WP 4000 – Product Development and Validation

CPP SAR numerical retracker for oceans

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In preparation to the Sentinel-3 mission, CNES has developed the Cryosat Processing Prototype (CPP)** with the final objective:

- To develop and test SAR dedicated processing methods over ocean,
- To assess in-orbit performances of the SAR mode data over ocean (but also other surfaces types like inland water, coastal, …) and in the same manner the quality of the SAR altimeter processing method,
- To maintain data quality continuity between SAR mode and LRM,
- To provide an emulated LRM reference (aka Reduced SAR) for calibrating SAR altimeter results over identical sea state. To ease the comparison, SAR and RDSAR data are generated at the same along-track point location allowing both retrievals to be directly subtracted.

CPP RDSAR: SAR echoes simulator
1. **To assemble 4 x 64 pulses**
   Point position is defined at the nadir point location and time-tagged (time taken at the center of the 4 bursts)

2. **To correct the AGC**
   Amplitude correction are extracted from CAL1 and added to the on-board AGC to compensate echoes amplitude (common with SAR processing)

3. **To align the 4x64 pulses**
   - Undo the on-board alignment (dedicated to the tracking echo) that is not correcting shift inside bursts
   - Apply a finer shift to I,Q echoes using the precise radial velocity provided by the orbit ephemeris

4. **To generate RDSAR echoes**
   For each of the 4*64 echoes (I and Q) corrected for distance, $I^2+Q^2$ spectrum is derived. The 20 Hz RDSAR 128-points waveform is then computed by summing the 4*64 $I^2+Q^2$ waveforms.
5. **To compute the tracker ranges and correct it for the USO frequency shift**

First the tracker range is corrected for a distance corresponding to the radial satellite movement during half cycle duration. Additionally, an USO drift correction (due to ageing of the oscillator) is added to them.

6. **To apply the internal path correction**

The internal path delay correction that accounts for any range drift due to the offset of the RIR position is not applied (it is a bias, identical for each mode)

7. **To correct the tracker range for the Doppler correction**

caused by the Doppler shift in the line of sight to the nadir direction

8. **To correct the waveforms from LPF mask**

To correct the echo waveform from the thermal noise effects (a unique filter is employed for this purpose)
9. **To retrack 20-Hz RDSAR waveform**
   - To retrieve range, significant wave height, backscattering coefficient and mispointing angle, conventional. A 4-parameter conventional Brown ocean retracker (MLE4) is required for adequately fitting waveforms since the CryoSat-2 satellite exhibits unstable off-nadir mispointing angle in flight.
   - LUT corrections are applied to retrievals to account for notably the Gaussian approximation of the PTR in the retracking algorithm scheme

10. **To compute the backscatter coefficients**
    \[
    \sigma_0 = 30 \log_{10}(Orb) + 10 \log_{10}(R_{\text{earth}} + Orb) + 10 \log_{10}(Pu) + \text{constant}
    \]
    where \( Orb \) is the distance from satellite to ellipsoid

11. **To compute the SLA**
    \[
    \text{SLA} = Orb - \text{Range} - \sum C_i - MSS
    \]
    where \( C_i \) is the sum of all the corrections needed to take into account the atmospherically effects and the geophysical phenomena
CPP SAR: data and method overview

Equatorial Pacific SAR mode ocean test area
- low ocean variability (so easing the inter-mission calibration with conventional altimetry satellites),
- few occurrences of rain and sigma0 blooms events,
- mean SWH around 2 meters and mean wind around 7 meters (so the sea state is close to the mean conditions).

This site has been used for successfully validating the CPP reduced SAR data

Data used
- One subcycle of data (30-day duration) in May 2012: CPP SAR, CPP RDSAR

Metrics
To analyze the continuity at the LRM/SAR mode transition
- Along-track data on the pass 82 subcycle 30
- Comparison of averaged data per band of latitude
L2 PRODUCT VALIDATION

INPUTS

• WP2000 recommendations

• CNES/CLS database (L2 CPP SAR)

• CNES/CLS database (other EO satellite data and atmospherical/geophysical corrections)

WP4000
Analysis and validation of CPP SAR for open ocean

ATBD

Product validation report
CPP SAR: along a single track P082 C30

- Quite good agreement between SLA/SWH SAR and RDSAR with however a slight bias to determine

- Great similarity between SAR and RDSAR to capture same ocean structures

  ➔ CPP SAR method enables very consistent sigma0 retrieval

- SAR data are less noisy than RDSAR data as expected

- Mispointing angle processed at 0.1 Hz (from star tracker) is obviously less noisy than the 1 Hz RDSAR retrieved mispointing angle
CPP SAR: 1-Hz noise performance

For SWH=2m
- precision 1-Hz range:
  5.6 cm in SAR
  10.4 cm in RDSAR
- precision of 1 Hz SWH:
  41 cm in SAR
  64 cm in RDSAR

Lower 1Hz noise on SLA/SWH SAR than the RDSAR one as expected
10 tracks of data already show the good agreement between SAR and RDSAR processing for SLA, SWH and sigma0 data:

- **SLA**: slope 0.92
- **SWH**: slope 1.07
- **sigma0**: 0.98

Rather more difficult question to answer for the mispointing angle.
CPP SAR: Analysis bench of one subcycle of data

Geographical distribution of the range differences between RDSAR and SAR appear mostly correlated to waves

- bias of near 10 cm in waves
- bias of near 3 cm in range
CPP SAR: Dependencies

- Ranges dependency on SWH over the Pacific region
  ➔ Difference of ranges is about 0.5% SWH

- No apparent dependencies of the numerical SAR model wrt the across mispointing angle and the radial velocity
To assess the quality of the sea level spectrum at all spatial scales, the spectral analysis should be able:

- To detect noise level @ high frequency
- To identify correlated errors for scales between 10 and 80km
- To check consistency of the oceanic signal @ high wavelength

- The SAR data provide a noise level close to 5.5 cm at 20 Hz (the full altimetry resolution) whereas the precision of LRM altimeters is equal to 8-9 cm (and 11 cm with the CPP RDSAR method)
CPP RDSAR: map of data continuity

Good general agreement between LRM and RDSAR data over the region and notably at the transition between modes (only slight differences in mispointing angle appear)

→ Reduced SAR retrieval results are found to be very consistent with the ocean structure as observed by the LRM.
Conclusions and Perspectives

• The continuity assessment between LRM and RDSAR data shows in general a very good agreement at the transition, with no significant bias in SLA and SWH.

• The CPP reduced SAR L2 products are thus a good LRM-reference during SAR-mode maintaining the continuity with the LRM mode data and then allowing the assessment of the in-orbit performances of the SAR mode data.

• Known limitations and shortcomings of this method will be addressed and improved in future versions of the CPP products:
  – a data gap of 2.5 seconds occurs in the RDSAR data set at the transition between LRM and SAR mode, such impacting the full LRM/RDSAR continuity.
  – Appropriate look-up tables have to be computed to take into account the high RDSAR noise effects and correct the estimations (range, significant wave height, sigma0 and mispointing angle) issued from an ocean analytical retracking algorithm.

• CPP SAR/RDSAR products are now available on a CNES/CLS ftp server. Feedback from users of CryoSat-2 CPP products will help to consolidate the CPP processing.
WP4000: CNES/CLS Numerical SAR Retracker (1)

- Method consists in retrieving geophysical parameters by fitting the multi-looked waveforms with a numerical SAR ocean model
  - As for conventional altimetry, the estimated parameters are expressed as:
    \[ \theta_n = \theta_{n-1} - g (B^T B)_{n-1}^{-1} (BD)_{\theta_{n-1}} \]
    - \( \theta_n \): estimated parameter at iteration \( n \)
    - B,D: partial derivatives and residuals matrix
    - g: loop gain (between 0 and 1)
  - Partial derivatives of the mean return power are computed numerically wrt the retrieval parameters (e.g., range, SWH, ...) from model differencing
  - The finite-difference method involves a database of pre-computed echo models (generated off line by the simulator), that considers the sensitivity to parameter estimates such as along/ across-track mispointings, varying altitude and satellite velocity, ..
  - At each iteration \( n \), models using the current estimation vector \( \theta_{n-1} \) are directly taken from the database in the retracking schemes

- This method is currently implemented in CNES CPP processing chain. This solution is based on the use of fixed mispointing angles applied to the echo models (work is ongoing to investigate an improved solution based on varying mispointings)
- First results have been assessed through Cal/Val process and recently communicated at the “20-years of Progress in Radar Altimetry” symposium, Coastal Altimetry workshop and OSTST 2012 meeting. Analyses of sensitivities of this solution are still under study.
WP4000: CNES/CLS Numerical SAR Retracker (2)

• SAR mode L1B data generated by CNES CPP are used as inputs to SAR retracker. This is motivated by the following reasons:

1. ESA L1B SAR products have been changed early this year to improve the sea ice processing (the new IPF data processing includes over-sampling in range and truncation, and azimuth Hamming weighting). **These changes made are not applicable to the exploitation of ocean data** (since waves and mispointing angles estimation requires full samples in the trailing edge). Presently, only CPP SAR L1B data ensures open-ocean applications to be performed (contributing to preparations for a prototype Sentinel-3)

2. The CPP SAR and RDSAR measurements are collocated allowing direct differences

3. To keep consistency between the way the waveform models are computed for the database and the L1B processing scheme (same Delay/Doppler processing and stacking schemes)