Improved Oceanographic Measurements from SAR Altimetry: Results and Scientific Roadmap from the ESA Cryosat Plus for Oceans Project

Benveniste, J.[1], Cotton, D.[2], Egido, A.[3], Nilo-Garcia, P.[4], Roca, M.[4], Gommenginger, C.[5] Cipollini, P.[5], Naeije, M.[6], Moreau, T.[7], Picot, N.[8], Fernandes, M.J.[9], Anderson, O.[10], Stenseng, L.[10], Cancet, M.[11], Dinardo, S.[12], Lucas, B.[13]

(1) ESA, (2) SatOC , (3) Starlab, (4) isardSAT, (5) NOC, (6) TU Delft, (7) CLS,

(8) CNES, (9) Porto University, (10) DTU, (11) Noveltis, (12) ESA, Serco, (13) ESA, Deimos

BACKGROUND

- ESA's CryoSat-2 mission is the first to carry a radar altimeter that can operate in SAR mode (delay-Doppler).
- Although the primary aim is land and marine ice monitoring, the SAR mode capability of the Cryosat-2 SIRAL altimeter also offers potential benefits for ocean applications, particularly in the coastal zone;
- The "**Cryosat Plus for Oceans**" (**CP4O**) project was dedicated to the exploitation of Cryosat-2 data over the open and coastal ocean.
- CP4O was supported by the ESA Support to Science Element (STSE) Programme and CNES, and brought together an expert European consortium, led by SatOC (UK).

CP4O Objectives and sub-themes

The general objectives of the CP4O project were:

• To build a sound scientific basis for new scientific and operational applications of Cryosat-2 data over the open ocean, polar ocean, coastal seas and for sea-floor mapping.

• To generate and evaluate new methods and products that will enable the full exploitation of the capabilities of the Cryosat-2 SIRAL altimeter, and extend their application beyond the initial mission objectives.

• To ensure that the scientific return of the Cryosat-2 mission is maximised.

The specific themes that will be addressed by the project are:

1) Open Ocean Altimetry;
2) High Resolution Coastal Zone Altimetry;
3) High Resolution Polar Ocean Altimetry;
4) High Resolution Sea-Floor Bathymetry.

NEW PRODUCTS DEVELOPMENT AND VALIDATION

The core of the Cryosat Plus for Oceans project was the development and validation of algorithms and processing schemes for new ocean products, based on Cryosat-2 data. 7 new experimental altimeter data sets and 3 new geophysical correction data sets were created, and are listed below

New Experimental Altimeter Data Sets

1. LRM for Open Ocean (TUDelft)
2. SAR for Open Ocean (Starlab, CLS)
3. SAR for Sea Floor Mapping (DTU Space)
4. SAR for Coastal Ocean (NOC)
5. SAR for Polar Ocean (DTU Space)
6. RDSAR for Open Ocean (CLS, TU Delft)
7. SARIn for Coastal Ocean (isardSAT)

Improved Geophysical Corrections:

1. Wet troposphere (U Porto)
2. Ionosphere (Noveltis)
3. Regional tide model (Noveltis)

Algorithm Theoretical Basis Documents and **Product Validation Reports** are available for each of these products.

Open Ocean RDSAR and SAR

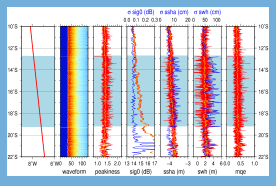


Figure 1: Time series of LRM – RDSAR- LRM data near St Helena in the South Atlantic, demonstrating consistency across the products. The blue sector represents the RDSAR coverage, the white LRM. *Credits* TU Delft

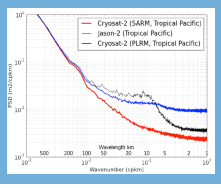
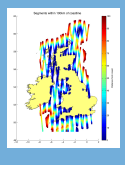


Figure 2: SAR mode (red) can resolve scales from 10-100km, not observable by conventional altimetry (Jason-2: Black, Cryosat-2 "Pseudo" LRM: blue) *Credits:* CNES/CLS

Coastal Ocean SAR and SARIN



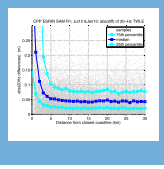


Figure 3: Cryosat-2 data provides measurements close to the coast (left panel), and maintains accuracy to within 5km (right), a significant improvement on previous missions. *Credits* NOC

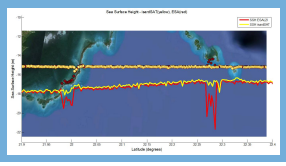


Figure 4: Examples of SARIN data during coastal transitions. Reprocessing (yellow) can correct the initially processed data (red) which selects reflections from bright targets away from the sub-satellite track. *Credits:* isardSAT

Polar Ocean SAR

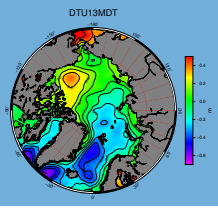


Figure 5: Cryosat-2 data provide important improvements to maps of Mean Dynamic Topography for the Arctic Ocean, and so support analysis of key ocean circulation features. *Credits* DTU Space

SAR for Sea Floor Mapping

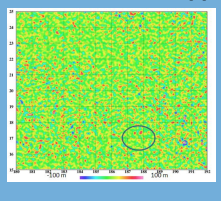


Figure 6: The retrieved residual bathymetry signal relative to a "pre" Cryosat-2 era bathymetry (DTU10 Bathymetry). There are some clear indications in the marked circle of a bathymetric/ tectonic feature that could be an improved mapping of an existing seamount or a mapping of an unknown sea mount.. *Credits* DTU Space

Improved Geophysical Corrections

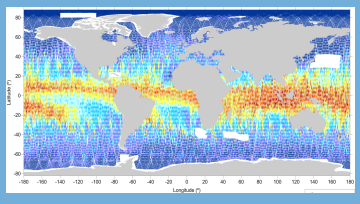


Figure 7 Wet Troposphere Correction from Dcomb algorithm estiamted for CryoSat-2 sub-cycle 35, using data from GNSS stations, MWR satellite data and the ERA interim model . *Credits* University of Porto

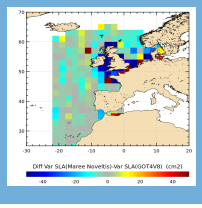


Figure 8: Regional Ride Model: Improvement in SLA variance (cm^2) between COMAPI (tide model used in CP4O) and GOT4.8 tidal model. *Credits* CLS.

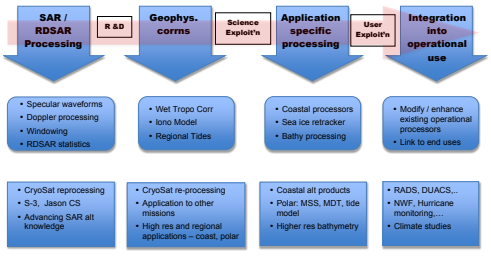
IMPACT ASSESSMENT

CLS carried out independent assessments of the demonstration data sets. Key findings were:

- o RDSAR: It was confirmed that the two schemes (TU Delft RADS, and CNES/CLS CPP) provided continuity across the transition from LRM to SAR mode, though some small discrepancies remained between ascending and descending tracks. Analysis of a longer data set is recommended to provide improved statistics and to identify any possible drifts
- o SAR: Agreement between the full implementation of the SAMOSA echo model and the numerical model in CPP is near perfect with both well suited to derive very accurate and precise SAR altimeter measurements. Modifications to correct errors at low SWH in a simplified (but more computationally efficient) version of SAMOSA are planned.
- o Geophysical Corrections: The new U Porto Wet Troposphere correction shows an appreciable improvement over the currently available model. The COMAPI regional tide model provides an improvement on North-Western European shelf at scales of 50-200 km. No improvement could be detected through the use of the new ionosphere model, but the area studied (Europe) is not the most dynamic region.

SCIENTIFIC ROAD MAP

Finally, the results of the Impact Assessment have been used to define an agreed **Scientific Roadmap** to ensure fullest possible exploitation of Cryosat-2 data over the oceans, and to support the transfer the results into scientific and operational activities.



CONCLUSIONS

CP4O has demonstrated that CryoSat-2 data provide users with significantly improved measurements over the ocean, and has developed and evaluated a series of demonstration products intended to exploit this capability. This work has required some in-depth studies and innovative technical developments, helping to build a better technical understanding of SAR altimetry over the oceans. Recommendations for further work and exploitation have been provided in a Scientific Road Map.