Improved SAR-mode ocean retrievals from new Cryosat-2 processing schemes

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To perform these studies, we take benefits of the availability of Cryosat-2 data and the existing tools:

- the easy-to-use and versatile **L0 to L2 SAR CNES Cryosat-2 processor (CPP)**,
- the **SAR altimeter simulator** to generate SAR echo models that mimic the altimeter response of any configurations (without the need to modify any analytical model formulation and with no approximations)

**Objectives**:
- To improve the noise reduction performance
- To ensure data quality continuity with LRM while not degrading small-scales signal (<100km)
DATA ANALYSIS AND ALGORITHMS VALIDATION

CRYOSAT-2 DELAY-DOPPLER PROCESSING (L0/L1B)

SIMULATION AND ECHO MODEL GENERATION

ECHO PROCESSING (L2) FOR PARAMETER ESTIMATION

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DATA ANALYSIS AND ALGORITHMS VALIDATION
SAR-mode measurements consist of:

- Averaging of co-localised Doppler beams (looks) in the stack
  - SAR power echo (multilooked)
- Multilooked SAR echo power
- Range integrated power in the stack

RETRIEVAL OF SAR OCEAN PARAMETERS

- Model fitted with waveform
  - Range, swh and sigma0 estimation

- No-degraded performances with 100 looks (even lower if no-mispointing)
  - Similar 20-Hz noise levels
  - No SLA bias and reduced SWH bias with PLRM
  - Same oceanic signal content (from spectra analysis)
RETRIEVAL OF SAR OCEAN PARAMETERS

From the actual processing/retracking scheme, outer looks have no impact on SAR performances (notably range)

How to take advantage from these contributions?

- No-degraded performances with 100 looks (and lower if no-mispointing)
- Similar 20-Hz noise levels
- No SLA bias and reduced SWH bias with PLRM
- Same oceanic signal content (from spectra analysis)
• High inhomogeneity between Doppler beams in a stack
  ▪ Along-track variation in amplitude from beam to beam due to antenna gain
  ▪ Different mean shapes in range due to inaccurate migration corrections

• Expected speckle noise reduction:
  • $\sqrt{N}$ in conventional altimetry since individual echoes are quite similar in amplitude $\alpha_i=0$ and incoherently cumulated

\[
\frac{a}{\sqrt{v}} = \frac{\sqrt{N}}{\sqrt{1 + \frac{1}{N} \sum_{i=1}^{N} \left( \frac{\alpha_i}{a} \right)^2}}
\]

Effective number of looks is lower than the number of beams
NEW SARM PROCESSING METHOD
L.Amarouche, SAR Altimetry Expert Group Meeting, Southampton, June 2013

- Number of effective Doppler beams
  - High speckle reduction for samples whose beam-to-beam discrepancies are low
  - Low speckle reduction for large variation of echo amplitude
  - Lowest values in the leading edge for low swh
  - increased noise level while retracking Doppler echoes at low wave height

[Graph showing equivalent independent pulses vs SWH in a stack]
OPTIMISED SAR OCEAN NUMERICAL RETRACKING

- CPP retrieval algorithm (MLE3) is based on a Newton-Raphson iterative least squares method which uses partial numerical derivatives of the multilooked model to solve the system (as for Levenberg-Marquardt method)

\[ \theta_n = \theta_{n-1} - g(BB^T)^{-1}(BD)\theta_{n-1} \]

- Un-weighted least-square estimator gives more importance to samples of high amplitude (given by antenna gain) and constrains the echo model to fit mostly with those samples (from the centered Doppler beams)

- More weight has to be assigned to low power samples of the waveform to constrain the model to fit those portions that originate from outer beams (toe)
A weighted MLE3 retracking (aka Maximum-likehood estimator algorithm) gives more importance to portions of the waveform with low power

\[
B_{rk} = \frac{1}{P_u} \frac{\partial V_k}{\partial \theta_m} \\
D_k = \frac{V_k - \tilde{V}_k}{P_u}
\]

\[
B_{rk} = \frac{1}{V_k + \varepsilon} \frac{\partial V_k}{\partial \theta_m} \\
D_k = \frac{V_k - \tilde{V}_k}{V_k + \varepsilon}
\]

- **Analysis of 1-month Cryosat-2 data**
  - Higher bias for low \( \varepsilon \)
  - No significant bias for \( \varepsilon = \frac{1}{4} V_{\text{max}} \)
  - 20-Hz noise reduction \( (\varepsilon = \frac{1}{4} V_{\text{max}}) \)
    - SLA 10% (SWH @2m)
    - SWH 20% (SWH @2m)
    - Sigma0 25% (SWH @2m)
  - Same oceanic signal content (from spectra analysis)

\( \varepsilon \) positive constant to prevent instabilities and numerical convergence issues
\( k \) samples from 0 to 127
\( m \) parameters \((\tau, \text{swh}, P_u)\)
INDIVIDUAL DOPPLER BEAMS RETRACKER

- An alternative processing method will be analysed that would further improve SARM performances:
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- Then “average” their estimates $\theta_k$

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- Making all Doppler beams with equal contribution to the noise reduction
  - With no beams weighting (e.g., antenna pattern compensation, stack beam weighting)

- Enabling to assess the model consistency (checking any discrepancies between nadir/off-nadir look estimates)
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• Beams alignment before multilooking can be disrupted by inaccurate COR2 command (computed on-board)
  ➔ Tracker range alignment is not applied herein (only distance migration correction) mitigating possible errors
INDIVIDUAL DOPPLER BEAMS RETRACKER

- No valuable data for tracks perpendicular to the coast line at distance < 4-5km despite its high along-track resolution

To edit inconsistent looks (after along-track Hamming weighting) still contaminated by land / calm sea

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$$\theta = \frac{1}{L} \Sigma (\theta_k + \theta_{k+1} + \theta_{k+2} + \theta_{k+3})$$
CONCLUSIONS & PERSPECTIVES

• Different configurations of Doppler processing have been studied showing potential improvement of SAR-mode performances
  ➢ A theoretical study based on the assessment of the SAR-mode speckle noise have shown the critical aspects of the actual SAR-mode processing
  ➢ The weighted likelihood estimator (to account for contributions of off-nadir Doppler beams in estimation - better noise reduction)
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- Major interest for SAR-mode missions (S-3, S-6, ..)
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• Major interest for SAR-mode missions (S-3, S-6, ..)
• On-going investigations applied to S-3 data with CNES Processor
• The existing tools (Processing Prototype, simulator and validation tools) are also used to study ice regions and in-land waters in SAR mode