# SAR altimetry over the ocean and the coastal zone: the new frontier

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## Motivation & Approach

Validation of Cryosat-2 Level 2 SAR took place in the context of the ESA STSE CryosatPlus for Oceans project (CP4O) to inter-compare Cryosat-2 Level 2 SAR geophysical quantities for different Level 2 SAR processing choices, and assess their validity against independent measurements from in situ sources and other satellites.

All L1B and L2 products used here were provided to the CP4O team by ESRIN and CNES.

The performance of different SAR L2 retracking methods were inter-compared by applying them to the same set of Cryosat-2 L1B SAR waveforms. For the most part, analyses focused on results obtained by retracking Cryosat-2 L1B waveforms from the CNES Cryosat Prototype Products (aka "CPP"). In this study, CNES CPP products were used in preference to Cryosat-2 operational products from ESA which are optimised for sea ice applications at the detriment of performance of SAR mode over water surfaces.

## Cryosat-2 SAR L1B and L2 datasets

The inter-comparison experiment focussed mainly on CNES Cryosat Prototype Products (aka "CPP") generated and distributed by CNES to other partners in CP4O.

The CPP dataset consisted of all Cryosat-2 data available in July 2012 and January 2013 in two regions: the Eastern North-Atlantic region (NAE) and the Central Pacific (PAC).

The results presented here relates solely to the CPP data in the NAE region, where in situ data are available for independent validation, both in the open ocean and in the coastal zone.

## An inter-comparison of SAR altimetry retracking methods with Cryosat-2 SAR data

This table summarises the different SAR altimeter L2 processing choices examined in the inter-comparison experiment performed during CP4O.

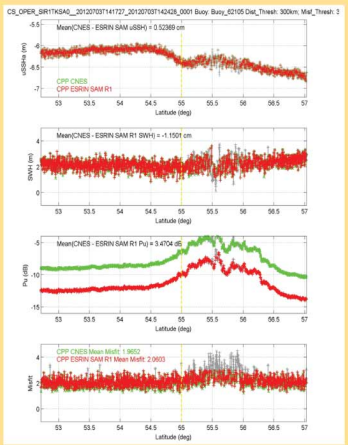
| Run reference | Cryosat-2 L1B product | SAR waveform model | Alpha_p LUT applied [2] | Peel effect applied [2] | Comment |
|---|---|---|---|---|---|
| CNES | CPP | Numerical retracker | N/A | N/A | N/A |
| ESRIN R1 | CPP | SAMOSA2 | Yes | Yes | Full SAMOSA model with Gaussian waves statistics [1] |
| ESRIN R3 | CPP | SAMOSA3 | Yes | Yes | Approximation of full SAMOSA model, omitting f1 |
| ESRIN R4 | CPP | SAMOSA3 | Yes | No | Sentinel-3 DPM baseline with inclusion of Gaussian PTR LUT correction |
| ESRIN R6 | CPP | SAMOSA3 | No | No | Sentinel-3 DPM baseline |
| ESRIN R5 | ESRIN FBR | SAMOSA2 | Yes | Yes | Same as ESRIN R1 but for different L1B |

The main points of interest are the comparisons of:

- CNES and R1: to compare SAR L2 retrieval with the SAMOSA SAR waveform model and the CNES numerical SAR retracker
- R1 and R3: to assess the impact of the SAMOSA3 approximation compared to the full SAMOSA2 model
- R1 and R5: to examine possible effects at L2 of differences in L1B waveforms

In R4 and R6, the L2 SAR retracking was not tailored to account for processing choices applied to L1B waveforms.

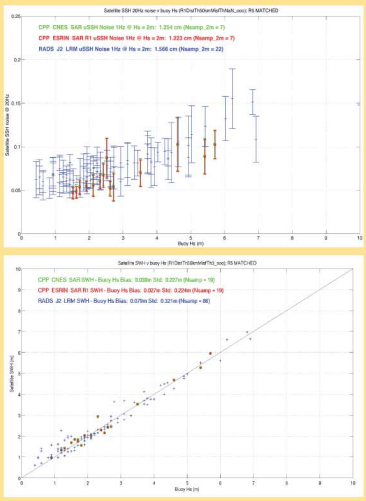
## An example of Cryosat-2 SAR L2 results with two SAR retrackers




The figure left shows L2 SAR results obtained with the SAMOSA retracker and the CNES retracker for a 50km data segment located off the West coast of Ireland. L2 quantities shown are (top to bottom): uncorrected Sea Surface Height (uSSH), Significant Wave Height (SWH), received Power (Pu, linked to the backscatter coefficient) and Misfit (i.e. mean square distance between the SAR L1B waveforms and the fitted model).

With the exception of the constant offset in Pu (linked to calibration), the agreement between the two SAR retrackers is remarkable.

## L2 SAR inter-comparison results over the open ocean

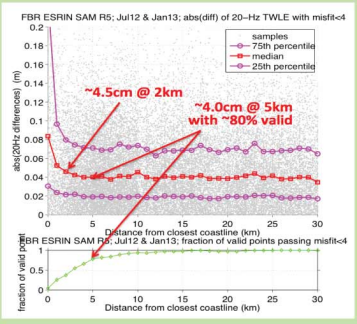


Analyses considered Cryosat-2 SAR 20Hz noise on uSSH and SWH as a function of buoy Hs (left, top) and L2 SWH against buoy Hs (left, bottom). Results are shown only for Cryosat-2 data during July 2012 and January 2013 obtained within 50km and 1 hour of buoys in open ocean around the UK.

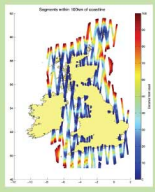
The table below summarises the results obtained with all L2 retrackers for 1Hz noise @ 2m significant wave height and the bias and scatter of Cryosat-2 L2 SWH against buoy Hs.

| Run reference | 1Hz Noise @ 2m | | SWH v buoy Hs | |
|---|---|---|---|---|
| | SSH (cm) | SWH (cm) | Bias (cm) | Std (cm) |
| CNES | 1.254 | 8.74 | 6.3 | 22.8 |
| ESRIN R1 | 1.223 | 8.62 | 5.1 | 22.5 |
| ESRIN R3 | 1.246 | 8.58 | 5.0 | 22.5 |
| ESRIN R4 | 1.246 | 8.52 | -15.8 | 22.2 |
| ESRIN R6 | 1.250 | 9.25 | -10.9 | 25.4 |
| ESRIN R5 | 1.218 | 8.42 | 5.2 | 22.7 |
| Jason-2 | 1.566 | 11.09 | 7.9 | 32.1 |

## 20Hz noise in the coastal zone




The figure (left) shows 20Hz noise on Total Water Level Envelope (TWLE) for Cryosat-2 SAR data around the UK, as a function of distance to the closest coast (shown in figure below). TWLE is the sea level inclusive of tides and pressure/wind effects.



## Conclusions

- L2 SAR retrackers based on the **SAMOSA analytical model [1] and the CNES numerical model give equivalent results.**
- Results with **SAMOSA3 (R3) and the full SAMOSA model (R1) show only marginal differences.**
- R4 and R6 show larger discrepancies, particularly against buoy SWH, confirming the **importance of accounting for L1B processing in the L2 SAR retracker.**
- There is **no significant bias between Cryosat-2 SAR SWH and wave buoys in the open ocean.**
- Analyses confirm the reduction in 1Hz noise for Cryosat-2 SAR SSH and SWH in the open ocean compared to pulse-limited Jason-2 altimetry (**SSH SAR ~1.25 cm against LRM ~1.57 cm; SWH SAR: 5.2 cm against LRM ~8 c; all for Hs = 2m**)
- Cryosat-2 SAR waveforms are generally **well-behaved in the coastal zone**
- In the coastal zone, 20Hz noise levels on Total Water Level Envelope is **4.5cm @5km from the nearest coast**, improving with misfit screening to **4.0cm @5km and ~80% valid points** or **4.5cm@2-3km with 40-50% valid points.**

## References

[1] Ray, C., C. Martin-Puig, M. P. clarizia, G. Ruffini, S. Dinardo, C. Gommenginger and J. Benveniste, SAR Altimeter Backscattered Waveform Model, IEEE Trans. GeoSci. And Rem. Sens., Vol. 53, Iss. 2., pp 911 – 919, 2014. DOI: 10.1109/TGRS.2014.2330423.

[2] Dinardo, S. and J. Benveniste, Guidelines for the SAR (Delay-Doppler) L1b Processing, ESA XCRY-GSEG-EOPS-TN-14-0042, Is. 2.3, 29/05/2013. https://wiki.services.eoportal.org/tiki- download_wiki_attachment.php?attId=2540

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