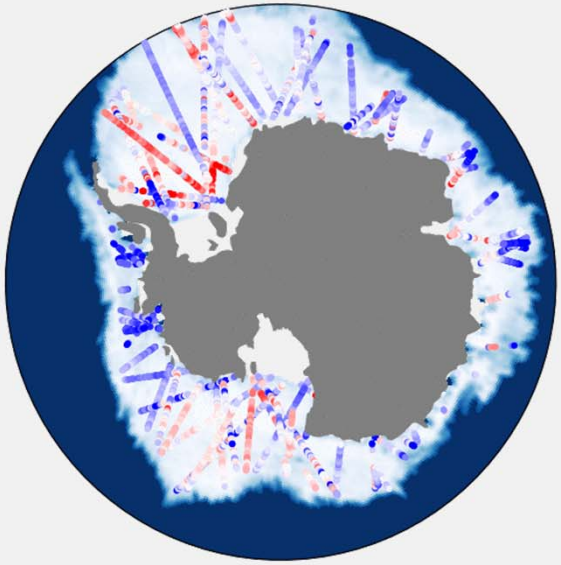
# Classification

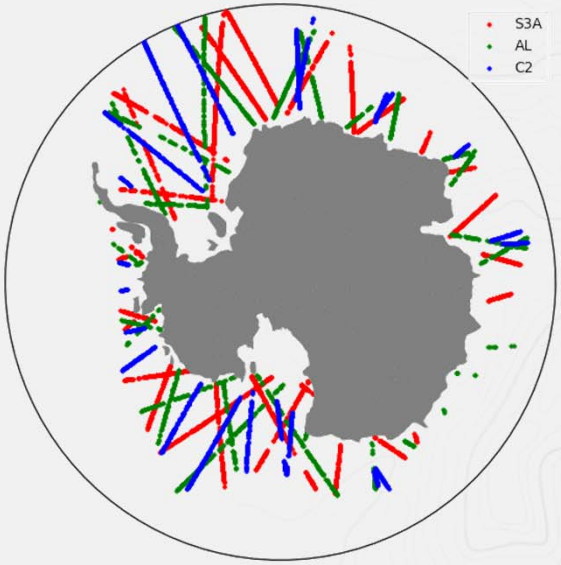
## Neural network classification



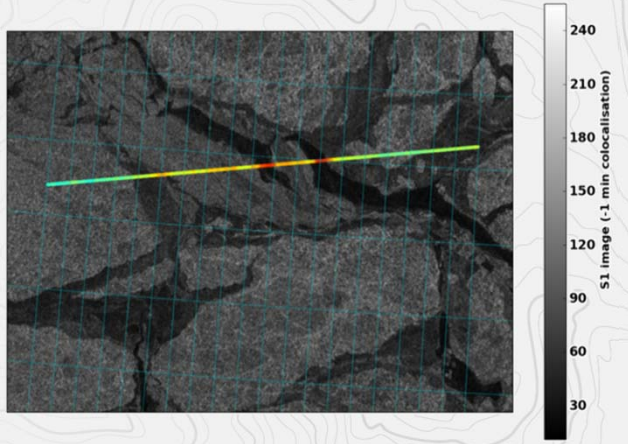

Waveform classes, from Poisson et al. (2018)

# Classification – Leads identification






Data points identified as leads by the waveform classification algorithm.




Backscatter from Sentinel-3A echoes overlaid by Sentinel-1 backscatter image (Aviso Image of the month, April 2018, powered by CLS)

# Retracking


## LRM Altimeters (AL,EN,J2,J3)

- Adaptive retracking modelling all kind of waveforms (see Poisson et al., 2018)

## SAR Altimeters (C2,S3A)

- S3PP retracking for S3A for Brownian echoes (estimation of range, significant wave height, power and slope of the trailing edge).
- TFMRA retracking for peaky echoes

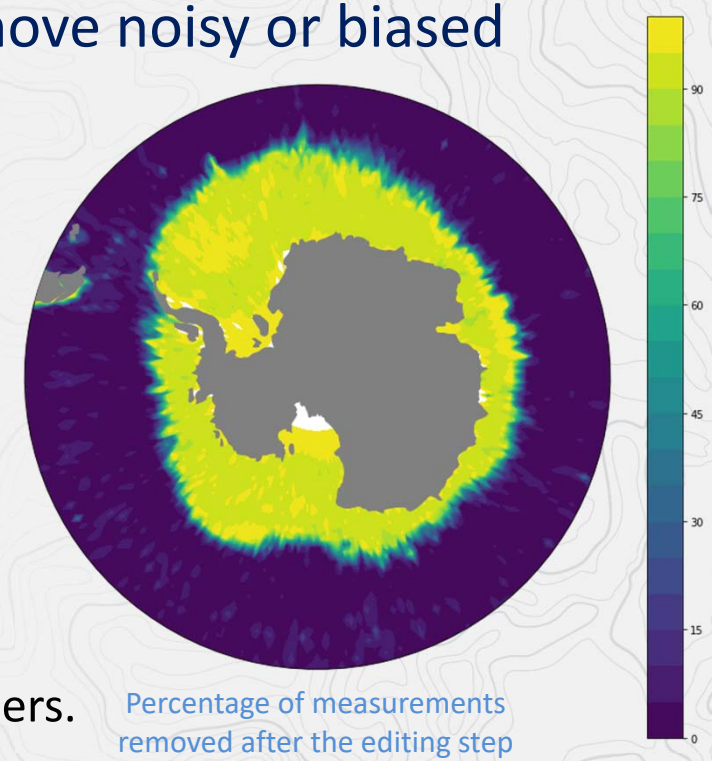
# Editing

## Multiple empirical criteria are used to remove noisy or biased data.

Such criteria include thresholds on:

- Mean Quadratic Error of the retracker
- Pulse Peakiness
- Sigma0
- Sea Ice Concentration (from OSISAF data)

An iterative editing then removes the remaining outliers.




Percentage of measurements removed after the editing step (AltiKa, July 2017)

# Geophysical corrections

## Up to date geophysical corrections are used:

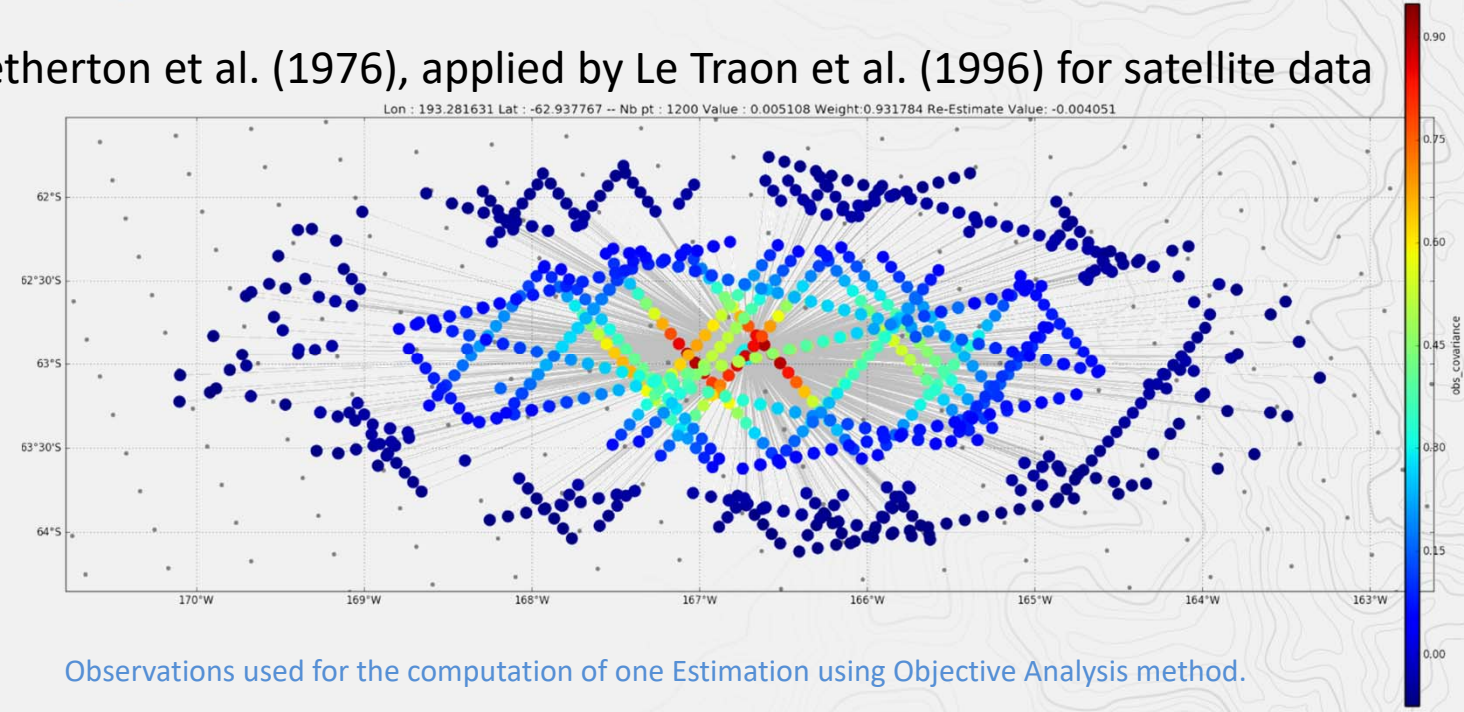
- Same geophysical corrections as DUACS
- Except Wet Tropospheric correction, ECMWF data used (data from the onboard radiometer unstable in sea ice zones)
- No waves in the leads -> no Sea State Bias corrections
- MSS CNESCLS15

# OBJECTIVE ANALYSIS

# Objective Analysis

## ➢ Principle

Based on Bretherton et al. (1976), applied by Le Traon et al. (1996) for satellite data




Observations used for the computation of one Estimation using Objective Analysis method.

# Objective Analysis

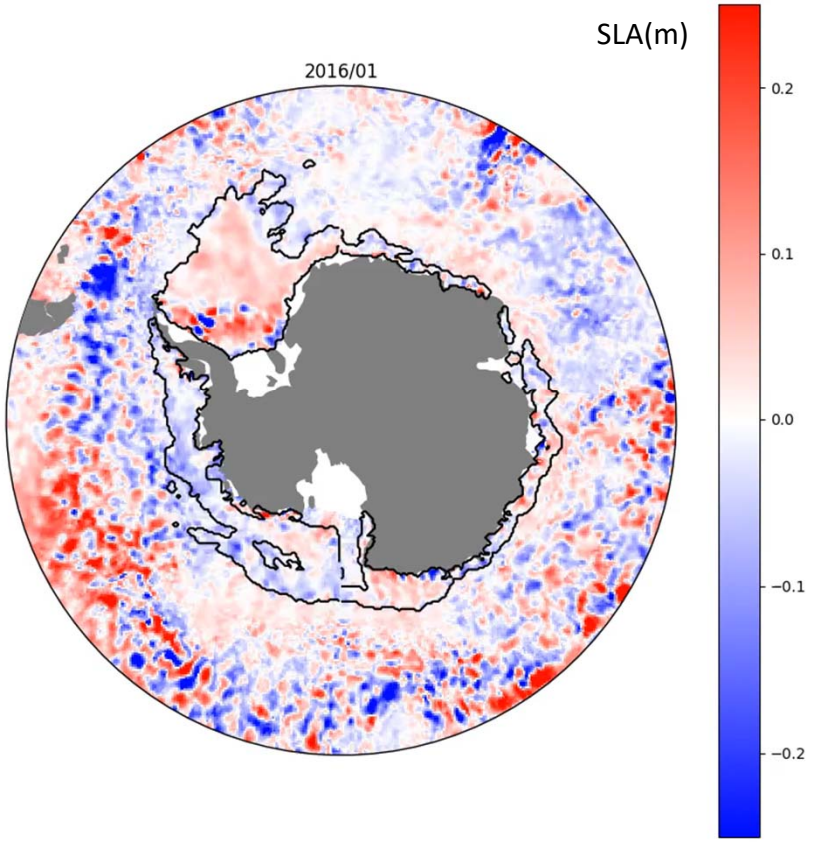
## ➢ Parameters

**DUACS DT2018 parameters are used and updated for the region using external data**

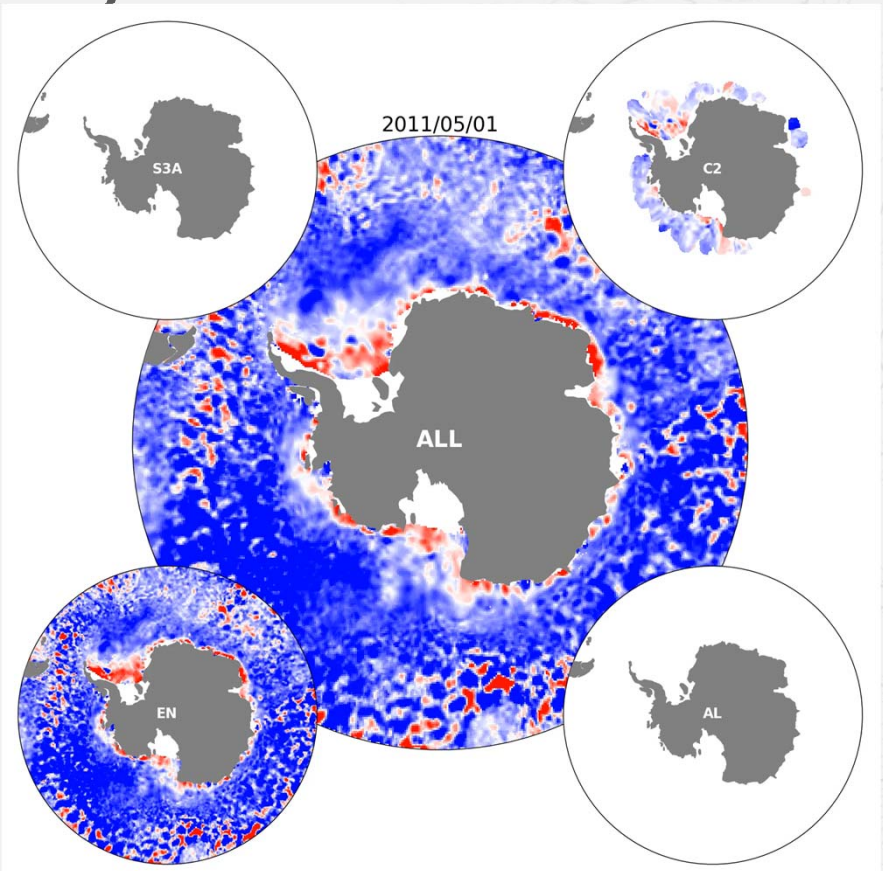
- Variance: DUACS Variance merged with *T. Armitage (2018)* SLA Variance
- Noise: MSS error + an instrumental error from DUACS + factor dependent of the measurement frequency.
- Correlation scales: recomputed based on GLORYS12 SLA fields (following *Brachet et al.(2004)* technique).
- Longwave errors: Estimated tidal errors.

# PRELIMINARY RESULTS

# Preliminary Results – Multimission SLA

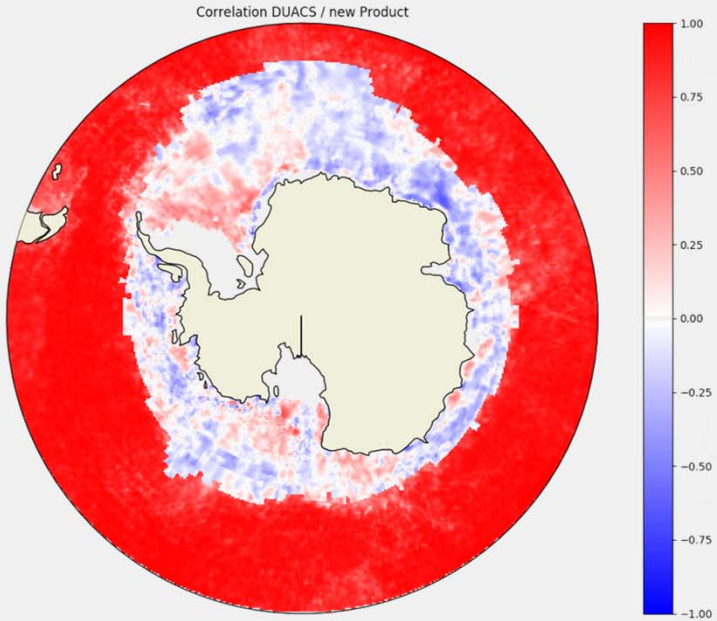


# Preliminary Results – Multimission SLA

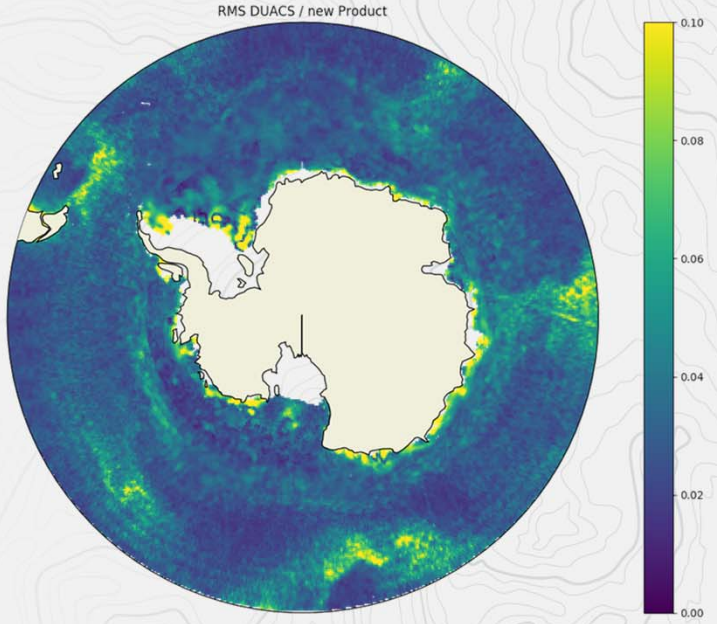


# VALIDATION

# Validation In Open Ocean



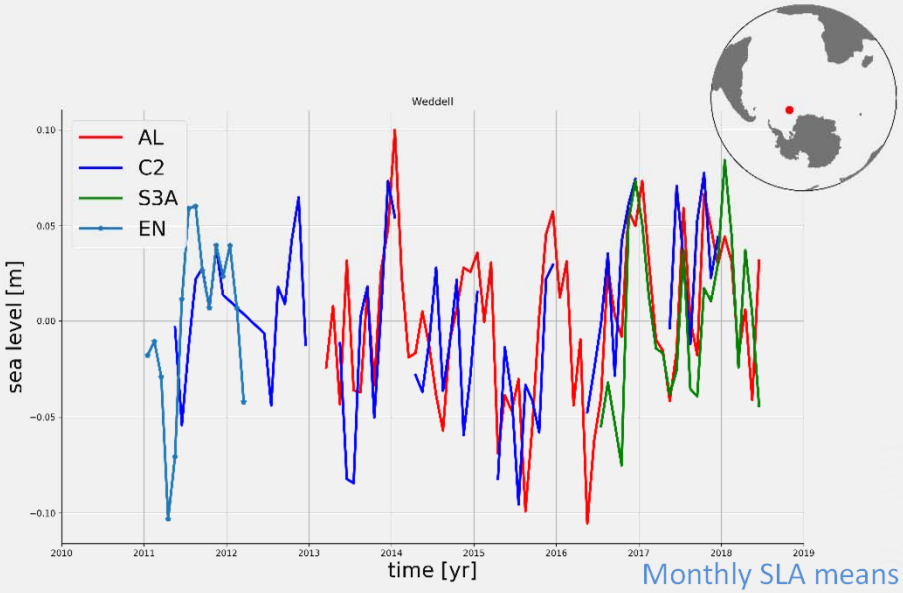

Correlation at each grid point between DUACS and Antarctic SLA Product

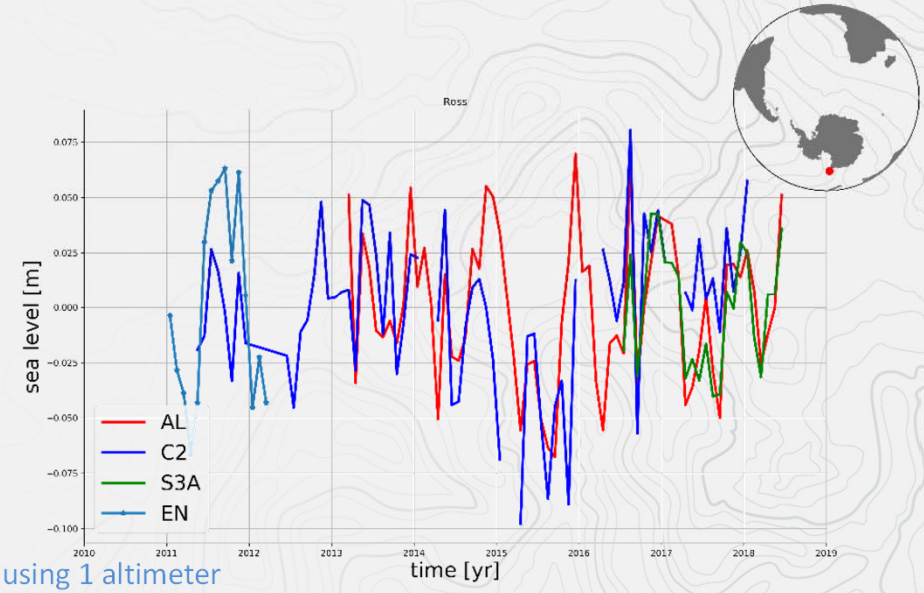



RMS at each grid point between DUACS and Antarctic SLA Product

Southern Ocean Product and DUACS → very similar in the open Ocean

# Validation – SLA in Sea Ice Zones seen by various altimeters

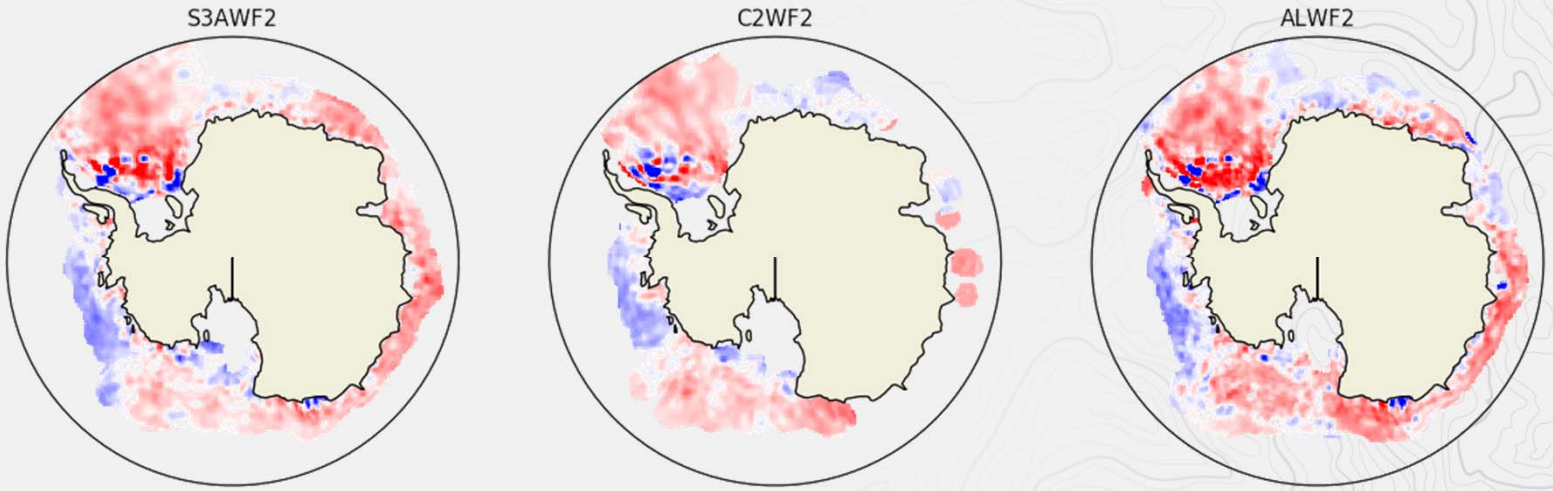


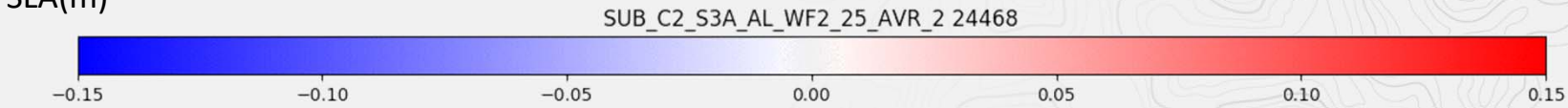

Monthly SLA means using 1 altimeter

Independent satellites see the same signal

# Validation – SLA in Sea Ice Zones seen by various altimeters



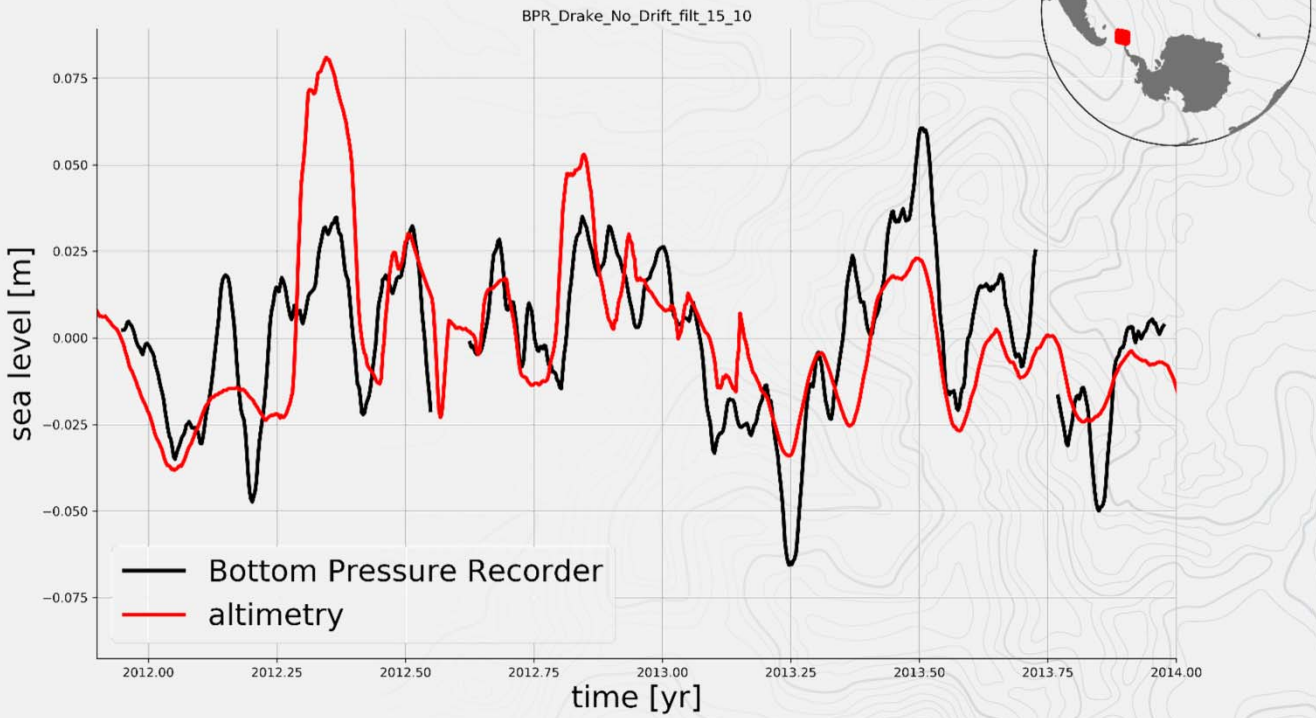

Outputs of Objective Analysis using only leads data of 1 mission.




Independent satellites see the same signal

# Validation Results – Comparison to Bottom Pressure Recorder

SLA consistent with external data




Bottom Pressure Recorder data / SLA grids averaged over 10 grid points in the Drake Passage

# CONCLUSIONS AND FUTURE WORK

# Conclusions and Future Work

- Open ocean SLA has been successfully recomputed with new parameters and from high resolution data.
- Continuity between open ocean and leads successfully achieved.
- High resolution multi-mission data allow us to see some new features.

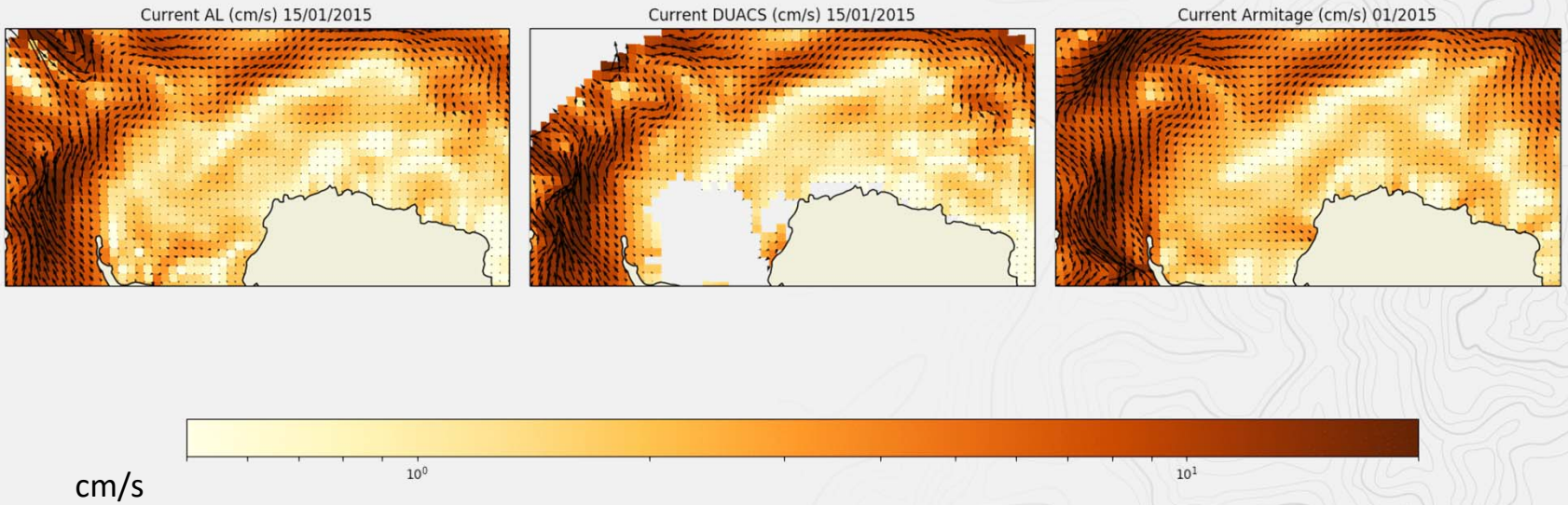
Future Work

- Tuning of Optimal interpolation parameters
- Comparison with Tide Gauges

- Seasonnal cycle of Southern Ocean Circulation
- Gyres behaviour

# Conclusions and Future Work

Contact:
mauger@groupcls.com




Source: NASA Earth Observatory maps by Joshua Stevens

## Diapositive 37

**AM(3** Auger Matthis (CNES); 21/10/2019

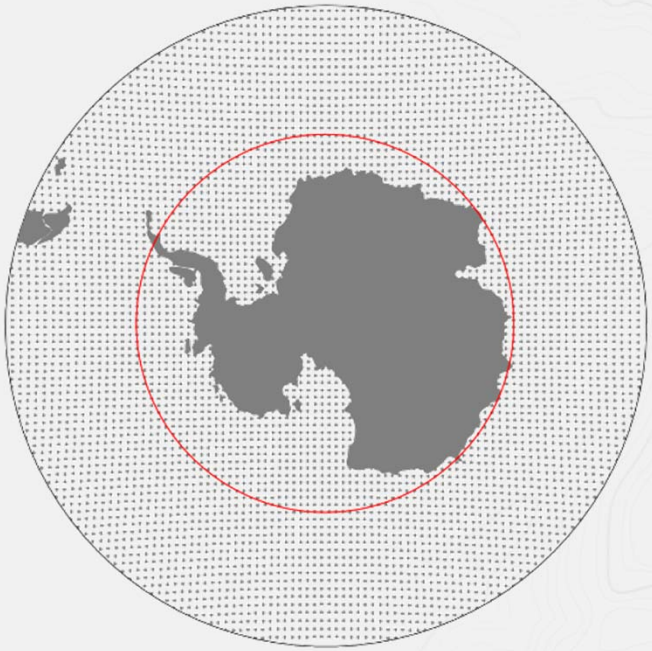
# Bibliography

Brachet, S., Le Traon, P. Y., Le Provost, C. (2004), Mesoscale variability from a high-resolution model and from altimeter data in the North Atlantic Ocean, J. Geophys. Res. 109, C12025.

Taburet, G., Sanchez-Roman, A., Ballarotta, M., Pujol, M.-I., Legeais, J.-F., Fournier, F., Faugere, Y., and Dibarboure, G.: DUACS DT-2018: 25 years of reprocessed sea level altimeter products, Ocean Sci. Discuss., https://doi.org/10.5194/os-2018-150, in review, 2019.

Armitage, T. W. K., Kwok, R., Thompson, A. F., & Cunningham, G. (2018). *Dynamic Topography and Sea Level Anomalies of the Southern Ocean: Variability and Teleconnections. Journal of Geophysical Research: Oceans, 123(1), 613–630.* doi:10.1002/2017jc013534

Longépé, N.; Thibaut, P.; Vadaine, R.; Poisson, J.; Guillot, A.; Boy, F.; Picot, N.; Borde, F. Comparative evaluation of sea ice lead detection based on SAR imagery and altimeter data.
IEEE Trans. Geosci. Remote Sens, 2019.

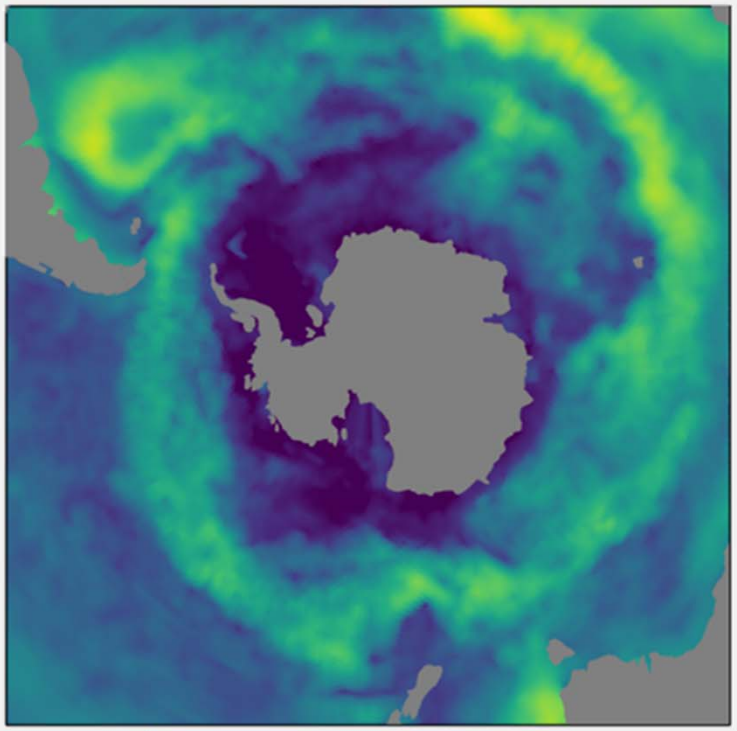


South Limit of Jason Orbit

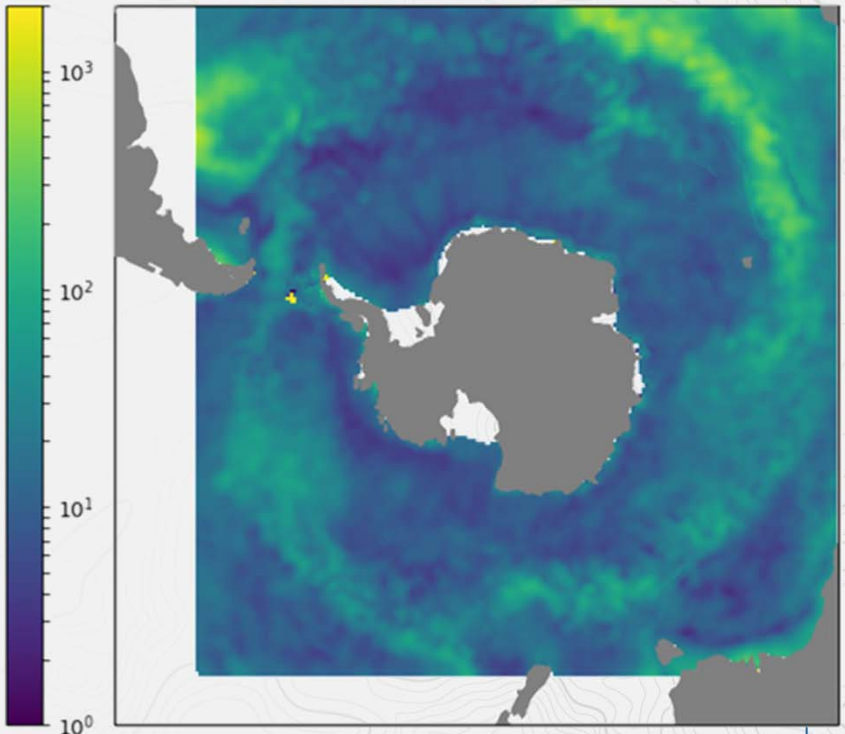
AM(1
AM(2

# Objective Analysis - Variance

DUACS Variance



Armitage Variance






*Matthis Auger*

*Ocean Surface Topography Science Team 2019*

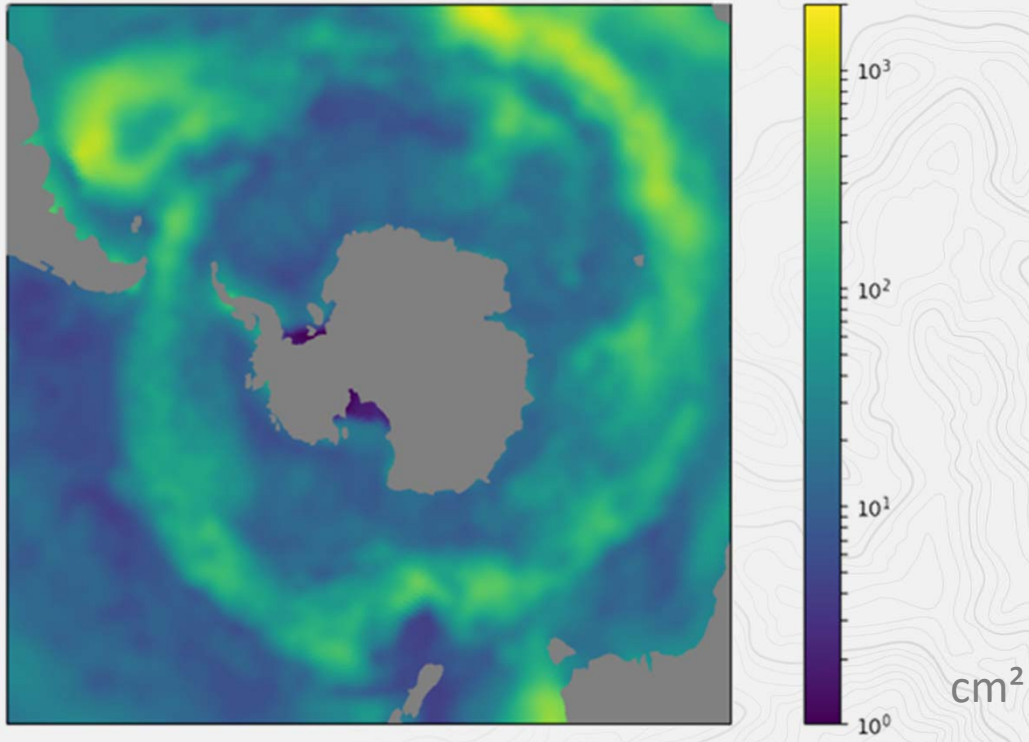
## Diapositive 40

**AM(1** Auger Matthis (CNES); 29/09/2019

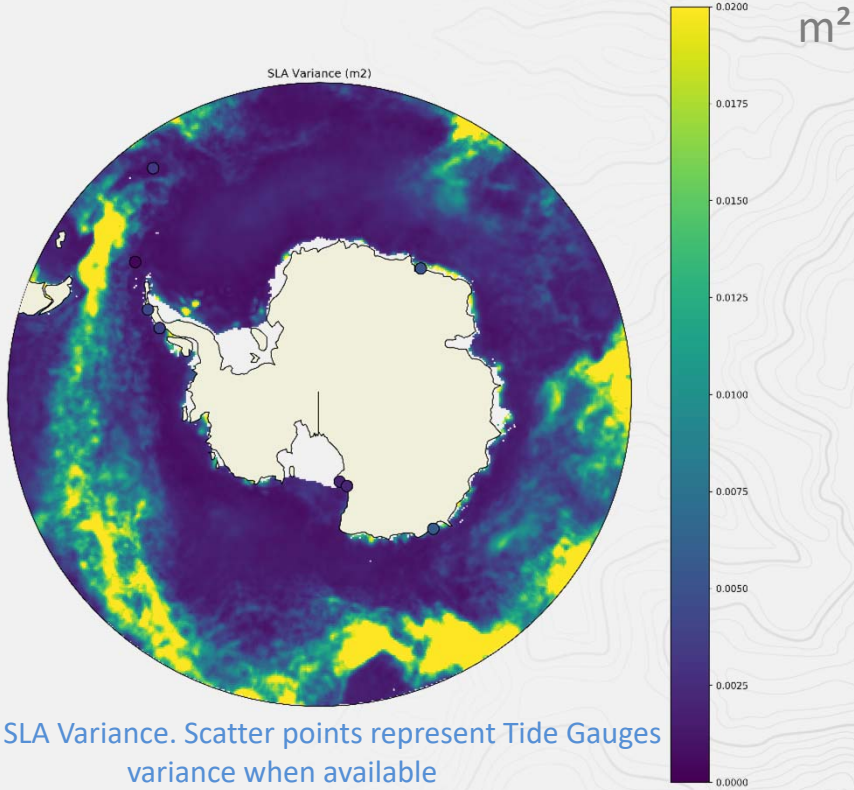
**AM(2** Auger Matthis (CNES); 29/09/2019

# Objective Analysis - Variance

Southern Ocean Product Variance

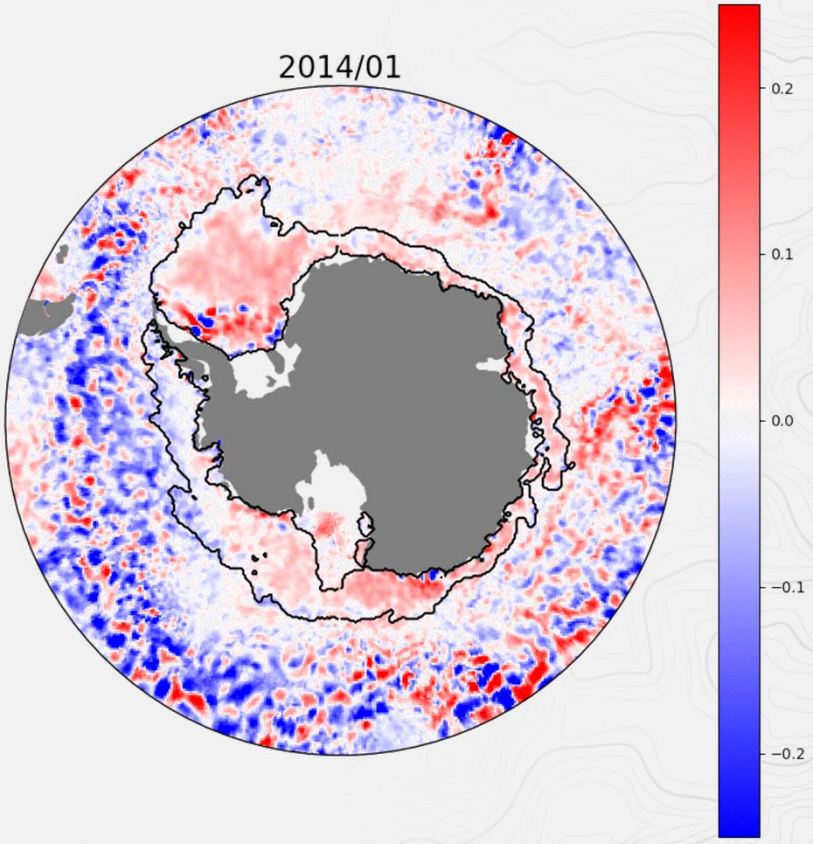


# Validation using tide gauges

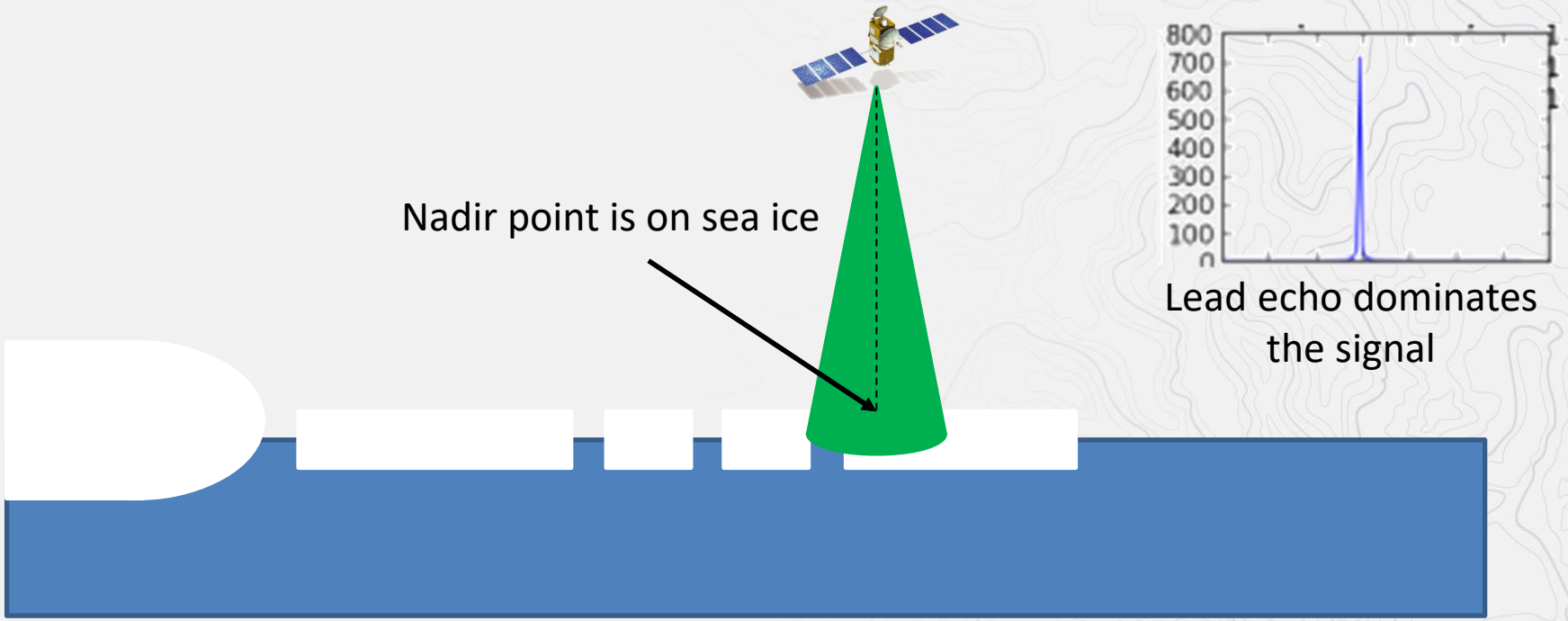



Map of SLA Variance. Scatter points represent Tide Gauges variance when available

# Preliminary Results – Multimission SLA



# Snagging / Off-Nadir Hooking

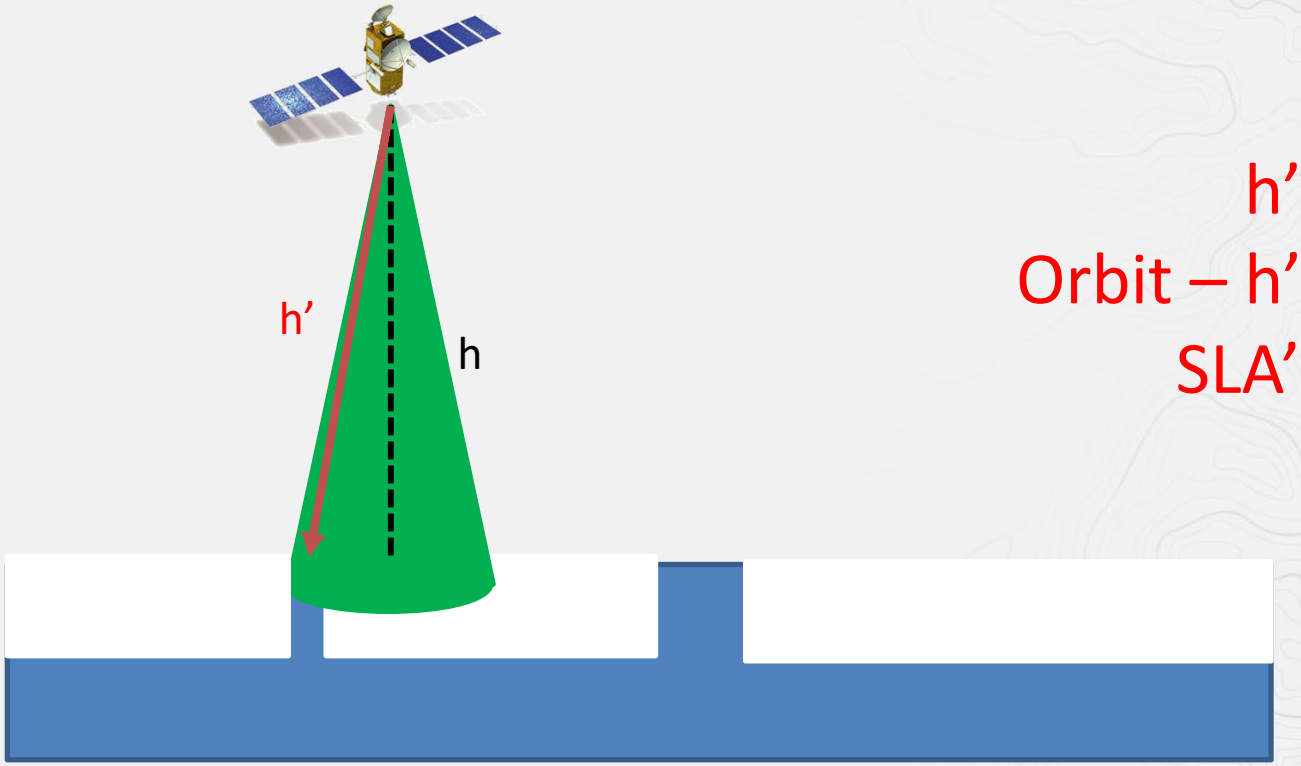






Lead echo dominates the signal

# Snagging / Off-Nadir Hooking

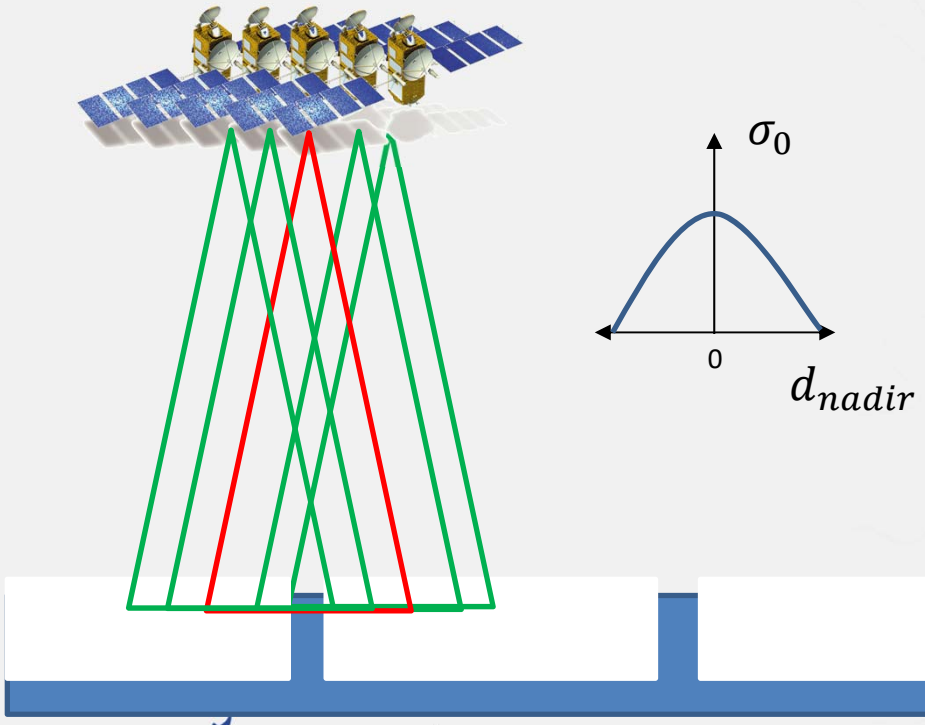



h' > h

Orbit – h' < Orbit – h

SLA' < SLA

# Snagging / Off-Nadir Hooking






How to get rid of “Hooked” data ?

- Identify lead data with classification.
- Remove all data that is not a local maxima of sigma0 in that lead.