Ocean Surface Topography Science Team Meeting, 21-25 October 2019, Chicago, IL

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Reducing the high-frequency noise in Jason-3 and Sentinel-3A SWH data

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Motivation (1/3) → room for improvement

- Boosted interest in SWH parameter
  - Development of new retracker (ADAPTIVE) that better fits conventional LRM waveforms and reduces the 20-Hz SWH noise level by -60% for Jason-3 [Thibaut et al, 2017]
  - Availability of several processings for SAR altimetry data that allow to resolve shorter-scale ocean features (<100 km) [Dinardo et al, 2015; Phalippou and Demeester, 2011; Moreau et al, in preparation]
  - Growing interest to maximize coastal retrievals and to analyze wave-current interactions that predominates at scales below 100 km [Ardhuin et al, 2017; Quilfen and Chapron, 2019]
- Start of the ESA Sea-State Climate Change Initiative activity in 2018 to compare different SWH estimations through a Round Robin exercise to select the best algorithm and construct a consistent SWH dataset

→ **CNES/CLS participation amongst several teams to the ESA Sea-State CCI project by providing SWH datasets for the Round Robin evaluation**

Motivation (2/3) → improvement in precision aspect

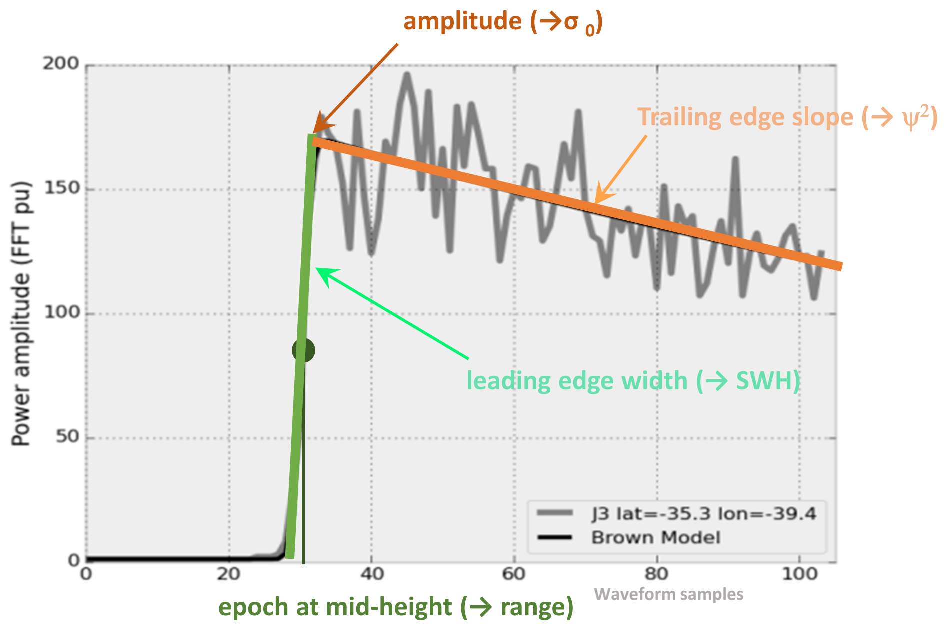
- Different aspects could be improved:
  - accuracy, precision, continuity between different altimetric missions, stability in time-series, correlated errors, …

- We focus here on the SWH data precision to improve the signal-to-noise ratio to increase the consistency between different missions and processing algorithms at intermediate scales and identify short wavelength features (< 100 km).

- We propose an additional post-processing step that is not in the family of noise filtering approaches (i.e. low-pass filtering) where one gets systematic loss of small-scale geophysical information depending on the cut-off choice.

- We rather propose an empirical correction that reduces the high-frequency variability in the SWH estimations

Motivation (3/3) → observations of correlated errors



- Retracking algorithms are used to fit altimeter waveforms to give simultaneous estimates of range, significant wave height (SWH), backscatter coefficient (σ0) and provide sometimes also the slope of the waveform trailing edge (ψ^2)
- Estimated from noisy waveform inputs, these estimates display correlated errors
  - in σ0 and ψ^2 values from the trailing edge data
  - In SWH and range values from the leading edge data
- Several studies [Zaron and DeCarvalho, 2016; Tran et al, 2019; Quartly et al, 2019] have improved the precision of the SSH estimations by reducing the correlated errors between range and SWH
- The objective here is to perform similar empirical adjustment to improve SWH estimations

OUTLINE

- Data analyzed
- Cross-spectral analyses
- Empirical model to reduce high-frequency noise in SWH
- SWH spectrum impact
- Variance reduction statistics
- Coastal results
- 1-Hz benefit

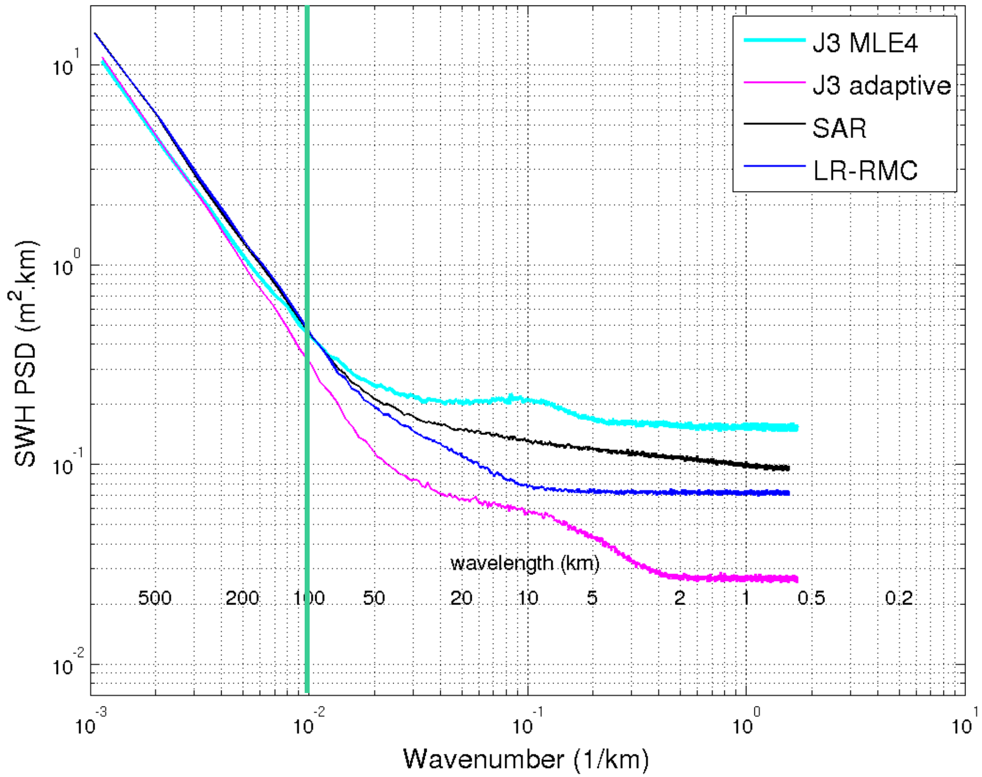
Data analyzed → high-rate 20-Hz products

- **Jason-3**
  - Cycles 23-59 (1-year)
  - MLE4 retracker for conventional LRM data
  - Numerical ADAPTIVE retracker

- **Sentinel-3A**
  - CNES S3 Processing Prototype (F. Boy)
  - Cycles 6 to 20 (1-year)
  - Unfocused SAR (SAR mode) processing
  - Low-resolution with range migration correction (LR-RMC) processing

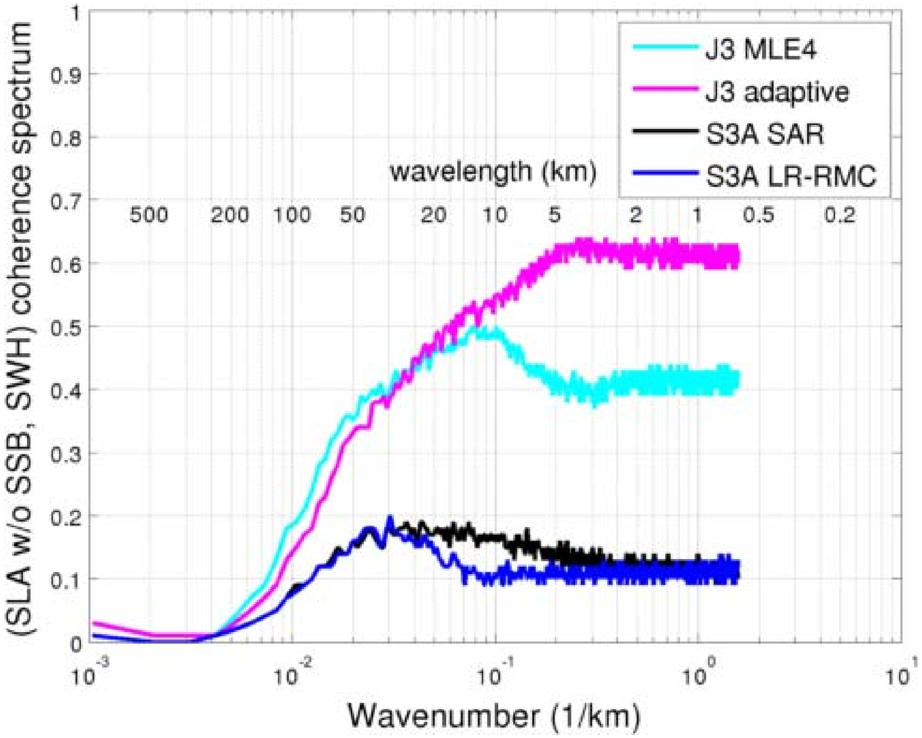
- SWH estimations from conventional altimetry (adaptive retracker) are less noisy than SAR SWH (UF-SAR or LR-RMC)

- No white noise floor but a red noise is observed for UF-SAR SWH



Noise Floor (cm rms)			
MLE4	ADAPTIVE	SAR	LR-RMC
51	21	39	34

Cross-spectral analyses →Magnitude-squared coherency



- MSC is the square of the linear correlation coefficient between two variables with respect to wavelength (λ)
- Here is the relationship between SLA (Orbit – Range – MSS) and SWH, not in order to analyze SSB range correction but to display how variances in SLA and variances in SWH are related for λ < 100 km
- For Jason-3 retrackers, more than 40% of the variances are correlated for λ < 50 km, reaching ~60% for λ < 5 km in the case of the adaptive retracker
- For Sentinel-3A, this correlation is lower than 20% for λ < 50 km
- These indicate that the reduction of the correlated high-frequency errors should be larger for conventional LRM data than in the case of the delay-doppler data

Empirical model

- Mimic the Zaron and DeCarvalho [2016]'s empirical approach developed to correct 1-Hz SSH by reducing the SSH noise correlated with the SWH noise

- Tran et al [2019] adapted the approach to correct high-rate (20-Hz) SSH data with a high-frequency adjustment (HFA) term to better isolate the retracker-based noises: SSH_corr = SSH - HFA

- The HFA approach is reverse here to correct 20-Hz SWH values by reducing the SWH noise correlated with the SLA noise: SWH_corr = SWH - HFA

  - For J3:

    $$HFA = (\alpha + \beta * SWH\_smooth\_xkm)*(SLA - SLA\_smooth\_ykm)$$

    $$SLA = ORBIT - range - MSS\_CNESCLS2015$$

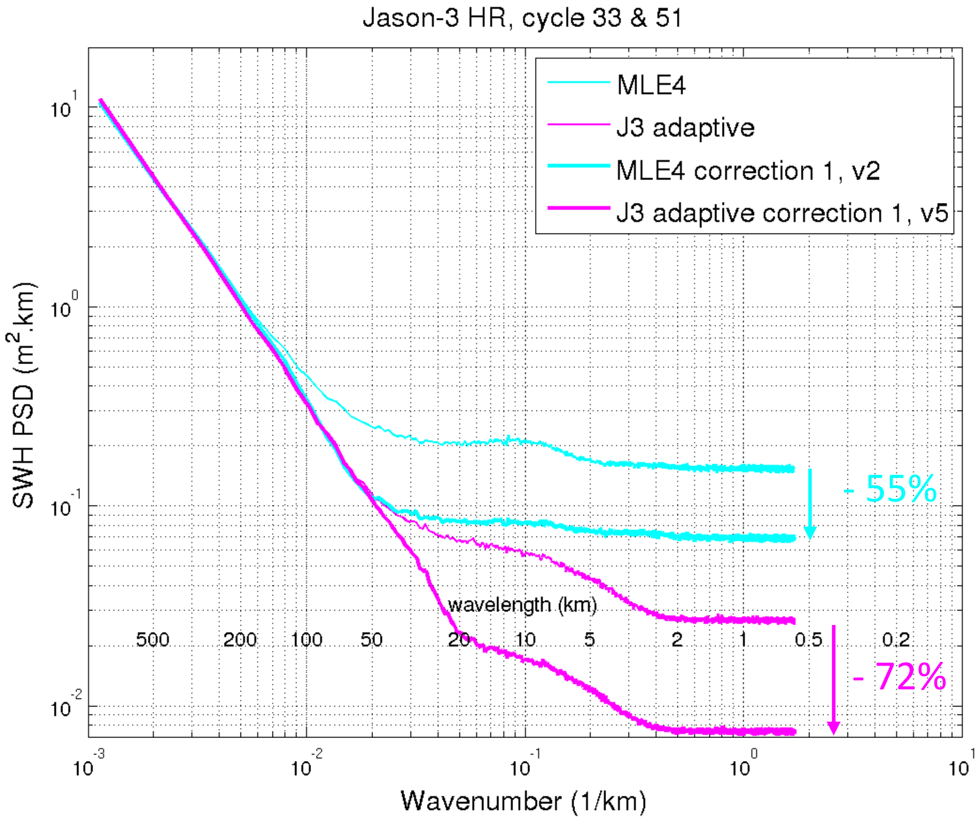
  - For S3A:

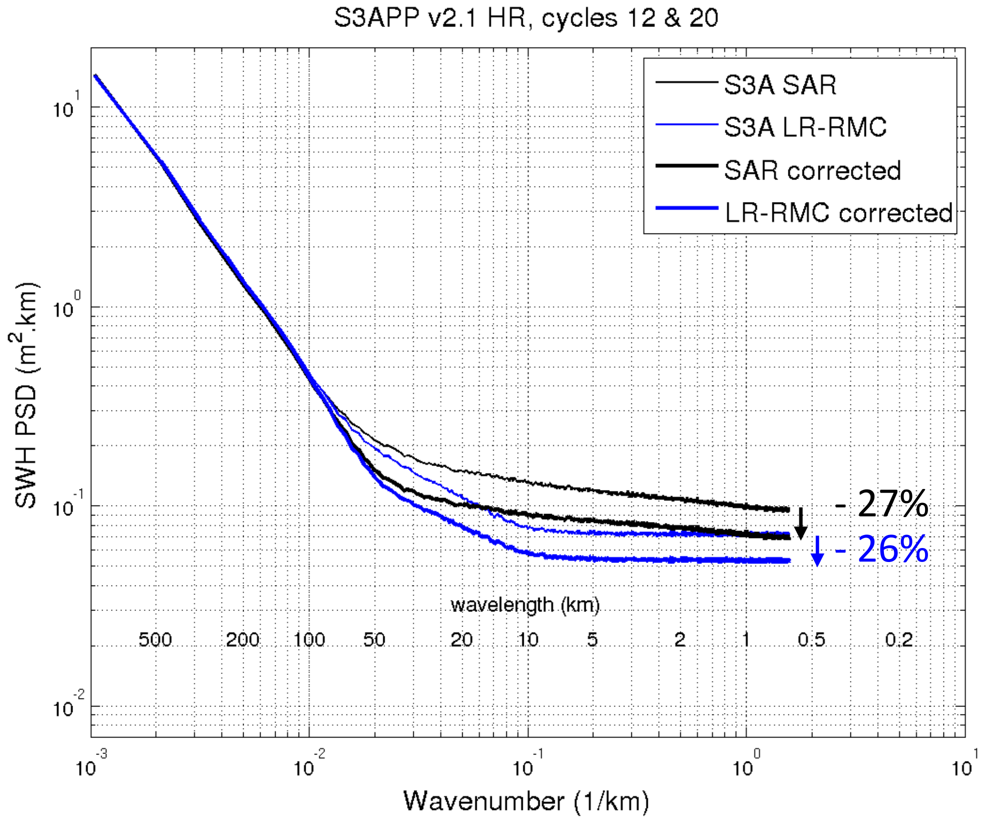
    $$HFA = (\alpha + \beta * SWH\_smooth\_xkm^{-1} + \gamma * SWH\_smooth\_xkm^{-0.5})*(SLA - SLA\_smooth\_xkm)$$

    $$SLA = ORBIT - range - S3A\_Mean\_Profile$$

  - the data filtering depends on mission, processing mode, retracking algorithm

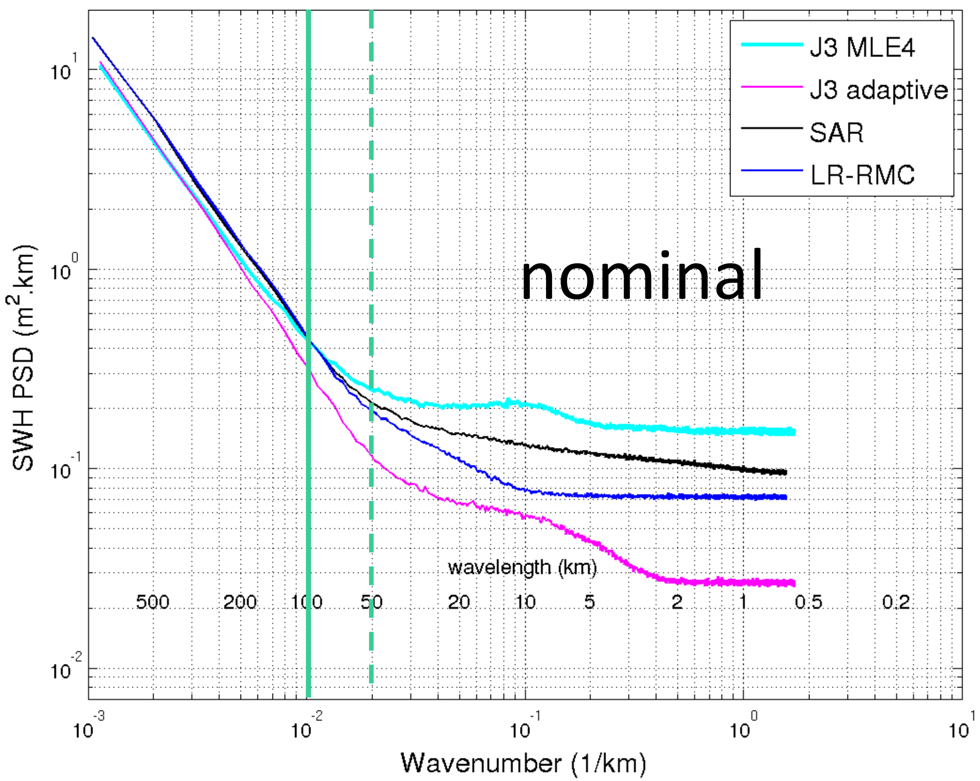
SWH spectra

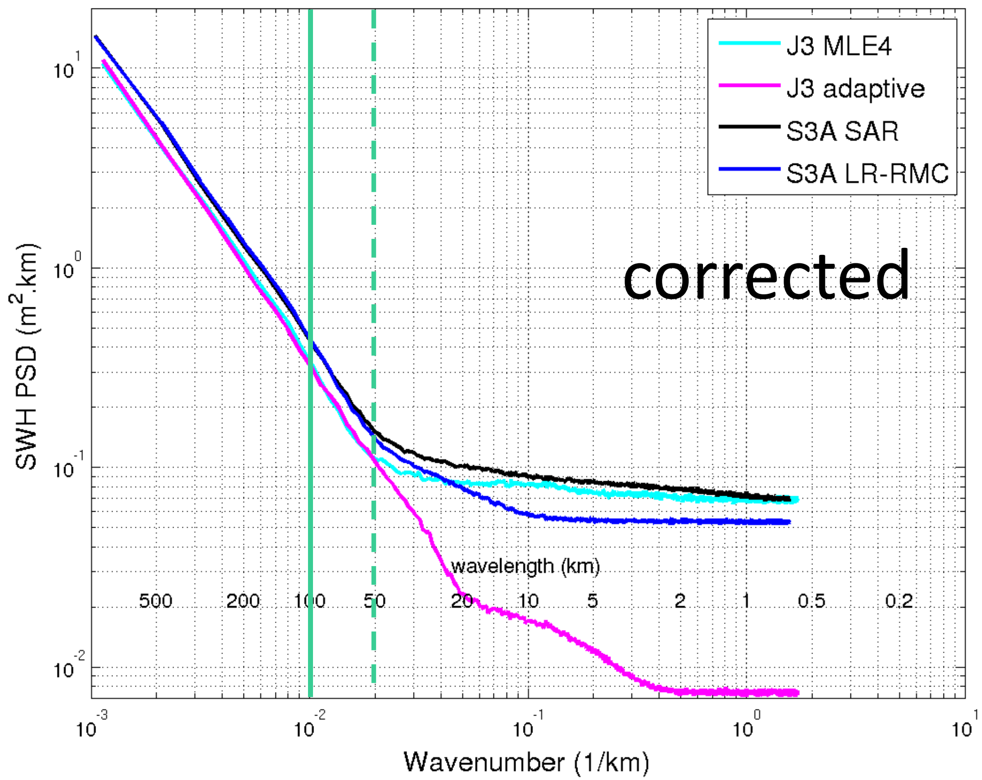




- By design, only SWH data content at λ < 100 km is impacted
- SWH variance is largely reduced in this high-frequency interval

SWH spectra → improved consistency between missions for λ in [50, 100] km
variance of corrected MLE4 close to variance of corrected UF-SAR





Noise Floor (cm rms)							
MLE4	MLE4_corr	ADAPTIVE	ADAPTIVE_corr	SAR	SAR_corr	LR-RMC	LR-RMC_corr
51	34	21	11	39	33	34	29

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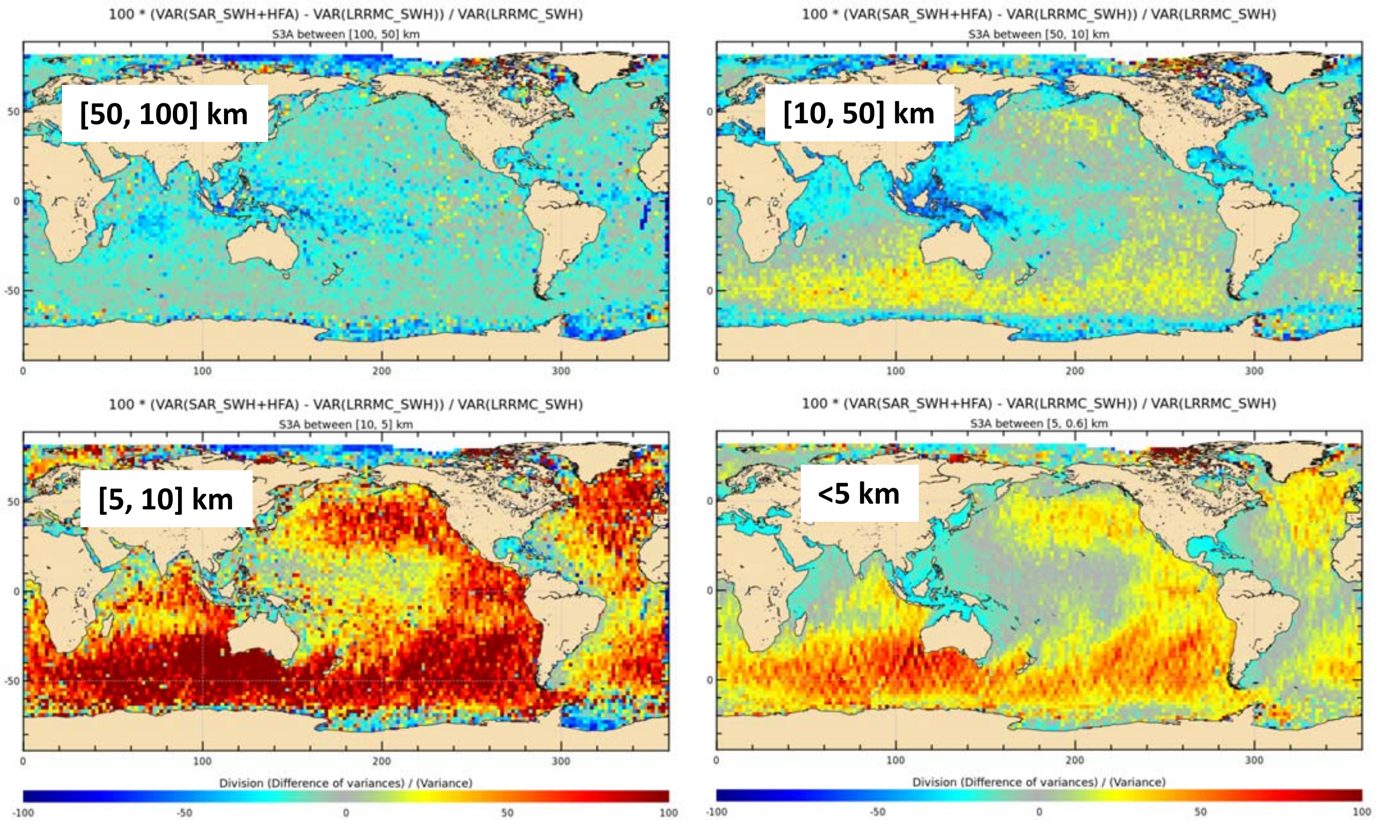
variance comparison (%) → feature in SAR red noise

var(SWH_SAR+HFA) **vs** var(SWH_LRRMC)



var(SWH_LRRMC) **>** var(SWH_SAR+HFA)

var(SWH_LRRMC) **<** var(SWH_SAR+HFA)

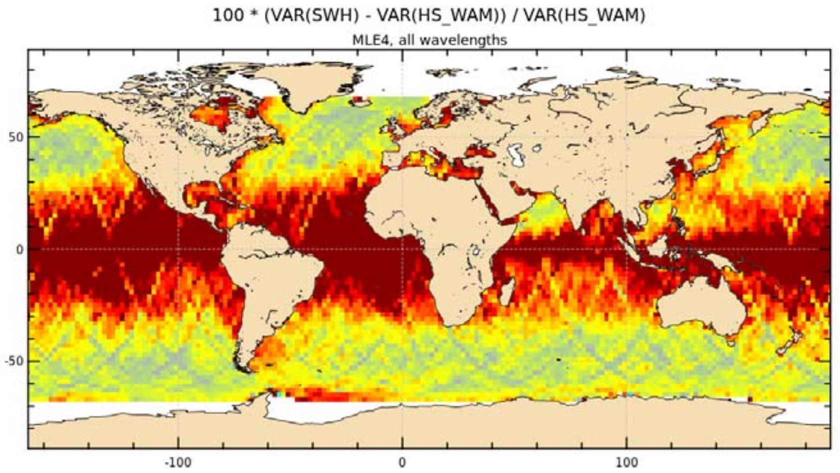
- SAR spectral slope ("red noise") is still there for λ < 50 km after HFA application
- By lowering the high-frequency variability at a level similar to the LR-RMC one, differences can be more easily described
- Clear correlations with swell regions are shown
- Confirming previous results on swell induced effects [Moreau et al, 2018; Raynal et al, 2018]

Variance reduction maps

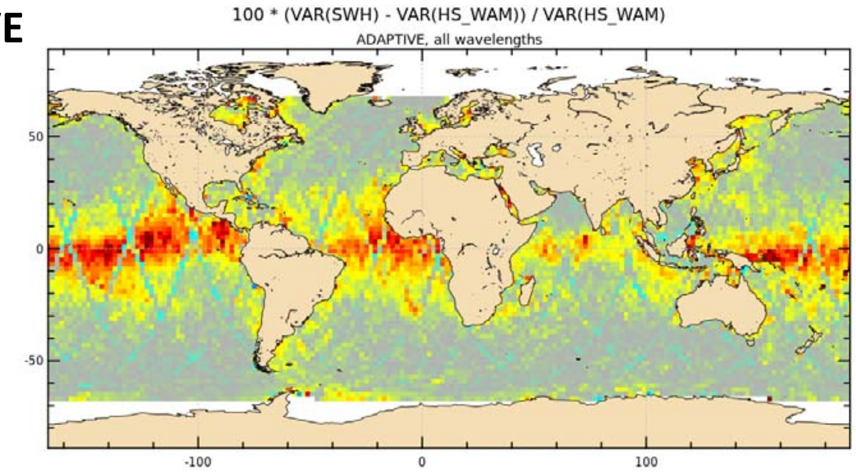
Variance comparison (%), nominal data, MF-WAM used as reference

Percentage of Variance reduction (considering one year of data)
PVR = 100 * (var(New_SWH) – var(reference_SWH)) / var(reference_SWH)

MLE4

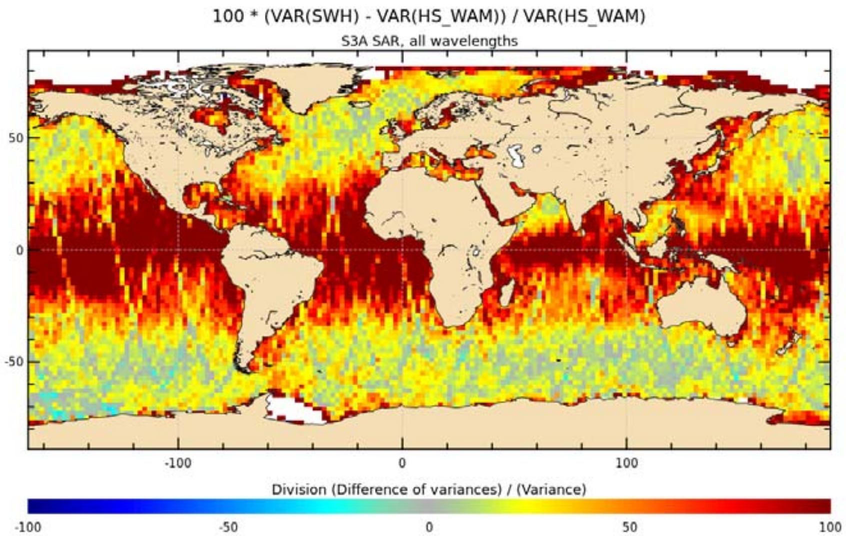


ADAPTIVE

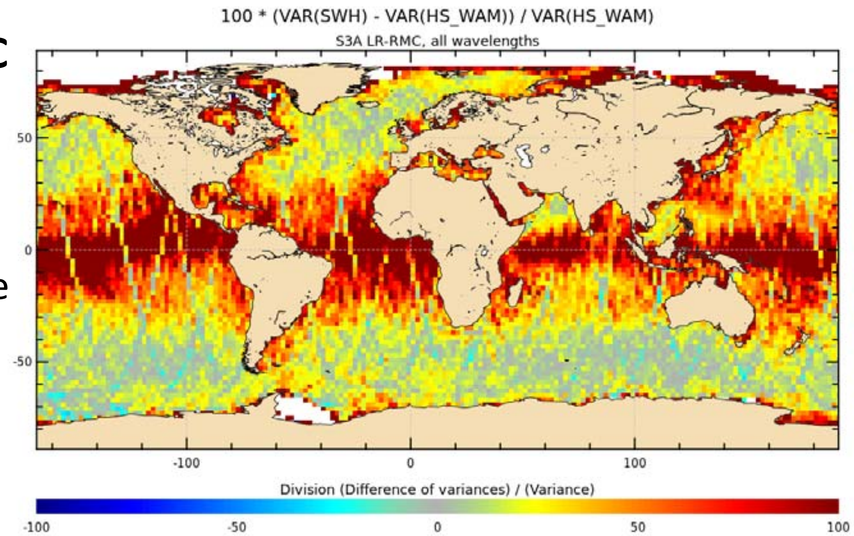


Altimetric SWH data are highly variable in the inter-tropical regions where low SWH conditions are observed

SAR



LR-RMC

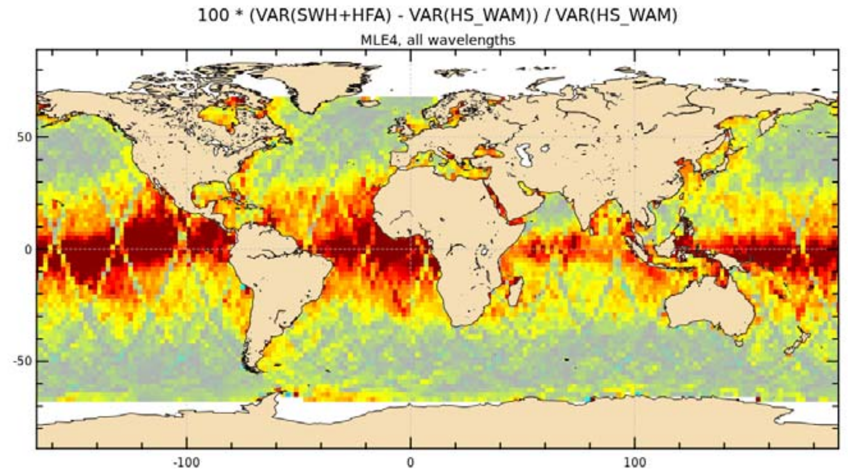


The ADAPTIVE estimations display the lowest variabilities when one compares with those from the model data → retrieved waves are more stable in time

Variance reduction maps

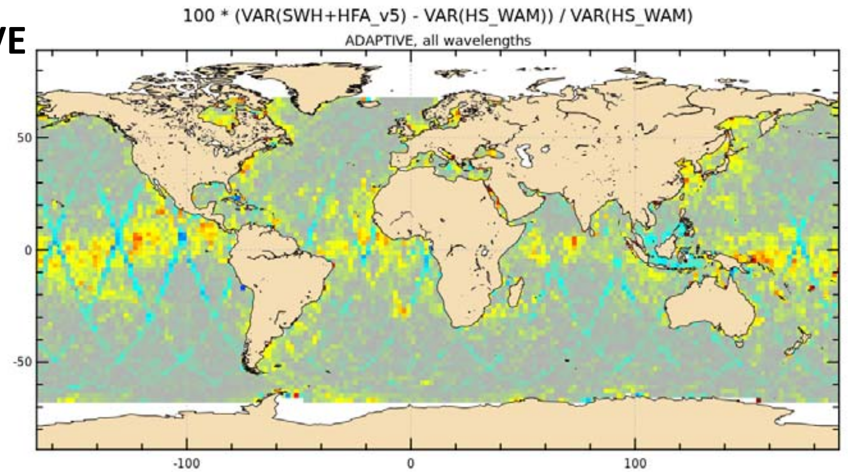
Variance comparison (%), corrected data, MF-WAM used as reference

Percentage of Variance reduction (considering one year of data)
PVR = 100 * (var(New_SWH) – var(reference_SWH)) / var(reference_SWH)

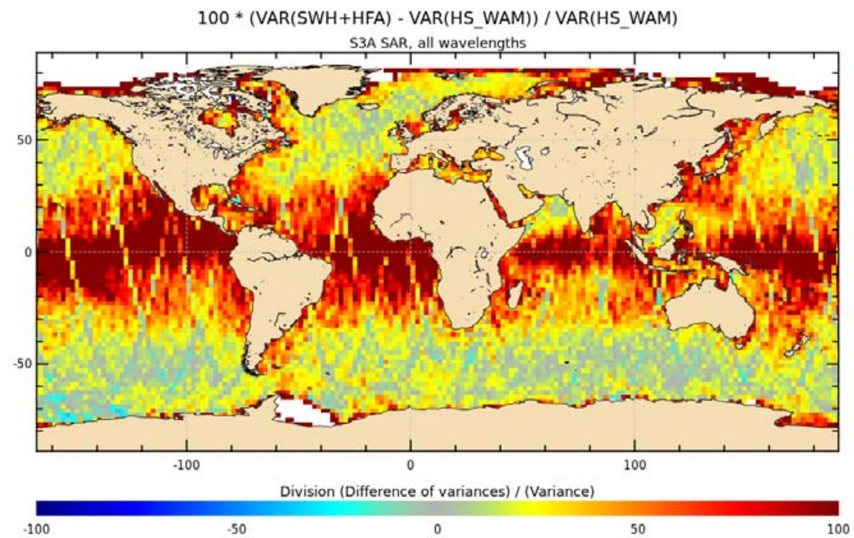


MLE4 + HFA

ADAPTIVE + HFA

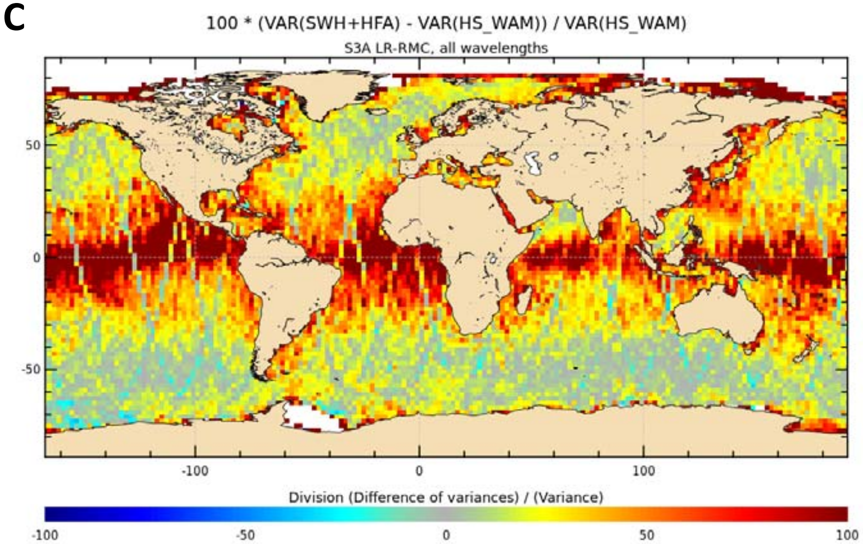


The extent of the red color zone tightens around the equator



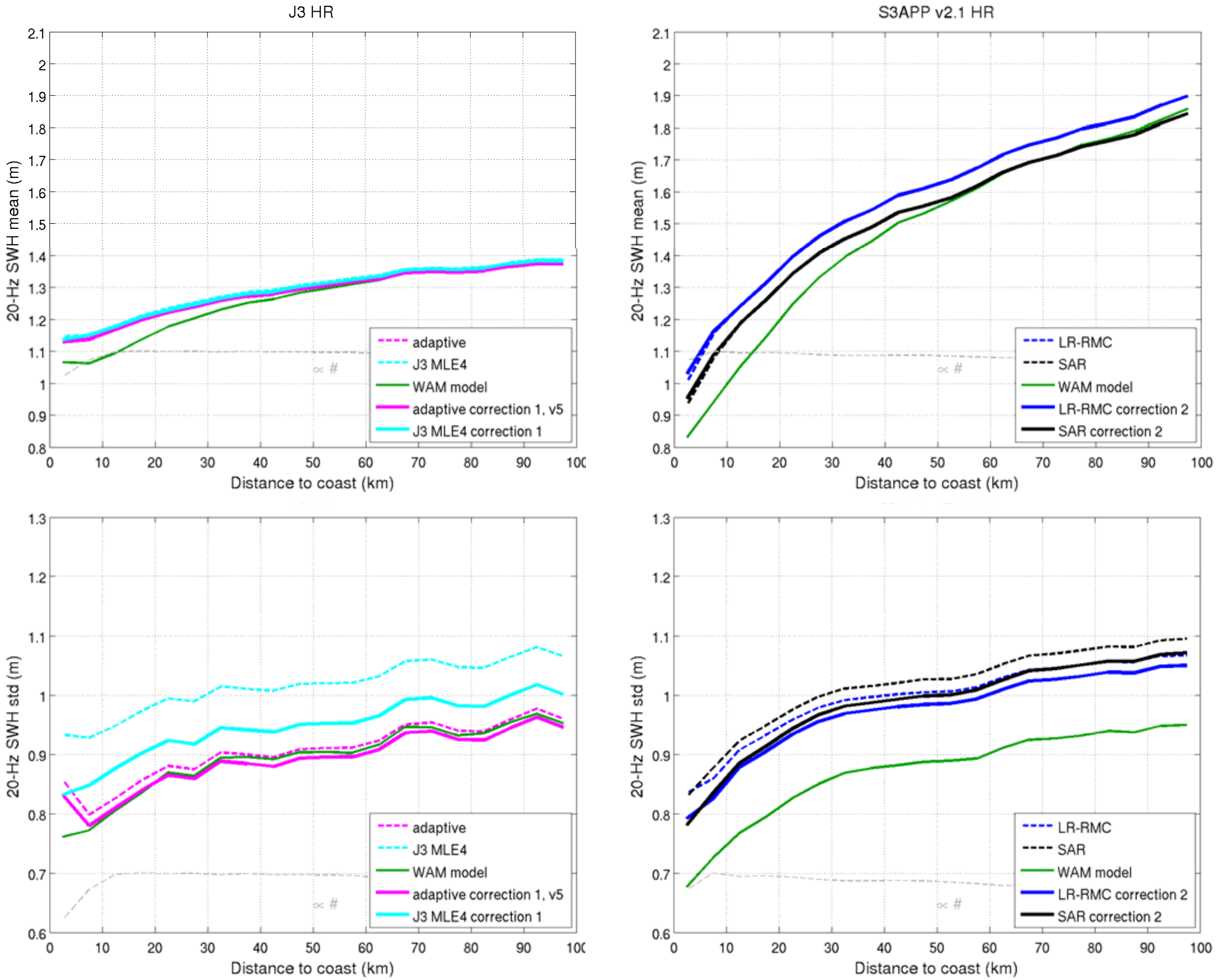
SAR + HFA

LR-RMC + HFA



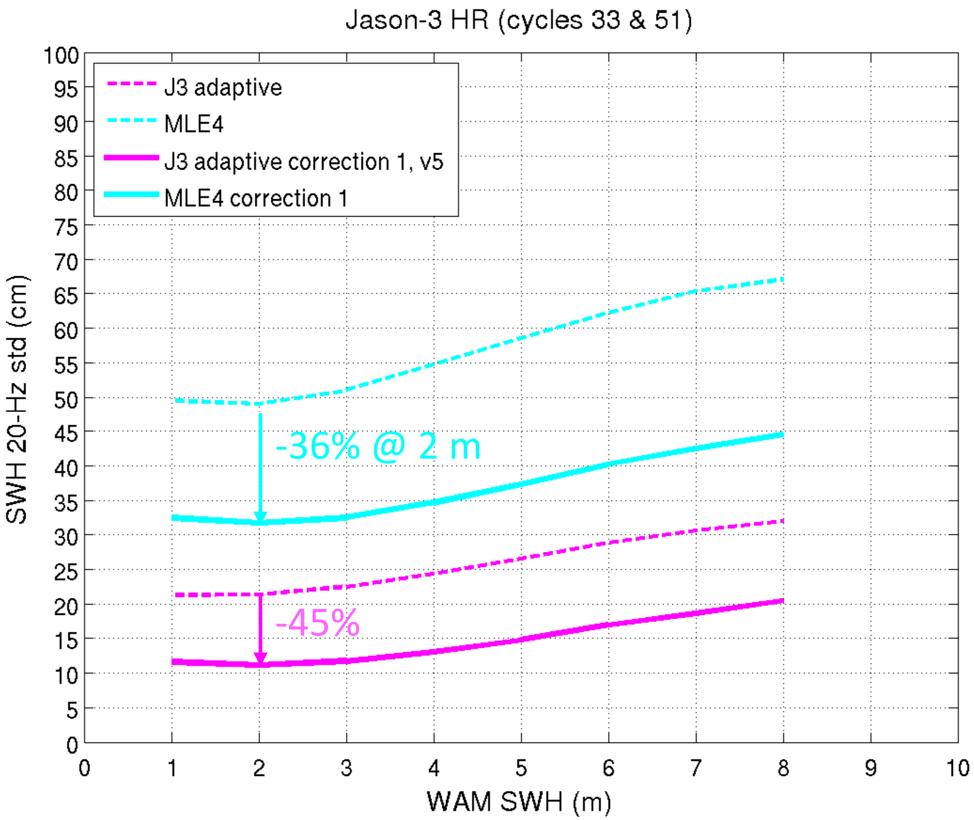
The reduction of the HF noise leads to reduce the local temporal variability which is now closer to model variations → help for model assimilation exercise to better seen shorter-scale features?

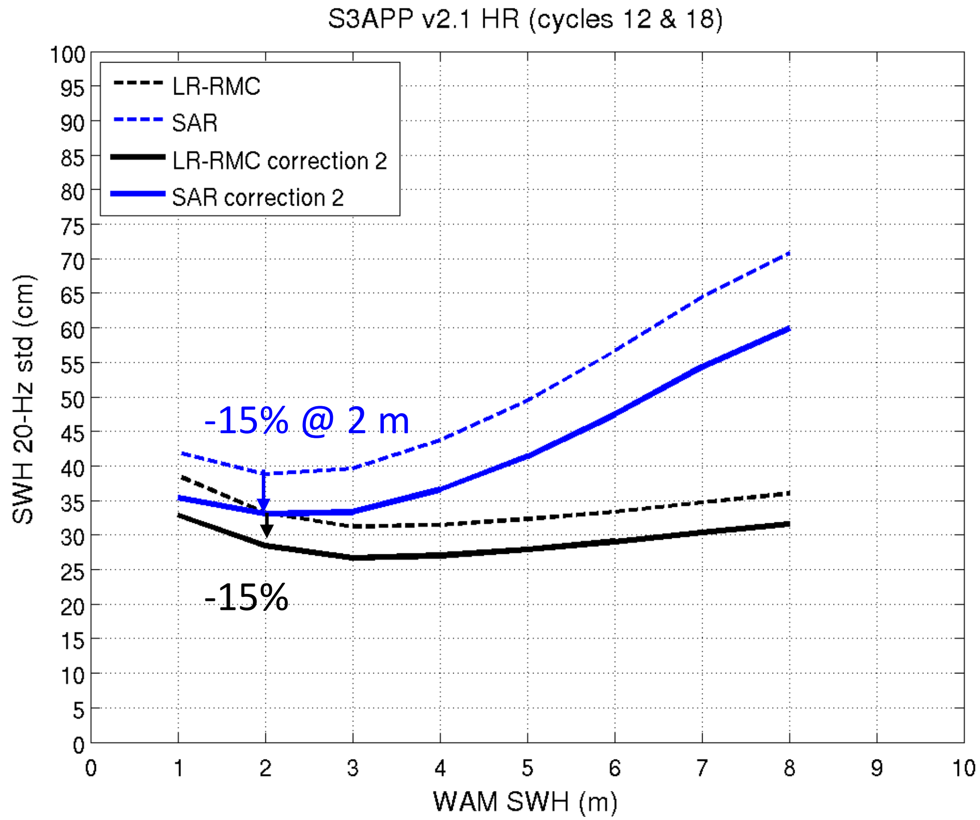
Coastal results



- No change is observed in term of bias
- Reductions of the data variability are obtained even in coastal regions

1-Hz benefit





- The reduction of the high-frequency content in 20-Hz data leads automatically to reduce the 1-Hz data noise

Conclusions

- Large improvements are obtained in the retrieval of SWH estimations
  - for LRM data thanks to Adaptive retracker + HFA
  - for SAR data thanks to LR-RMC processing + HFA

- These two solutions have been provided for the ESA Sea-State CCI Round Robin exercise; Quartly [2019] followed close pathway; have a look at F. Schlembach's poster presenting the Round Robin results; have a look also at Y. Quilfen's poster presenting another approach for denoising SWH data.

- LR-RMC demonstration products will be made available by the end of the year and a paper is in preparation [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 project)

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Thank you