CP40 was lead by SatOC Ltd UK, the project team included:

Collecte Localisation Satellites (Toulouse, France), **Denmark Technical University** (Copenhagen, Denmark), **isardSAT** (Barcelona, Spain), **National Oceanography Centre** (Southampton, UK), **Noveltis** (Toulouse, France), **Starlab** (Barcelona, Spain), **Technical University of Delft** (Delft, Netherlands), **The University of Porto** (Porto, Portugal).

Project Manager: **Dr. David Cotton** (SatOC, UK)

Project Scientific Officer: **Dr. Jérôme Benveniste** (ESA/ESRIN, Italy)

Project Scientific Support: **Salvatore Dinardo** (SERCO/ESRIN), **Bruno Lucas** (DEIMOS/ESRIN)

→ CRYOSAT PLUS FOR OCEANS

Results of the application of CryoSat data to Ocean Studies

www.satoc.eu/projects/CP40

stse support to science element

→ CRYOSAT OFFERS IMPROVED OCEAN MEASUREMENTS

The ESA CryoSat-2 mission is the first space mission to carry a radar altimeter that can operate in Synthetic Aperture Radar (SAR) mode, as well as the more conventional Low Rate Mode (LRM), and also the SAR Interferometric mode (SARin). Although the prime objective of the CryoSat-2 mission is dedicated to monitoring land and marine ice, the SAR mode capability of the CryoSat-2 SIRAL altimeter offers significant potential benefits for ocean applications, based on expected performance enhancements which include improved range precision, finer along track spatial resolution, and an improved ability to provide measurements close to the coast.

→ CRYOSAT PLUS FOR OCEANS (CP40)

The **Cryosat Plus for Oceans** (CP40) project was supported by ESA under the Support to Science Element Programme, and ran from June 2012 to October 2014. The objectives of CP40 were:

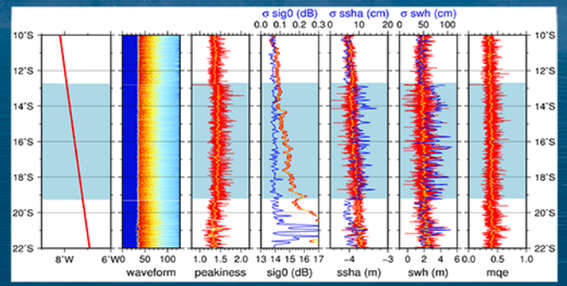
- to build a sound scientific basis for new scientific and operational applications of CryoSat-2 data over the open ocean, polar ocean coastal seas and for sea-floor mapping.
- to generate and evaluate new methods and products that will enable the full exploitation of the capabilities of the CryoSat-2 SIRAL altimeter, and extend their application beyond the initial mission objectives.
- to ensure that the scientific return of the CryoSat-2 mission is maximised.

→ CP40 RESULTS

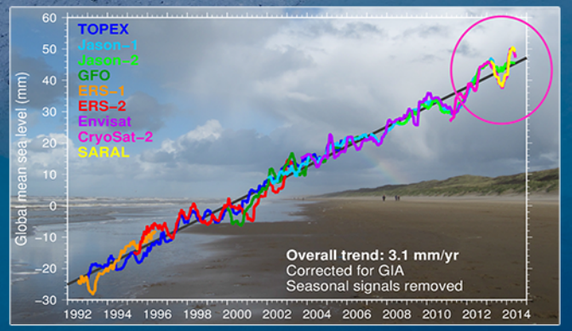
CP40 demonstrated that CryoSat-2 data provide users with significantly improved measurements over the ocean, and developed and evaluated a series of demonstration products to take advantage of this capability. Also a better technical understanding of the SAR altimetry over the ocean was achieved and recommendations for further work and exploitation provided in a Scientific Roadmap. The work was carried out under four sub-themes: Open Ocean Altimetry, Coastal Zone Altimetry, Polar Ocean Altimetry, and Sea Floor Altimetry.

Open Ocean Altimetry

CP40 developed and evaluated schemes to produce two types of ocean products derived from CryoSat-2 SAR mode data: SAR products which take full advantage of the higher along track resolution offered by the SAR, and "RDSAR" products which convert SAR Full Bit Rate Data to LRM data, aiming to provide similar signal characteristics and so ensure continuity between ocean products generated from SAR and LRM source data.
Ocean SAR products were generated by two SAR processing schemes, one based on the SAMOSA analytical SAR echo model, and a second based on a numerical echo model implemented by CNES in the CPP data product. Assessment showed the two products to perform equivalently, both clearly demonstrating an ability to detect and map oceanographic features at shorter spatial scales than can be resolved by conventional Low Rate Mode altimetry (10-80km). Assessment of the RDSAR product confirmed that this processing can provide continuity within the CryoSat mission, between data collected under LRM and SAR modes, and also between CryoSat data and the existing historical altimeter data archive, used to monitor sea level since 1985.



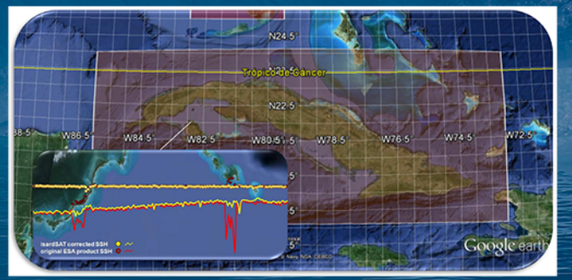
Sequence of LRM – RDSAR- LRM data close to St Helena in the South Atlantic Ocean, demonstrating consistency across the products. The blue sector represents the RDSAR coverage, the white LRM. (Credits TU Delft)



Long Term trend in global sea level, as measured by satellite altimeters. The Cryosat-2 contribution is in magenta and circled. (Credits TU Delft)

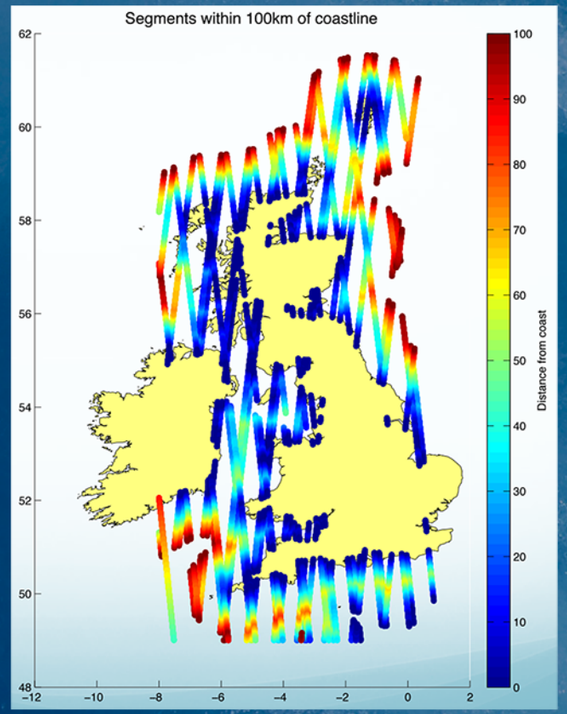
Coastal Zone Altimetry

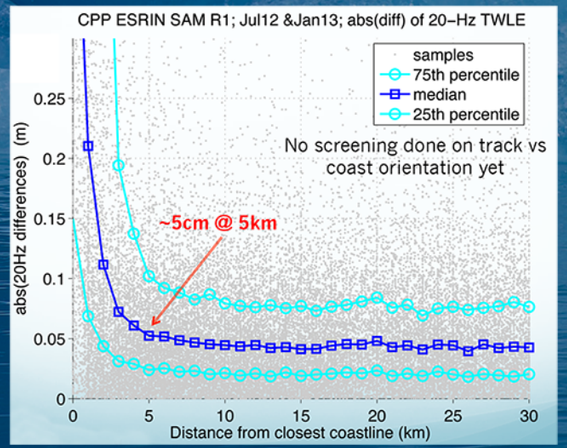
Cryosat-2 SAR Mode data offer important new measurement capability in the Coastal Ocean through finer spatial resolution, improved retrieval accuracy and lower sensitivity to land contamination, and so are able to deliver high-quality altimeter measurements closer to the shore, improving the estimation of coastal sea level changes, the detection of coastal features (coastal current jets, coastal wave set up, coastal tides) and the characterisation of inshore wave conditions.
CP40 has also demonstrated the potential of Cryosat-2 SARIn mode data to help discriminate and mitigate land contamination signals from off-nadir land targets (e.g. steep cliffs) in SARin waveforms over coastal regions.



Examples of SARin data during transition from coast to land. Reprocessing (yellow) can correct the initially processed data (red) which selects reflections from bright targets away from the sub-satellite track. (Credits: isardSAT)

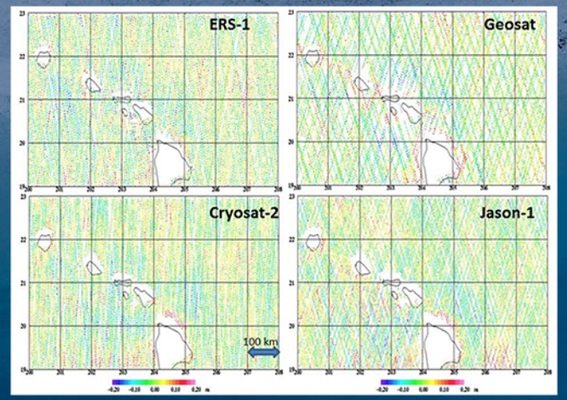
right panel: CryoSat-2 data provide measurements close to the coast (top right panel), and maintain accuracy to within 5km (bottom right panel), a significant improvement on previous missions. (Credits NOC)





Sea-Floor Altimetry:

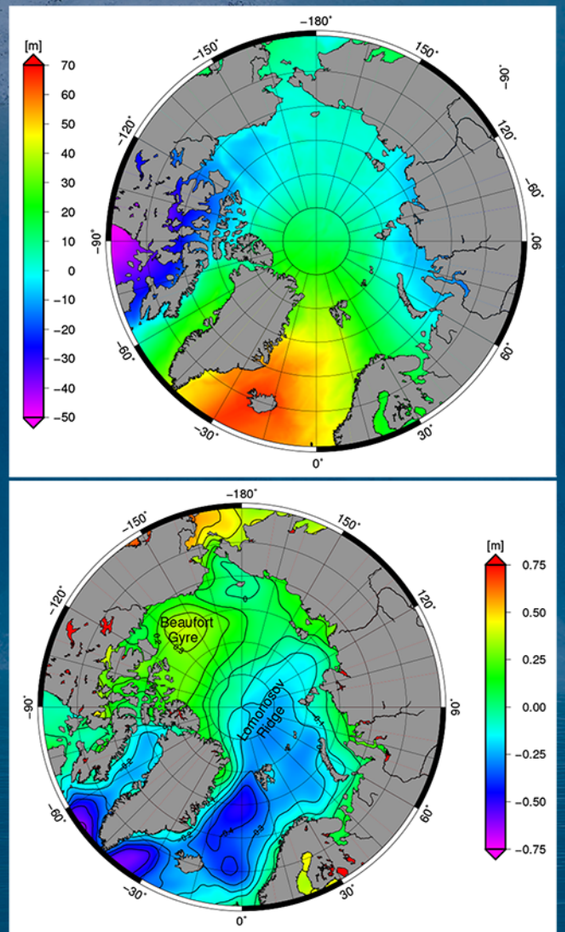
CP40 investigated the potential offered by the higher resolution and improved Signal to Noise Ratio of Cryosat-2 SAR Mode data to resolve short-wavelength sea surface signals caused by sea-floor topography elements and to map uncharted sea- mounts/trenches. A year long SAR data set over an area of the South Pacific Ocean is currently being processed and analysed.



Residual geoid height relative to EGM2008 (in meters) derived from 1 year of four different geodetic satellite altimeter missions around the Hawaiian islands. One degree in longitude on the x-axis corresponds to roughly 100 km at the given latitudes, as illustrated in the lower left figure. (Credits DTU Space)

Polar Ocean Altimetry:

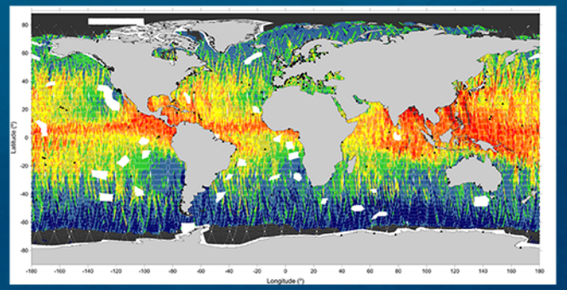
CP40 supported the development of new processing schemes applicable to sea-ice affected regions, allowing Cryosat-2 SAR Mode data to be used to build new models for the Artic Mean Sea Surface and Dynamic Topography. These models are already providing important new insights into Polar Ocean Dynamics.



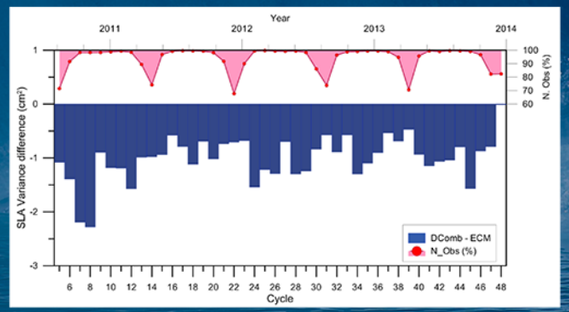
New models of the Polar Ocean Mean Sea Surface and Mean Dynamic Topography (DTU13 MSS, DTU13 MDT), produced through CP40. (Credits DTU Space)

Geophysical Corrections:

Cryosat-2 does not carry a Microwave Radiometer (for wet troposphere), and only operates at a single frequency (dual frequency allows a direct estimate of the ionospheric delay). Therefore, to ensure the benefits of SAR altimetry are fully realized for measurements over the ocean, CP40 supported the development of improved Geophysical Corrections for Wet Troposphere, Ionosphere and Regional Tide.



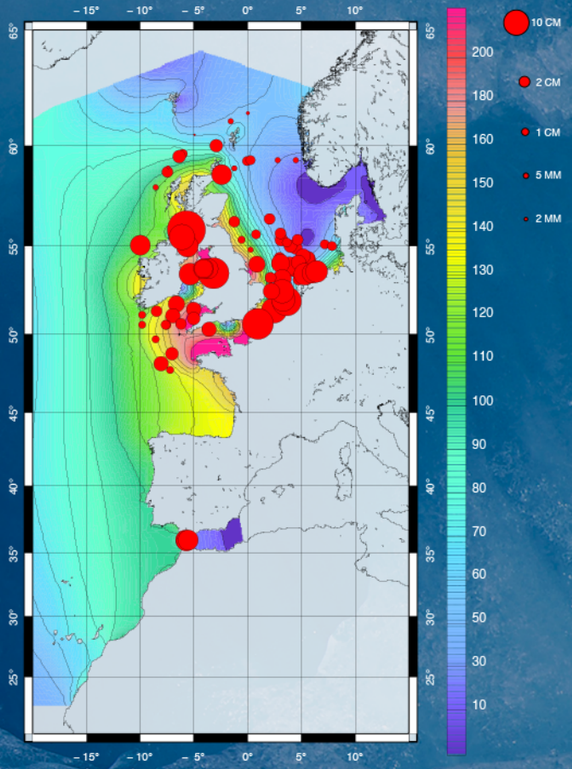
Wet Tropospheric correction (WTC) from DComb algorithm (in colour) estimated for CryoSat-2 Sub-cycle 16 by objective analysis using data from GNSS stations (black triangles), MWR images from Remote Sensing satellites and ERA Interim model. Zones where the WTC for this sub-cycle only rely on data from ERA are shown in grey; CryoSat-2 data unavailability is shown in white.
(Credits: University of Porto)

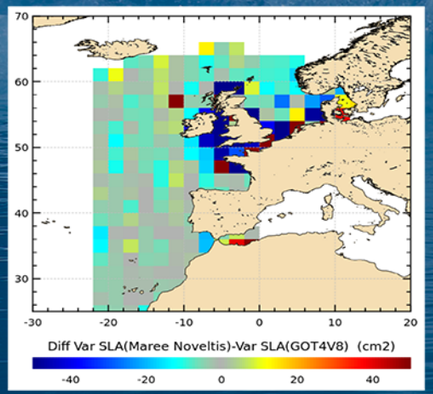


SLA variance difference (cm²) for each CryoSat-2 cycle between DComb (implemented in CP40) and ECMWF Operational Model. (Credits U. Porto).

top right panel: Amplitude of the M2 tidal wave from the COMAPI regional model (CNES project). The red dots superimposed are the vector differences between the model and tide gauge stations. The size of the dots is proportional to the misfit between the model and the observation. (Credits: NOVELTIS)

bottom right panel: Improvement in SLA variance (cm²) between COMAPI (used in CP40) and GOT4.8 tidal model. (Credits CLS).





→ PROJECT OUTPUTS AND RECOMMENDATIONS

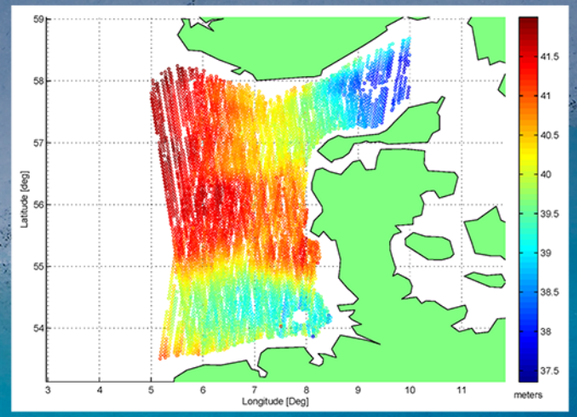
CP40 outputs

CP40 has provided a number of outputs which are freely available to the whole satellite oceanographic community through the project website (www.satoc.eu/projects/CP40):

- User Requirements Survey
- State of the Art Report for SAR Altimetry
- Demonstration Products
- Impact Assessment
- Scientific Roadmap and Recommendations

CP40 Demonstration Cryosat SAR Products

The table below lists the coverage of the demonstration products created for CP40. Reports are available that describe how these products were generated and validated. These products are available for download on request.



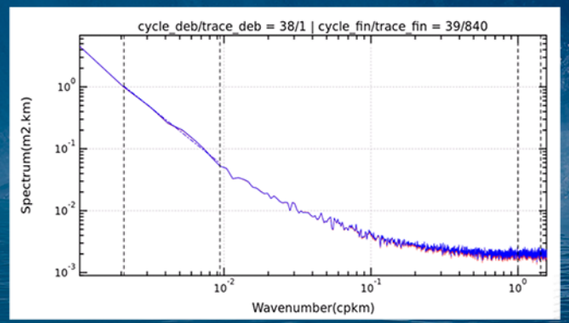
Sea Surface Height at German Bight in SAR mode. (Credits ESRIN)

Theme	Product	Partner	Area	Time Period
Open Ocean	RDSAR	TU Delft	Pacific and N Atlantic SAR boxes	July 2012, Jan 2013
	RDSAR	CNES/CLS	All SAR areas	Whole Mission
	SAR	Starlab	Pacific and N Atlantic SAR boxes	July 2012, Jan 2013
	SAR	ESA	Pacific SAR boxes	July 2012, Jan 2013
	SAR	CNES/CL	All SAR areas	Whole Mission
Open and Coastal Ocean	SAR	ESA / NOC	N Atlantic SAR boxes	July 2012, Jan 2013
Polar Ocean	SAR	ESA / DTU	Lats > 60N	March 2012, April 2012, Sept 2012
Sea Floor Mapping	SAR	ESA / DTU	Pacific SAR boxes	1 x 369 day cycle, starting 01/10/2012
Corrections	Wet Tropo	U Porto	Global	July 2012, Jan 2013
	Ionosphere	Noveltis	Med / European Shelf	Jan 2011- Jan 2013
	Regional Tides	Noveltis	NE Atlantic (Coastal)	Jan 2011- Jan 2013

Impact Assessment

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

- **RDSAR**: It was confirmed that the two schemes considered (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 investigate if a drift evolving with time is present
- **SAR**: Agreement between the full implementation of the SAMOSA echo model and the numerical model in the CPP products 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 the SAMOSA model are recommended and planned.
- **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.



Sea Level Spectrum peformed for SAMOSA (red) and CPP (blue). Both SAR retrackers allows 1-Hz product users to recover smaller wavelengths (10-80 km) of interest for oceanography (Credits: CLS)

Scientific Roadmap and Recommendations:

The Roadmap provides recommendations for further work, ranging from technical research to better understand fundamental SAR altimetry, to exploitation of SAR altimeter data in operational applications: