Sea State Climate Change Initiative

2nd Workshop on Waves, Surges and Coastal Hazards

10-15 November 2019 | Melbourne

Guillaume Dodet[1] and Fabrice Ardhuin[1] (on behalf of the Sea State CCI Team)
[1]Laboratory for Ocean Physics and remote Sensing (LOPS), Brest, France

Motivation

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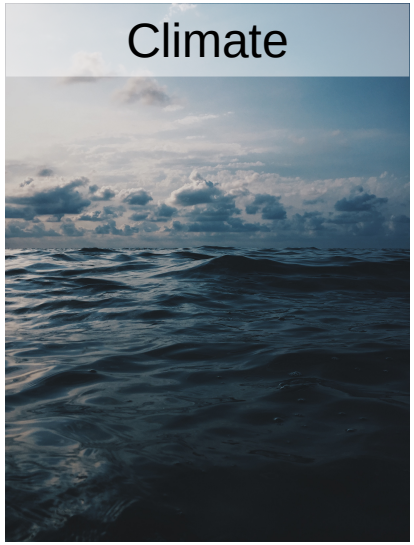
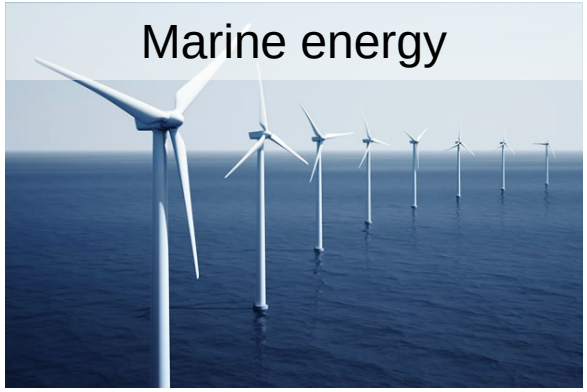
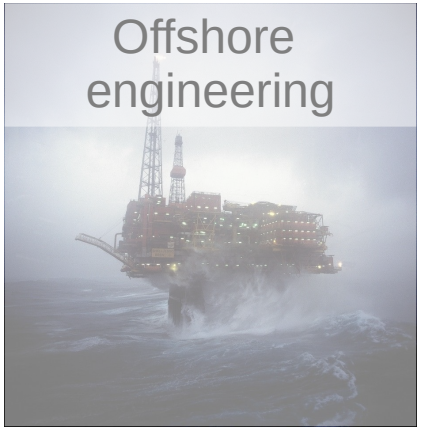


SEA STATES IMPACT



Motivation

Climate



SEA STATES IMPACT

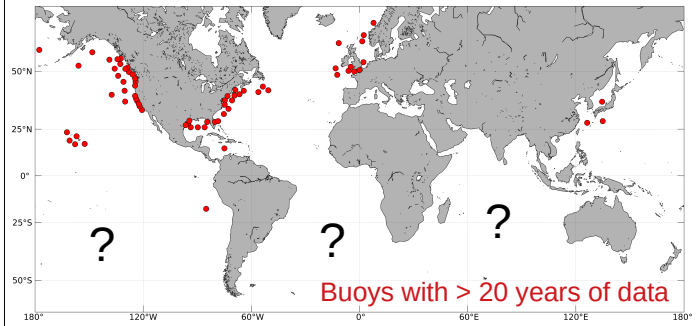
Motivation

Climate Data Record *(US National Research Council)* :

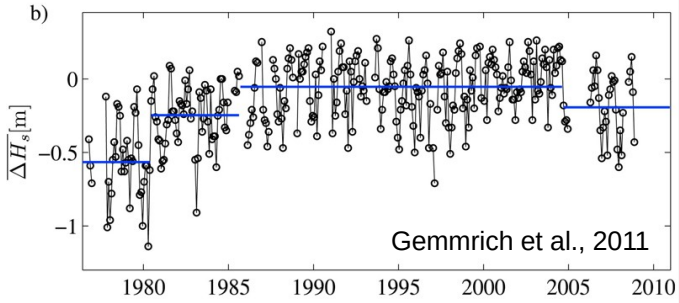
A time series of measurements of sufficient ***length, consistency*** *and* ***continuity*** *to determine* ***climate variability and change***

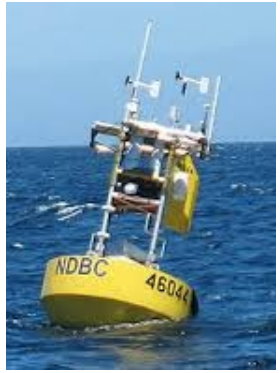
Motivation

Long-term in-situ data are sparse...



… and not always consistent





… due to changes in buoy hull and payloads

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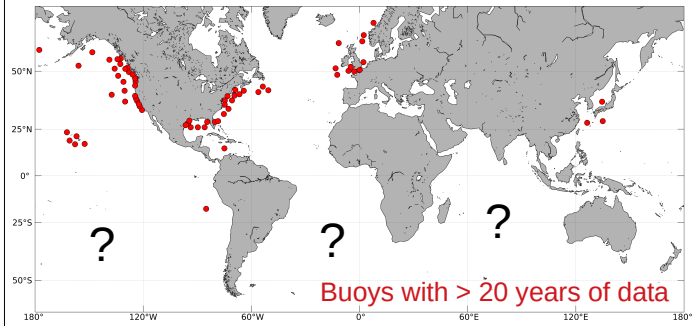

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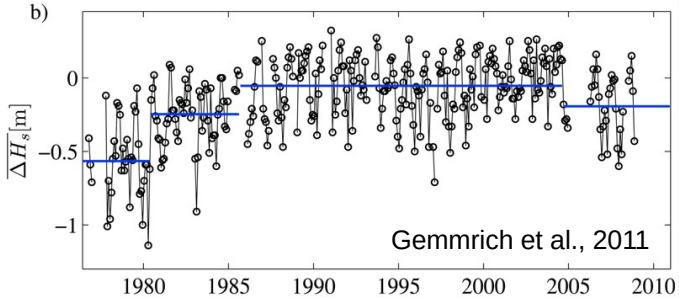

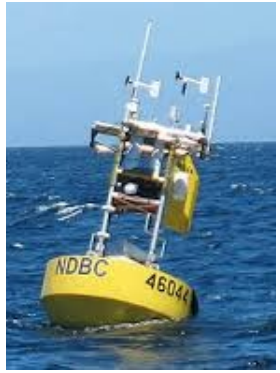

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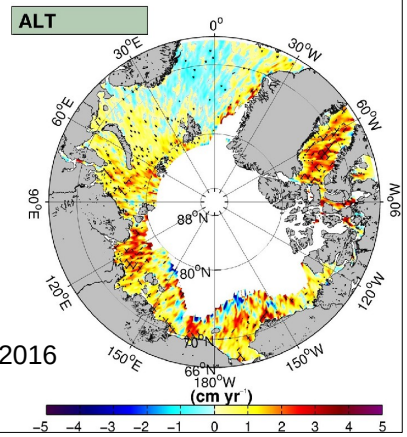
Rapid changes observed in the Arctic due to changes in sea ice extent and wind conditions

Stopa et al, 2016



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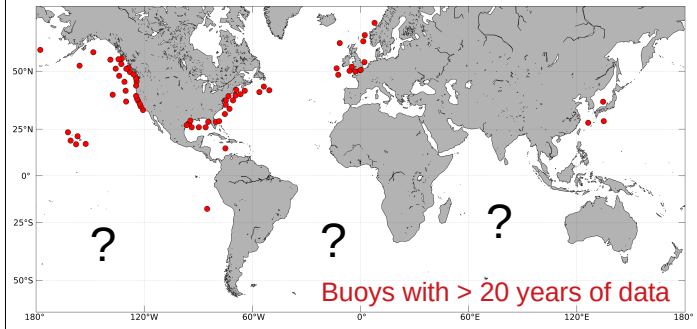

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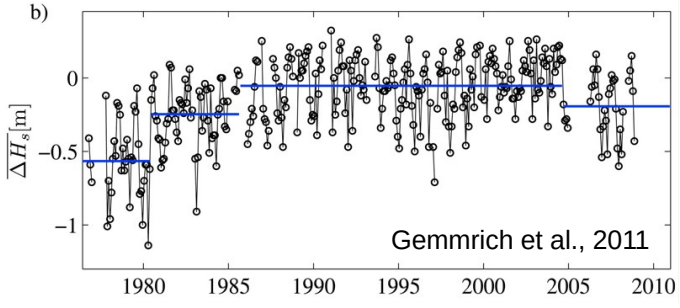

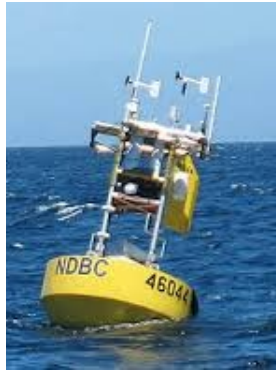

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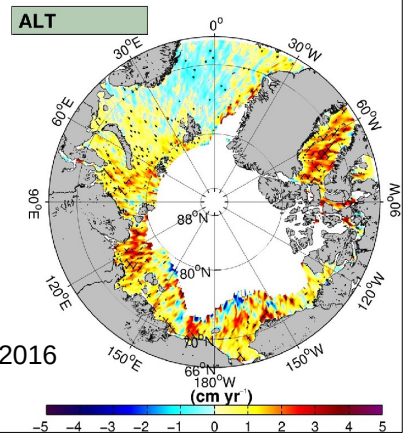

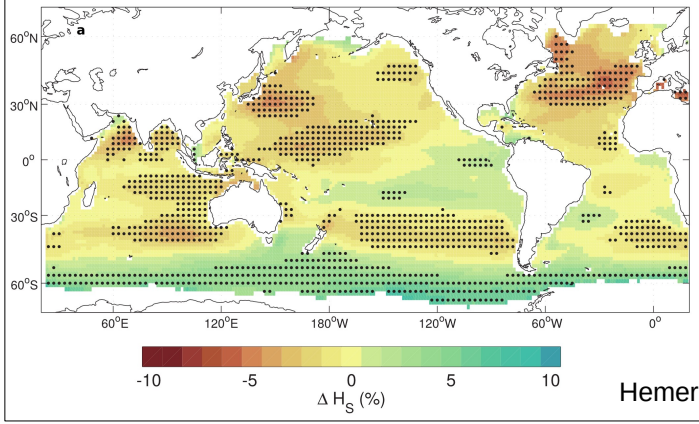

Large uncertainties remain in past trends and projected changes

Hemer et al, 2013

Context

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1992, *Earth Summit*, Rio de Janeiro

154 Member states

sign the

United Nations Framework Convention on Climate Change

to

stabilise greenhouse gas emission and prevent dangerous anthropogenic interference with Earth's climate system.

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GCOS GLOBAL CLIMATE OBSERVING SYSTEM

to

- *Meet the needs of UNFCCC in terms of climate observing system (COS)*
- *Report on adequacy of current COS*
- *Provide guidance for improvement of COS*

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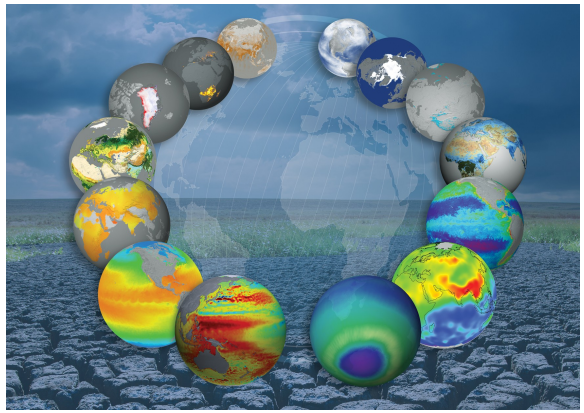
defines

esa CNSA इसरो isro NASA cnes

Governmental space agencies

contribute to observe

Essential Climate Variables (ECVs)



The ESA Climate Change Initiative

The objective of the CCI programme is to realise the full potential of the long-term global Earth Observation archives as a significant contribution to the ECV databases required by the UNFCCC

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WORKFLOW

- User Consultation and Requirements
- Algorithm Development
- System Development
- Data Collection, Production and Validation
- Climate Data Record Assessment

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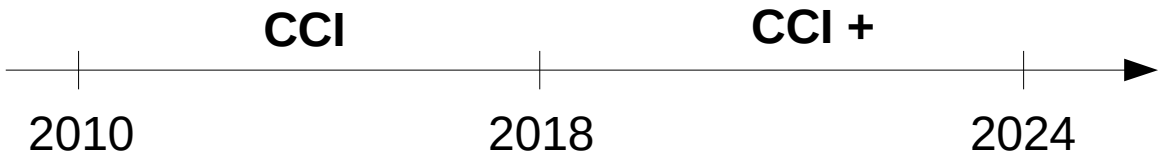

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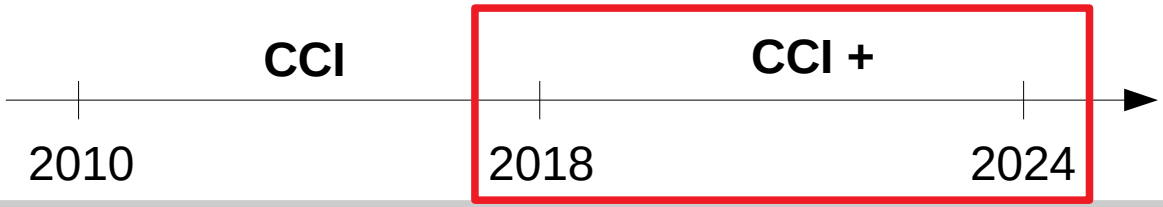


Essential Climate Variables

The Sea State CCI project

Science lead : Fabrice Ardhuin (LOPS)
ESA Technical Officers : Craig Donlon, Paolo Cipollini
Consortium : 15 European partners
+ 4 international experts

Objective : produce a **sea state Climate Data Record** based on satellite Earth Observations (Conventional and Delay Doppler Radar Altimeter, Synthetic Aperture Radar)

“sea state” = not only significant wave height … but also **spectral parameters**

CCI also provides **feedback to GCOS** on requirements based on user consultation

Product	Frequency	Resolution	Uncertainty	Stability
Hs	3-hourly	25 km	10 cm	5 cm

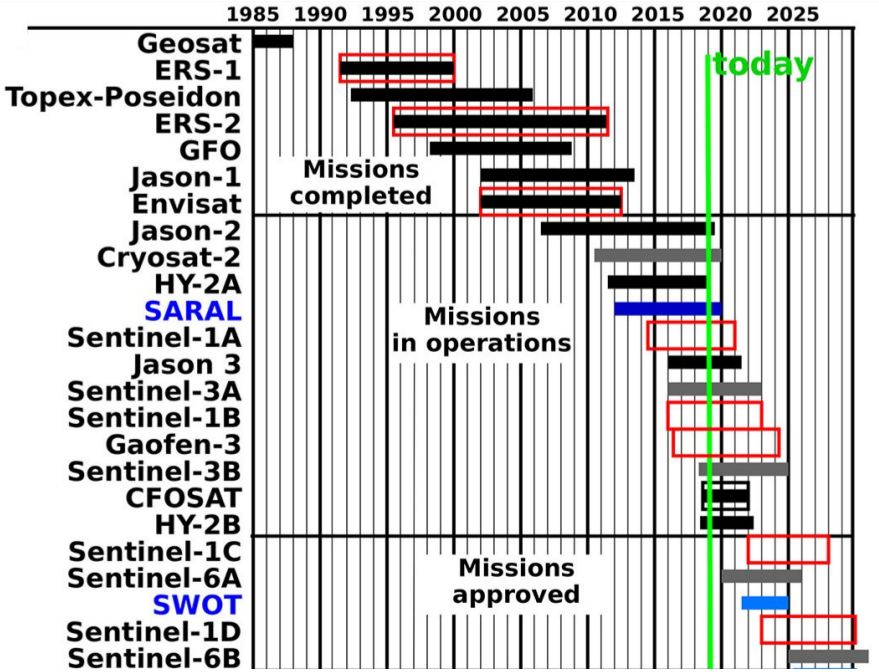
GCOS-195, Status of the Global Observing System for Climate, October 2015

Challenges

Challenges

Radar altimeters (Ku, Ka, Delay Doppler)
-> Hs

Synthetic Aperture Radar and SWIM
-> wave spectra



Ardhuin, F., Stopa, J.E., Chapron, B., Collard, F., Husson, R., Jensen, R.E., Johannessen, J., Mouche, A., Passaro, M., Quartly, G.D., Swail, V., Young, I., 2019.
Observing Sea States. Front. Mar. Sci. 6.

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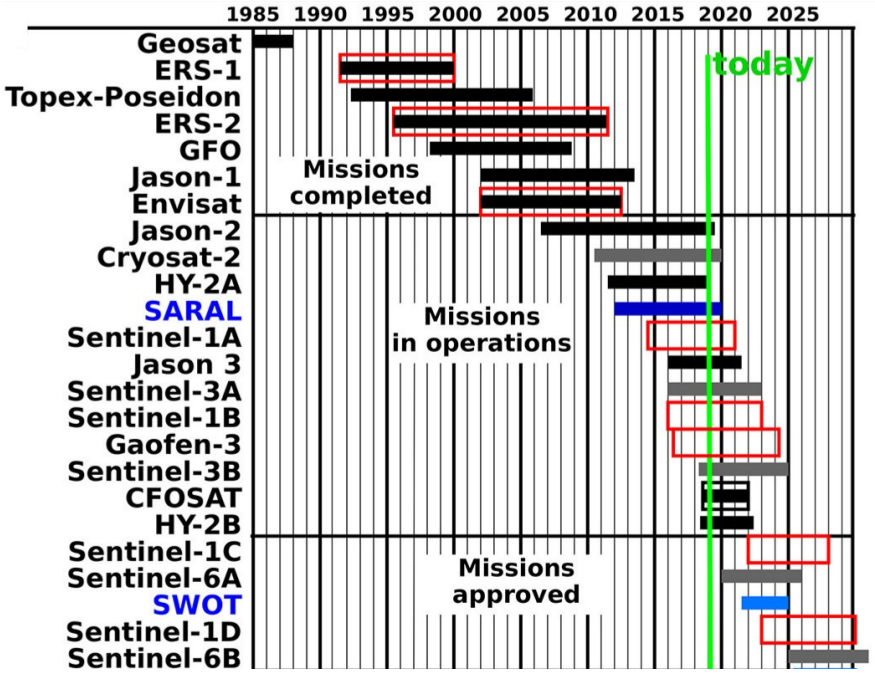
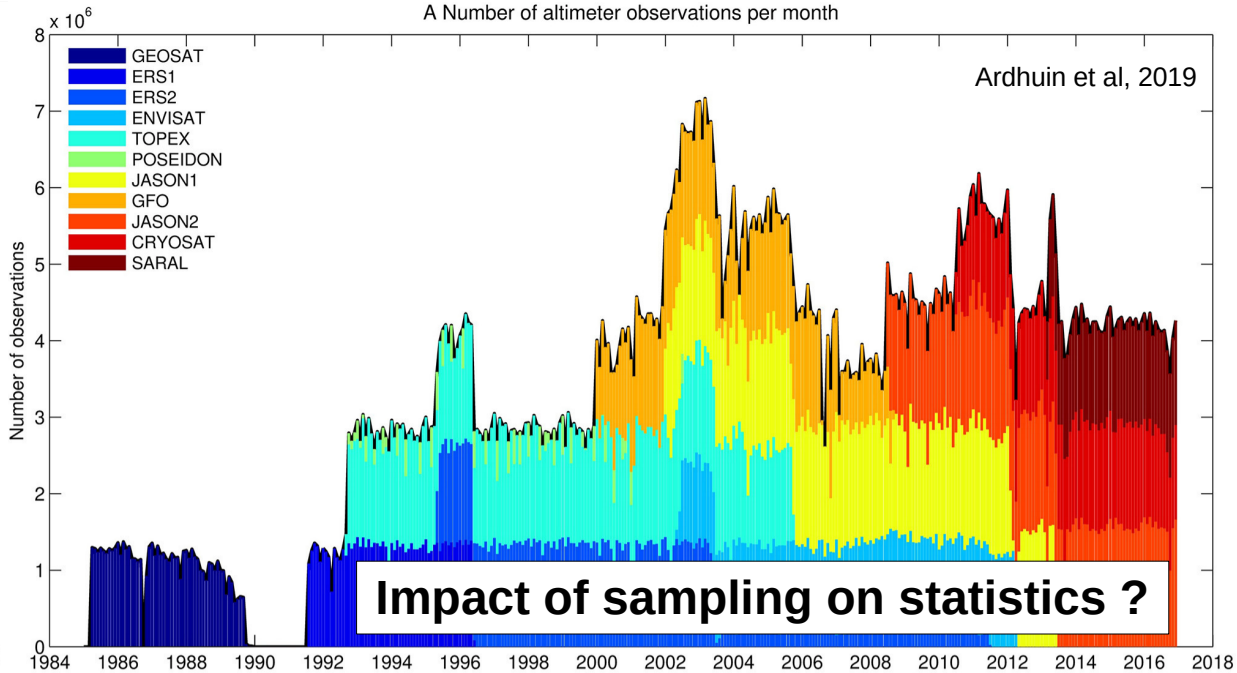
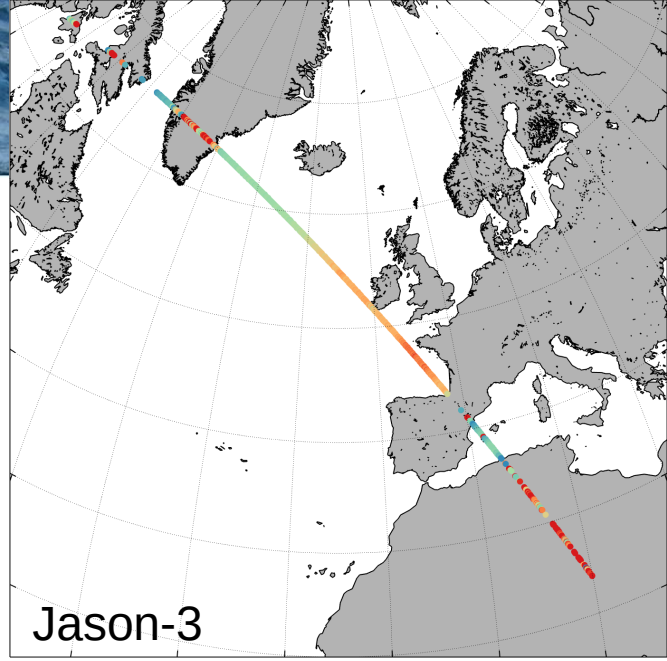


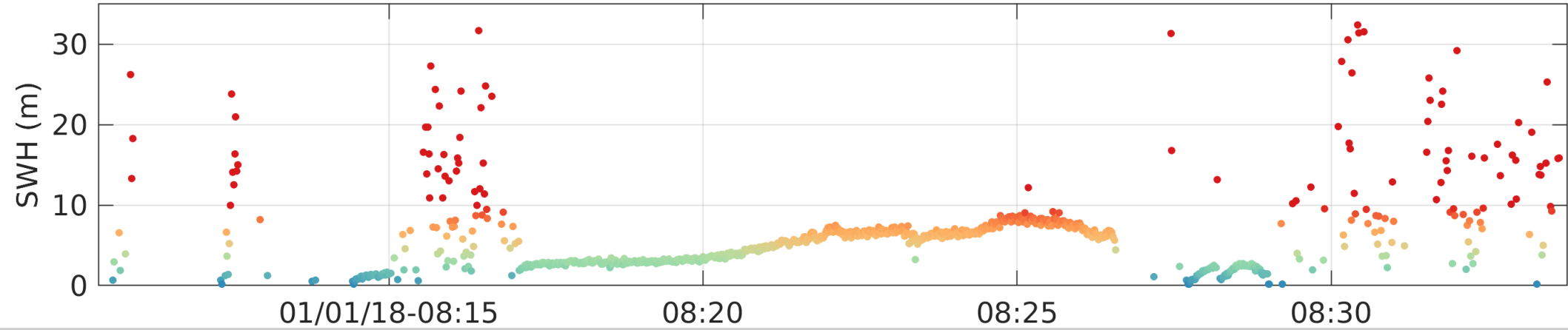


Challenges

Many **corrupted swh records** due to :

- Land
- Ice
- Rain
- Slicks





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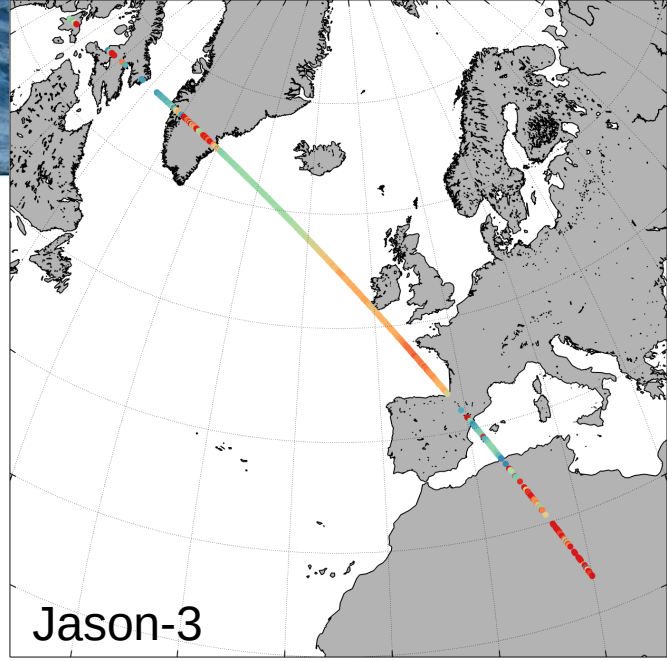
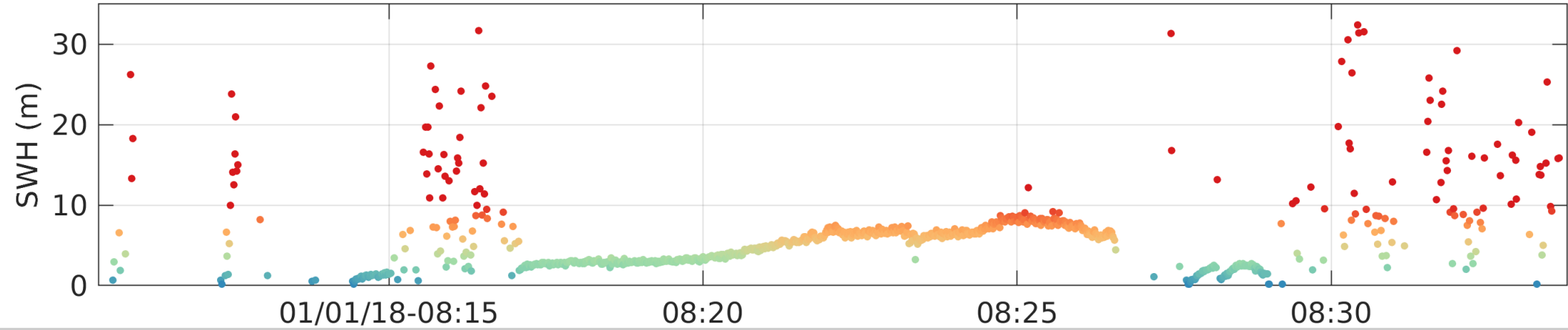
+ low signal to noise ratio at scales < 100 km





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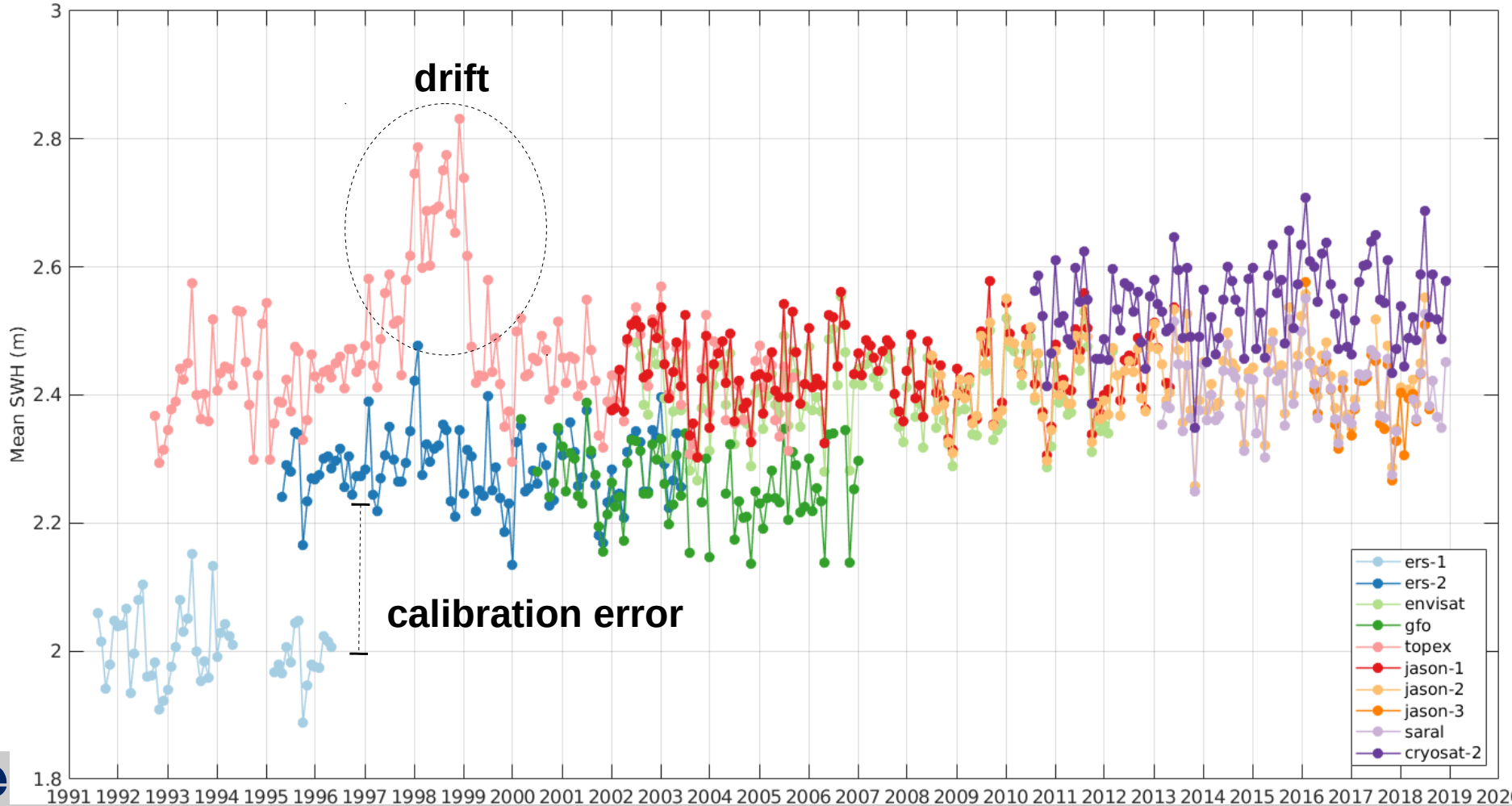
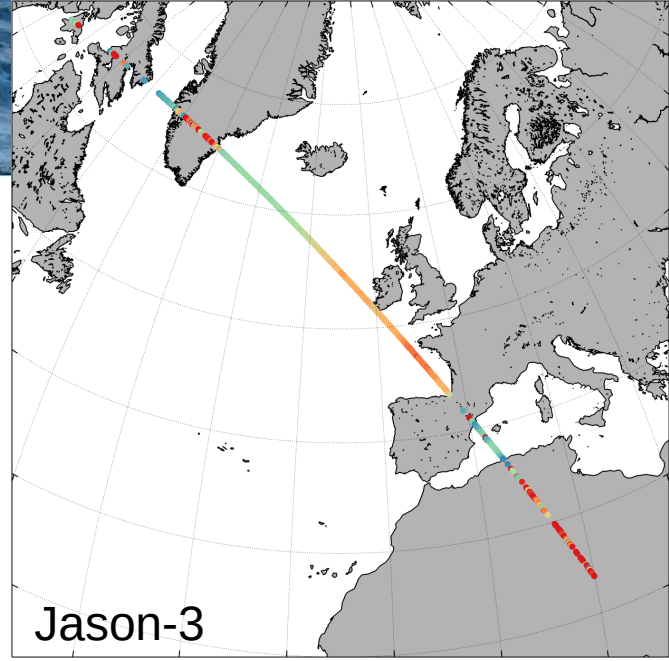
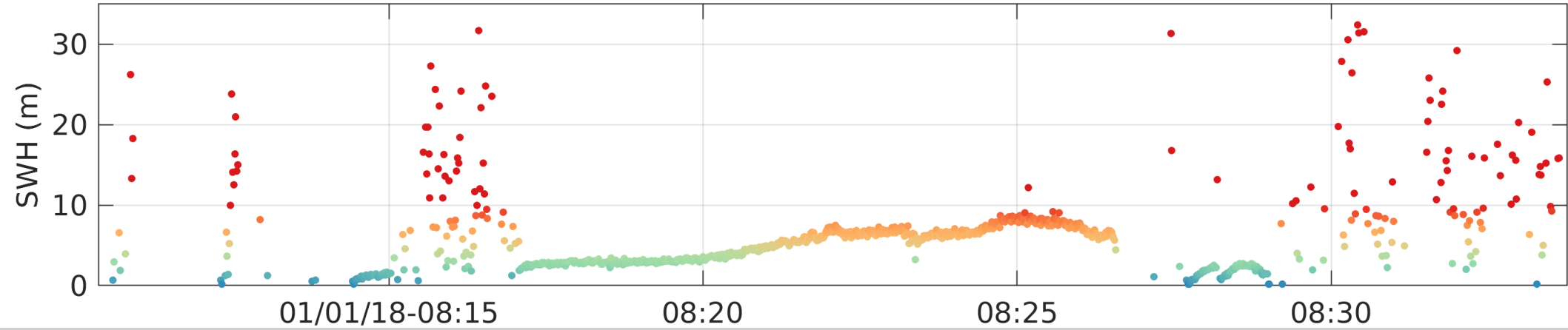

drift
calibration error
Mean SWH (m)
3
2.8
2.6
2.4
2.2
2
1.8
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
ers-1
ers-2
envisat
gfo
topex
jason-1
jason-2
jason-3
saral
cryosat-2

3 steps to make data more consistent

Step 1 : Quality checks





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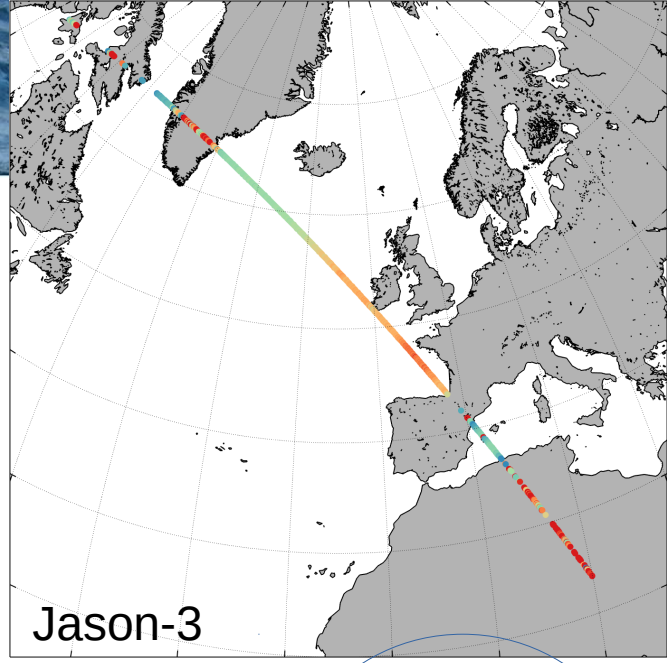
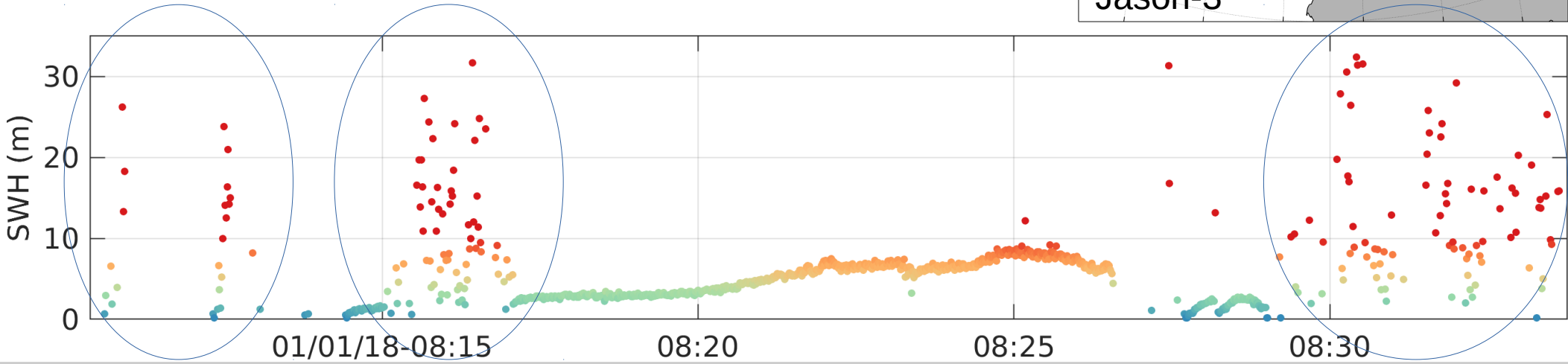
A 1-Hz swh record is rejected in case of :

- Land or ice contamination (ice mask from Sea Ice CCI)
- Undefined or negative sigma0, ssh and swh values
- Unrealistic swh gradient
- Insufficient number of valid 20-Hz waveforms
- Large RMS deviation from the mean swh





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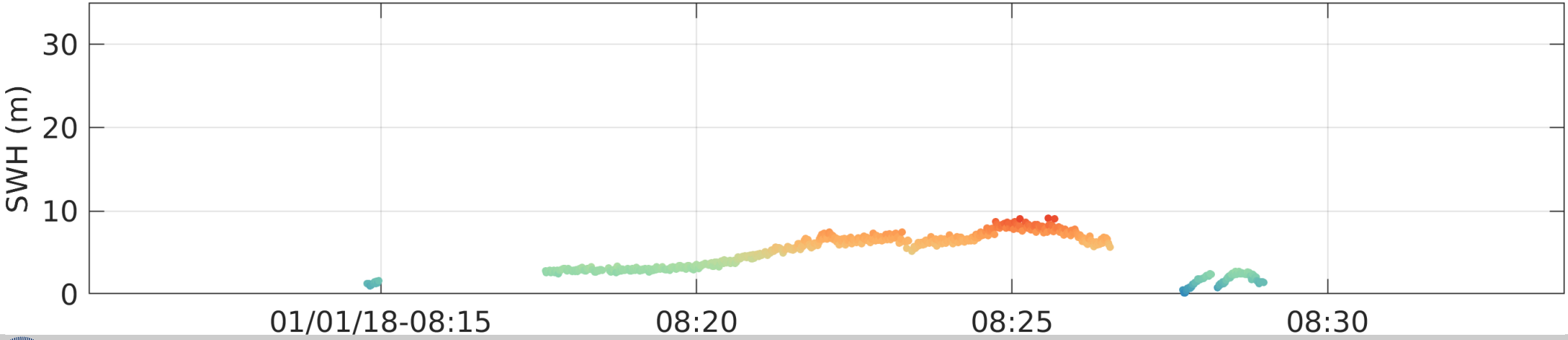
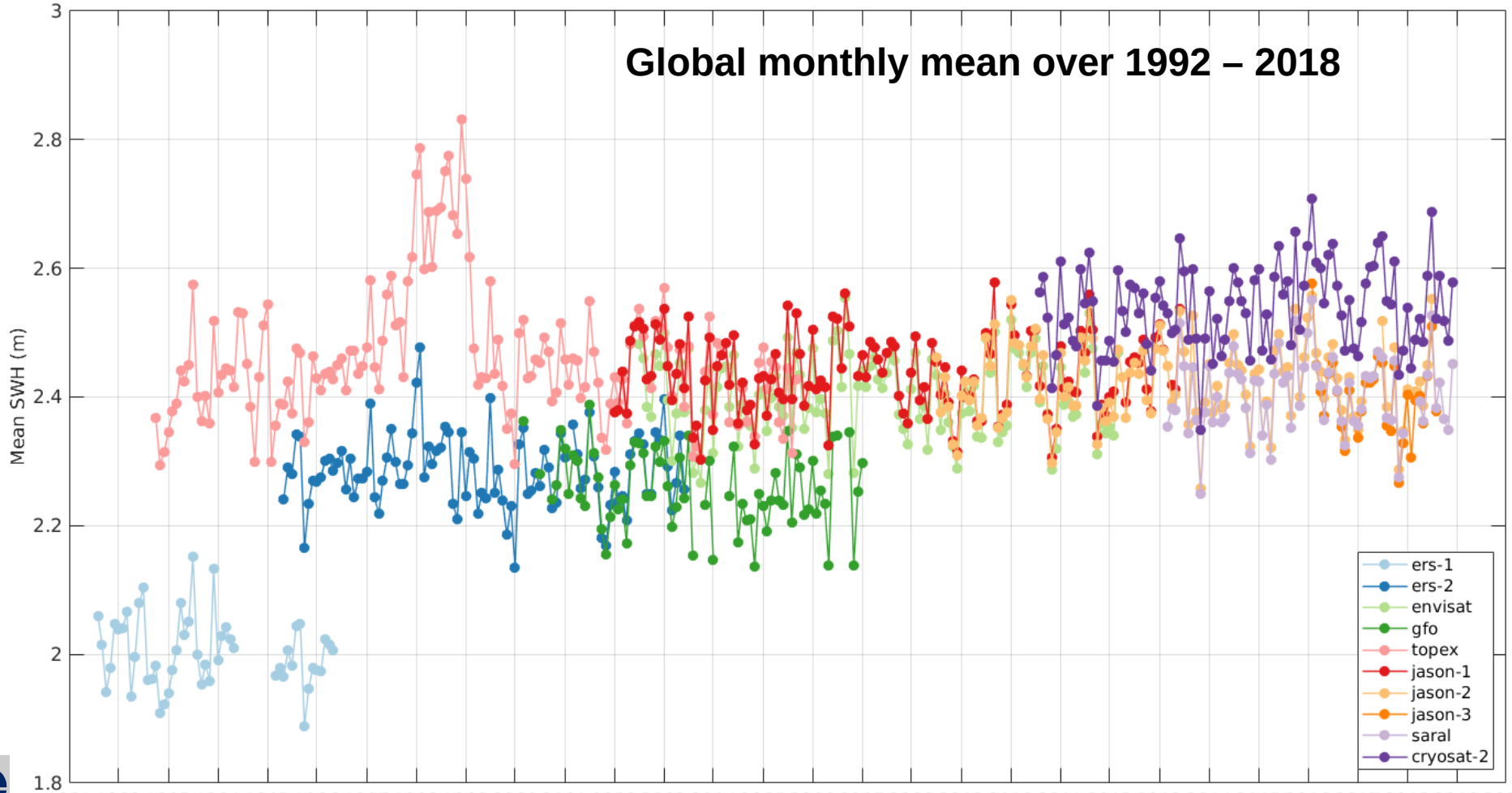


Step 2 : Inter-calibration



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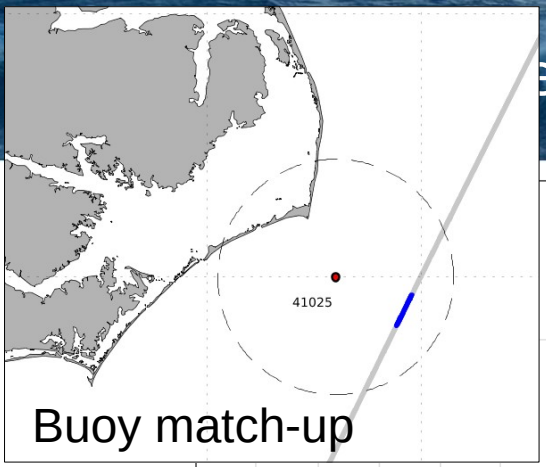
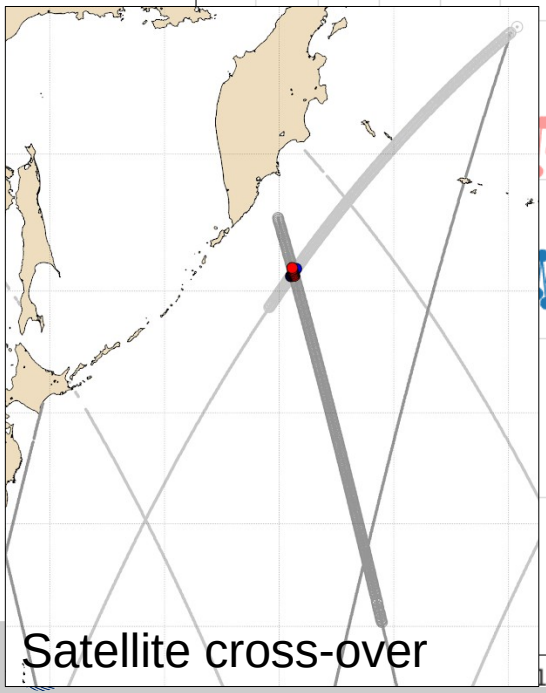
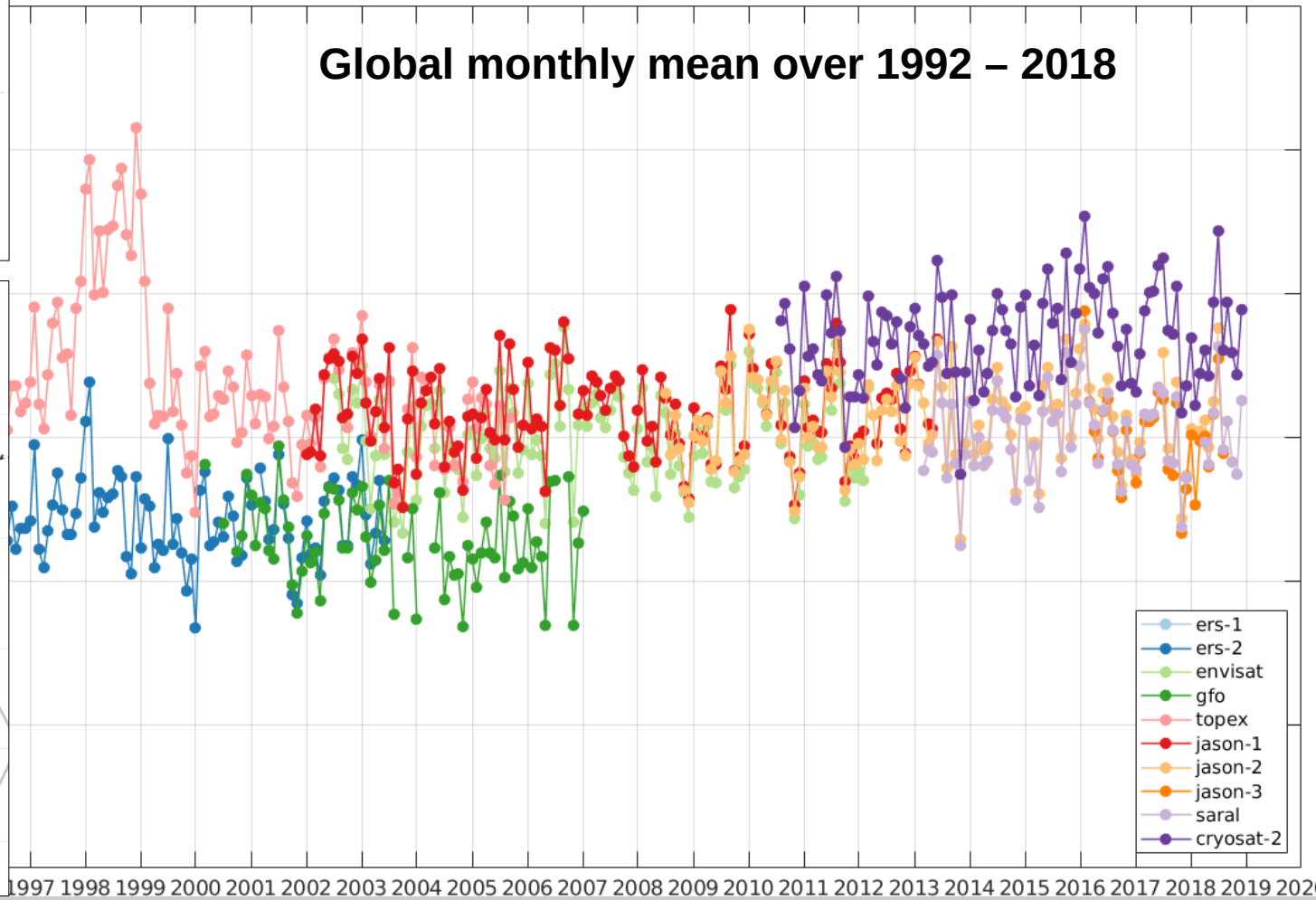


Buoy match-up



Satellite cross-over



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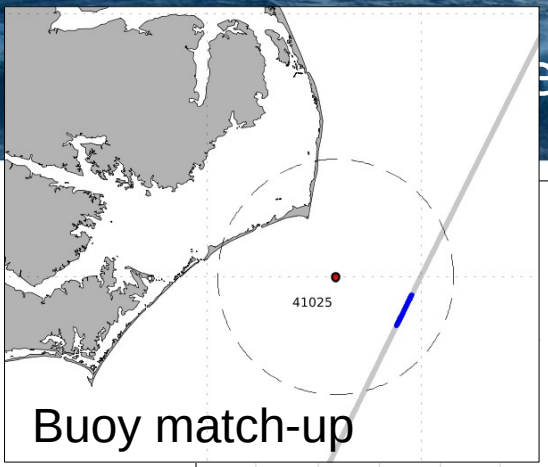

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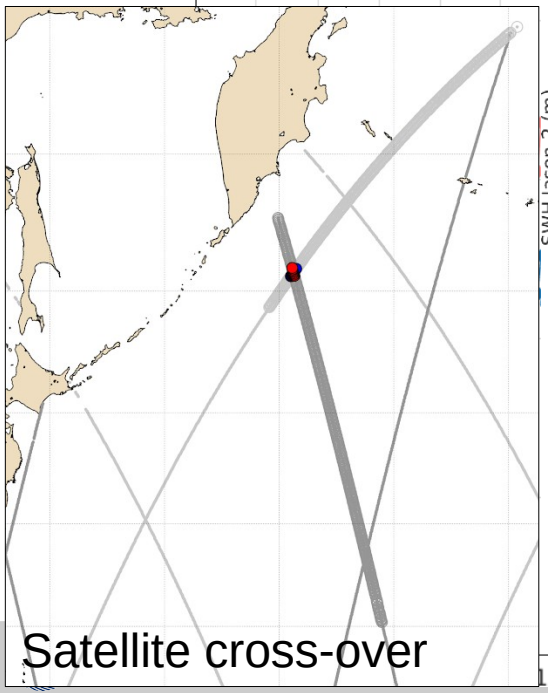
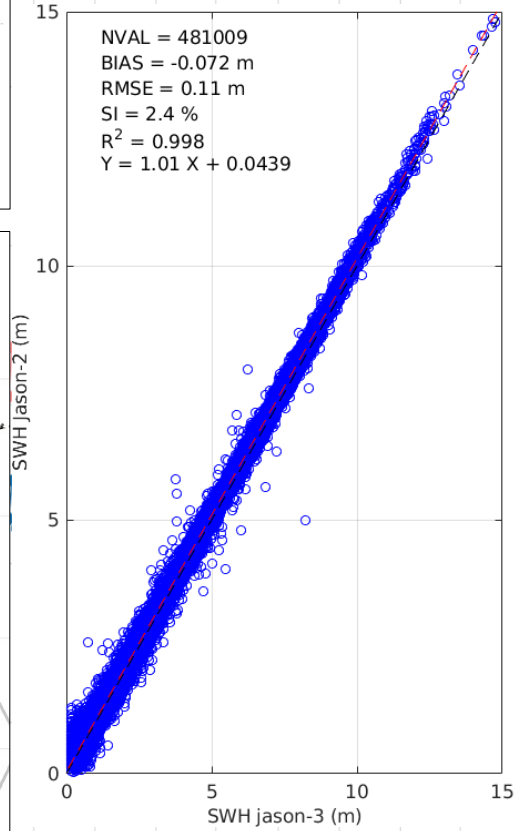
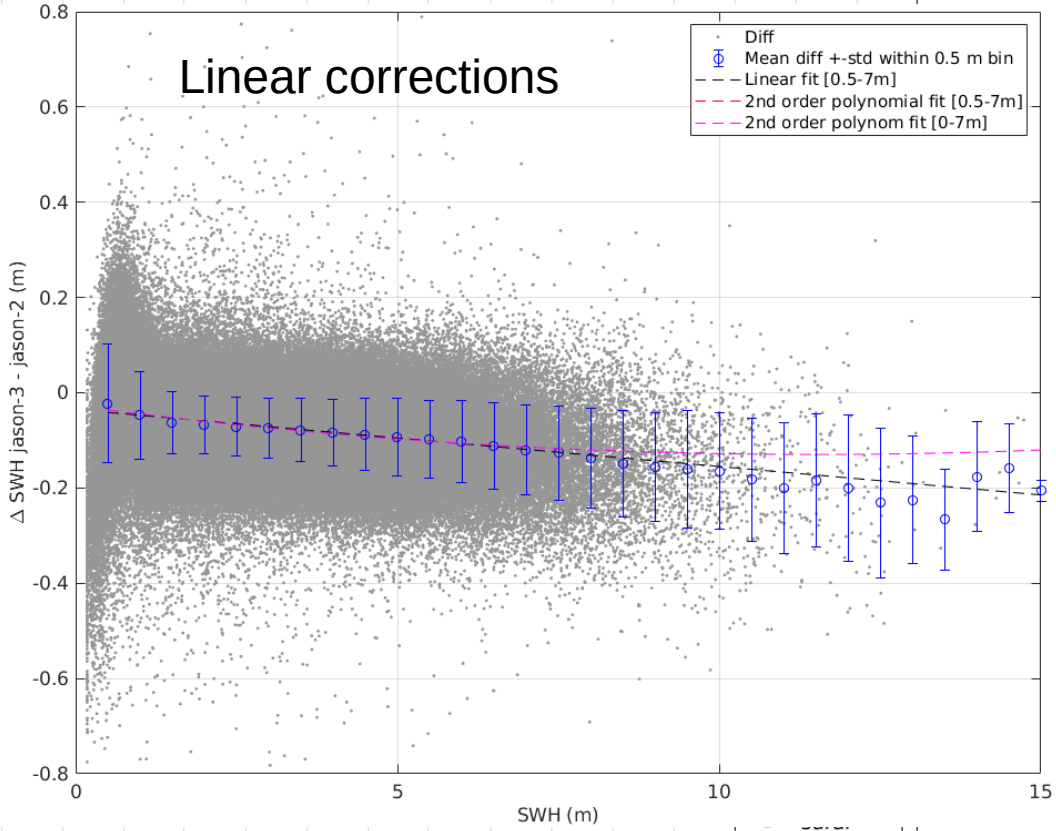


Satellite cross-over

JASON-3 VS JASON-2



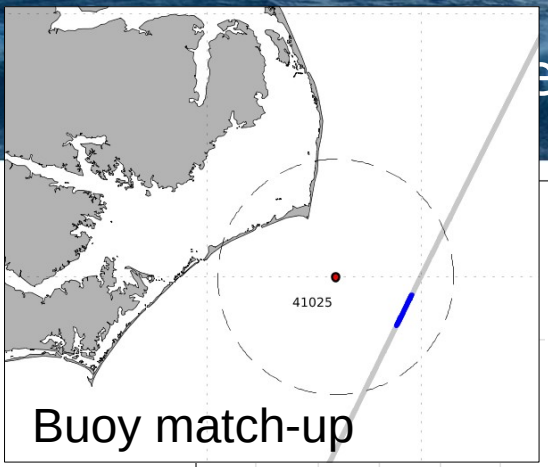
Linear corrections



1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

er-calibration

CRYOSAT-2 VS JASON-2



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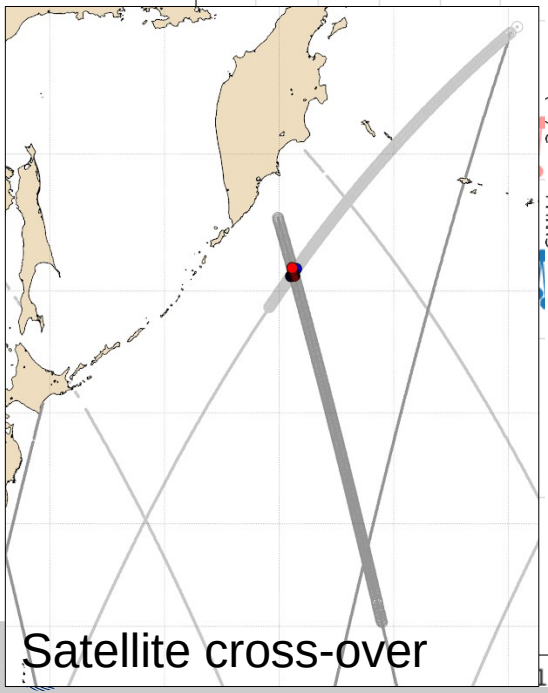

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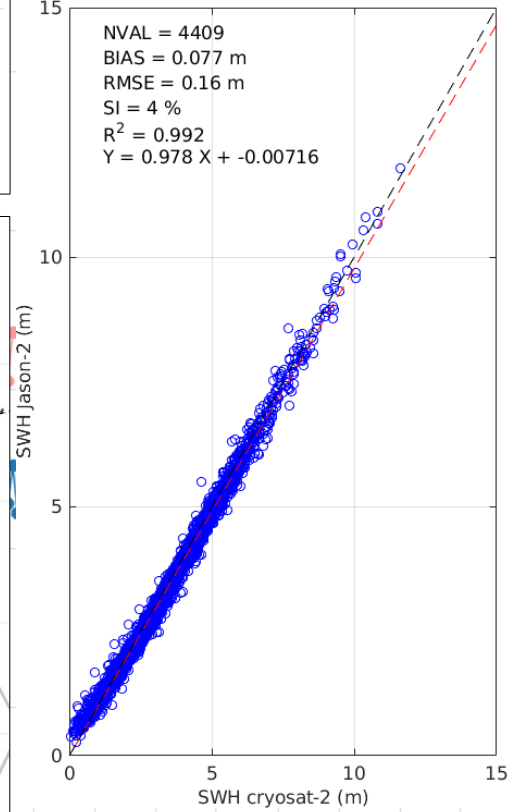
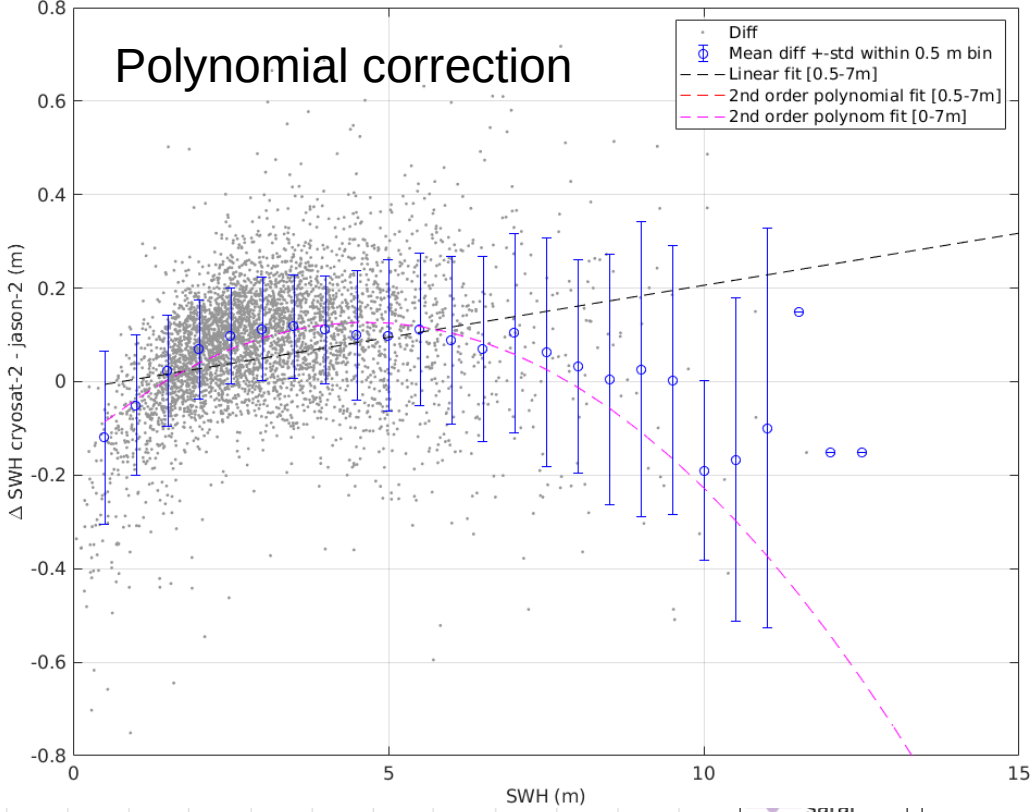


Polynomial correction



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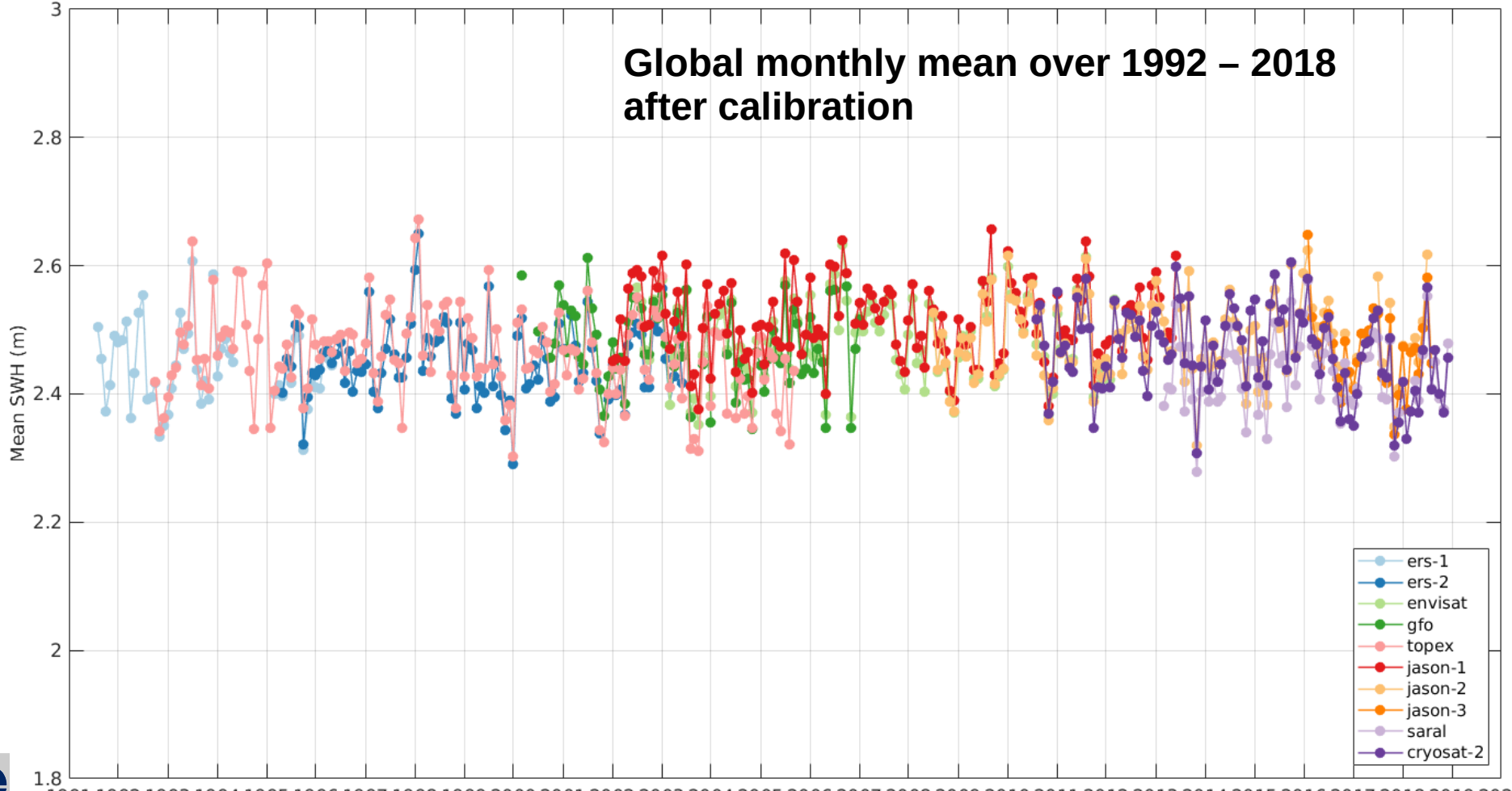
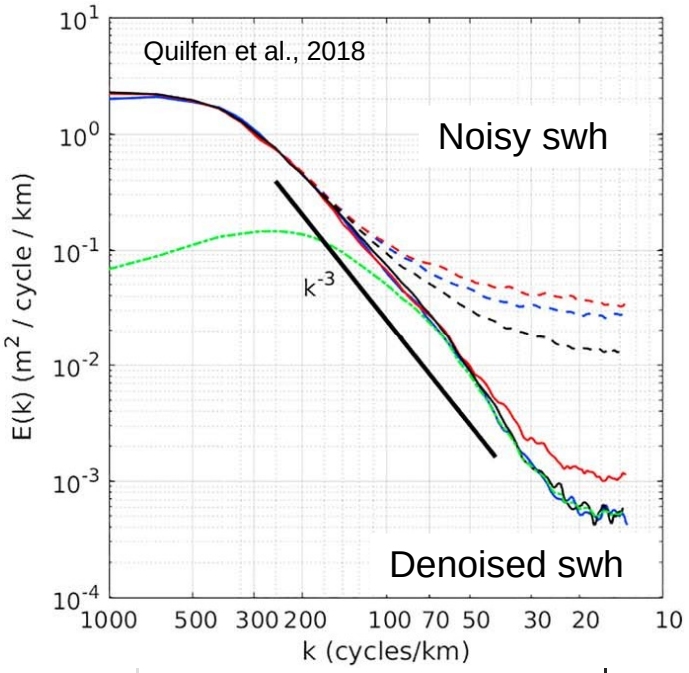
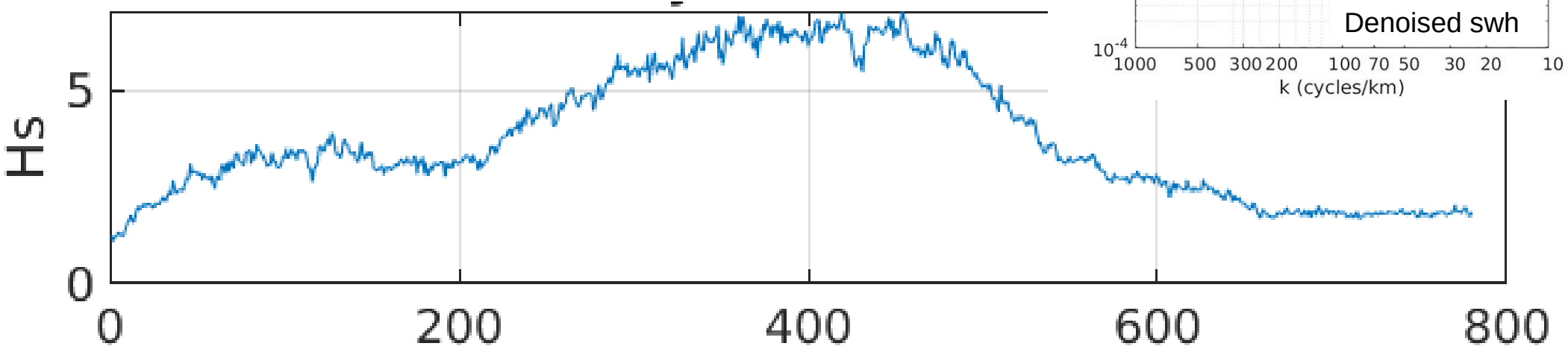


Step 3 : Adaptive denoising

- At **scale < 100km**, the along-track signal is very noisy





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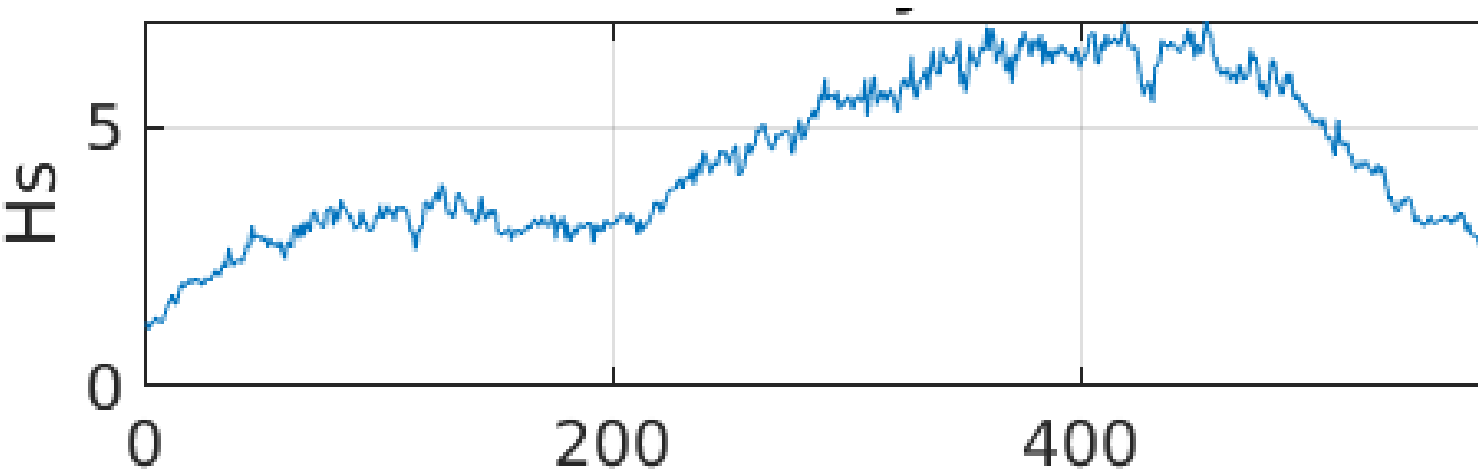
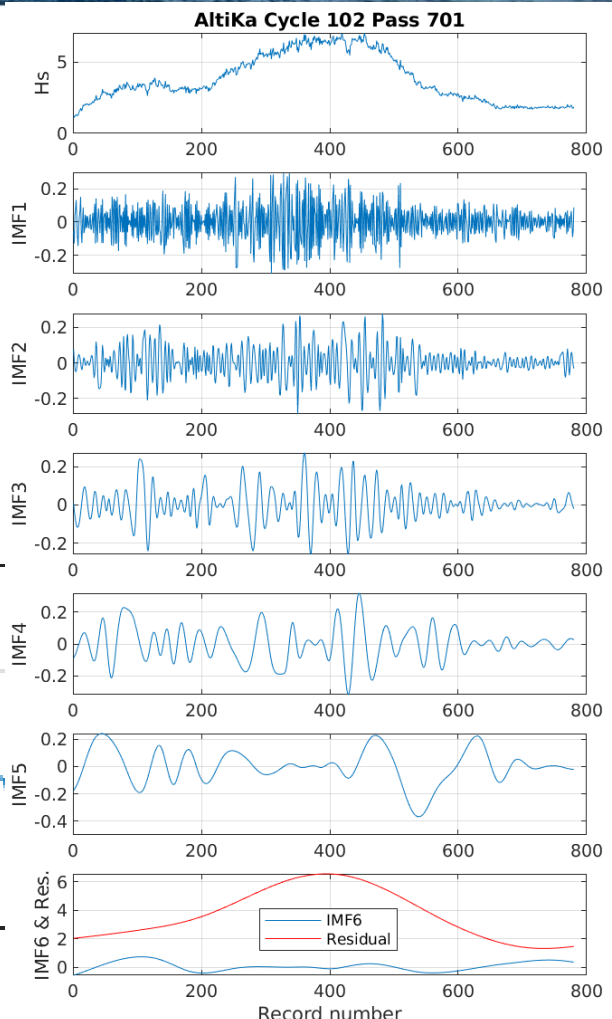
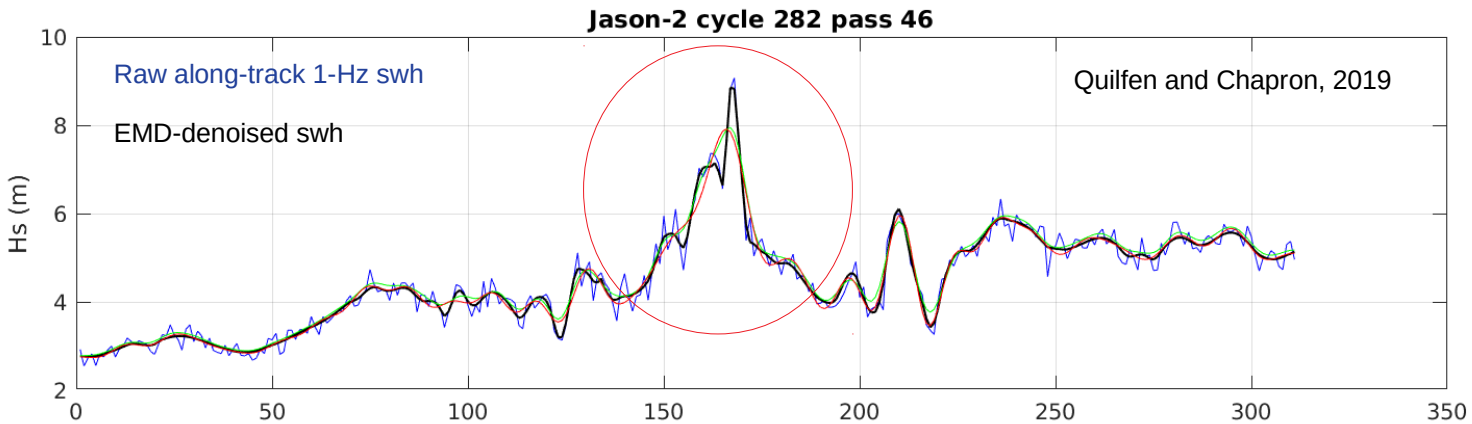
- At **scales < 100km**, the along-track signal is very noisy
- A denoising method based on **Empirical Mode Decomposition** and **wavelet thresholding** is implemented

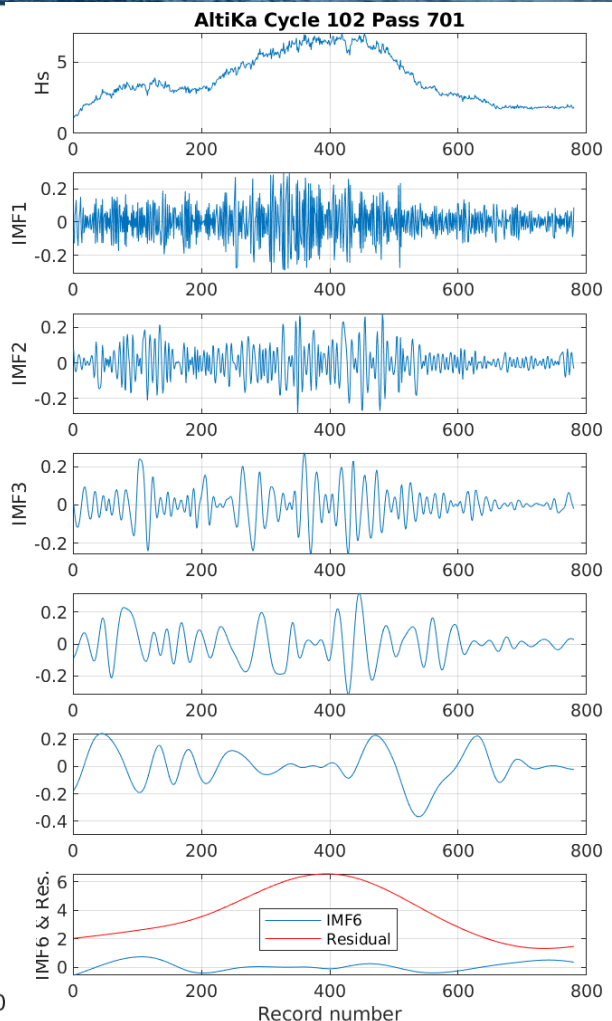




Step 3 : Adaptive denoising

- At **scales < 100km**, the along-track signal is very noisy
- A denoising method based on **Empirical Mode Decomposition** and **wavelet thresholding** is implemented
- Improved mapping of **strong gradients** and **extreme values**





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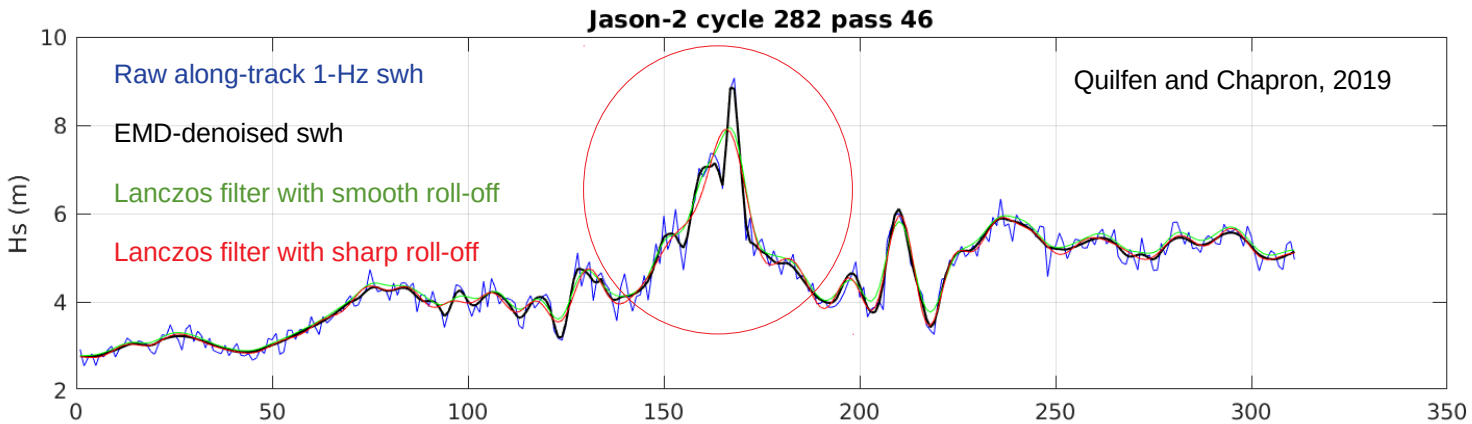
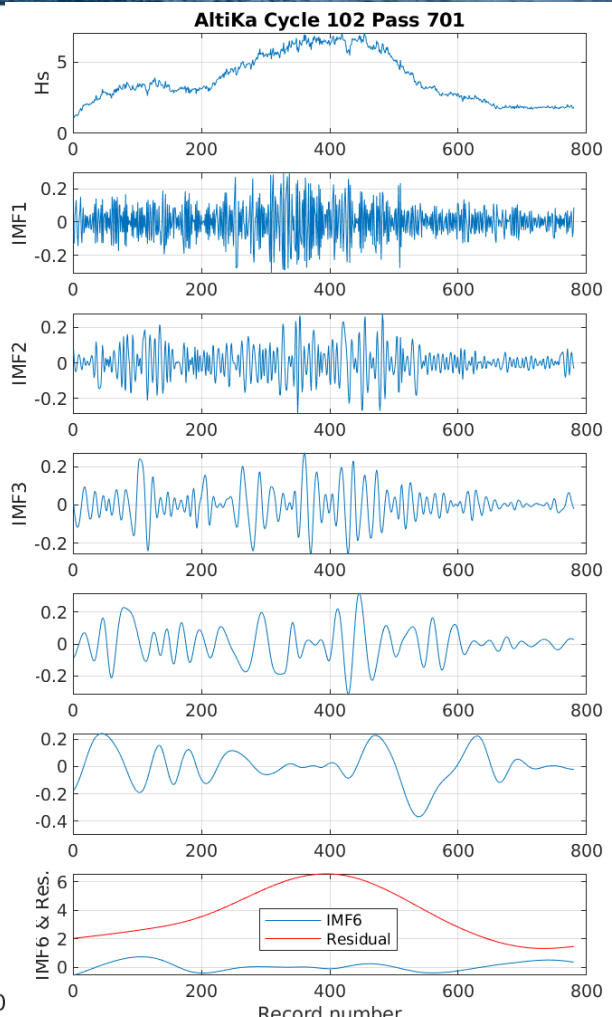
- A denoising method based on **Empirical Mode Decomposition** and **wavelet thresholding** is implemented
- Improved mapping of **strong gradients** and **extreme values**
- **Adaptive** method suited for **non-linear** and **non-stationary** processes





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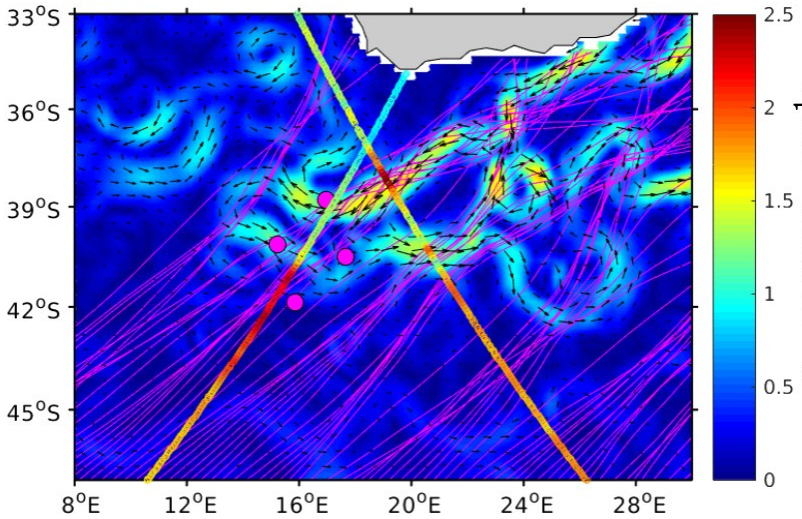
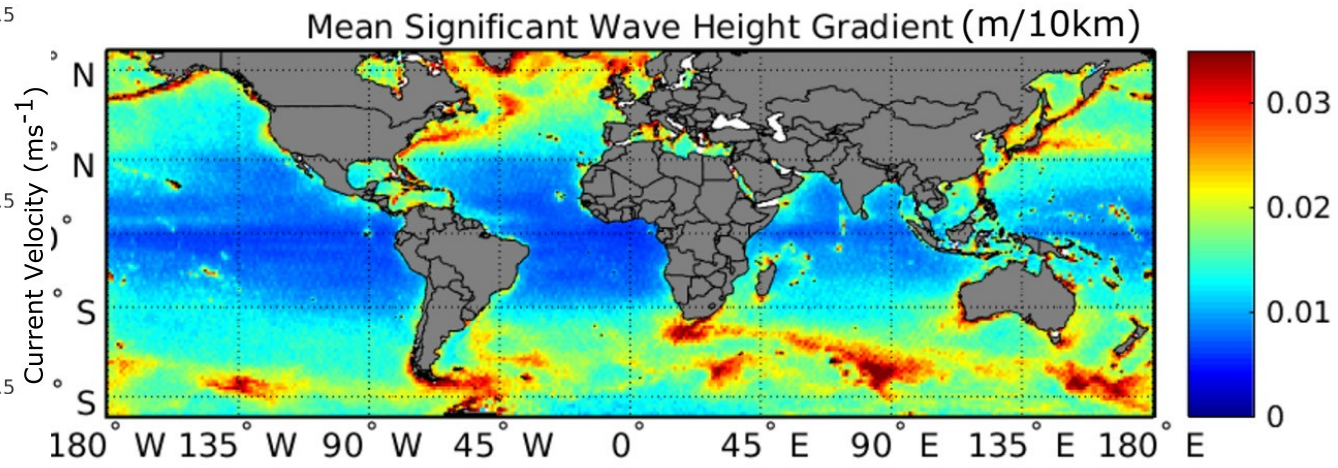
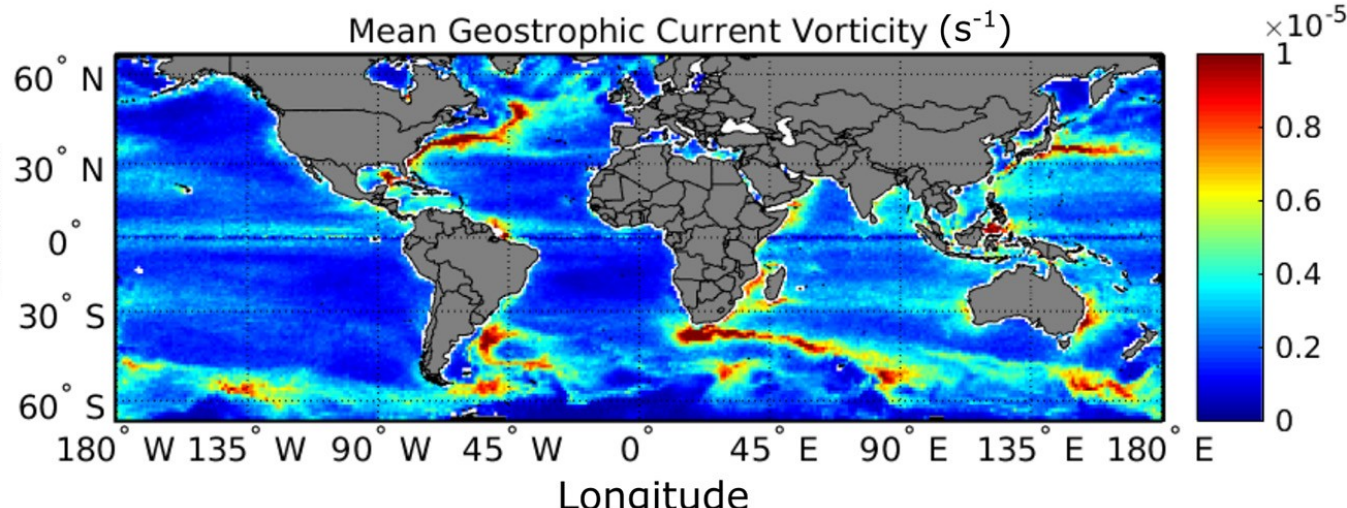


Quilfen et al., 2018





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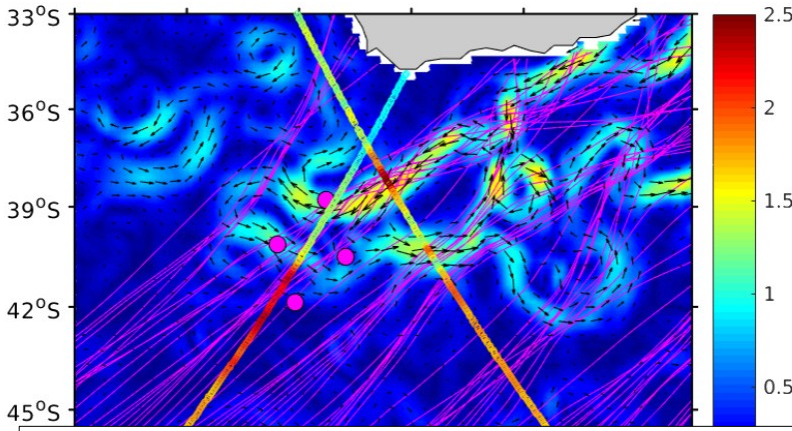
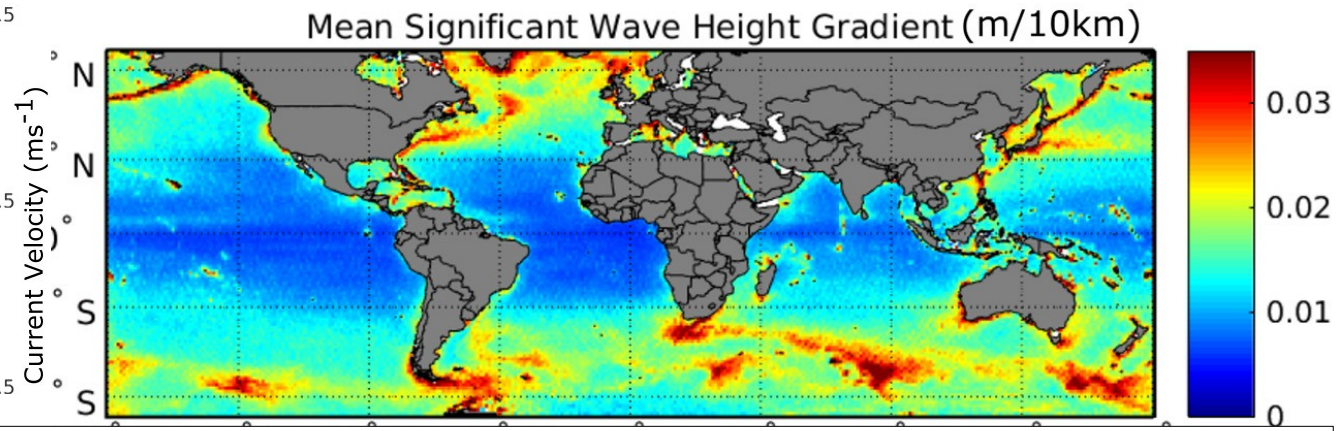




Huang, N.E., Shen, Z., Long, S.R., Wu, M.C., Shih, H.H., Zheng, Q., Yen, N.-C., Tung, C.C., Liu, H.H., 1998. The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences 454, 903–995.

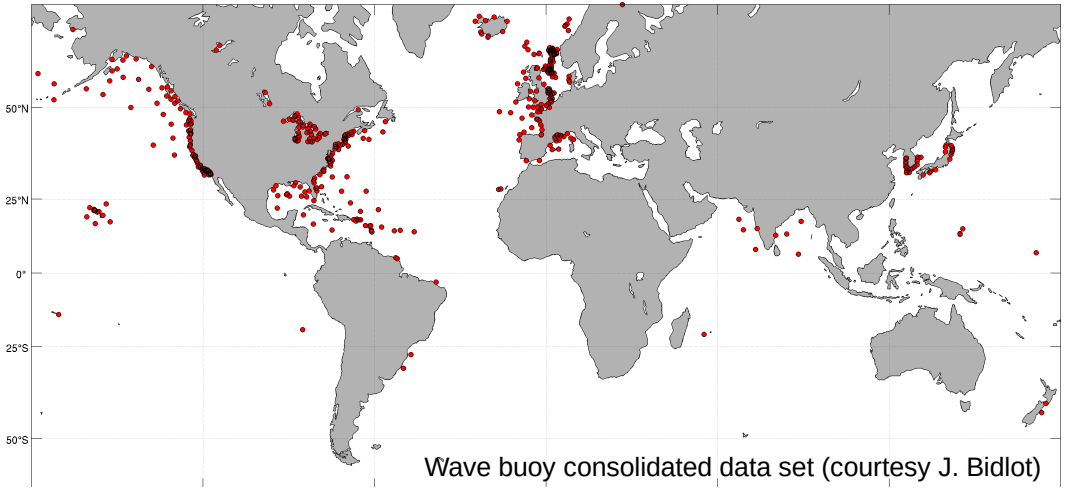
Kopsinis, Y., McLaughlin, S., 2009. Development of EMD-Based Denoising Methods Inspired by Wavelet Thresholding. IEEE Transactions on Signal Processing 57, 1351–1362. https://doi.org/10.1109/TSP.2009.2013885

Quilfen, Y., Yurovskaya, M., Chapron, B., Ardhuin, F., 2018. Storm waves focusing and steepening in the Agulhas current: Satellite observations and modeling. Remote Sensing Of Environment 216, 561–571.

Quilfen, Y., Chapron, B., 2019. Ocean Surface Wave-Current Signatures From Satellite Altimeter Measurements. Geophysical Research Letters 46, 253–261.

The Sea State CCI dataset V1

- Available and documented on : https://forms.ifremer.fr/lops-siam/access-to-esa-cci-sea-state-data/
- 1-Hz along-track and monthly gridded (1°) products
- 26 years of data, from 1992 (ERS-1) to 2018
- Include calibrated and denoised significant wave height + auxiliary data
- Future version will include improved retracking for swh and spectral data (SAR)



Wave buoy consolidated data set (courtesy J. Bidlot)

MISSION	NYEAR	NCOLOC	BIAS (M)	RMSE (M)	NRMSE (%)	SI (%)
ers-1	3	1018	-0.072	0.26	9.95	8.41
ers-2	17	9207	0.014	0.24	10.41	8.96
envisat	11	8286	0.044	0.23	10.05	8.58
gfo	9	5221	0.026	0.26	10.91	9.46
topex	12	7797	0.014	0.24	9.74	8.39
jason-1	12	11094	0.010	0.22	9.58	8.31
jason-2	11	14395	0.069	0.21	9.67	7.86
jason-3	3	4181	0.097	0.21	9.95	7.48
saral	6	7876	0.088	0.21	10.14	7.96
cryosat	9	7913	0.048	0.19	9.00	7.57
AVERAGE	**9.3**	**7698.8**	**0.034**	**0.23**	**9.94**	**8.30**

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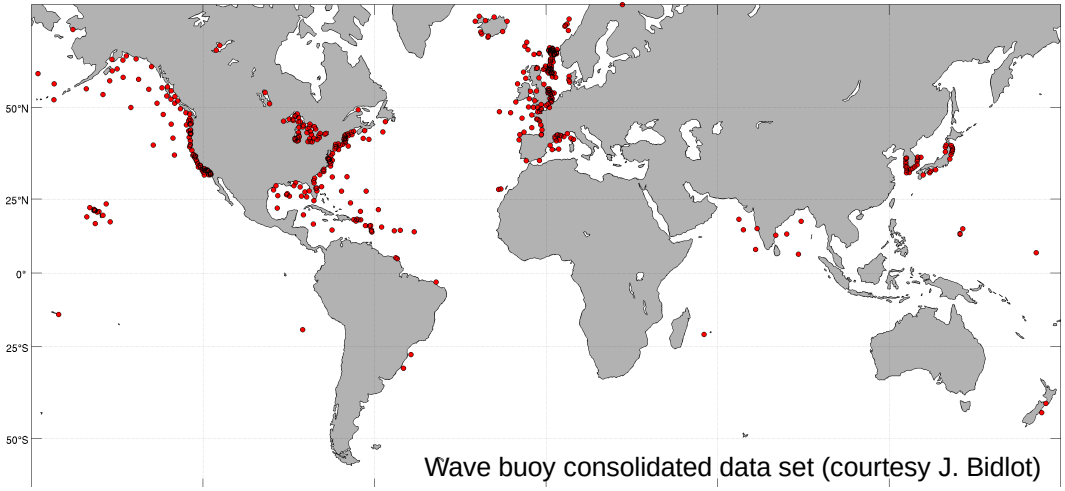

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Summary

Sea State is now acknowledged as a key parameter for climate science

- Now well recognized within IPCC reports (e.g. COWCLIP contributions)
- New Essential Climate Variable of the Global Climate Observing System
- Dedicated CCI project funded by ESA

The Sea State CCI is producing a climate quality Sea State dataset

- Open access and well documented
- Includes calibrated and denoised swh (+spectra parameters in next version)
- Designed for investigating long-term trends, extremes, mesoscale variability, interactions with other components of the Earth system (CCI ECV)

Your feedback will help us to improve this data

- Data available on https://forms.ifremer.fr/lops-siam/access-to-esa-cci-sea-state-data/
- User Consultation Meeting and online survey
- CCI will provide feedback to GCOS on requirements based on user consultation


...thank you
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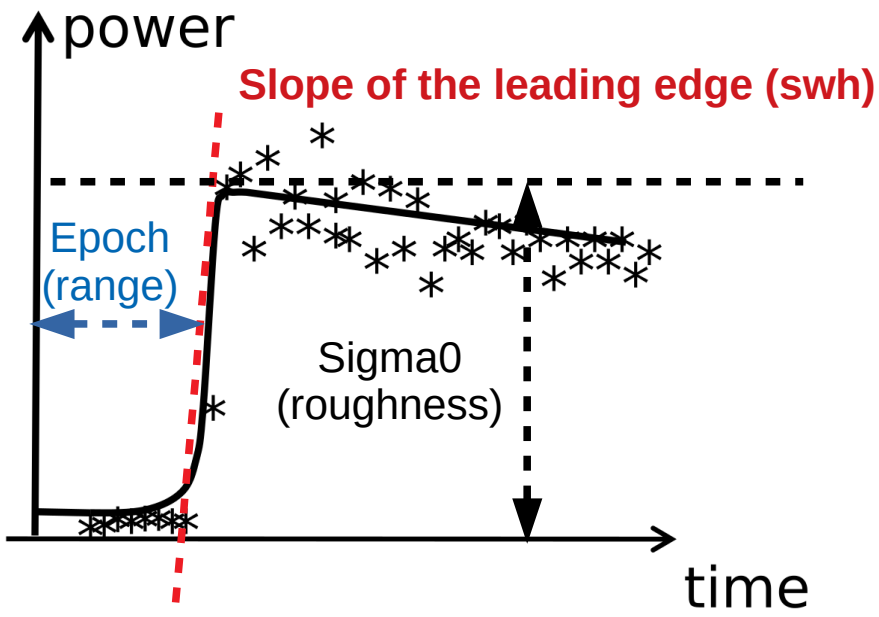
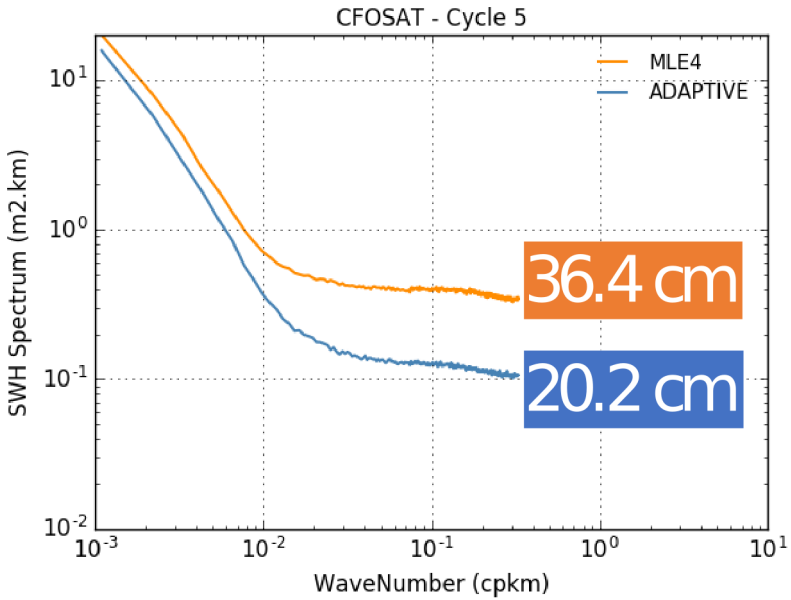
Retracking algorithm

- Most research has focused on the improvement on range estimation (for ssh, sla, msl trends)
- Current developments on SWH retrieval from waveform retracking are being assessed by CCI team



Waveform retracking = fitting a model (solid line) through a measured waveform (stars)



Example of lower noise level in CFOSAT measurements with the ADAPTIVE retracker