Wave height estimation from altimeter measurements

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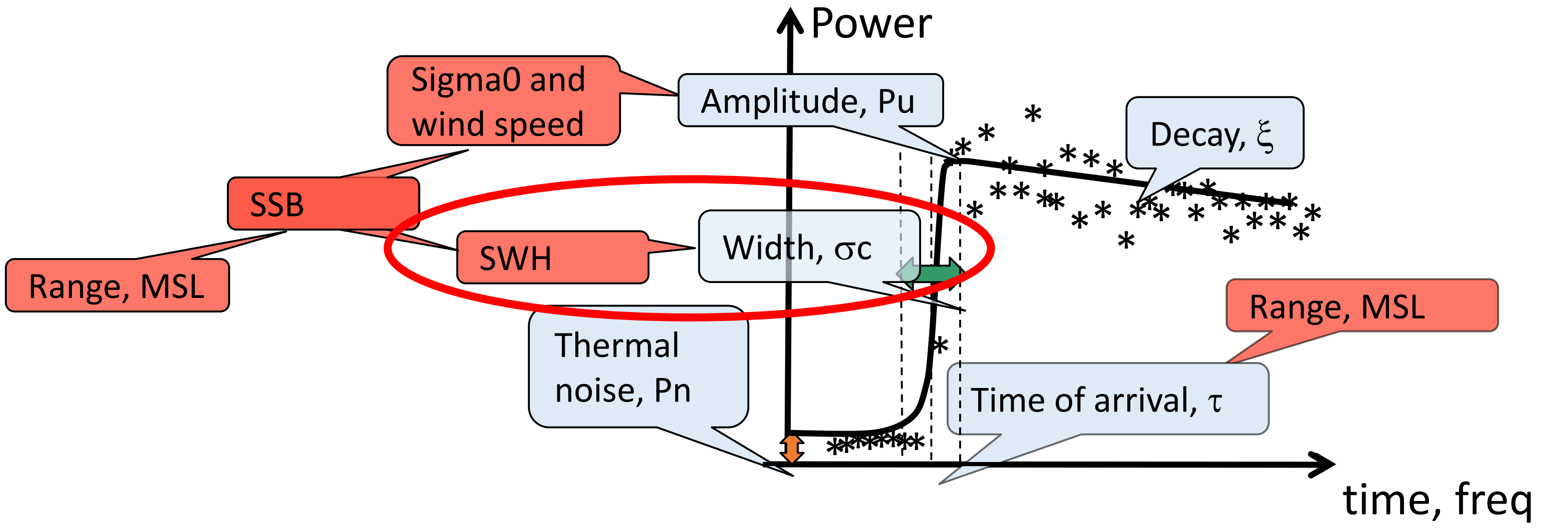
Wave Height in altimetry : room for huge improvements

- Until now, most of research in altimetry has focused on the improvement of range estimation for deriving SSH, SLA, MSL trend, observation of small scales, MSS, etc …
- But, altimeter waveforms also contain information of wave height (over ocean) that can thus be estimated ➔ Role of the retracking algorithm



- Computing Cramer Rao Bounds of the estimator has shown that huge improvements could be done, in particular on wave heights [Mailhes, Thibaut & al, 2008]
- Improvement of the Wave Height performances could be beneficial for analyzing surface currents [Ardhuin & al, 2017].

Wave Height in altimetry : room for huge improvements

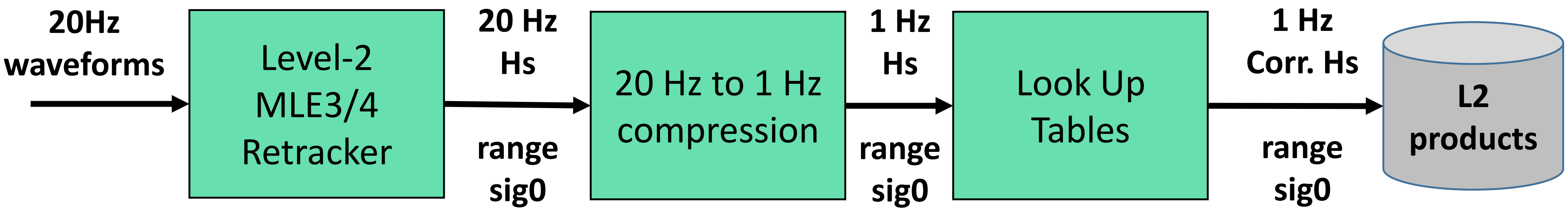
Recently, in particular in the Sea State CCI activity, many studies have been carried out by different teams to provide better wave height estimates (Hs) ie :

- ❑ To improve Hs accuracy (wrt in-situ for example) & precision (std, HF PSD noise level)
- ❑ To guarantee a good continuity of Hs between different missions whatever the operated mode (LRM or SAR) or the frequency (Ku or Ka)
- ❑ To insure stability with time of the retrievals (whatever the ageing of the instrument - Point Target Response) to allow monitoring climatic evolution (especially for Sentinel-3 drifting by 1 cm/year wrt ECMWF due to evolution of the PTR : S.Dinardo communication to MPC. Not corrected yet)
- ❑ To remove correlated errors at large scales (Hs SARM dependancy on Hs) and sub-mesoscale effects (swell impact on SARM data)

This talk gives a review of the progress made by CLS/CNES teams in LRM & Delay-Doppler Altimetry, for estimating wave heights (CNES funding)
The dataset are provided to SI-CCI for evaluation

Current processing implemented for conventional altimetry

Jason-1/2/3, Envisat/RA-2, Saral/AltiKa, CS-2 and S-3 P-LRM



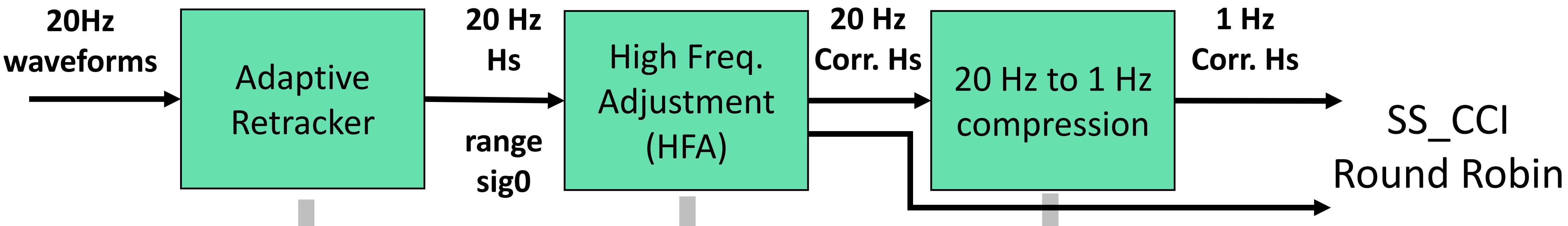
MLE convergence criterion degraded to LS convergence criterion
Gaussian PTR

Mean value over 20 measurements

LUT accounting for the Gaussian approximation of the Point Target Response

New processing chain proposed for conventional altimetry

J3 data set delivered for Sea State CCI Round Robin
(but applicable to any other conv. altimeters)

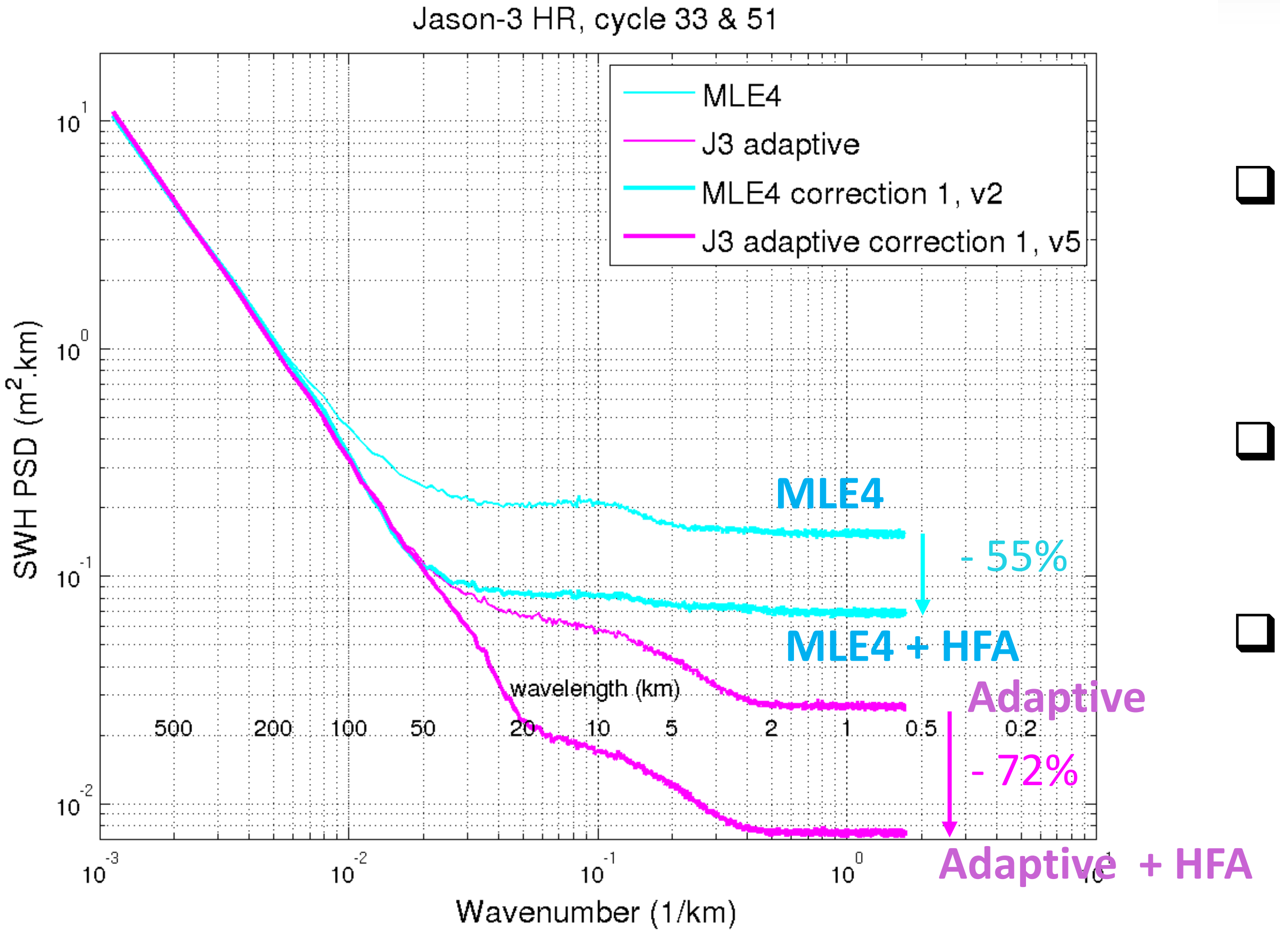


True MLE convergence criterion accounting for speckle distribution
Numerical solution accounting for real PTR
No empirical adjustment
No corrections via Look Up Tables

Mean value over 20 measurements

Equivalent to Zaron' correction for ranges (OSTST 2015)
[Tran & Vandemark, 2019]

Evaluation : Hs Power Spectral Density



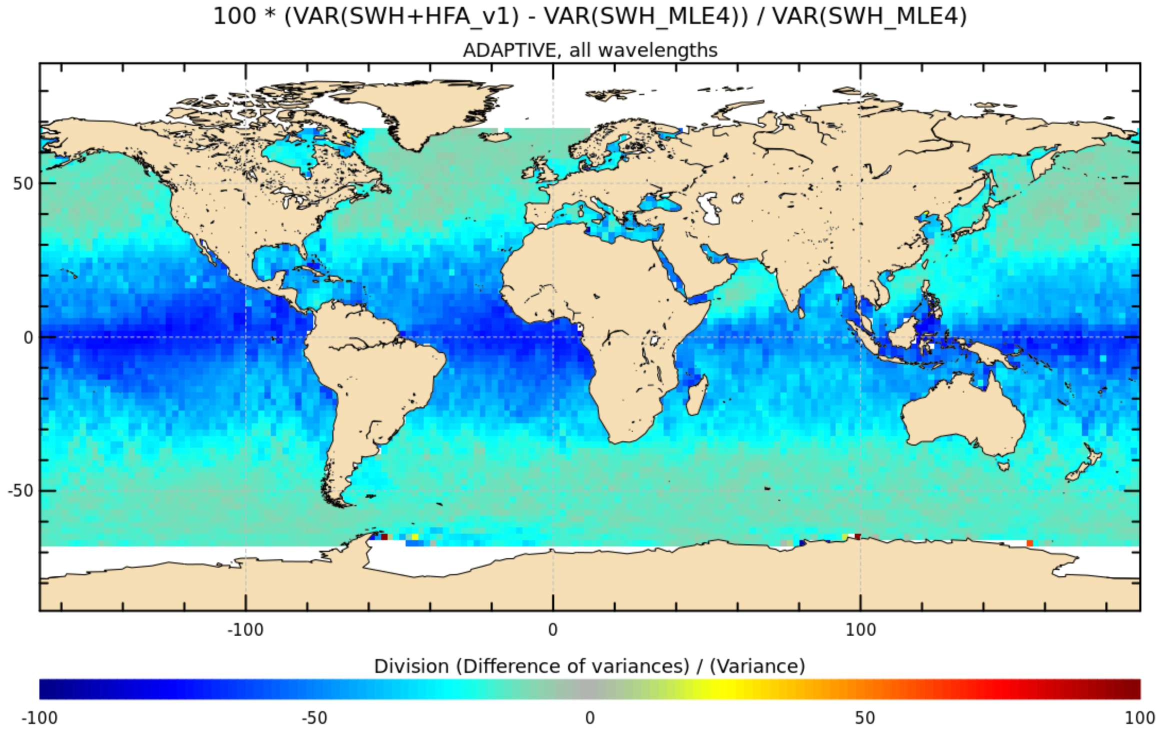
- HF energy hugely reduced along with significant reduction of the spectral bump obtained with adaptive and HF_Adjustment wrt MLE4
- Denoising Hs leads to less noisy SSB (especially for Adaptive for which sig0 displays lower bump effect)
- In addition, much better sigma0 with Adaptive compared to MLE4

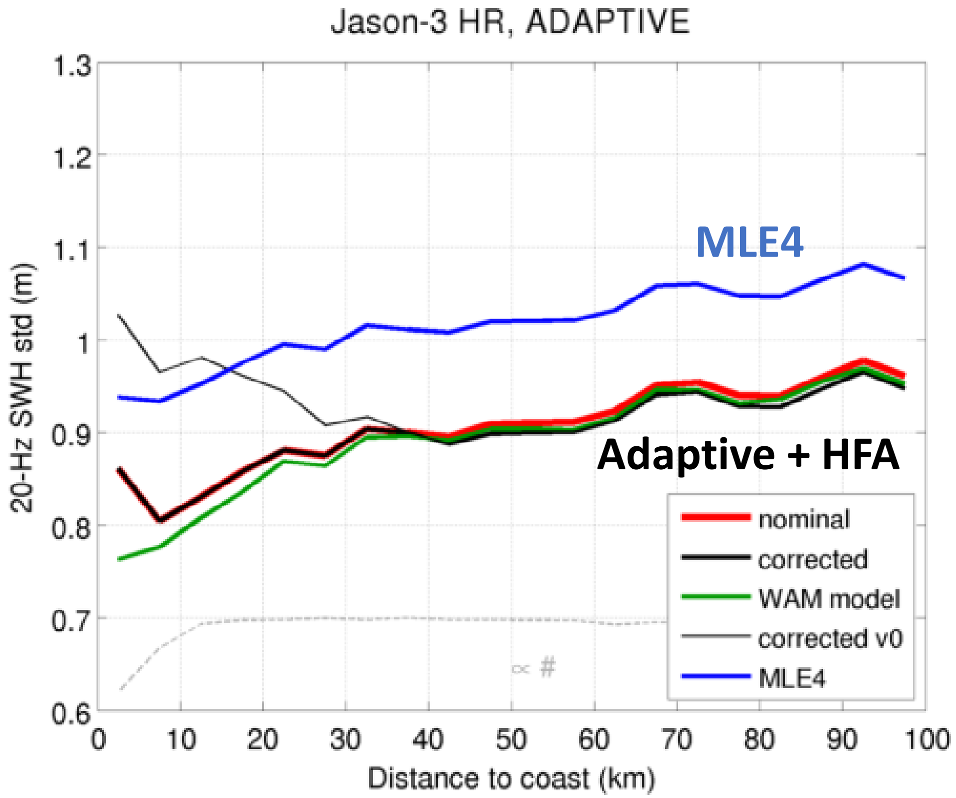
Noise Floor (cm rms)			
MLE4	MLE4 + HFA	Adaptive	Adaptive + HFA
51	34	21	11

Evaluation : Hs variance reduction wrt MLE4

Percentage of Variance reduction

PVR = 100 * (var(New_Hs) – var(reference Hs)) / var(reference Hs)





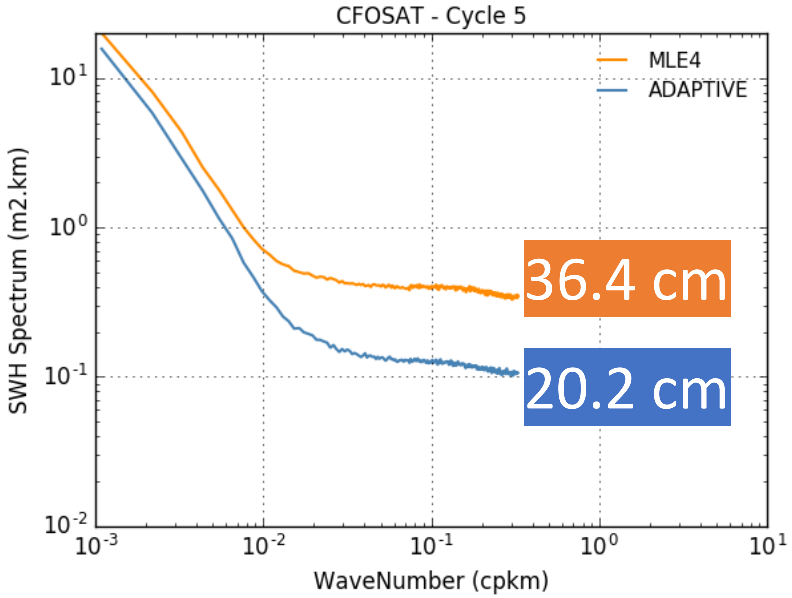
(Adaptive + HFA) wrt MLE4
-30%
(when considering all wavelengths)

Improvement in coastal zones wrt MLE4

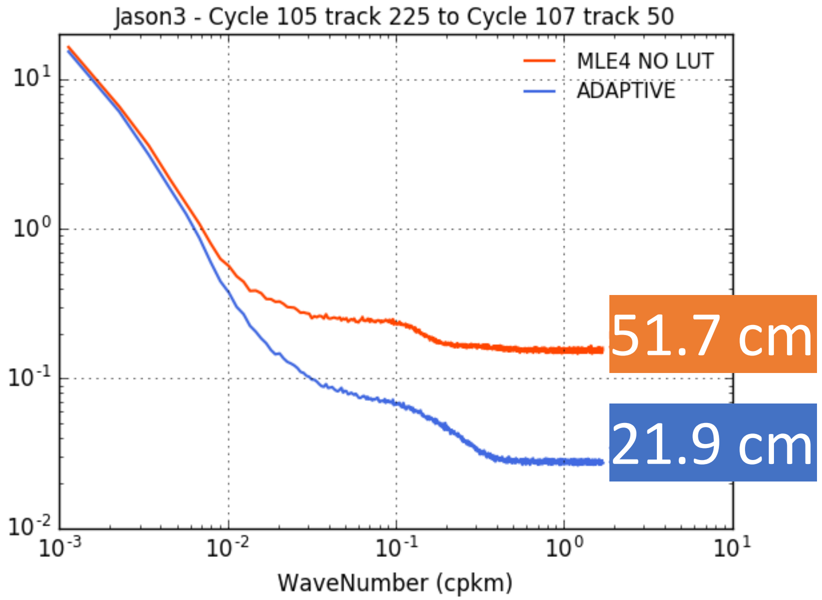
Adaptive Retracker already operational

- **CFOSAT :** Adaptive retracker already implemented in the ground segment (not yet HFA)

CFOSAT



Jason-3



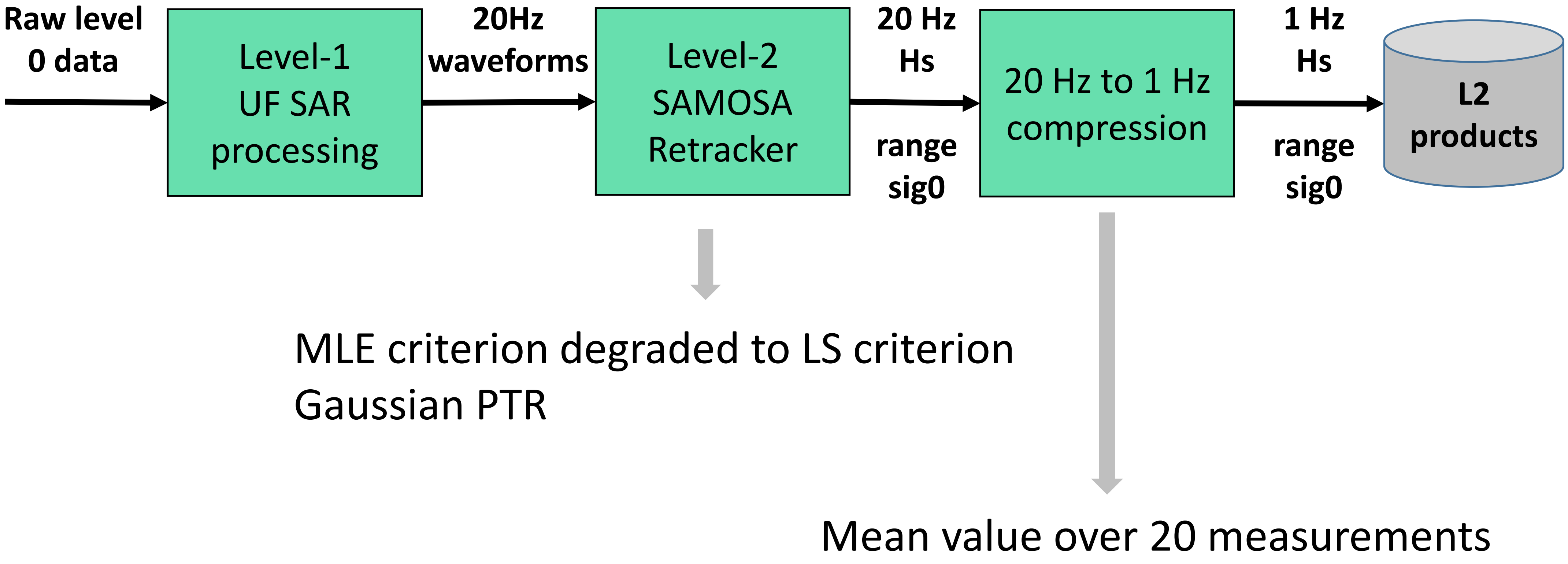
45 % noise reduction with Adaptive
Less than J3 but explained by the number of indivual pulses > J3

58% noise reduction with Adaptive

- **Jason-3 GDR-F** : Adaptive retracker + HFA will be provided (+ MLE3/4)

Current processing implemented for Delay-Doppler Altimetry

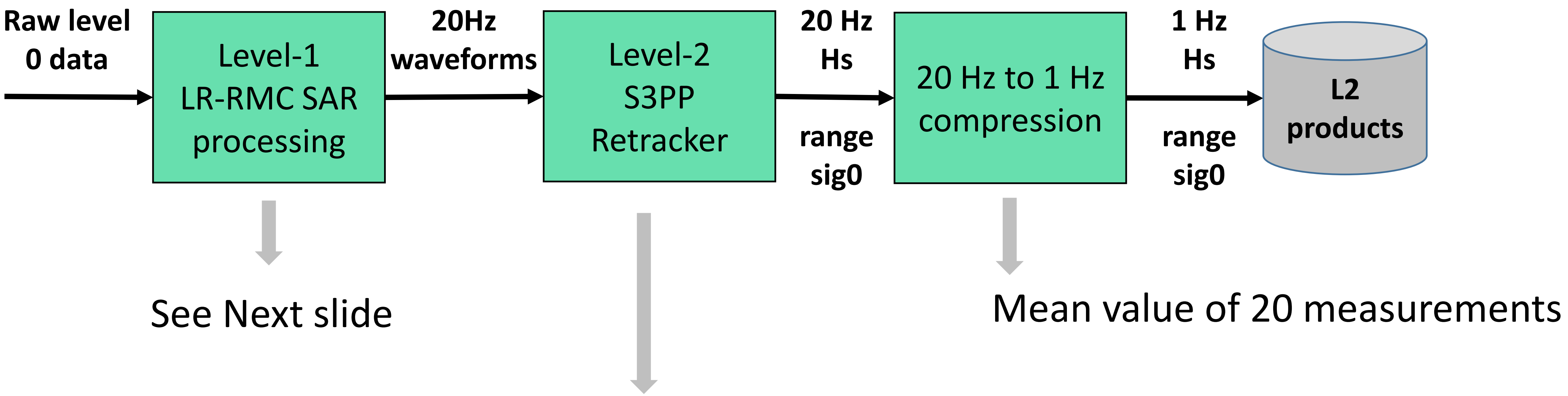
CS-2 and S-3 SAR mode



New processing chain proposed for Delay-Doppler Altimetry

S-3 SAR mode CNES Processing Prototype (F.Boy)

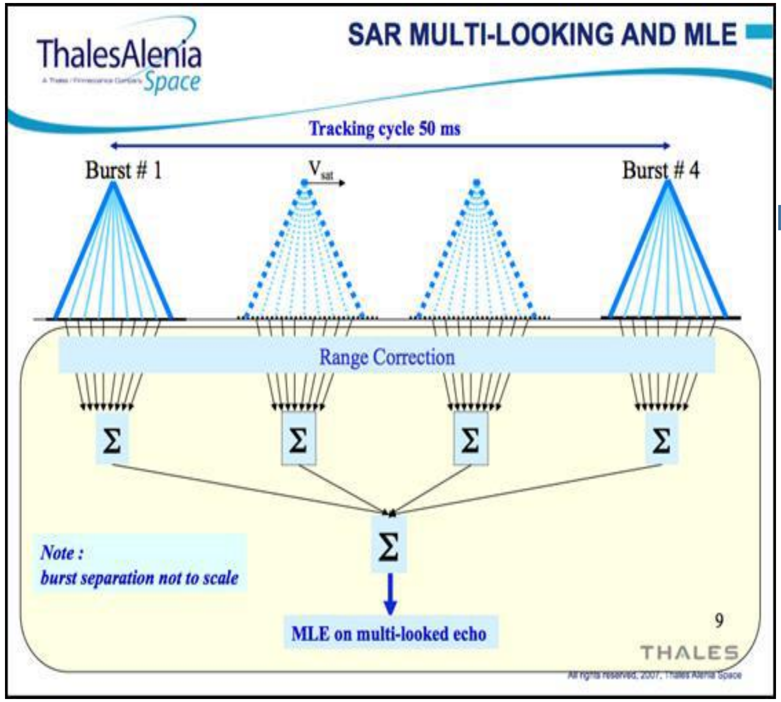
S3 data set delivered for Sea State CCI Round Robin
(but applicable to any other SAR altimeters)



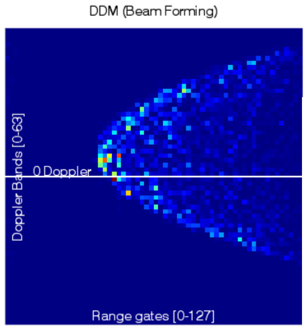
MLE criterion degraded to LS criterion
Sinc PTR
(Performances equivalent to SAMOSA rtk)

Level-1 LR-RMC Delay Doppler processing

Firstly implemented by TAS for CS-2 on-ground validation [Phalippou and Demeester, 2011]

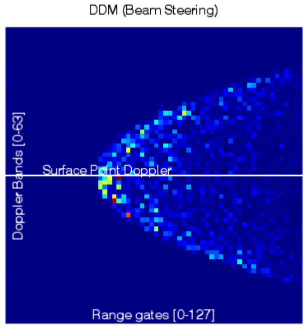


1



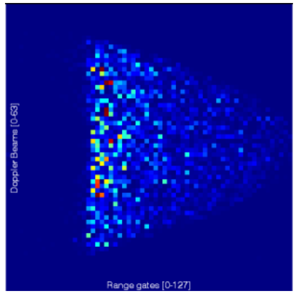
Beam forming

2



Beam stearing
(On nadir
Location)

3



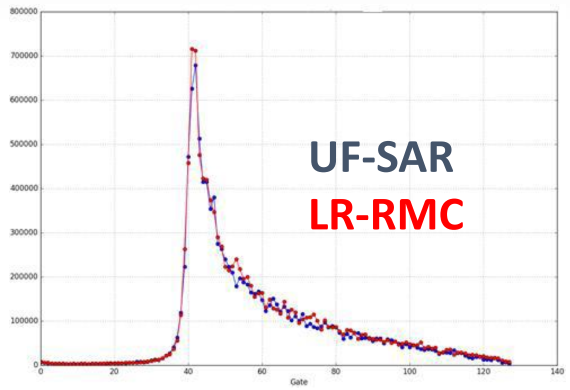
Range
Migration
Correction

4

Σ

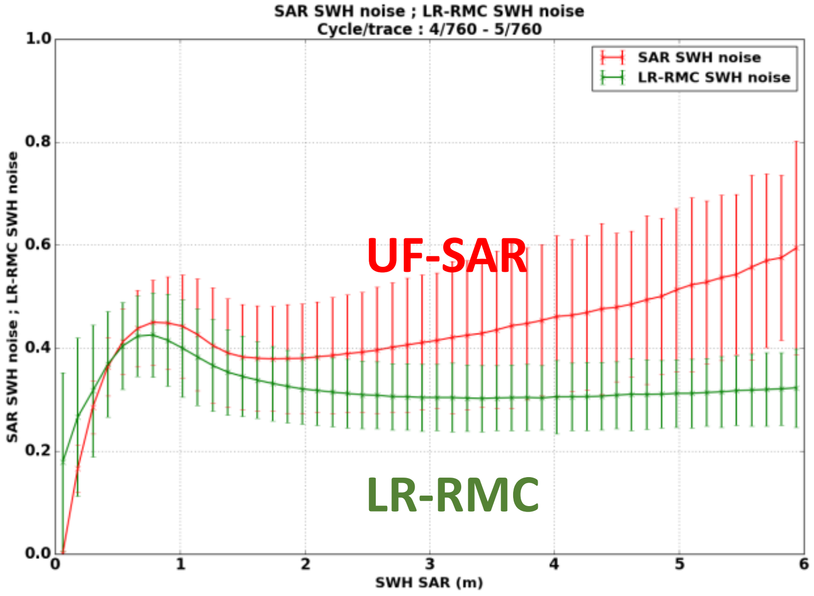
Stacking within the tracking cycle
(4 bursts)

Level-1 LR-RMC Delay Doppler processing



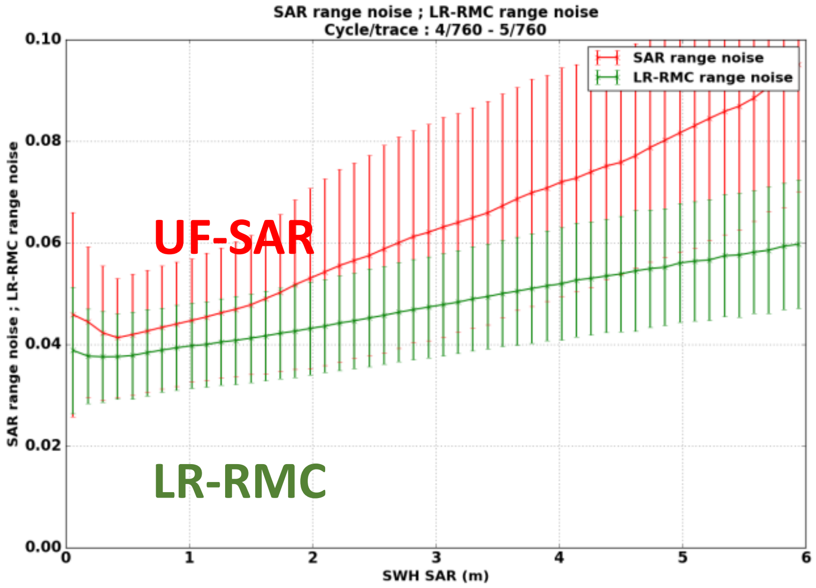
- ❑ Similar shapes (thanks to RMC)
- ❑ Nadir look/beam are the same
- ❑ Same level of SNR
- ❑ But different on-ground resolution and ML/Stacking duration

SWH

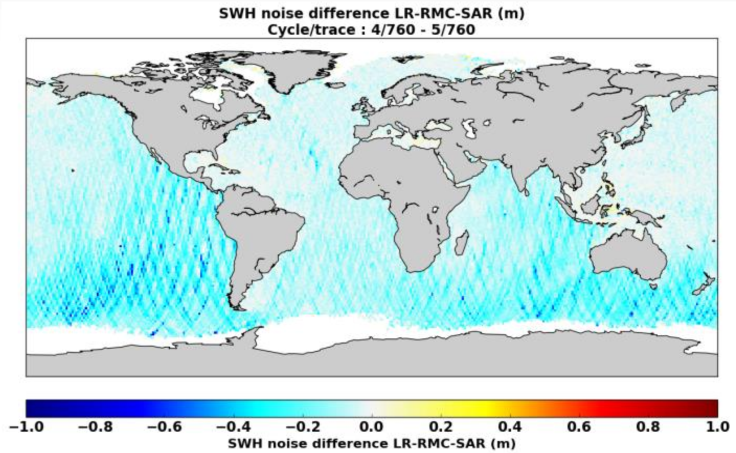


Large noise reduction wrt UF-SAR

Range



Evaluation : reduction of sensitivity to swell



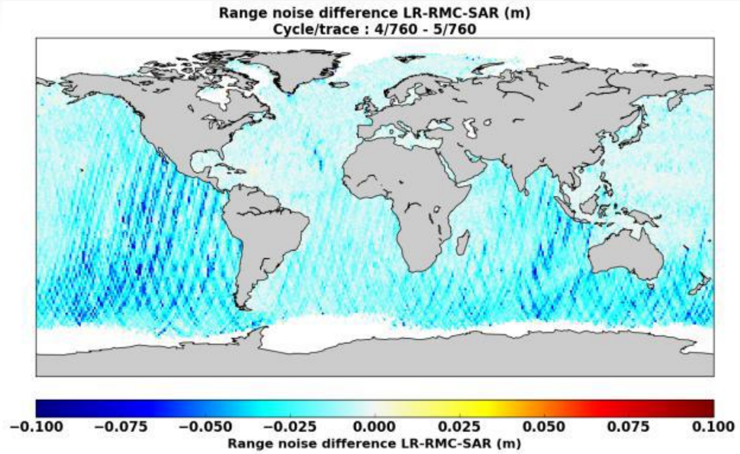
Maps of Noise difference

→

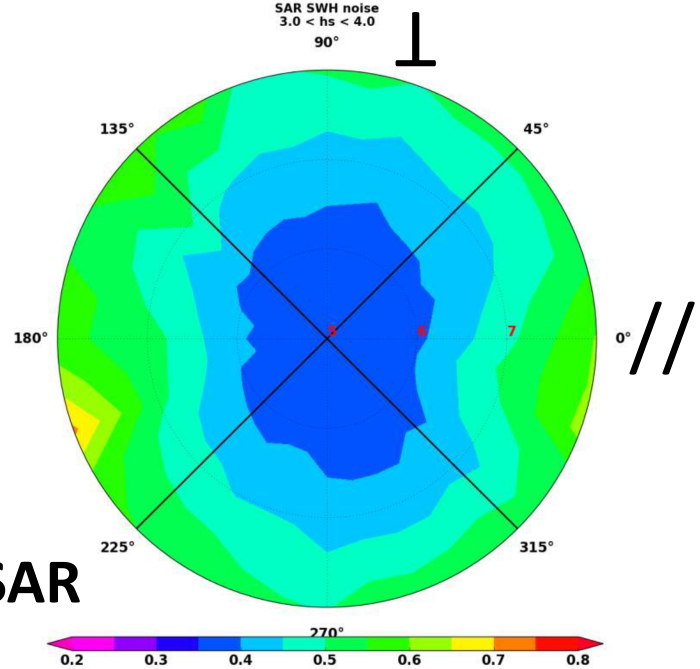
High reduction for specific sea conditions

→

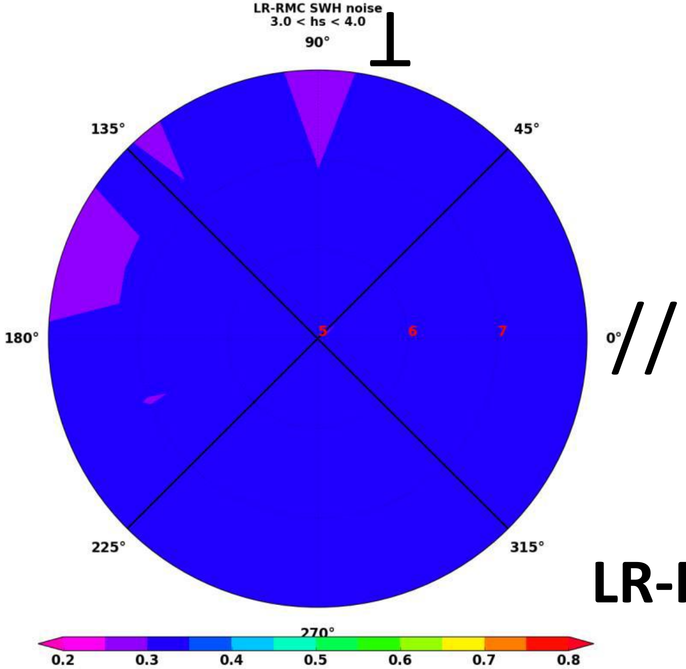
Swell regions



SWH noise level versus relative angle to swell & T02 (Wave watch 3)

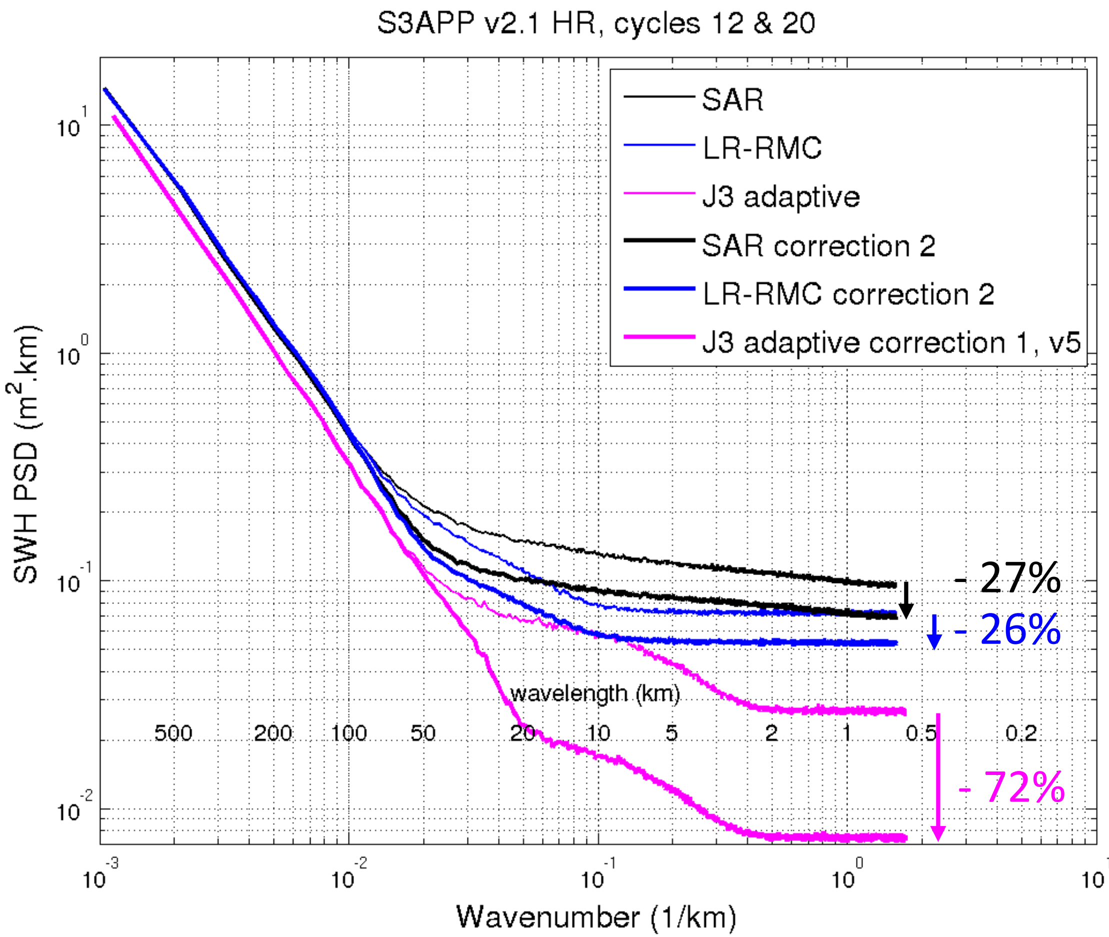


Unfocused SAR



LR-RMC SAR

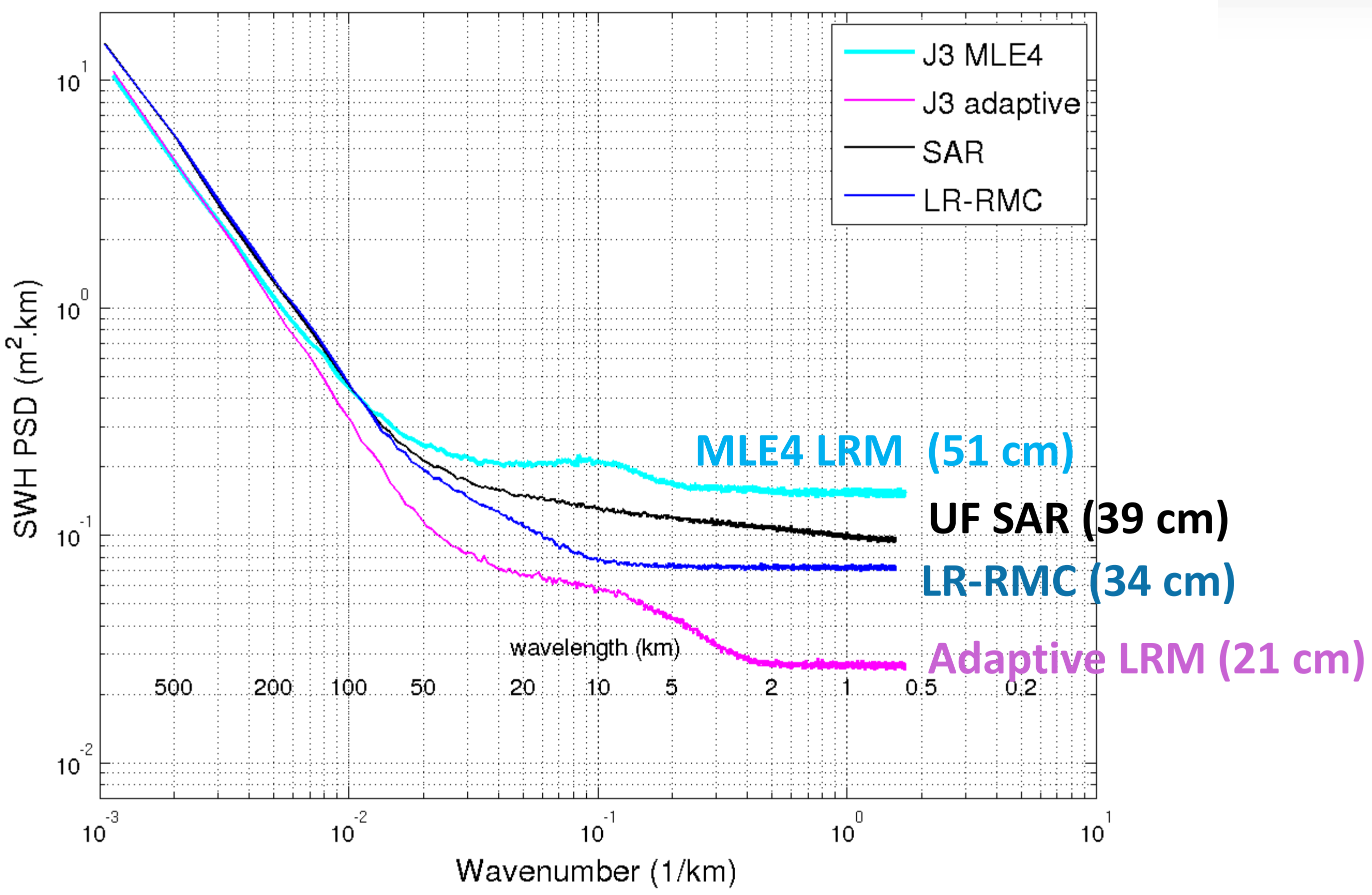
Evaluation : Hs Power Spectral Density



- Reduction of HF energy with HFA
- Reduction of HF energy with LR-RMC (wrt UF-SAR)

Noise Floor (cm rms)			
SAR	**SAR + HFA**	**LR-RMC**	**LR-RMC + HFA**
39	33	34	29

LRM versus Delay Doppler ?



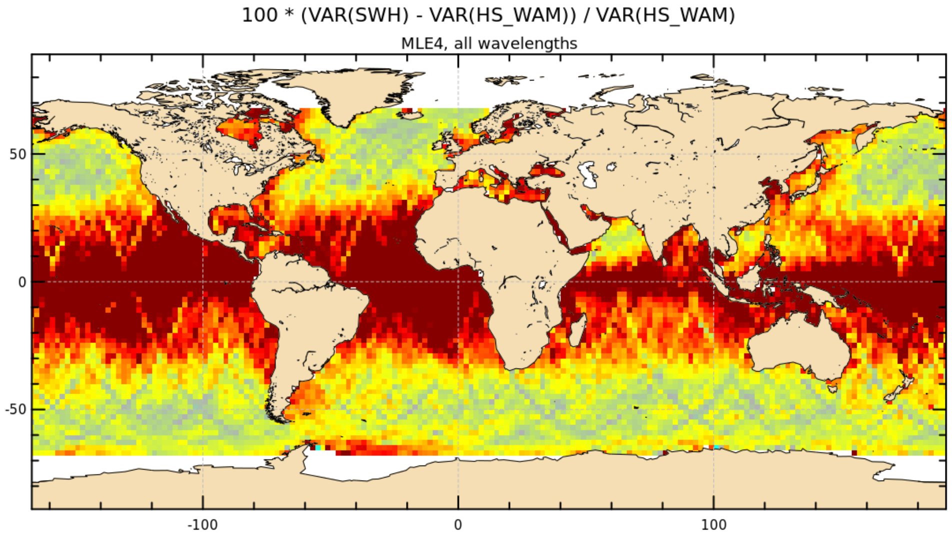
- **Hs from conventional altimetry (with Adaptive + HFA) less noisy than HS SAR with UF-SAR or LR-RMC**
- Model still to be improved for using MLE criterion in SAR (UF or LR-RMC)

LRM versus Delay Doppler ?

Percentage of Variance reduction (considering one year of data)

PVR = 100 * (var(New_Hs) – var(reference_Hs)) / var(reference_Hs)

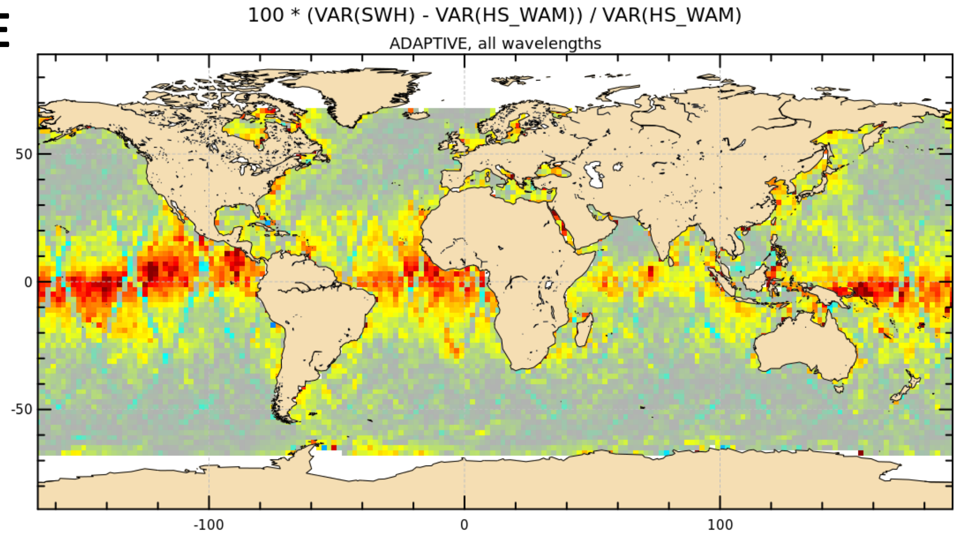
Variance comparison (%), Nominal data, WAM used as reference

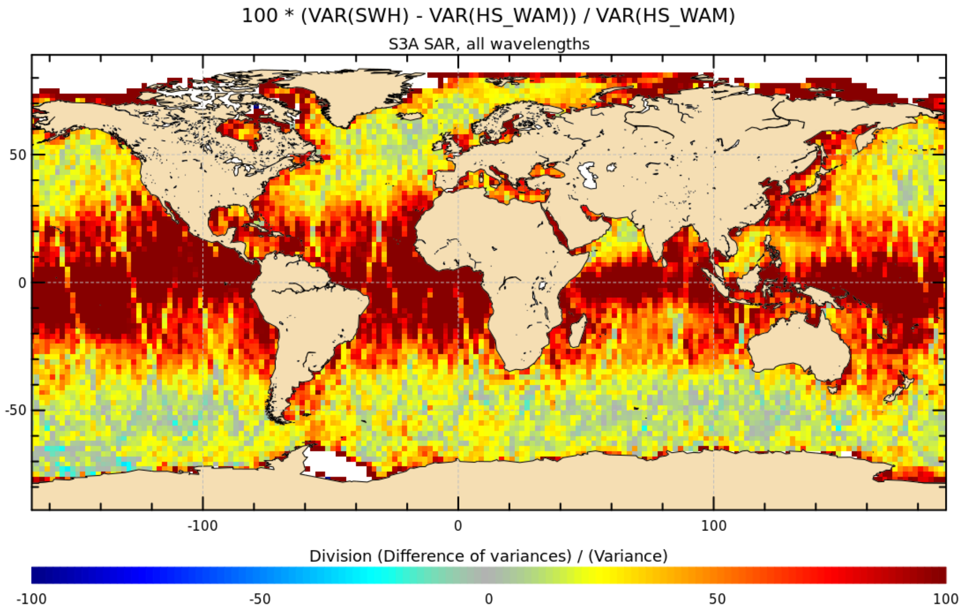


MLE4

ADAPTIVE

SWH data are highly variable in the inter-tropical regions where low SWH conditions are observed

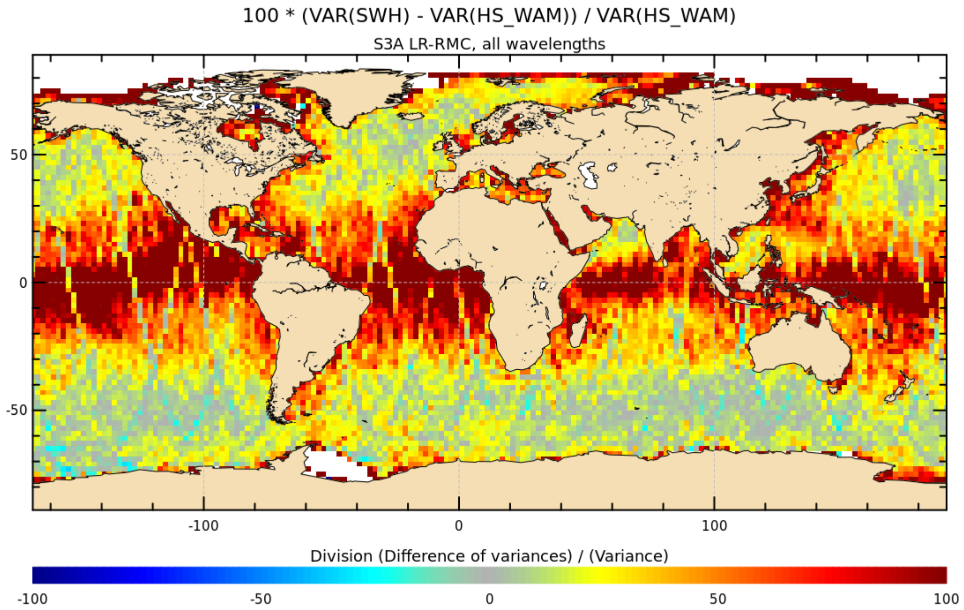




SAR

LR-RMC

The ADAPTIVE estimations display the lowest variabilities when one compares with those from the model data

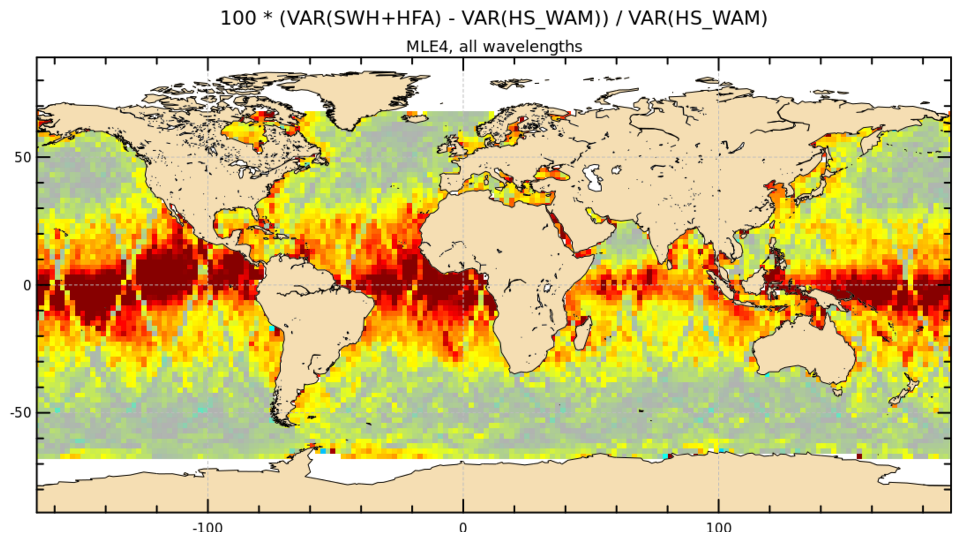


LRM versus Delay Doppler ?

Percentage of Variance reduction (considering one year of data)

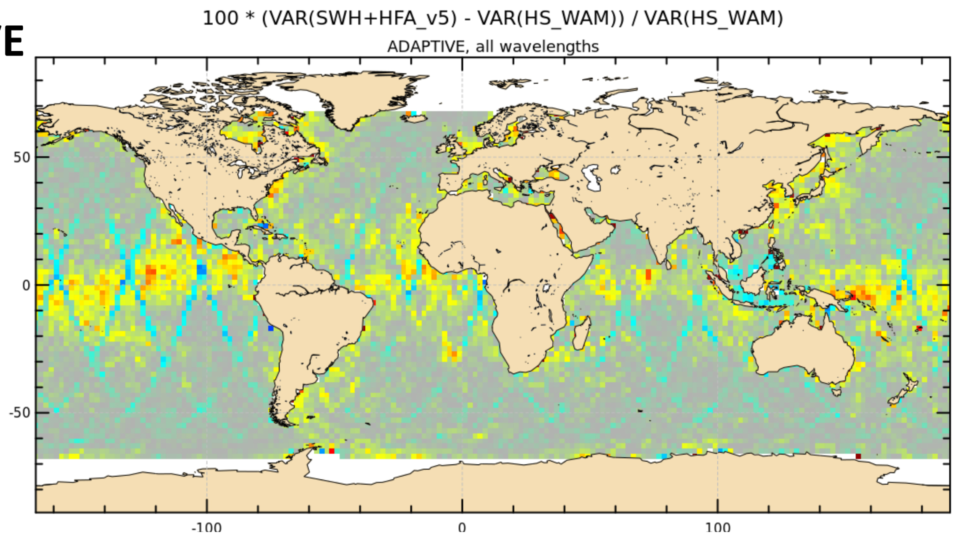
PVR = 100 * (var(New_Hs) – var(reference_Hs)) / var(reference_Hs)

Variance comparison (%), Corrected data, WAM used as reference

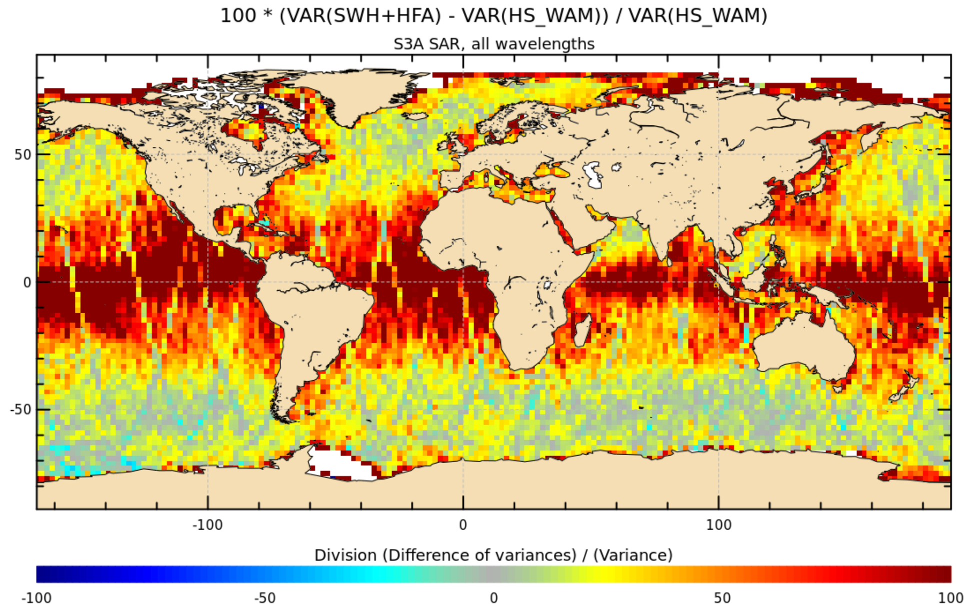


MLE4 + HFA

ADAPTIVE + HFA

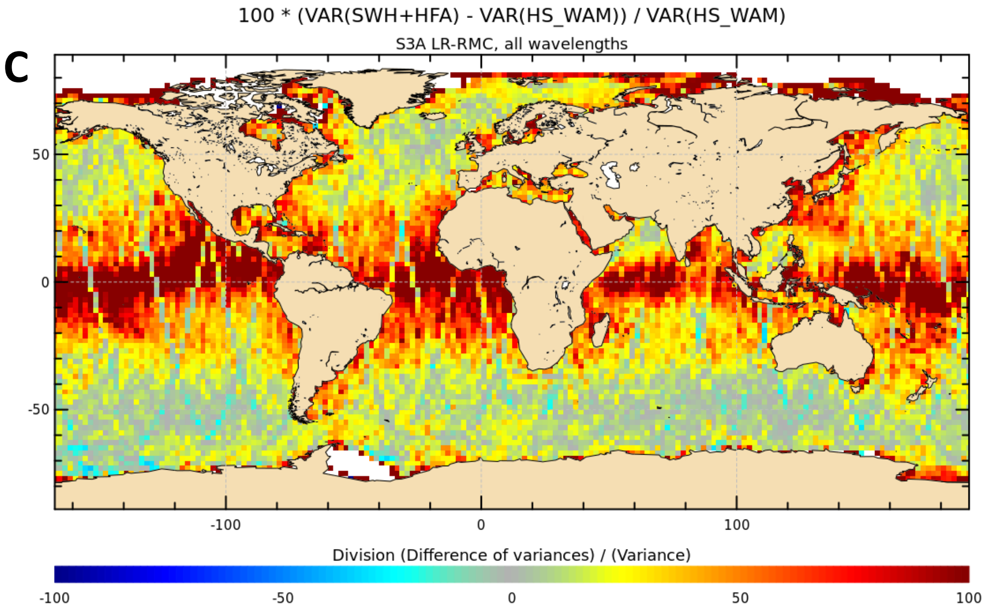


The extent of the red color zone tightens around the equator



SAR + HFA

LR-RMC + HFA



The reduction of the high-frequency noise leads to reduce the local temporal variability which becomes closer to model variations

Conclusions

- Impressive improvements for retrieving Hs from Altimetry (LRM & SAR)
  - In LRM thanks to Adaptive retracker + HF Adjustment
  - In Delay-Doppler thanks to LR-RMC + HF Adjustment
- Evaluation of Jason-3 and Sentinel-3 data set in Sea State CCI Round Robin (wrt to other solutions) : results announced at PM2
- LR-RMC demonstration products will be made available by the end of the year and a paper is to be published [Moreau et al; 2020]
- Adaptive retracker + HFA will be used in the reprocessing of ERS and ENVISAT/RA-2 in the frame of the Fundamental Data Record For Altimetry activity (ESA funding)
- A paper has been submitted in Advance Space Research [Tran et al, 2019]

Assessing the effects of sea-state related errors on the precision of high-rate Jason-3 altimeter sea level data

N. Tran[a], D. Vandemark[b], E. D. Zaron[c], P. Thibaut[a], G. Dibarboure[d] and N. Picot[d]

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THANK YOU

C L S :   f o r   E a r t h ,   f r o m   S p a c e

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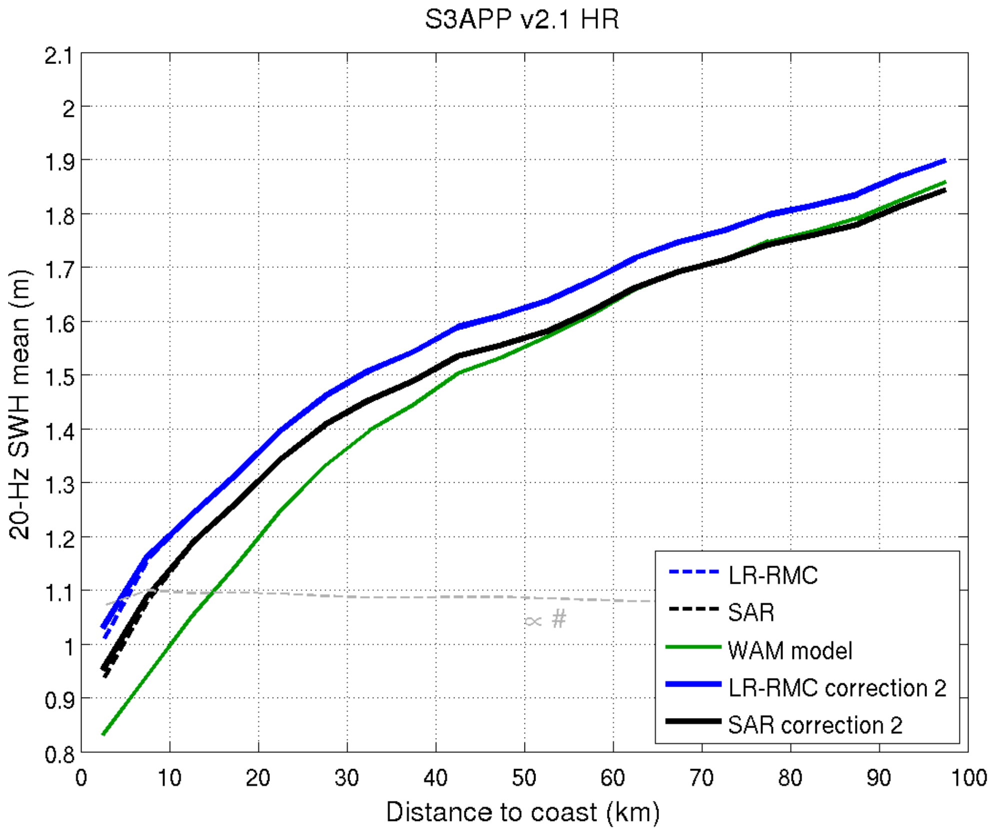
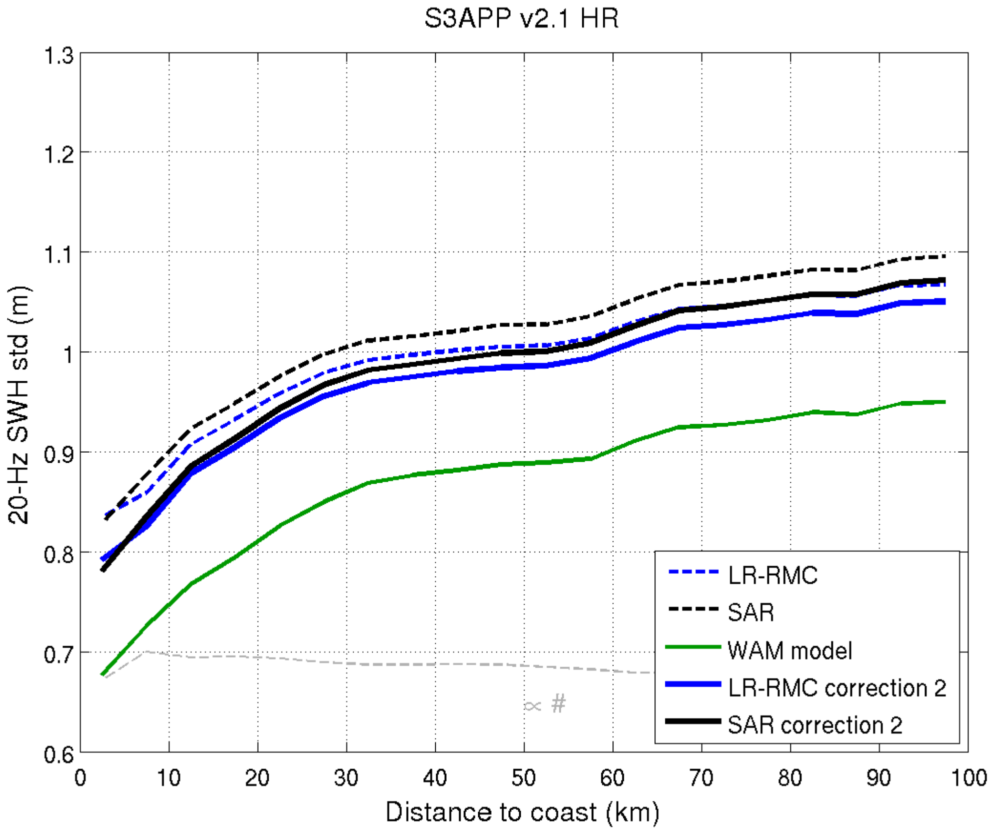
Evaluation at the coasts





- ❑ No change in term of bias
- ❑ Reduction of the data variability even in coastal regions

Abstract

Wave Height estimation from altimeter measurements

P. Thibaut, N. Tran, T. Moreau, L. Amarouche, F. Piras (CLS), F.Boy , N.Picot (CNES)

In the last years, huge efforts have been done by different teams to improve the estimation process for both conventional and Delay Doppler altimeter echoes. All the research has been mainly focused on the improvement of Sea Surface Height estimations, especially to better access the small scales of the ocean topography. However, the retracking algorithm provides, in addition to the sea surface height, an estimation of wave heights which properties can be closely correlated to ocean currents [Ardhuin & al, 2017]. It is thus crucial to guaranty that waves are estimated as accurately and precisely as possible.

In 2008, a paper [Mailhes & al, 2008] focusing on the estimation of Cramer Rao bounds (CRB) for conventional radar altimeter waveforms showed that there was space for improving the estimation of the sea surface height on the one hand but even more, for improving the significant wave height, knowing that the variance of any unbiased estimator of the altimetric parameters is bounded below by its Cramer-Rao bound (CRB).

To improve the retracker performances for LRM measurements, CLS developed and successfully validated a solution called "Adaptive Retracker", implementing a new waveform model and a Nelder Mead optimization method with exact likelihood criterion. Dramatic improvements in the estimation performances over ocean have been observed (respectively 10% and 60% of noise reduction on range and significant wave height).

Recently, similar developments have been conducted at CLS for Delay Doppler measurements (Cryosat-2 and Sentinel-3A).

In addition to improving the estimation process, it has been shown [Tran & al, 2019] that the level of noise affecting SWH signals can be strongly reduced by exploiting the correlation existing between significant wave height and range errors due to the retracking algorithm.

We propose in this talk to characterize the performances obtained on SWH estimations when using together a better estimation process and a high frequency denoising method exploiting the range/SWH correlation. This processing solution is the one that has been proposed for evaluation in the Sea State Climate Change Initiative.

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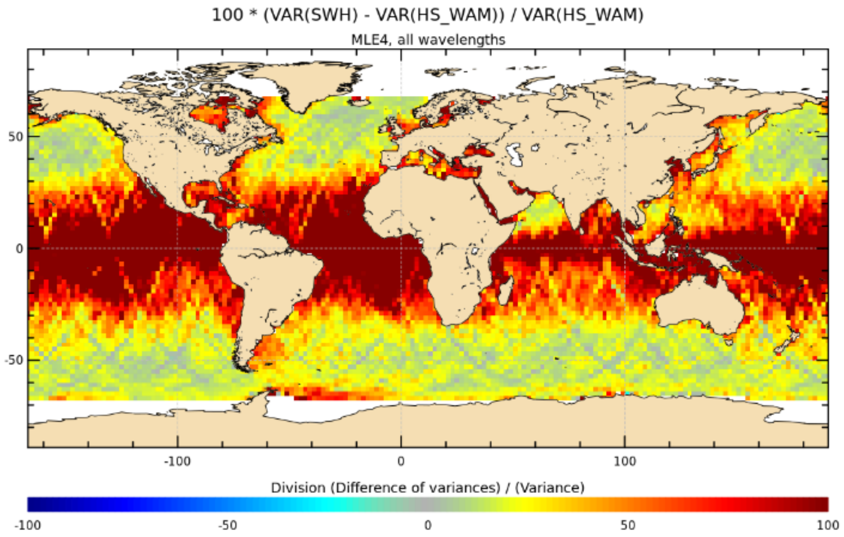
Evaluation : Hs Variance reduction

Percentage of Variance reduction (considering one year of data)

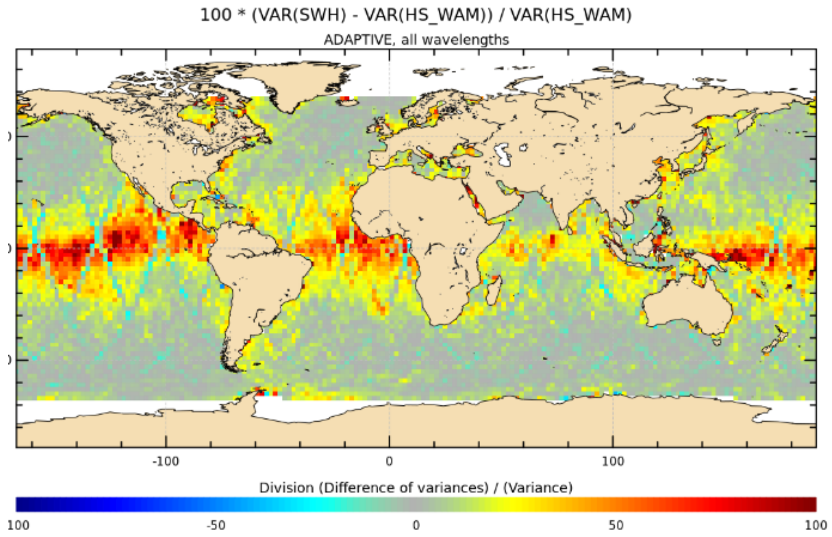
PVR = 100 * (var(New_Hs) – var(reference_Hs)) / var(reference_Hs)

(WAM taken as reference)



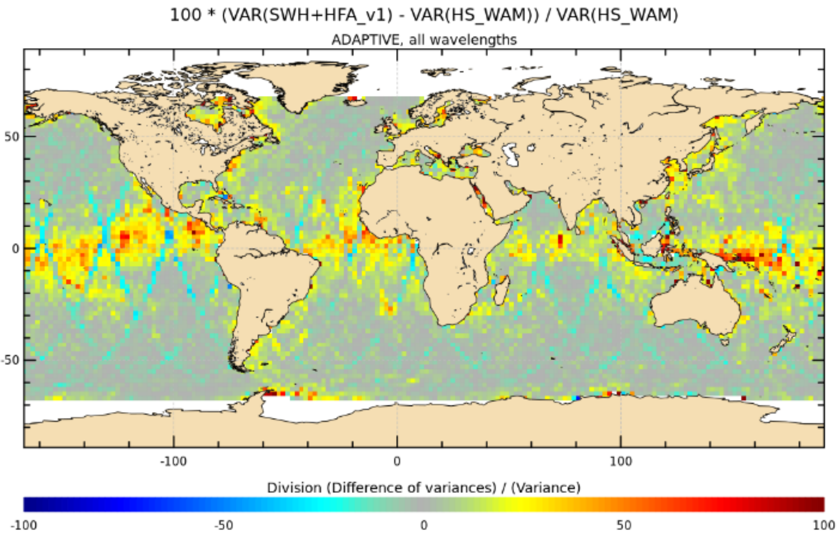
MLE4

+ 61%



Adaptive

+ 13%



Adaptive + HFA

+ 7%