FastAdaptiveS6: an optimal retracking solution for the analysis of Sentinel-6 LRM data

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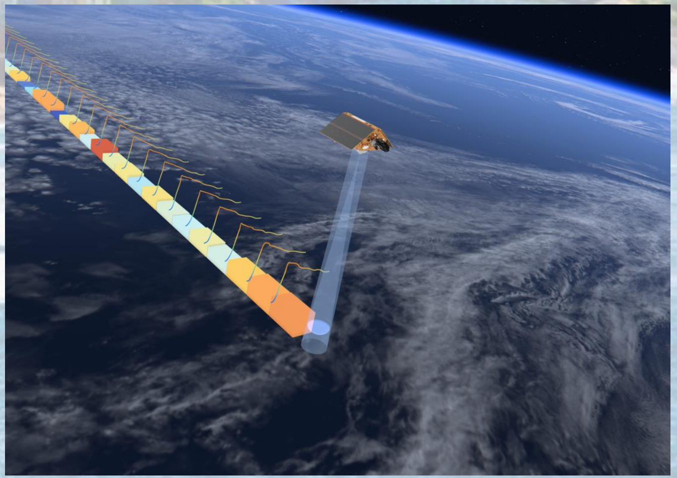


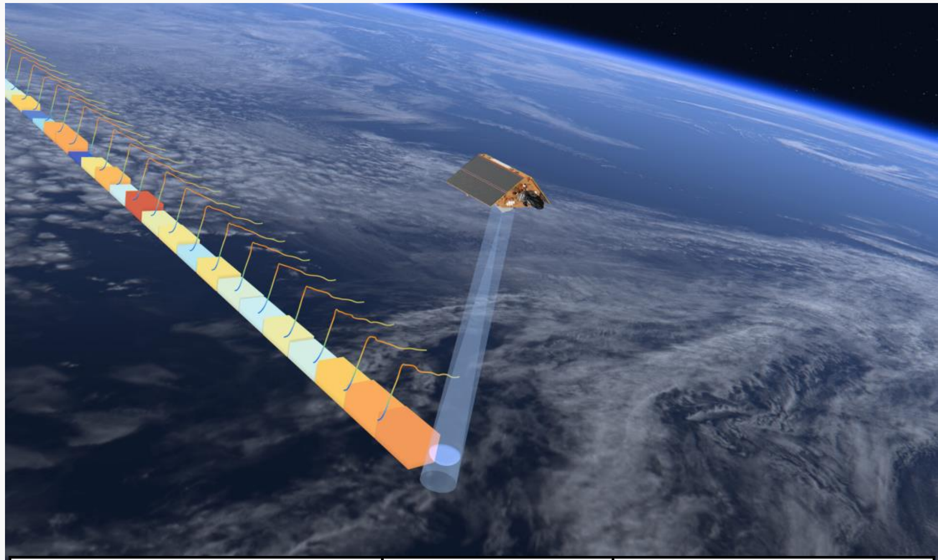
Context and motivation

To ensure the continuity and the robustness of the parameter estimation, a retracking algorithm should account for:

- the **real time evolution of instrumental properties**, as the Point Target Response (**PTR**),
- a **realistic waveform noise characterization**

An accurate noise characterisation is particularly important for S6 as the pulse-to-pulse correlations linked to the S6 PRF configuration may impact the parameter estimation if not correctly accounted for (e.g. [Egido & Smith 2018])

Current solutions implemented in the S6 ground segment do not meet this goal



Current S6 retrackers	real PTR	Realistic waveform noise
MLE4	✗	✗
NUM_RTK PDAP	✓	✗

FastAdaptiveS6: optimal retracker solution based on FAD [Mangilli et al OSTST22] and tailored for Sentinel-6

S6 waveform noise characterisation

Theoretical signal (=waveform model)

$$S(k) = s_t(k, \theta) + n'(k)$$

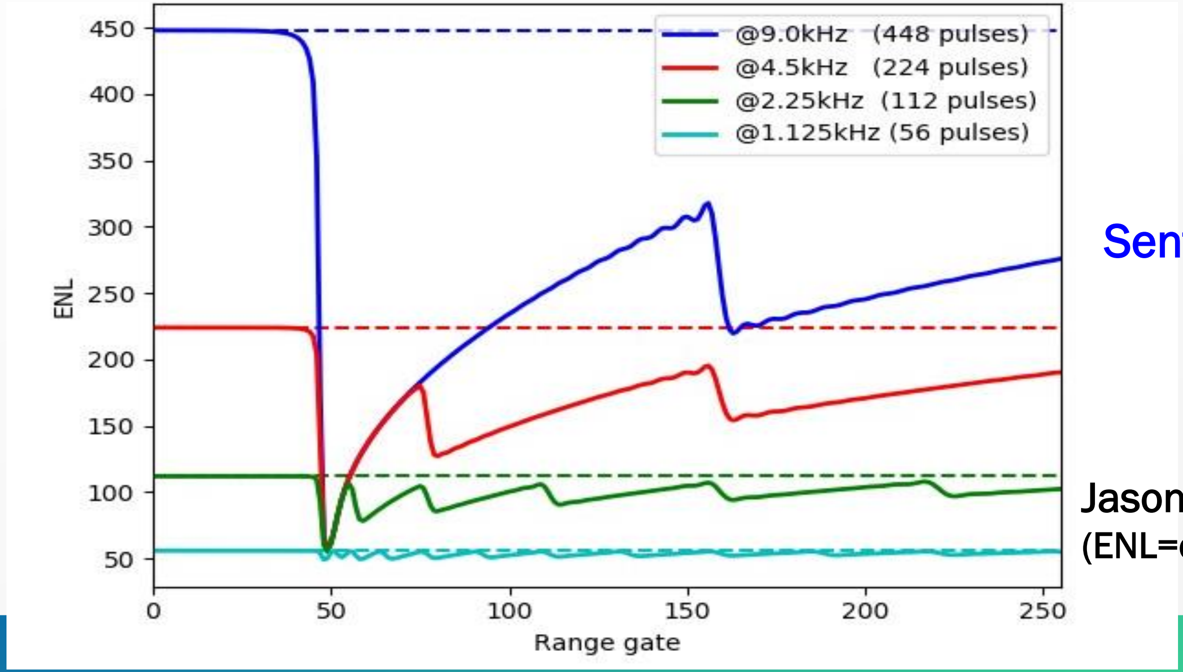
Gamma distributed multiplicative noise

On board averaging of N echos. For N big enough, the Gamma distribution converge to a Gaussian distribution (central limit theorem)

Gaussian distribution

$$\sim \mathcal{N}\left(0, \frac{s_t^2(k,\theta)}{ENL}\right)$$

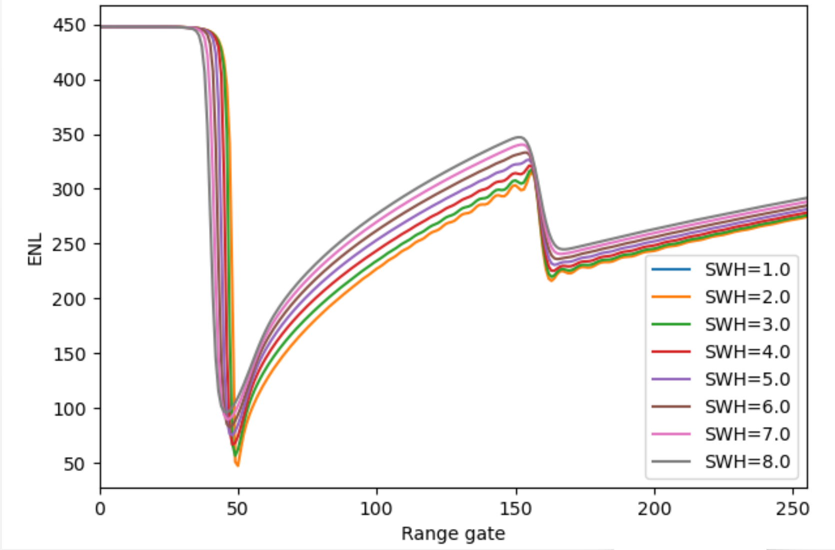
ENL(<N): Effective Number of Looks: depends on the Pulse Repetition Frequency



Sentinel-6

Jason3 (2kHz)
(ENL=const~90)

$$ENL = ENL(k, \theta) \sim ENL(k, \mathrm{SWH})$$



The FastAdaptiveS6 retracker

- The <u>likelihood function</u> (join probability of the measurements **y** given the model $s_t(\theta)$) is a multi variate Gaussian distribution with mean s_t and noise covariance matrix C (see e.g. [Rodriguez 1998], [Halimi et al 2015]) :

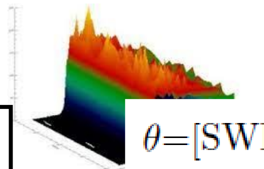
$$-2ln\mathcal{L} = (\mathbf{y} - \mathbf{s}_t(\theta))^T \mathbf{C}^{-1}(\theta)(\mathbf{y} - \mathbf{s}_t(\theta)) + const$$

Waveform noise covariance matrix $$C_{k_n k_n} = \frac{s_t^2(k_n, \theta)}{\mathrm{ENL}(\mathrm{k_n}, \theta)}$$

- Maximum Likelihood Estimator equivalent to Weighted Least Squares estimator
- FADS6 Weights computation: the model dependent noise variance is included in the fit function (global fit approach)

FastAdaptiveS6

Model



θ=[SWH, epoch, Amplitude, γ]

4 parameters **Adaptive Model convolved with the instrumental PTR**

Estimator

Weighted Least Square

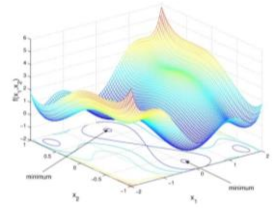
$$\hat{\theta}_{WLS} = argmin[(\mathbf{y} - \mathbf{s}_t(\theta))^T \mathbf{C}^{-1}(\theta)(\mathbf{y} - \mathbf{s}_t(\theta))]$$

NUM_RTK PDAP

4 parameters **Brown Model convolved with the instrumental PTR**

Ordinary Least Square

Optimisation

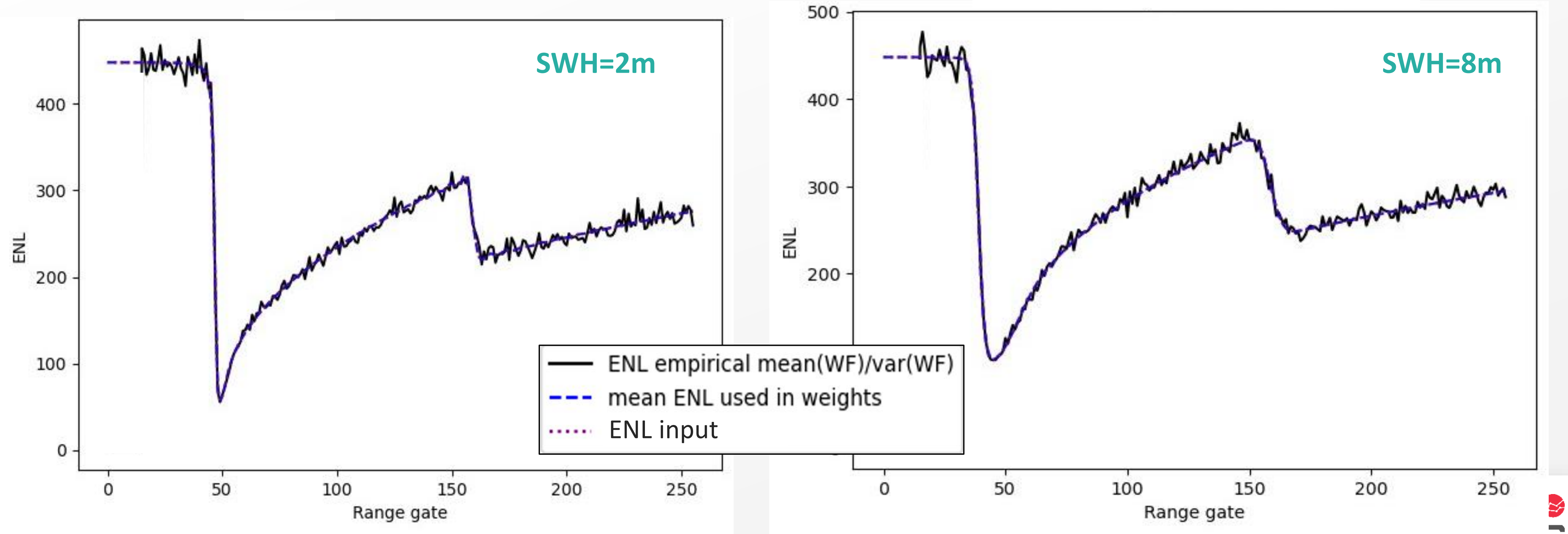


Levenberg-Marquardt minimization

- FADS6 main computational cost is due to the PTR convolution with a factor of 64 oversampling and not to the optimisation step (the same as for the numerical retracker)

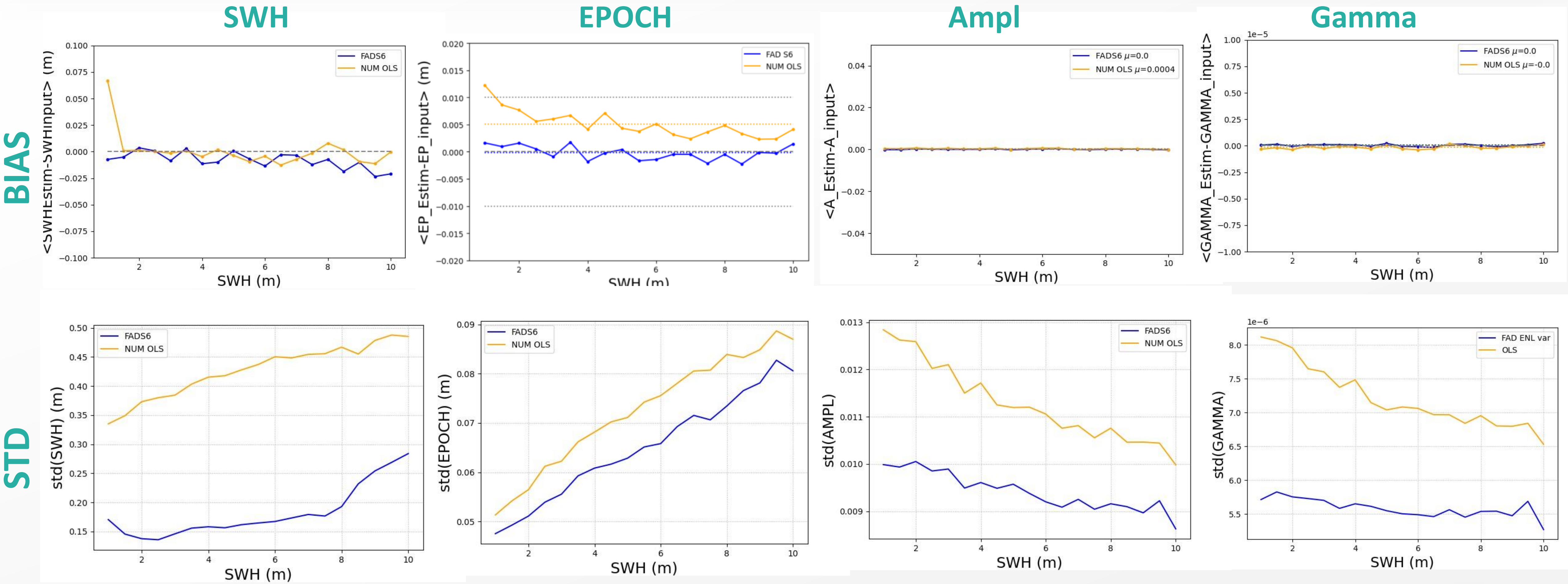
FastAdaptiveS6: results on simulations

- **Sentinel-6 simulations** generated with the **Adaptive model** with sinc2 PTR and a **multiplicative speckle noise with a gamma distribution and varying ENL(k,SWH).**
- 3000 sims for different sets with SWH inputs from 1m to 10 m. A_in=1, Ep_in=0.1 (gates), γ_in=4.e-4



FastAdaptiveS6: results on simulations

Comparison of results obtained with the FastAdS6 and NUM Ordinary Least Square (same model, no weights)



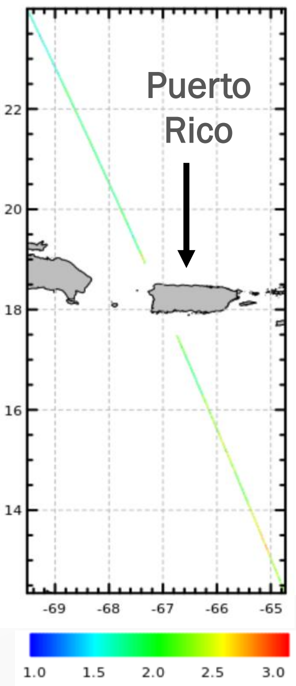
FastAdaptiveS6: unbiased and optimal. Significative noise reduction for all the parameters wrt OLS.

NUM OLS: epoch bias for all SWH bins up to ~1cm and SWH bias of ~6 cm for small SWH=1m

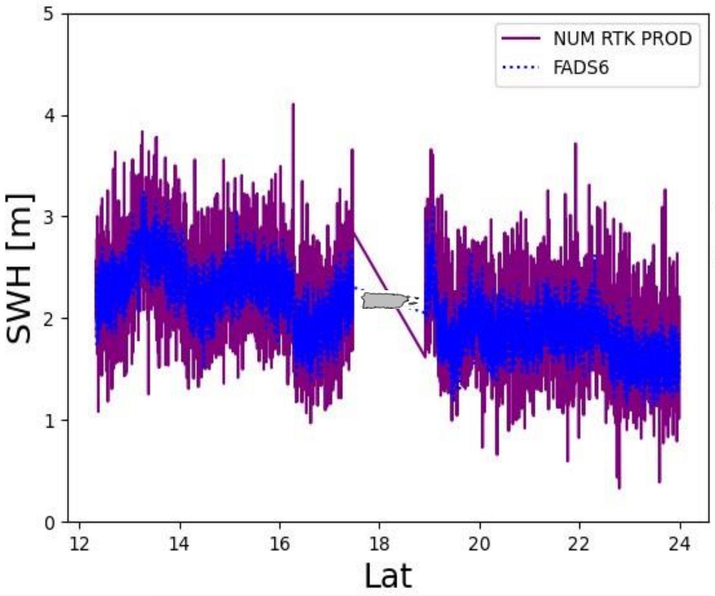
FastAdaptiveS6: results on Sentinel-6 data

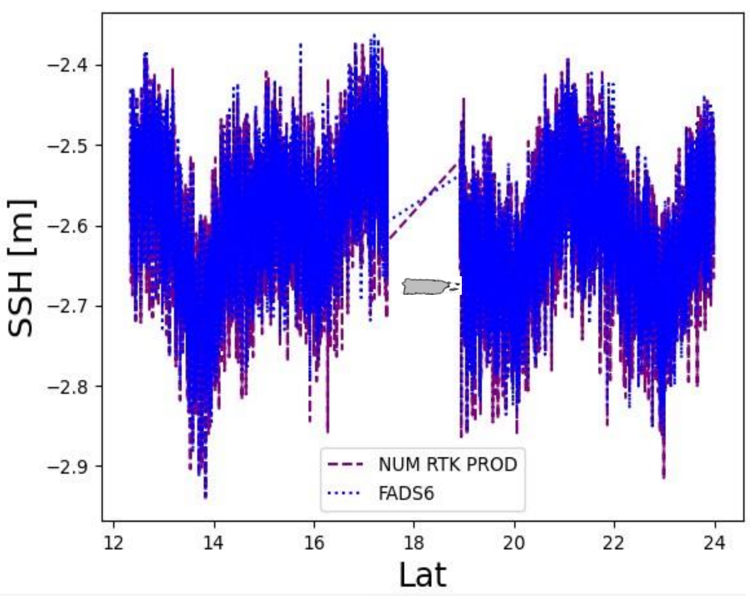
Sentinel-6 20 Hz waveform data over ocean for cycle 24 (July 2021) are analysed with the **FastAdaptiveS6** retracker and the results are compared with the **NUMERICAL retracker** outputs (PDAP f08 products).

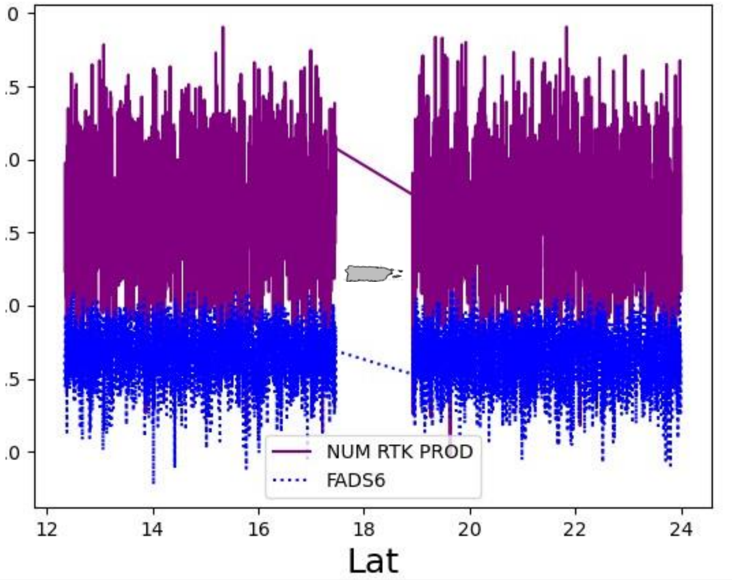
S6 c 24 pass 152



SWH FADS6







FastAdaptiveS6 results :

- Are **compatible with the NUM_RTK** for **SWH and RANGE**
- Shift in the amplitude of ~1dB wrt to the NUM_RTK (PDAP L1 total power issue?)
- **Significative noise reduction** of the parameters estimation wrt existing solutions

FastAdaptiveS6: fit performance

Reduced chi2: square of the residuals weighted by the data variance and normalized by the number of degree of freedom

chi2 at best fit

$$\hat{\chi}^2 = \frac{1}{\nu}\chi^2(\bar{\theta}_p)$$

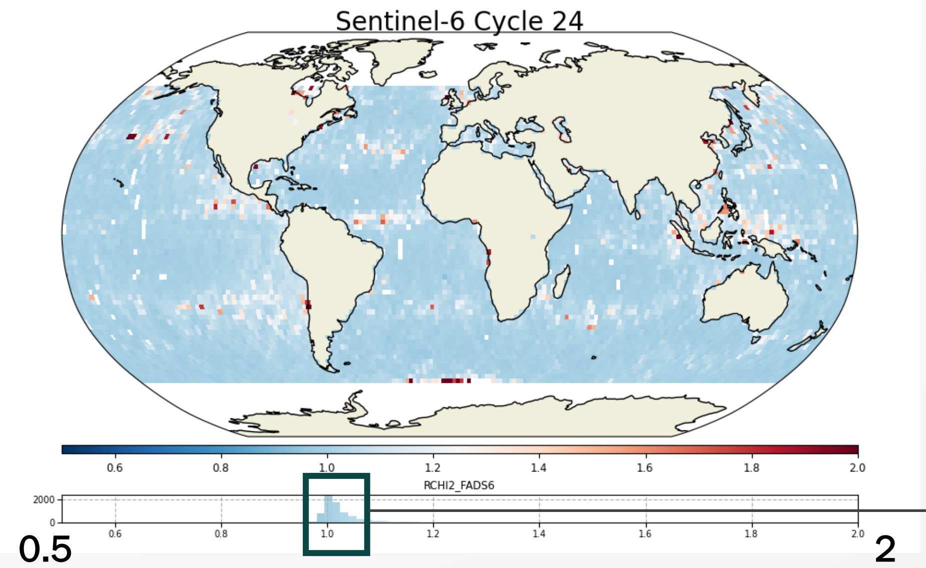
Number of degrees of freedom (N_samples-N_parameters)

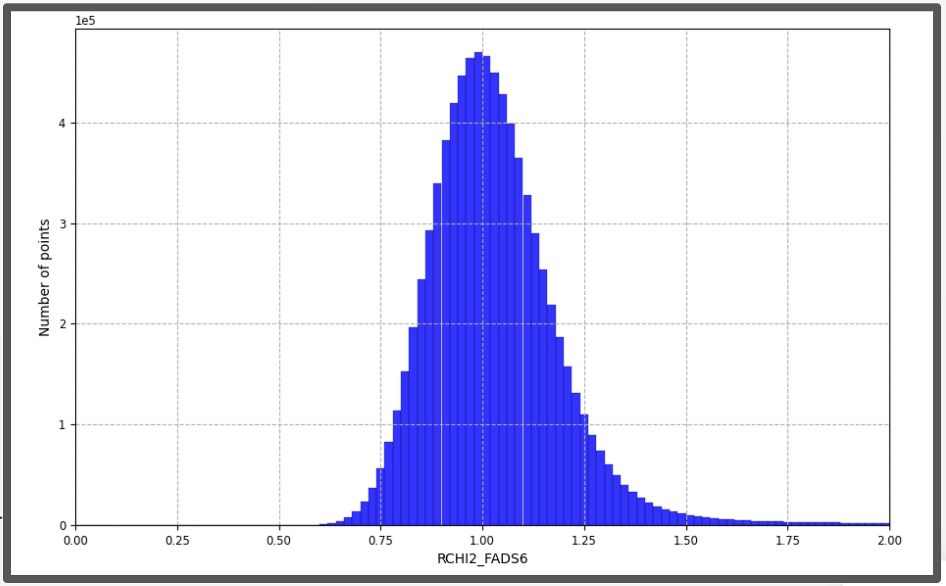
Vector of residuals

$$\chi^2 = \mathbf{r}^T \mathbb{C}^{-1} \mathbf{r} \simeq \sum_i \left(\frac{r_i}{\sigma_i}\right)^2$$

Inverse of the noise covariance matrix

Good fit performance: reduced chi2 around 1 (model in agreement with the data within the data variance)

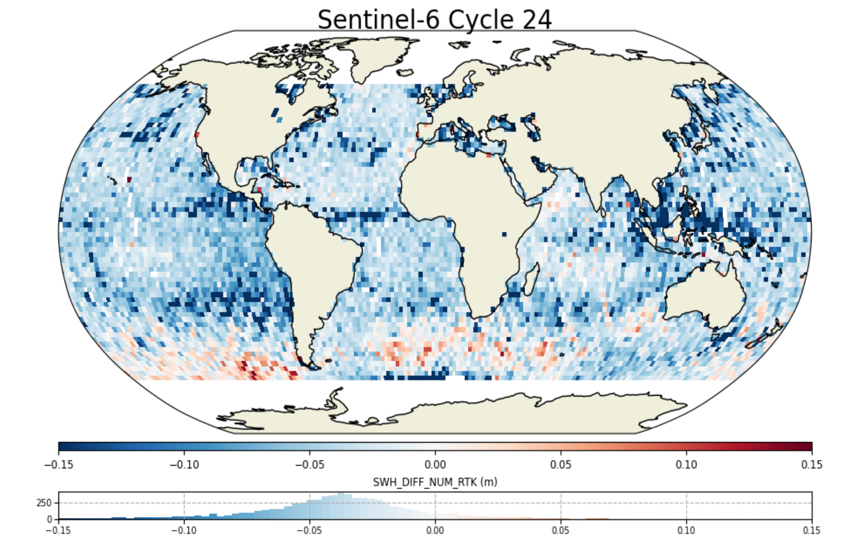




Good and stable fit performances for the FADS6 over all the cycle

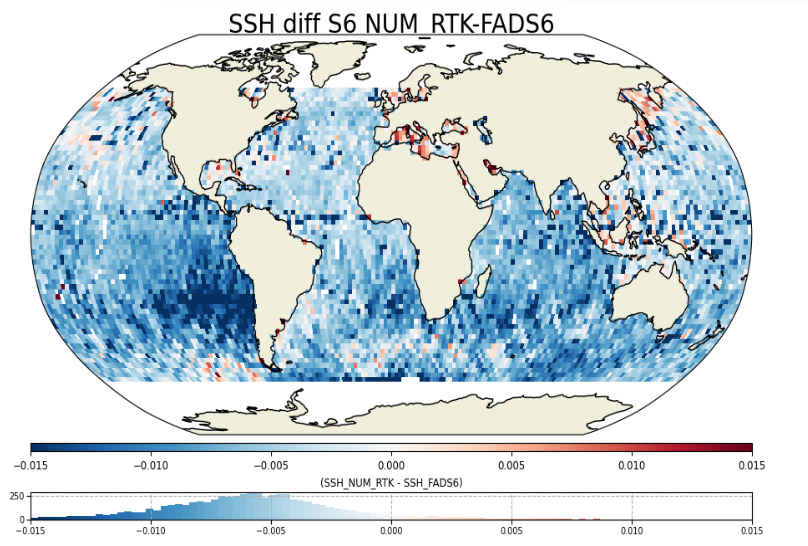
NUM RTK PDAP and FastAdaptiveS6: Maps difference

SWH DIFF



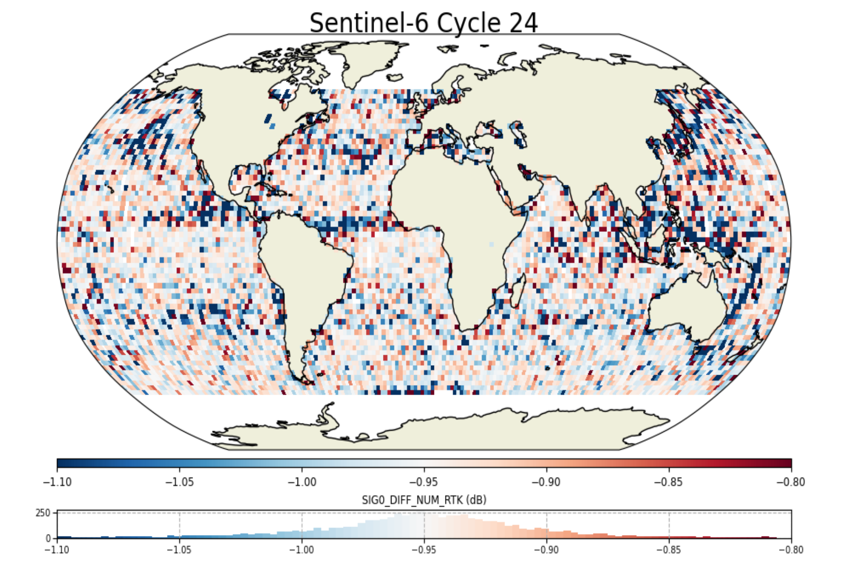
-10cm +10cm

SSH DIFF



-1.5cm +1cm

10LOG10(AMPL) DIFF

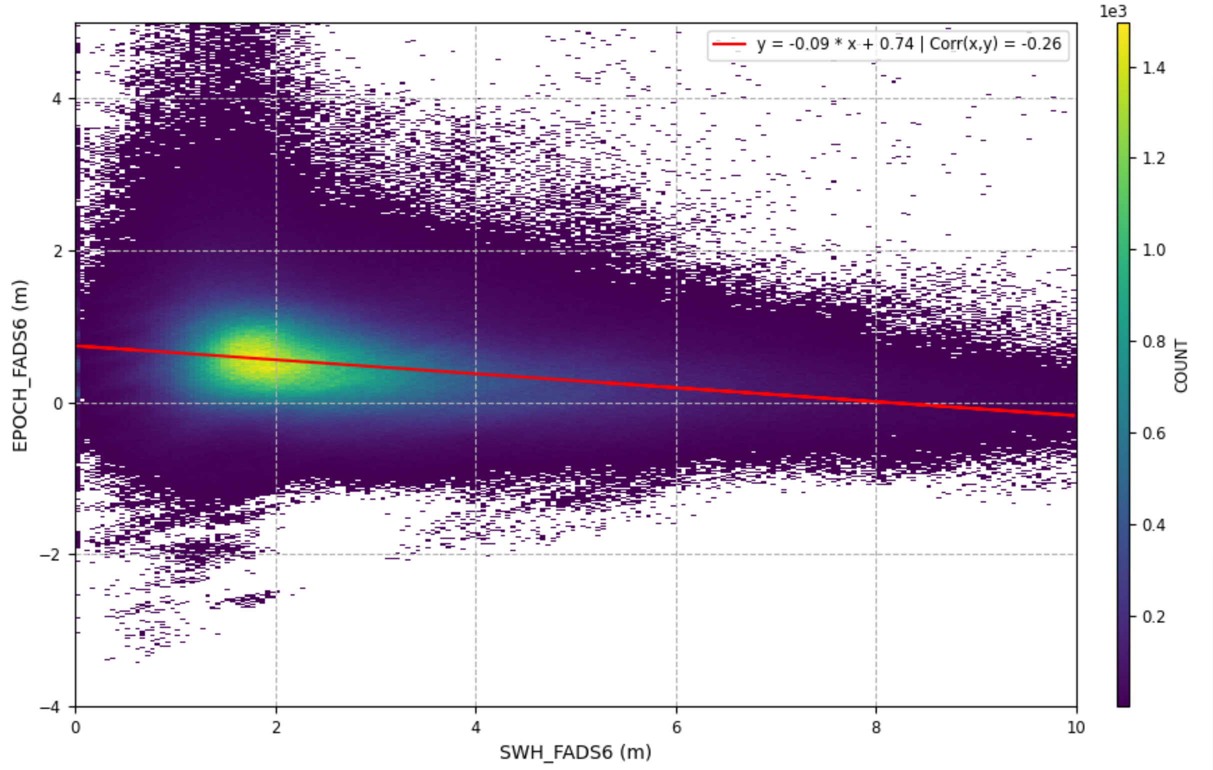


- 0.95

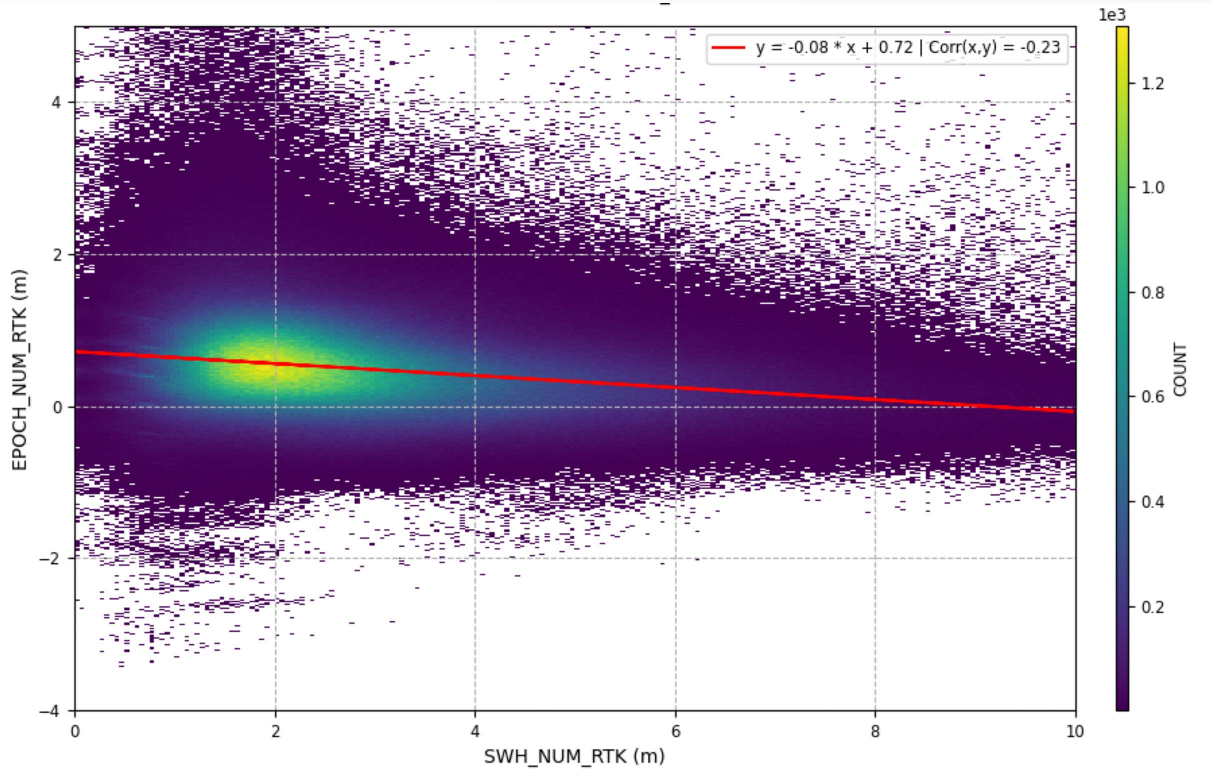
- Overall compatible results for the estimation of SWH and RANGE
- Amplitude difference around 0.95 dB likely due to a total power computation issue in PDAP L1
- SWH dependence in the ssh difference of ~2 cm under investigation
- Different sea states seem to have a different impact on the two retrackers (different SSB needed)

Parameters correlation: EPOCH vs SWH

FADS6



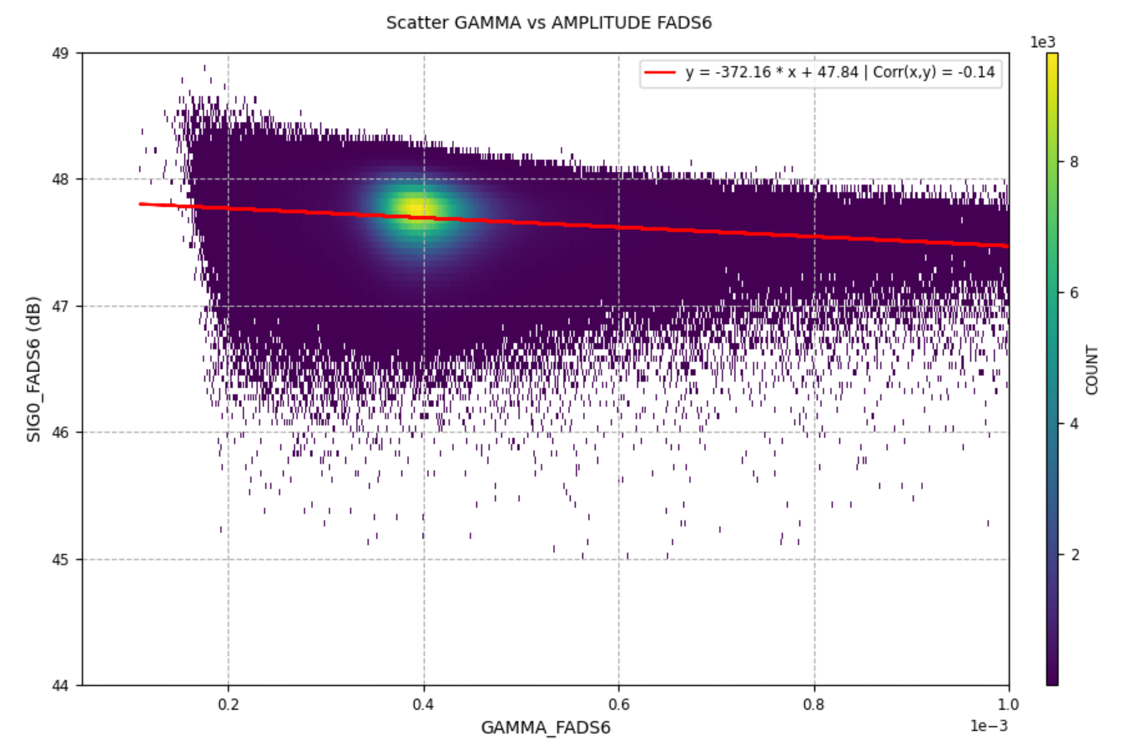
NUM_RTK PROD



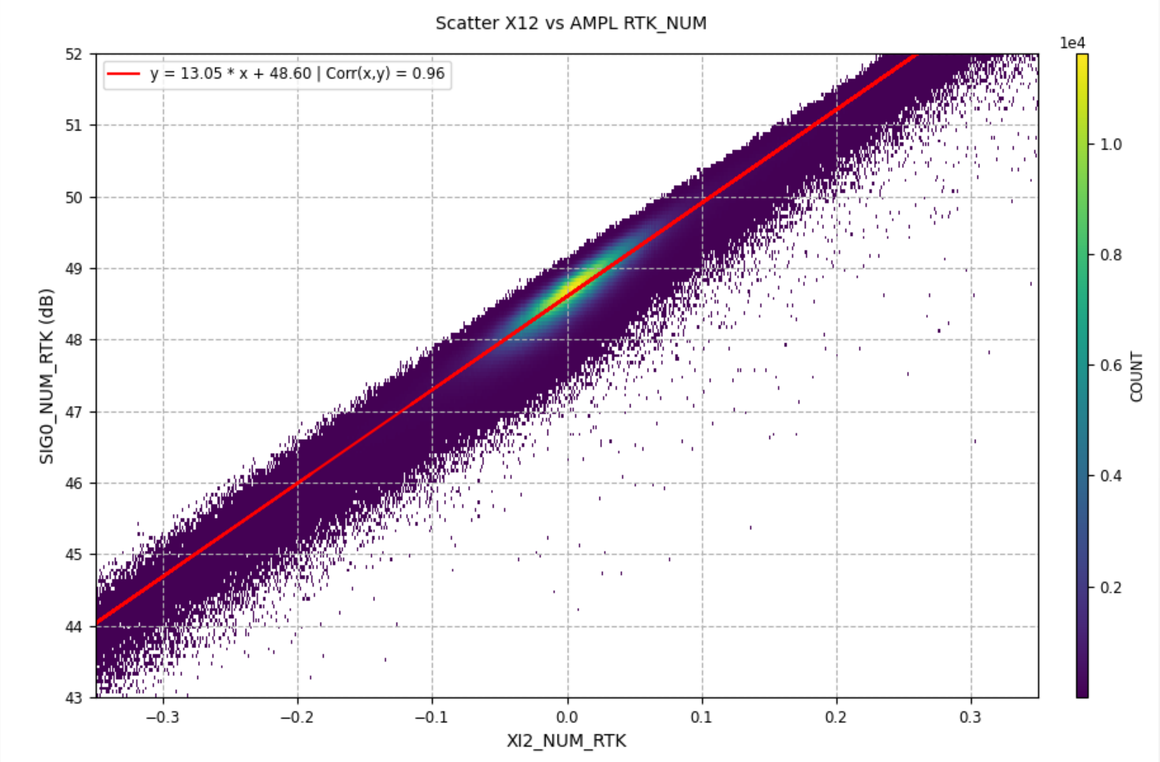
- Overall, similar distribution and correlation of the measurements for both retrackers
- Less dispersion for FADS6

Parameters correlation: AMPLITUDE vs GAMMA/XI2

FADS6

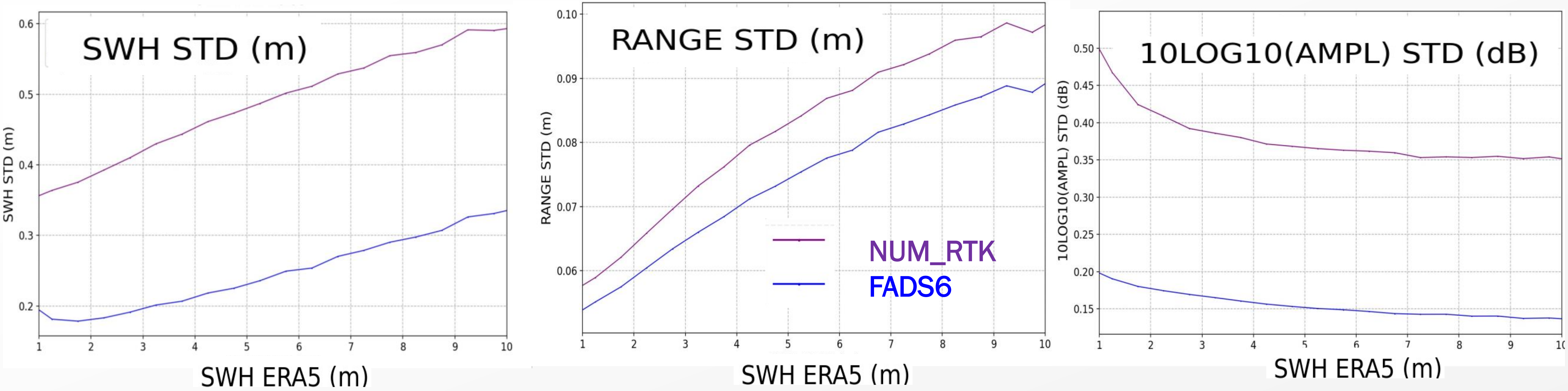


NUM_RTK PROD



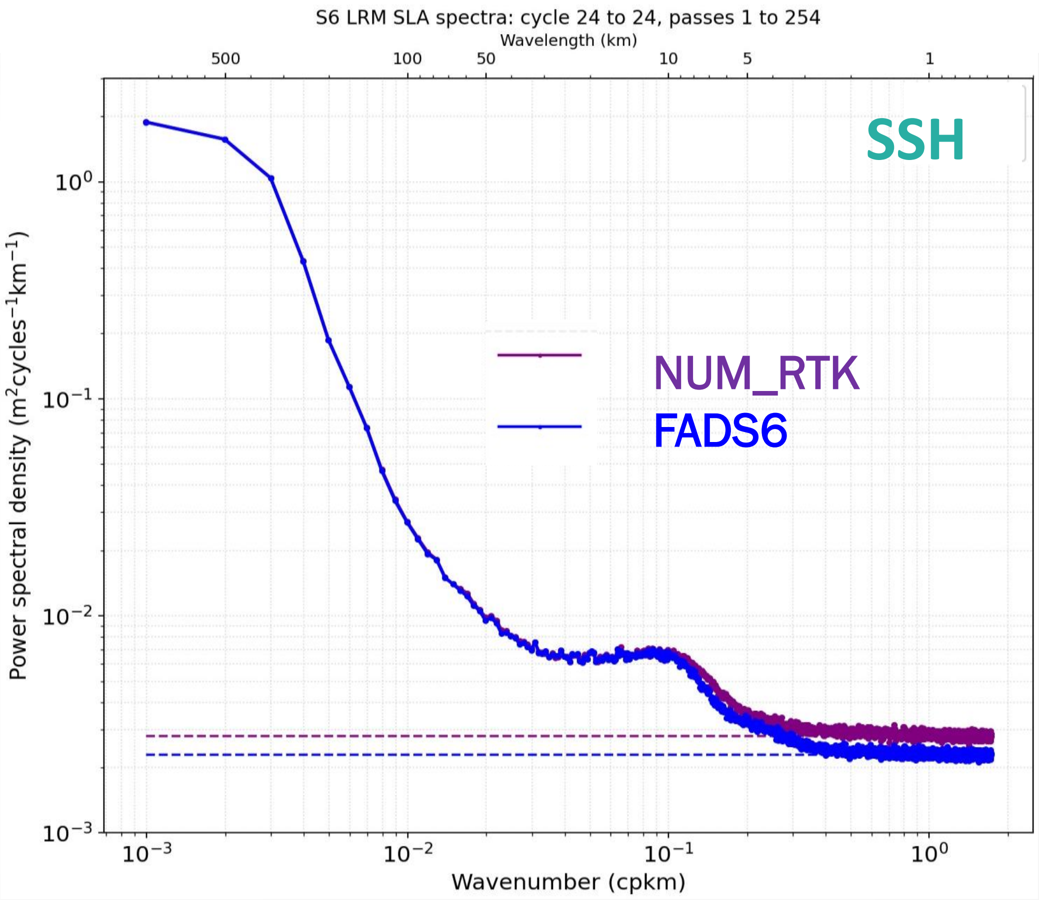
- Almost no correlation (r=-0.14) between the amplitude and gamma parameters for the FADS6
- High correlation (r=0.96) between the amplitude and the mispointing parameters for the NUM_RTK
- Because of the different model with much lower correlations, the FADS6 allows to significantly improve the estimation of the amplitude/sigma0 wrt the NUM_RTK

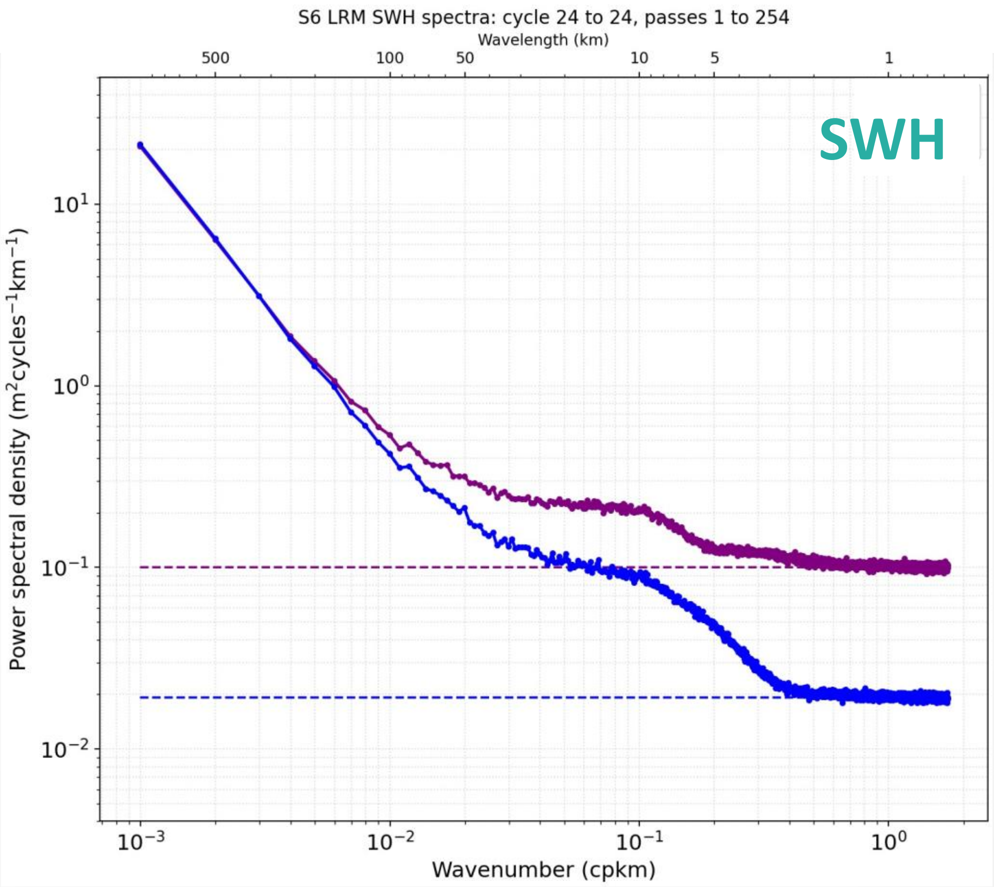
Parameter errors at 1 Hz



- Significative improvement of the FADS6 estimations for all parameters wrt existing solutions
- The improvement is compatible with the improvement seen on simulations and when comparing MLE4 and Adaptive estimates on Jason-3 data

SSH and SWH spectra



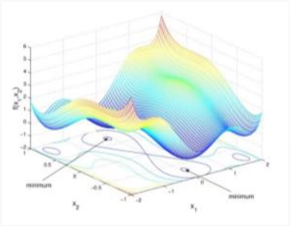


- FastAdaptiveS6 spectra show **<u>significative noise reduction</u>** wrt to the NUM_RTK
- The improvement is ~60% for SWH and ~10% for SSH, in line with the Adaptive vs MLE4 comparison for Jason3
- Same spectral content at large scales
- Similar short-wavelength correlated errors

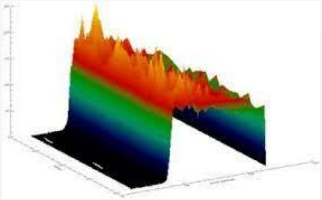
Conclusions and perspectives

	MLE4	NUM_RTK	FastAdS6
Optimal parameter estimation (noise reduction)	✗	✗	✓
CPU time	✓	✓	✓
GMSL stability (PTR)	✗	✓	✓
Multi-surface processing (continuity between open ocean and polar ocean)	✗	✗	✓

Sentinel-6 PDAP

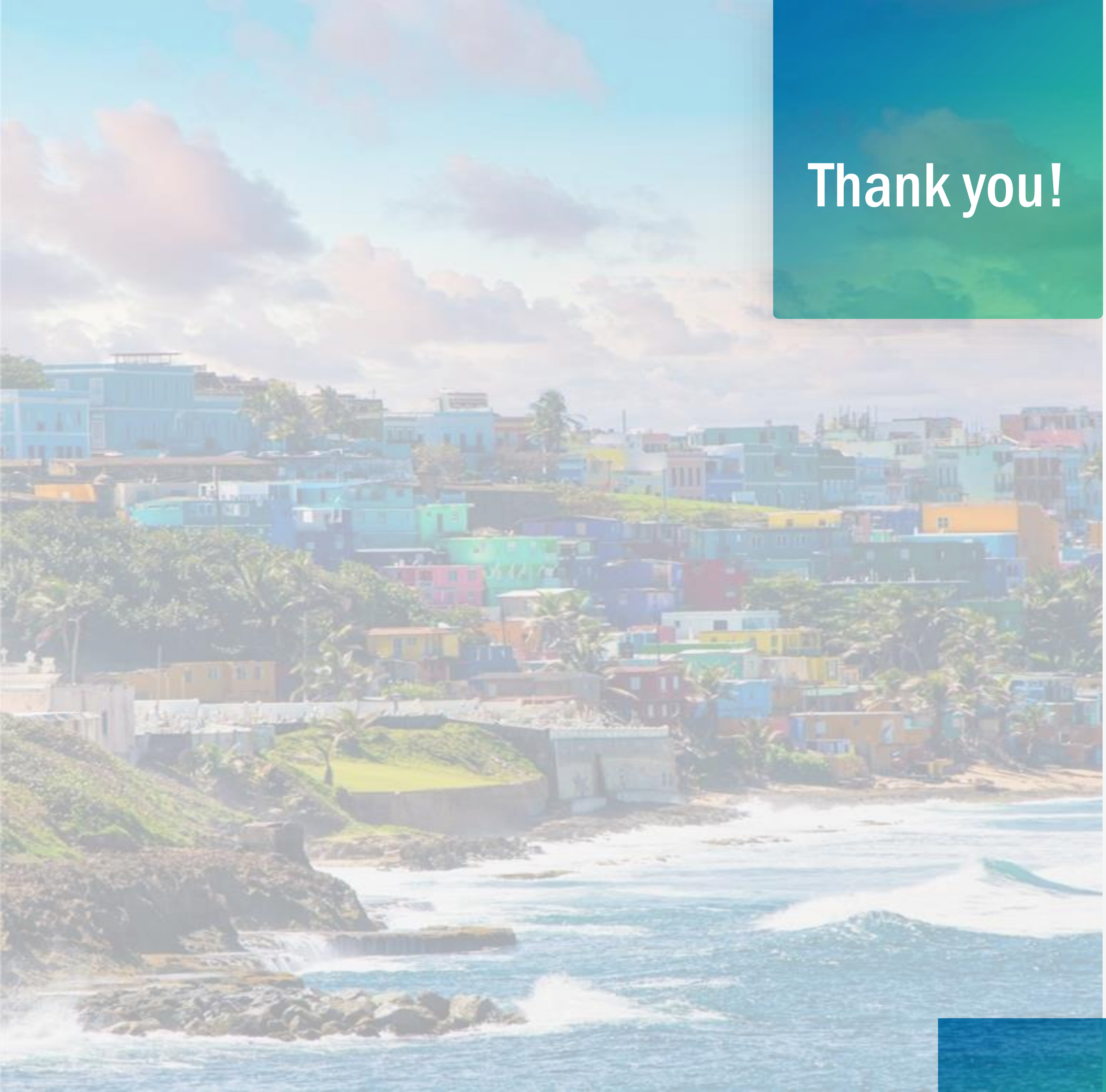


Estimator & Optimisation

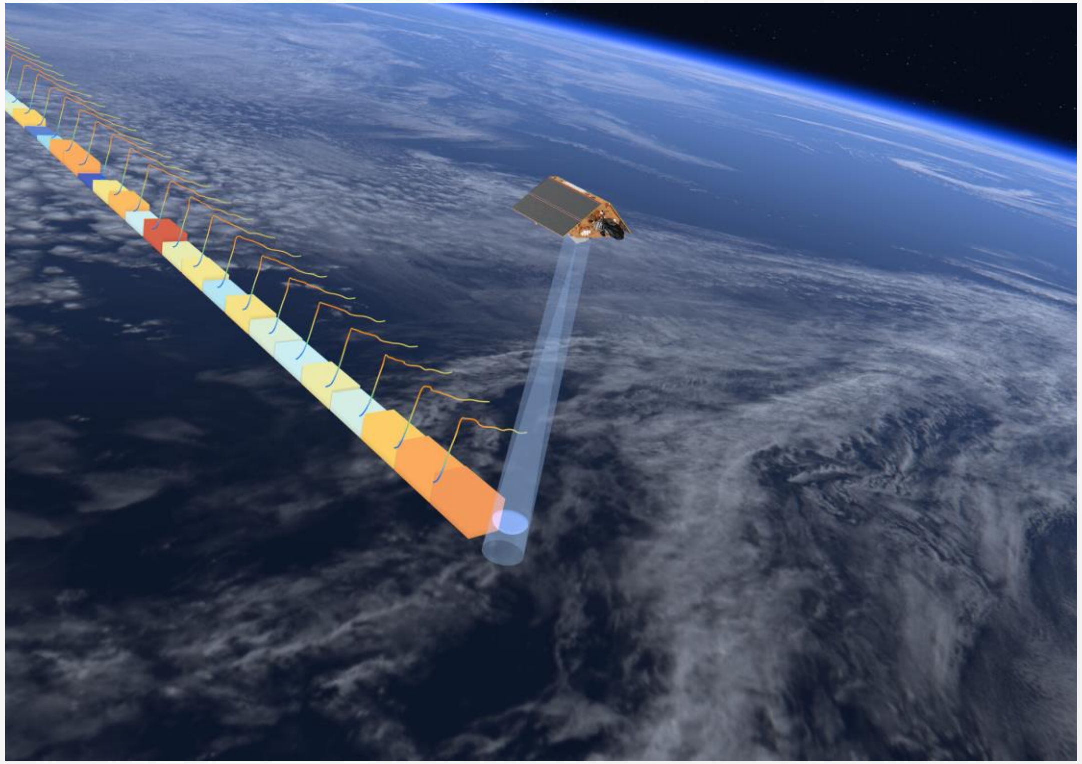


Model

- **First results obtained with the FastAdaptiveS6 are promising!** More extensive tests foreseen, including comparison with Jason-3 outputs (Adaptive and MLE4) during the tandem phase
- **Work in progress:** FADS6 configuration for sea ice and coastal waveform data
- **Perspectives:** the FastAdaptive approach could be used for current/future LRM mission (S6, SWOT-nadir, S3C/D PLRM) and adapted for SARM data



Thank you!



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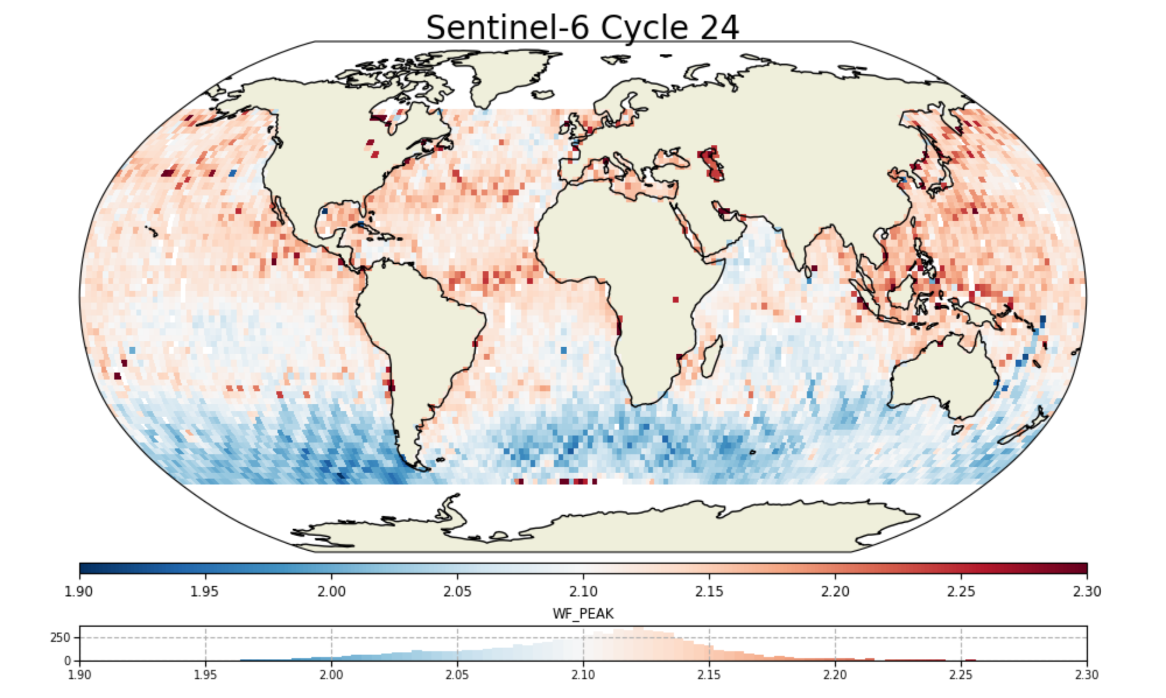
Waveform Peakiness and rain flag maps

WAVEFORM PEAKINESS



RAIN FLAG