ThalesAlenia Space
A Thales / Finmeccanica Company

Optimal re-tracking of SAR altimeter echoes over open ocean: Theory versus results for SIRAL2 data

L. Phalippou & F. Demeestere

THALES

OSTST 2011

INTRODUCTION

- Motivation
  - To confirm the reduction of noise on range and significant wave height (see Phalippou and Enjolras, igarss 2007)
  - To demonstrate the feasibility of re-tracking with numerical power waveform model and its compatibility with real time processing
  - To support the preparation of future missions (Jason-CS / POSEIDON-4 …)

OPTIMAL RE-TRACKING

OPTIMAL "the best solution in a statistical sense"=> MLE

Model of Waveforms
Forward Model

Parameters to retrieve
Range, sigma0, SWH

$$J(\boldsymbol{\alpha}) = [\mathbf{z}_{obs} - f(\boldsymbol{\alpha})]^T \; \mathbf{C}_{\mathbf{n_o}}^{-1} \; [\mathbf{z}_{obs} - f(\boldsymbol{\alpha})]$$

Measured
Waveforms

Measurement noise
Covariance Matrix
Speckle + Thermal

Noise in the retrieval of α : Cramer-Rao bound

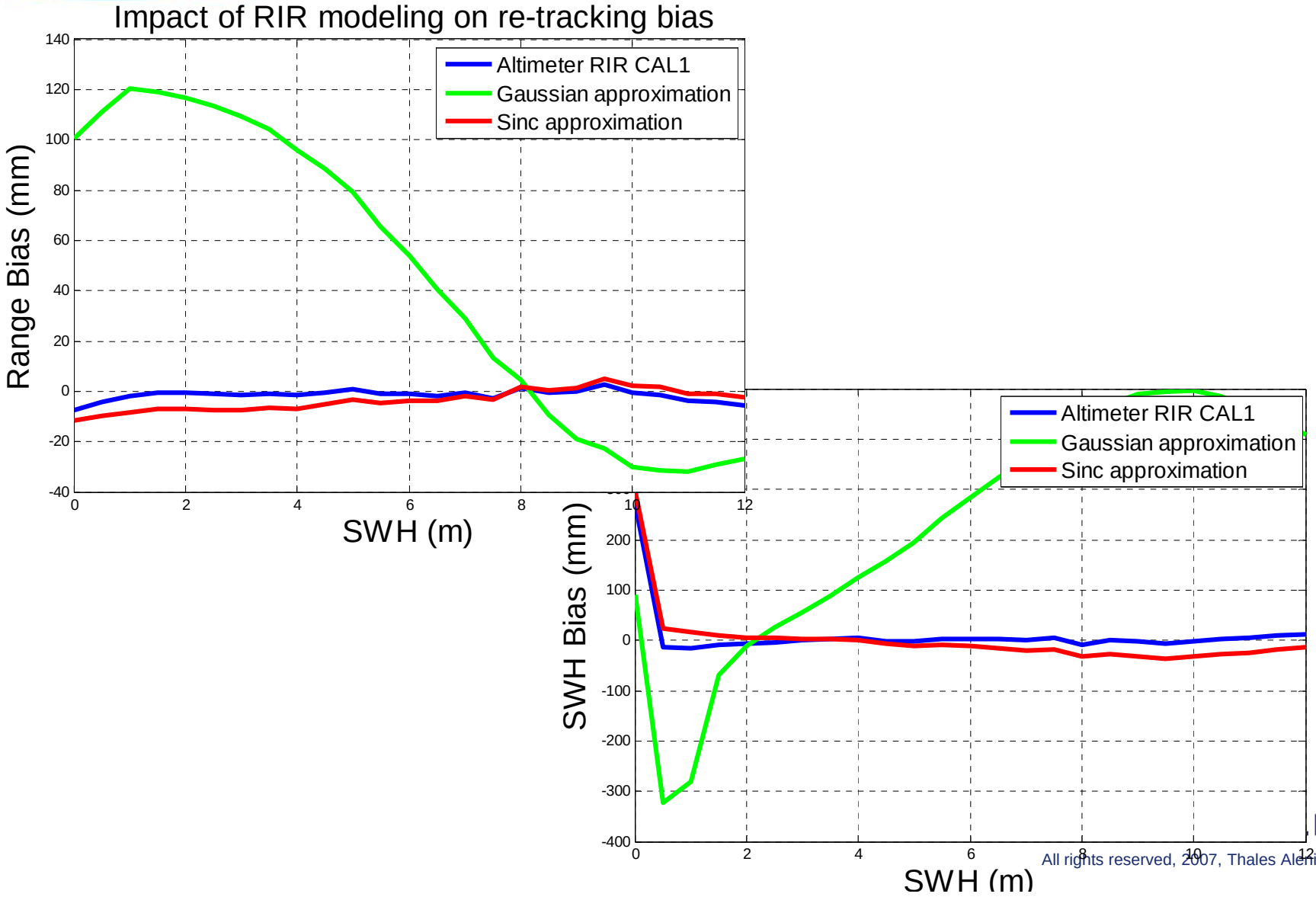
$$\mathbf{C}_{\boldsymbol{\alpha}} = \left[\mathbf{K}^T \; \mathbf{C}_{n_o}^{-1} \; \mathbf{K}\right]^{-1} \qquad K(i,j) = \frac{\partial f_i(\boldsymbol{\alpha})}{\partial \alpha_j}$$

WHAT WE NEED

- **AN ACCURATE UN-BIASED FORWARD MODEL**
  - The model must re-produce the physics of the measurements including the instrument characteristics and the data processing as accuratly as possible
  - The model must be free from systematic error
  - Any systematic error in the model will be mapped into « non-random errors » in the retrieved geophysical products
  - No specific need for analytical modeling

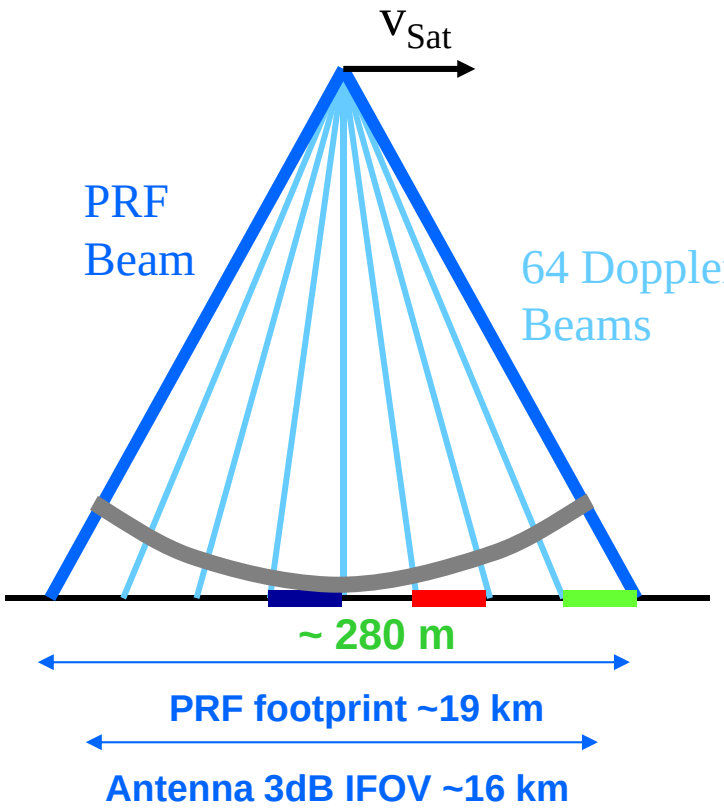
- **MODEL OF THE MEASUREMENT ERRORS STATISTICS**
  - Noise source : Thermal noise and speckle noise
  - Multilooking different mean power wavefoms shall be accounted for

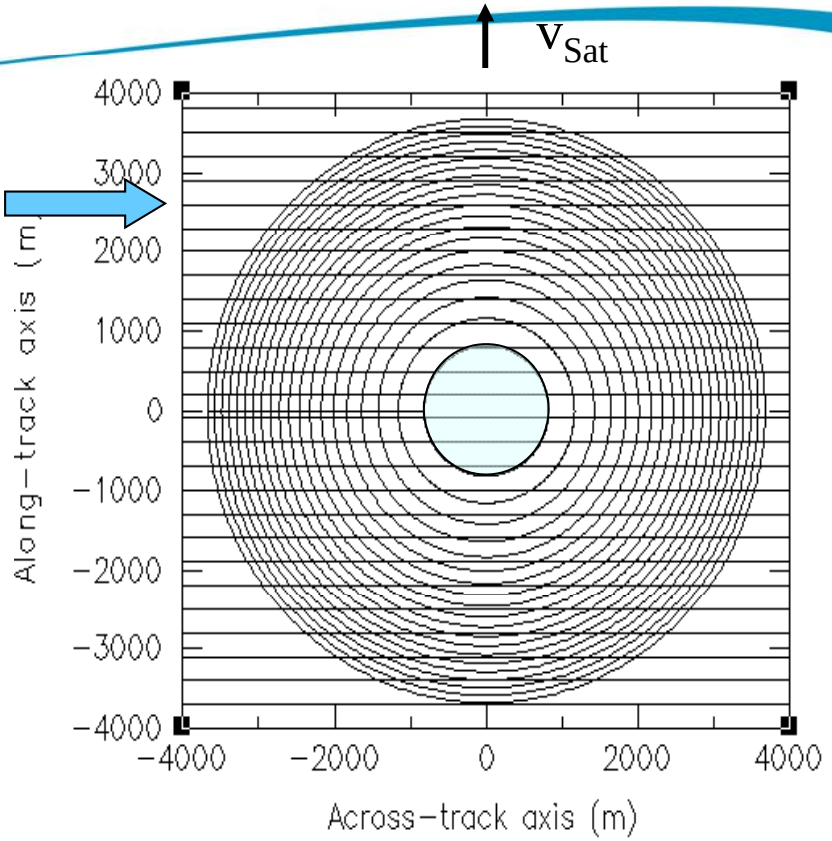
Model vs « bias » : e.g. the RIR

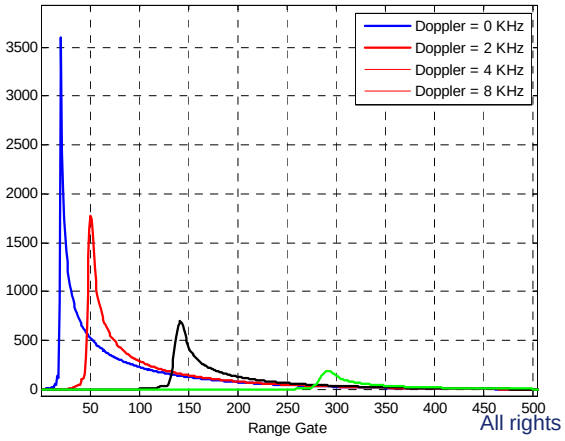


SIRAL FLAT SURFACE RESPONSE

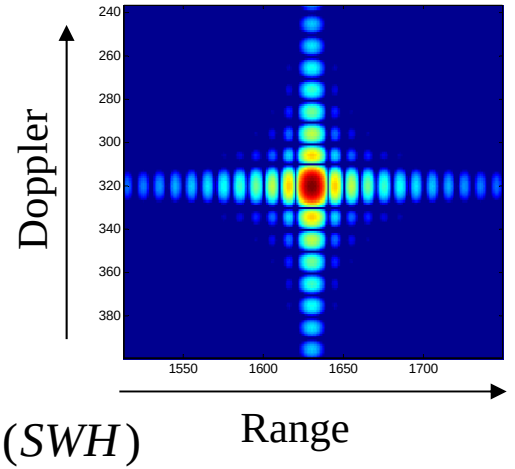
For Top Hat Azimuth & Range Impulse Responses







WAVEFORMS MODEL



- **The Point Target Response of 2D Impulse Response**
  - Product of 2 sinc function (Deramp in time, FFT in azimuth)

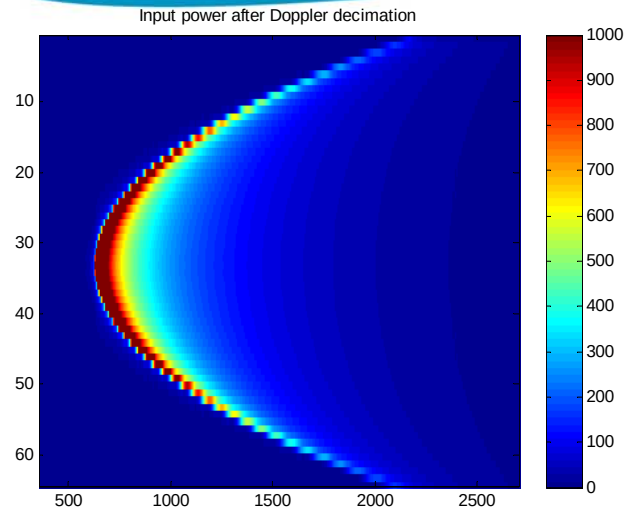
- **Mean Waveform, a function of Doppler x_i and time t**

$$P(x_i,t) = cte\ sigma0\ G^2(x_i,t)P_{flat}(x_i,t) * RIR(t) * AIR(x) * sea\_pdf(SWH)$$

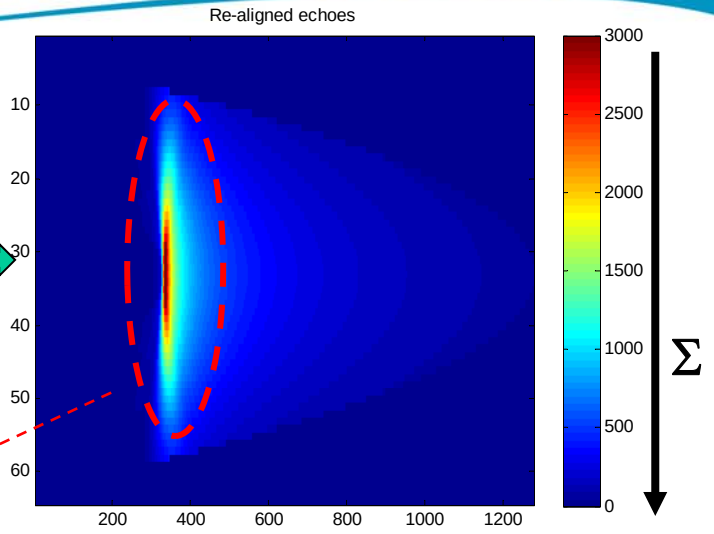
- **Geophysical Variables : unknown to be retrieved**
  - Range, Wave Height H1/3, sigma0

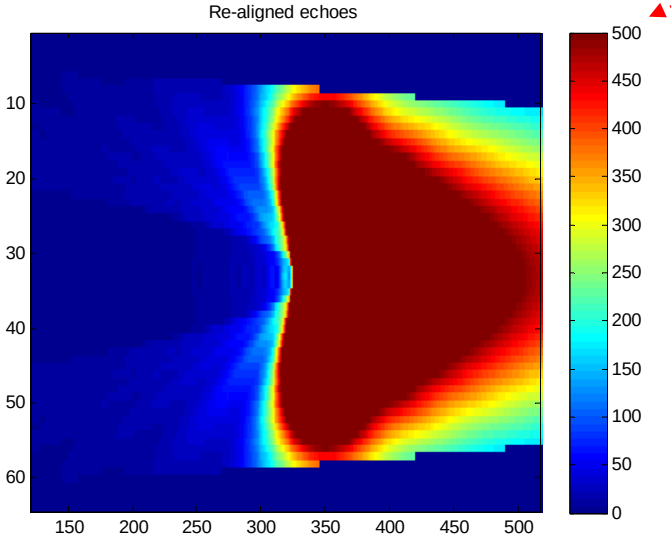
- **The a priori information – i.e. information known with "sufficient" accuracy**
  - Geometry (orbit, ellipsoid / geoid , sat velocity vector …)
  - Antenna : fine characterization on ground, pointing (star tracker)
  - Range and Azimuth impulse responses : calibration in flight
  - Receive chain transfer function CAL2 filter
  - Sea state height pdf (gaussian, or skewed …) driven by H1/3
  - Model (pdf) of speckle and thermal noise

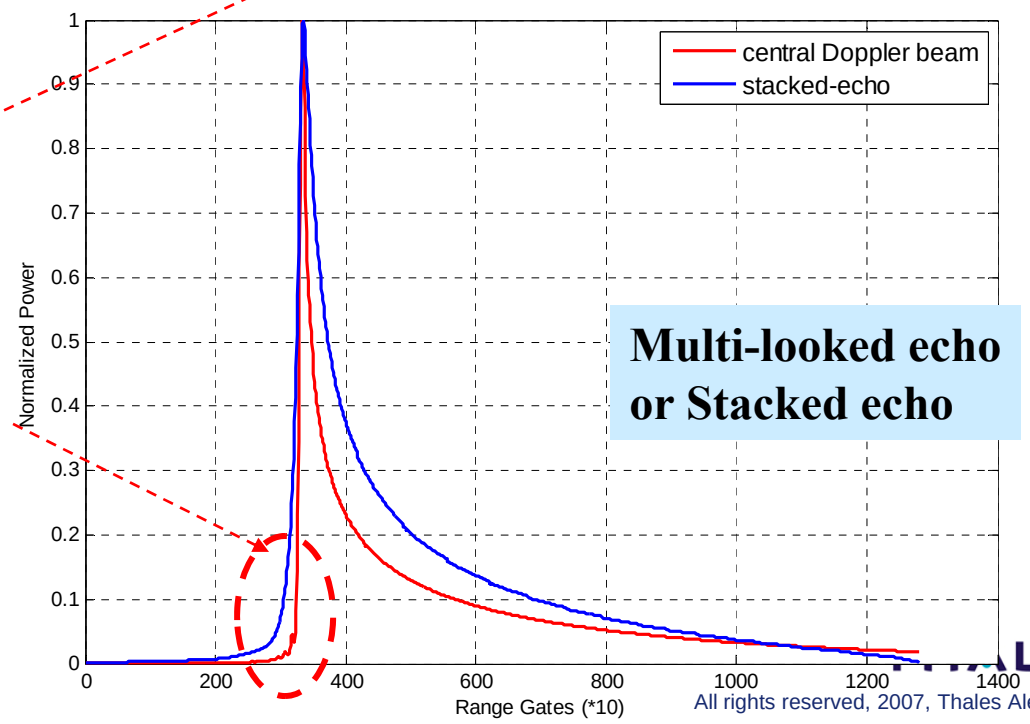
Slant Range Correction & Stacking



Slant Range Corr.
Re-alignment
of leading edge

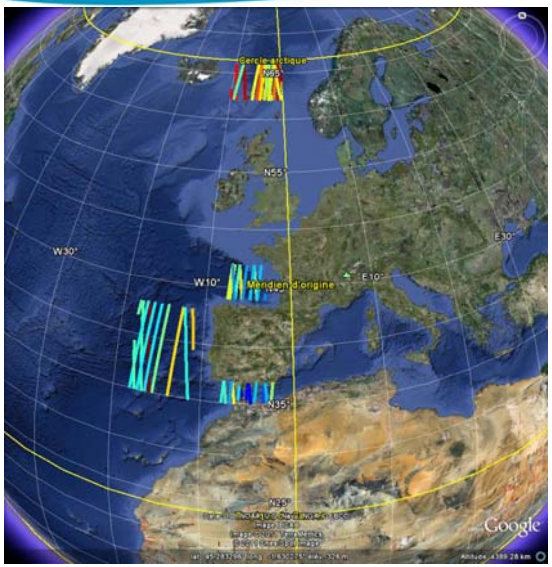


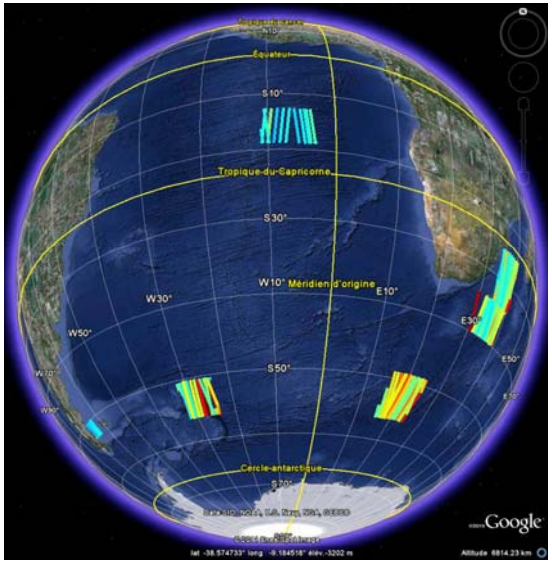




Multi-looked echo or Stacked echo

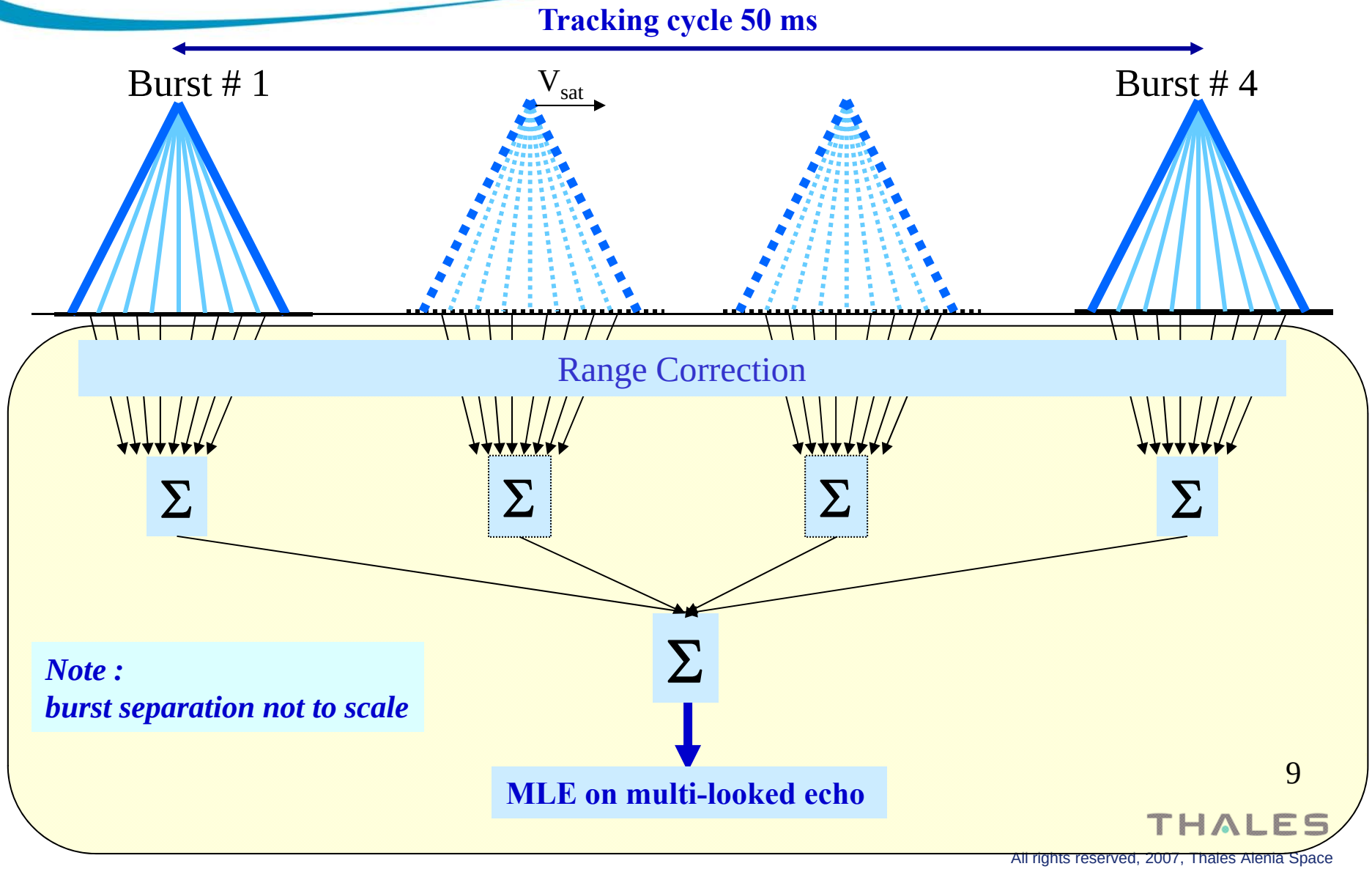
SIRAL2 DATA





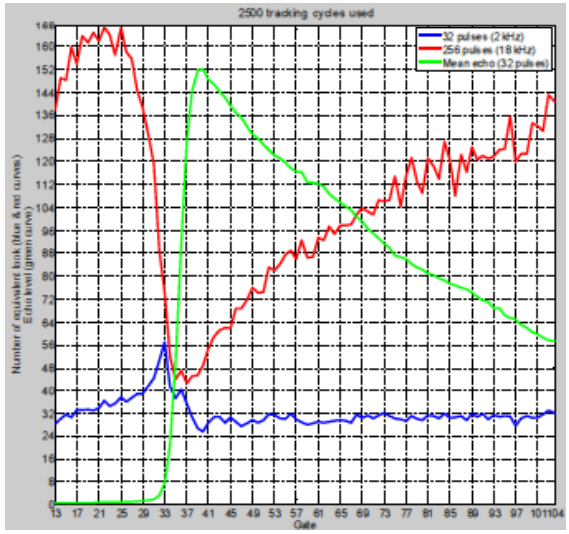
- **147 orbit sections**
  12 000 s, 90 000 km, 240 000 tracking cycles
- **Takes : March 2011**
- **Full Bit Rate (FBR). I/Q data.**
- **10 zones sampling various sea state**
  SWH [0 - 10 m]
- **Re-tracking of SAR acquired data**
  - SAR re-tracking
  - “LRM” re-tracking for relative comparisons
- **Mean Sea Surface : ACE2 dataset**

SAR MULTI-LOOKING AND MLE

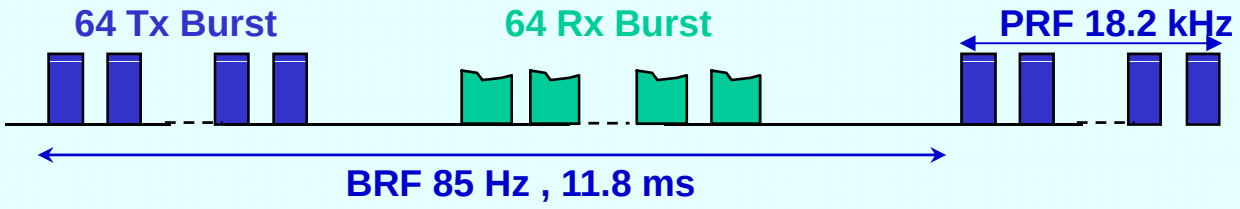


NUMBER OF LOOKS

- **SAR DATA WITHOUT SAR PROCESSING (LRM re-tracking)**
  - Number of looks is sized by the speckle decorrelation of the pulse limited footprint surface
  - For Pulse Limited altimeters the “decorrelation PRF” ~ 2 kHz for the PLF (e.g. Jason, ENVISAT)
  - For SIRAL the lower limit for **ENL in “LRM like” is ~ 760 @ 1 sec** due to closed burst mode (760=18 kHz / 2 kHz / 11.8 ms)

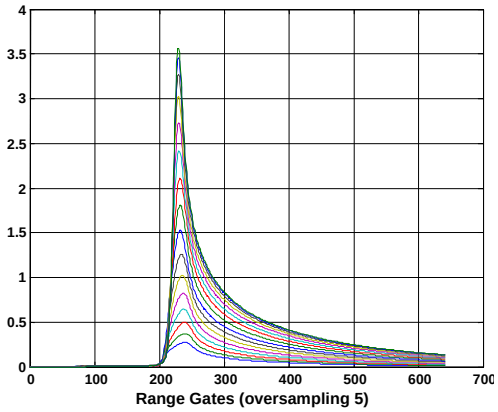


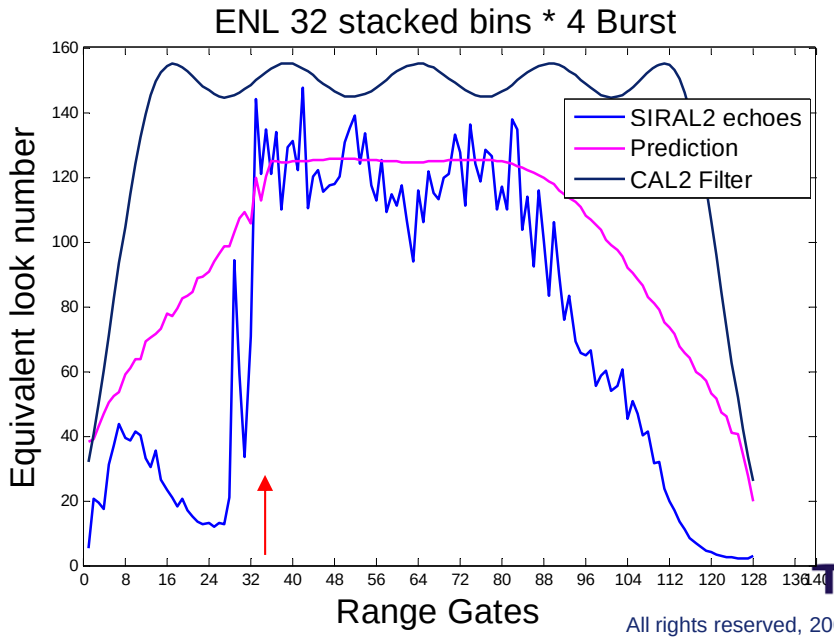
SIRAL SAR- MODE TIMING



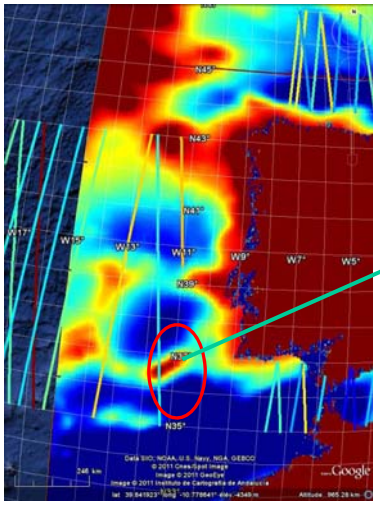
Efficient number of looks

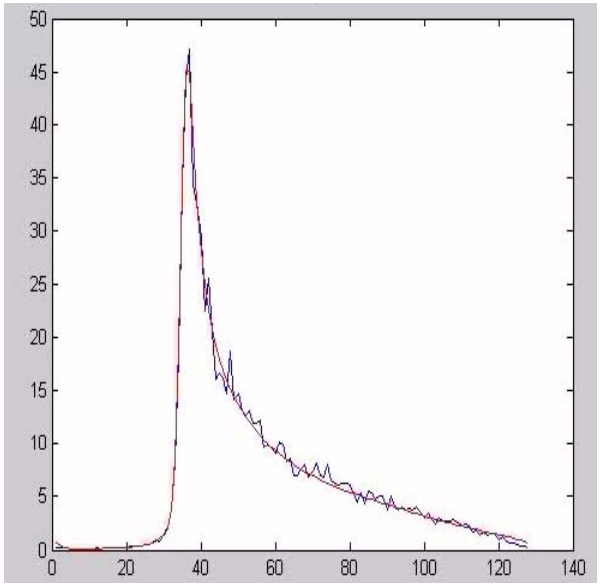
- **SAR DATA WITH SAR PROCESSING**
  - Doppler filtering de-correlates the Doppler beams.
  - Burst to burst echoes are also decorrelated
  - 32 central Doppler bins per burst are kept (minor changes with 64 bins)
  - 32 bins / 11.8 ms. **ENL SAR (max) = 2700 / sec**
  - BUT variation of the mean power waveforms with Doppler bin must be accounted for computing the Effective Number of Looks (ENL)



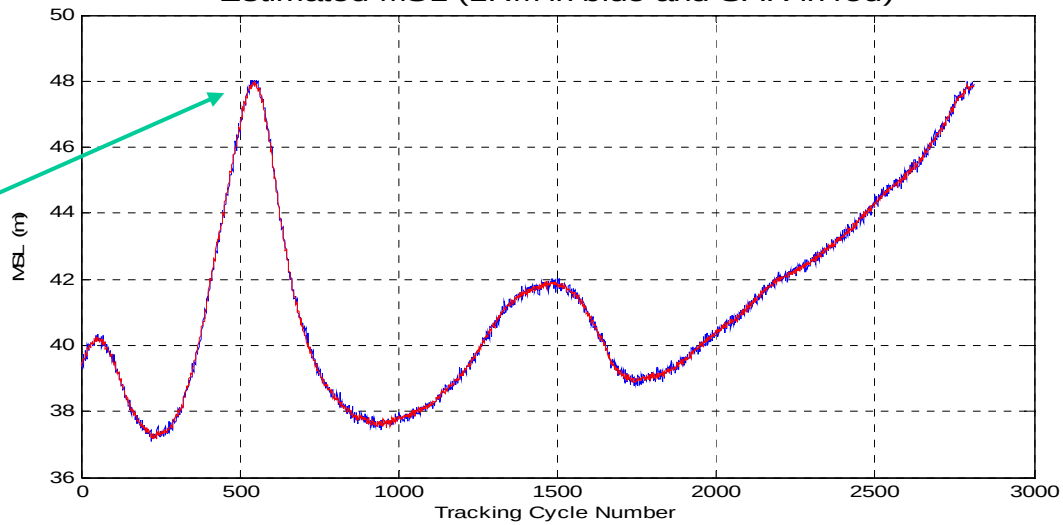


SAR VS LRM PROCESSED AND MSL

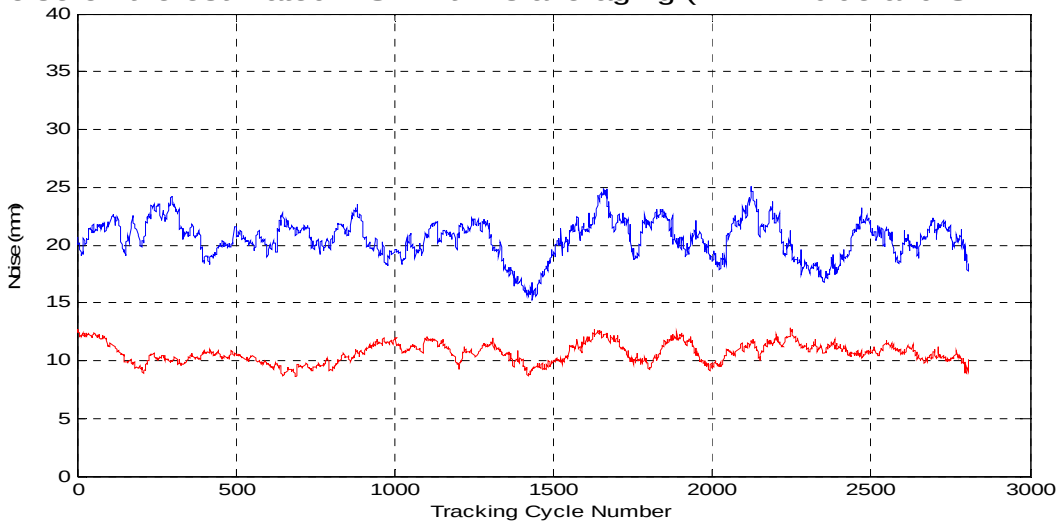




Estimated MSL (LRM in blue and SAR in red)



Noise on the estimated MSL with 1s averaging (LRM in blue and SAR in red)

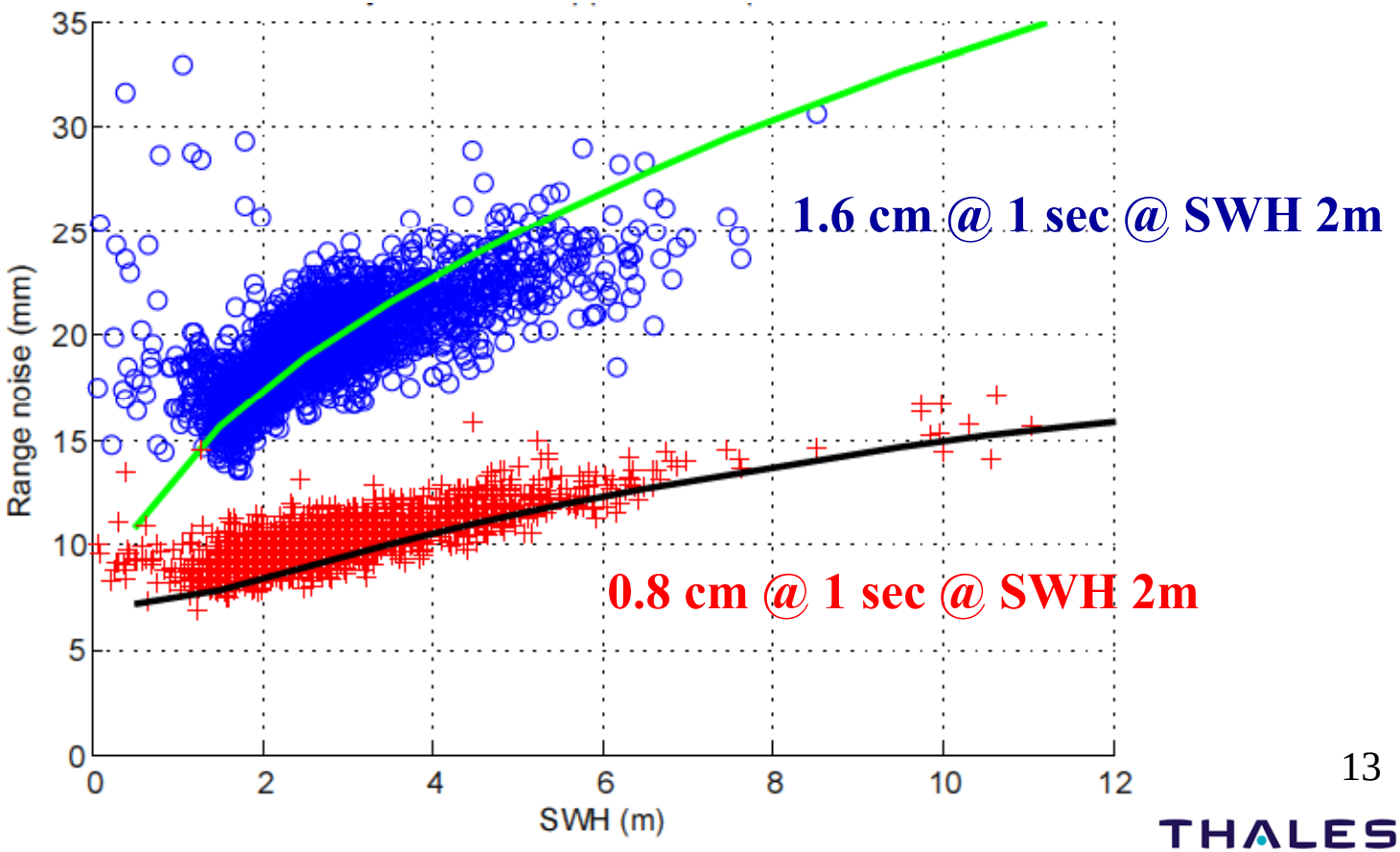


RANGE NOISE

SAR mode acquired data

without SAR processing "LRM like" (blue), with SAR processing (red)

12 000 s, 90 000 km, 240 000 tracking cycles

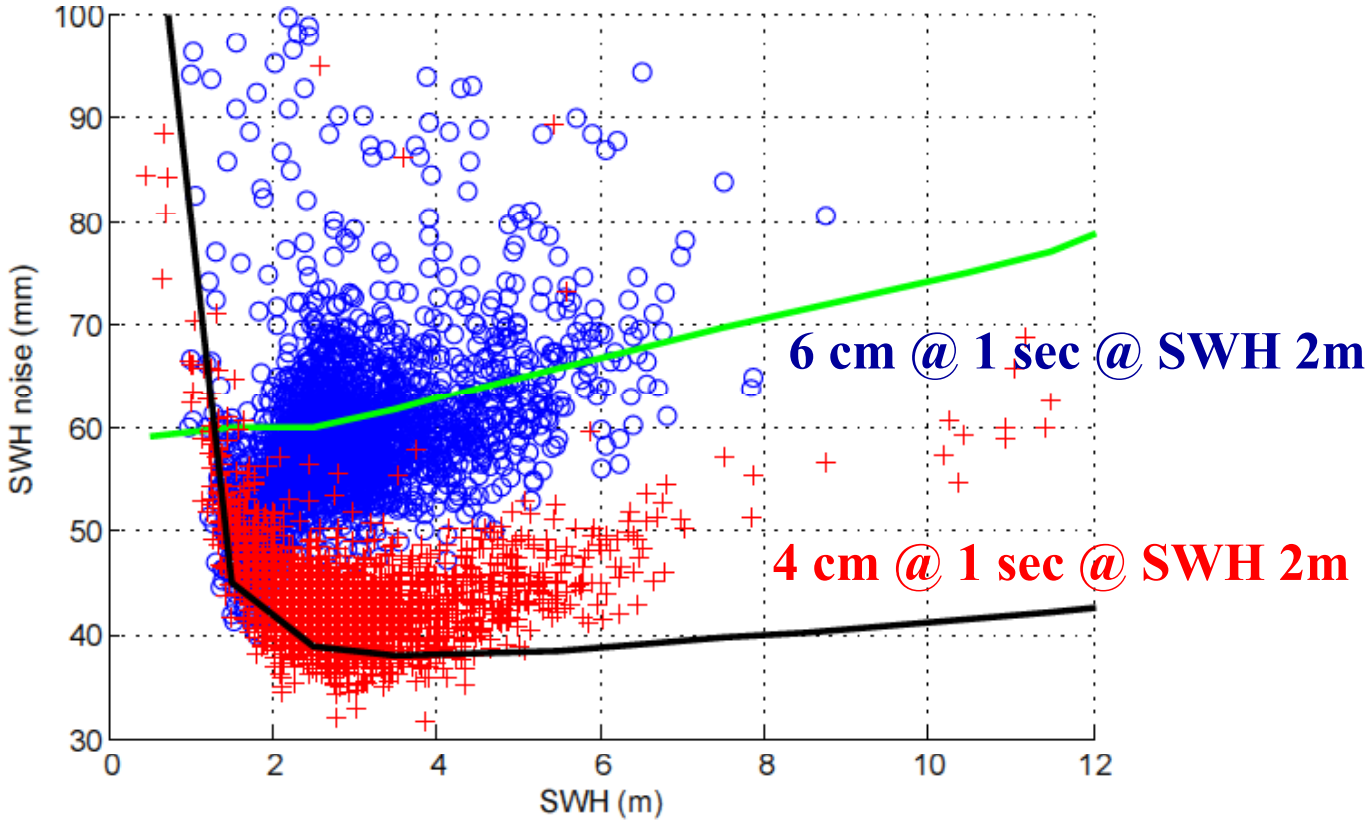


SWH NOISE

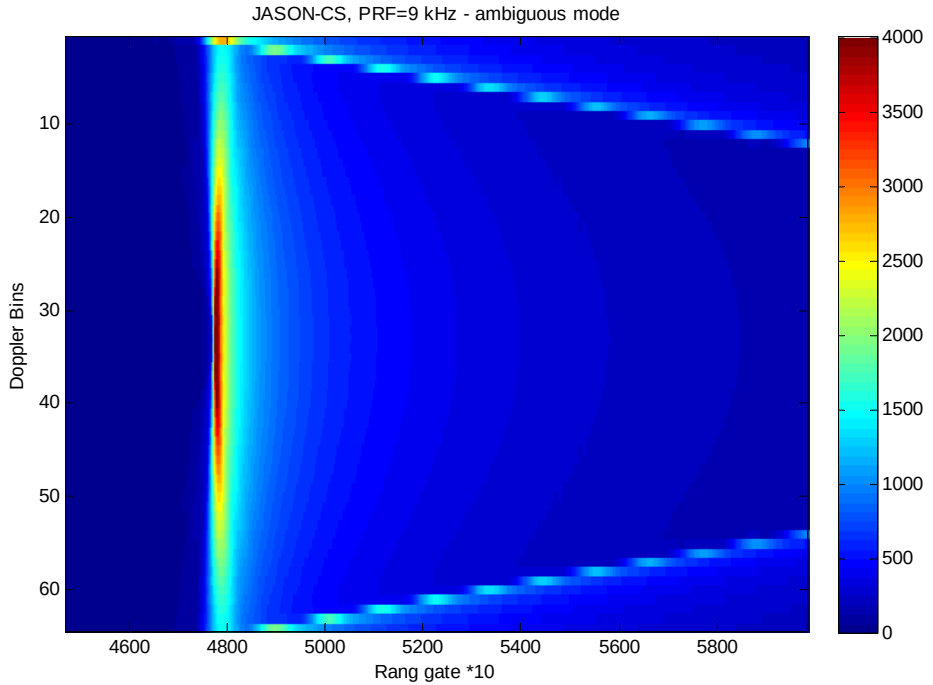
SAR mode acquired data

without SAR processing "LRM like" (blue), with SAR processing (red)

12 000 s, 90 000 km, 240 000 tracking cycles



- **Simulation for Inter-leaved Tx-Rx possibly with Doppler ambiguity**
  - To allow continuity of 2 KHz Ku mode => interleaved high PRF mode
  - To preserve pulse length - SNR constraints
  - PRF can be decreased wrt SIRAL = > Doppler ambiguity can be modeled and accounted for in the retrieval or removed by range filtering ….
  - On Board Processing (echo stacking only)



CONCLUSIONS

- **FINDINGS**
  - SIRAL capability to improve ocean range noise : ~0.8 cm @ 2 m SWH @ 1 sec is now demonstrated on real data
  - SAR echoes re-tracking with accurate numerical modeling of the waveforms is the way forward
  - Data are processed in ~ real time on standard PC: computation time is not an issue
  - Interest of the method for LRM re-tracking (EMB ?)
  - Theory can be used for designing new missions

- **NEXT** …
  - Validation versus other missions / in situ data.
  - Multi-looking strategy (steering of Doppler beams)
  - Feedback for JASON-CS design and performances for open ocean and OBP

SIRAL SAR MODE

- SIRAL on CryoSat
  - **Altitude** **720 km**
  - **Antenna** **~1.2 m**
  - **Radar Frequency** **13.575 GHz**
  - **Chirp (FM) Bandwidth** **320 MHz**
  - **Time resolution** **3.125 ns**
  - **SNR (σ_0=15 dB)** **37 dB** (after SAR filtering)