Status and Perspectives for Wave Height estimation from altimeter measurements

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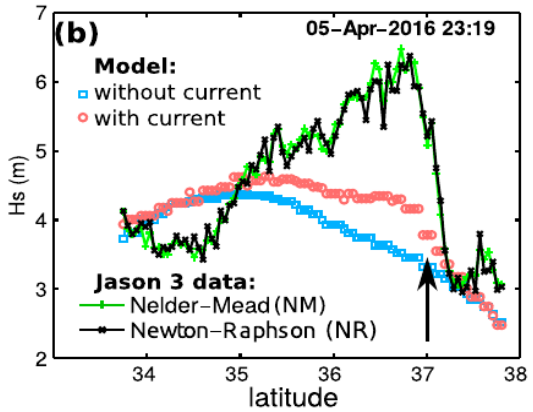
Rationale

- For many years, most of research is conducted on SLA and debates are mostly focused on it, in particular in this splinter when speaking about retracking
- But, wave height is also a **key parameter** derived from altimetry
  - for long term climate monitoring
  - for operational marine services
  - for coastal studies (coastal erosion …)
  - for extreme events
  - because of impacts on SSH via SSB
  - because of its correlation with currents
  - …



Courtesy F.Ardhuin, JGR 2017

- Objective: review of wave heights as provided by the different altimeter systems
  - Accuracy
  - Precision
  - Bias/Noise correlated to the wave period

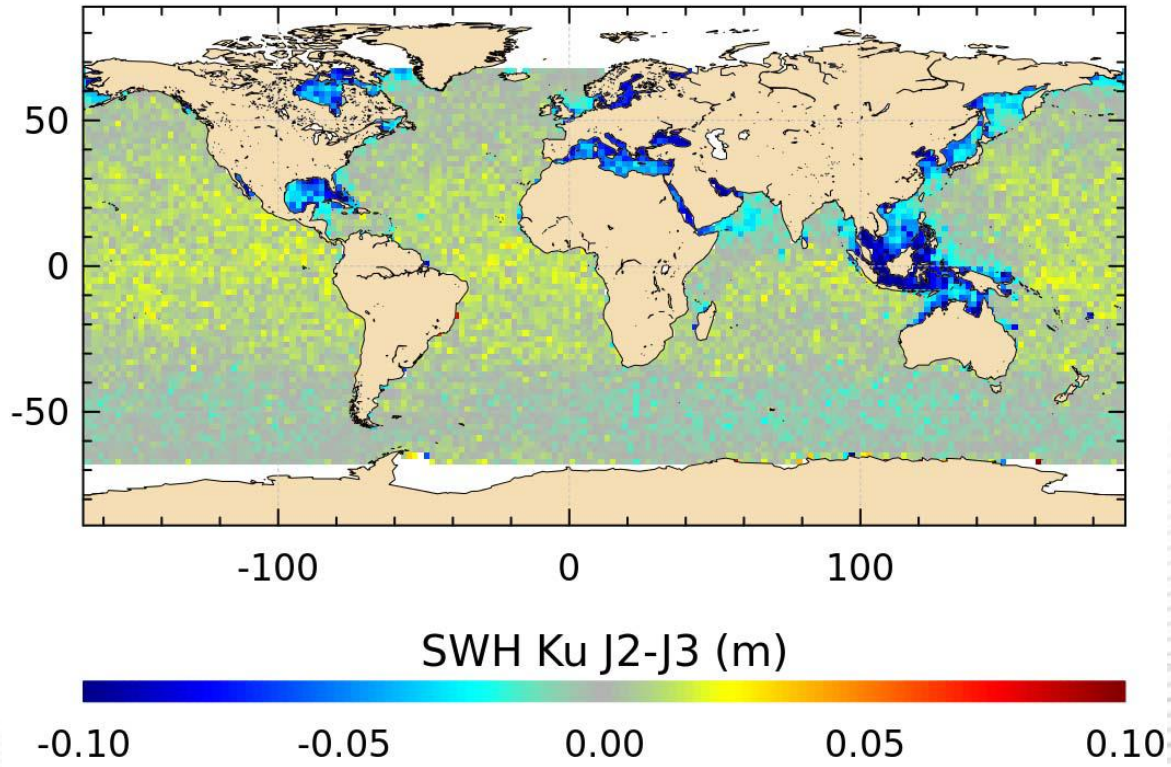
  ➔ Objective to get higher performances and continuity between missions

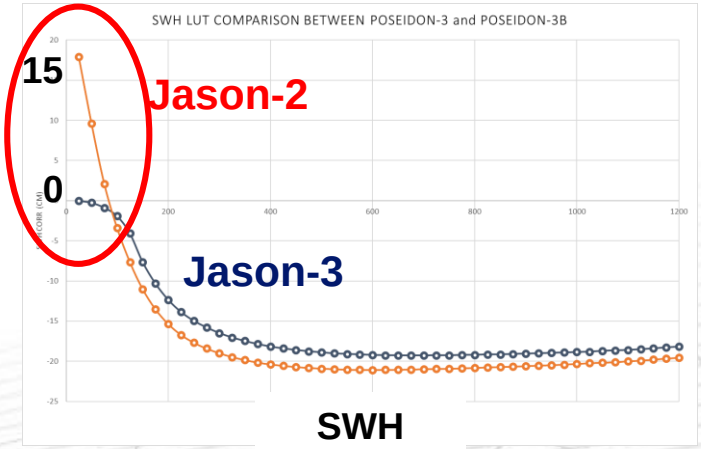
Missions are already providing very nice SWH estimates but there are still **areas for improvement** in the processing

Biases

Jason-2 / Jason-3

- Jason-2 and Jason-3 fully consistent (+-2cm) except for very small SWH (below 1m)
- Differences are explained by the evolution of LUT corrections (Jason-2 not yet reprocessed)



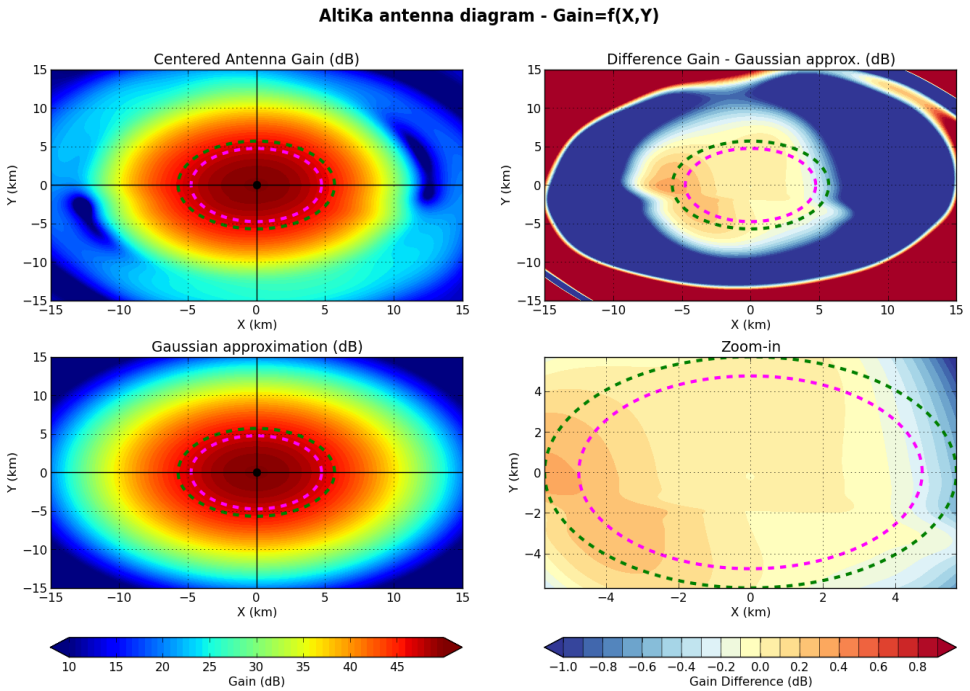


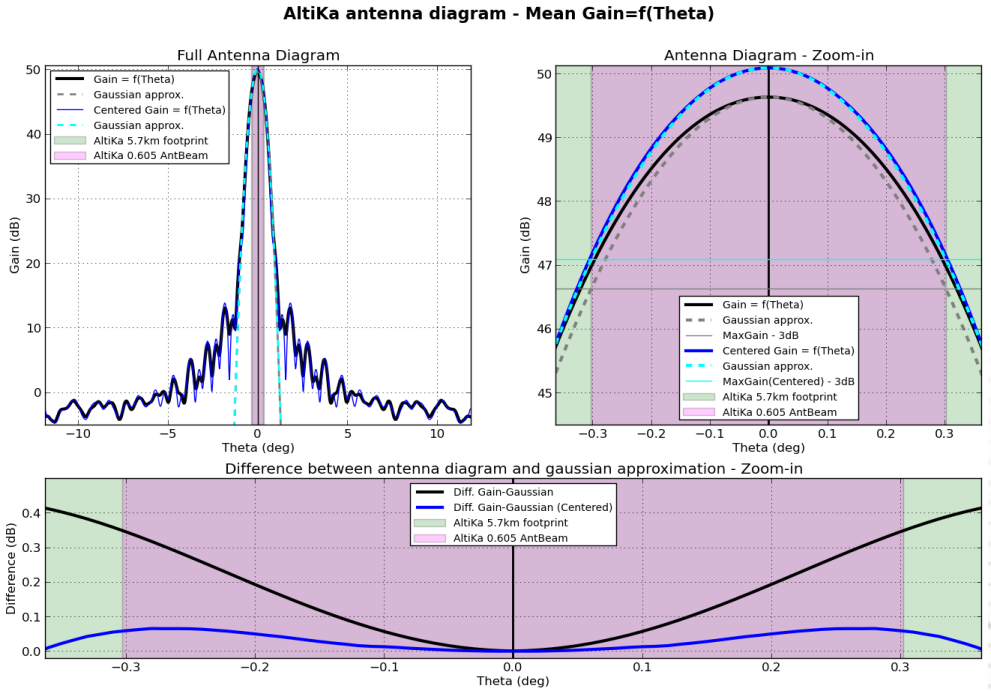
SWH corrections for POS3 and POS3-B

Biases

Saral / AltiKa

The gaussian approximation for the Antenna Gain Pattern is not fully valid for small apertures (~0.6 deg) (cf S.Le Gac at OSTST, 2016)





Impacts on SWH can be accounted for by LUT provided as a function of SWH.

Biases

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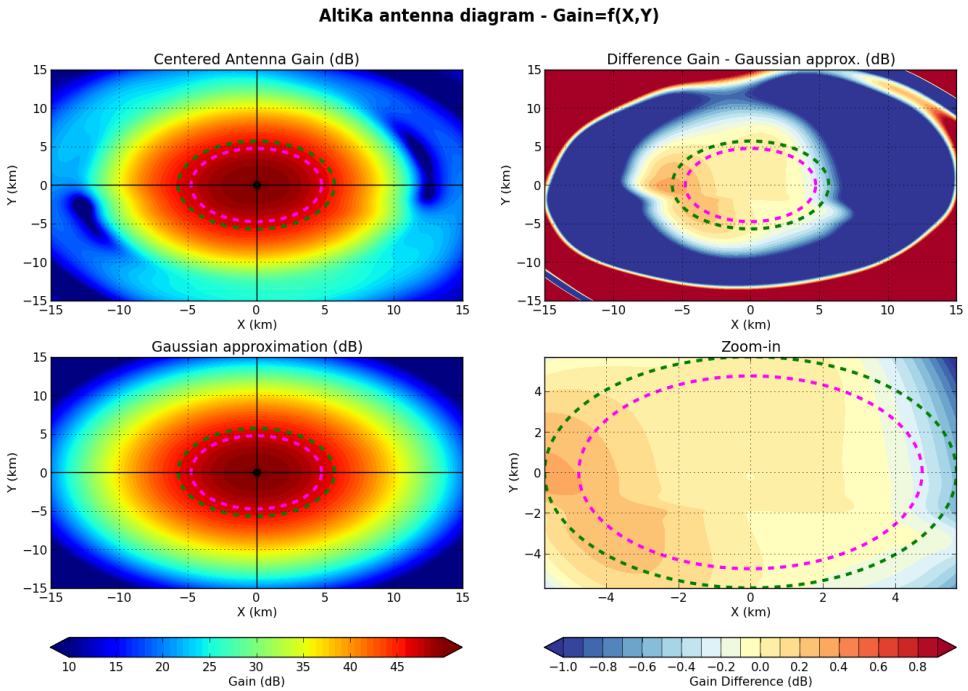
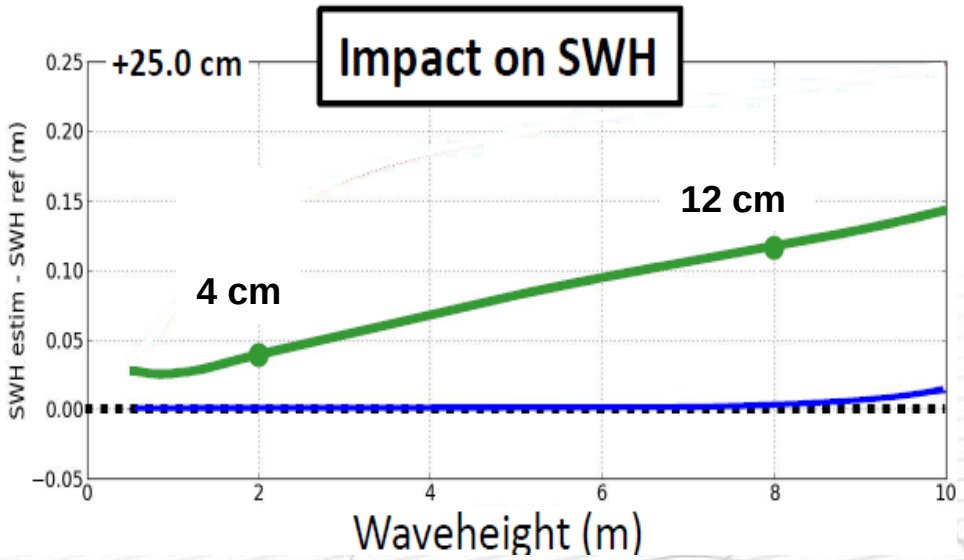




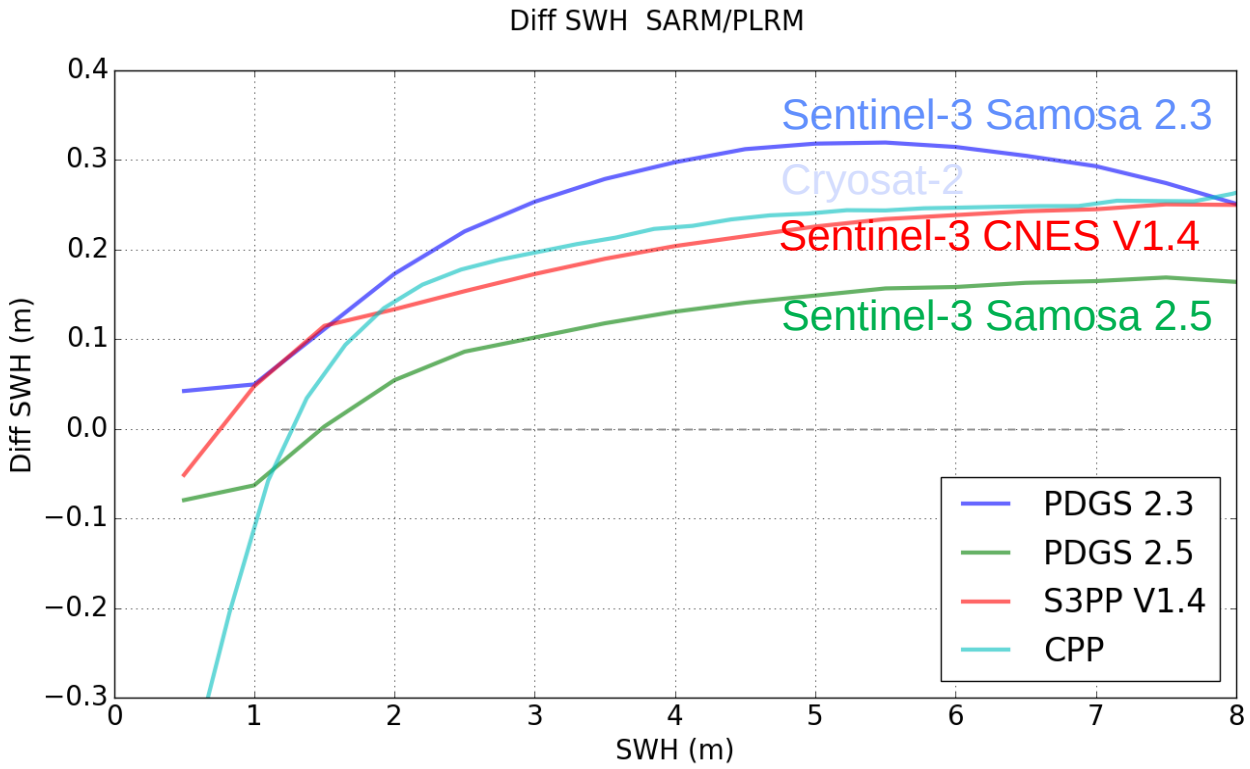
It depends also on pointing angle (gaussian approx. even worse during mispointing events) and we all know that Saral experienced in the past some pointing issues.
Ongoing reprocessing activity (GDR-E) at CNES with new LUT including real antenna pattern. Products will be available soon.

Biases

Sentinel-3A

Different SAR processors are showing a similar behavior when looking at SARM/PLRM differences

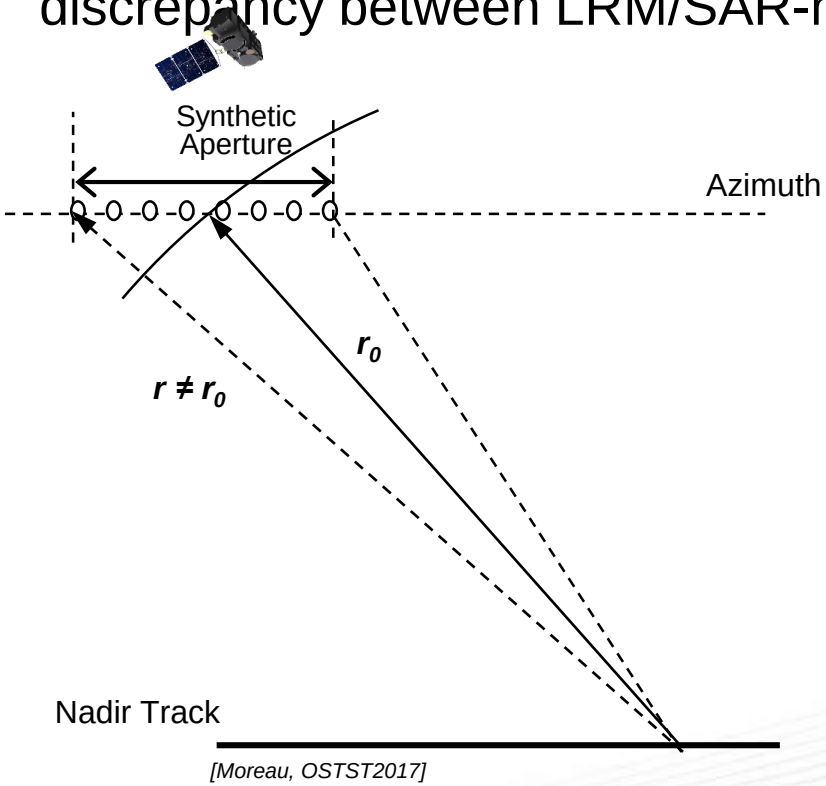
- ~ bias of about 15cm for SWH > 2m with
- dependency with SWH in particular for small waves



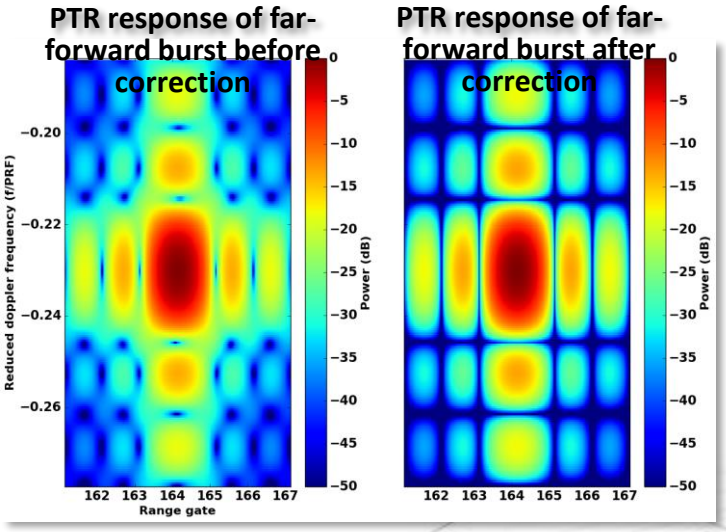
Biases

Sentinel-3A

Accounting for « range walk » in SAR processing allows reducing SWH discrepancy between LRM/SAR-mode

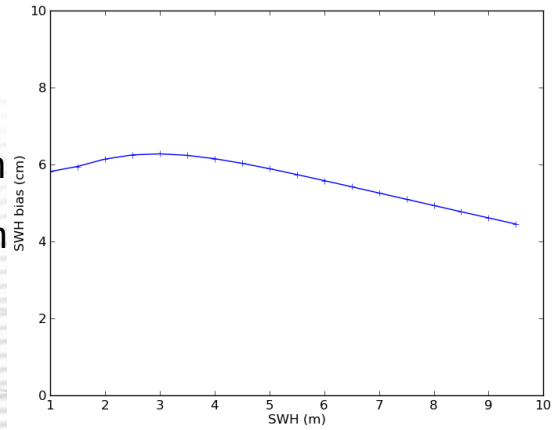


[Moreau, OSTST2017]



6 cm

4 cm



RW correction removes 5 cm to current SAR SWH with no big dependency with SWH

(see T.Moreau, OSTST 2017)

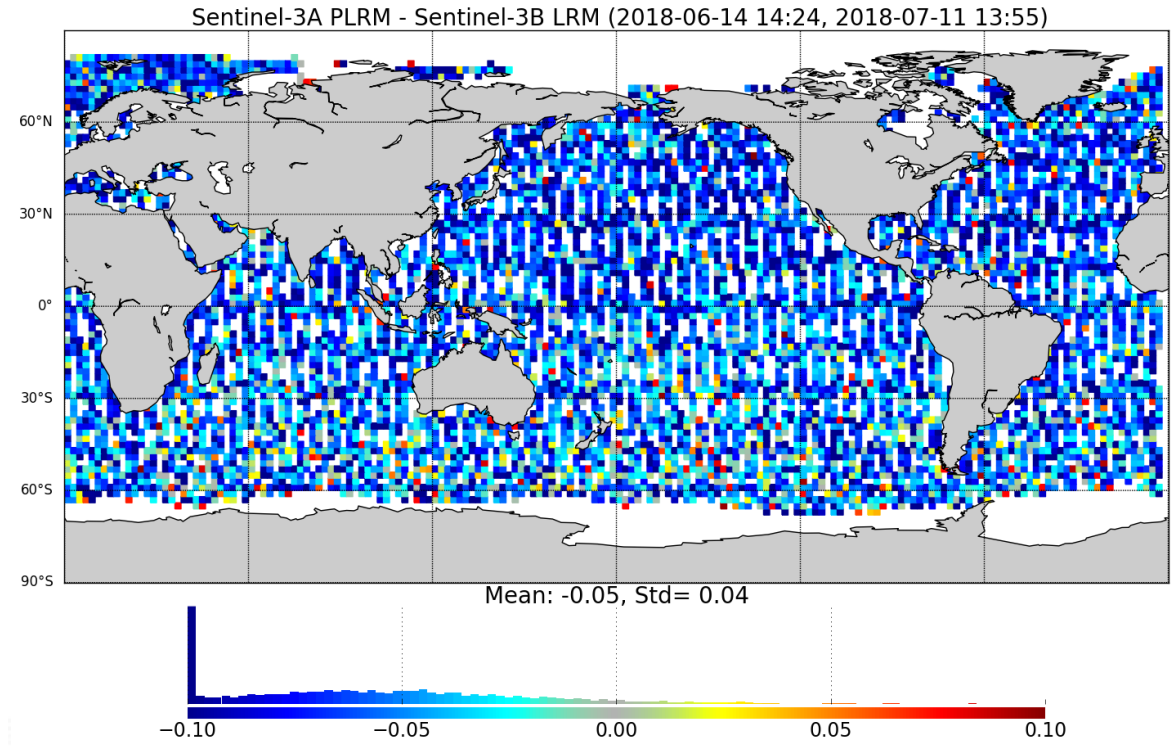
But not introduced yet in the operational processor (only in CNES processing)

Biases

First look at Sentinel-3A / Sentinel-3B tandem phase

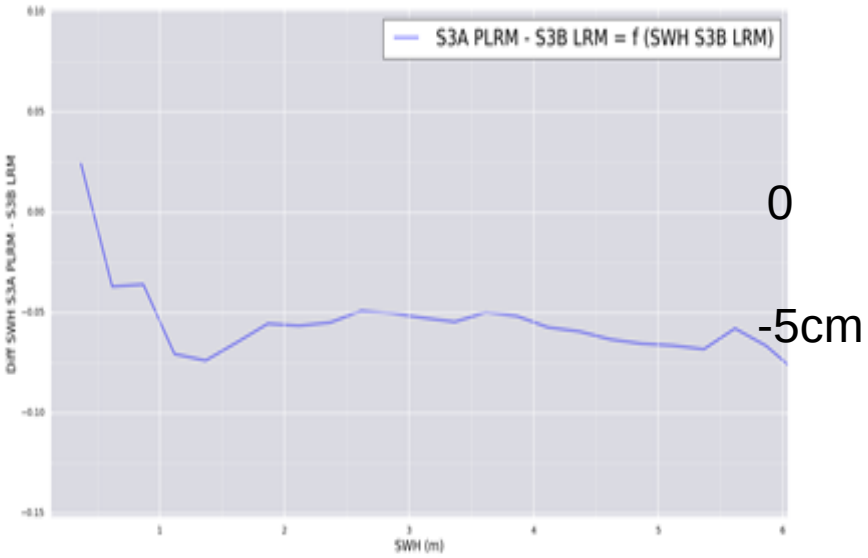
A bias can be seen between PLRM (which is the reference when looking at SAR data) and LRM which is not explained by LUT differences ➔ ongoing activity to better understand these differences

Map of PLRM / LRM SWH differences



(source S3PP CNES processing)

S3A PRLM – S3B LRM



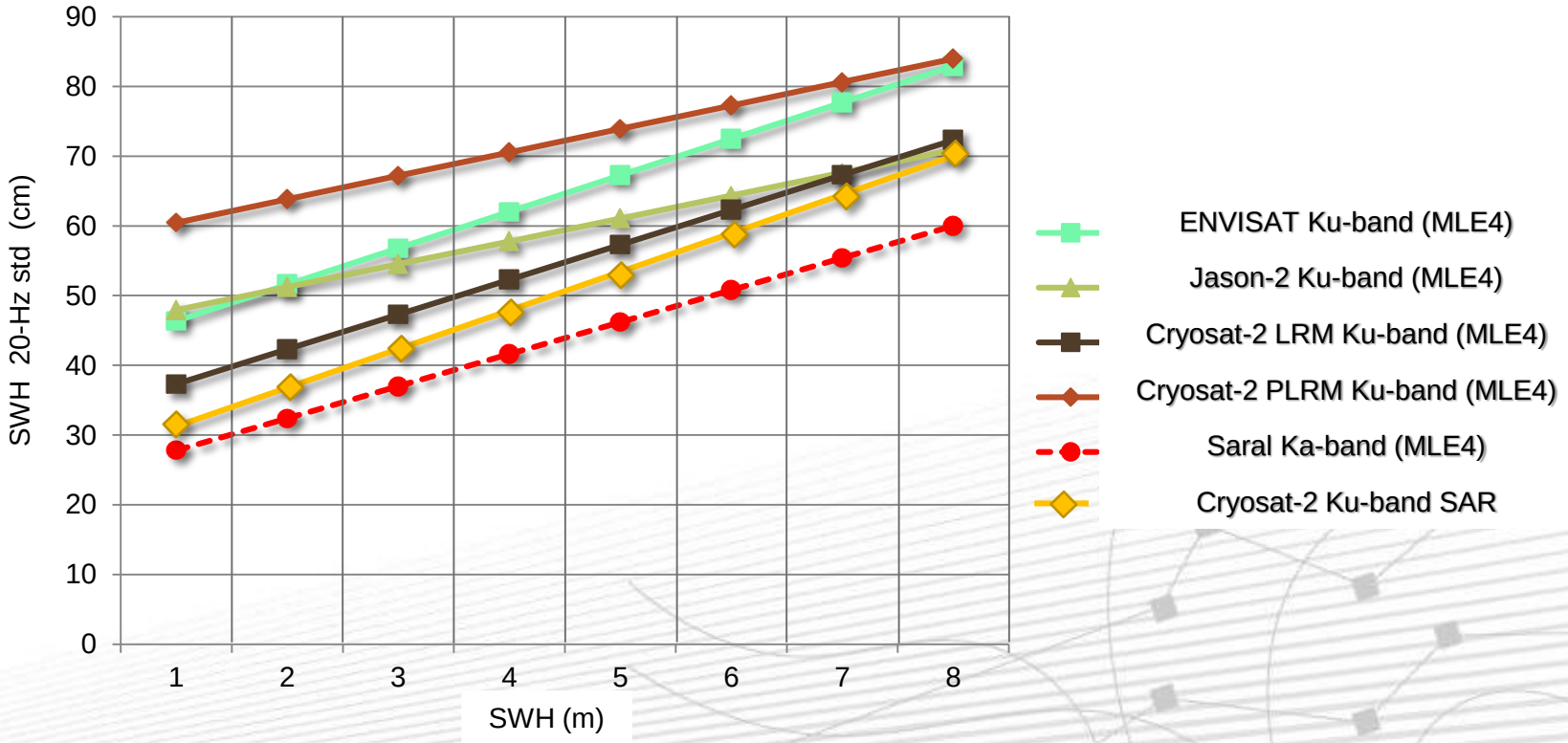
Quite stable above 1m SWH

Precision

What about precision of estimation ?

It can be shown with two different metrics:

- ❑ **20Hz/40Hz standard deviations**
- ❑ Power Spectral Density



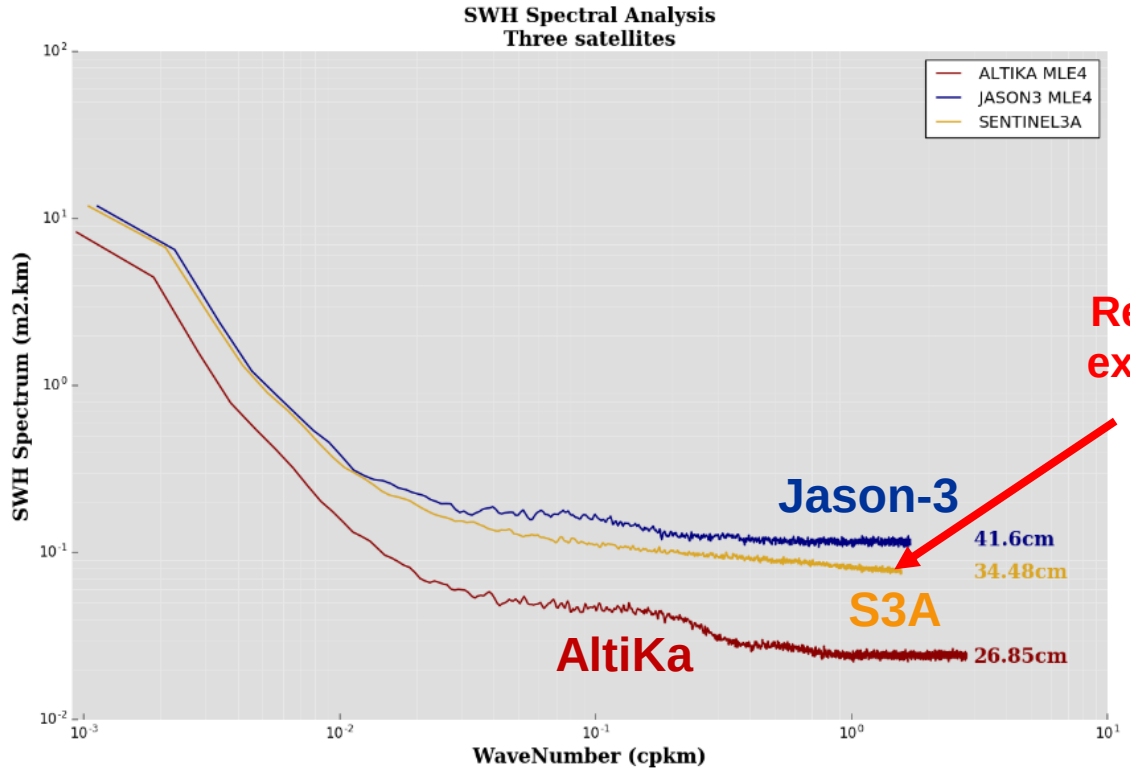
Precision

What about precision of estimation ?

It can be shown with two different metrics:

- ❑ 20Hz/40Hz standard deviations
- ❑ **Power Spectral Density**

Both metrics are consistent if looking at HF noise level



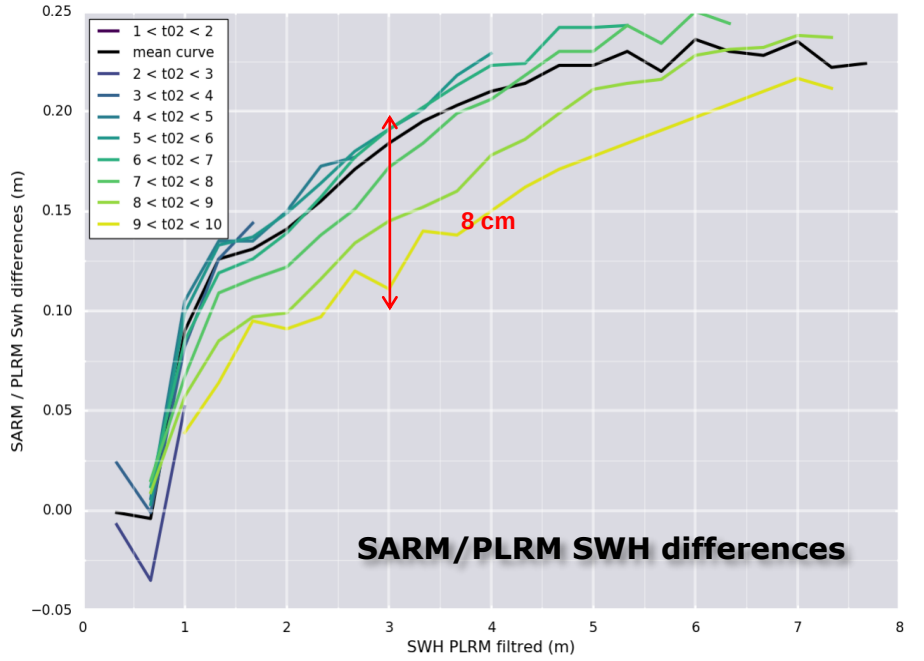
Red noise in SAR PSD spectrum explained by the correlation with swell (M.Raynal & al, 2018)

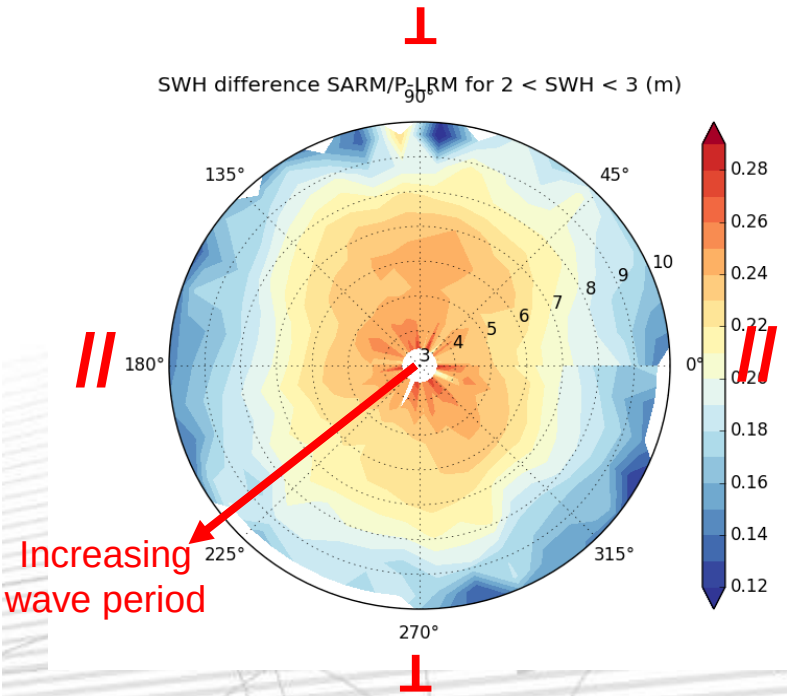
Dependencies

Analysis of swell induced errors (S-3A)

[Moreau et al., Adv & Space Research, 2018]

- **Increase of noise level with SWH, swell period and for swell parallel to satellite flight direction Strong impact of T02 on SAR mode SWH** (8 cm between 5s and 10s period for SWH = 2.7m)





Solutions

How to improve SWH estimation ?

(see P.Thibaut talks in La Rochelle & Miami at OSTST, 2016-2017)

LRM

Cramer Rao Bound computation clearly indicates huge potential to improve SWH estimation (more than other parameters) (Mailhes & al, Proc of Eusipco Conference, Edinburgh, 2008).

The variance of any unbiased estimator of Pu, t and SWH is bounded below by its corresponding Cramer-Rao bound (CRB) which is obtained by inverting the Fischer Information Matrix

CLS/CNES decided to change the estimation method (Newton Raphson in MLE4 but that can be considered as a least square method) and we moved **to a true Maximum Likelihood Estimation method that accounts for speckle distribution** (True Likelihood criterion with a Downhill Simplex method) ➔ Nelder Mead solution

Adaptive Retracker

It accounts as well for the true Instrumental characteristics (PTR) and has been fully validated. 20Hz estimation are directly usable without any Look Up Tables. And many other qualities (for range, sigma0, peacky echos, continuity, …..)

Potential drifts of instrumental features are directly taken into account

(Note that SAR S3 SWH is drifting by 1 cm/year wrt ECMWF due to evolution of the PTR : S.Dinardo communication to MPC. Not corrected yet)

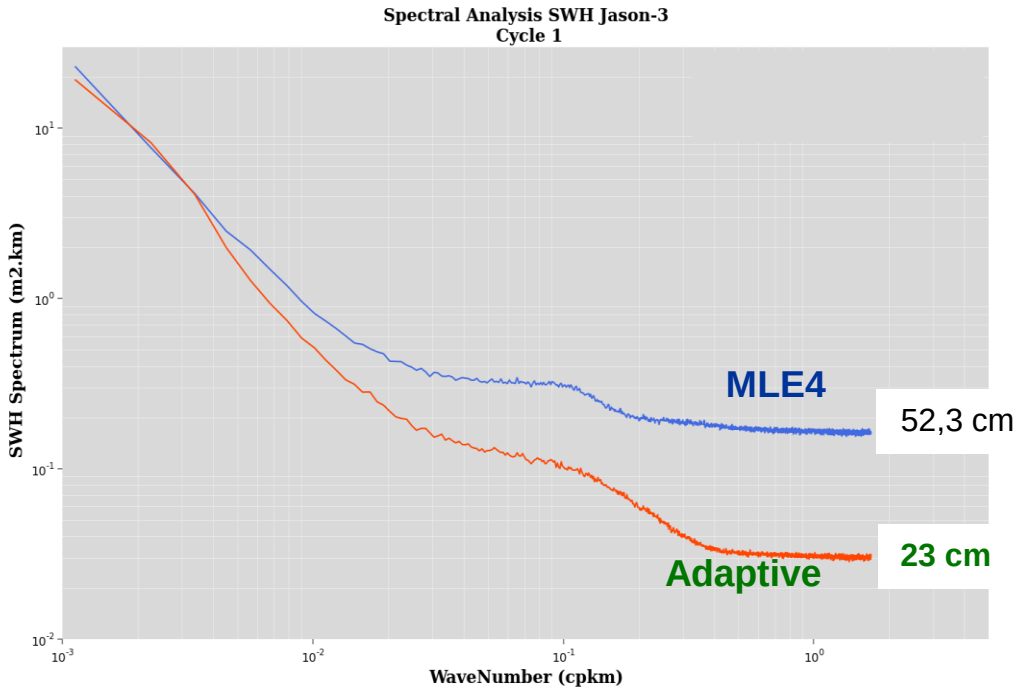
Solutions

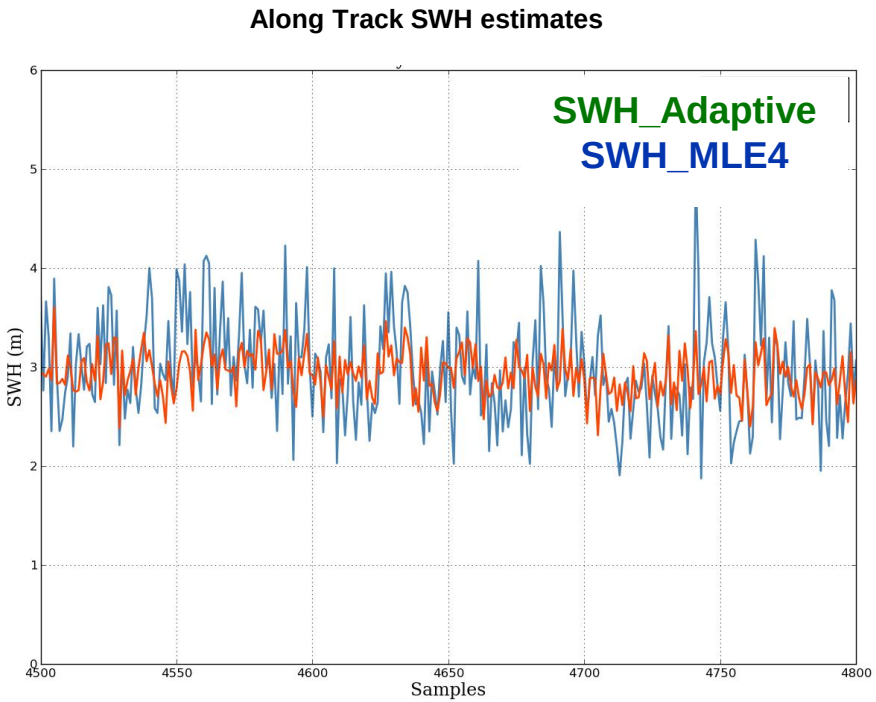
Adaptive Retracker (Jason-3)

LRM

Results are spectacular in particular regarding SWH estimates

Spectral analysis shows clear reductions of the 20Hz noise level with the Adaptive retracker ➔ -60% for SWH

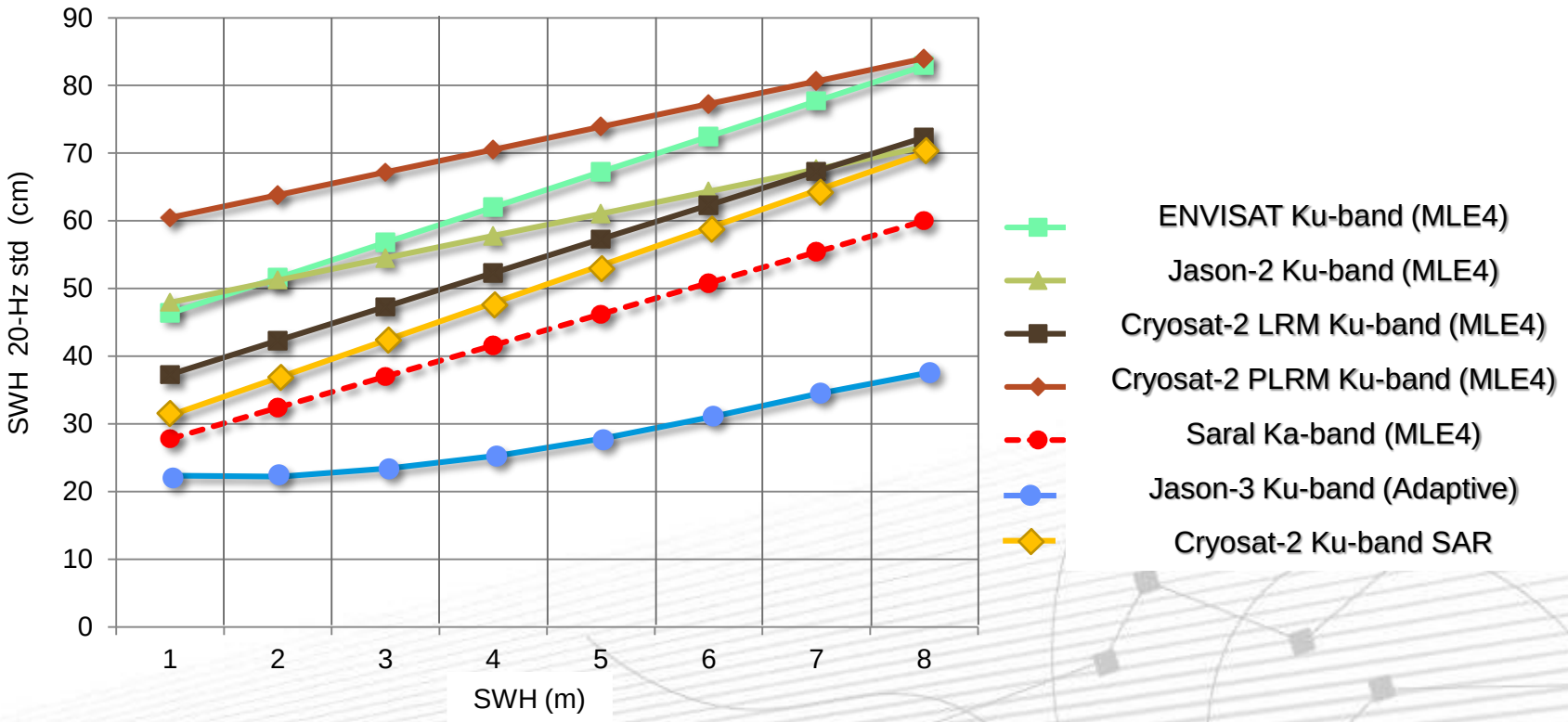




Solutions

Adaptive Retracker (Jason-3)

LRM



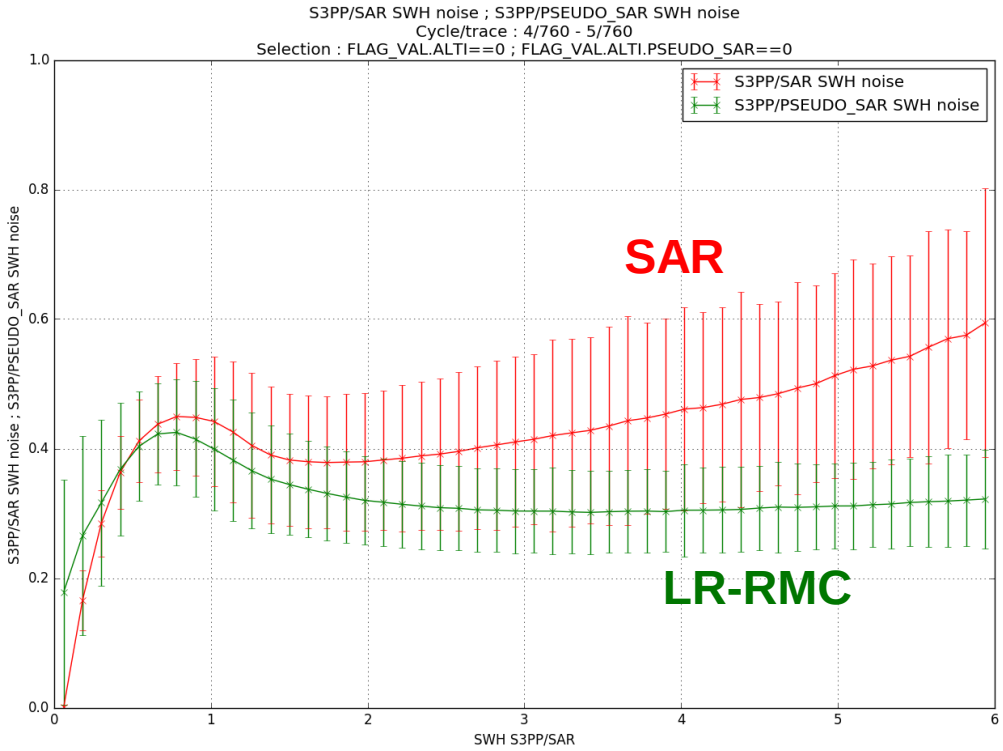
Solutions

LR-RMC processing (S-3)

SAR

(see F.Boy talk in Miami OSTST, 2017
& T.Moreau talk, this session)

New way to process the SAR data at Level-1.



Clear reduction of SWH noise level wrt to SAR (~-40%)

Solutions

LR-RMC processing (S-3)

SAR

(see F.Boy talk in Miami OSTST, 2017
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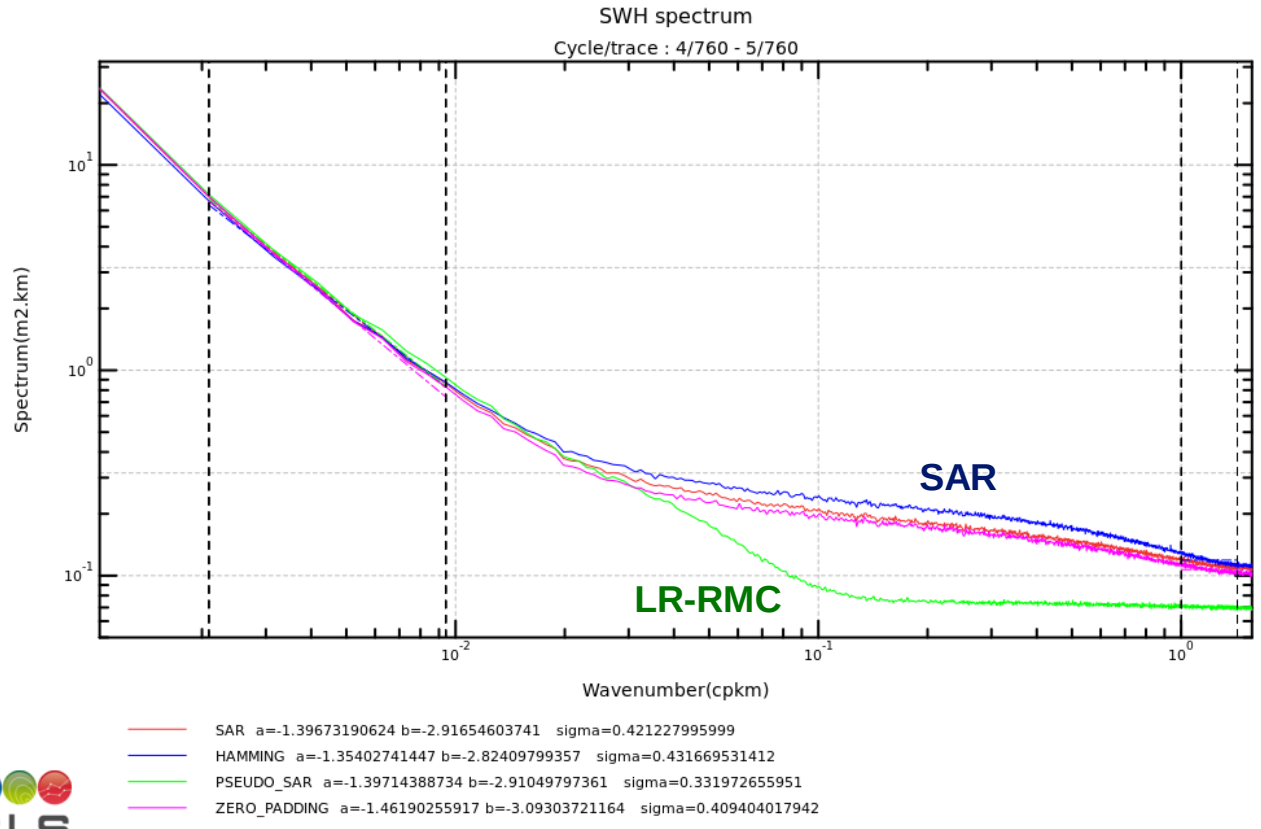


SAR spectrum is largely impacted by swell for scales < 50km

LR-RMC spectrum is cleaner despite a very low filtering effect at 20km (antenna footprint)

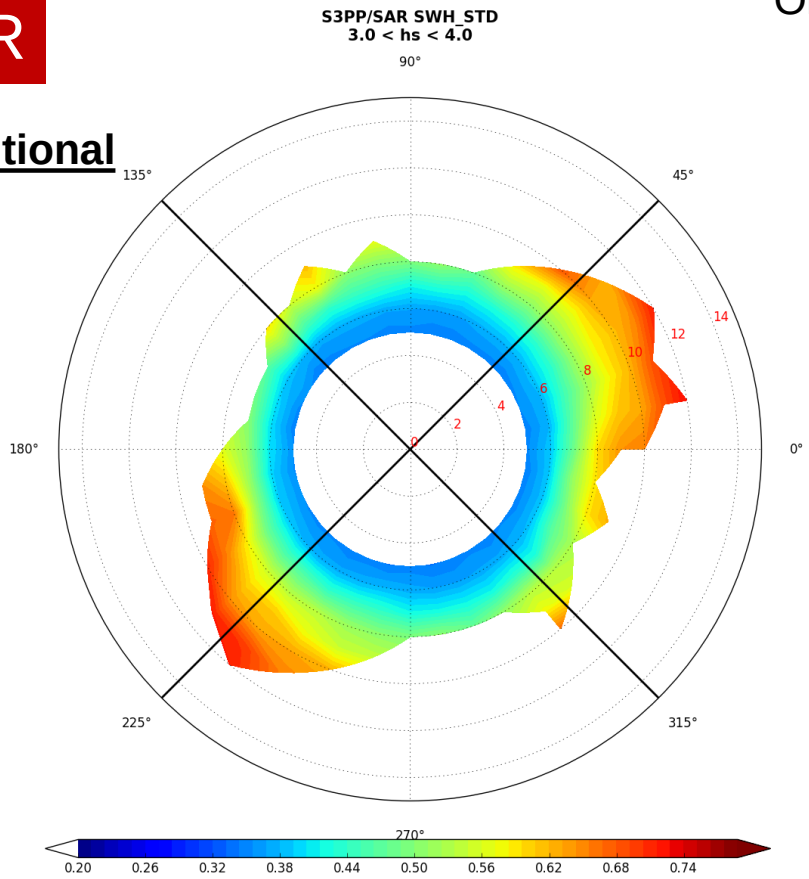
Solutions

LR-RMC processing (S-3)

SAR

On swell induced effects

Conventional SAR



Noise level depends on sea-state parameters (wavelength and direction)

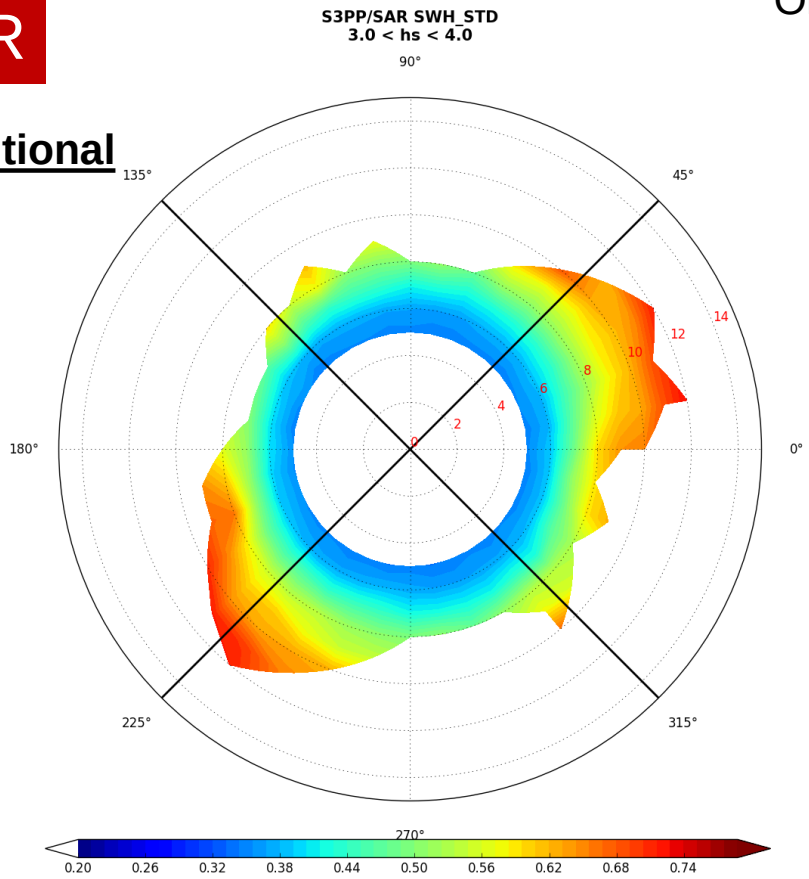
Solutions

LR-RMC processing (S-3)

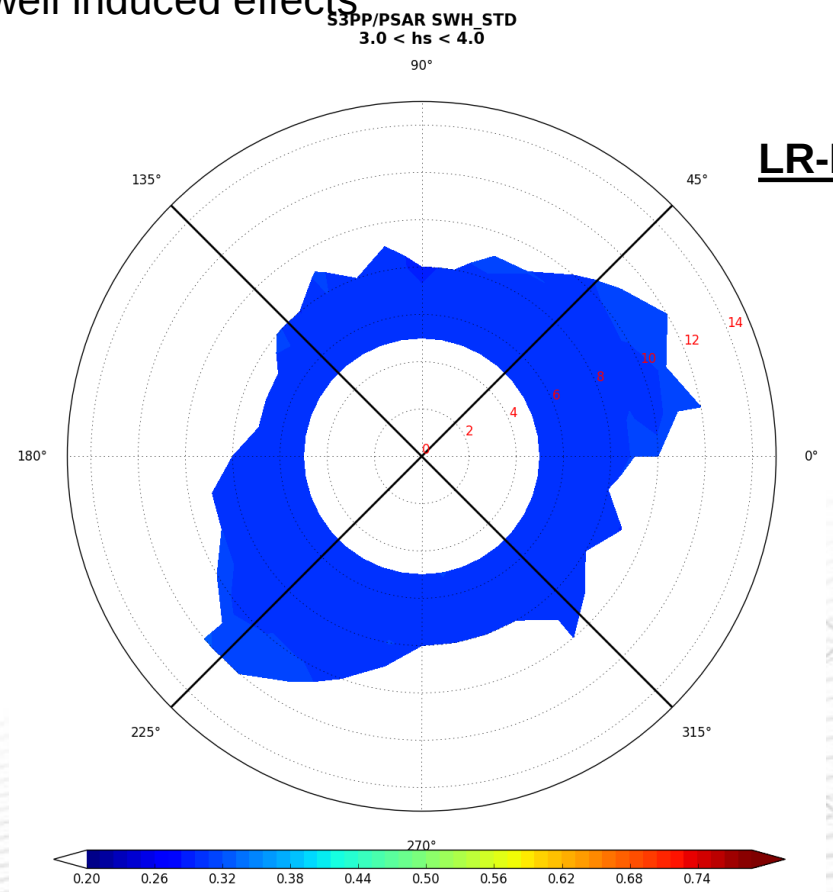
SAR

On swell induced effects

Conventional SAR



LR-RMC



Noise level depends on sea-state parameters (wavelength and direction)

No more dependency on sea-state parameters (wavelength and direction)

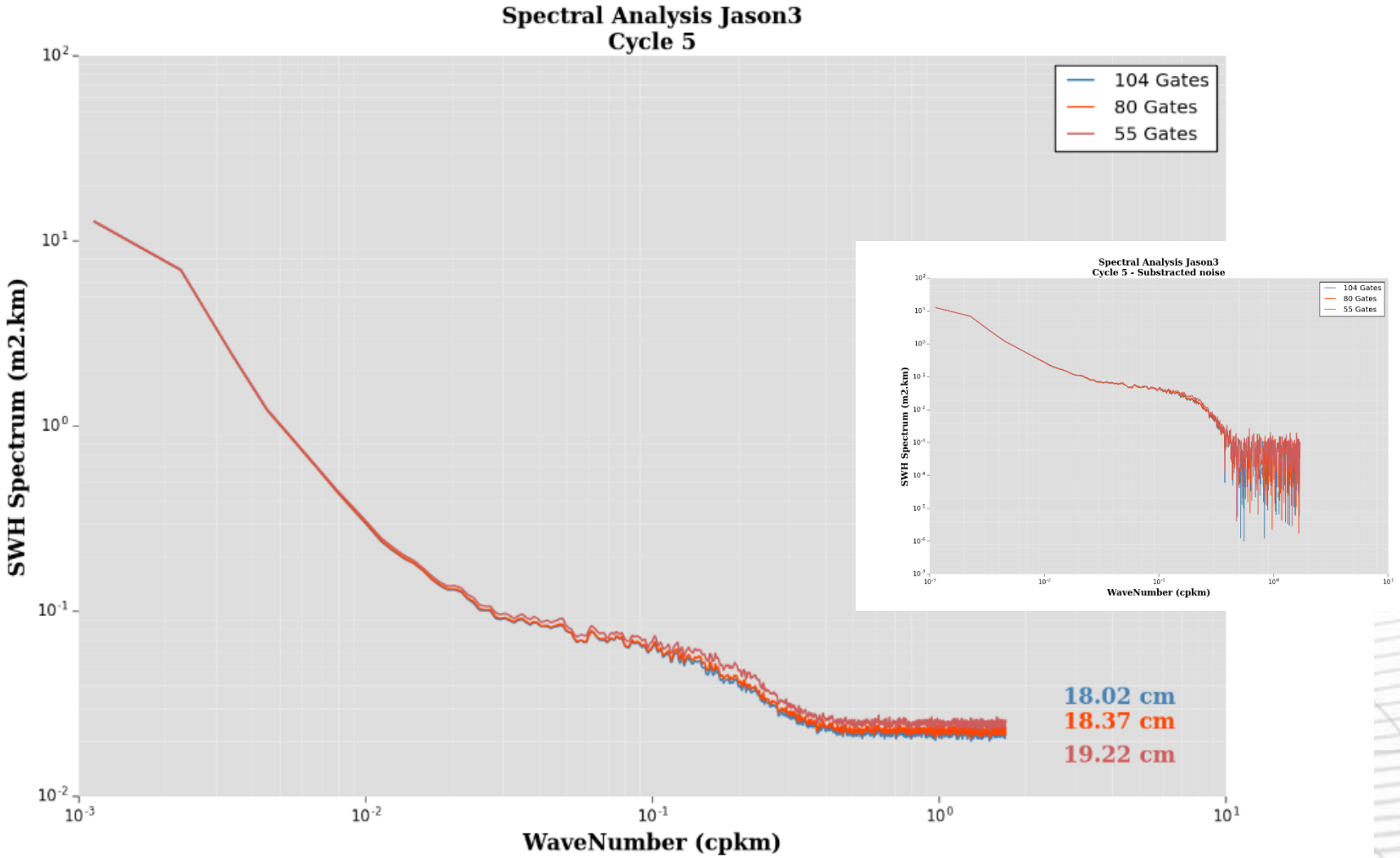
Conclusion

- Still some improvements to be done on Jason and Saral missions (future reprocessing)
- Very powerfull «Adaptive method» retracker for LRM ready to be implemented.
- Swell induced errors observed in SAR can be removed by using LR-RMC L1 processing ➔ clear improvement of performances wrt SAR
- New retracking strategies oriented towards SWH improvements could be investigated (as 2pass retrackers for SSH, …)
- For SAR, performances are still not fully satisfactory and work has to be done before the Sentinel-6 mission which will be a reference mission for Copernicus (Jason-Continuity of Service)
- CFOSAT mission very soon
- Ongoing ESA CCI-Sea-State activity conducted by F.Ardhuin to compare different estimation solutions (alti and SAR images) and to produce the best data for each mission. Have a look at M.Passaro poster presenting the algo.Dev team in CCI.

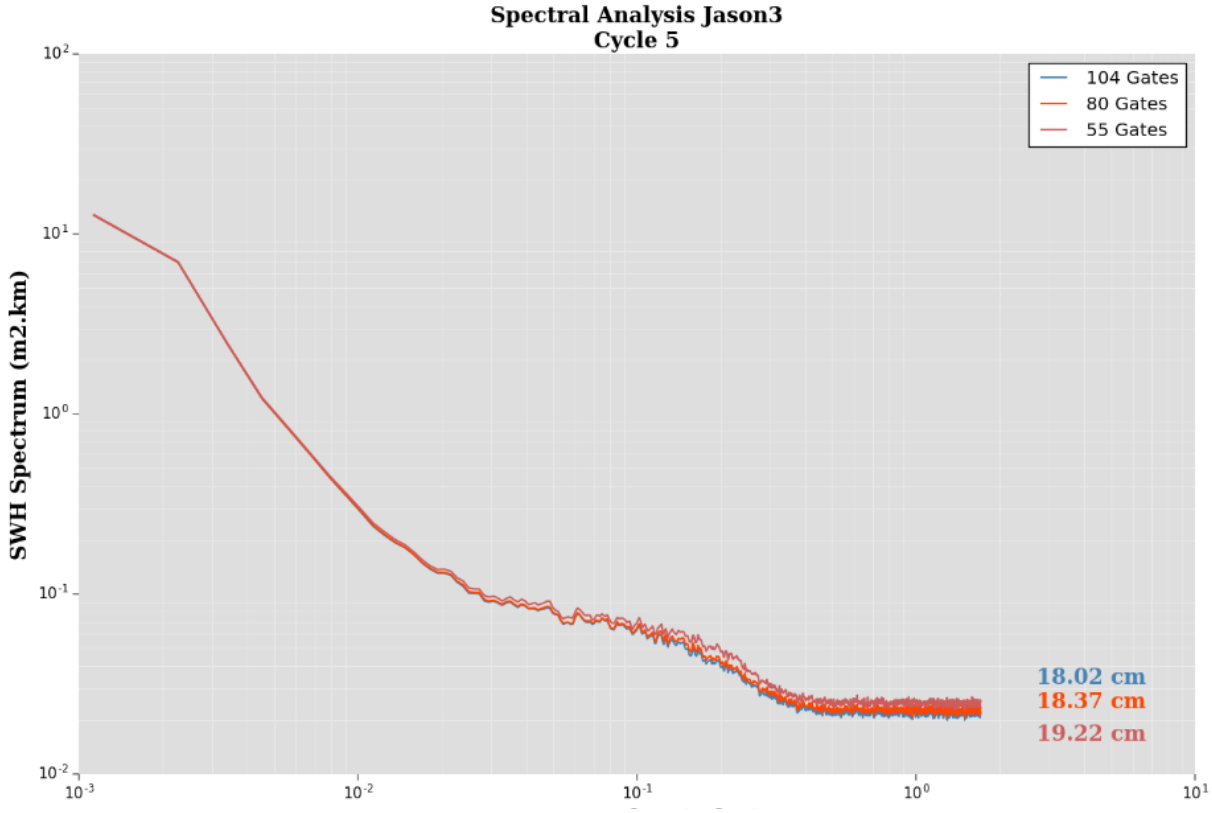
… Thank you for your attention …

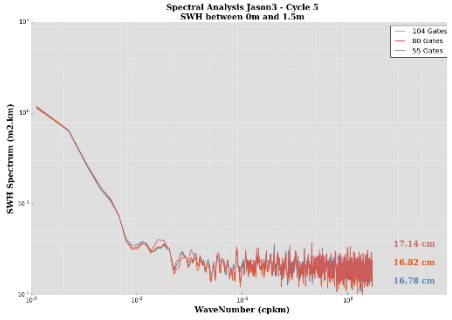
… Back up slides …

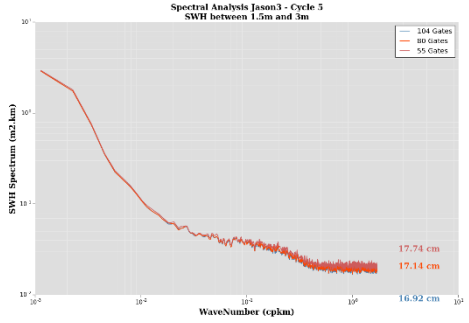
Reduction of the Retracking Window

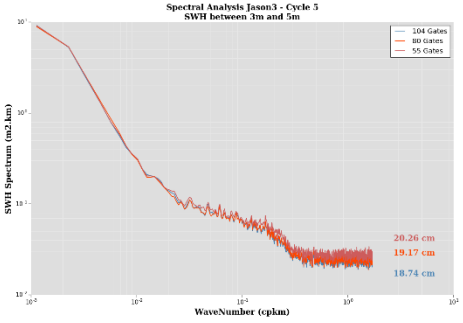


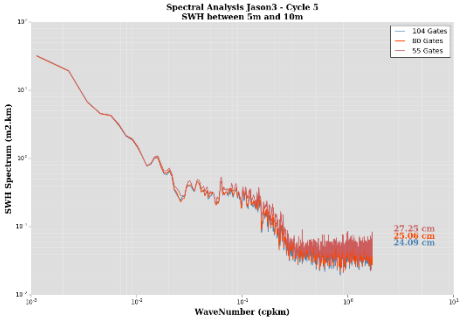
Reduction of the Retracking Window

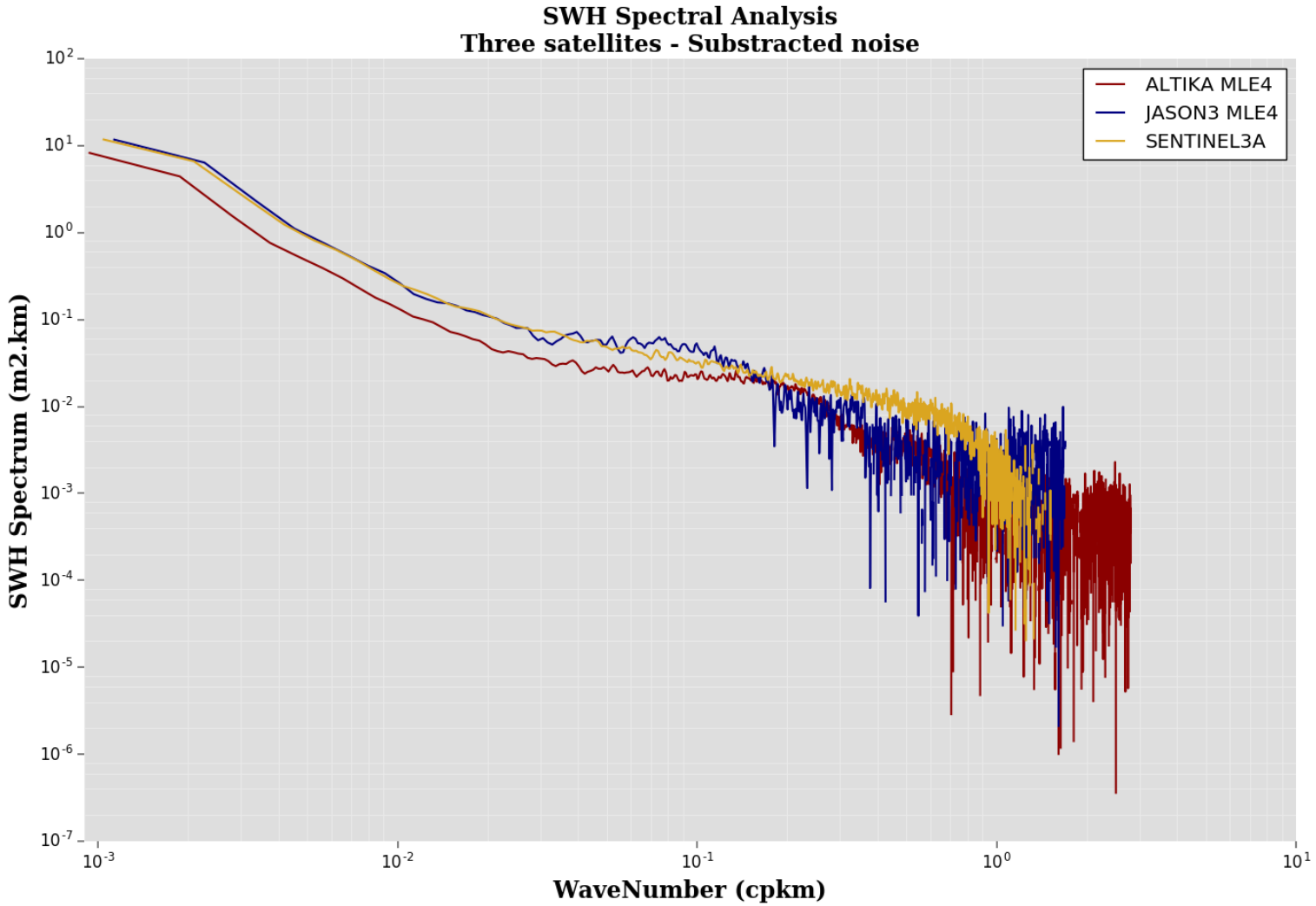


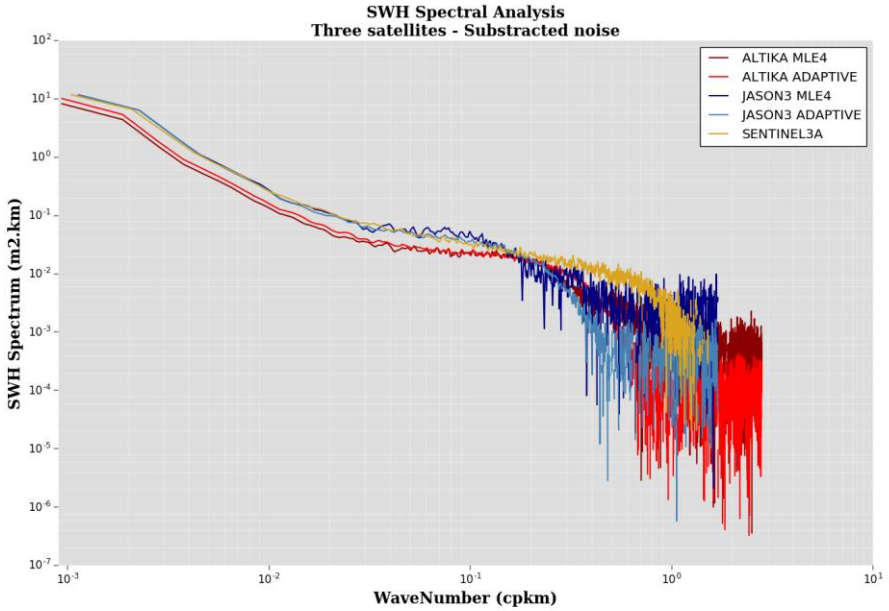









SWH Spectral Analysis
Three satellites - Substracted noise
ALTIKA MLE4
JASON3 MLE4
SENTINEL3A
SWH Spectrum (m2.km)
WaveNumber (cpkm)
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}


SWH Spectral Analysis
Three satellites - Substracted noise
ALTIKA MLE4
ALTIKA ADAPTIVE
JASON3 MLE4
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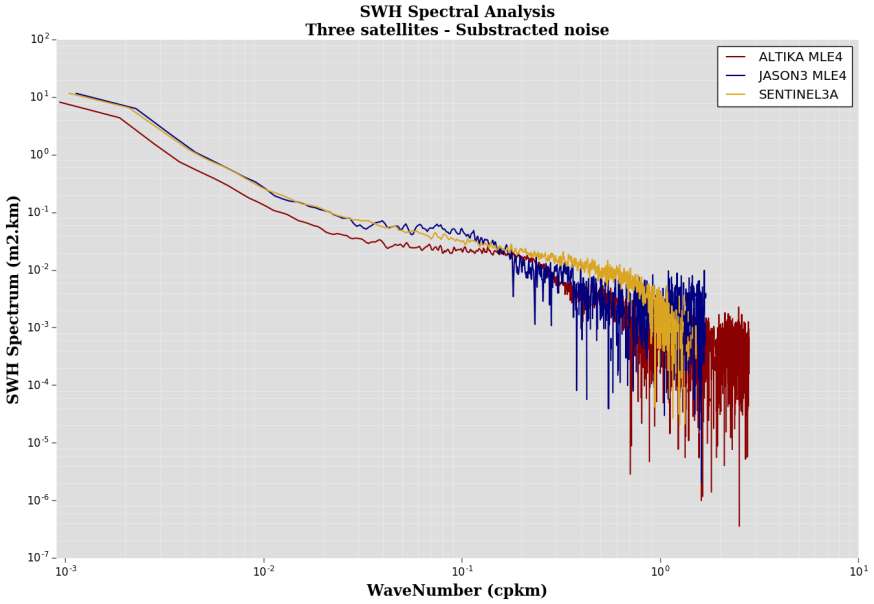
SWH Spectrum (m2.km)
WaveNumber (cpkm)


SWH Spectral Analysis
Three satellites - Substracted noise
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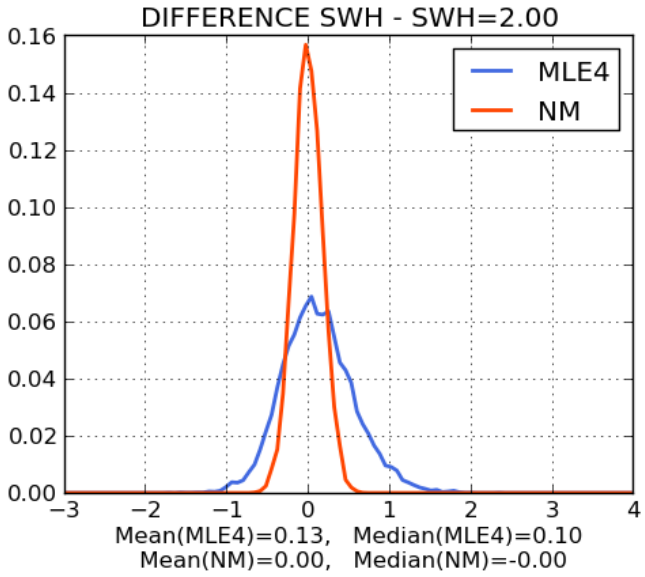
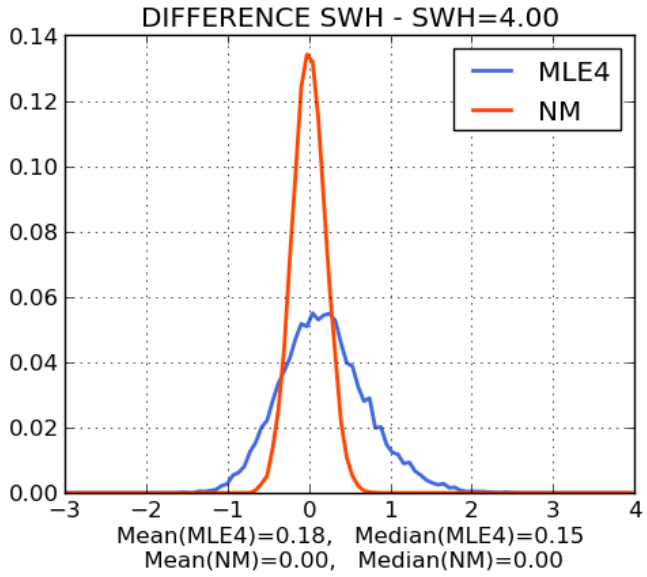
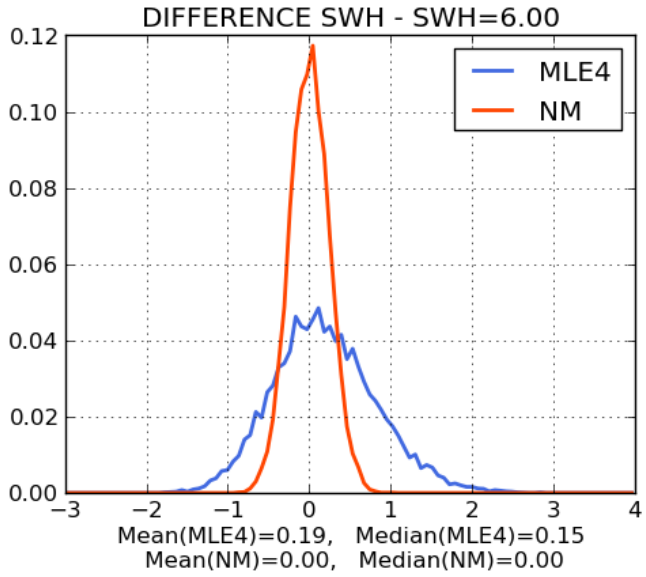
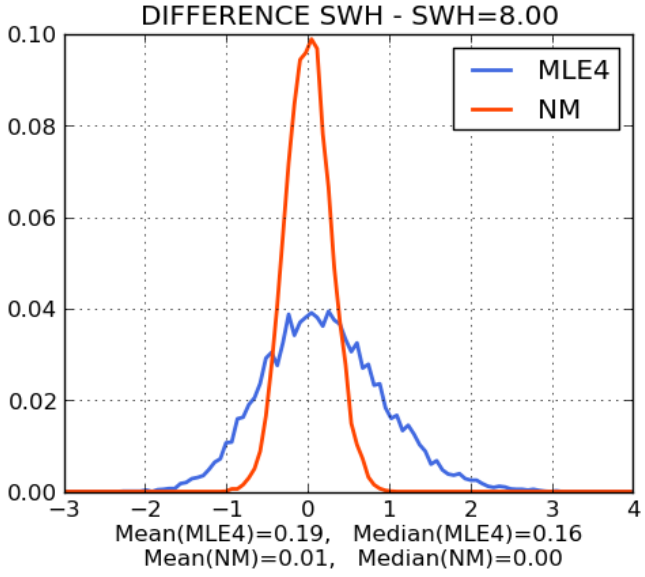
SENTINEL3A
SWH Spectrum (m2.km)
WaveNumber (cpkm)

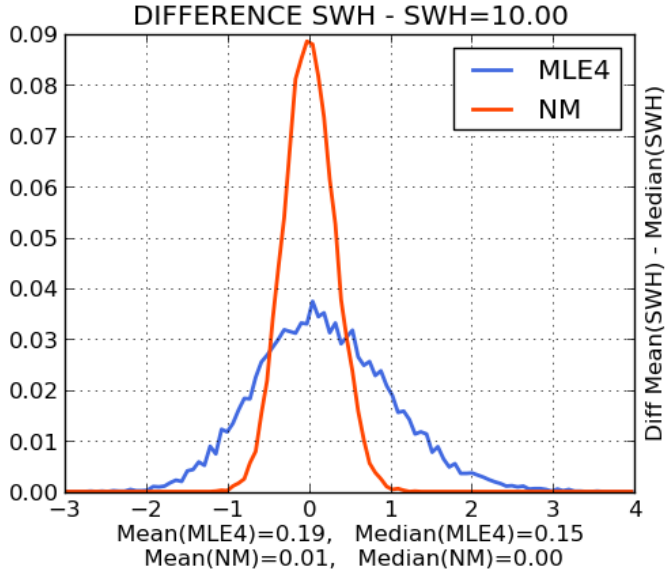
Computation of MLE4 LUTs

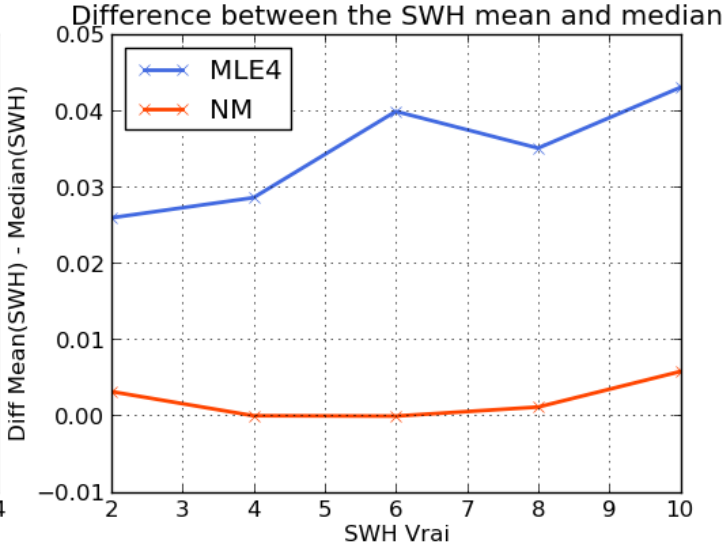




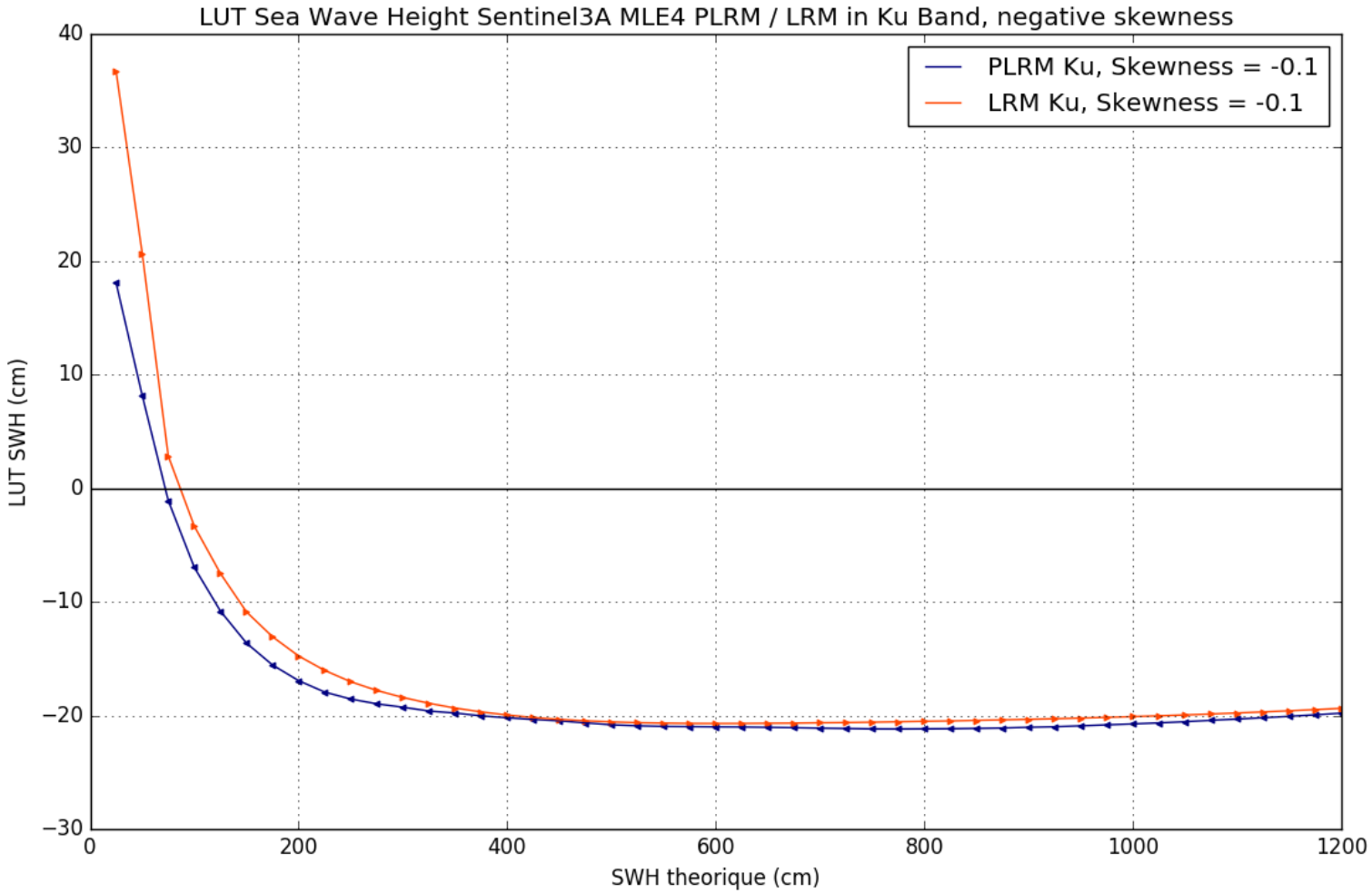








Difference between PRL and LRM Look Up Tables for Sentinel-3 A and B

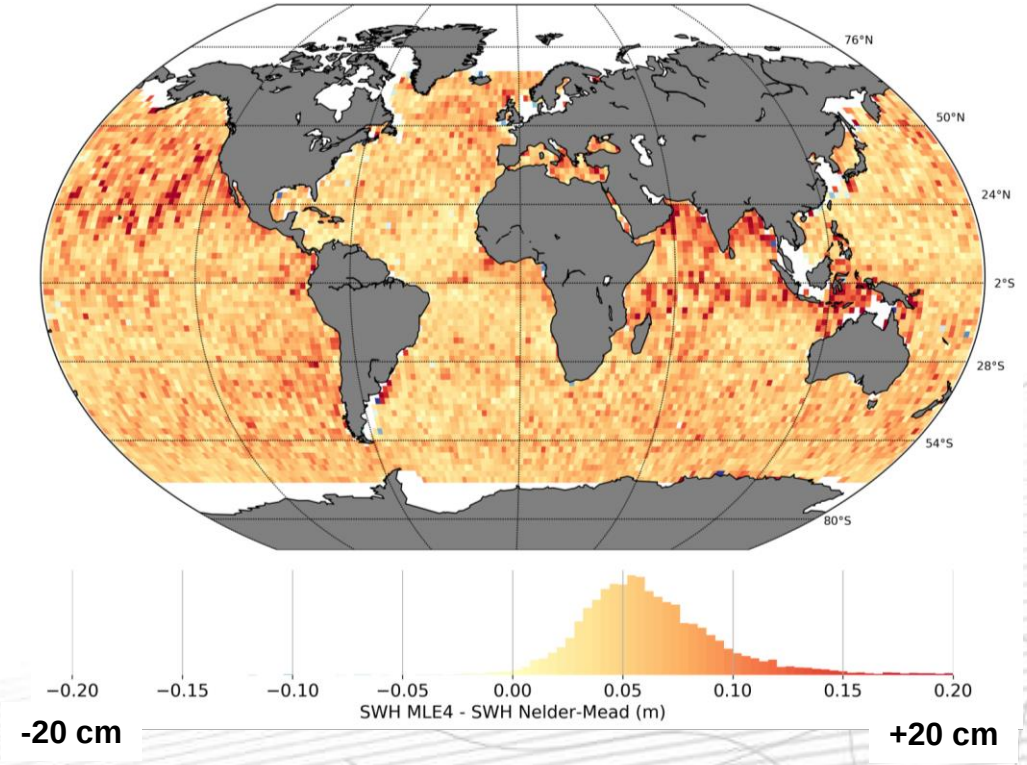


Solutions

Adaptive Retracker (Jason-3)

LRM

SWH_MLE4 – SWH_Adaptive



MLE4 estimates account for LUT

Biases

Saral / AltiKa