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Support to Science Element (STSE)

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Cryosat+: Ocean Theme

CP4O – Cryosat Plus 4 Oceans

Proposal for Work to be carried out under a Contract Change Notice

Submitted by
Satellite Oceanographic Consultants (UK)
in partnership with
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isardSAT (Spain)
NOC - The National Oceanography Centre (UK)
Noveltis (France)
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Glossary

AltiKa	Joint Indian/French Ka band altimeter mission
CCN	Contract Change Notice
CLS	Collecte Localisation Satellites
CNES	Centre National d'Etudes Spatiales
COASTALT	ESA-funded project to develop coastal use of satellite altimetry.
COMAPI	Coastal Modeling for Altimetry Product Improvement – A regional tide model for the North Eastern Atlantic and Mediterranean developed by Noveltis
CP4O	Cryosat Plus for Oceans
DTU-Space	Technical University of Denmark, National Space Institute, Copenhagen, Denmark.
Envisat	ESA Earth Observation Mission (2002-2012)
ESA	European Space Agency
ERS1/2	ESA Earth Observation Missions 1991-2000, and 1995-2011
FBR	Full Bit Rate data
FES2012	Global Tide model (Finite Element Solution) developed in 2012.
KO	Kick Off
LRM	"Low Resolution Mode" - equivalent of the "conventional" altimeter product
MWR	Microwave Radiometer
NOC	National Oceanography Centre, UK
PMP	Project Management Plan
RADS	Radar Altimeter Database System. Global altimeter database maintained by TU Delft
RA2	The ENVISAT Radar Altimeter
RDSAR	Reduced SAR mode data
SAMOSA	Former ESA SAR altimeter project, also refers to the SAR altimeter ocean echo model developed in this project
SAR	Synthetic Aperture Radar
SARAL	Ka Band altimeter on board AltiKa
SARin	Synthetic Aperture Radar Interferometric Mode.
SatOC	Satellite Oceanographic Consultants, UK
Sigma-0	Surface radar backscatter at normal incidence
SIRAL	The altimeter (with SAR mode operation) on Cryosat-2
SSH	Sea Surface Height
STSE	Support to Science Element
SWH	Significant Wave Height
TG	Tide Guage
TWLE	Total Water Level Envelope
WP	Work Package

Reference Documents

RD1: Cotton P.D., SatOC: CP4O Technical Proposal, November 2011
RD2: Cotton P.D., SatOC: CP4O Financial, Management and Administrative Proposal, November 2011
RD3: ESA: Cryosat +: Ocean. Statement of Work. EOEP-STSE-EOPS-SW-11-0001, August 2011
RD4: ESA: STSE-Cryosat + Ocean ESRIN Contract No 40000106169/12/I-NB.

1 Introduction

1.1 Introduction

Cryosat Plus for Oceans (CP4O) is a two year programme carried out with funding from ESA under the Support to Science Element programme. Additional funding was provided by CNES to support important CLS participation in the programme. €300,000 funding was provided by ESA. The project Kick Off was in June 2012 and the current planned completion date is October 2014. The proposal in this document is for further activities to be carried out under a contract change notice, to enable key developments to support applications particularly in the areas of polar, and coastal oceanography and so ensure the fullest possible exploitation of CryoSat-2 data in ocean applications.

1.2 Cryosat Plus for Oceans (CP4O)

The ESA Cryosat-2 mission is the first, and currently only, space mission to carry a radar altimeter that can operate in Synthetic Aperture Radar (SAR) mode. 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 also presents the opportunity of demonstrating significant potential benefits of SAR altimetry for ocean applications, based on expected performance enhancements which include improved range precision and finer along track spatial resolution. The benefits offered by SAR altimetry are now so well recognised that has been adopted for the major future satellite altimeter missions, including Sentinel-3 and Sentinel-6/Jason-CS

The general objectives of the original "Cryosat Plus for Oceans" (CP4O) proposal (RD.1) 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.

1.3 Justification for a CCN

Whilst the initial results of CP4O are highly promising and have confirmed the potential of SAR altimetry to support new scientific and operational oceanographic applications, it has also become apparent that further work is needed in some key areas to fully realise the original project objectives.

An initial implicit assumption in the Cryosat Plus for Oceans Statement of Work (RD.3), and hence in the CP4O proposal (RD.1), was that the products developed and evaluated in CP4O would be built on stable and mature ESA Cryosat-2 data sets. In fact SAR altimetry is still an evolving technology, and during the period of the CP4O projects understanding of how best to process SAR echoes has continued to develop.

Indeed, the ESA processing chain for Cryosat-2 data has itself evolved significantly throughout the period of the CP4O project, with members of the CP4O project team contributing to that evolution.

Thus the CP4O project was working against a background of change and it is perhaps inevitable that additional work is needed to realise the objectives of the original CP4O proposal – to ensure that the scientific return of the Cryosat-2 Mission is maximised.

We therefore propose four additional activities that the CP4O team believe are of high priority in meeting the original project objectives. These activities are listed in Table 1.1:

	Description	Partners
1.	SARin for Coastal Altimetry, Improved SARin processing for Test Data Set Generation.	isardSAT
2.	Implementation of a Regional Tidal Atlas in the Arctic Ocean.	Noveltis, DTU Space
3.	Improvements to the SAMOSA re-tracker implementation and Evaluation- Optimised Thermal Noise Estimation.	STARLAB, SatOC
4.	Extended evaluation of CryoSat-2 SAR data for Coastal Applications	NOC

Table 1.1 Proposed Activities for a CP4O CCN

Further work is needed to complete the development of some products and algorithms initiated in the main CP4O contract, in the area of coastal and polar applications and in the refinement of the SAR altimeter echo model that forms the basis of the re-tracker solution applied in the Sentinel-3 ground segment.

Activities (1) and (4) will enable better application of Cryosat-2 SAR data in coastal areas, in terms of developing and evaluating improved processing approaches. Activity (2) will provide a state of the art regional tidal atlas for the Polar Ocean, necessary because results from the main CP4O project have demonstrated current tide models have significant errors. Activity (3) will support the implementation and evaluation of a significant improvement to the implementation of the SAR Altimeter Echo Model (SAMOSA) that is applied within the Sentinel-3 altimeter processing chain. Results in the main CP4O project have shown that the estimate of Significant Wave Height in particular will be improved.

All of these tasks fall within the objectives of the Cryosat-2 Plus for Oceans statement of work, as they contribute to maximising the exploitation of Cryosat-2 data in ocean applications (in the coastal ocean, open ocean and polar seas). It was not possible to accomplish these tasks within the scope of the main CP4O project, as the necessary additional developments could had not been anticipated with the understanding of the state of the art that was known at the time of writing the proposal. Work within CP4O has demonstrated the clear requirement for this additional activities and the benefits that will be achieved in terms of improved applications of Cryosat-2 data.

1.4 Proposal Content

The following sections provide: a detailed description of the technical requirements and the specific activities planned within each task (Section 2); management arrangements, including timetable (Section 3); a work breakdown structure and work package descriptions (Section 4).

2 Description of Proposed Activities

2.1 WP 1000 - SARin for Coastal Altimetry. Improved SARin Processing for Test Data Set Generation

2.1.1 Description

The main objective of the study undertaken by isardSAT in the first phase of the CP4O project was to show the improvement of SSH estimates by making use of the phase information contained in SARin data, with the main focus on coastal areas where land contamination is predominant.

The progress done by isardSAT in this first phase has shown promising results, which adding to it an additional effort could allow for having an excellent reference Test Data Set for the next to come Sentinel-3 validation campaign.

The algorithms developed will deal with some yet unsolved waveforms contamination problems and eventually could be refined to be pre-operational. Dedicated retracking methods developed from an improved SAMOSA model will be also addressed by isardSAT, to derive the SSH variable. The results will be used to build a valuable CryoSat-2 Test Data Set for coastal areas, with a better quality than the current CryoSat-2 products, regarding the SSH series.

The Test Data Set will be constructed from some specific areas located inside the CP4O dedicated SARin mask in the Cuban Archipelago. It covers different coastal zones scenarios including cays, reefs, and 4 coastal fronts, becoming a special test zone for coastal applications.

2.1.2 Partners

isardSAT will carry out this activity.

2.1.3 Timescale

3 months are required to complete this activity.

Assuming the work starts in January 2015, the work will be completed in March 2015.

2.1.4 Required Inputs

Data Sets: L1b, L2 and L2I of selected zones or tracks over SARin patches

2.1.5 Deliverables

The deliverable from this activity will be:

D1.1 – Test Data Set with guidance notes including high level SARin processing and results.

2.2 WP 2000 – Implementation of a Regional Tidal Atlas in the Polar Ocean

2.2.1 Description

The Arctic Ocean is a challenging region for tidal modeling, because of its complex and not well-documented bathymetry, combined together with the intermittent presence of sea ice and the fact that the in situ tidal observations are rather scarce at such high latitudes. As a consequence, the accuracy of the global tidal models

decreases by several centimetres in the Polar Regions. In particular, it has a large impact on the quality of the altimetry SSH in these regions (ERS1/2, Envisat, CryoSat, SARAL and the future Sentinel-3 mission).

The implementation of a regional, high-resolution tidal model in the Arctic Ocean becomes particularly relevant after the successful reprocessing of the CryoSat-2 data over the Arctic Ocean, in the framework of the CP4O project. Indeed, better tides in this region would improve the quality of the CryoSat-2 SSH and of all derived products.
Thanks to the contribution of DTU, the model would benefit from the assimilation of the most complete altimetry dataset ever used in this region, including Envisat and SARAL data up to 82°N and the CryoSat-2 reprocessed data between 82°N and 88°N. The combination of all these satellites would give the best possible coverage of altimetry-derived tidal constituents and would strongly constrain the model in order to obtain a highly accurate regional tidal solution in the region. The available tide gauge data would also be used either for assimilation or validation.

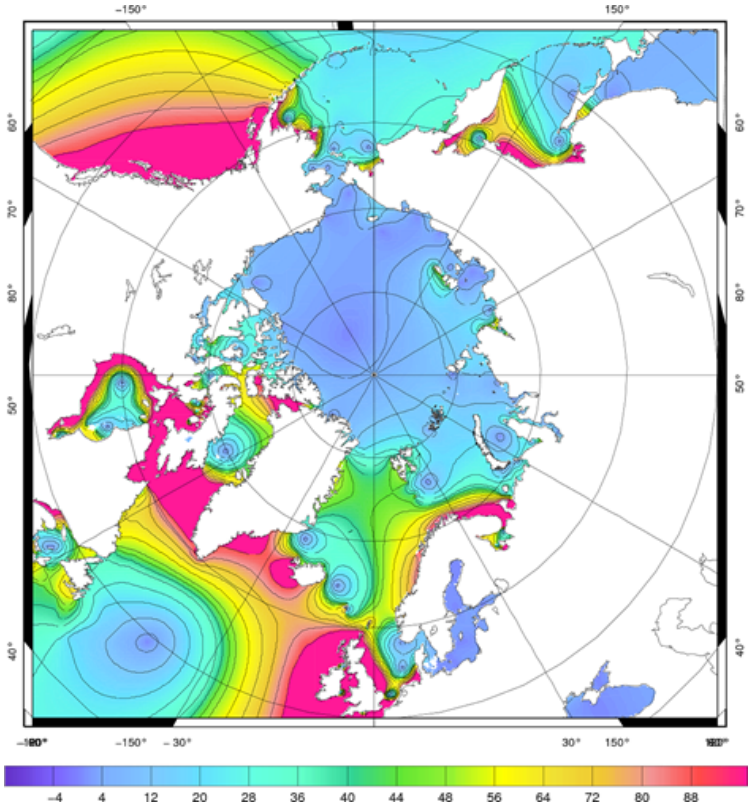

Figure 2.1 FES2102 M2 wave amplitude in the Arctic Ocean

The methodology proposed to develop this model is well-known by Noveltis as it was already used to implement the COMAPI regional tidal models as well as the FES2012 (Figure 2.1) and the future FES2014 global models.

It consists of the following steps:

- Run TUGO hydrodynamic model in the area;
- Assimilate the altimetry and tide gauges observations provided by DTU after specific selection, processing and validation, adapted to the peculiarities of the Arctic Ocean;

- Compare the regional tidal model to its global competitors and provide evaluation using the CryoSat-2 altimetry observations in the area.

It must be noticed that this model would benefit to all the altimetry missions flying beyond 60°N and would also be of great interest for many other ocean activities in this highly strategic region, such as maritime and industrial applications.

2.2.2 Partners

Noveltis and DTU Space will carry out this activity. Noveltis will be responsible for the tidal modeling, assimilation and validation, DTU Space for processing the Cryosat-2 data and the other altimeter data necessary for the assimilation.

2.2.3 Timescale

10 months are required to complete this activity.
Assuming the work starts in October 2014, the planned timing of activities is:

- Production of data (DTU): October 2014 to April 2015
  - Processing upgrades from CP4O
  - Retracking and editing of CryoSat data
  - Integration of other satellite products and derivation of the tidal constituents
- Hydrodynamic modelling + ensemble modelling (NOVELTIS): November 2014 to March 2015
- Assimilation and validation (NOVELTIS): April 2015 to July 2015

2.2.4 Required Inputs

- CryoSat-2 SAR data (from 50°N to maximum extent, all mission period)
- Envisat data (from 50°N to maximum extent, all mission period)
- SARAL data (from 50°N to maximum extent, all mission period)
- In situ data
- Bathymetry

2.2.5 Deliverables

The deliverables from this activity will be:
D2.1 – Technical Report
D2.2 – Tidal Atlas for Elevations, on a regular grid

2.3 WP 3000 – Improvements to the SAMOSA re-tracker Implementation and Evaluation – Optimised Thermal Noise Estimation

2.3.1 Description

The objective of this activity is to provide an optimised method for the estimation of thermal noise on the SAR waveforms, to implement this in the operational SAMOSA re-tracker, generate a validation data set and carry out an independent evaluation. It is expected that a more precise estimate of the waveform thermal noise will provide an improved Significant Wave Height measurement.

The thermal noise is a key parameter in the retracking of the SAR waveforms, as it

affects directly on the estimation of SWH. An optimized method should be implemented in order to have a precise estimation of this parameter. The estimation and introduction of the thermal noise on the SAMOSA model was part of the tasks to be performed by Starlab within the CP4O contract. This was done by means of an empirical method that measures the noise level directly on the SAR-Waveform by considering the range gates previous to the waveform leading edge. The noise floor was considered attending to the leading edge position variability. However, the method could be highly optimized attending to the SSH and SWH parameters.

The new method of estimating the thermal noise will be optimized to determine the range bins prior to the waveform leading edge that best represent the SAR waveform noise floor. This will be based according to the leading edge position of the model according to the SWH and SSH retrieved values.

The data will also be processed with the SAMOSA model as described in the S3-DPM, in order to demonstrate the usefulness of the model improvements

The new development will be validated by SatOC against CPP data, in situ data (from the Wavenet and UKMO buoys around the UK), and Envisat data.

The following tasks will be carried out:

Part 1 SAMOSA Model Updates:

- To develop and implement an optimized method for the estimation of thermal noise on the SAR waveforms (STARLAB)

Part 2 Generation of Validation Data Set

- To generate a year long data set (July 2010 – July 2011) for the NE Atlantic (STARLAB)

Part 3 Data Set Evaluation / Verification

- To evaluate this dataset including comparisons against Cryosat-2 CPP SAR data, Envisat data, and in-situ data (SatOC)

2.3.2 Partners

STARLAB and SatOC will carry out this activity. STARLAB will be responsible for implementing the improved thermal noise estimation and generating the validation data set. SatOC will be responsible for evaluating this data set.

2.3.3 Timescale

9 months are required to complete this activity.
Assuming the work starts in October 2014, the planned timing of activities is:
SAMOSA Model Updates (STARLAB): October 2014 to Dec 2014
Generation of Validation Data Set (STARLAB: Jan- March 2015
Evaluation of Data Set (SatOC): April 2015 to June 2015

2.3.4 Required Inputs

- CryoSat L1b SAR data (NE Atlantic, July 2010- July 2011)
- Cryosat L1b SAR data (South Pacific SAR Patch, July 2010-July 2011
- Cryosat CPP SAR data
- Envisat Data (NE Atlantic and S Pacific SAR patch, July 2010- July 2011)
- In situ data (NE Atlantic): Wavenet and UKMO buoys

2.3.5 Deliverables

The deliverables from this activity will be:
D3.1 Technical Note: Thermal noise estimation method integrated within the SAMOSA model retracker.
D3.2 Evaluation Data Set (July 2010- July 2011). NE Atlantic
D3.3 Technical Note with evaluation of Test Data Set

2.4 WP 4000 – Further Evaluation of Cryosat-2 SAR Data in Coastal Applications

2.4.1 Description

Analysis carried out within CP4O has highlighted the potential of Cryosat-2 in the coastal zone in terms of low measurement noise. This part of the analysis has looked at the differences of consecutive 20-Hz measurements around the coast of the UK in order to derive an estimate of the noise, and found that CryoSat-2 20-Hz data feature a 5-cm noise level up to 5Km from the coast. (Figure 2.2)

However the analysis in the original contract has only used two months of data and has not taken into account the relative orientation of the tracks and the coastline (i.e. the angle of approach). This needs now to be investigated. Further work carried out in the original CP4O contract looked at comparison with tide gauges but found large biases that need to be assessed and corrected. Once this is done it should be possible to investigate the effect of angle of approach on the correlation between altimetry and tide gauges.

We therefore propose to reassess the 20-Hz noise as a function of both distance from coast and angle of approach, using a larger dataset (at least one year of data), and then to validate the CryoSat-2 heights (expressed as Total Water Level Envelope, TWLE) against Tide Gauge levels from the UK network.

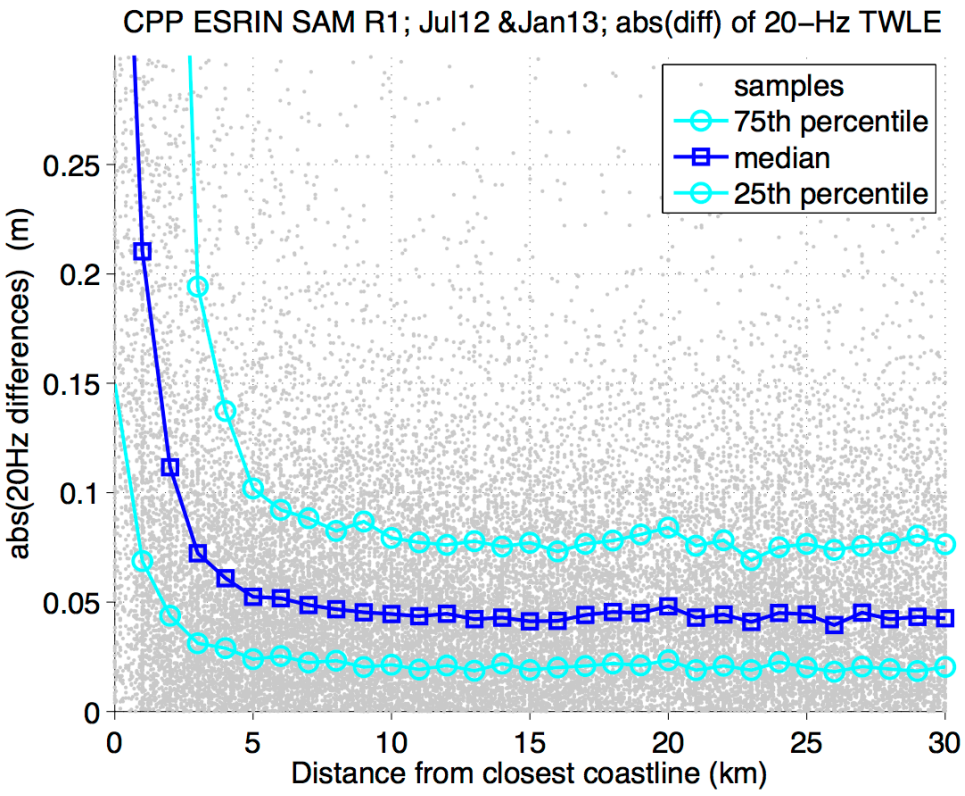

Figure 2.2 Estimate of Noise Level in Range with distance from the coast

Objectives
Assessing the noise performance in the coastal zone
Identifying and removing biases as far as possible
Validating CroySat-2 data for coastal sea level applications

Detailed tasks
- Compute angle of approach
- Update corrections from RADS, correct for all known instrumental biases, compute TWLE
- Compute 20-Hz differences and bin differences in function of angle of approach and distance from coast, then compute statistics
- Create match-up pairs of altimeter/TG TWLEs and compute statistics (biases, Standard Deviations)

2.4.2 Partners

NOC will carry out this activity.

2.4.3 Timescale
3 months are required to complete this activity.
Assuming the work starts in October 2014, the work will be completed in December 2014

2.4.4 Required Inputs
- CryoSat SAR L2 data around UK. July 2010-July 2011 are proposed to be in line with other datasets
- RADS data for same period (already available)
- In situ data from UK Tide Gauge Network (already available)

2.4.5 Deliverables
D4.1 Technical Note on CryoSat-2 SAR performance in the coastal zone (possibly to be then converted into a paper for submission to peer-reviewed journal)