A step towards the characterization of SAR Mode Altimetry Data over Inland Waters – SHAPE Project

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Context

The SHAPE project:

“Sentinel-3 Hydrologic Altimetry Processor prototype”

Funded by ESA through the SEOM Programme Element to prepare for the exploitation of Sentinel-3 data over the inland water domain, with Objectives:

• **Characterize available SAR mode data over inland water.**
• Assess the performances, in Hydrology, of applying the Sentinel-3 IPF to CryoSat-2 data and emulating repeat-orbit Alti-Hydro Products (AHP).
• Analyse weaknesses of the Sentinel-3 IPF at all levels.
• Assess the benefits of assimilating the SAR/RDSAR derived AHP into hydrological models.
• **Design innovative techniques to build and/or to refine the L1B-S and assess their impact onto L1B and AHP.**
• **Improve SAR/RDSAR retracking over river and lakes.**
• Provide improved L2 Corrections (tropospheric, geoid) for Sentinel-3 over land and inland water.
• Specify, prototype, test and validate the Sentinel-3 Innovative SAR Processing Chain for Inland Water.
**Context**

**Even with SAR mode, Alti-Hydrology is a difficult topic**

- Very wide variety of scenarios
- Wide across-track integration $\rightarrow$ loss of accuracy & precision.
- Off-NADIR hooking: tracker window not always centered at NADIR
- Space and time variability of the water area with:
  - low waters $\rightarrow$ contaminated waveforms due to sand banks ...
  - High waters $\rightarrow$ flooded areas sometimes (outside water masks)

**Questions**

- How to characterize Sentinel-3 waveforms over inland from CryoSat-2 data ?
- Is geodetic orbit an issue ?
Objectives

Look for specific features of SAR data over inland waters to be exploited @:
- Stack Masking → production of “decontaminated” Waveforms
- Retracking → provide context information for parameters tuning

SAR data is here:
- Individual Echoes from CryoSat-2 (FBR or L1A)
- Stacks or L1B-S
- SAR waveforms (and RDSAR)

Despite a huge variety of scenarios BUT this Characterization Exercise shall be: an automated (massive), Simple and quantitative classification of cases with the available auxiliary data:
- Water mask information
- Instrument footprints
- Lets try to classify from the Water Fraction
Method
**Method**

- Compute the **Intersection Area** of the Footprint and Water Mask
- WaterFraction = Intersection_Area / Instrument_Footprint_Area
- Define **N color coded classes** according to the Water Fraction:
  - Class 1: [0, 20] %
  - Class 2: [20, 40] %
  - Class 3: [40, 60] %
  - Class 4: [60, 80] %
  - Class 5: [80, 100] %
- **Statistics** (from beam behaviour param.) per class.
- **Mean Waveforms** per class.
- Analyse these results for classes with **equalized population**
Method

Beam Behaviour Parameters employed to characterize the Stacks via their across-track integration → **Range Integrated Power (RIP)** :

- **Mean STDEV** of the Gaussian PDF fitting the RIP (**1 per record**)
- **Mean Centre** of the Gaussian PDF fitting the RIP (**1 per record**)
- **Scaled Amplitude** : amplitude scaled in dB/100 (**1 per record**)
- **Skewness** : asymmetry of the stack RIP distribution (**1 per record**)
- **Kurtosis** : peackiness of the stack RIP distribution (**1 per record**)
Method

Beam-Doppler footprint (eq. From CryoSat-2 handbook)

Across-track beam size

\[ D = h \cdot \tan(\theta_B + \theta/2) - h \cdot \tan(\theta_B - \theta/2) \]

- \( \theta \) the antenna beam width at -3 dB,
- \( \theta_B \) the angle of the central beam

Along-track beam size

\[ \Delta x = \frac{h \cdot \lambda}{2 \cdot v \cdot 64} \cdot \text{PRF} \]
Experiment Set-Up
Experiment Set-Up

- CryoSat-2 L1-B **Baseline C** data over **Amazon**
- Time Period: The whole year 2014
  - 280 L1B files (319523 records)
- Variable Instrument parameters read in the L1-B files
  - Satellite velocity
  - Tracker range
  - Latitude, longitude of the records
- Fixed Instrument Parameters:
  - Bandwidth
  - PRF
  - Antenna dimensions
  - Carrier frequency
- Auxiliary data: old SWBD water masks covering Amazon
Results
Results

Raw data selection: 319523 records, smallest 3200 records
Histogram Equalisation (random data selection): 2000 records/class
Results

Histogram Equalisation (random data selection) : ±3200 records/class

![Histogram of the Water Fractions](image)

for cryosat2.esa.1b.C : 'ratio_water_pix_in_DF'
Results

Mean Waveforms in Watt (linear scale)
Results

Mean Waveforms in Watt (linear scale) (Zoom)
Results

Mean Waveform for class 1 - Water fraction: 0 - 20 %
Results

Mean Waveform for class 3 - Water fraction: 40 - 60%
Results

Mean Waveform for class 4 - Water fraction: 60 - 80%
Results

Mean Waveform for class 5 - Water fraction: 80 - 120 %

Bin number

Mean Waveform

1e-11
Results

Log scaled Mean Waveform (Blue) in Watt for Class 1

![Graph showing Log scaled Mean Waveform for Class 1](image-url)
Results

Log scaled Mean Waveform (Blue) in Watt for Class 2

Mean Waveform for class 2 - Water fraction : 20 - 40 %
Results

Log scaled Mean Waveform (Blue) in Watt for Class 3
Results

Log scaled Mean Waveform (Blue) in Watt for Class 4
Results

Log scaled Mean Waveform (Blue) in Watt for Class 5
Results

Log scaled Mean Waveform (Blue) in Watt for WFR=100%
Results

Log scaled Mean Waveform (Blue) in Watt for WFR=0%

Mean Waveform for water fraction class 1
Results

Huge variety of waveforms within classes (class 1 here)
Results

Huge variety of cases within class 1
Results

Huge variety of cases within class 2
Results

Huge variety of cases within class 3
Results

Huge variety of cases within class 4
Results

**Less variety** of cases within class 5
Results
Results

RIP STDEV vs (RIP Kursosis, Water Fraction)
Results

RIP STDEV vs (RIP Skewness, Water Fraction)
Results

RIP Skewness vs RIP (Kurtosis, Water Fraction)
Results

- Overview: all classes are quite heterogeneous but some statistical trends can be detected:

- **High Water Fraction** classes:
  - STDEV often **High**, Kurtosis often **Low**: along-track angular distribution of backscattered power varies smoothly from beam to beam (azimuth look angle) but
    - CAUTION: RIP peackiness (along-track) is not not linked to waveforms peakiness (across-track).
    - Skewness (asymmetry) is often **Low**: The High Water Fraction class offers a more symmetric power response as a function of the azimuth look angle than others

- **Intermediate Water Fraction** classes:
  - wide span of both STDEV and Kurtosis:
    (wide variety of angular responses) ← ? → (wide variety of water body sizes, locations and roughness).
  - wide span of Skewness: probably for the same reasons.

Cases with assymetric backscattered power ← ? → cases with side lobes contamination.

- **Low Water Fraction** cases:
  - Difficult to interprete since the NO WATER case seems to dominate the class and it encompasses a big variety of targets and backscattering properties. This pushes to add the 0% class.
Results

RIP Centre vs RIP(STDEV, Kurtosis) for ALL classes
Results

RIP Centre vs RIP(STDEV, Kurtosis) for **class 1** view 1
Results

RIP Centre vs RIP(STDEV, Kurtosis) for **class 1** view 2
Results

RIP Centre vs RIP(STDEV, Kurtosis) for class 2 view 1
Results

RIP Centre vs RIP(STDEV, Kurtosis) for class 2 view 2
Results

RIP Centre vs RIP(STDEV, Kurtosis) for **class 3** view 1
Results

RIP Centre vs RIP(STDEV, Kurtosis) for class 3 view 2

3D Space-Time Sampling for cryosat2.esa.l1b.C : 'stack_centre' for class 3
Results

RIP Centre vs RIP(STDEV, Kurtosis) for class 4 view 1
Results

RIP Centre vs RIP(STDEV, Kurtosis) for class 4 view 2
Results

RIP Centre vs RIP(STDEV, Kurtosis) for **class 5** view 1
Results

RIP Centre vs RIP(STDEV, Kurtosis) for **class 5** view 2
Results

RIP Centre vs (Kurtosis, Water Fraction)

3D Space-Time Sampling for cryosat2.esa.l1b.C : 'stack_centre'
Results

RIP Skewness vs RIP(Kurtosis, STDEV) for ALL classes
Results

RIP Skewness vs RIP(Kurtosis, STDEV) for **class 1** view 1

3D Space-Time Sampling for cryosat2.esa.l1b.c : ‘stack_skewness’ for class 1
Results

RIP Skewness vs RIP(Kurtosis, STDEV) for class 1 view 2

3D Space-Time Sampling for cryosat2.esa.l1b.C : ‘stack_skewness’ for class 1
Results

RIP Skewness vs RIP(Kurtosis, STDEV) for class 2 view 1

3D Space-Time Sampling for cryosat2.esa.l1b.C : ‘stack_skewness’ for class 2
Results

RIP Skewness vs RIP(Kurtosis, STDEV) for **class 2** view 2

3D Space-Time Sampling for cryosat2.esa.l1b.C : 'stack_skewness' for class 2
Results

RIP Skewness vs RIP(Kurtosis, STDEV) for class 3 view 1
Results

RIP Skewness vs RIP(Kurtosis, STDEV) for class 3 view 2
Results

RIP Skewness vs RIP(Kurtosis, STDEV) for class 4 view 1
Results

RIP Skewness vs RIP(Kurtosis, STDEV) for class 4 view 2
Results

RIP Skewness vs RIP(Kurtosis, STDEV) for **class 5** view 1
Results

RIP Skewness vs RIP(Kurtosis, STDEV) for class 5 view 2
Conclusions
Conclusions

• As expected: Mean Waveforms vary from very chaotic at Low Water Fraction to very smooth at High Water Fraction (ocean like).

• Water Classes are quite heterogeneous and trends are not sharp.

• High Water Fraction classes exhibit smooth and symmetrical along-track angular responses.

• Intermediate Water Fraction classes: wide span of both STDEV, Kurtosis and skewness (Stacks are statistically more peaky and asymmetric in the along-track direction).

• Skewness, Kurtosis and Standard Dev of the RIP seems to be inter-dependent parameters, nevertheless they could help estimate the water Water Fraction classes as a self standing method from the altimetry data only (flagging).
Next Steps?

- Strange jumps found in Baseline-C L1B data could be related to the changes in the platform attitude processing in this baseline. Redo same exercise over Baseline-B and compare the rough results with those of the Baseline-C then decide to keep going or not with baseline-C.
- Extend the Scaled Amplitude to Watt conversion to the RIP.
- Analyse the diversity of Waveforms in each class.
- Repeat the exercise with updated water masks & Use platform attitude for an improved footprint placement.
- Compute Antenna Gain weighted Water Fraction instead of Water Fraction.
- More editing: use products quality flags
- Seasonal Climatologies to better understand the Relationships between parameters within a Water Fraction Class
- Refine the Analysis with using the Pulse-Doppler Footprint as well and discriminate when water at NADIR.
- Repeat the whole analysis for the full STACKS instead of the RIP.
THANK YOU FOR YOUR ATTENTION