Convergent solutions for retracking conventional and Delay Doppler altimeter echoes

P.Thibaut , F.Piras, J.C.Poisson, T.Moreau : *Collecte Localisation Satellite, France*
A.Halimi : *Heriot-Watt University, Edinburgh, UK*
F.Boy, A.Guillot, S.Le Gac, N.Picot : *Centre National d'Etudes Spatiales, France*

Ocean Surface Topography Science Team Meeting , Oct 2017, Miami, USA

Summary

- Reminder of the basics of the Adaptive Retracker method for conventional altimetry and main figures of performance
- Consistant approach for Delay Doppler measurements
- Introduction of a « roughness parameter » in LRM and DD models
- Illustration of the benefits
  - Blooms / Rain / Internal Waves
  - SLA and freeboard estimations at high latitudes
- Conclusions

Retracker = A model + an estimation method

A model

For LRM and SAR modes, the echoes can be expressed as the convolution (with different geometries) of 3 terms (Brown/Hayne model) :

$$S(t) = FFSR(t) \circledast PDF(t) \circledast PTR(t)$$ *in LRM*

$$S(t,f) = FFSR(t,f) \circledast PDF(t) \circledast PTR(t,f)$$ *in SAR*

t: time, f: doppler frequency (cf, Boy, 2016, TGRS)

- FSSR (Flat Sea Surface Response)
- PDF(Probability Density Function of the heights)
- PTR (Point Target Response: XT for LRM, XT & AT for SAR)

CNES/CLS have made the choice to derive the FSSR **analytically (LRM and SAR) and numerically (SAR)**
PTR and PDF are **always introduced numerically**

CNES Processing Prototype (CPP & S3PP)

Halimi's model published in TGRS, 2013

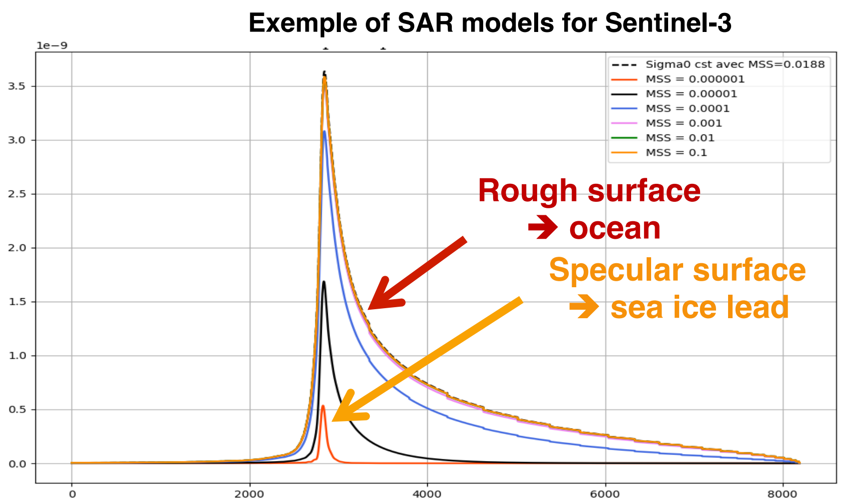
Retracker = A model + an estimation method

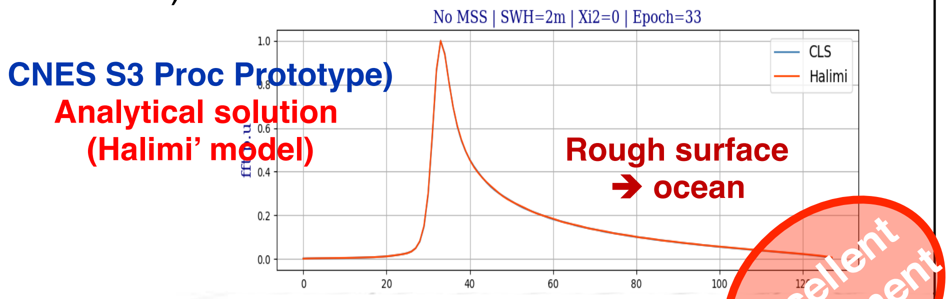
A model

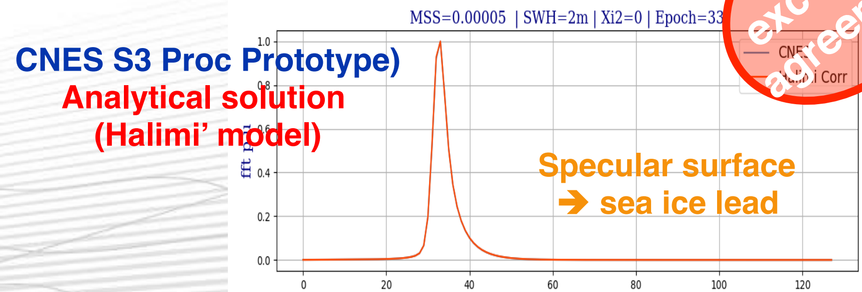
➔A mesure of the roughness of the surface (mean square slope parameter) is introduced in the FSSR [$\sigma^0 = R^2 (1+\alpha) / mss$]

(see Jackson 1992; Amarouche 2007; Poisson & Quartly submitted in 2016)

- ❑ In the numerical FSSR (CNES Sentinel-3 Processing Prototype)
- ❑ In the analytical FSSR (Hayne model and Halimi model)



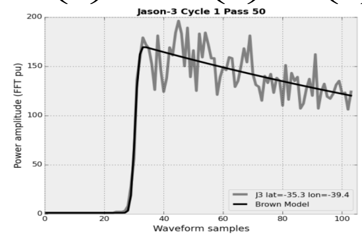




Retracker = A model + an estimation method

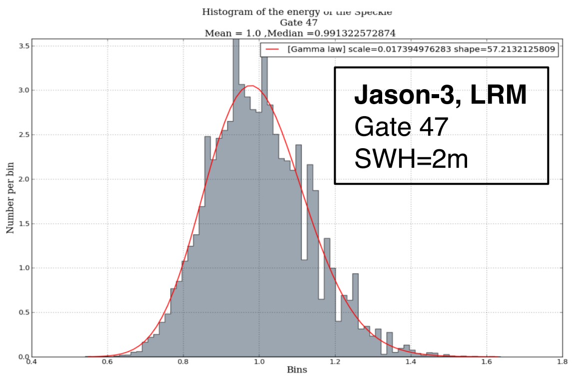
An estimation method

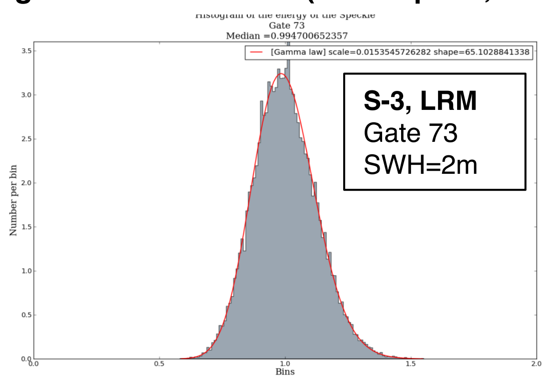
$$Y(t) = S(t).B(t)$$

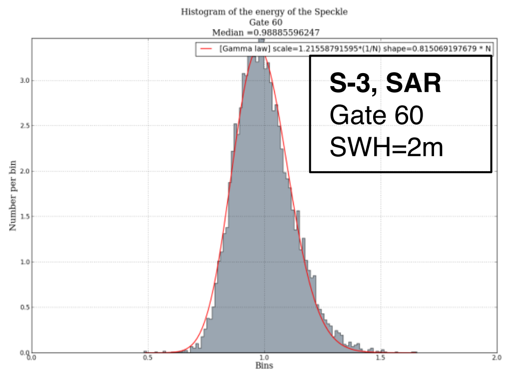


➔ Least square method for MLE3/4
➔ Maximum likelihood estimation procedure that assumes the knowledge of the speckle noise distribution corrupting the echoes (multiplicative)

Statistics of the speckle, computed for each range gate of 20Hz homogeneous waveforms (same epoch, SWH, sigma0)







Speckle = Gamma distribution (1/N, N)

with N constant whatever the range gate (N=90 waveforms averaged for J3)	N decreasing with range bin number

CNES/CLS Adaptive Retracker

Model with mss (with real PTR)

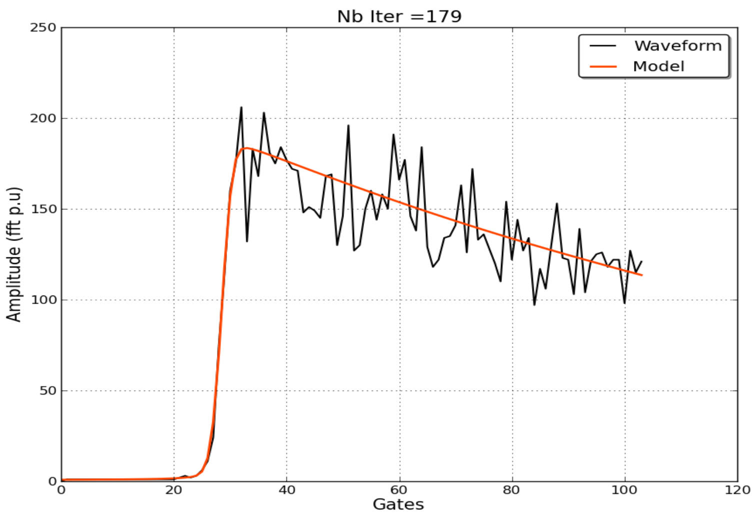
+

Nelder Mead Optimization

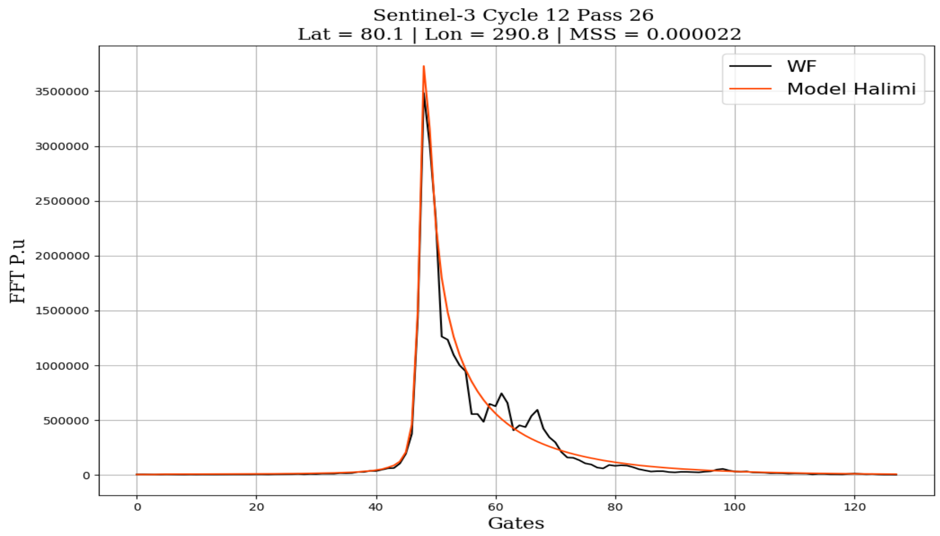
with Speckle-adapted likelihood criterion

Convergence of the retrackers

Adaptive LRM

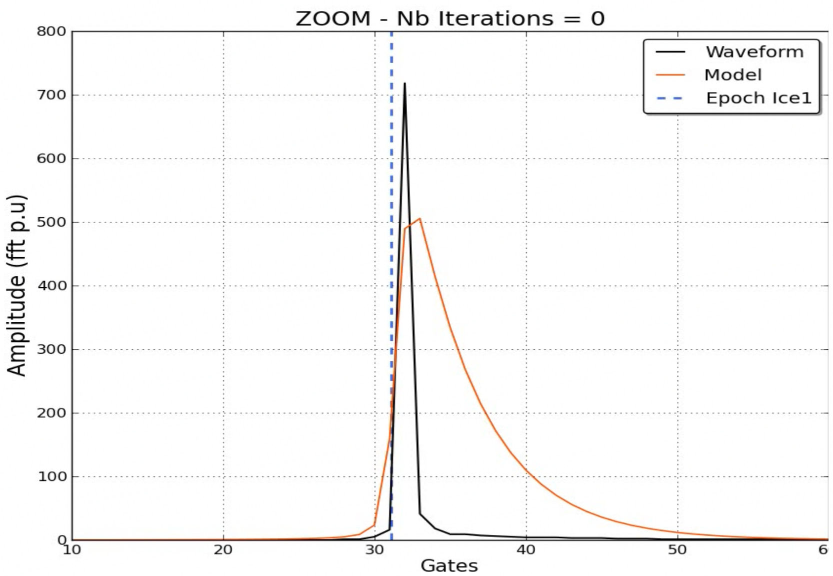


Adaptive SAR

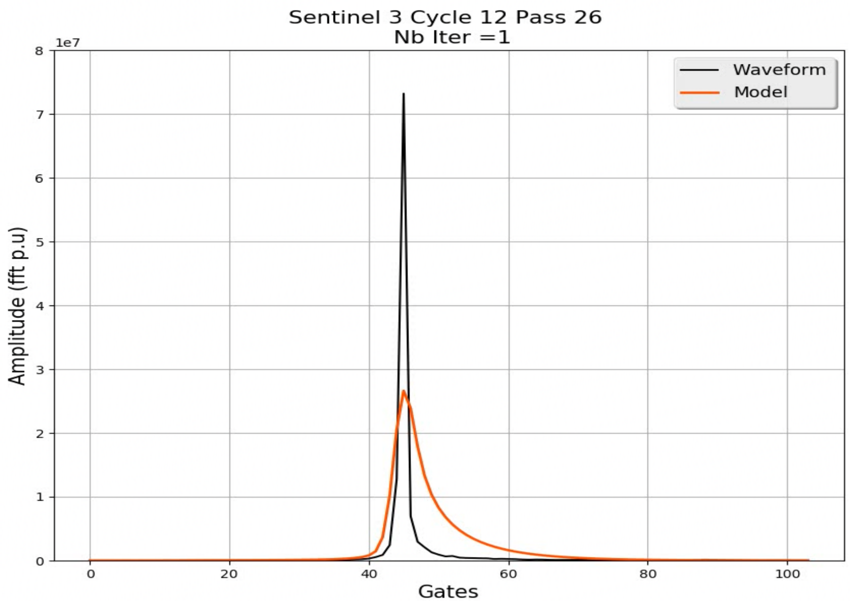


Convergence of the Adaptive retracker over sea ice returns

Jason-3 adaptive retracker fitting peaky echo



Sentinel-3 adaptive retracker fitting peaky echo



Convergence of the Adaptive retracker over sea ice returns

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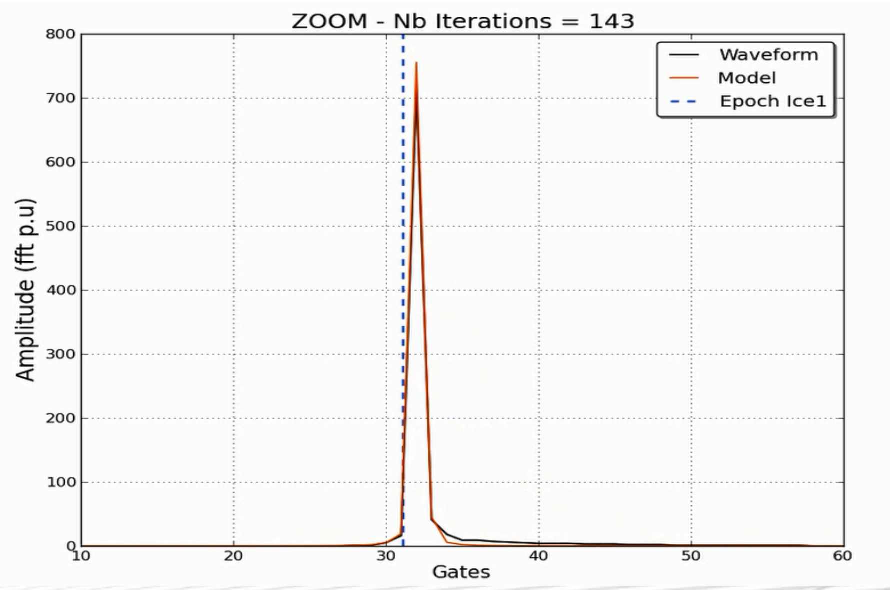

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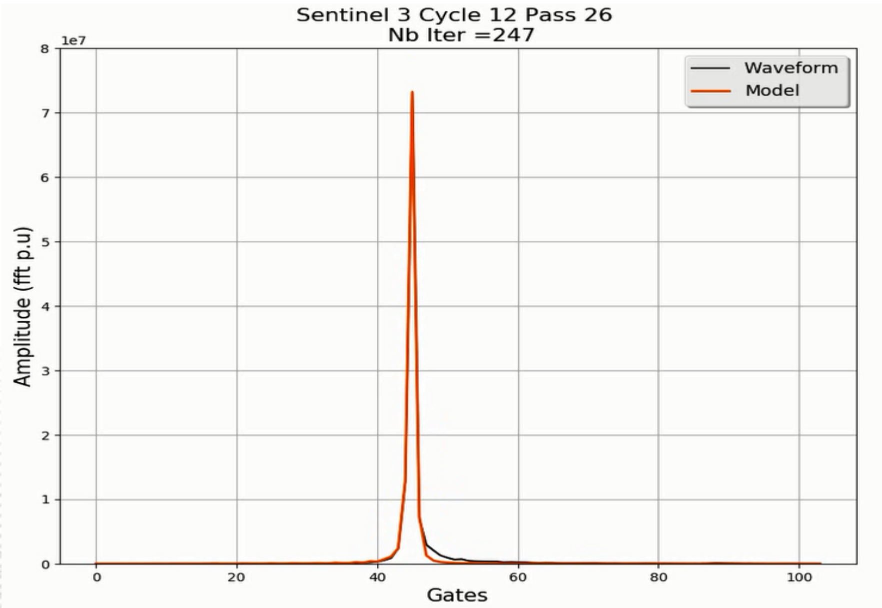
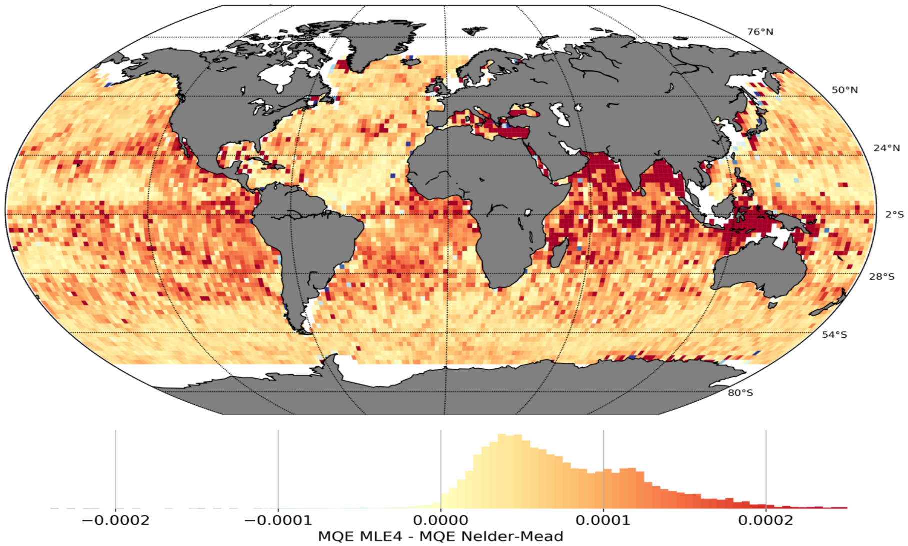
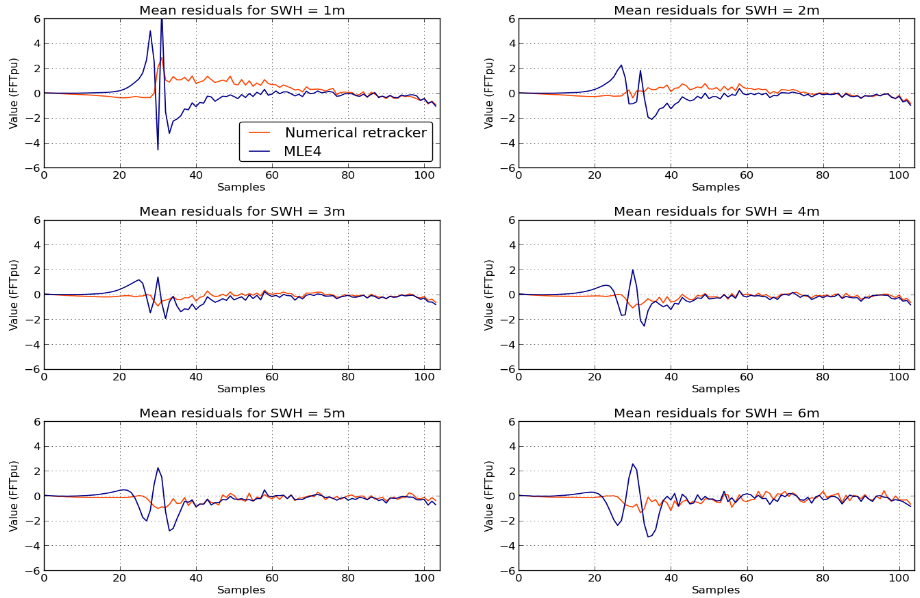


Adaptive wrt MLE4 (Jason-3)

Fit between waveforms and model largely improved





MQE_Adaptive < MQE_MLE4
especially for small waves
(PTR accounted for)

Residuals_Adaptive < Residuals_MLE4
especially for small waves

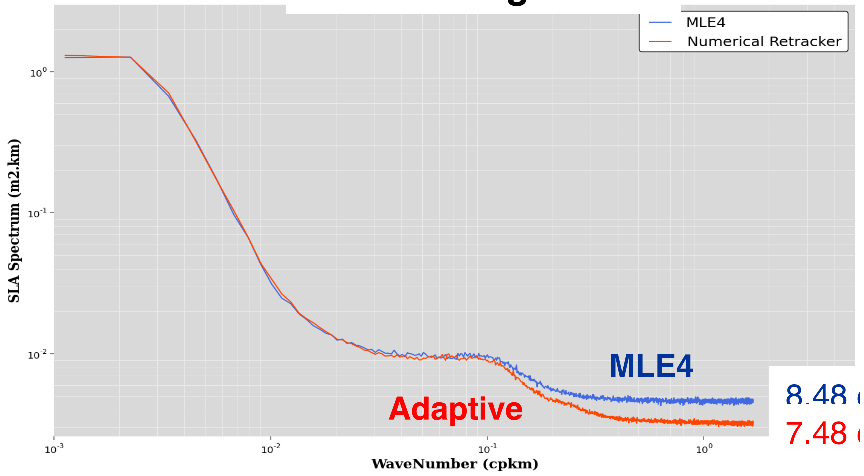
Adaptive wrt MLE4 (Jason-3)

Spectral analysis shows clear reductions of the 20Hz noise level

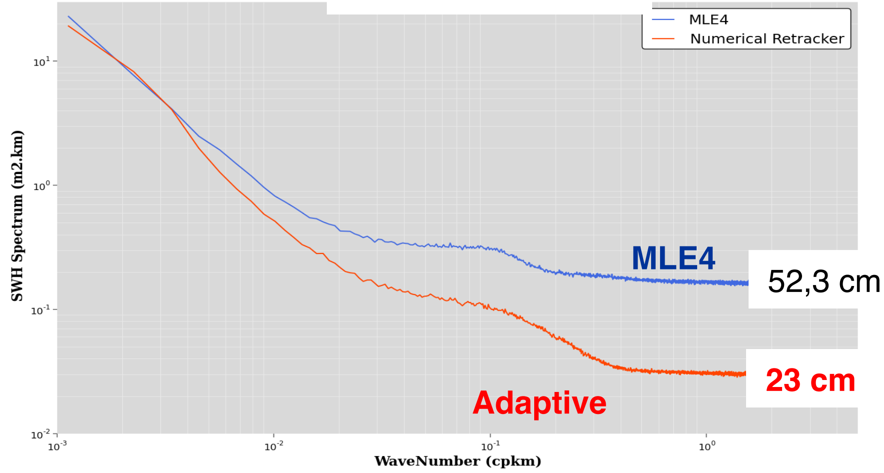
-10% for Epoch

- 60% for SWH

Orbit – Range - MSS



SWH

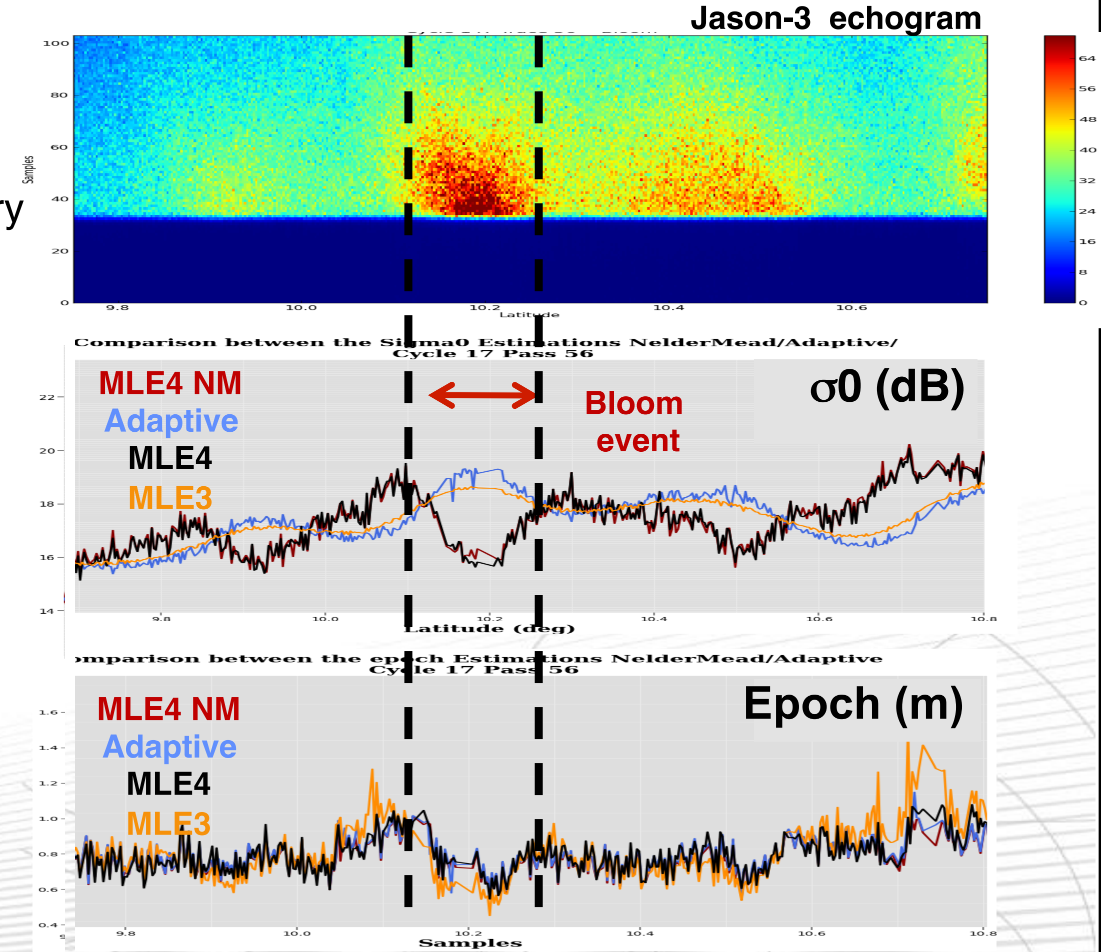


Benefits over bloom events

➔ Bloom event characterized by local very high backscattering coefficients (specular ocean surface)

➔ Much better estimation of the sigma naught coefficient with Adaptive (consistant with MLE3)

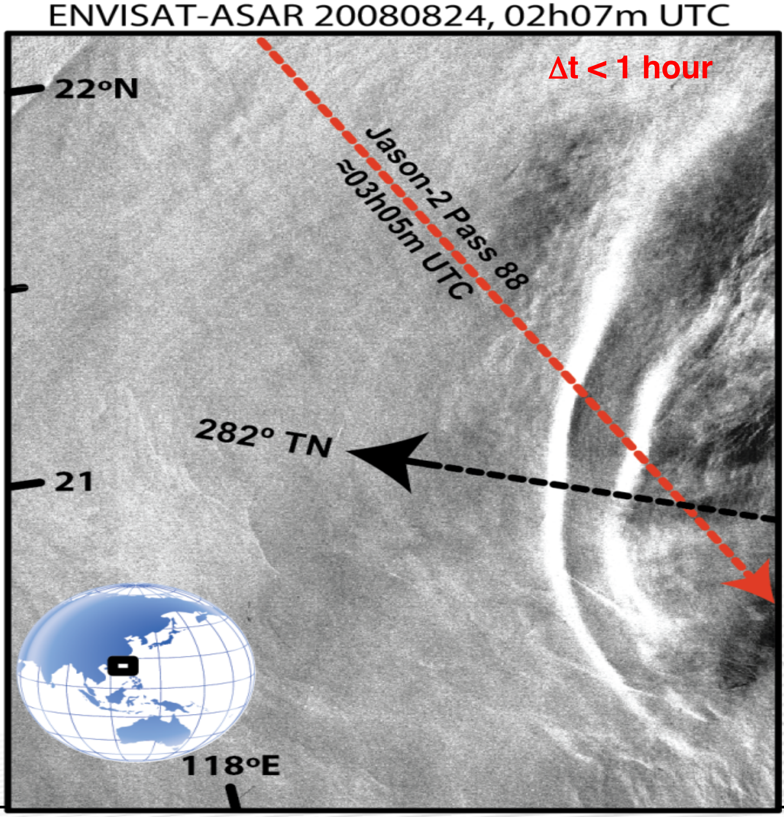
➔ No significant difference of epoch wrt MLE4

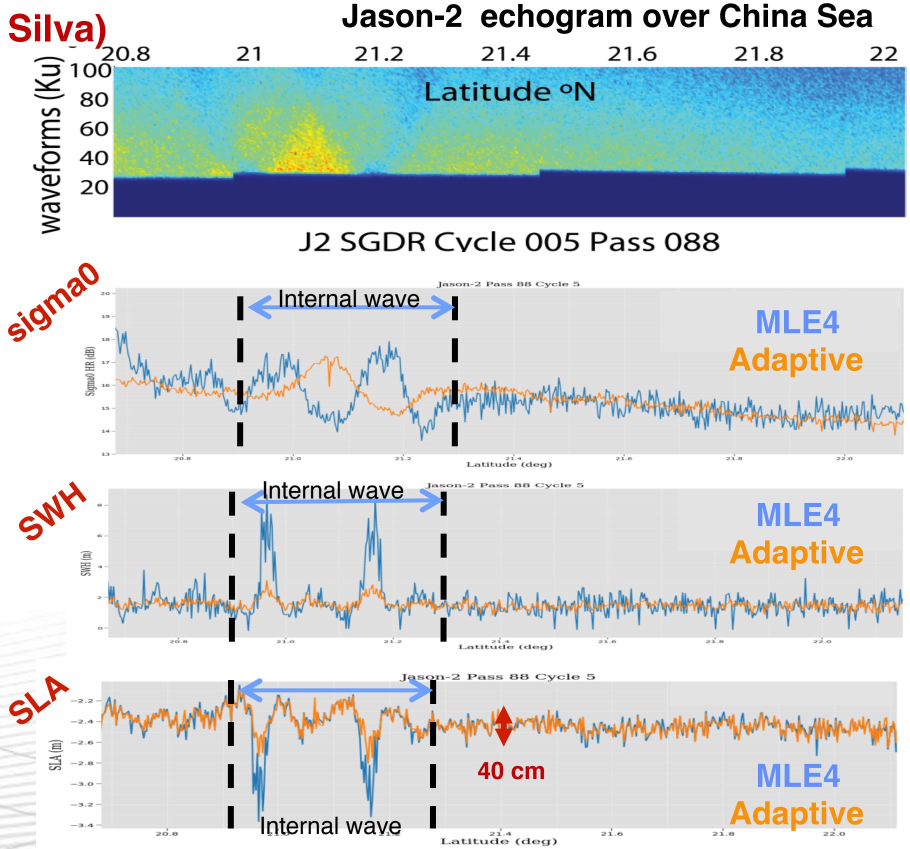


➔ Same behavior over rain cells

Benefits over internal waves

(Case study presented in OSTST 2016 by José Da Silva)





Benefits over sea ice regions

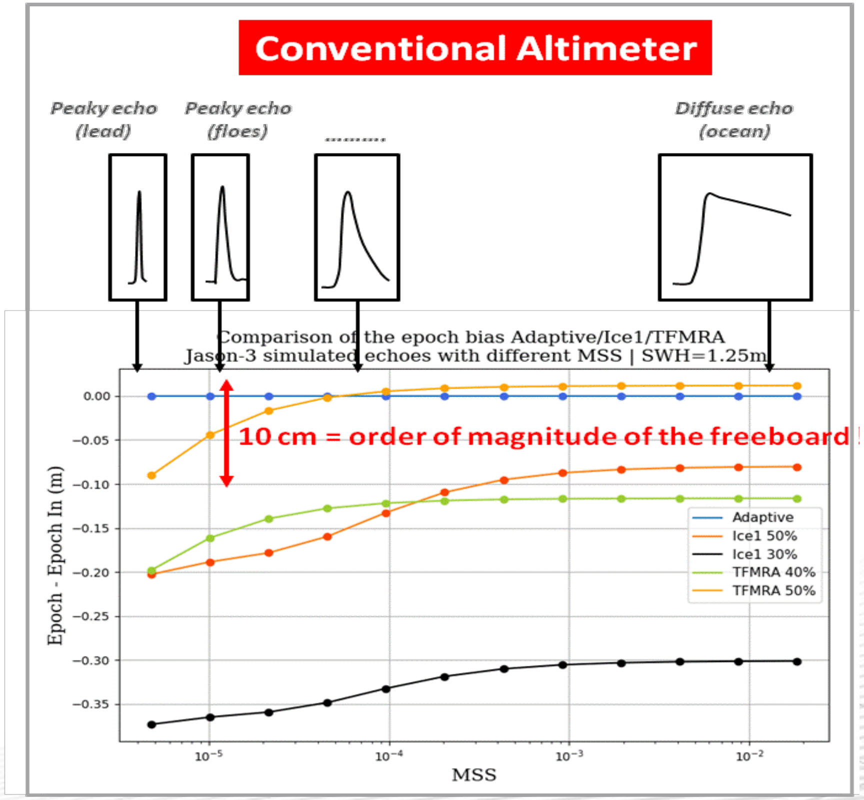
- At present, all teams in charge of sea ice regions are using **empirical retrackers** (sea_ice, TFMRA, ice-1, OCOG, …) for leads and sea ice returns
  - Fast and robust (but sometimes largely wrong). No physical basis
  - Instrumental PTR and AntGain not accounted for (potential drifts, unconsistency between missions)
  - Strong variation during the season (FYI, MYI)
  - SWH/roughness not estimated and not accounted for
  - No continuity with ocean measurements

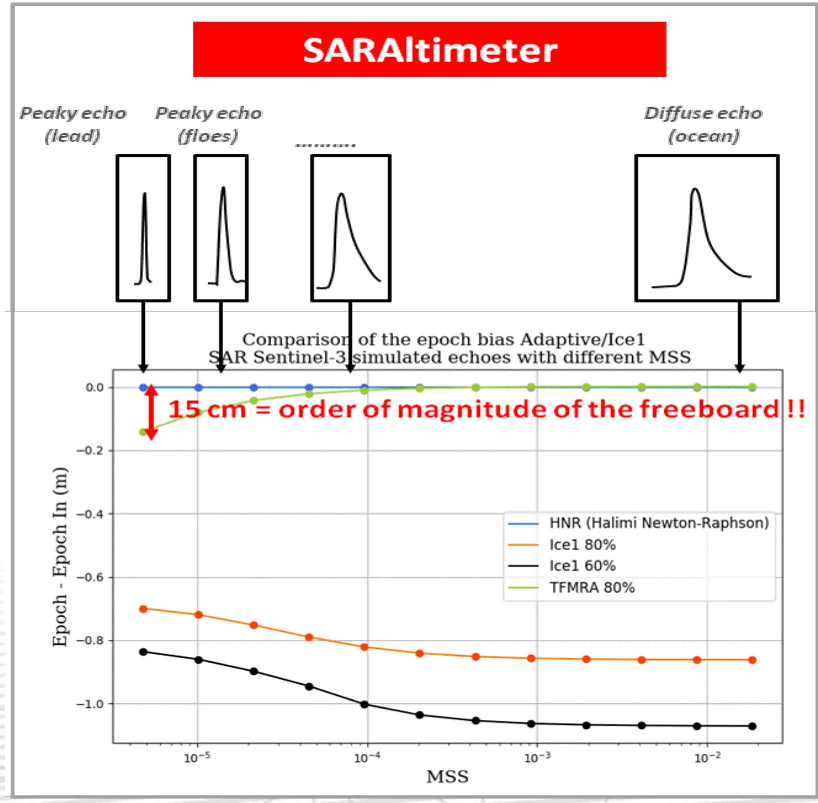
- **Adaptive retracker** (for leads and sea ice returns)
  - Physical basis, no arbitrary/empirical threshold
  - Homogeneity for all missions/modes (Ku/Ka, LRM/SAR)
  - PTR and AntGain accounted for
  - SAR Level-1 processing accounted for
  - Fitting criteria provided for editing use
  - Same model for peaky and diffuse echo
  - Ensures continuity with ocean measurements

➔**Powerful method for SLA estimation in the Arctic, for Freeboard estimation and for ensuring the link between both parameters**

➔On going assessment in the frame of the **ESA CryoSeaNice Project (wrt in-situ)**

Biases induced by empirical retrackers





Conclusions (1)

- A **consistant approach** has been derived for retracking conventional and Delay Doppler measurements
  - Physical solution for the Flat Sea Surface Response: analytical (Halimi) or numerical (CNES S3 Processing Prototype)
  - PTR accounted for (1D in LRM, 2D for DD) ➔ important for climatic studies
  - Roughness of the surface has been introduced in the models
  - Speckle noise statistics accounted for allowing to use a true likelihood criterium in the optimization process (Nelder Mead optimization method)
- **Dramatic benefits for open ocean processing**
  - Huge noise reduction for SWH and range (-30% to 60% for SWH in LRM/DD)
  - No need to use LUT corrections
  - Better estimation over blooms/rain/internal waves events (high frequency signals)

Conclusions (2)

- **<u>Dramatic improvements (again) for sea ice</u>** (over leads and sea ice) and **<u>for hydrological measurements</u>**. Ongoing studies to quantify the impact on radar freeboard and ice thickness estimations.
  - Ensure the continuity between open ocean and sea ice regions and in estuaries
  - Extension of the SLA to the north
- Compatible with all level-1 processing evolutions
  - 0 padding
  - Hamming function
  - PTR improvement (see T.Moreau's talk)
  - LR-RMC (see F.Boy's talk). Tests to be done but performances should be improved again
- Huge potential for reprocessing all missions : Conventional and Delay Doppler

  Should be considered in current/future ground processing chains, especially for Sentinel-3A/B/C/D and Sentinel-6

… *Thank you for your attention* …