CNES Involvement on SAR altimetry:
RDSAR and SAR processing techniques and Results

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Doppler altimetry activities on CNES side: History

<u>In the 2000's:</u>

-First analyses of SAR/Doppler mode for WSOA payload, initially planned on Jason-2

-Participation to the definition of SIRAL instrument on CryoSat-1

-Several studies with Boost and CLS on the SAR capabilities over ocean

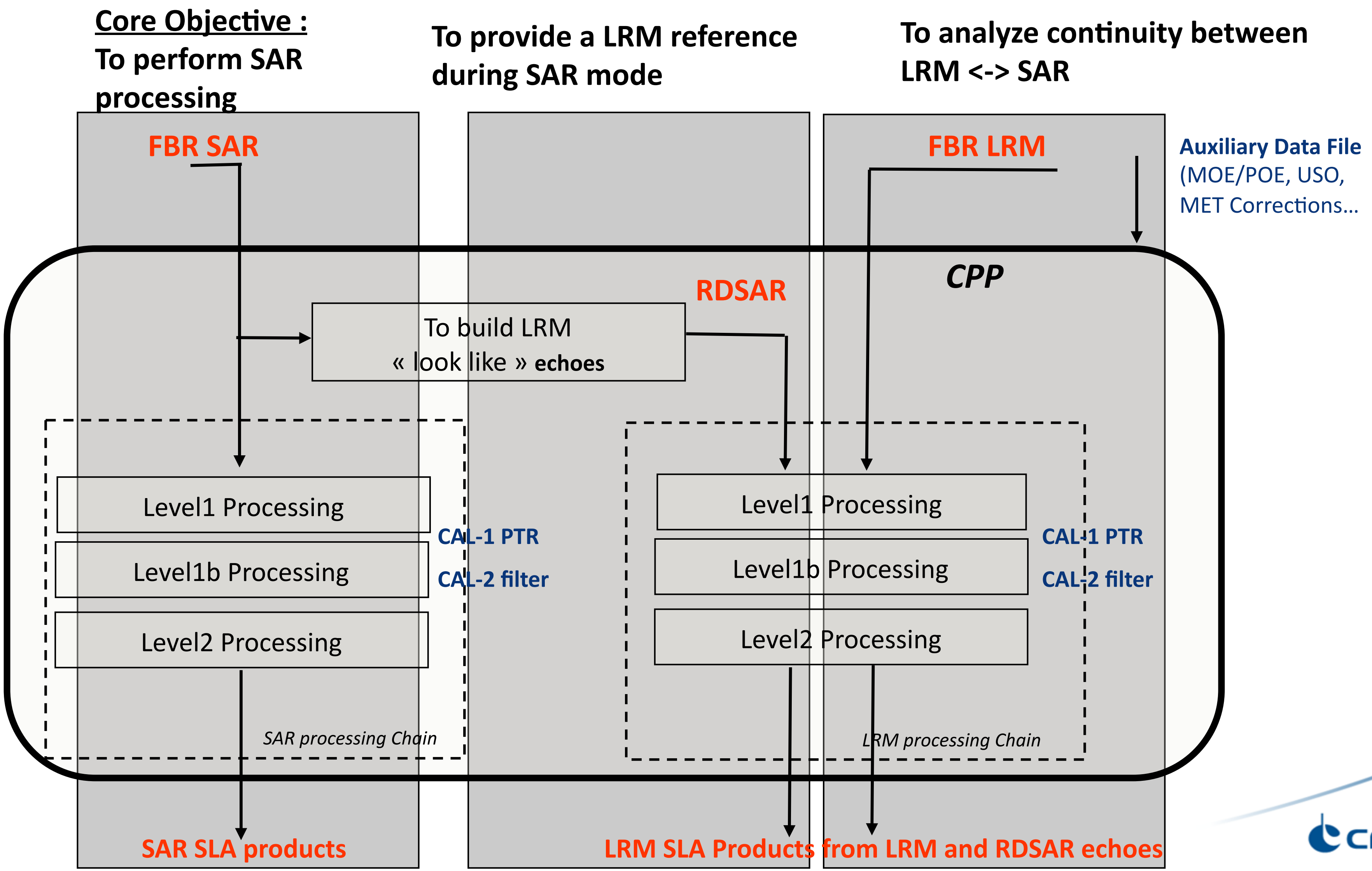
<u>For Sentinel-3,</u> CNES provides ESA with a support for the topography mission performances. In that frame, to contribute to the processing algorithm solution for SAR Mode data over ocean and inland water, CNES has developed:

- Simulators (SARM altimeter simulators)
- L0 to L2 SAR, RDSAR and LRM processing methods (validated using CRYOSAT-2 data ie CPP)
- and performed several studies: swell impact on SARM performances, stacking improvements, sea state bias for Doppler altimetry.

We have also provided a support to the development of the SPS, GPP and L2PAD.

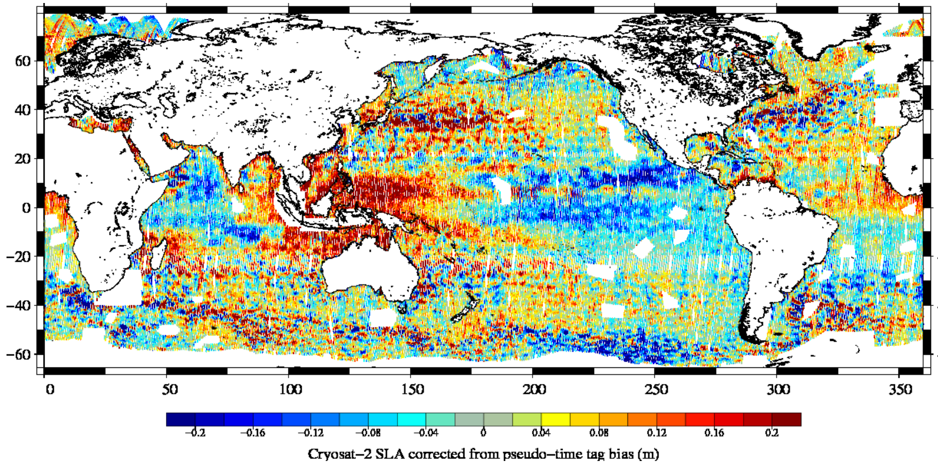
<u>For Jason-CS</u>, our goal is to ensure a continuity with all previous developments/studies and to take the benefits of existing tools:→ **must be adapted to the interleaved mode**.

CryoSat Processing Prototype
LRM, SAR and RDSAR processing techniques

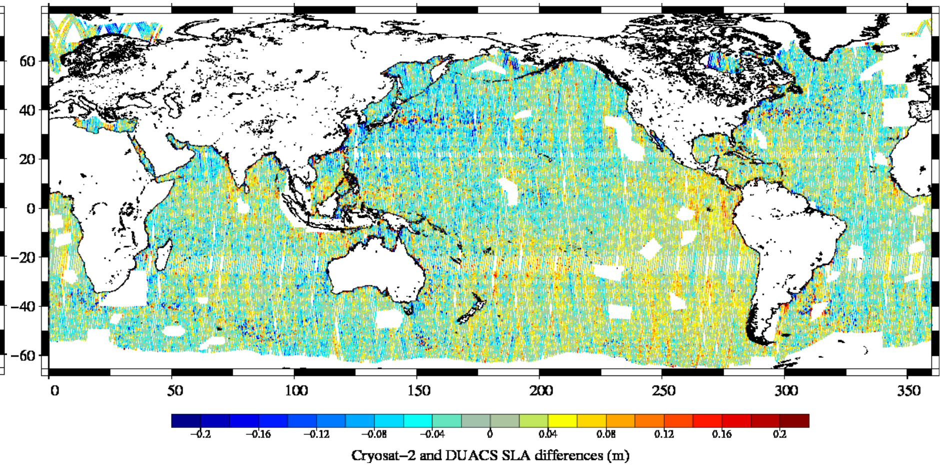


Cryosat Processing Prototype: LRM Processing chain

→ **CPP LRM processing chain developped following Jason-2 standard.**



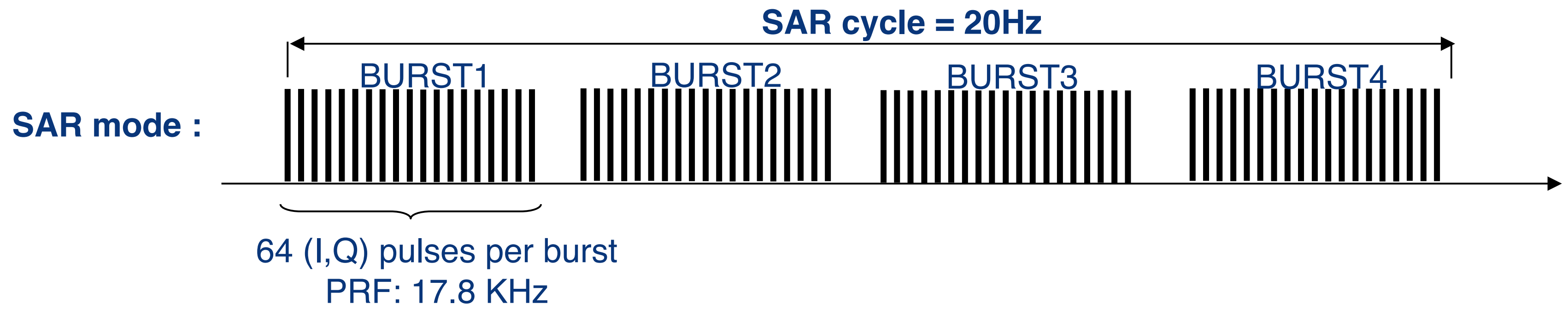
CryoSat-2 SLA (respect to the MSS) over December, 2010.



SLA differences between CryoSat-2 and DUACS

- Very good agreement between Cryosat-2 LRM and Jason-2
- Same level of performances than Jason-2
- Results presented at OSTST, 2011
- With ESA agreement, the CPP products have been integrated in the CNES DUACS system in April-2012.
- Used as a reference for the development of the new ESA Cryosat Ocean Processor.

Cryosat Processing Prototype:
How to provide a LRM reference during SAR mode?



- Each individual (I,Q) pulse is a LRM-like echo
- To build a pseudo-LRM echo from SAR measurements (RDSAR), pulses must be aligned on the same range reference gate and then (I2+Q2) accumulated over a cycle (as performed by a conventional altimeter).
- **But** the pulses provided by the SAR altimeter are partially on-board corrected for radial velocity (from burst to burst) so the pulses slides inside the range window within a burst.

RDSAR techniques:

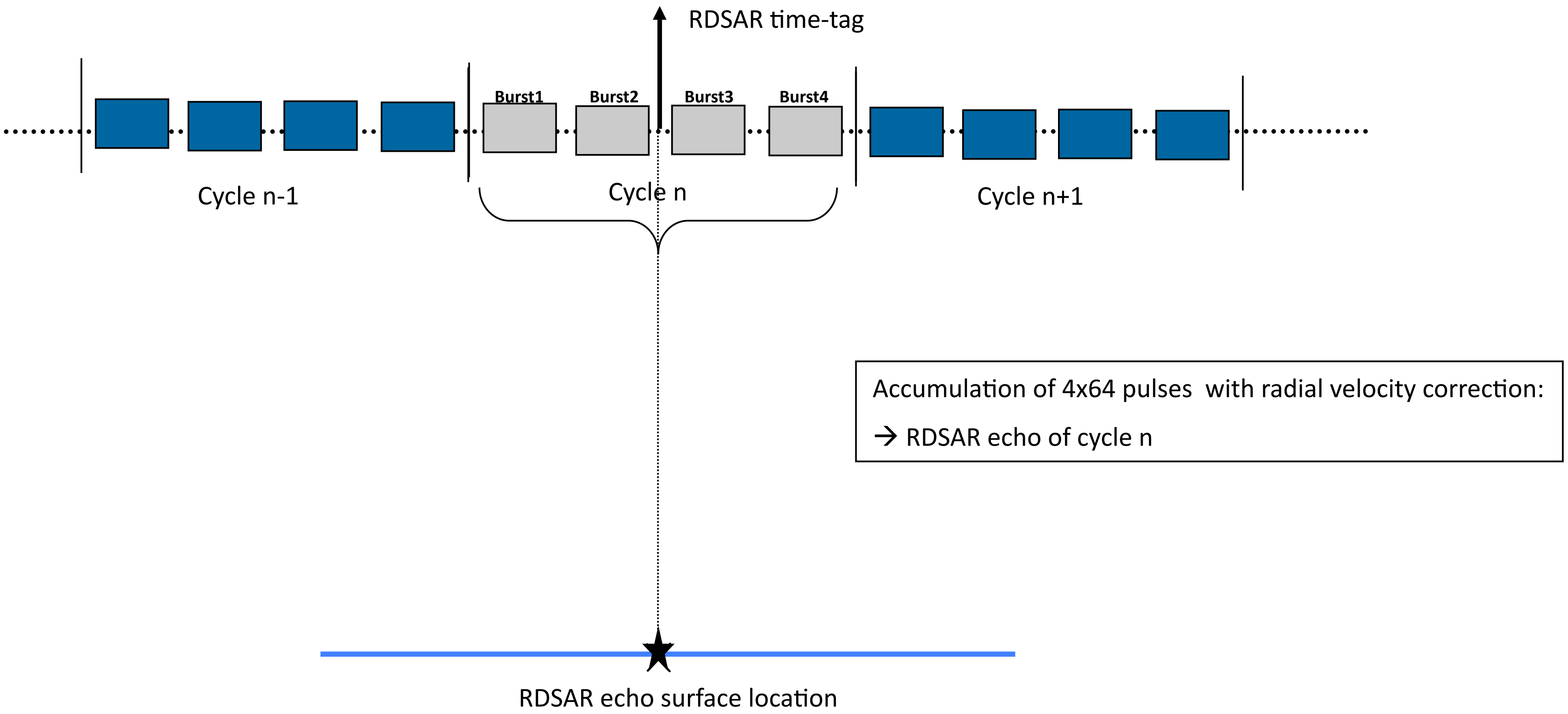
- To undo partial alignment performed on-board by the altimeter (using COR2 command)
- To perform an accurate alignment of the pulses using the radial velocity provided by the orbit ephemeris on the same range reference.
- To perform an I2+Q2 accumulation of all aligned pulses over each cycle (256 pulses but only 32 full uncorrelated)

RDSAR echoes are processed using the LRM processing chain.

CryoSat Processing Prototype:
SAR processing chain

<u>Level-0 and Level-1b Processing:</u>

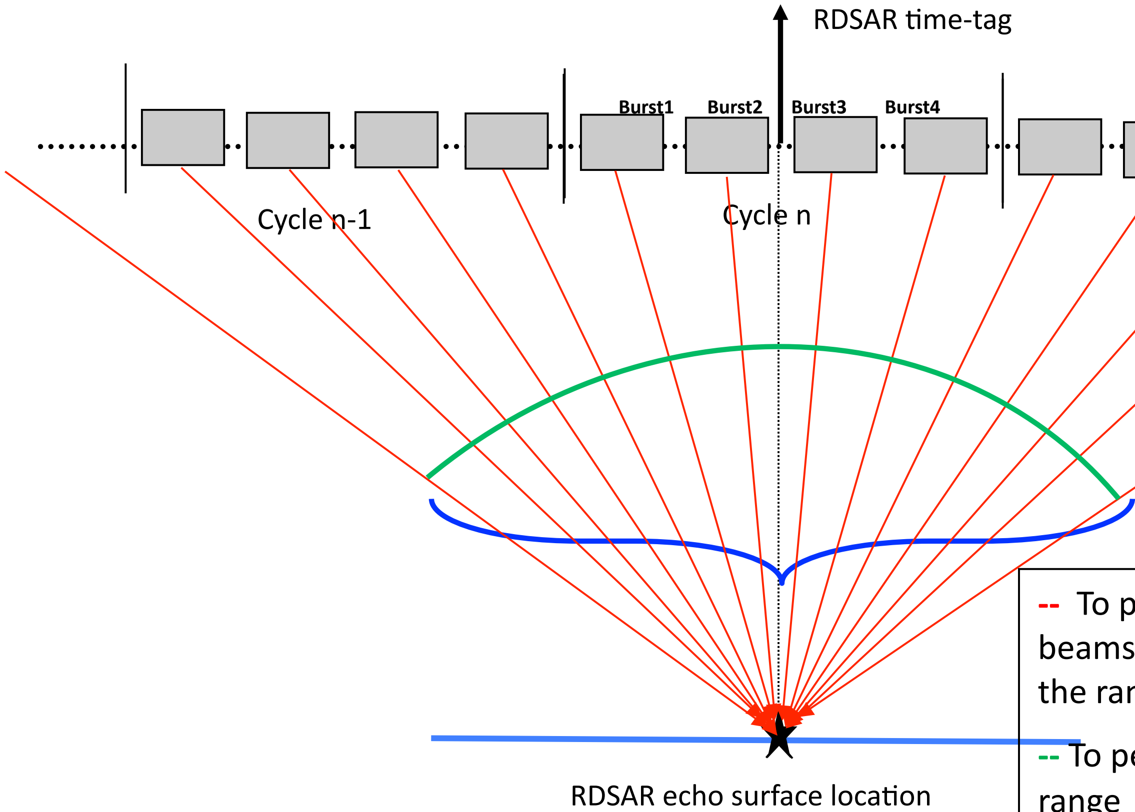
Performed using the RDSAR mesurements as surface point reference,



CryoSat Processing Prototype: SAR processing chain

<u>Level-0 and Level-1b Processing:</u>

Performed using the RDSAR mesurements as surface point reference,



-- To perform an azimuth FFT, to Focus the doppler beams on the RDSAR surface location and to correct for the range doppler effect

-- To perform the range migration + to align the tracker range

-- To multilook all the single looks

NB: echoes are corrected for AGC command.

CryoSat Processing Prototype
SAR processing chain

Doppler Echo model:

Numerical computation of the radar echo (after SAR processing):

$$\mathrm{Echo} = \mathrm{FSSR} \otimes \mathrm{IRs} \otimes \mathrm{PDF}$$

Single Looks

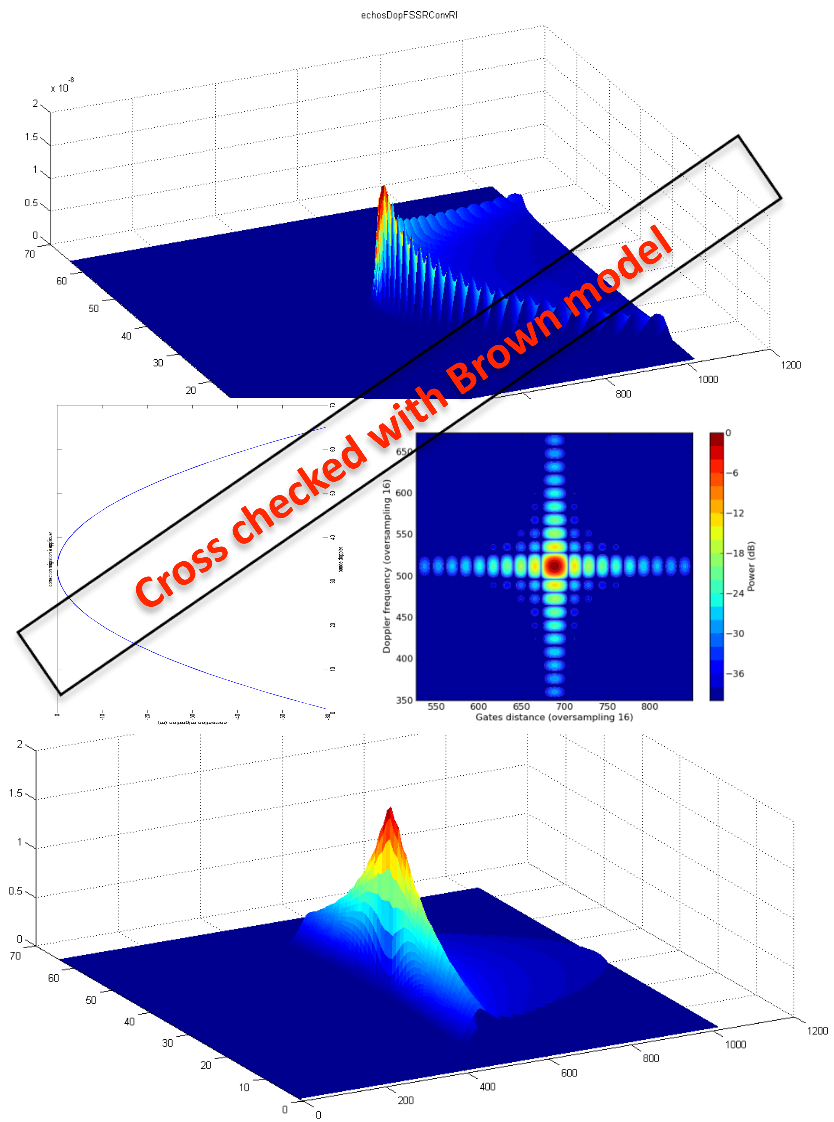
- Computation of the FSSR for each doppler band (64). Mispointing is taken into account.
- Convolution with Instrument and Azimuth Impulse Response

Multi Look

- Then, range migration is performed to align each single looks
- Sum of each range migrated Singlelook: multilook Doppler echo
- Convolution with the PDF of SWH

Note that without range migration, this computation leads to a LRM echo model (without Brown approximations)

→ **Usefull for validation**



CryoSat Processing Prototype: SAR processing chain

<u>Numerical approach?</u>

<u>Advantages:</u>

this approach allows to take into account any instrument characteristics (sinc PTR, antenna ellipticity, **POS4 doppler ambiguities**…)

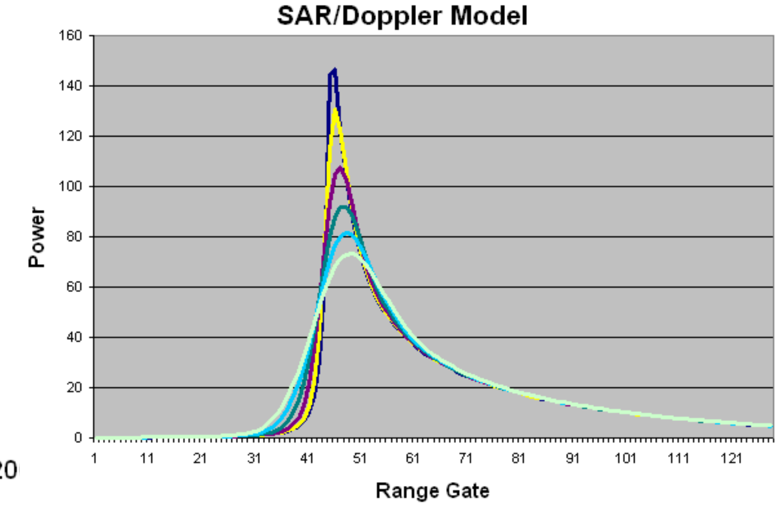
<u>Drawback:</u>

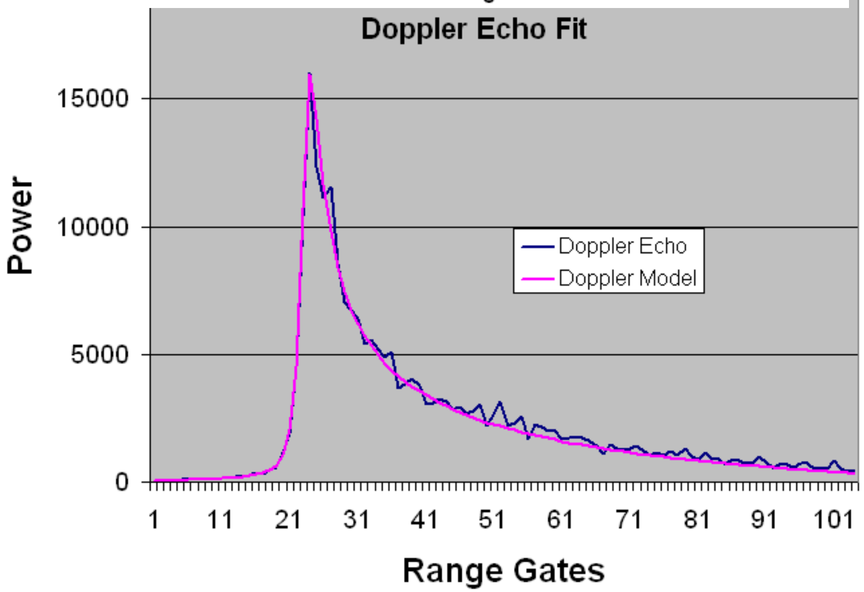
requires CPU but this is easily managed using pre-computed database

<u>Retracking:</u>

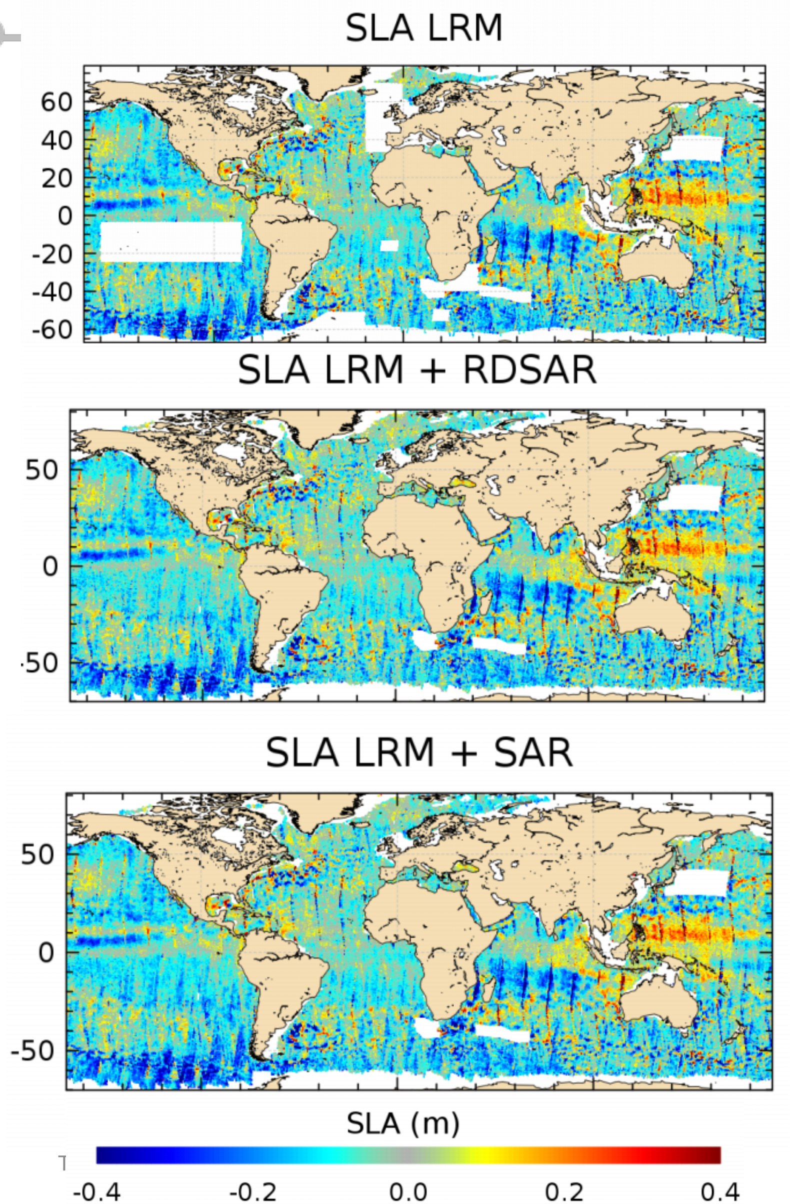
in heritage from Jason-2 MLE3 but:

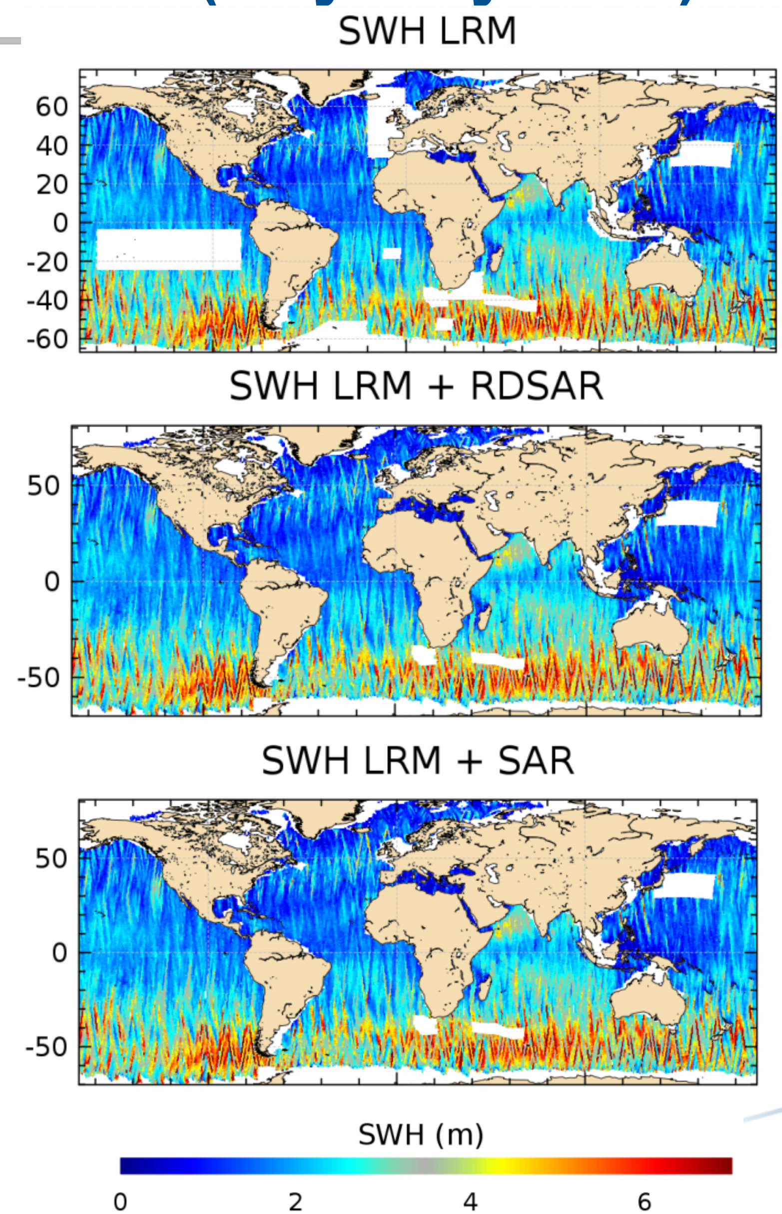
- **Model derivatives are numerically computed**
- **Use of mispointing angle given by the StarTrackers** as an input (required because of the Doppler echo model sensitivity to mispointing variation). ST measurements have been aligned on the altimeter pointing reference frame.





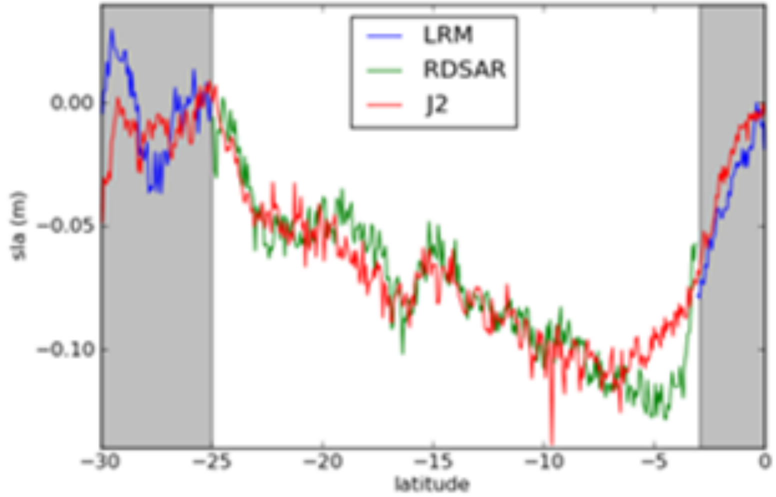
CryoSat Processing Prototype:
SAR results over 3 months (May-July 2013)

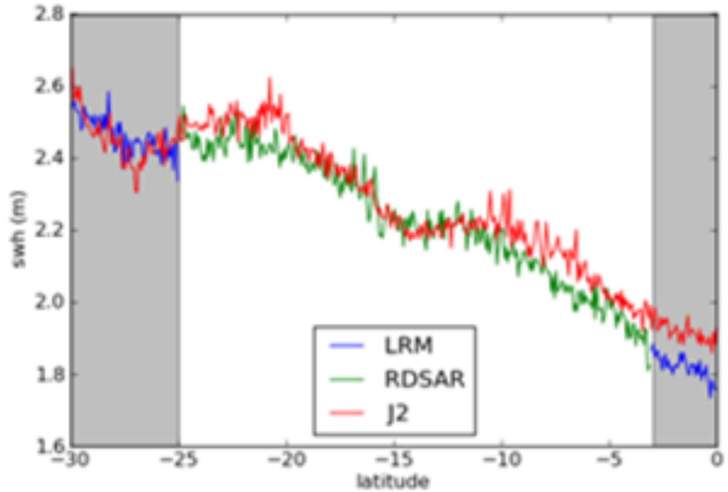




CryoSat Processing Prototype:
SAR results over 3 months (May-July 2013)

<u>LRM <-> RDSARcontinuity analysis:</u> Averaged values by latitude band





<u>SLA:</u>

- Very good LRM-RDSAR continuity (green plot, delta at transition less than 1 cm)
- Very good agreement between RDSAR and J2

Good confidence in the RDSAR reference to calibrate SAR results.

<u>SWH:</u>

- Good LRM-RDSAR continuity but can be improved (delta at transition few cm)
- Good agreement between RDSAR and J2

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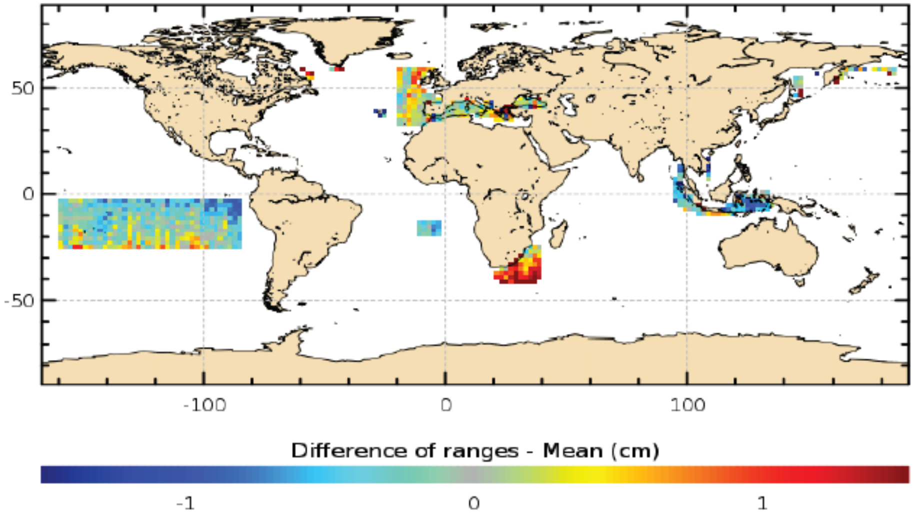
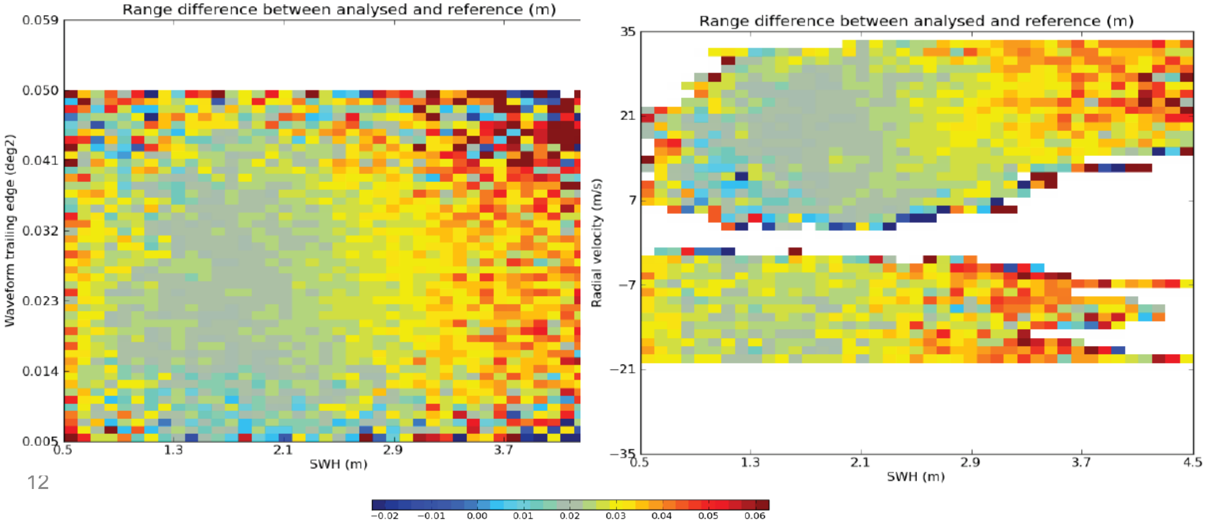
CryoSat Processing Prototype:
SAR results over 3 months (May-July 2013)

<u>SAR-RDSAR differences analysis:</u>



Sea Level Anomalies:

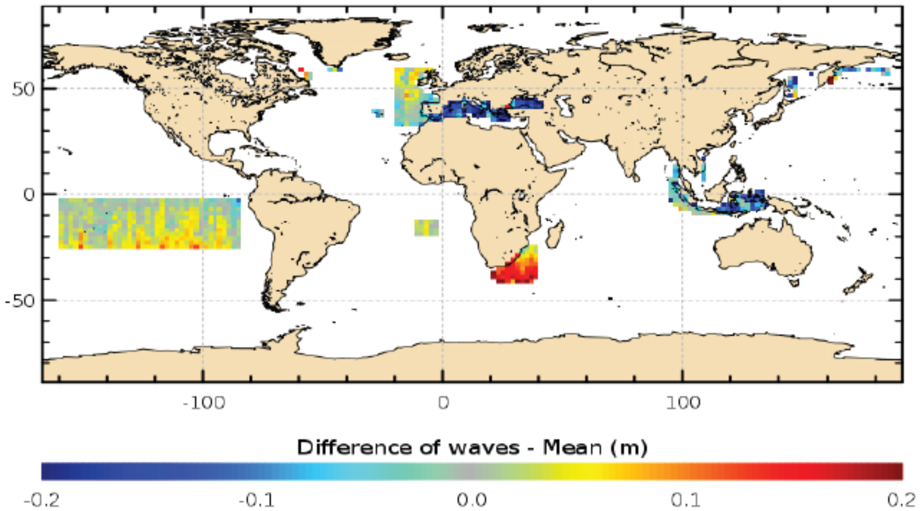
- About 3 cm mean bias between SAR and RDSAR
- **<u>But very low differences amplitude (+/- 1,5 cm)</u>**



- No radial velocity dependency
- No mispointing dependency
- **0,5% SWH dependency**

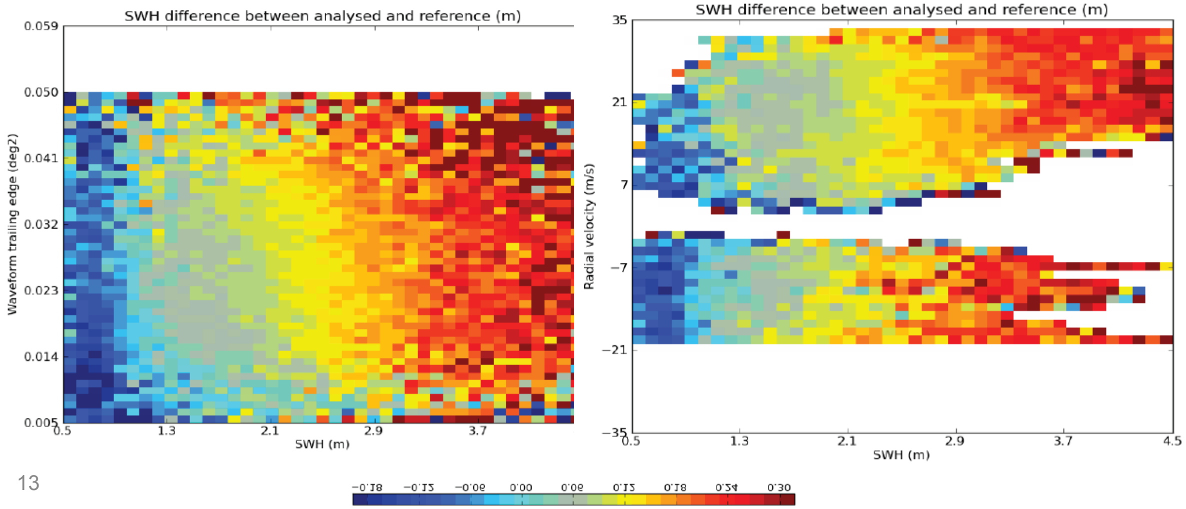
CryoSat Processing Prototype:
SAR results over 3 months (May-July 2013)

<u>SAR-RDSAR differences analysis:</u>



SWH:

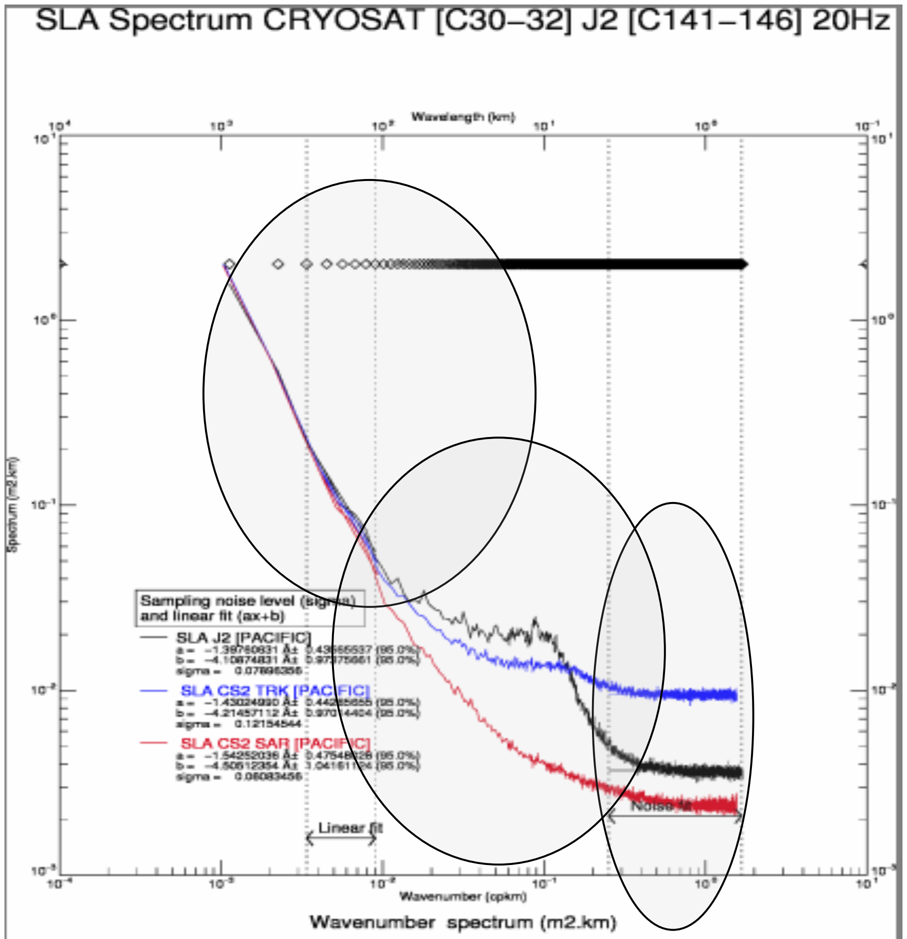
- Very low mean bias between SAR and RDSAR (2 cm)
- Differences amplitude = +/- 20 cm



- No radial velocity dependency
- Low mispointing dependency
- **5-10% SWH dependency**

CryoSat Processing Prototype:
SAR results over 3 months (May-July 2013)

<u>SLA SPECTRAL ANALYSIS:</u>



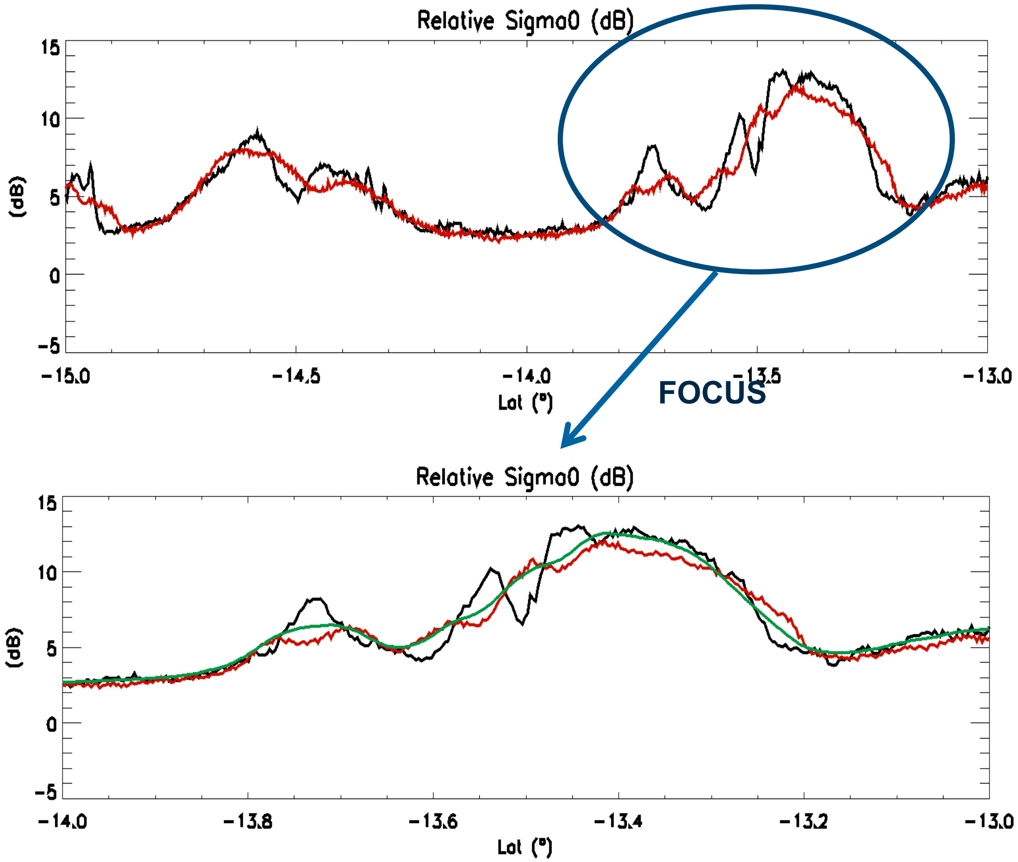
- All spectra are superimposed for wavelength larger than 100 km. SARM processing is not affected by any error in the medium/large mesoscale band.
- A white noise plateau is visible on all spectra for wavelengths ranging from 600 m to approximately 3 km. The blue spectrum (Cryosat, pseudo-LRM) is largely higher than Jason-2 (sqrt3 as expected) . The SAR spectrum (red) exhibits a white noise plateau lower than Jason-2's (by approximately 30%).
- For wavelengths ranging from 7 to 100 km: although the black (LRM) and blue (pseudo-LRM) spectra exhibit a spectral "bump", the red spectrum (SARM) does not

SARM provides with more trustworthy SLA dataset to observe scales ranging from 10 to 100km.

CryoSat Processing Prototype:
SAR results over 3 months

<u>SAR and RDSAR Sigma0:</u>

Relative Sigma0=10log(Pu) +30log (Alt) + 10log (Er + Alt)



- **SAR altimetry (black) measures small scales signal**, not seen by the conventional approch (red ie RDSAR)

- Green plot is the result of SAR sigma0 filtered at 20km.
- The SAR 20km-filtered sigma0 agrees with RDSAR.

→ **Small scales signals seem to be smoothed by the 20km disc shaped LRM footprint.**

CNES Cooperation

- **CryoSat Reprocessing Campaign and Pis cooperation:**
  - ✓ On-going CPP reprocessing of one year of CRYOSAT data from FBR products kindly delivered by ESA.
  - ✓ Global LRM/SAR/RDSAR coverage
  - ✓ Generation of NetCDF products following Jason-2 standard
  - ✓ Products are made available on a FTP server
  - ✓ Co-operation with Pis to get an independent assessment of CPP products over deep ocean, coastal areas and hydrology

- **Co-operation with LEGOS team**
  - ✓ To develop SAR processing adapted to coastal regions and in-land waters.
  - ✓ To develop new methods for ice.

- **Participation to the CP4O project with ESA:**
  - ✓ Cross comparison with other SAR/RDSAR techniques.

General studies and Jason-CS

General studies:

-**Swell impact on SAR performances:**

- First results presented during the CryoSat wokshop meeting

-**Sea State Bias for Doppler altimetry:**

- Planned to start in 2014

-**Small scales signal analysis:**

- Full explanation of the SLA spectral differences between SARM and LRM

-**Coastal and inland water doppler altimetry:**

- Collaboration with legos to developp adapted method

-**Level1B processing review:**

- How to better stack the SAR data?

For Jason-CS,

Our goal is to ensure a continuity with all previous developments/studies and to take the benefits of existing tools:

→ must be adapted to the interleaved mode

→ **specific attention to the RMC process and to the SAR ambiguities**

Conclusion

- **CryoSat Processing Prototype:**
  - Full processing chain for SAR, RDSAR and LRM

- **Data quality assessment of three months of CY data**:
  - LRM: same level of performances than Jason-2
  - RDSAR: good continuity with LRM
  - SARM:
    - SARM SLA noise is 30% lower than in LRM
    - SARM provides with more trustworthy SLA dataset to observe scales ranging from 10 to 100km and allows to measure small scale sigma0 signals.
    - Low SAR-RDSAR differences

- **Reprocessing campaign:**
  One year of LRM/SAR/RDSAR data soon available to Pis from FBR products kindly provided by ESA.

- **Jason-CS:**
  - **Plan for adapting our tools to the interleaved mode.**

Performances *Vs* Modes

Data Processing	Altimeter mode: LRM Mode	Altimeter mode: SAR Burst Mode	Altimeter mode: SAR Interleaved mode
LRM Processing	X (1.3 cm)	X RDSAR (2.2 cm)	X (1.3 cm *)
SAR Processing	N/A	X (0.8 cm)	X (0.5 cm)

Noise Measurement @2m @1s

* : Better noise vs conventionnal LRM for high SWH

	Pros	Cons
LRM	- Long lasting experience - Large Circular footprint - SSB solution available - Continuity with TP/JA1&2&3	- Long lasting experience … may mask a systematic error. - Individual PRF echoes not available - Noise level 1Hz ≠ Noise 20Hz - Weird Spectrum bump content for wave-lenghts 80-20 kms
SAR	- Reduced azimuth resolution: (300m x 10 kms) - Flexible ground processing – can be tuned depending on surface type and applications - Reduced noise level: 1 cm @1Hz (1.4 cm for LRM) – very interesting for a large set of applications (geophysics, mesoscale) - Trustworthy spectrum content for wave-lenghts 80-20 kms (to be confirmed with OSTST support)	- SAR geophysical assessment needs to be done - Pseudo_LRM has a degraded accuracy (2 cm) - Swell correlation ? Sensitivity to mispointing ? - SSB solution if the SAR mode is reduced to a sub set of the ocean ? - Low SWH not determined accurately today

	Pros	Cons
Interleaved	**LRM + SAR Advantages** **+** - LRM better than JA2 one's - Advanced SAR reduced noise level: **0.5 cm at 1Hz** - Simultaneously SAR and LRM to improve the data processing even for LRM.	**None**