New Powerful Numerical Retracker Solution Accounting for Speckle Noise Statistics

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Summary

- For years, CLS has been conducting studies (for CNES, ESA) to improve the retracking function for all altimeter missions, all modes (LRM / PLRM / SAR), over all surfaces (ocean / hydro / sea ice / ice sheets)
- Our aim was to converge to an homogeneous physical solution applicable to any altimeter mission, any surface (rubbing out discontinuities at transitions) and accounting for instrumental characteristics (LRM & SAR)
- Many configurations have been tested, results have been compared, performances have been largely improved
- This talk presents one of the main outcomes of these studies : a new powerful numerical retracker, already implemented in the Jason-3 Peachi prototype.

Role of the retracker (LRM/SAR)

➔ To derive geophysical parameters from one (or several) waveforms

The retracker is based on two main components:

- ❑ **<u>A model</u>**: many solutions accounting or not for real instrumental charact. (Brown, Numerical from simulations (like S3PP), Samosa, Halimi, …)
- ❑ **<u>An estimation process</u>**: many solutions to fit the model with N parameters: epoch, SWH, Power, skewness, Decay, ….
  (LSE, MLE (Newton Raphson, Levenberg Marquardt), Bayesian, MAP, Kalman, …)

➔ Final performances of the retracker closely linked to the consistency between model and estimation strategy

The model

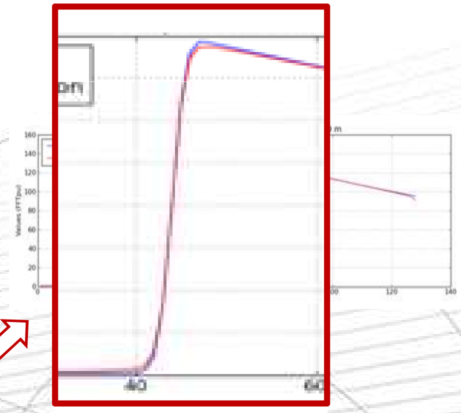
For LRM mode and for SAR mode, the echo can be expressed as the convolution (on different geometries) of 3 terms (Brown/Hayne) :

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

$$\boxed{S(t,f) = FFSR(t,f) \circledast PDF(t) \circledast PTR(t,f)}$$ *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)

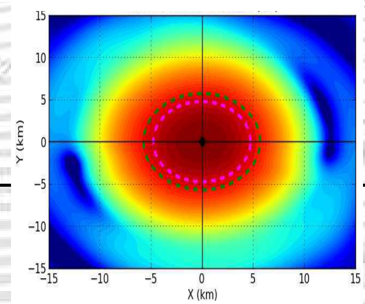


❑ Current solutions in official processing chains (LRM or SAR) approximate the PTR by one gaussian (Jason, Saral, RA-2, CS-2/S3 SAR) : MLE3/4 or SAMOSA (several gaussians for Topex)

❑ Already shown in previous meetings, importance to account for :

- the real PTR in a numerical model *(in LRM : Thibaut & al, OSTST 2012; in SAR : Boy et al, OSTST 2014).*
- the antenna gain pattern *(in LRM - Saral : Le Gac & al, OSTST 2015)*

Saral Antenna Gain Pattern

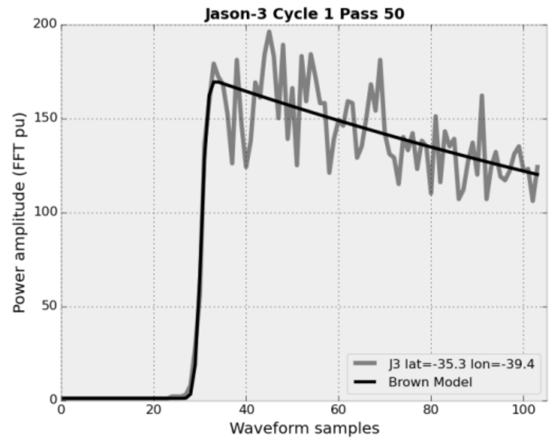


The estimation method

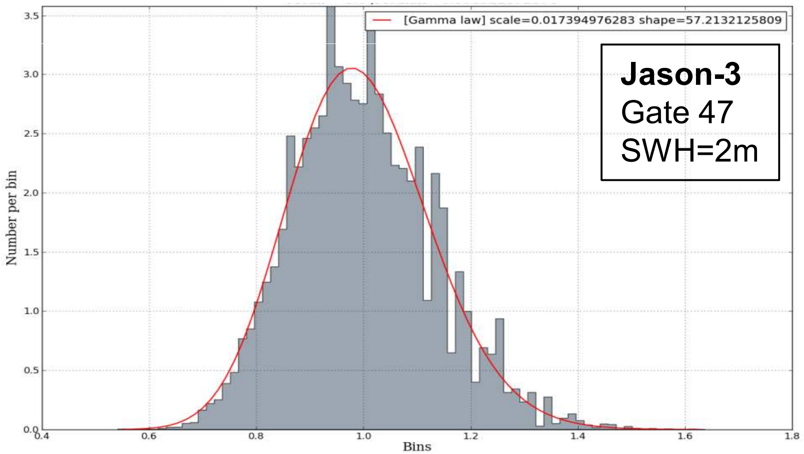
The estimation strategy is based on a maximum likelihood estimation procedure

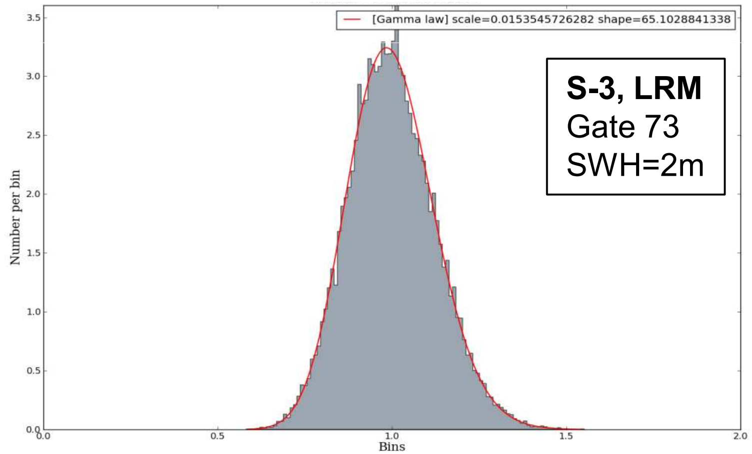
- ❑ Maximizes the observation statistics
- ❑ Assumes the knowledge of the speckle noise distribution corrupting the echoes (multiplicative)

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



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)

The estimation method

- Knowing the Gamma distribution of the speckle, the likelihood criterion can be written as :

$$C = Cste + N.\sum_{t=1}^{K}\frac{y_t}{S_t} - (N-1).\sum_{t=1}^{K}\ln(y_t) + N.\sum_{t=1}^{K}\ln(S_t)$$

Challenor & al , 1990
N : number of individual pulses
K : number of range gates

BUT

The **Newton Raphson (NR)** or the **Levenberg Marquardt (LM)** algorithms implement a descent gradient method :

$$\nabla C(\theta) = \frac{1}{Pu^2}\sum_{t=1}^{K}\frac{\partial S_t}{\partial \theta}(y_t - S_t)$$

We recall that these two methods are used in all operational ground processing chains:

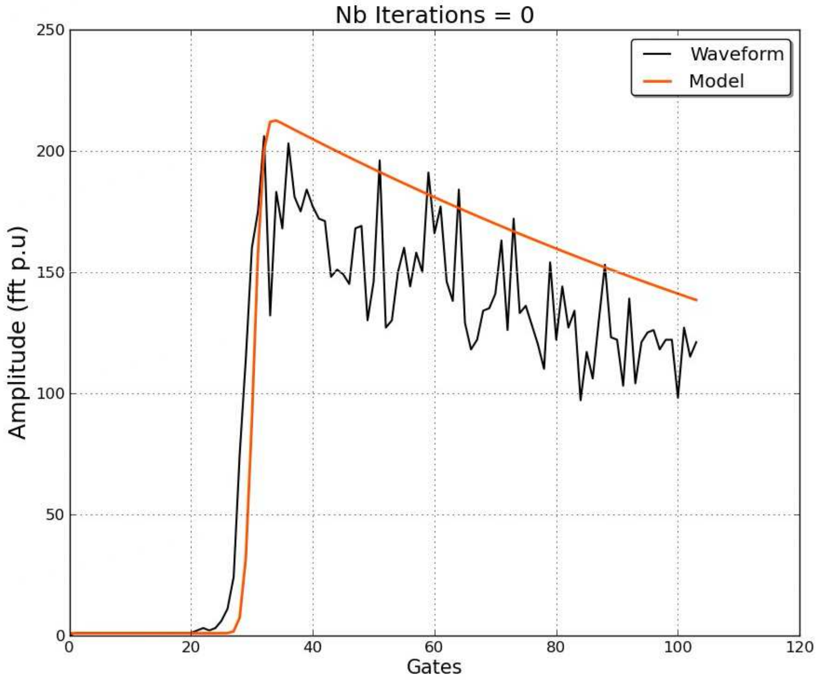
- NR : Jason-1/2/3, Saral, CS-2/S3 CNES Processing Prototypes
- LM : Envisat/RA-2

Alternative

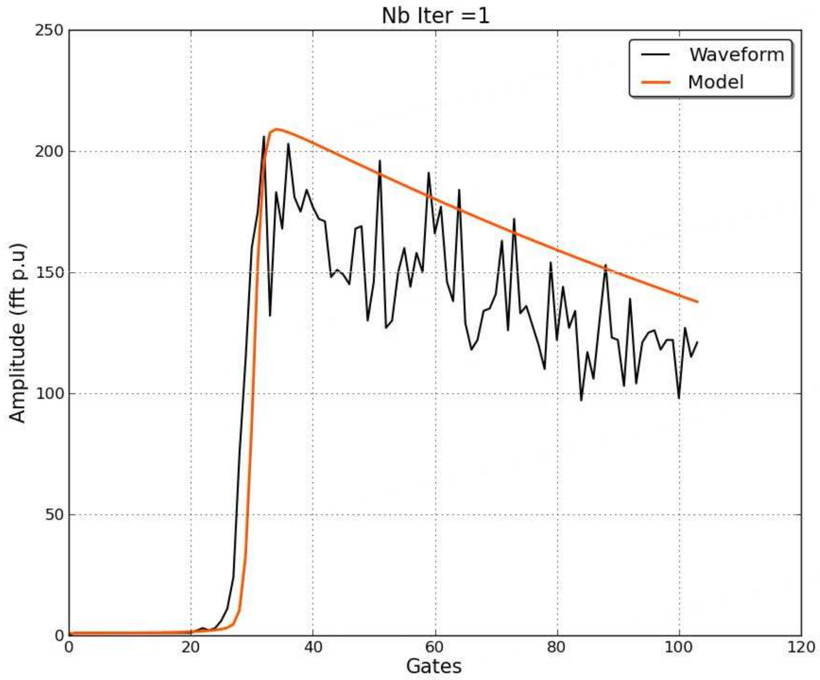
We propose to use a **Numerical Nelder Mead** method (also known as Downhill Simplex method) that accounts for the exact Likelihood criterion and thus accounts for the number of individual pulses that are averaged.

Convergence of the retrackers

MLE4

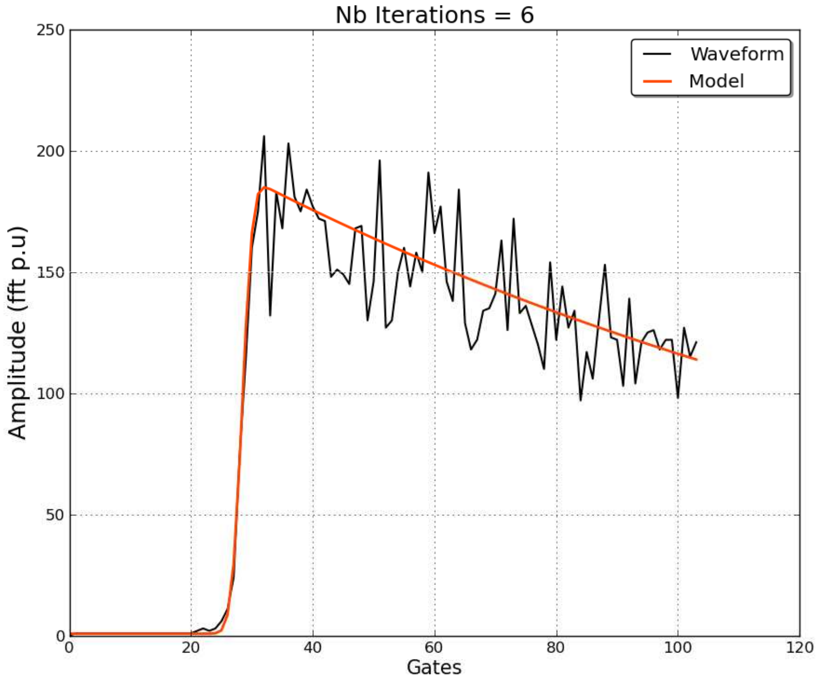


Numerical Nelder Mead



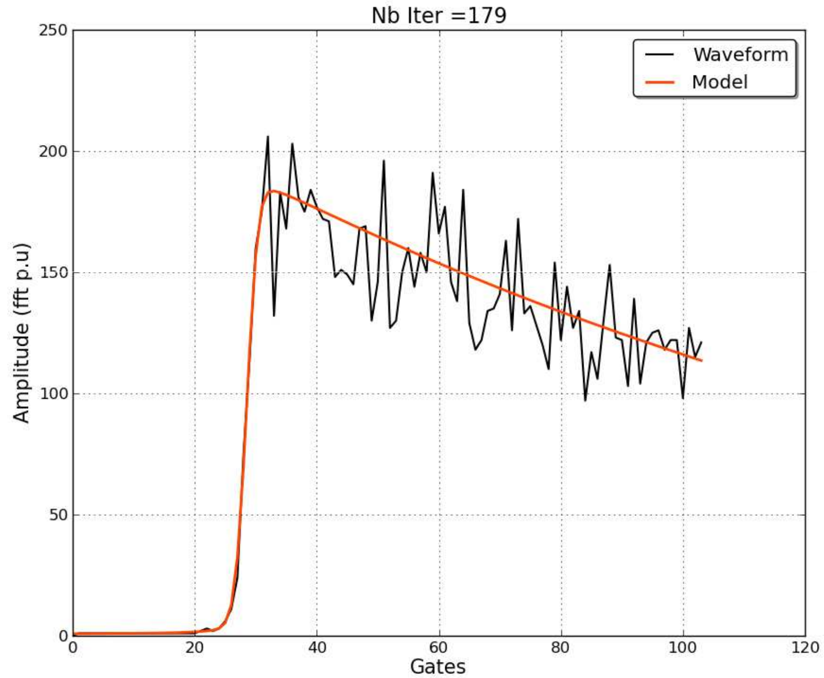
Convergence of the retrackers

MLE4



6 iterations, 6 models per iteration

Numerical Nelder Mead



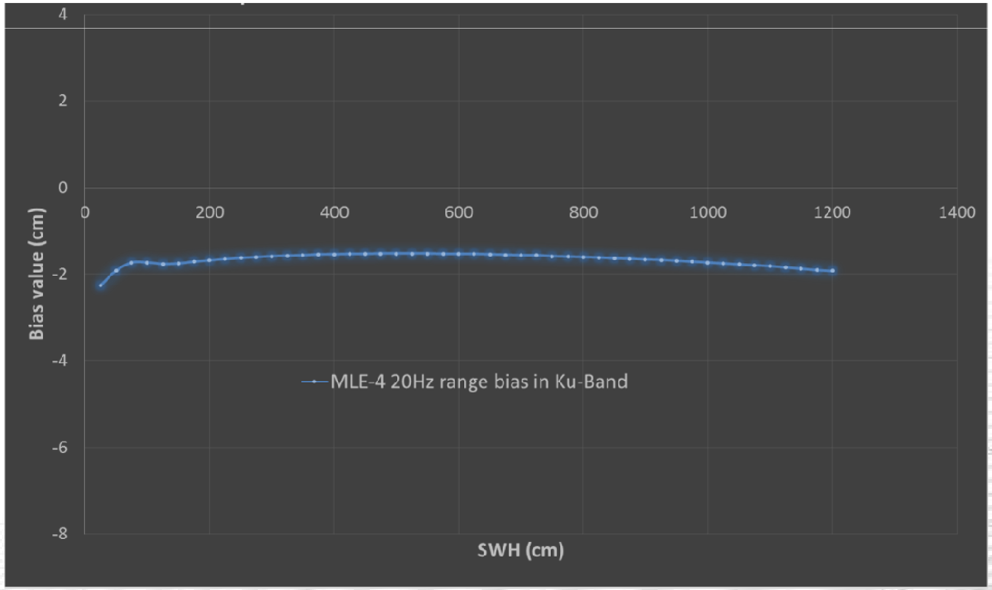
~180 iterations, 1 model per iteration
More CPU is need. Not a problem
for an operational ground processing

Performances of the retrackers: Impact on Look-Up Tables

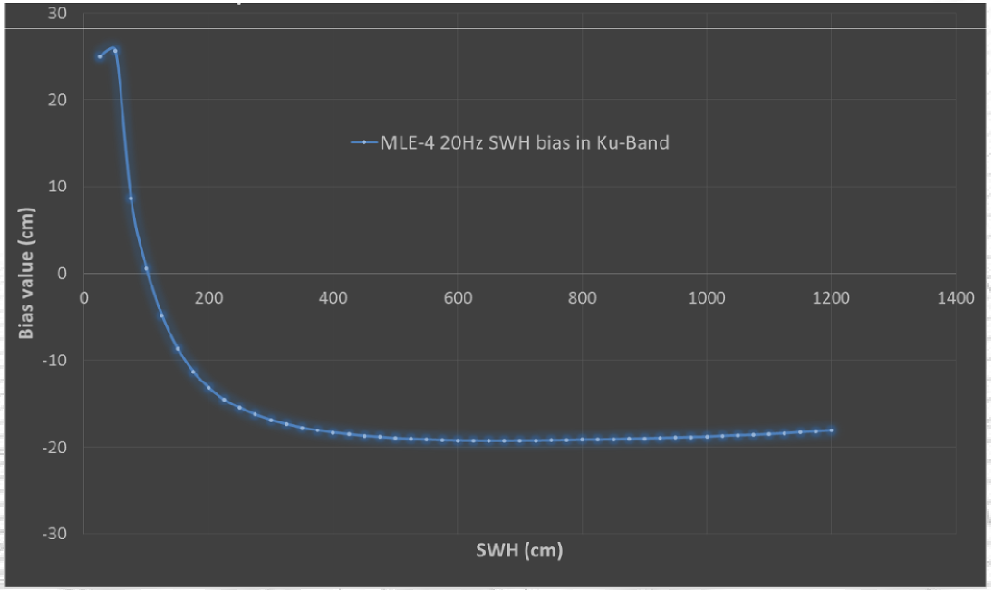
- **LUT with current Ku-band retracker (Jason-2/Jason-3/Saral) : MLE4**

*Hayne model (**Gaussian PTR**) + **Newton Raphson** algorithm (degraded Likelihood Function)*
Estimation at 20Hz (40Hz for Saral) corrected at 1Hz with Look Up tables

Jason-3 Range Look Up Table



Jason-3 SWH Look Up Table

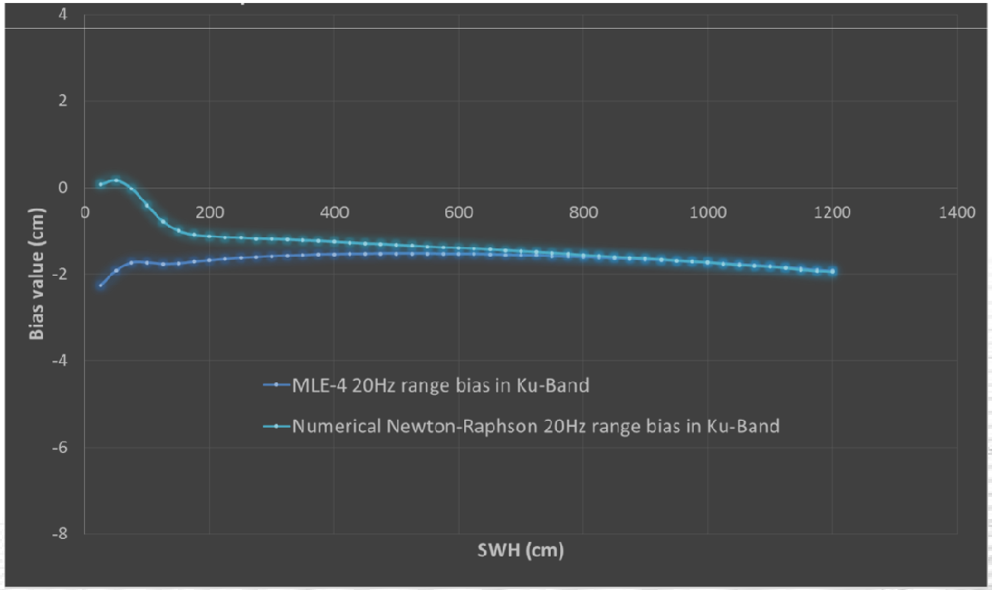


Performances of the retrackers: Impact on Look-Up Tables

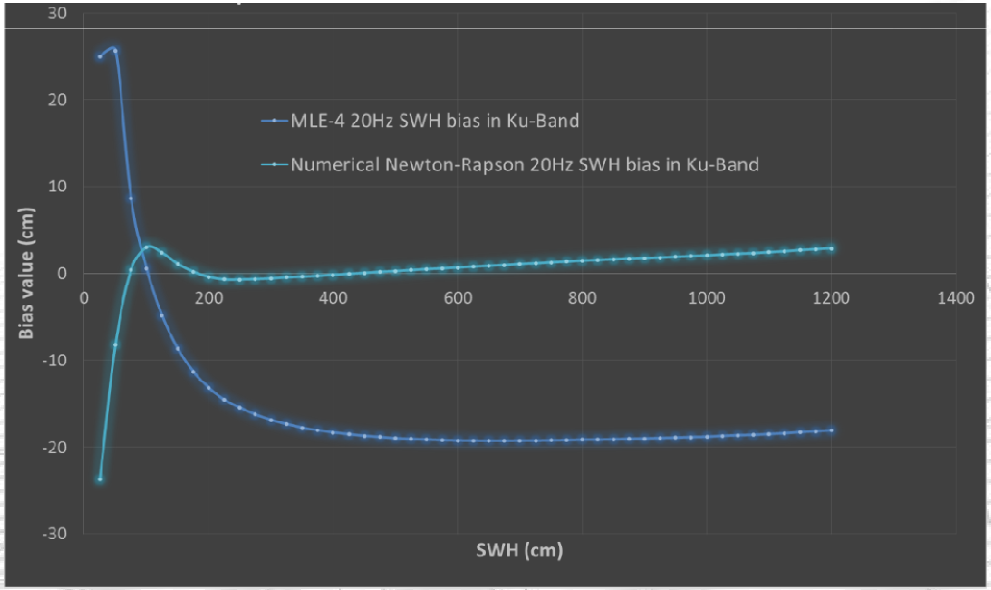
- **LUT with Numerical Ku-band retracker (in Peachi Jason-3)**

*Hayne model + **<u>Real PTR</u>** + **<u>Newton Raphson</u>** (degraded Likelihood Function)*
Estimation at 20Hz (40Hz)
Look Up Tables are reduced but still required (not null)

Jason-3 Range Look Up Table



Jason-3 SWH Look Up Table



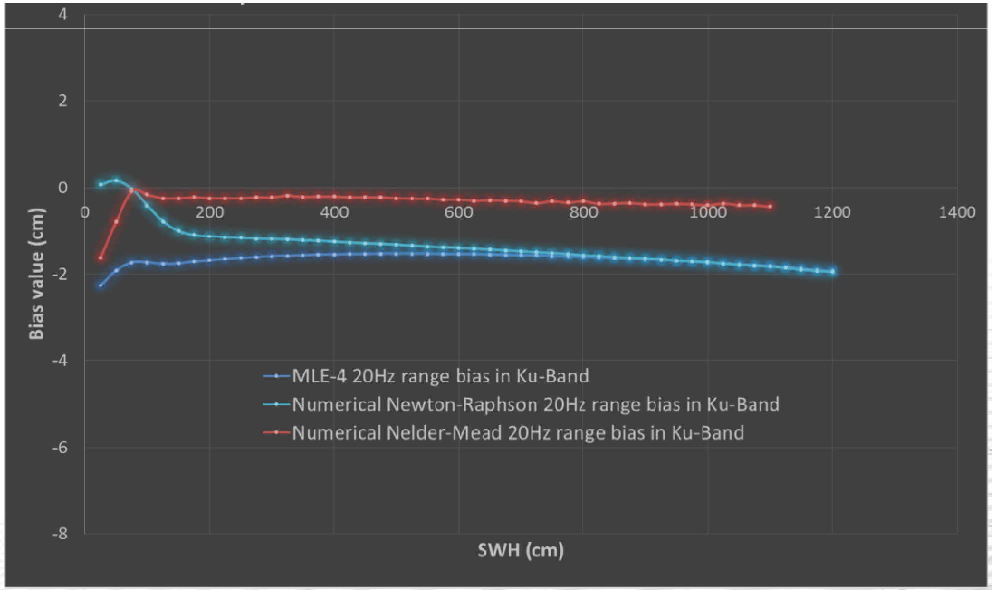
Performances of the retrackers: Impact on Look-Up Tables

- **LUT with Numerical Nelder Mead Ku-band retracker (in Peachi Jason-3)**

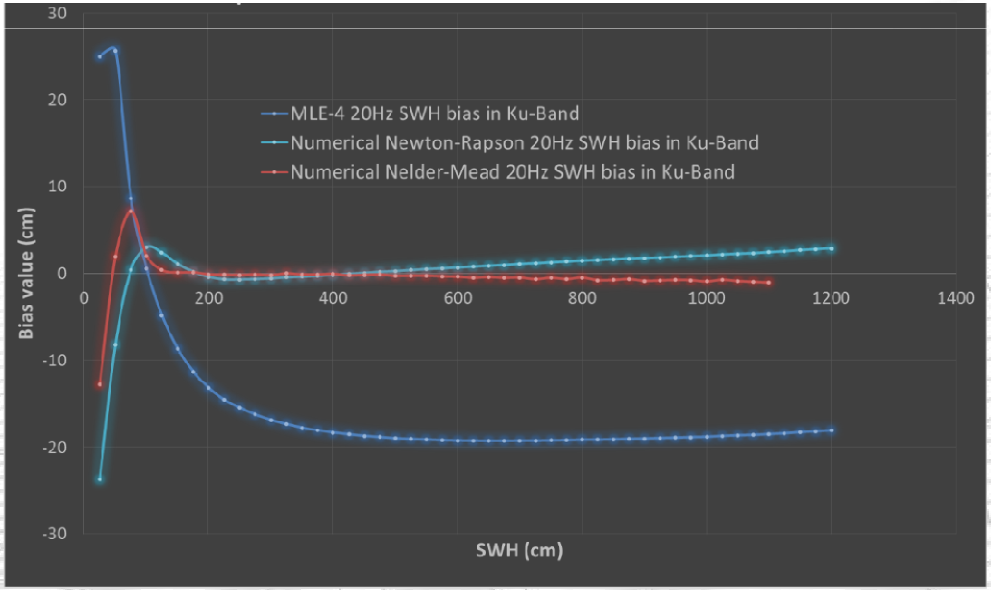
*Hayne model + **Real PTR** + **Nelder Mead** estimation with full Likelihood Function accounting for the speckle characteristics*
Estimation at 20Hz

LUT corrections become negligible

Jason-3 Range Look Up Table



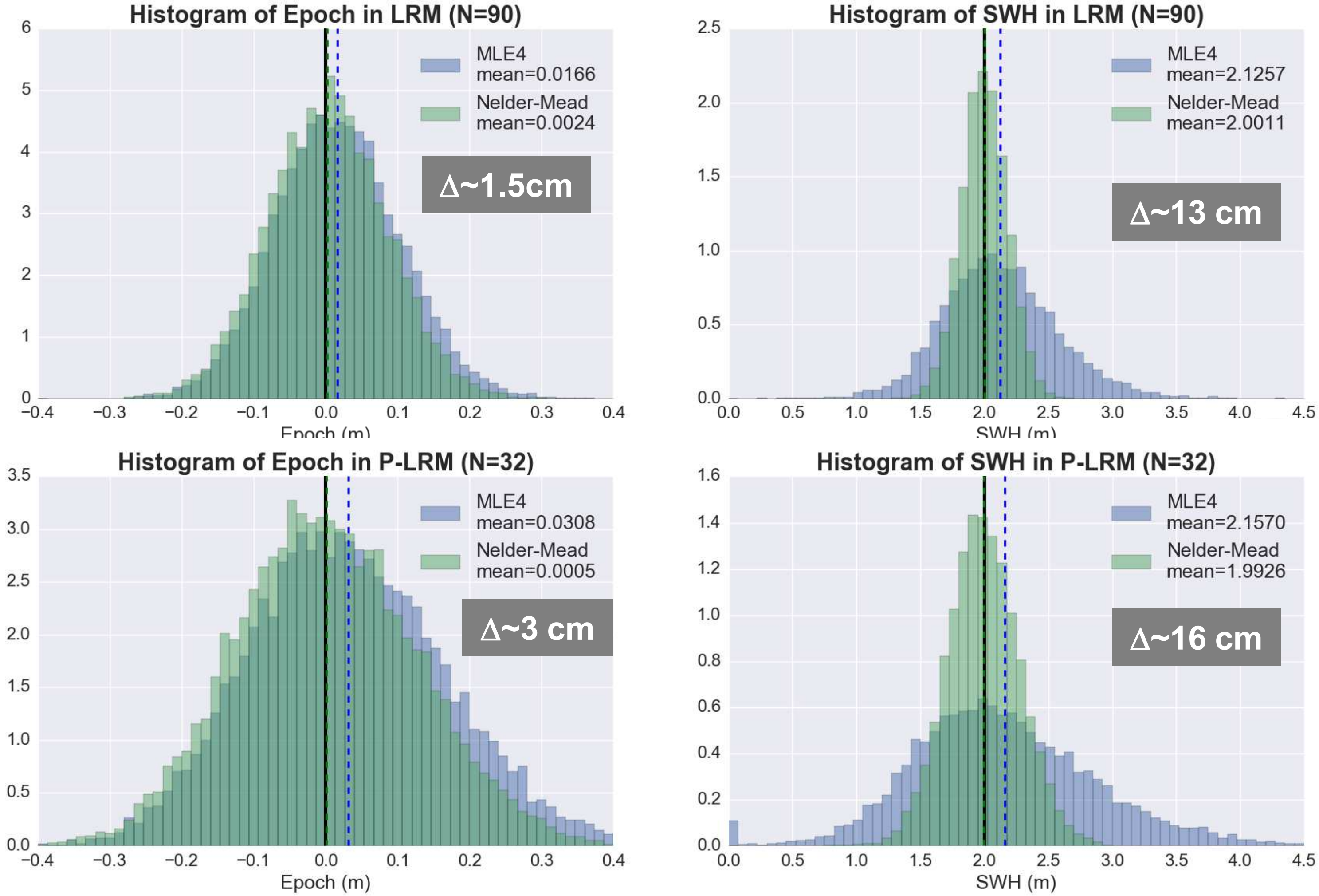
Jason-3 SWH Look Up Table



Performances of the Num. NM Rtk wrt speckle (simulation, SWH=2m)

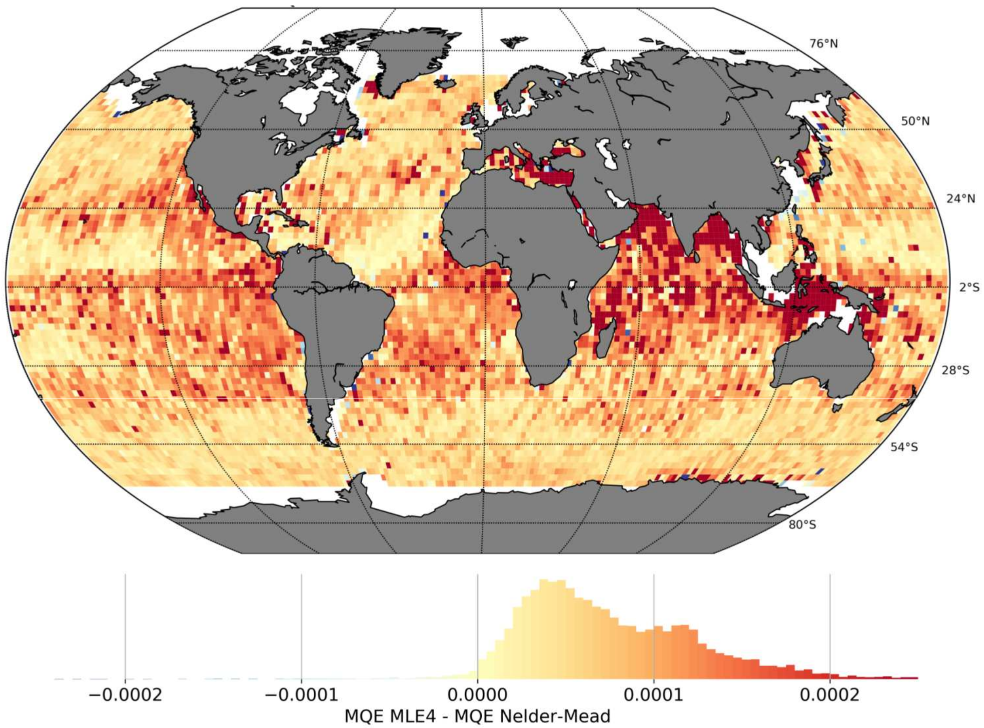
LRM J3
N=90

PLRM S3
N=32

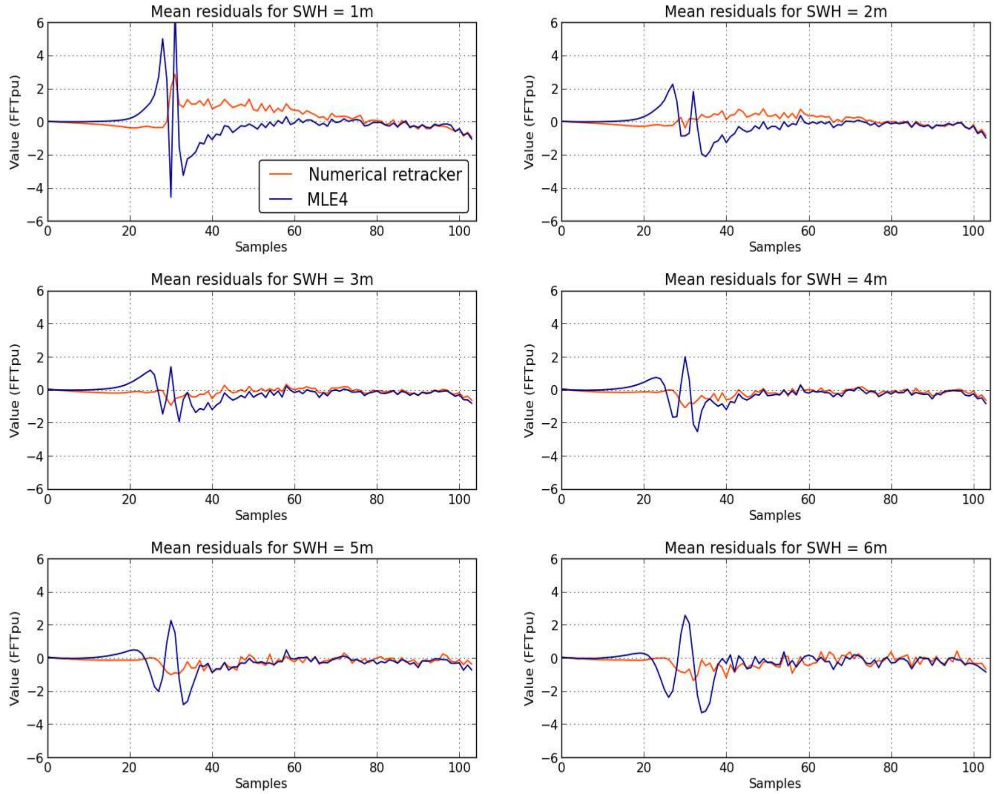


Numerical Nelder Mead wrt MLE4 (Jason-3)

Fit between waveforms and model <u>largely improved</u>



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



Residuals_NM < Residuals_MLE4
especially for small waves

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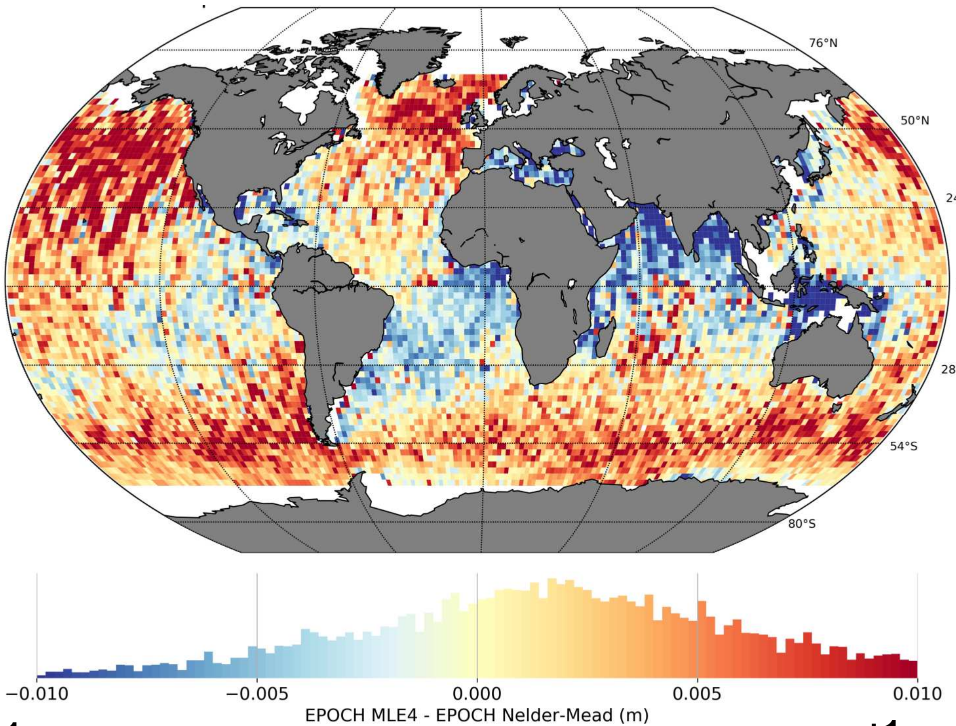
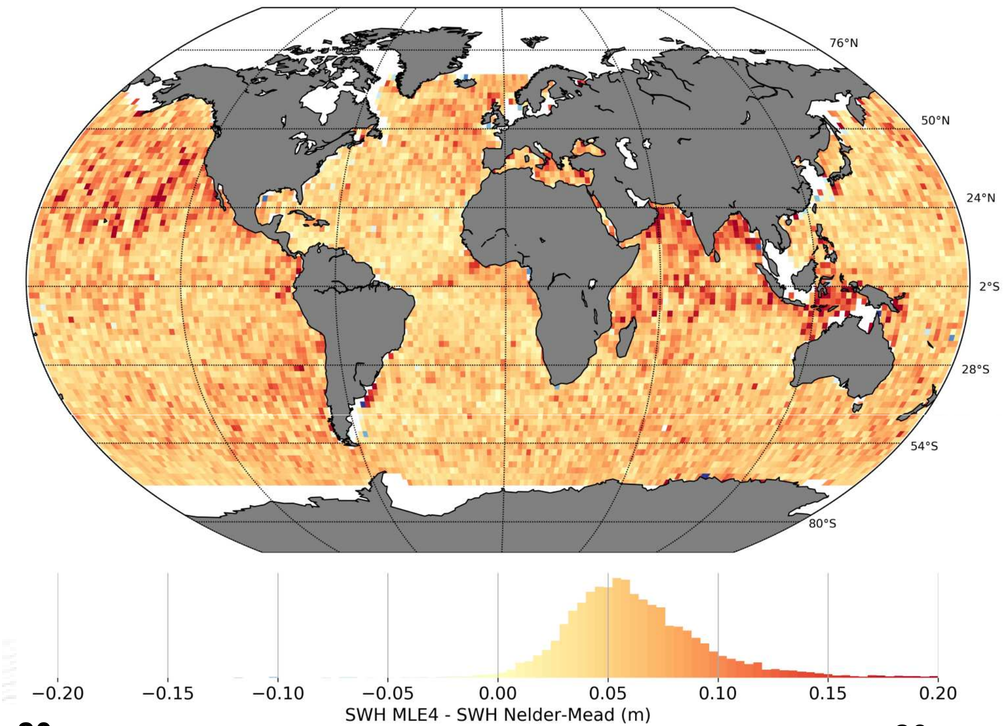
Numerical Nelder Mead wrt MLE4 (Jason-3)

Epoch_MLE4 – Epoch_NM



-1 cm **+1 cm**

SWH_MLE4 – SWH_NM



-20 cm **+20 cm**

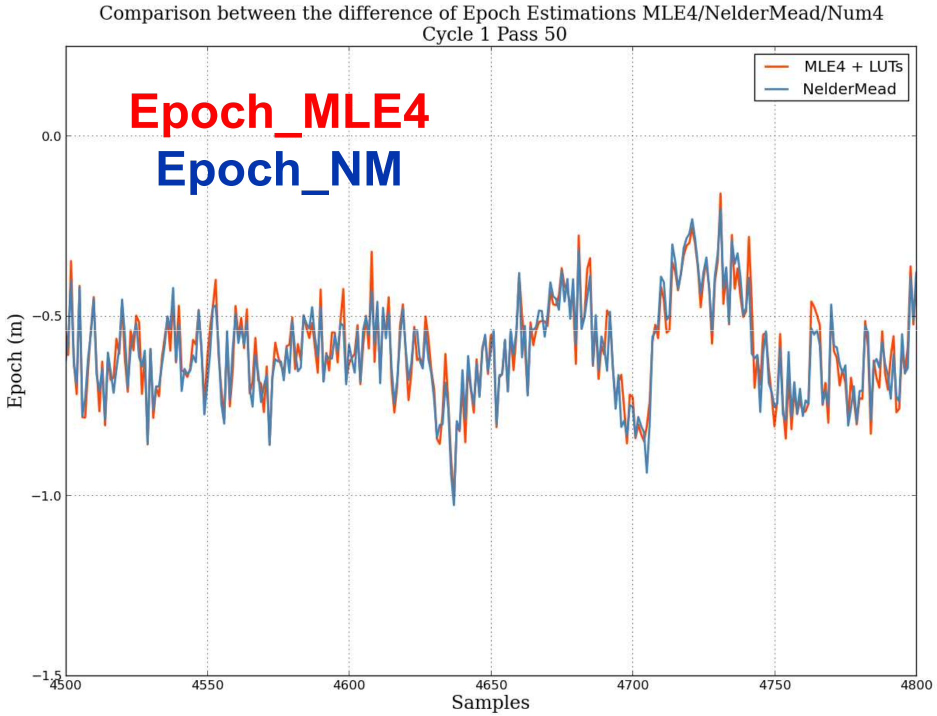
Absolute differences below 1 cm

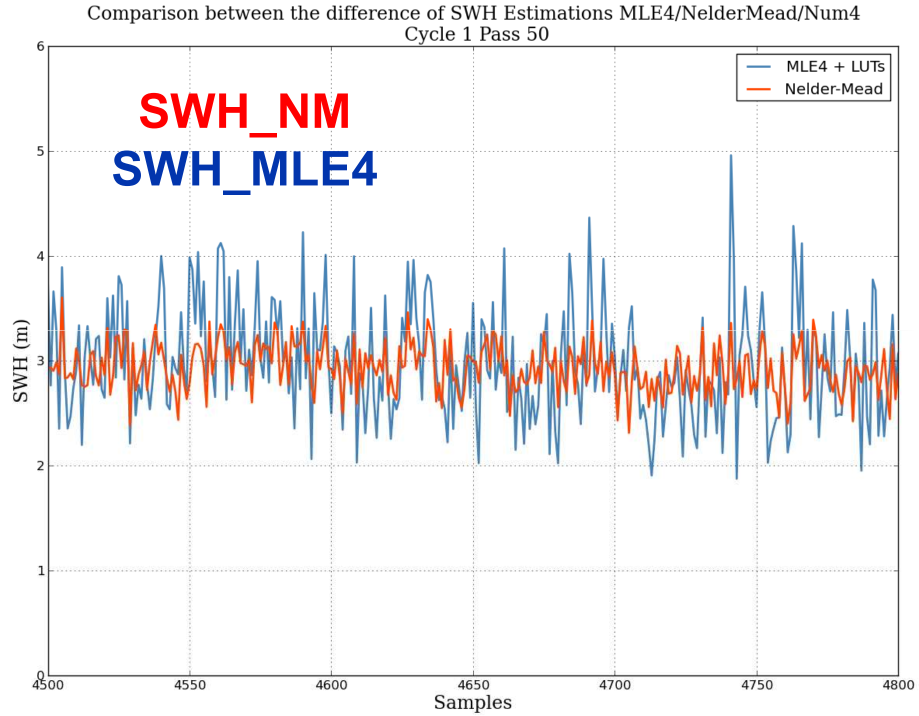
MLE4 over-estimates SWH (15 cm at low SWH)
➔ due to non-symetrical shape of the estimates used to compute the LUTs

MLE4 estimates account for LUT

Numerical Nelder Mead wrt MLE4 (Jason-3)

Noise on the along track estimates clearly reduced





MLE4 estimates account for LUT

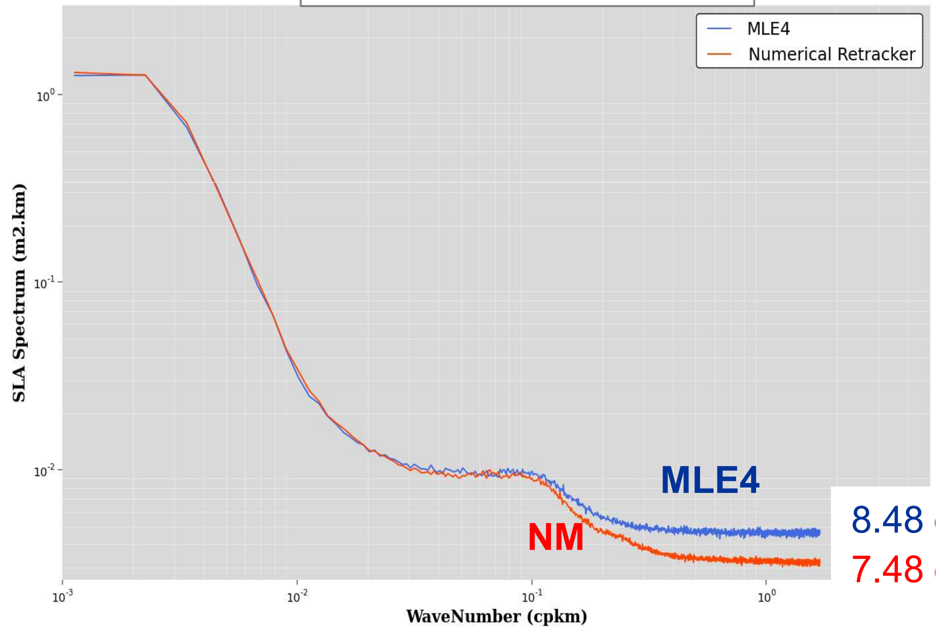
Numerical Nelder Mead wrt MLE4 (Jason-3)

Spectral analysis show clear reductions of the 20Hz noise level

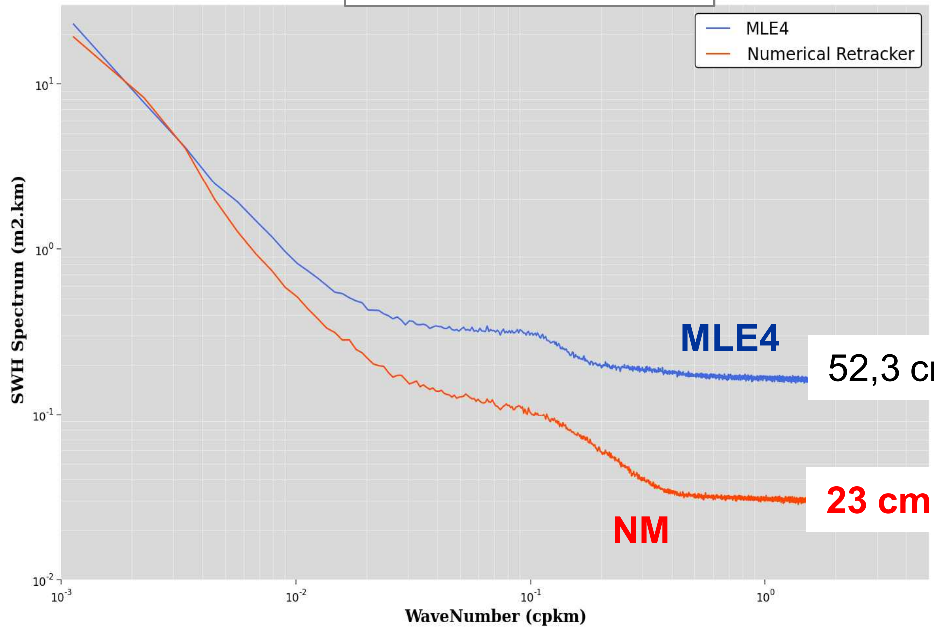
-10% for Epoch

- 60% for SWH

Orbit – Range - MSS



SWH

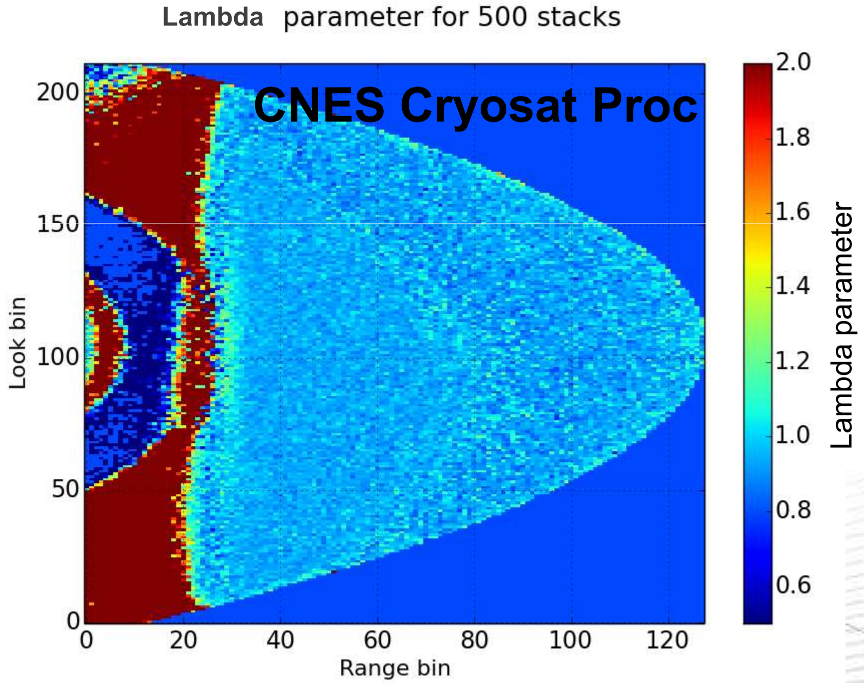


Why not for SAR retrackers ?
- SAR speckle distribution -

The speckle statistic is computed for homogeneous waveforms (same epoch, SWH, sigma0)

Single look echos

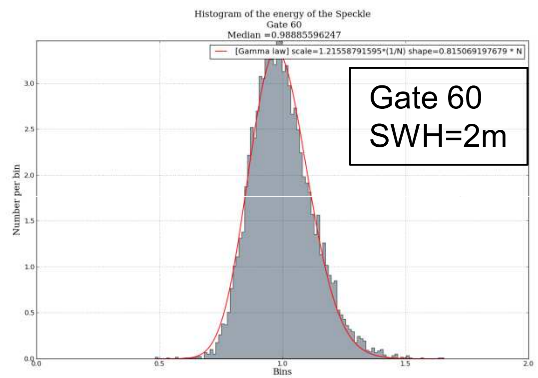
statistic for each range gate



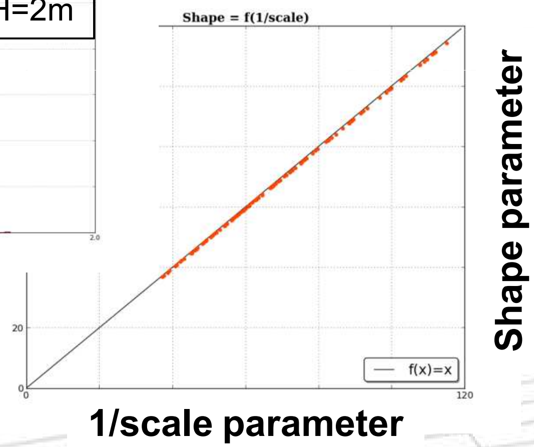
$$f(x;\lambda) = \lambda e^{-\lambda x}$$, with λ = 1

Multi-look echos

statistic for each range gate



CNES S3PP

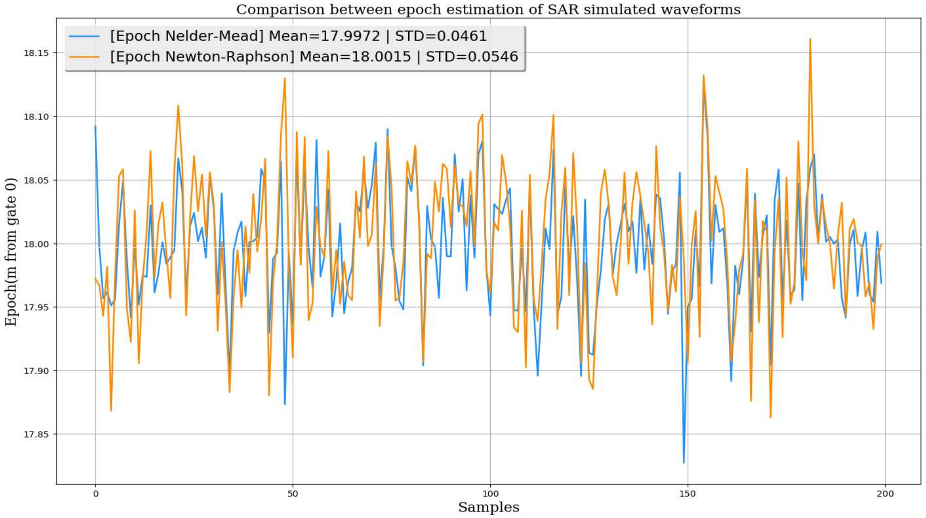


Speckle = Gamma distribution (1/N, N)

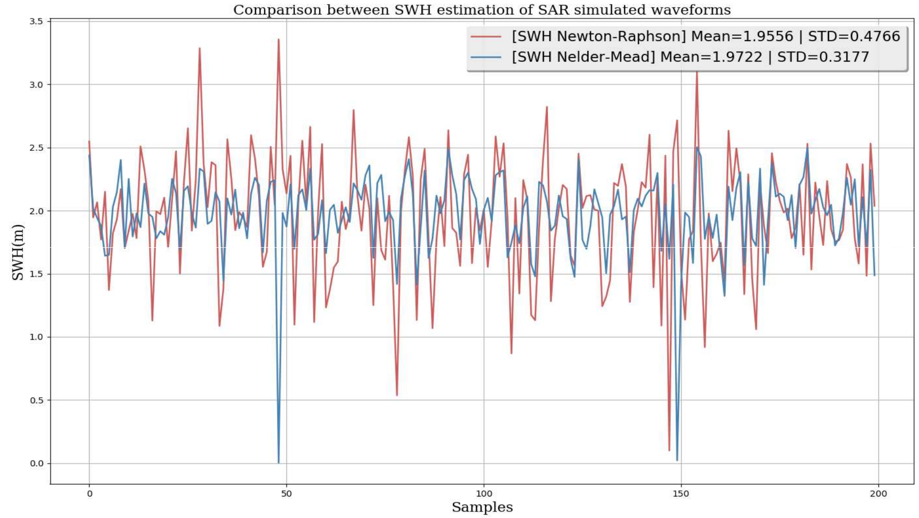
N decreasing with range bin number

Numerical Nelder Mead versus NR applied on SAR echoes

~15% range noise reduction



~33% SWH noise reduction



One step beyond : not a sign of madness !

Adaptive Retracker - an evolution of the Numerical Nelder Mead retracker

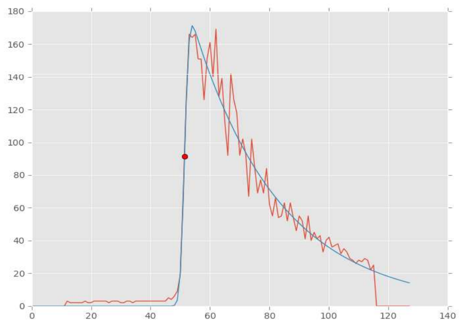
SeeThibaut & al, Eumetsat conf, 2016

$$\boxed{S(t) = FFSR(t) \circledast PDF(t) \circledast PTR(t)}$$

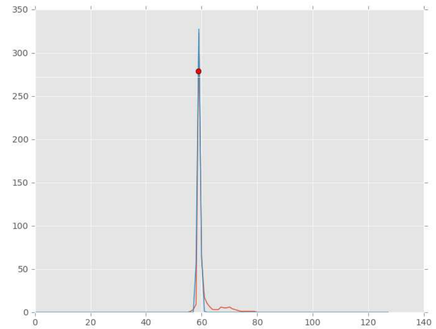
Introduction of the mean square slope (**mss**) in the FSSR

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

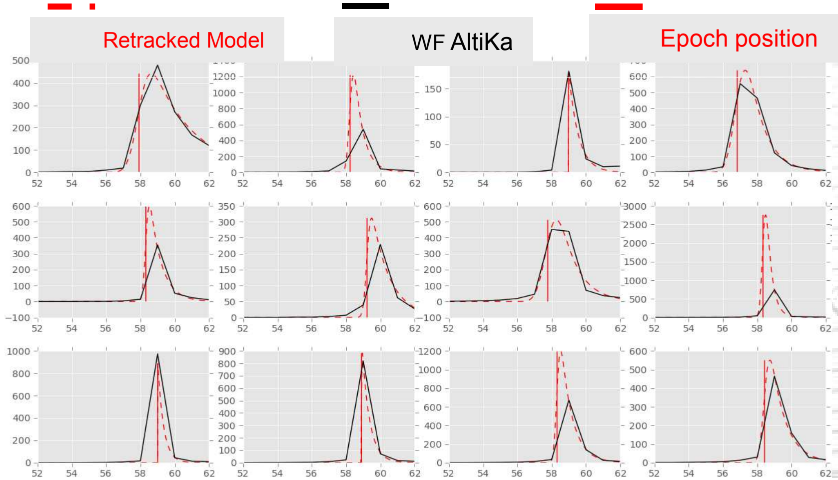
Model **flexible enough,** to fit **ocean echoes as well as peaky echoes** (sea ice and hydro) and still accounting for the instrument (**PTR**, **Antenna beamwidth**, etc …).



Waveform over ocean



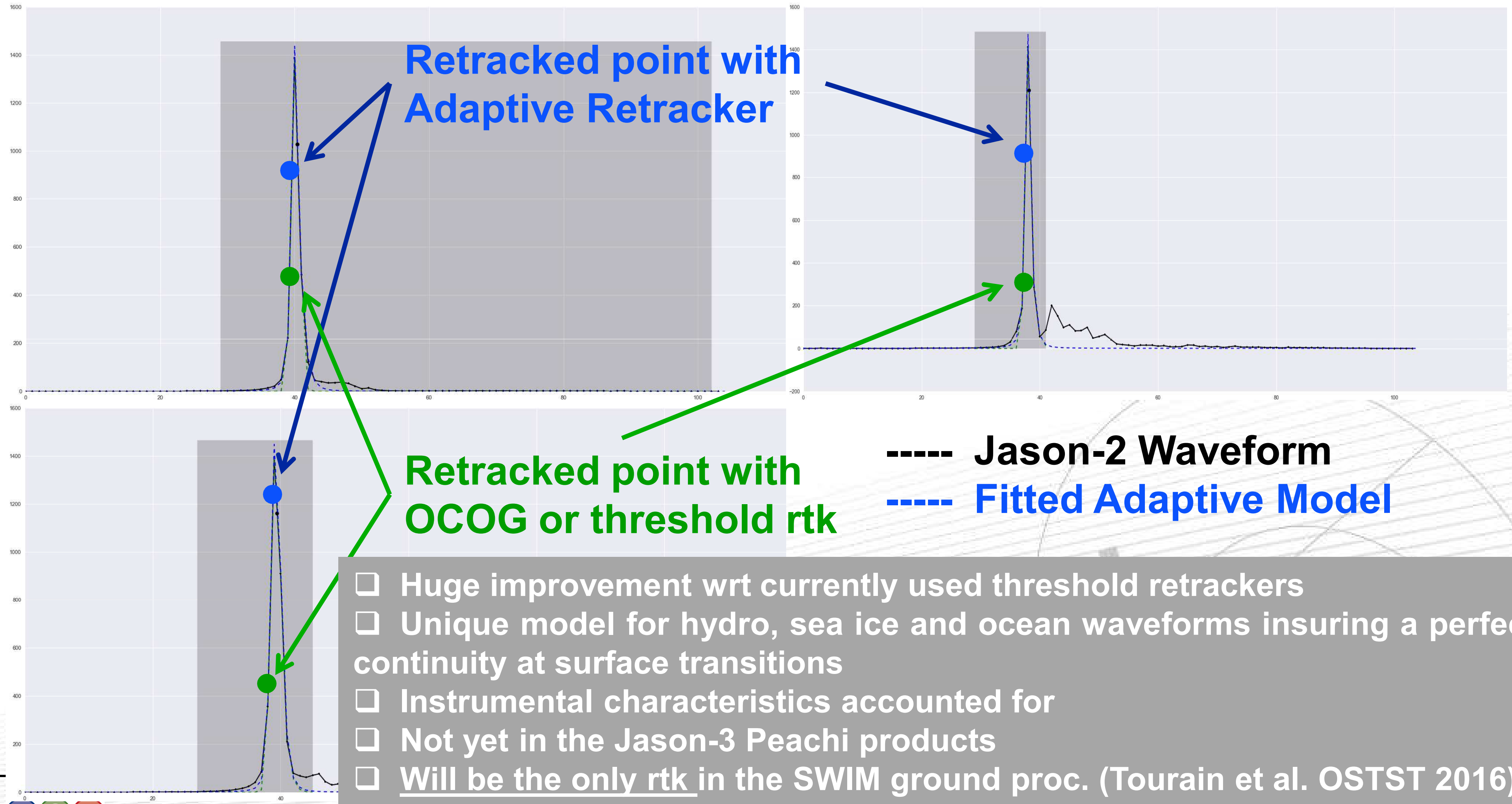
Waveforms over sea ice lead and hydro



The **Adaptive Retracker** uses the only few available points (3 or 4 or 5…) to adjust the model on peaky waveforms

Adaptive Retracker : An unique powerful retracker for all surfaces

Exemples over hydrological areas (RDV on Thursday, 10am in the «continental water session »)



- ❑ Huge improvement wrt currently used threshold retrackers
- ❑ Unique model for hydro, sea ice and ocean waveforms insuring a perfect continuity at surface transitions
- ❑ Instrumental characteristics accounted for
- ❑ Not yet in the Jason-3 Peachi products
- ❑ Will be the only rtk in the SWIM ground proc. (Tourain et al. OSTST 2016)

Conclusions (1)

- CLS has conducted many studies (mainly for CNES) to improve the retracking function for all altimeter missions, all modes (LRM/PLRM/SAR), over all surfaces (ocean/hydro/seaice/ice sheets)
- Accounting for the speckle statistics is crucial when retracking

  ➔ Numerical Nelder Mead solution

  - ✓ Provides good estimates at 20Hz
  - ✓ Reduces the residuals of the waveform fitting
  - ✓ Allows removing LUT corrections
  - ✓ Enhances the performances
    - LRM = -10% noise in range, -60% noise in SWH
    - SAR = -10% noise in range, -25% noise in SWH
- Jason-3 Peachi products include this solution (have a look at them) (have a look at the JPL R.Shah's poster)

Conclusions (2)

- Results have been shown for LRM but method applicable in SAR
- Huge potential for reprocessing all missions
  (even for Topex with corrupted PTR !)
- Possibility to enhance performances for non-oceanic surfaces and continuity with deep ocean if using an Adaptive Retracker
  - crucial for hydro at estuaries and lakes
  - crucial for sea level in leads, extension of SLA to the north and estimation of sea ice freeboard and thickness (Poisson & al, OSTST 2015, Reston)

- One recommandation :

Adopt the Numerical Nelder Mead solution for Jason-3

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

Diapositive 22

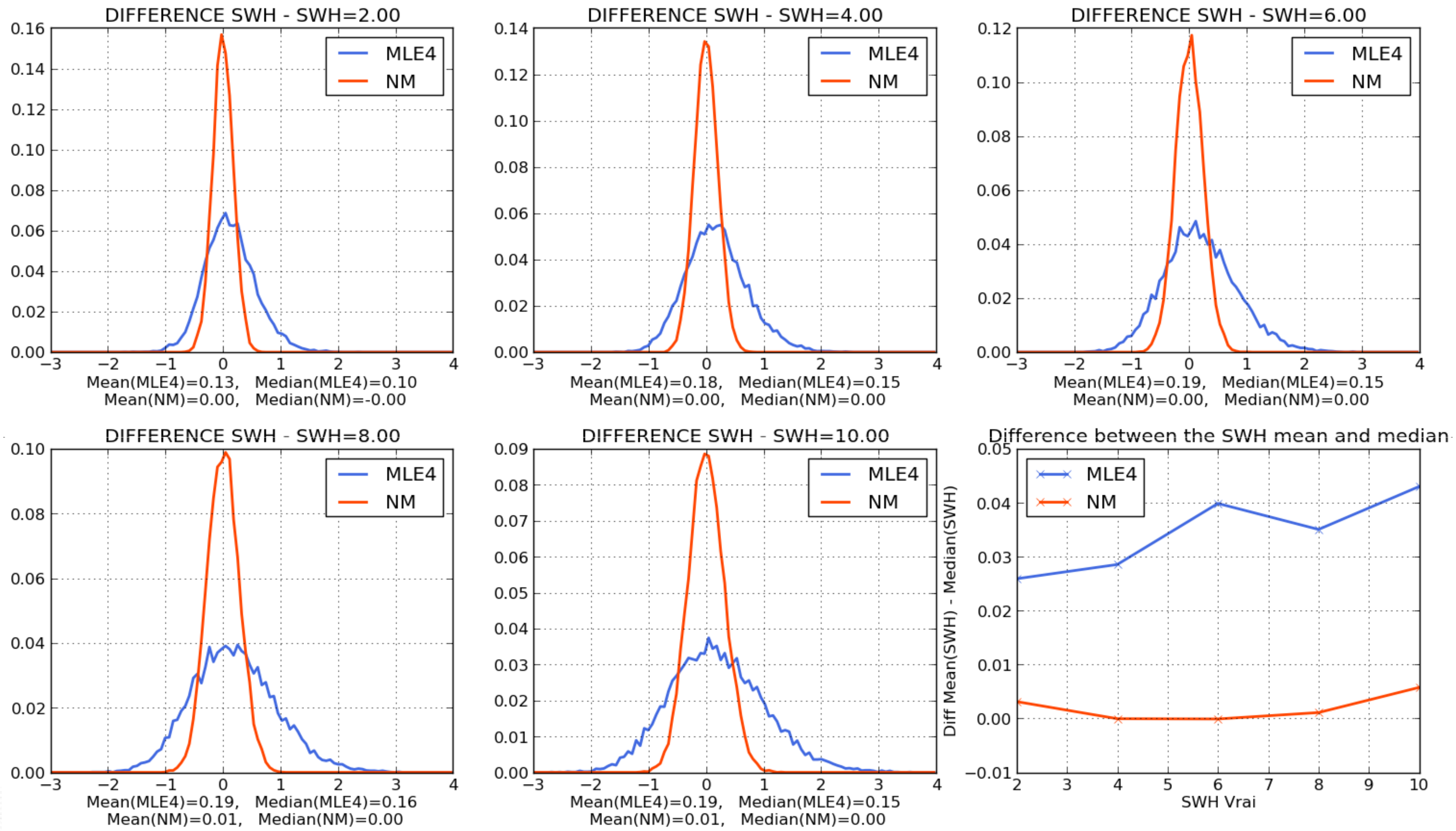
p2 Numérique ?
pthibaut; 19/09/2016

… Thank you for your attention …

For observing all surfaces without discontinuities : Adopt the Adaptive !

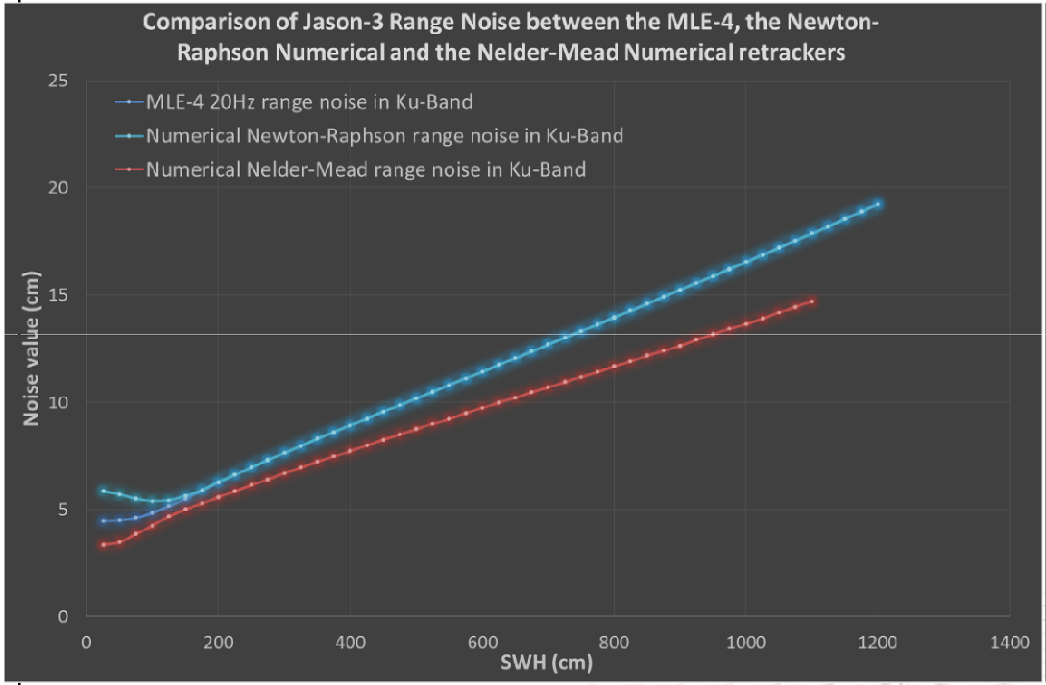
… Back up slides …

Computation of MLE4 LUTs



Noise reduction induced by Numerical and Nelder Mead retracker with respect to MLE4

Jason-3 Range Noise Table



Jason-3 SWH Noise Table