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

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BACKGROUND

- 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 by CNES

The objectives of CP4O 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.
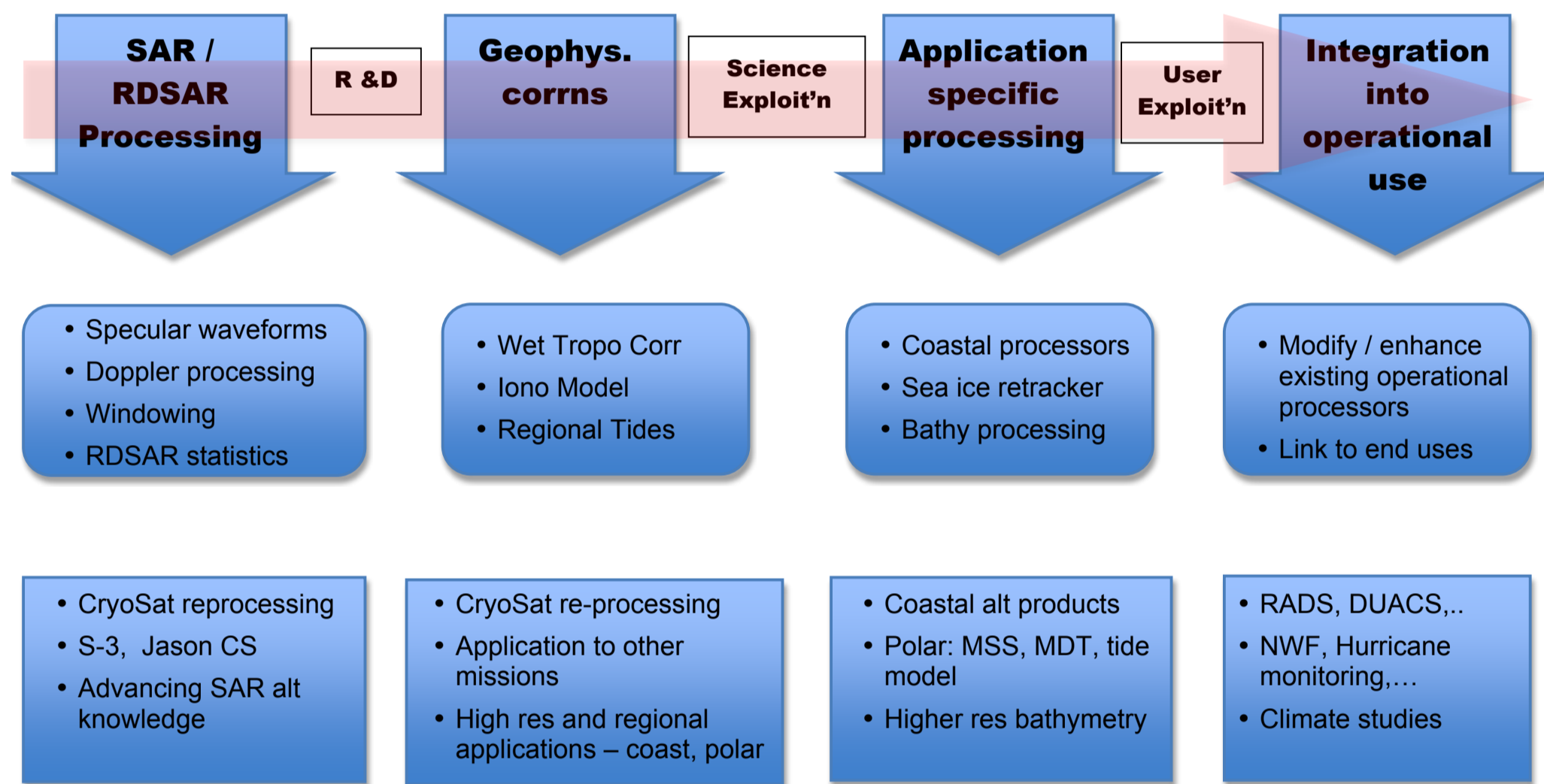- To ensure that the scientific return of the CryoSat-2 mission is maximised.

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 accurate SAR altimeter measurements.

o Geophysical Corrections: The U Porto Wet Troposphere correction showed an 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

The results of the project were used to define an agreed **Scientific Roadmap** to support the transfer the results into scientific and operational activities.

CP4O CCN1

Additional work was supported under a CCN, under the themes:

1. SIRAL coastal processing
2. A new Arctic Tidal Atlas using CryoSat-2 data
3. Improved estimates of thermal noise in the SAMOSA echo model
4. An extended evaluation of CryoSat-2 SAR mode data in the coastal zone

SIRAL Coastal Processing

An improved coastal processing scheme was developed and tested for SARIN mode over the Cuban Coast

The approach that was developed analysed **window delay, and fitted a smoothed model** to avoid jumps. This was used to **identify the ocean surface tracking point, truncate waveform** and re-track. This approach can also be used in SAR mode and LRM data.

Analysis of one full year of data demonstrated isardSAT retrievals were much less noisy than ESA standard product, giving a 60% improvement in performance in terms of reduction of SSH Standard Deviation.

New Arctic Tidal Atlas

DTU Space
National Space Institute

The Arctic Ocean is a challenging region for tidal modelling. The accuracy of the global tidal models decreases by several cm in the Polar Regions, impacting on the quality of the satellite altimeter sea surface heights and the altimetry-derived products.

NOVELTIS and DTU Space developed a regional, high-resolution tidal atlas in the Arctic Ocean. In particular, this atlas benefits from the assimilation of Envisat data up to 82°N and CryoSat-2 data between 82°N and 88°N. The combination of these satellite altimetry missions gives the best possible coverage of altimetry-derived tidal constituents. The available tide gauge data were also used for data assimilation and validation.

A key development was the application of a high resolution unstructured mesh for the underlying hydrodynamic model.

This work is being continued under a further CCN

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 at www.satoc.eu/projects/CP4O.
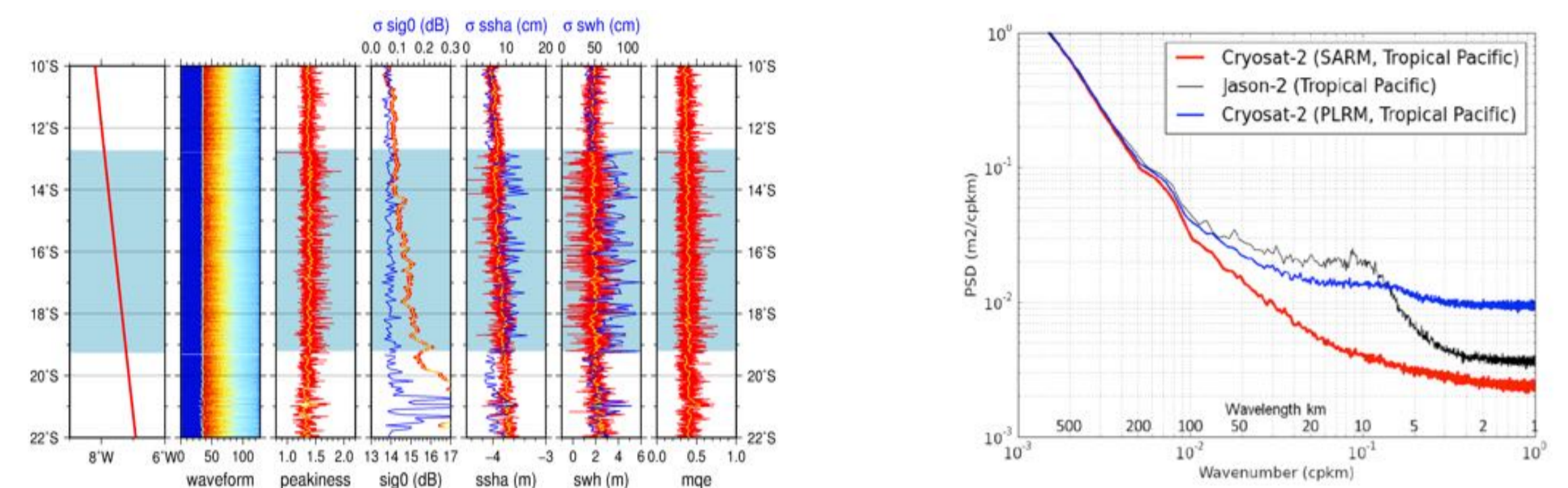
Open Ocean RDSAR and SAR

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
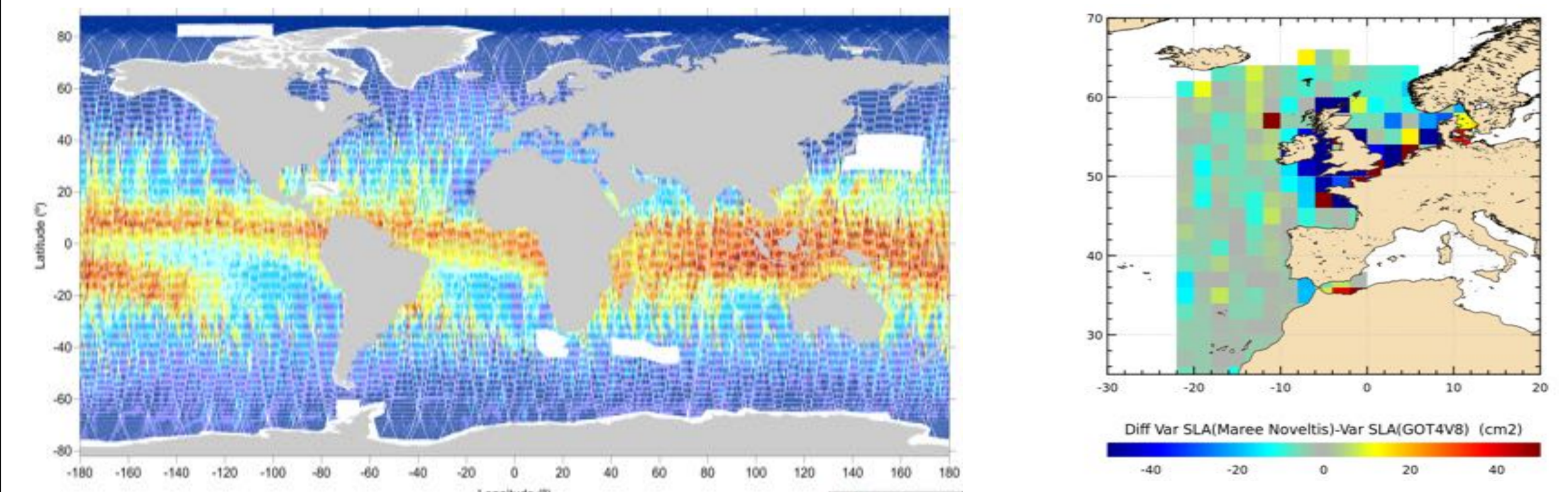
Improved Geophysical Corrections

Figure 3 Wet Troposphere Correction from Dcomb algorithm estimated for CryoSat-2 sub-cycle 35, using data from GNSS stations, MWR satellite data and the ERA interim model. *Credits* University of Porto

Figure 4: Regional Tide Model: Improvement in SLA variance (cm^2) between COMAPI (tide model used in CP4O) and GOT4.8 tidal model. *Credits* CLS.
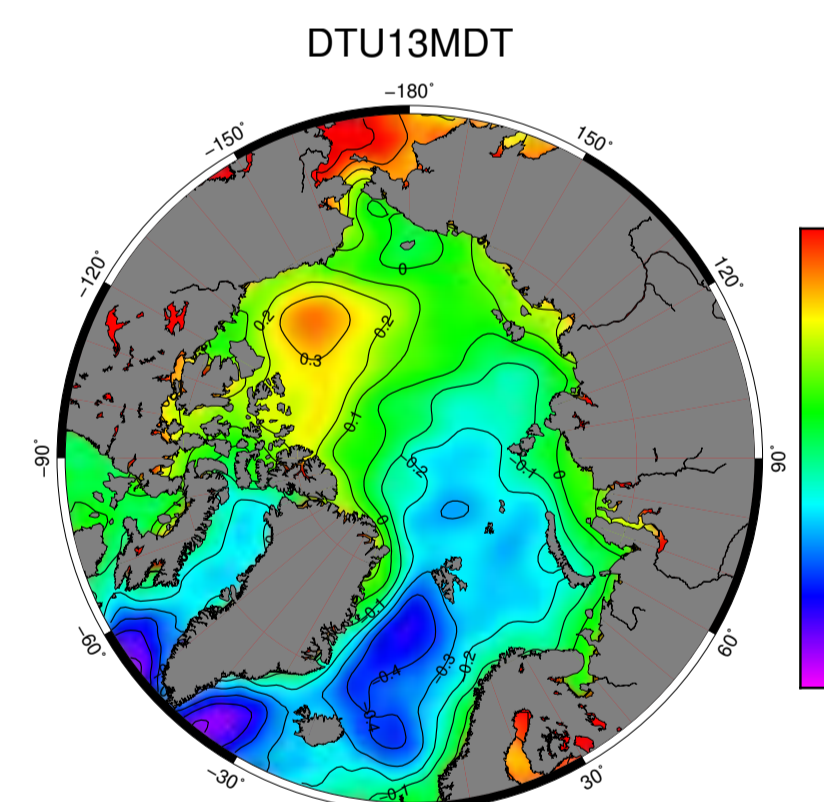
Polar Ocean SAR

DTU13MDT

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
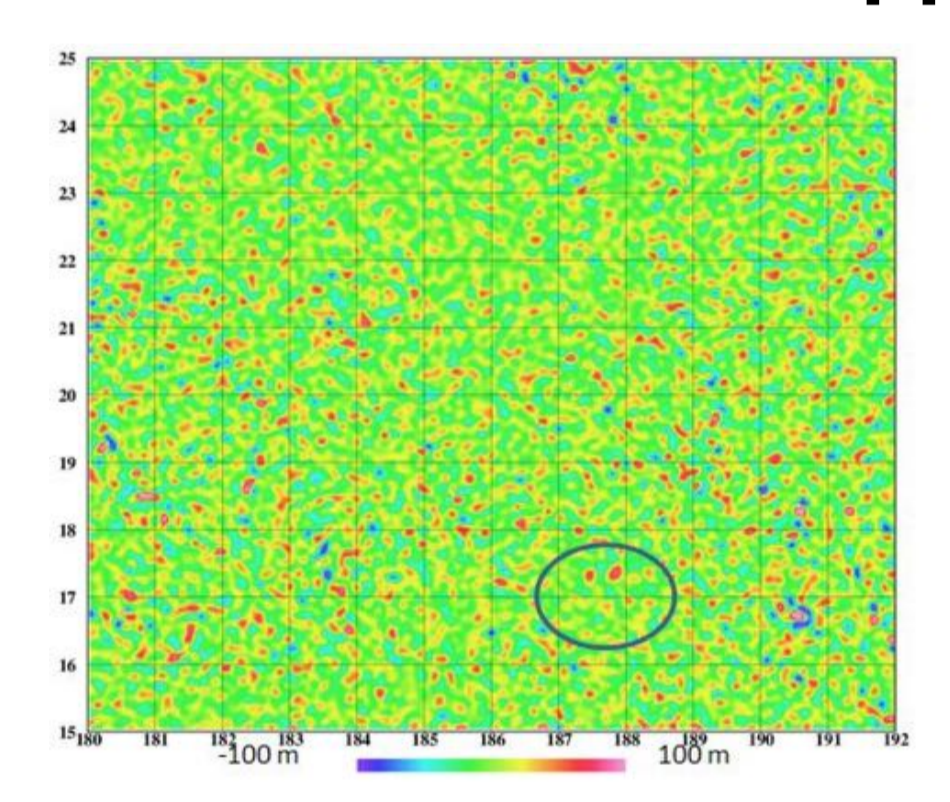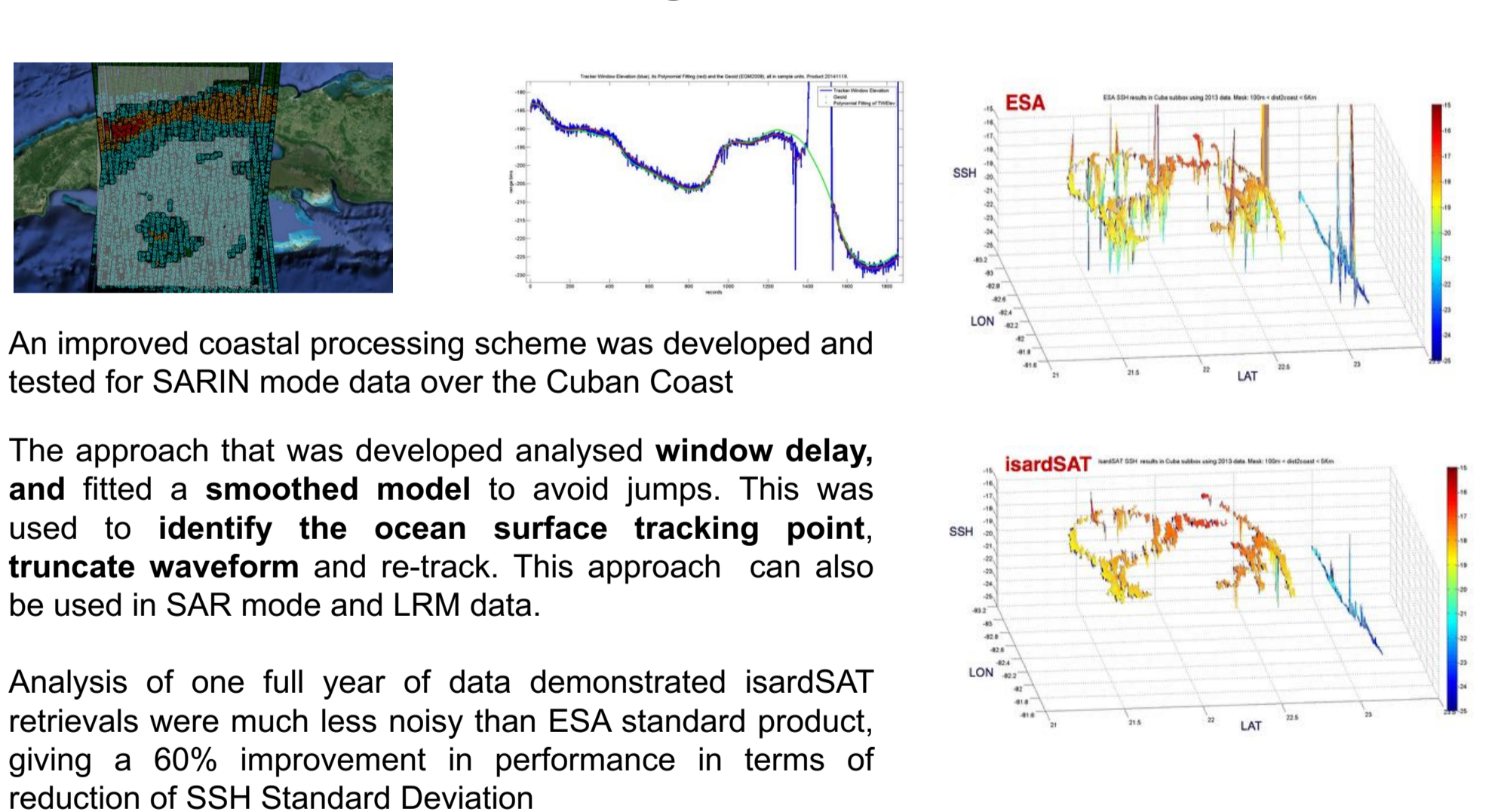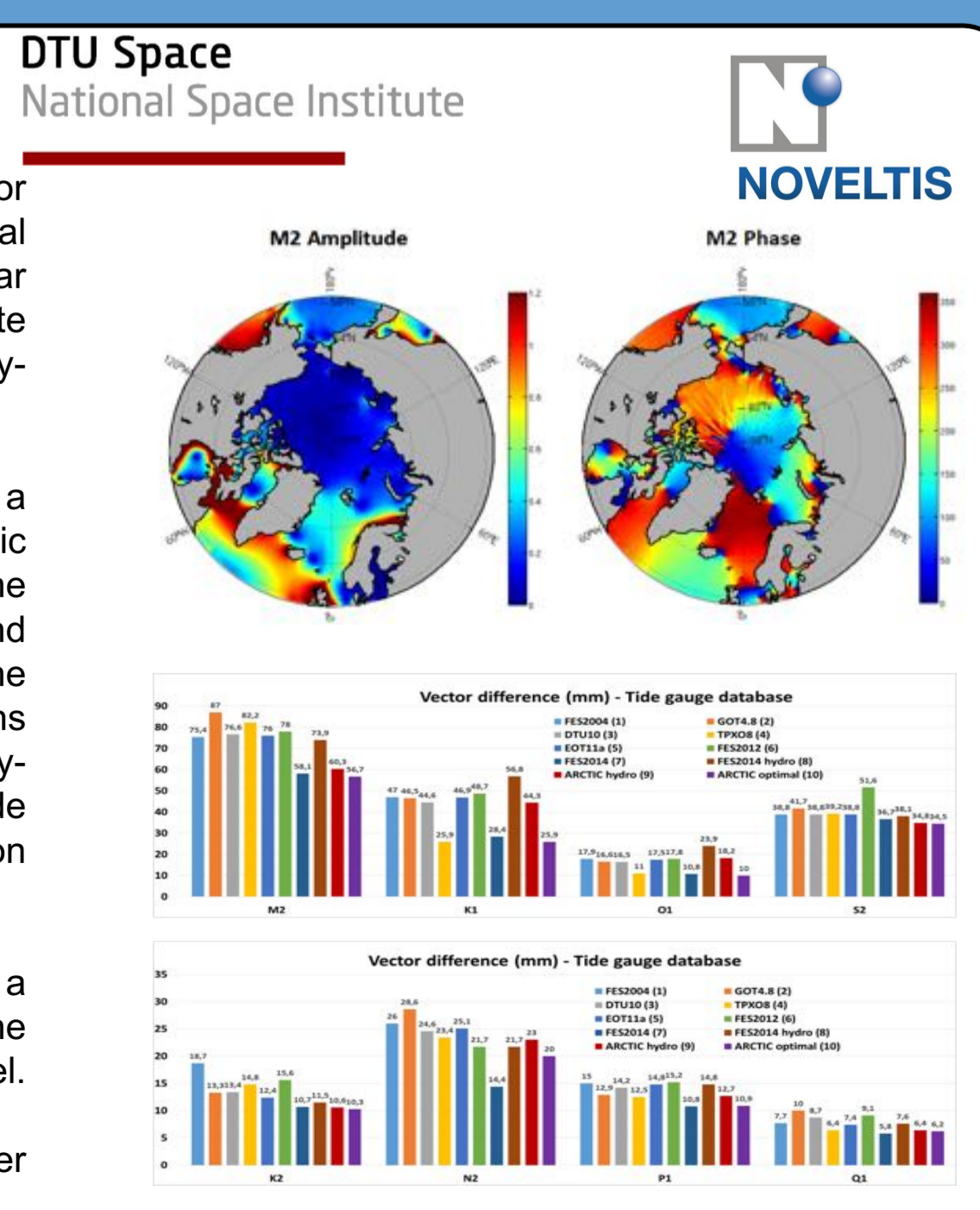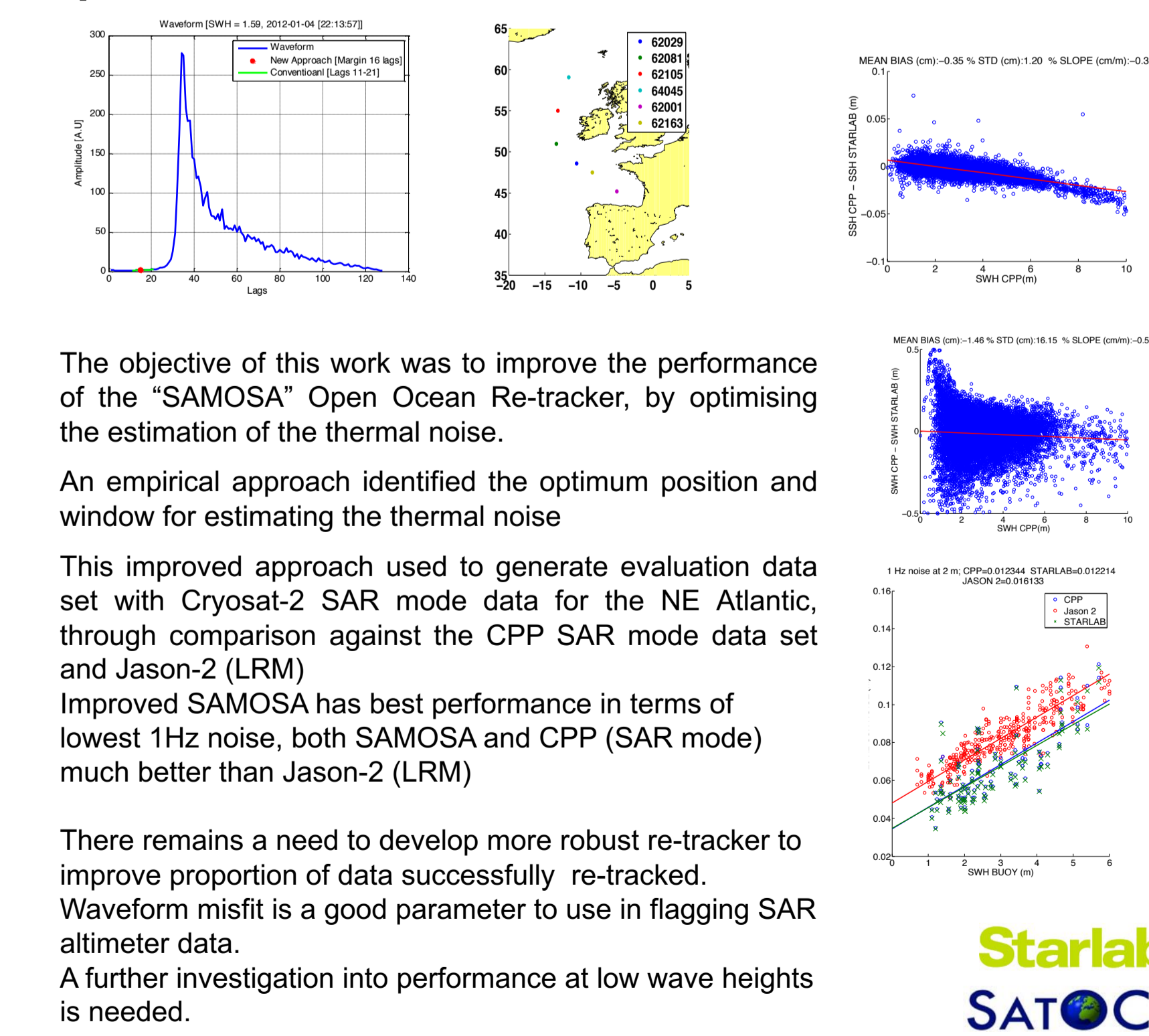
SAR for Sea Floor Mapping

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

### Improved Estimates of Thermal Noise in SAMOSA

The objective of this work was to improve the performance of the "SAMOSA" Open Ocean Re-tracker, by optimising the estimation of the thermal noise.

An empirical approach identified the optimum position and window for estimating the thermal noise

This approach used to generate evaluation data set with Cryosat-2 SAR mode data for the NE Atlantic, through comparison against the CPP SAR mode data set and Jason-2 (LRM)
Improved SAMOSA has best performance in terms of lowest 1Hz noise, both SAMOSA and CPP (SAR mode) much better than Jason-2 (LRM)

There remains a need to develop more robust re-tracker to improve proportion of data successfully re-tracked.
Waveform misfit is a good parameter to use in flagging SAR altimeter data.
A further investigation into performance at low wave heights is needed.

CryoSat-2 SAR mode data in the coastal zone
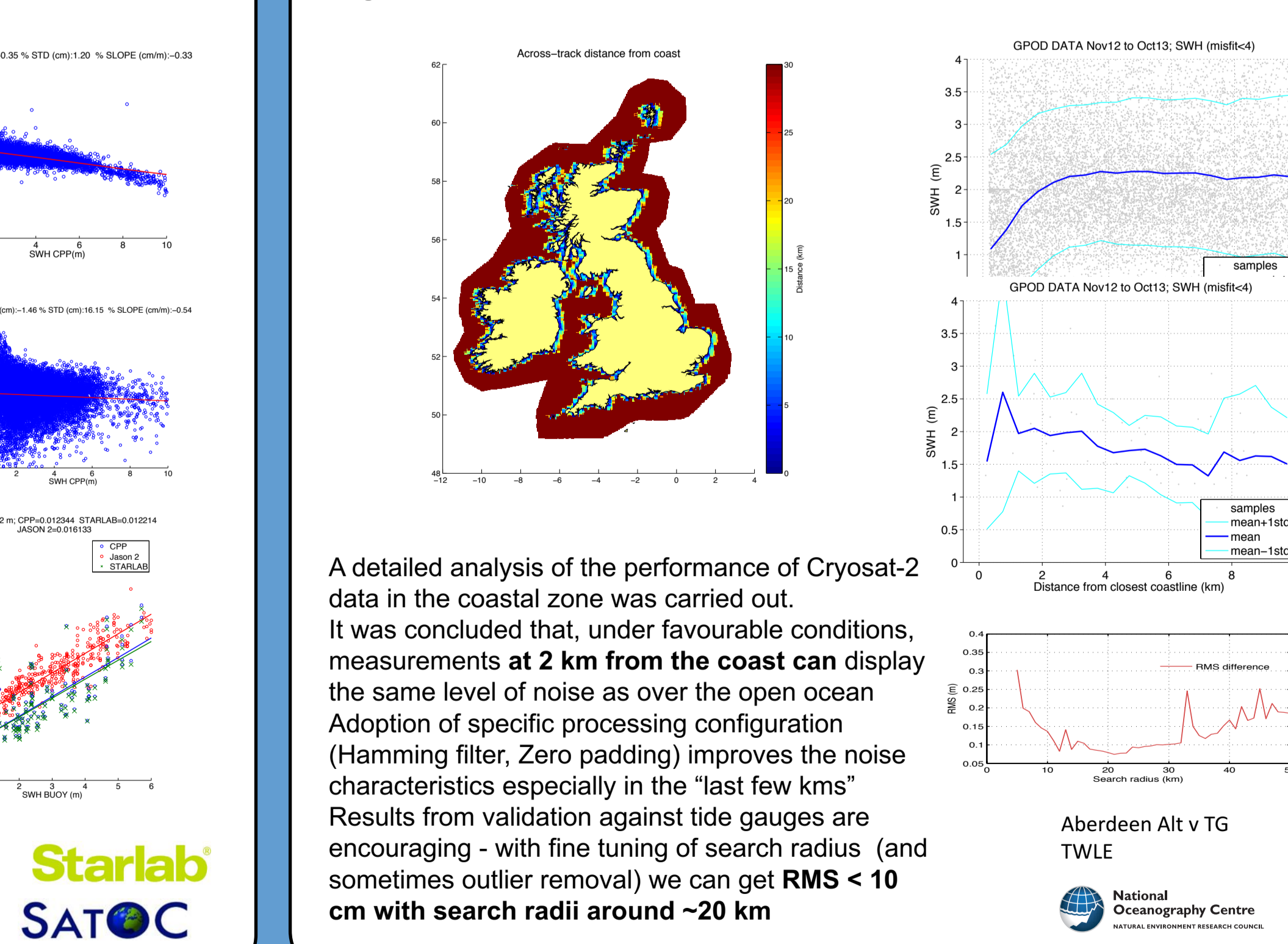
A detailed analysis of the performance of Cryosat-2 data in the coastal zone was carried out.
It was concluded that, under favourable conditions, measurements **at 2 km from the coast can** display the same level of noise as over the open ocean
Adoption of specific processing configuration (Hamming filter, Zero padding) improves the noise characteristics especially in the "last few kms"
Results from validation against tide gauges are encouraging - with fine tuning of search radius (and sometimes outlier removal) we can get **RMS < 10 cm with search radii around ~20 km**

Aberdeen Alt v TG TWLE

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.