DEVELOPMENT OF RADAR ALTIMETRY DATA PROCESSING IN THE OCEANIC COASTAL ZONE

ESA/ESRIN Contract No. 21201/08/I-LG – CCN 3 (Phase2)

EWP0 – Deliverable D0.1

COASTALT executive summary

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Revision History

Issue	Date	Change
1.0	19 June 2011	Initial Release
1.1	11 Oct 2011	Minor end-of-contract update: - Updated list of deliverables - Added as explicit achievements: product specification, handbook and final recommendations - Updated output lists - Minor addition to final recommendation 6 following final PM
2.0	29 June 2012	Final revision following completion of all deliverables and update of all project outputs Includes selection of COASTALT results (entirely new section section 2 added) Outputs now include the COASTALT CGDR (section 3) Added list of Acronyms
2.1	16 July 2012	Amendments following ESA revision of v 2.0: - added section 2.5 on WITM tide model, inclusive of figures for the most important tidal components. - added a recommendation about exploring the combination of the GPD wet tropospheric correction with other methods - add a recommendation about enhancing the coastal products with new coastal parameters Also added full list of COASTALT participants in section 1.

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Reference Documents

Proposal and Management/Phase 1:

[DRD] **COASTALT Data Requirement Document,** v. 2.0, COASTALT-DRD-20, 14/5/2008.

[FMA1] **COASTALT Financial, Management and Administrative proposal**, December 2007, in response to ESA Invitation to Tender (ITT) AO/1-5429/07/I-LG.

[FMA2] FCUP/Hidromod unsolicited **Financial And Management Proposal** issued in Response to AO/1-5429/07/I-LG, FCUP-COAS-PRO-07-002, November 2007;

[GAN] **COASTALT Gantt Chart v 5.0** including CCN, issued 20/04/2009

[PMP] **COASTALT Project Management Plan v 3.1**, COASTALT-PMP-31, 20/04/09

[TP1] **COASTALT Technical proposal**, December 2007, in response to ESA Invitation to Tender (ITT) AO/1-5429/07/I-LG.

[TP2] FCUP/Hidromod unsolicited **Technical Proposal** issued in Response to AO/1-5429/07/I-LG, FCUP-COAS-PRO-07-001, November 2007;

Proposal and Management/Phase 2:

[TP2] **COASTALT Proposal for Extended work (COASTALT Phase2)** Version 1.0, 1st November 2009, in response to ESA COASTALT 2 Statement of Work

[GAN2] **COASTALT2 Gantt Chart v 1.4** issued 07/02/2011

[PMP2] **COASTALT2 Project Management Plan v 1.3**, COASTALT2-PMP-13, 07/02/2011

Deliverables/Phase 1:

[D1] **Report on User Requirements for Coastal Altimetry Products**, COASTALT Deliverables 1.1/1.2, v 1.1, 13 Oct 2008.

[D2] **Technical Note on Improvement of Corrections in Coastal Areas**, COASTALT Deliverables 2.1/2.2/2.3/2.4/2.5, v. 2.0, 17 Feb 2009.

[D21b] **Technical Note on Wet Tropospheric Corrections in Coastal Areas**, COASTALT Deliverable 2.1b, v 1.2, 30 Jun 2009

[D31] **Technical Note on Coastal Waveform Analysis**, COASTALT Deliverable 3.1, v 2.0, 28 Oct 2008.

[D32d] **COASTALT Waveform Retracker Design Definition File (DDF)**, COASTALT DDF001 (part of Deliverable 3.2), v.1.2, 28 Jul 2009.

[D32s] **COASTALT Waveform Retracker Software Technical Specifications (STS)**, COASTALT STS001 (part of Deliverable 3.2), v.1.2, 28 Jul 2009.

[D33] **Validation Test Plan**, COASTALT Deliverable 3.3, v. 3.0, 20 May 2009.

[D34] **Retracking improvement validation report,** COASTALT Deliverable 3.4, v. 1.3, 14 Sep 2009.

[D35] **Report on Innovative Techniques**, COASTALT Deliverable 3.5, v. 1.1, 21 Apr 2010.

[D41] **Product Specification Document**, COASTALT Deliverable 4.1, v. 1.01rev2, 11 Dec 2009.

[D42] **ENVISAT Coastal Altimetry Product Handbook,** COASTALT Deliverable 4.2, v. 1rev0, 25 Nov 2009.

[D51] **Validation Plan**, COASTALT Deliverable 5.1, v. 1.0, 28 Nov 2008.

[D53] **Validation and Performance Assessment for NW Mediterranean and West of Britain**, COASTALT Deliverable 5.2/5.3, v 1.0, 16 Oct 2009.

[D54] **Validation and Performance Assessment on West Iberia**, COASTALT Deliverable 5.4, v 1.1, 23 Nov 2009.

[D6] **Outreach: website, sample data, use cases, tutorial and scientific papers**, COASTALT Deliverables 6.1 to 6.5, v 1.1, 14 Jan 2010.

[D61] **COASTALT Web site** http://www.coastalt.eu

[D71] **Phase 1 Executive Summary and Recommendations,** COASTALT Deliverable 7.1, v 1.0, 30 Nov 2009.

Deliverables/Phase 2:

[C2D12a] **COASTALT Processor v.2. Processor improvements: technical note**, COASTALT2 Deliverable 1.2a, COASTALT2-D12a-10, v 1.0, 25 July 2011.

[C2D12b] **COASTALT Processor: Plug&Play user guide**, COASTALT2 Deliverable 1.2b, COASTALT2-D12b-11, v 1.1, 02 June 2012.

[C2D15] **Coastal Mask utility and technical note**, COASTALT2 Deliverable 1.5, COASTALT2-D15-10, v 1.0, 30 April 2010.

[C2D21a] **Global assessment of GNSS-derived tropospheric corrections**, COASTALT2 Deliverable 2.1a, COASTALT2-D21a-11, v 1.1, 26/07/2010.

[C2D21b] **GPD output for CGDR for European coasts**, COASTALT2 Deliverable 2.1b, COASTALT2-D21b-11, v 1.1, 08/02/2011.

[C2D21c] **GPD global implementation**, COASTALT2 Deliverable 2.1c, COASTALT2-D21c-11, v 1.1, 05/08/2011.

[C2D21d] **Data combination and GPD validation**, COASTALT2 Deliverable 2.1d, COASTALT2-D21d-11, v 1.1, 29/09/2011.

[C2D22] **Local Tide Model for the West Iberian Region**, COASTALT2 Deliverable 2.2, COASTALT2-D22-11, v 1.1, 10/10/2010.

[C2D32] **Bayes Linear Retracking of Radar Altimeter Data**, COASTALT2 Deliverable 3.2, COASTALT2-D32-11, v 1.1, 28/05/2012.

[C2D33] **Development and Implementation of the Hyperbolic Pretracker**, COASTALT2 Deliverable 3.3, COASTALT2-D33-20, v2.0, 21/12/2011.

[C2D34D53] **Implementation of the Bayes Linear Retracker (D3.4) and validation on real waveforms (D5.3),** COASTALT2 Deliverables 3.4 and 5.3, COASTALT2-D34D53-10, v 1.0, 28/05/2012.

[C2D41a] **Product Specification Document,** COASTALT2 Deliverable 4.1a, COASTALT2-D41a-203 v 2.0rev3, 20/06/2011.

[C2D41b] **Envisat Coastal Altimetry Product Handbook,** COASTALT2 Deliverable 4.1b, COASTALT2-D41b-201, (ESA ref: ENVI-DTEX-EOPS-TN-09-0006), v2.0.1, 16/09/2011.

[C2D51] **CGDR over pilot sites,** COASTALT2 Deliverable 5.1, v 2.0r3, issued 11/10/2011.

[C2D52] **Report on validation of reprocessed height and waves,** COASTALT2 Deliverable 5.2, COASTALT2-D52-12b, v.1.2b, 10/01/2012.

[C2D01] **COASTALT Phase 2 Executive Summary and Recommendations,** COASTALT2 Deliverable 0.1, COASTALT2-D01-20 v.2.1, 16/07/2012. (This document)

[C2D02]=[D61] **COASTALT web site,** http://www.coastalt.eu, last updated on 16/07/2012.

List of Acronyms

Acronym	Definition
AGC	Automatic Gain Control
ASCII	American Standard Code for Information Interchange
BRAT	Basic Radar Altimetry Toolbox
CCI	ESA Climate Change Initiative
CCN	Contract Change Notice
CGDR	Coastal Geophysical Data Record
COASTALT	ESA Development of COASTal ALTimetry
COASTALT-SWT	COASTal ALTimetry Science Working Team
DUE	Data User Element
ECMWF	European Centre for Medium-Range Weather Forecasts
FTP	File Transfer Protocol
GNSS	Global Navigation Satellite System
GPD	GNSS-derived Path Delay
LPA	Land Percentage Algorithm
MPA	Mixed-Pixel Algorithm
MWR	Microwave Radiometer
NetCDF	Network Common Data Form
OPeNDAP	Open-source Project for a Network Data Access Protocol
RA-2	Envisat Radar Altimeter - 2
SAR	Synthetic Aperture Radar
SDR	Sensor Data Record
SGDR	Sensor Geophysical Data Record
SLA	Sea Level Anomaly
SRAL	Sentinel-3 SAR Altimeter
SSHA	Sea-Surface Height Anomaly
SWH	Significant Wave Height
ZHD	Zenith Hydrostatic Delay (= dry tropo dealy)
ZTD	Zenith Total Delay
ZWD	Zenith Wet Delay (= wet tropo delay)

1. COASTALT Executive summary

The COASTALT project, started in 2008, has reached completion having achieved a number of valuable results:

1) a survey of the potential user base which identified the **key requirements** for coastal altimetry product composition, posting rate and format [in Phase 1, in cooperation with the PISTACH Project];
2) the implementation of a **versatile prototype processor for coastal altimetry**; this is the fundamental tool for the generation of reprocessed coastal altimetry data (Coastal Geophysical Data Records or **CGDRs**) and at the same time can be used for further research and development work on retracking techniques and corrections;
3) a complete **specification of the coastal altimetry products**, extensively detailed and fully consistent with the CGDR products generated by the prototype processor;
4) an assessment of the various **corrections,** and in particular the research on and development of a **novel Wet Tropospheric correction** (GPD) based on GNSS measurements that improves the quality of range retrieval in the coastal region. This is one of the most innovative outcomes of COASTALT and has been the subject of two refereed papers;
5) The development of a **local tidal model** on one of the COASTALT pilot areas (West Iberia/Portugal coast)
6) the analysis of the peculiarities of the altimetric signal in the coastal zone and in particular of **bright targets** (which has led to two published refereed papers, plus others in preparation) and the preliminary design of two innovative retrackers (the 'Hyperbolic Pretracker' and the Bayes Linear retracker) retrieving the information from multiple waveforms at once. The Hyperbolic Pre-tracker prototype, which attempts to remove coastal artefacts in data prior to re-tracking, has shown successful cancellation of hyperbolic features from real Envisat Data so it remains a promising approach for future implementation; conversely, the Bayes Linear retracker prototype encountered numerical difficulties in its implementation, that led to unsatisfactory results from this particular retracker.
7) valuable work on the **techniques for visualization and validation** of altimetric data in the coastal zone, including the development of a suite of analysis routines for MATLAB;
8) the **coordination and moderation of a lively international community of coastal altimetrists**, via the COASTALT-SWT list and the leadership of the OceanObs'09 paper on Coastal Altimetry, and the organization of the highly successful **2nd, 3rd 4th and 5th Coastal Altimetry Workshop**, and last but not least the co-editorship and contribution to the first ever **refereed book** on coastal altimetry;
9) the **COASTALT web site http://www.coastalt.eu,** which constitutes a useful resource for the entire community, not just the project partners. All the information on COASTALT and related initiatives and the links to all posters and presentations from the Coastal Altimetry Workshop are available via the web site;

10) a comprehensive **handbook on coastal altimetry products** which give users plenty of background information on the Envisat Mission, a complete description of the coastal reprocessing used for the CGDR, examples of typical computation from altimetry data, the elucidation of all the corrections involved and some coastal case studies to illustrate the application of the data;
11) a set of **recommendations** for the future of coastal altimetry, to improve the accuracy of the products and to ensure that the community makes the most of the data.

The outputs of COASTALT, the outreach and coordination activities and the final COASTALT recommendations are presented in detail in the remainder of this document. The coastal altimetry work pioneered with COASTALT is continuing in the future with the development of coastal altimetry for storm surge studies within the **ESA Data User Element (DUE) eSurge Project**; we also envisage an extensive application of some techniques developed within COASTALT to the new **Delay-Doppler altimetry data now being collected by Cryosat-2 and, in the future, by the SRAL altimeter on board Sentinel-3.** This applies in particular to the retracking techniques tested in COASTALT [for which further validation studies are recommended], and to the new GPD Wet Tropospheric correction, which has also been recommended as the Wet Tropospheric correction of choice by the ESA Sea Level CCI Project.

This is a list of the institutions and scientists that have contributed to COASTALT:

- **NOC Southampton:** Paolo Cipollini (project manager), Valborg Byfield, Peter Challenor, Scott Gleason (now at Concordia Univ., Montreal), Christine Gommenginger, Graham Quartly, Helen Snaith, Mikis Tsimplis, Luke J. West;
- **NOC Liverpool:** Phil Woodworth, Judith Wolf;
- **CNR Pisa:** Stefano Vignudelli, Andrea Scozzari;
- **University of Cadiz**: Jesus Gómez-Enri;
- **Starlab Barcelona:** Cristina Martin-Puig (now at IsardSAT), Marco Caparrini, Laura Moreno;
- **University of Porto:** M. Joana Fernandes, Luisa Bastos, Clara Lázaro, Alexandra Nunes. Nelson Pires, Machiel Bos (CIIMAR), Isabel Araujo (CIIMAR), Susana Barbosa (now at University of Lisbon);
- **University of Lisbon (phase 2 only):** Susana Barbosa;
- **Hidromod (phase 1 only):** Henrique Coelho.

ESA scientific officer: Jérôme Benveniste, supported by Salvatore Dinardo and Bruno Manuel Lucas.

2. COASTALT Result Highlights

In this section we describe some of the results of COASTALT that have particular significance in terms of setting the recommendations and the path for future development (like user requirements and processor development). We include the discussion on some of the most innovative techniques explored by COASTALT (like the sequential retrackers, not always successful as explained in §2.3) and on one achievement of COASTALT that is indeed ready for operational transition, i.e. the GPD Wet Tropospheric correction which has now been adopted as the correction of choice by the ESA Sea Level CCI Project. The complete archive of Project deliverables, giving the full picture of what the Project has achieved, is available on the COASTALT web site at http://www.coastalt.eu/results .

2.1. Establishing the user requirements for coastal altimetry data

A joint PISTACH and COASTALT survey [D1] provided valuable information to draw the user requirements for the new altimetry product. A total of 53 replies to the questionnaire were received, mostly from public research institutions. The public institutions working on operational products were well represented, while just 8% the replies came from private industry.

The COASTALT results in all cases have confirmed the indications drawn from the PISTACH sub-sample and can be seen as an independent validation of the PISTACH survey, and vice versa.

As a general indication, we can say that remote sensing data are used as a valuable tool alongside modelling and data assimilation for the purposes of research or operational services. These applications are of varying natures, with Near Real Time and delayed mode studies being more common among the community. The length of the datasets needed/used depends on the application. In the case of operational services, some of them near-real-time, the data required in most of the cases is one day long or shorter, while for research studies the dataset more requested is between one and ten years.

For the observation zone there is no clear preference among near shore, coastal zone and Open Ocean, and in consequence the typical distance to the shoreline varies in a balanced way.

The answer about the purpose for the altimetry products reveals that for the research community the main focus is on the analysis of ocean processes, while the operational community tends to require altimeter data more for model validation or assimilation into models.

The physical processes most frequently studied in the community are the Sea Surface height and the Sea Level Anomaly, and as it can be foreseen, the most frequently used parameter is the Surface elevation. It is important to highlight that wind and wave parameters are of great interest for operational forecasting centres. Currents were also suggested despite not being an option in the initial list.

The analysis of the current and preferred accuracy and precision requirements for different classifications of users has been very helpful; in many occasions the current product does not satisfy clearly the user in terms, for instance, of the accuracy of the SWH or the radiometric accuracy on sigma nought.

Concerning required supplementary data, the community prefers quality controlled data for its purposes, complementing the altimetric information in most cases with Optical, SAR or infrared data equally.

Finally, preferred formats among the community are NetCDF and ASCII while FTP and OPeNDAP are the most desirable delivery options. The preferred latency of data is the best achievable (~daily) for the whole the community, independently of the nature of the centre.

2.2. The COASTALT Processor

The COASTALT processor is one of the main legacies of COASTALT. It ingests Envisat Sensor Geophysical Data Record (SGDR) data (and is fully compatible with the recently reprocessed V2.1 SGDR) and produces the reprocessed coastal altimetry data – i.e the Coastal Geophysical Data Records (CGDRs) by retracking and updating some of the corrections.

The COASTALT Processor is not an operational processor, but has always been intended as a Research & Development tool, that as well as providing the standard products (i.e. the L2 products propagated from the SGDR) outputs the L2 results from a custom suite of retrackers. These consist of a Brown retracker, a specular retracker and a mixed (Brown + specular) retracker [D32d][D32s] allowing investigation of the suitability of these retrackers in the coastal zone, when the waveform is affected by proximity of land or other target peculiarities (Gómez-Enri et al, 2012; Scozzari et al., 2012).

The development of the COASTALT processor has been one of the main activities in the Project and since the start of Phase 2 (2010 onwards) has been carried out under revision control (using the popular *Apache Subversion* system) and aiming at full compliance with a full set of Product Specifications also defined by COASTALT [C2D41a].

To give an idea of the amount of development involved, the revision which generated the latest products (CGDR v2.0r3, fully compliant with product specification v2.0r3 described in [C2D41a]) is rev 91 (subsequent updates to the subversion archive, up to the current rev99 have only added documentation and examples without changing the source code). The latest improvements that led to this version are detailed in [C2D12a]. CGDR data over the COASTALT pilot tracks (shown in figure 1) have been made available publicly since October 2011 (a free registration form is required).

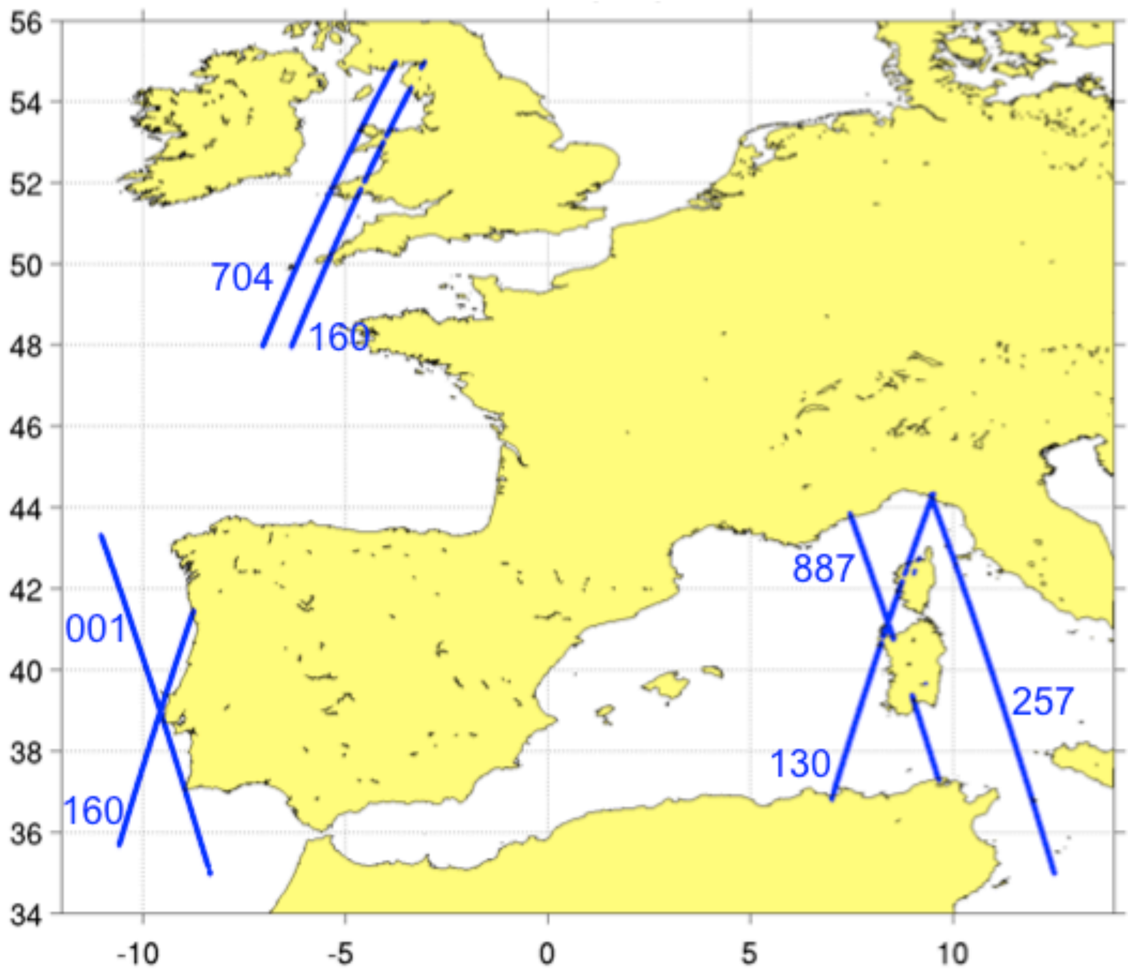

Figure 1 – the pilot Envisat tracks for which the CGDRs are open to public access in COASTALT

The processor moreover enables users to test and implement their own retracker options. To this end, a 'plug and play' capability was built into the processor software [C2D12b]. The current implementation is limited to a FORTRAN module, with a maximum of 7 fitted parameters.

2.3. Innovative retracking techniques

Hyperbolic Pretracker

One of the foci for innovative retracking research in COASTALT has been on the design and implementation of a hyperbolic pretracker specifically for the Envisat RA-2 altimeter. This technique is much better at coping with multiple discrete targets than an approach that treats each waveform in isolation thus neglecting the contextual information from neighbouring waveforms.

The work started from the construction of a waveform simulator whose characteristics matched those of the instrument — specifically, this meant careful tuning to get leading edge slope and position of half-power point in exact agreement with the RA-2 altimeter. This simulator was used to generate waveforms as the virtual instrument overflies a small rectangular patch of enhanced variability (a "bright target") possibly representing glassy seas. From a number of such (noise-free) simulations spanning the narrow altimeter swath it was possible to use mathematical inversion techniques to produce a set of weights for estimating intensities of such hyperbolae, and then remove these features from the 2-D waveform space (essentially ‘cleaning’ the waveforms). This was initially demonstrated in a number of simulated examples, described in [C2D33]

The following figures show some examples of where the hyperbolic pretracker does a good job or removing the unwanted features in real Envisat data (indeed, the pretracker can be used to provide an estimate of where the features are and of their intensity, although the emphasis here is on their efficacy at extracting unwanted contaminants from marine altimeter waveform data). It should be noted that the present implementation does not work well in all cases, as discussed later.

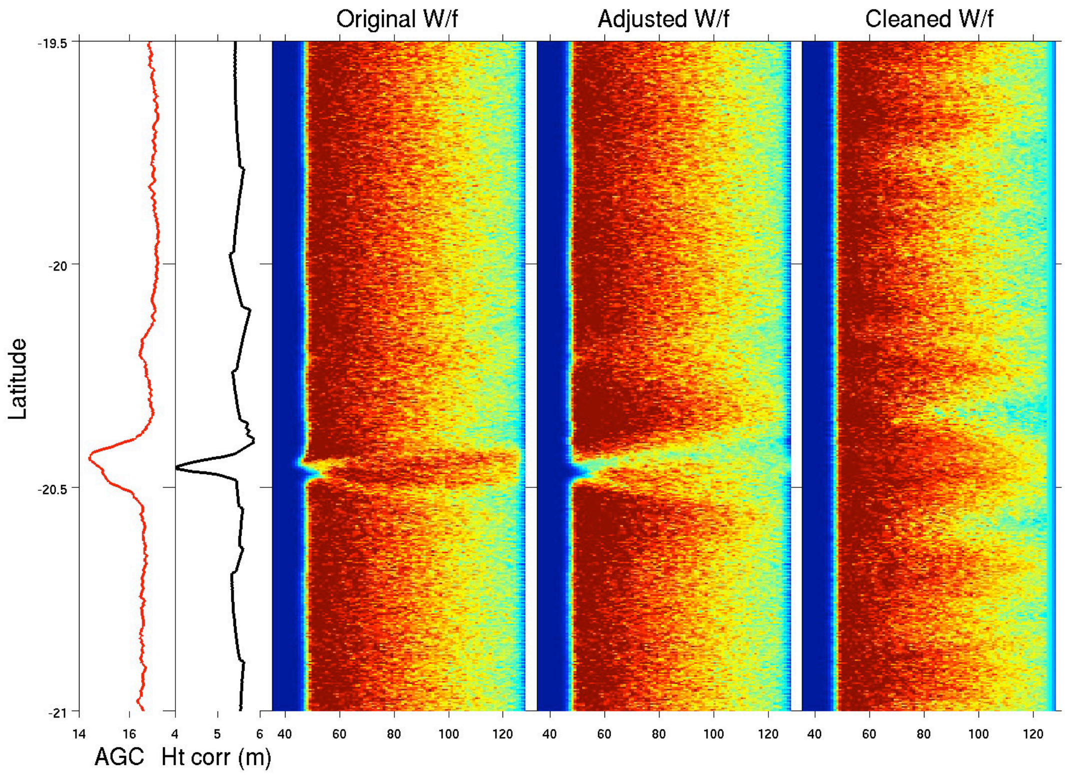

Fig. 2: A simple mid-ocean case with a reduction in AGC (first panel) and movement of the tracker (second panel). The other three panels show original raw waveform data, same after AGC scaling and shifts applied and finally after the hyperbolic pretracker has removed the "weak target" feature. (The value used for ht_corr is altitude - tracker window - geoid.)

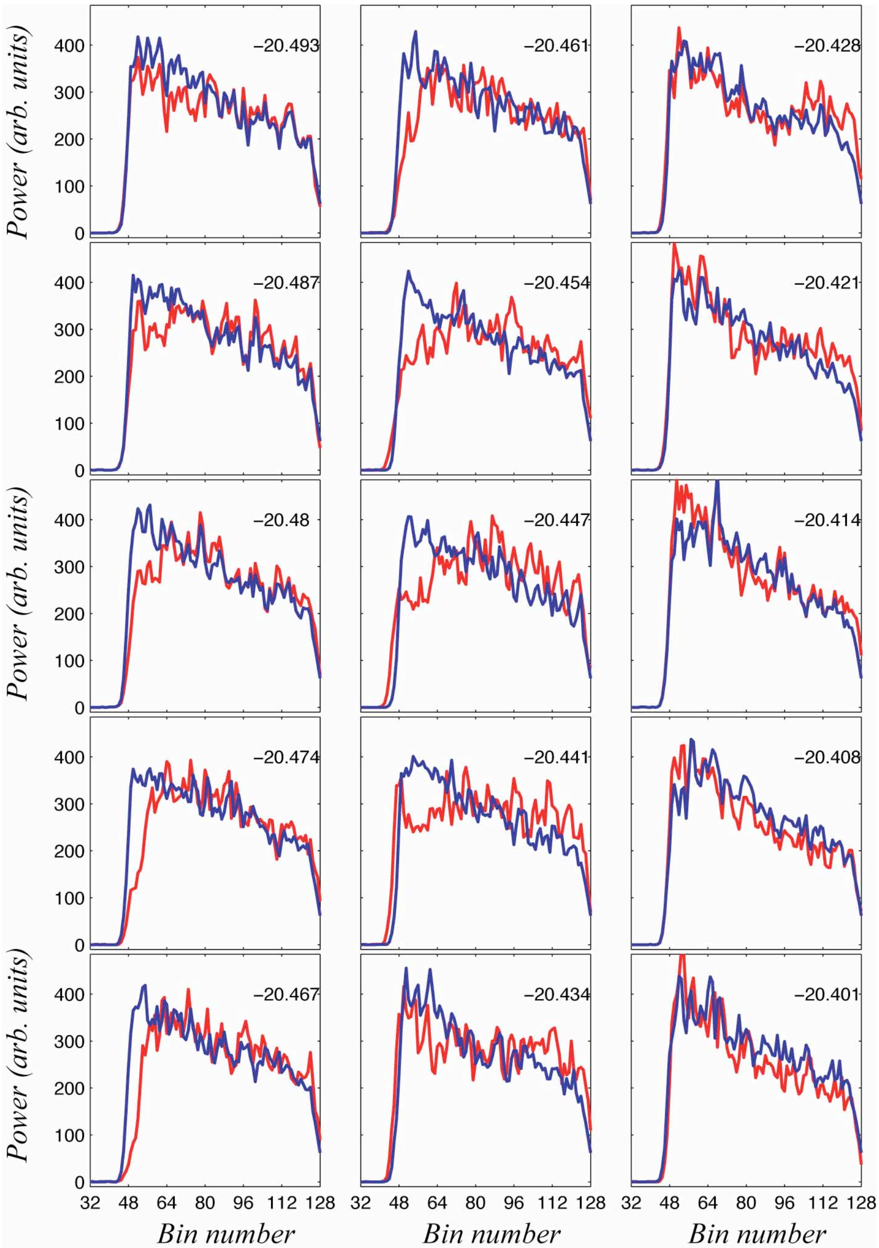

Fig. 3: Portrayal of every second waveform across the weak target shown in Fig. 2. Red line shows original signal and blue that after the pretracker applied to clean it up.

Other succeeding examples are taken from Envisat overpasses of Pianosa Island in the Tuscan Archipelago, which has proven to be of great interest because of its frequent but intermittent occurrence of a bright target just to the north of the island coupled with a permanent weak target feature due to the island itself (Gómez-Enri et al., 2010, Quartly, 2010).

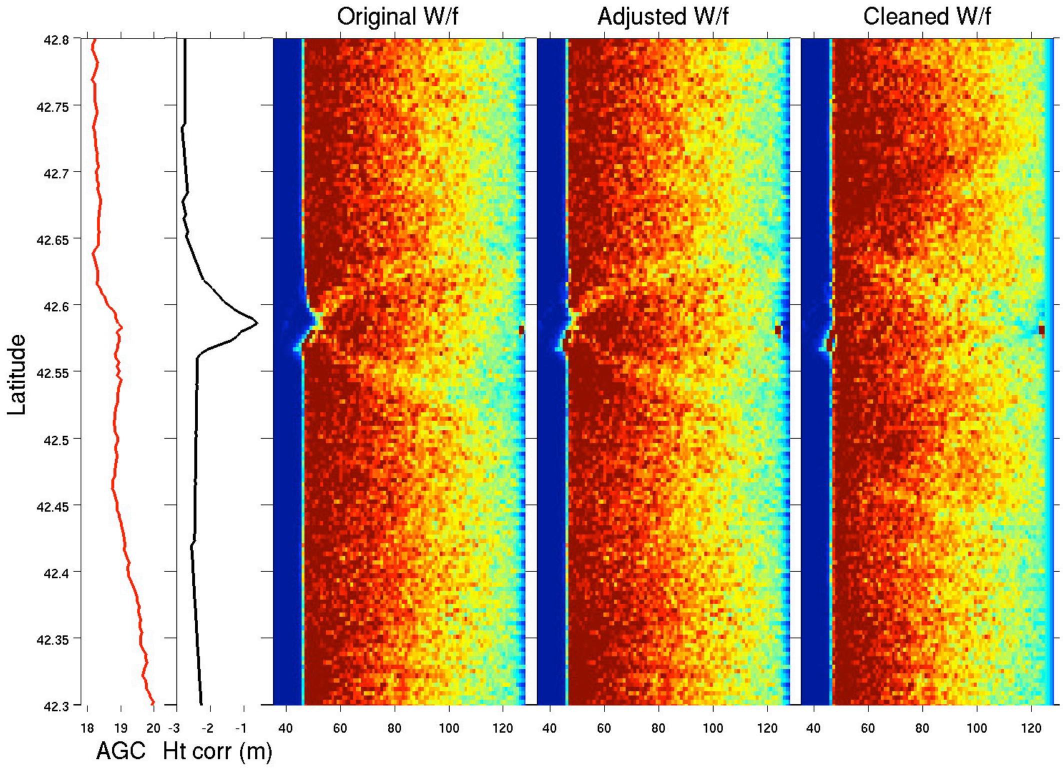

Fig. 4: Another example (case P04) — Envisat pass near Pianosa, cycle 040

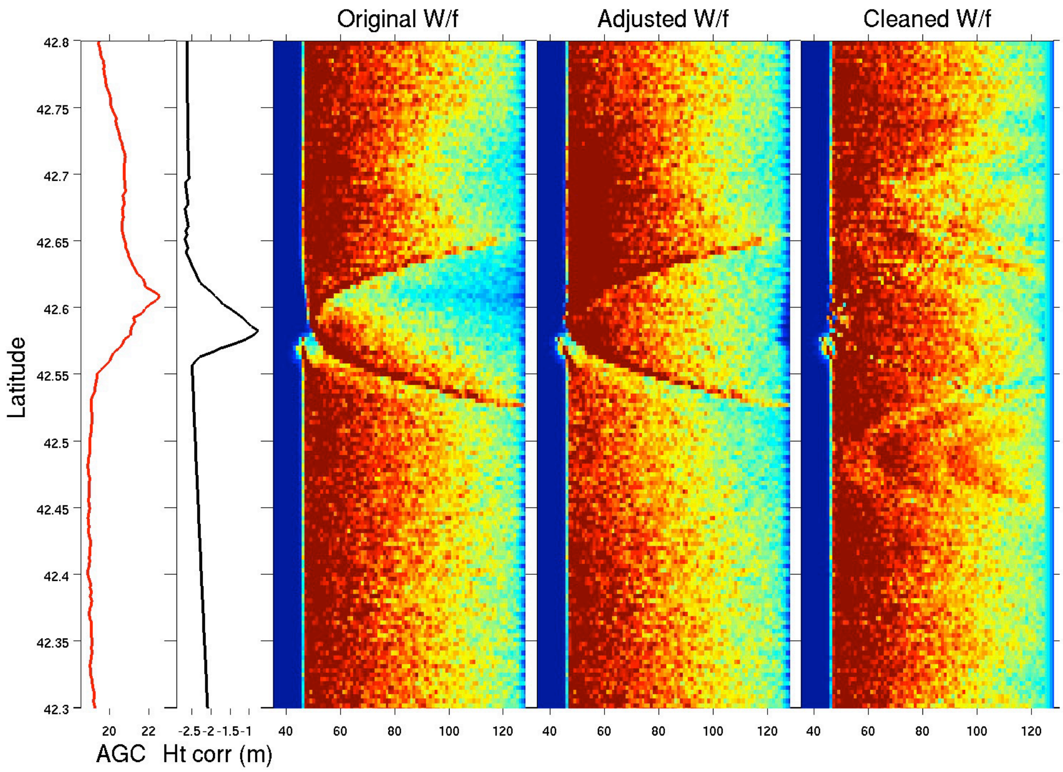

Fig. 5: Another example (case P08) — Envisat pass near Pianosa, cycle 068

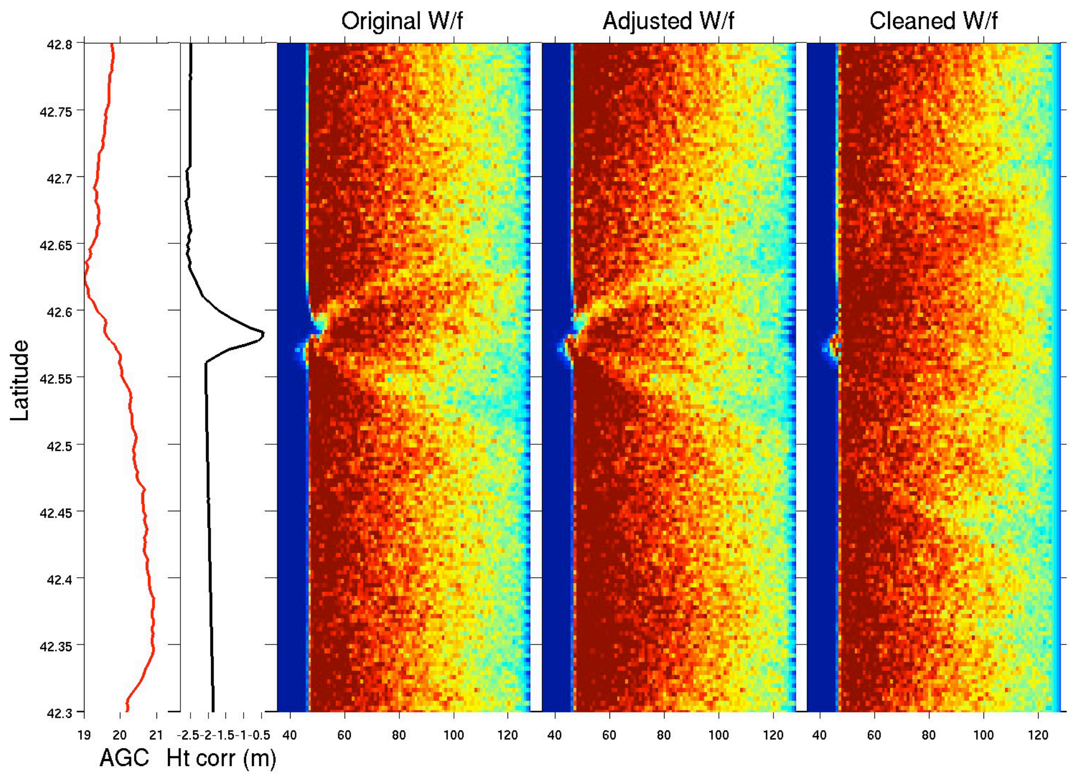

Fig. 6: Another example (case P09) — Envisat pass near Pianosa, cycle 069

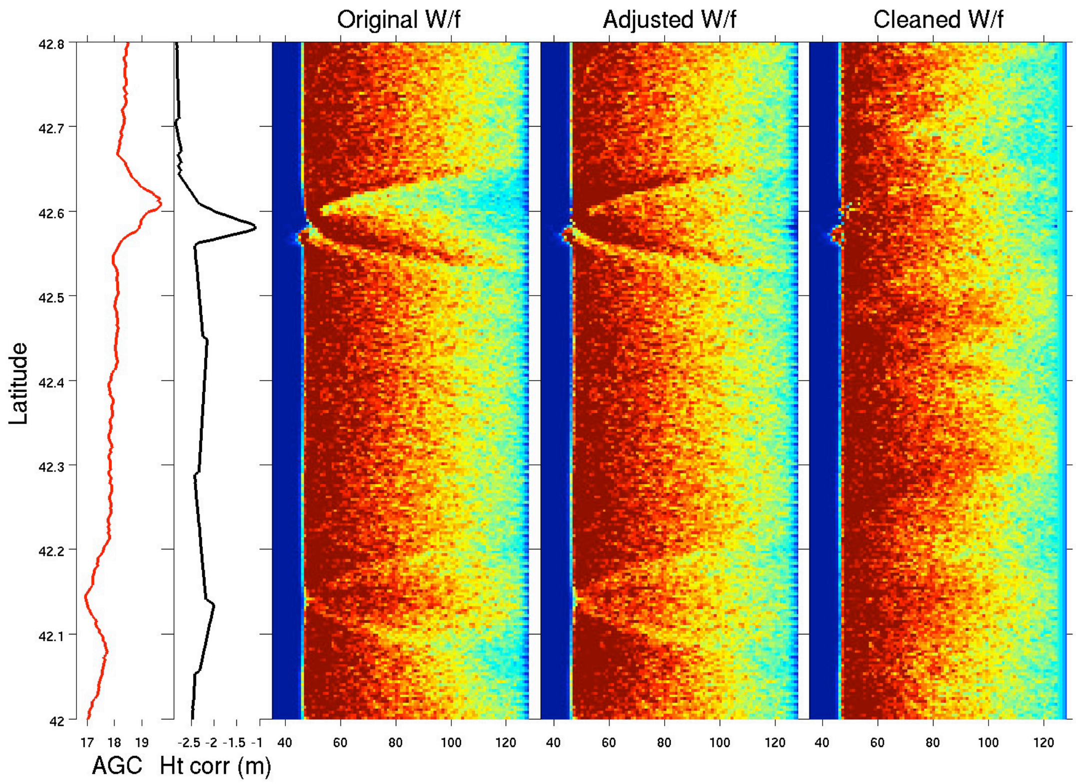

Fig. 7: Another example (case P13) — Envisat pass near Pianosa, cycle 073

In conclusion, the hyperbolic pretracker has been shown to be a robust tool for locating and removing hyperbolic features within the 2-D waveform data, performing the job very reliably with simulated data over complex scenarios with realistic levels of fading noise. The resultant cleaned waveforms (e.g. Fig. 3) are much more amenable to a conventional waveform retracker. The use of this technique as a pre-processor means that it can be implemented along with other waveform-fitting techniques (independent of whether they are fitting for skewness, mispointing etc.). However, the technique, in its present form, does not restore absolutely all input data into Brown-like waveforms; in some cases the output is still so far from that expected from scatter from a homogeneous surface, as to be unsuitable for Brown retracking.

For use with real altimeter data, the waveforms need a degree of "massaging" — correcting for changing AGC and movement of tracker window; this has not been as simple as initially believed. And indeed a number of problems persist when there are small movements of tracker leading to alternately positive and negative anomalies at the leading edge. Despite this, the hyperbolic pretracker is able to work with many examples of real waveform data containing bright target features as shown above (the relevant datasets have been provided to ESA for further validation).

A number of concerns for a full implementation remain, and are listed in [C2D33]. We recommend that future research is carried out on these specific aspects.

Bayes Linear Retracking

Work carried out in WP3 (Retracking) during Phase 1 of COASTALT (see [D35]) had already identified the Bayes Linear Technique as one of the most promising to carry out sequential retracking of waveforms. Therefore it was decided to dedicate significant efforts to try and develop this technique in Phase 2 of COASTALT, to the point where it would be possible to plug it in the COASTALT processor. The theory was fully developed and is described in [C2D32] alongside the retracker implementation in R language. This theoretical framework remains valid and in the opinion of the COASTALT scientists should be considered for further investigations.

The initial plans were to test the Bayes Linear retracker over real waveforms; however the numerical implementation of this particular retracker has proved very difficult. Despite many efforts, which included translating the R code into C++ (partly for performance reasons, but also with the intention that this would be an intermediate step towards plugging it into the COASTALT Processor), we have not resolved the numerical problems, so this aspect of the Project has not been successful. The R and C++ codes have been provided to ESA for further analysis should the Agency choose to pursue this line of research further.

2.4. The GPD wet tropospheric correction

The design, development and assessment of the GNSS-Derived Path Delay (GPD) correction for wet tropospheric effects has been one of the most successful aspects of COASTALT. In particular this has achieved:

- Full design and implementation of the technique as described in Fernandes et al., 2010.

- A global assessment of the correction, which showed in particular that the ECMWF-derived Zenith Hydrostatic (i.e. 'dry') Delay (ZHD), is the most suitable dataset to separate the GNSS-derived Zenith Total Delay (ZTD), at global scale, into the dry and wet components. [C2D21a]
- The GPD wet tropospheric correction has been successfully computed for the COASTALT CGDR 1Hz points and interpolated to 18Hz, and is provided in the CGDR v2.0r3 alongside an interpolation flag and a formal error field [C2D21b]
- A global implementation of the GPD algorithm was carried out at University of Porto enabling the computation of the wet tropospheric correction, everywhere over ocean, including the coastal areas and the high latitude regions. Figure 8 shows an example of the global GPD correction for Envisat cycle 58. The correction is continuous with respect to the original MWR correction, replacing this one whenever a point is considered to have an invalid MWR value. There is a very good agreement between the Zenith Wet Delay (ZWD, i.e. the Wet tropospheric correction) derived from the GNSS path delays and the corresponding value determined from ECMWF. The mean difference has an absolute value less than 3 mm and the standard deviation is 13 mm. [C2D21c]

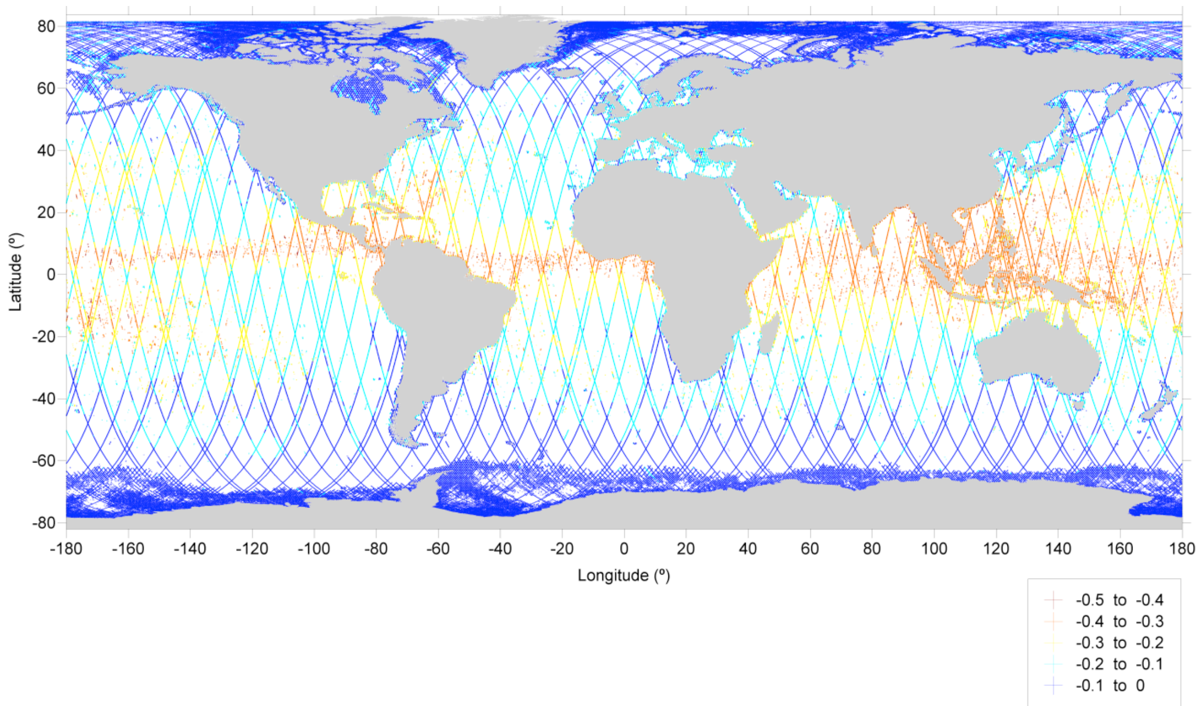

Fig.8 – Estimated GPD wet tropospheric correction (in m) for Envisat cycle 58, plotted only in those locations where the original MWR-derived correction is not valid

- A study was then conducted on the variability of the spatial correlation of the ZWD field using global ECMWF grids, accompanied by a comparison of the GPD correction with other approaches (models, 'mixed-pixel' algorithm or MPA and 'land proportion' algorithm or LPA) – this is the only validation possible at the moment in the absence of a ground truth. One example of this comparison is shown in Fig.9. It showed the GPD estimates to produce more reliable corrections than the other two algorithms, which can show some noisy behavior. However we believe that a mixed approach, for example, a mixed MPA and GPD approach can improve the Path Delay retrieval in some of the most problematic configurations. [C2D21d]

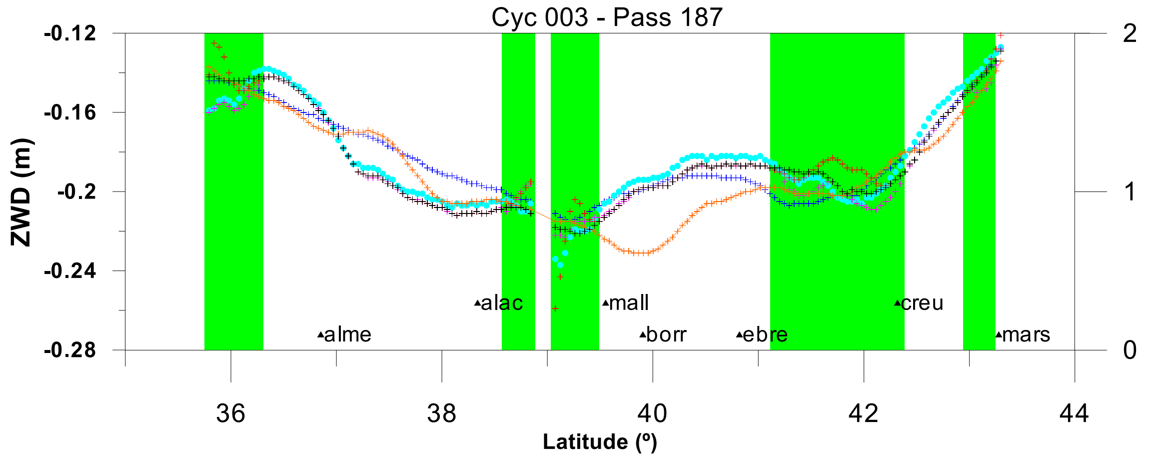

Fig.9 – ZWD for Jason-2 pass 187 cycle 3: ECMWF (blue), ALADIN (orange), GPD (black), MPA (cyan), LPA (pink) and original MWR correction (red).

2.5. WITM - a local tide model for Western Iberia

Work carried out in Phase 1 of COASTALT had already identified a need for local tide models to be used in preference of the global ones, for all those applications where the tide needs to be subtracted.

As a demonstration of this approach, a local tide model, **WITM (West Iberian Tide Model)** has been computed in Phase 2 for one of the COASTALT pilot regions (Western Iberia/Portugal coast, 12ºW ≤ λ ≤ 7ºW and l36ºN ≤ φ ≤ 44ºN), for the period 1991-2005. The model includes the main tidal harmonics M2, S2, N2, K2, K1, O1, P1, Q1, Mf, Mm and Ssa. Values at the open boundaries are taken from the tidal elevations of the global FES2004 model; use of other models (GOT4.7, EOT08a and TPXO.7.2) for the boundary conditions was tested and results in differences of as large as 8 mm at the coast for the tidal elevations.

This model has been computed with a time sampling of 30 minutes and a spatial sampling of 0.01°x0.01° and has been available to the Agency and the COASTALT Partners via the Project FTP site.

The model results have been validated by performing tidal analyses on residual satellite altimetry time-series for the TOPEX/Poseidon and Jason-1 satellite at cross-over points. Envisat cross-overs were also considered but the results of the harmonic analysis for the Envisat satellite were noisier (probably due to the smaller number of repeats at each cross-over) and were not used for the validation.

In addition, the tidal harmonics for tide gauges that are available in the WITM domain were collected from the available literature. Comparison with tide gauge data and the tidal harmonics derived from satellite altimetry data show that WITM performs well in comparison with recent global ocean tide models which have these observations assimilated into them.

Slight misfits observed in some regions could be improved if higher resolution bathymetry from the Hydrographic Institute were available for this study (ETOPO1 was used), which unfortunately was not possible to obtain.

After the tidal maps for the main harmonics were computed, the results were smoothly adjusted to fit the TOPEX/Poseidon observations at the cross-over points perfectly. The adjustments were computed, for each harmonic, for the in and out-phase (also called quadrature) of the tide. For harmonics M2, S2, N2, K1 and O1 these are plotted in the upper two panels of Figures 10 to 14. The lower two panels in each figure show the situation before and after assimilating these observations into the tide model.

Finally, the tidal maps were converted into maps of tidal elevations using the *hardisp* program by D. Agnew.

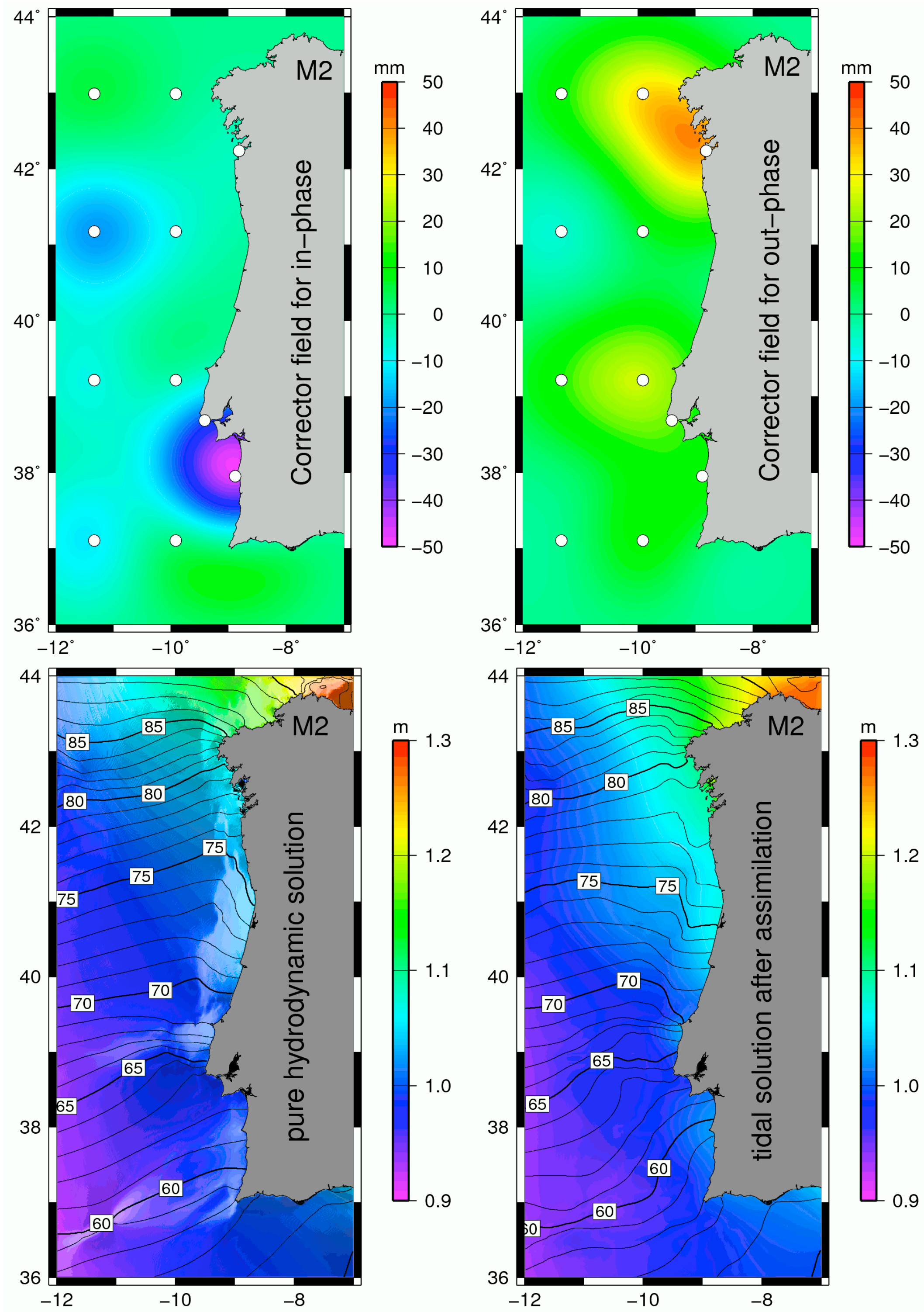

Fig. 10. The corrector fields for harmonic M2 and their effect on the tidal solution.

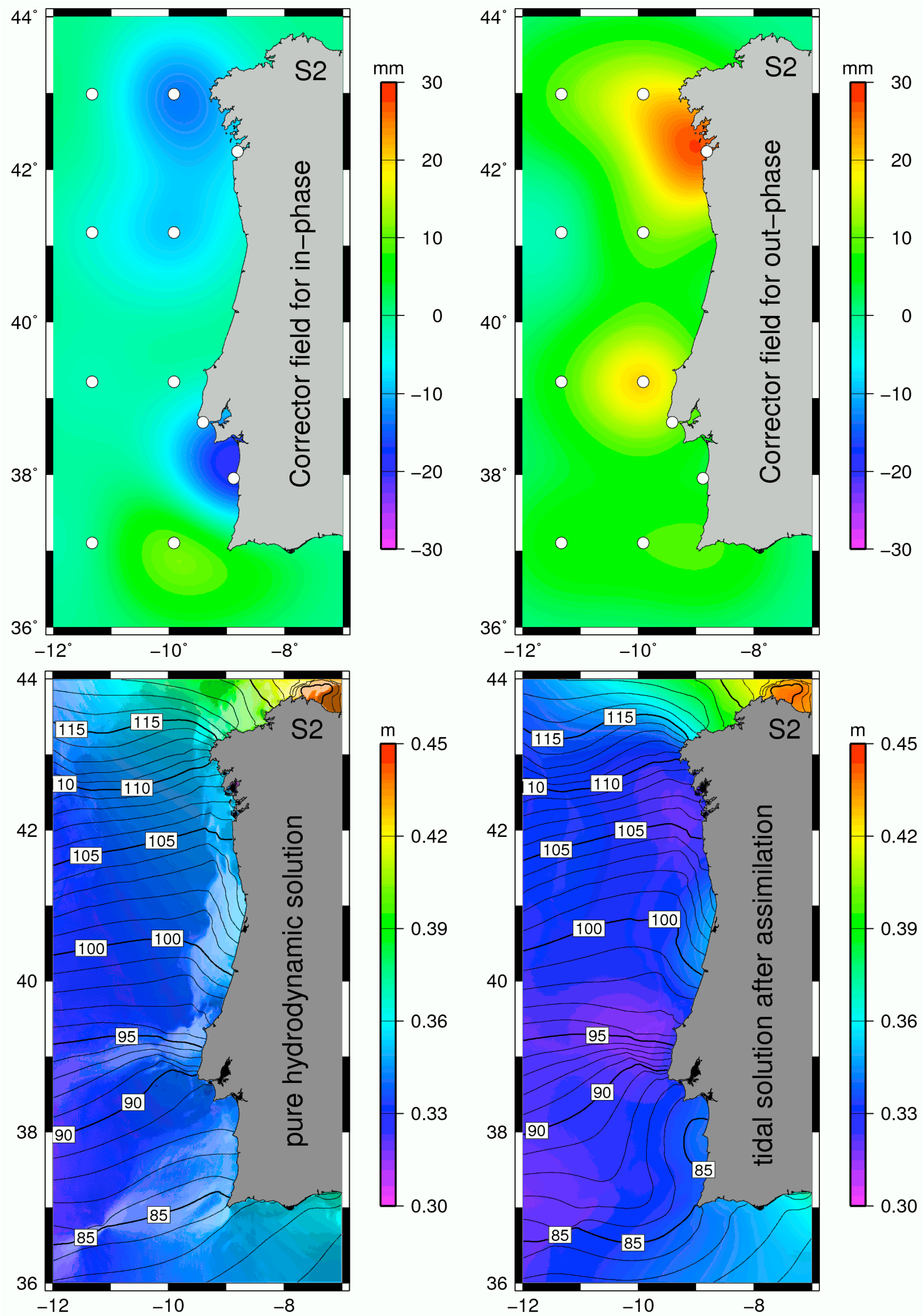

Fig. 11. The corrector fields for harmonic S2 and their effect on the tidal solution.

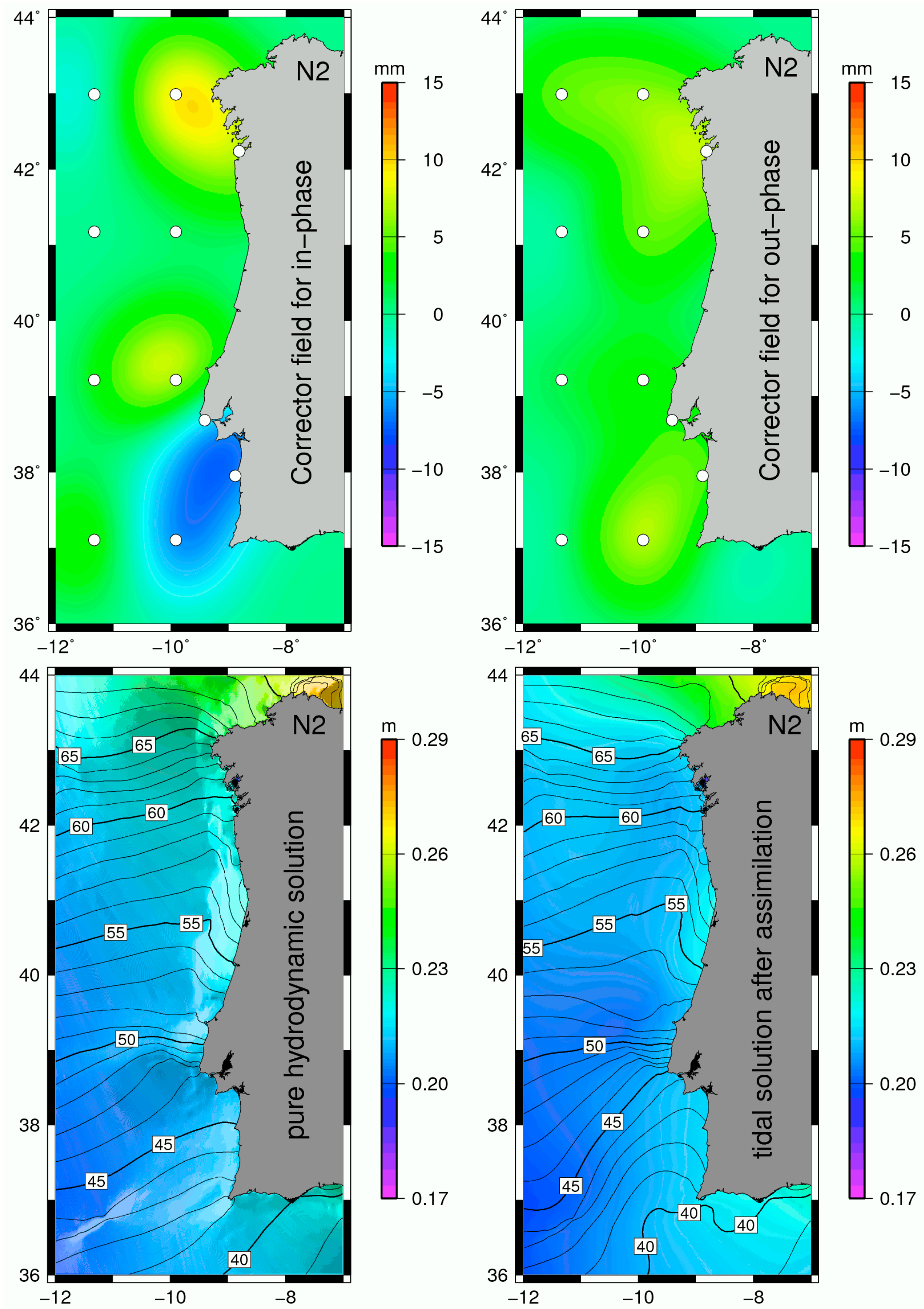

Fig. 12. The corrector fields for harmonic N2 and their effect on the tidal solution.

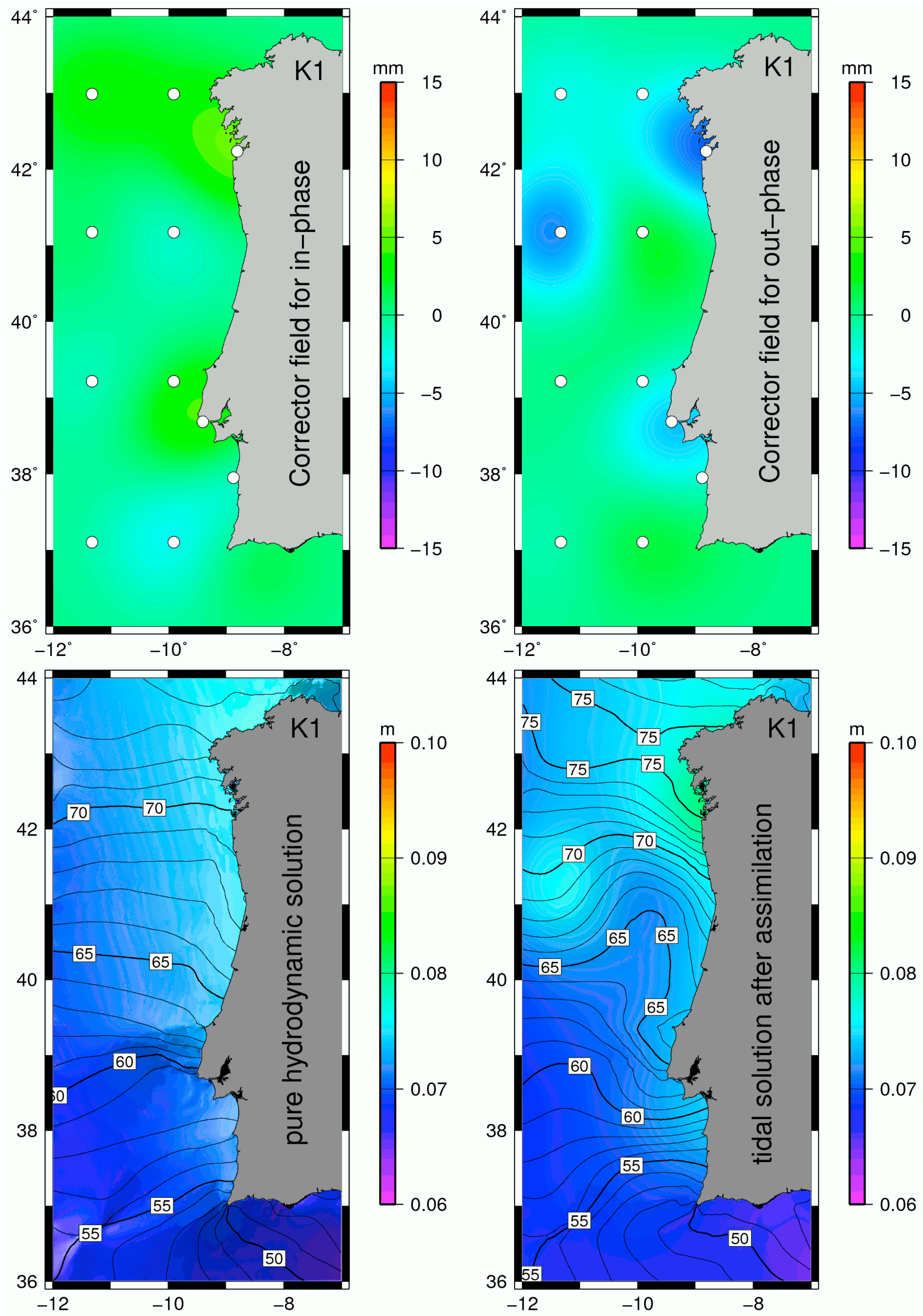

Fig. 13. The corrector fields for harmonic K1 and their effect on the tidal solution

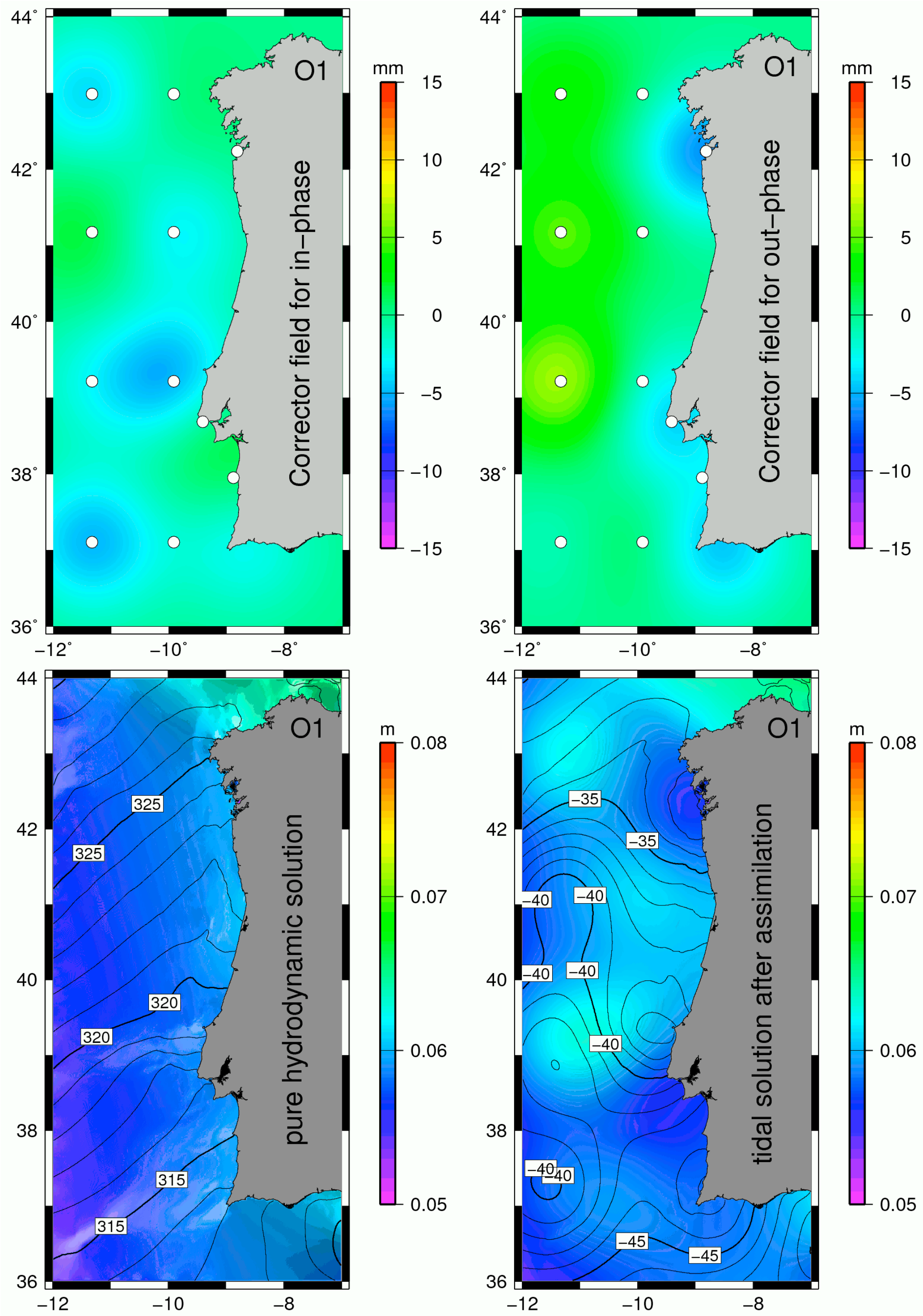

Fig. 14. The corrector fields for harmonic O1 and their effect on the tidal solution.

3. COASTALT Output

3.1. Papers, Presentations and Posters

The activity in the project has resulted into a large number of output/dissemination items, which are all listed in the Annex. First and foremost, the sound scientific quality of the work is testified by the production of **nine refereed publications**: Gomez-Enri et al, Fernandes et al (2), Scozzari et al, Woodworth and Horsburgh, Dufau et al., Gommenginger et al., Obligis et al, Vignudelli et al.

Obviously, the publication work does not stop with the nominal end of the project, but we envisage that it should result into a few more papers: for instance a follow-on paper to Gomez-Enri et al. (2010) and Scozzari et al (2012) is in preparation by Univ. Cadiz and CNR; another paper is in preparation on the SWH validation in the Gulf of Cadiz (some of the relevant material has been included in the Handbook [C2D41b]).

In addition, the COASTALT partners have authored 12 non-refereed papers, and more than 50 presentations as well as 28 posters at international conferences and meetings. The full list is on the COASTALT web site http://www.coastalt.eu and in the Annex to this document.

3.2. COASTALT CGDR data

The COASTALT CGDRs v2.0r3 have been made available to the general public since October 2011 – the announcement was given by the COASTALT Project manager at the 5th Coastal Altimetry Workshop in San Diego.

So far, 15 scientists from different countries (including India, Brazil, Malaysia, South Africa, Iran and some EU) have requested access to the COASTALT pilot reprocessed CGDR. The COASTALT Project manager will monitor usage of the data in the forthcoming months by polling these scientists.

3.3. COASTALT at the centre of the Coastal Altimetry Community

COASTALT has been (and is) at the focus of the international community of researchers involved in the development of coastal altimetry, as proved by the following:

Coastal Altimetry Workshops

COASTALT Project staff have participated in the 1st International Workshop on Coastal Altimetry in Silver Spring, USA, and then have taken the lead in organizing the highly successful 2nd 3rd 4th and 5th workshops in Pisa (Nov 2008), ESRIN Frascati (Sep 2009), Porto (Oct 2010) and San Diego (Oct 2011). These workshops have acted as a showcase of some of the results of the Project. The COASTALT project manager and COASTALT staff are currently busy organizing the 6th edition of the Workshop, to be held in Riva del Garda, Italy, on 20-21

September 2012. In summary, this successful series has been firmly established with a strong contribution by the COASTALT project, and remains the main focus for the international community of scientists working on coastal altimetry, who are coordinated via the COASTALT site at http://www.coastalt.eu/community. COASTALT science and results will also be presented at the '20 Years of Progress in Radar Altimetry' Symposium (Venice, 24-29 September 2012), in particular contributing to a keynote talk on coastal altimetry in the opening session.

COASTALT-SWT

The project coordinator moderates the COASTALT-SWT (Coastal Altimetry Science Working Team) mailing list, with more than 200 subscribers. Details of the list are also available on the COASTALT Web site.

Community White Paper on Coastal Altimetry

The project coordinator was the lead author of the Community White paper on "The role of Altimetry in Coastal Observing System" written for the OceanObs'09 Conference in Venice, September 2009 (Cipollini et al., 2010).

COASTALT and Coastal Altimetry book

The COASTALT partnership has provided two editors (Stefano Vignudelli and Paolo Cipollini) to the book *Coastal Altimetry* by Springer-Verlag; another editor is the COASTALT Scientific Officer on ESA's side, Jérôme Benveniste. Several COASTALT members have contributed significantly to a few of the (refereed) chapters of the book, which is now **the fundamental reference book** for this developing field.

Coastal Altimetry User Handbook

Another very important output from the project is the **User Handbook** (Envisat Coastal Altimetry Product Handbook [C2D41b]) coordinated by Helen Snaith in EWP4. This will be made available by ESA in the suite of Envisat Handbook documents and will undoubtedly be a long-lasting legacy of COASTALT.

The above outreach and international coordination work has ensured that ESA-sponsored research and development in this novel sector remains at the forefront of the international community, thanks to its investment in COASTALT.

4. Lessons Learnt and Recommendations

4.1. Phase 1 Recommendations and how they have been implemented

At the end of Phase 1 (November 2009) the project had already identified a number of recommendations that are described in [D71]. These recommendations are revisited here and we give details on how they have been tackled during Phase 2:

Phase 1 Recommendation 1.1: the GPD correction should be extended and plugged into the COASTALT processor

The Wet Tropospheric is the single correction that promises the most dramatic improvements in the coastal zone. Several research groups in the world are testing new schemes for this correction. COASTALT is at the forefront of this research with the GNSS-based estimation of Path Delay (GPD Technique), designed and prototyped by the University of Porto. Since its start this technique has been met with considerable interest in the several conferences and meeting where it has been presented. In Phase 2 of COASTALT we have fully implemented and validated the technique and the GPD correction files have been incorporated into the products with the “addcorr” module, which is part of the processor development

Phase 1 Recommendation 1.2: a case study based on local accurate tidal models should be demonstrated

The availability of tidal and HF models will of course depend on the particular region, and for some applications (for instance surge studies) these signals should not be removed. However it is important to demonstrate, perhaps with one pilot example, that local tidal models can be successfully employed to improve the recovery of the signal due to the coastal currents. In Phase 2 of COASTALT we have develop a local tidal model for West Iberia (WITM) and this has been tested alongside the global models.

Phase 1 Recommendation 1.3: the development, debugging, testing and maintenance of the coastal Altimetry processor (including thorough low-level quality control of the products) are key issues, so plenty of resources should be allocated to these before passing to validation.

The core of coastal altimetry processing remains a software code (processor) capable of retracking the altimetric waveforms and applying the best selection of corrections available. We have learnt in Phase 1 of COASTALT that implementing such a processor is a very demanding task, which requires a thorough quality control of the new products, so enough resources should be allocated to it prior to committing to the validation of those products against in situ measurements. A significant amount of resources in Phase 2 have been devoted to further debugging and improvement of the processor and have resulted in improved products for scientific validation; however we have learnt at our expenses that as software and calibration issues are resolved one by one, other issues arise and that the optimization of the processor is a very lengthy and time-consuming task. More work remains to be done and this is reflected in the final recommendations in the next section.

Phase 1 Recommendation 1.4: research on coastal retracking, and in particular innovative retrackers, must be continued as it promises to significantly improve the estimation of the geophysical parameters

The research in WP3 has confirmed that a very significant improvement is expected in the coastal region when dedicated retrackers are employed; these include specular and mixed retrackers and also more innovative techniques such as the Bayes and 2-D retrackers studied in WP3.5, which may form the nucleus for a new generation of retrackers for future missions. Again, despite the significant efforts on this (which included a successful Hyperbolic pretracker software, and unsuccessful attempts at prototyping a Bayes Linear retracker), we COASTALT partners feel that further optimization of the retrackers and analysis of the differences between the various retrackers are needed and therefore we repeat this recommendation in the final set of recommendations (and we are keeping on working on this particular issue).

Phase 1 Recommendation 1.5: the processor must be modularized to allow easy pluggin-in of new retracking modules, and its usability must be improved.

The possibility of swapping retrackers, quickly testing new ones or tuning the parameters of the existing ones is the way to an efficient optimization of the retracking schemes. This has been pursued during phase 2 of the project and the processor has been re-engineered to achieve a 'plug-and-play' capability

Phase 1 Recommendation 1.6: proper documentation on the new products is a priority; where possible, this documentation should also fill the information gaps due to the incomplete/missing documentation on the parent data.

Throughout COASTALT there has been a strong interaction between the staff involved in WP3 (the Retracking/Processor workpackage), the staff involved in WP4 (the Products specification workpackage) and ESA. This interaction included detailed scrutiny and discussion of the SGDR products that are ingested by the COASTALT processor to generate the CGDR, and has unveiled some shortcomings in the documentation available from ESA for the Envisat SGDR products. A number of detailed issues have therefore been passed to ESA at Project Meetings. The main lesson learnt is that documentation is crucial to ensure both exploitation of the current product, and development of new products and proper documentation on the CGDR must be provided. This has been achieved in Phase 2 thanks to the Product Specification Document and the CGDR User Handbook, two key deliverables of the project.

Phase 1 Recommendation 1.7: once the products are mature, we need more investments in outreach and capacity building, including careful selection for user-friendly example material aimed at non-experts.

COASTALT had an outreach package that aims at producing simple tutorials to introduce users to the capabilities of the new data. The work to prepare BRAT-based tutorials has soon faced a few problems due on one side to the non-maturity of the early CGDRs, and on the other side to the difficulties by BRAT to ingest and compare data at different rates and the lack of high resolution coastlines. These problems have been followed up directly with the BRAT Help Desk, and have led to a full set of recommendations [see D6] on adaptation and modification of BRAT software routines and on making the COASTALT product compatible with BRAT. The main lesson learnt is that effective tutorials need a careful selection of case studies; however, as also highlighted by WP1 and by the international contacts of COASTALT staff, there is a potentially wide base of users who would be keen to take up coastal altimetry techniques, including from developing countries. The COASTALT partnership remains committed to dissemination of the results and outreach activities, including training. Project staff (P. Cipollini, H. Snaith) have given lectures on coastal altimetry and its potential application in a number of international Schools, listed in the Annex.

4.2. Final Recommendations (F-Recomm) from Phase 2

A first set of recommendations are continuing recommendations on issues already identified in Phase 1 of the project:

F-Recomm 1: further work is needed on the retrackers, both theoretical and in terms of optimization and intercalibration

"Theoretical" means improvement of the existing models (just to make an example including the effect of white caps) or the development of new models (for instance scattering from non-linear surfaces). "Optimization and intercalibration" means not only runtime optimization, but most importantly and assessment of biases and other differences amongst different retrackers, and the development of a set of criteria for retracker selection. We believe that an international exercise for the intercalibration of the various retrackers would be extremely beneficial and that the Space Agencies should support that.

F-Recomm 2: innovative retrackers (which use information in adjacent waveforms) need further R&D to move from concepts to simulations and eventually comparison with real data

This is a most promising field already identified in Phase 1 and the difficulties in the development and implementation of some of the ideas tested (Bayes Linear Retracker, 2-D retracker) should not deter from pursuing further development, with the hope of achieving a full validation of these innovative techniques,

F-recomm 3: to facilitate the work of developers, testers, and the uptake of the data by 'expert users', coastal altimetry processors must be open, flexible, expandable, easily upgradable and fully documented.

Other recommendations arise from the scrutiny of the altimetric data and corrections in the coastal zone and from the interaction of COASTALT with the coastal altimetry community at large:

F-Recomm 4: the whole issue of filtering for the various corrections needs to be revisited, with correlation scales clearly identified and data screening and filtering schemes clearly recommended [these may depend on the application to some extent]

A good example is the work carried out in D2.4 about the correlation scales for the Tropospheric corrections. But other corrections that crucially need a better assessment of the optimal filtering scheme are the ionospheric and the SSB one. A related issue is to see which corrections need to be computed at full rate (18Hz) or if some of them can be interpolated from lower rate data.

F-Recomm 5: the SSB correction needs a reassessment in the coastal zone, with the investigation of specific models.

This is a recommendation that has come out from discussion at the various Coastal Altimetry workshops and is perceived as scientifically challenging, but conducive to very useful results.

And then there are recommendations to ensure that the community makes the most of the data; first one on validation, and then on how the COASTALT work should be extended to other regions and sensors, and how applications of altimetry should be supported:

F-Recomm 6: Validation is crucial and should be supported further

There is in particular a clear need to establish protocols

F-Recomm 7: The techniques developed in COASTALT and similar projects, and the relevant processors should be extended to ensure multi-mission capability.

This applies in particular to the new and forthcoming Delay-Doppler altimetry missions (Cryosat-2, SRAL on Sentinel-3) and to AltiKa, who have intrinsically better capabilities in the coastal zone. This multi-mission capability is one of the objectives, for instance, of the follow-

on work to COASTALT in the ESA DUE eSurge project, which has just started (June 2011).

F-Recomm 8: Coastal Altimetry applications should be supported and encouraged, with easy data access, outreach and training activities, and demonstration studies

The aforementioned eSurge project is a clear example of the transition to applications, but several other possible applications are listed and described in the OceanObs'09 Community White Paper on Coastal Altimetry (Cipollini et al, 2010)

Finally, the following two recommendations came out of discussions between the COASTALT staff and the Agency when wrapping up the executive summary of the project:

F-Recomm 9: The GPD wet tropospheric correction method is extremely promising, but further studies are encouraged on developing a mixed approach that explore the effectiveness of combining different wet tropospheric techniques by mean of Objective Analysis

For instance, techniques that can be combined with GPD are the Mixed-Pixel Algorithm (Brown, 2010)[1] and the Land Proportion Algorithm (Desportes et al., 2007)[2]

F-Recomm 10: coastal altimetry products should be enhanced by inclusion of parameters that help with the screening of the various corrections, like coastal proximity and land fraction in the footprint(s)

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[1] Brown, S. (2010) A novel near-land radiometer wet path delay retrieval algorithm: application to the Jason-2/OSTM advanced microwave radiometer. *IEEE Trans Geosci Remote Sens* 48(4). doi:10.1109/TGRS.2009.2037220

[2] Desportes, C., E. Obligis and L. Eymard (2007) On the wet tropospheric correction for altimetry in coastal regions. *IEEE Trans. Geosci. and Remote Sens.*, vol 45, no 7, pp. 2139-2149

5. Conclusions

With COASTALT, ESA has created an asset that:

- is capable to impact beneficially on the exploitation of ESA Earth Observation data and the uptake, by coastal users, of the data coming from past, present and future missions;
- places ESA-funded research in this novel sector clearly at the focus of the international scene.
- lays the foundation for future developments extending coastal altimetry to other missions and to applications of high societal impact (like the storm surge monitoring and forecasting in the new ESA DUE eSurge project)

Finally, we note explicitly that all the recommendations listed above are in line with the statement with which the scientists taking part in the 3rd Coastal Altimetry Workshop (Frascati, 2009) called for future R&D in Coastal Altimetry:

> *"The Participants to the 3rd CA-WS recommend the continuation of those initiatives (like PISTACH and COASTALT) aiming at the development and distribution of coastal altimetry products and associated documentation".*

ANNEX: COASTALT full list of outputs

A.1. Refereed Papers (total = 4)

J. Gómez-Enri, S. Vignudelli, G.D. Quartly, C.P. Gommenginger, P. Cipollini, P.G. Challenor and J. Benveniste, Modeling Envisat RA-2 waveforms in the coastal zone: Case-study of calm water contamination, *IEEE Geosci. Rem. Sensing Lett.*, vol. 7, no. 3, pp 474–478, July 2010.

M. J. Fernandes, C. Lázaro, A. L. Nunes, N. Pires, L. Bastos, V. B. Mendes, GNSS-derived Path Delay: an approach to compute the wet tropospheric correction for coastal altimetry, *IEEE Geosci. Rem. Sens Lett.*, vol. 7, no. 3, pp. 596–600. July 2010.

A. Scozzari, J. Gómez-Enri, S. Vignudelli, and F. Soldovieri, Understanding target-like signals in coastal altimetry: experimentation of a tomographic imaging technique, *Geophys. Res. Lett.*, *39*, L02602, doi:10.1029/2011GL050237.

M.J. Fernandes, N. Pires, C. Lázaro, A.L. Nunes, Tropospheric delays from GNSS for application in coastal altimetry. *Adv. Space Res.* (2012), http://dx.doi.org/10.1016/j.asr.2012.04.025

A.2. Book chapters (refereed) (total = 5)

C. Dufau, C. Martin-Puig C., L. Moreno, User requirements in the coastal ocean for satellite altimetry, in *Coastal Altimetry*, Eds S. Vignudelli, A. Kostianoy. P. Cipollini, J. Benveniste, Springer, 2011 [contribution in cooperation with the PISTACH Project]

C. Gommenginger, P. Thibaut, L. Fenoglio-Marc, G. Quartly, X. Deng, J. Gómez-Enri, P. Challenor, Y. Gao., Retracking altimeter waveforms near the coasts - A review of retracking methods and some applications to coastal waveforms, in *Coastal Altimetry*, Eds S. Vignudelli, A. Kostianoy. P. Cipollini, J. Benveniste, Springer, 2011 [contribution in cooperation with the PISTACH Project]

E. Obligis, C. Desportes, L. Eymard, J. Fernandes, C. Lázaro, A. Nunes, Tropospheric corrections for coastal altimetry, in *Coastal Altimetry*, Eds S. Vignudelli, A. Kostianoy. P. Cipollini, J. Benveniste, Springer, 2011 [contribution in cooperation with the PISTACH Project]

P.L. Woodworth and K. Horsburgh, Surge Models as Providers of Improved Inverse Barometer Corrections for Coastal Areas, in *Coastal Altimetry*, Eds S. Vignudelli, A. Kostianoy. P. Cipollini, J. Benveniste, Springer, 2011

S. Vignudelli, P. Cipollini, C. Gommenginger, S. Gleason, H. Snaith, H. Coelho, J. Fernandes, C. Lázaro, A. L. Nunes, J. Gómez-Enri, C. Martin-Puig, P. Woodworth, S. Dinardo, J. Benveniste, Satellite Altimetry: sailing closer to the coast, in D.L. Tang (ed.), *Remote Sensing of the Changing Oceans*, DOI 10.1007/978-3-642-16541-2_11, Springer-Verlag, Berlin Heidelberg 2011

A.3. Books:

Vignudelli S., Kostianoy A. G., Cipollini P., Benveniste J. (Editors), in Coastal Altimetry, Springer-Verlag Berlin Heidelberg, doi:10.1007/978-3-642-12796-0, 578 pp, 2011

A.4. Community White Paper – OceanObs'09

[COASTALT contributed to this in collaboration with many members of the international coastal altimetry community:]

P. Cipollini, J. Benveniste, J. Bouffard, W. Emery, C. Gommenginger, D. Griffin, J. Høyer, K. Madsen, F. Mercier, L. Miller, A. Pascual, M. Ravichandran, F. Shillington, H. Snaith, T. Strub, D. Vandemark, S. Vignudelli, J. Wilkin, P. Woodworth, J. Zavala-Garay, "The Role of Altimetry in Coastal Observing Systems", in *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society* (Vol. 2), Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E. & Stammer, D., Eds., ESA Publication WPP-306, 2010.

A.5. Conference and other non-refereed papers (total = 12)

(most recent first)

IGARSS 2012: Paolo Cipollini, Jérôme Benveniste, Craig Donlon, "Coastal Altimetry: recent progress and application to storm surge research", *extended abstract for IEEE IGARSS 2012*, Munich, Germany, 24-29 July 2012 (includes material from COASTALT)

EARSel 2011: I. Caballero, J. Gómez-Enri, G. Navarro, P. Villares, Towards a validation of Envisat RA-2 high rate significant wave height in coastal systems: case study of the Gulf of Cadiz, 5th EARSeL Workshop on Remote Sensing of the Coastal Zone, Prague, Czech Republic, 1st – 3rd June, 2011.

EOS summary of 4CA-WS: M. J. Fernandes, J. Benveniste, S. Vignudelli, Improved Coastal Altimetry Could Contribute to the Monitoring of Regional Sea Level Trends., Eos Trans. AGU, Vol. 92, No. 16, pp 136, 2011.

ESA Living Planet 2010: G. D. Quartly, Hyperbolic Retracker: Removing Bright Target Artefacts from Altimetric Waveform Data, *Proceedings of ESA Living Planet Symposium*, Bergen 2010, ESA SP-686.

MTS/IEEE OCEANS2009: S. Vignudelli, P. Cipollini, C. Gommenginger, H. Snaith, H. Coelho, J. Fernandes, J. Gómez-Enri, C. Martin-Puig, P. Woodworth, S. Dinardo, J. Benveniste, The COASTALT Project: Towards an Operational Use of Satellite Altimetry in the Coastal Zone, *Proceedings of OCEANS 2009 MTS/IEEE Biloxi Conference*, Biloxi, Mississippi, USA, 26-29 October 2009, CD.

EOS summary of 3CA-WS: S. Vignudelli, J. Benveniste, Coastal Altimetry Progresses Toward Applications *EOS Transaction American Geophysical Union*, 91(5), 45, doi:10.1029/2010EO050006, 2010.

SPIE Newsroom: J. Gómez-Enri, S. Vignudelli, G. Quartly, C. Gommenginger, J. Benveniste, Bringing satellite altimetry closer to shore, SPIE Newsroom, doi: 10.1117/2.1200908.1797.

SPIE 2009: J. Gómez-Enri, P. Cipollini, C. Gommenginger, C. Martin-Puig, S. Vignudelli, P. Woodworth, J. Benveniste, P. Villares, Improving coastal altimeter products by a new retracking approach, *Proceedings SPIE Vol. 7473, Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2009*, C. R. Bostater, Jr., S. P. Mertikas, X. Neyt, M. Velez-Reyes (Eds), Berlin, Germany, 31 August 2009, doi:10.1117/12.831080

OceanObs'09: P. Cipollini, C. Gommenginger, H. Coelho, J. Fernandes, J. Gómez-Enri, C. Martin-Puig, H. Snaith, S. Vignudelli, P. Woodworth, S. Dinardo, J. Benveniste, Experimental coastal altimetry data from the COASTALT project, *Additional Contribution to the OceanObs'09 Conference*, Venice (Italy), 21-25 September 2009. (extended abstract)

SPIE 2008: J. Gómez-Enri, P. Cipollini, C. Gommenginger, C. Martin-Puig, S. Vignudelli, P. Woodworth, J. Benveniste, P. Villares, COASTALT: improving radar altimetry products in the oceanic coastal area, *Proceedings SPIE Vol. 7105, Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2008*, C. R. Bostater, Jr., S. P. Mertikas, X. Neyt, M. Velez-Reyes (Eds), Cardiff, U.K., 15-18 September 2008, DOI: 10.1117/12.802456

EOS summary of 2CA-WS: J. Benveniste, S. Vignudelli, Challenges in Coastal Satellite Radar Altimetry, *Eos Trans. AGU*, 90(26), 225, and relevant Supplementary material. doi:10.1029/2009EO260007, 2009.

IAG GGEO 2008: Fenoglio-Marc L., Fehlau M., Ferri L., Becker M., Gao Y., Vignudelli S.: Coastal Sea Surface Heights from Improved Altimeter Data in the Mediterranean Sea, In *Proceedings of IAG International Symposium on Gravity, Geoid and Earth Observation (GGEO2008)* (S. Mertikas, Editor), Chania, Greece, 23-27 June 2008, Springer-Verlag Berlin Heidelberg, 135 (33), 253-261 doi:10.1007/978-3-642-10634-7_33, 2010.

A.6. Presentations (total = 55)

(most recent first)

COSPAR 2012: P Cipollini, J Benveniste, S. Vignudelli and the COASTALT Team, COASTALT Project’s contribution to the development and dissemination of coastal altimetry, talk at 39th COSPAR Scientific Assembly, Mysore (India), 14 - 22 July 2012.

MOMAR Workshop: P Cipollini, New Earth Observation products for Regional & Coastal Oceanography: the contribution of Coastal Altimetry, *invited talk at MOMAR final Workshop “Coastal Observing and Forecasting Systems, Today & Tomorrow”*, Livorno, Italy, 18-19 April 2012.

GODAE COSS-TT: Jérôme Benveniste, Paolo Cipollini, Nicolas Picot, The contribution of altimetry to monitoring and forecasting the coastal ocean, *International Workshop of the GODAE Coastal and Shelf Seas Task Team (COSS-TT),* University of Miami, Florida, USA, 10–12 January 2012.

RESELECASEA: Stefano Vignudelli and the COASTALT Team, "Coastal Altimetry - a Review", *presented ad RESELECASEA Project Workshop*, Bogor, Indonesia, 16-18 November 2011.

OSTST 2012: Paolo Cipollini, Coastal Reflections: New Science and Open Questions from the Coastal Altimetry Workshop, *keynote talk at the Ocean Surface Topography Science Team (OSTST) meeting*, San Diego, USA, 19-21 October 2011. (includes contributions from COASTALT)

5CA-WS: Paolo Cipollini and the COASTALT Team, Recommendations for the Future of Coastal Altimetry, *talk at 5th Coastal Altimetry Workshop*, San Diego, USA, 16–18 October 2011.

5CA-WS: Joana Fernandes, Clara Lázaro, Miguel Salgado, Alexandra Nunes, Paolo Cipollini, Wet Tropospheric Correction: filling the gaps from coast to coast, *talk at 5th Coastal Altimetry Workshop*, San Diego, USA, 16–18 October 2011.

5CA-WS: Paolo Cipollini and the COASTALT Team, Technical Achievements and Data from the COASTALT Project, *talk at 5th Coastal Altimetry Workshop*, San Diego, USA, 16–18 October 2011.

5CA-WS: J. Gómez-Enri, I. Caballero, G. Navarro, S. Vignudelli, B. Tejedor, P. Cipollini and P. Villares, Advances in the Validation of Coastal Altimetry Full Rate Wave Data (COASTALT Project), *talk at 5th Coastal Altimetry Workshop*, San Diego, USA, 16–18 October 2011.

COASTALT Final WS: Paolo Cipollini, COASTALT Executive summary and Recommendations, *talk at COASTALT final open Workshop*, ESRIN, Frascati, Italy, 21 June 2011.

Mediterranean Sea Level WS: P. Cipollini and the COASTALT Team, The contribution of Coastal Altimetry to Mediterranean Sea Level Research, *presented by M. Tsimplis at the Workshop on unresolved issues in Mediterranean Sea Level*, Mallorca (Spain), 30 May-1 June 2011.

EGU 2011: Cipollini P., Benveniste J., Gommenginger C.., and COASTALT team, COASTALT: an international effort to enable science with coastal altimetry, *European Geosciences Union (EGU) General Assembly*, Vienna, Austria, 3-6 April 2011, Vol. 13, EGU2011-13431, 2011.

Chania 2011: Vignudelli S., and COASTALT team, Coastal Altimetry: past, present and future, *Technical Workshop on Satellite Altimetry Calibration & Deformation Monitoring with GNSS*, Chania, Greece, 20-21 January, 2011. (invited talk)

AARSE 2010: Bernard S., Byfield V., Cipollini P., Rouault M., Vignudelli S., Realizing the potential of coastal altimetry for Africa, *8th International Conference of the African Association of Remote Sensing and the Environment (AARSE)*, Addis Ababa, Ethiopia, 25-29 October, 2010.

OSTST Lisbon 2010: Cipollini P., Vignudelli S., and COASTALT team, Coastal Altimetry moving: an update on the COASTALT Project, *Ocean Surface Topography Science Team Meeting (OSTST)*, Lisbon, Portugal, 18-20 October, 2010.

4CA-WS: M. J. Fernandes, C. Lázaro, N. Pires, M. Salgado, A. Nunes, P. Cipollini, GPD- Towards a Global Implementation, *4th Coastal Altimetry Workshop*, University of Porto, Porto, Portugal, 14-15 October, 2010.

4CA-WS: Gomez-Enri J., Scozzari A., Quartly G., Vignudelli S., Cipollini P., Benveniste J., and COASTALT team, Quality Checking and Validation of Coastal Altimetry: Strategy and Preliminary Results, *4th Coastal Altimetry Workshop*, University of Porto, Porto, Portugal, 14-15 October, 2010.

4CA-WS: Gomez-Enri J., Vignudelli S., Cipollini P., Tejedor B., Villares P., Some Advances in the Coastal Envisat RA-2 Data Validation in the Gulf of Cadiz (Spain), *4th Coastal Altimetry Workshop*, University of Porto, Porto, Portugal, 14-15 October, 2010.

4CA-WS: Cipollini P., and COASTALT team, International Efforts to enable Science with Coastal Altimetry, *4th Coastal Altimetry Workshop*, University of Porto, Porto, Portugal, 14-15 October, 2010.

4CA-WS: Snaith H., and COASTALT team: COASTALT: The new Coastal Altimetry Products from the COASTALT Project, *4th Coastal Altimetry Workshop*, University of Porto, Porto, Portugal, 14-15 October, 2010.

IGARSS 2010: Cipollini P., Challenor P., Coelho H., Fernandes J., Gomez-Enri J., Gommenginger C., Martin-Puig C., Quartly G., Snaith H., Vignudelli S**.**, Woodworth P., Dinardo S., Benveniste J., Progress in Coastal Altimetry: outcomes of the COASTALT project, *International Geosciences and Remote Sensing Symposium (IGARSS)*, Honolulu, Hawaii, US, 25-30 July, 2010.

IGARSS 2010: López-León P., Gómez-Enri J., Tejedor B., Aboitiz A., Vignudelli S., Villares P., Envisat RA-2 sea level data validation using mean sea level data from a tide gauge in the Gulf of Cadiz (Spain), *International Geosciences and Remote Sensing Symposium (IGARSS)*, Honolulu, Hawaii, US, 25-30 July, 2010.

COSPAR 2010: Cipollini P., Barbosa S., Gommenginger G., Fernandes J., Gomez-Enri J., Martin-Puig C. Vignudelli S., Woodworth P., Benveniste J., Bastos L., Byfield V., Challenor P., Dinardo S., Gleason S., Lázaro C., Luca B. M., Moreno L., Nunes A., Pires N., Quartly G., Scozzari A., Snaith L., Tsimplis M., Wolf J., Altimetry in the coastal zone: summary and outlook of the COASTALT project, *38th Committee on Space Research (COSPAR) Assembly*, Bremen, Germany, 18 -25 July, 2010.

ESA Living Planet 2010: P. Challenor and I. Andrianakis, The Bayes Linear Altimeter Retracker, *European Space Agency ENVISAT Living Planet Symposium*, Bergen, Norway, 28 June – 2 July, 2010.

ESA Living Planet 2010: S. Barbosa**,** M. J. Fernandes, C. Lázaro, A. Nunes, N. Pires, P. Cipollini, Validation of coastal altimetry data along the west Iberian coast, altimetry *European Space Agency ENVISAT Living Planet Symposium*, Bergen, Norway, 28 June – 2 July, 2010.

ESA Living Planet 2010: M. J. Fernandes, C. Lázaro, A. Nunes, N. Pires, P. Cipollini, Tropospheric corrections for coastal altimetry *European Space Agency ENVISAT Living Planet Symposium*, Bergen, Norway, 28 June – 2 July, 2010.

ESA Living Planet 2010: Cipollini P., Vignudelli S., and COASTALT Team, Coastal Altimetry moves forward: a summary of the COASTALT project, *European Space Agency ENVISAT Living Planet Symposium*, Bergen, Norway, 28 June – 2 July, 2010.

ESA Living Planet 2010: Gómez-Enri J., Quartly G., Vignudelli S., Cipollini P., Scozzari A., Flashes of brilliance: Investigating causes of altimeter anomalies in the coastal zone, *European Space Agency ENVISAT Living Planet Symposium*, Bergen, Norway, 28 June – 2 July, 2010.

ESA Living Planet 2010: López-León P., Gómez-Enri J., Tejedor B., Vignudelli S., Villares P., Flashes of brilliance: Investigating causes of altimeter anomalies in the coastal zone, *European Space Agency ENVISAT Living Planet Symposium*, Bergen, Norway, 28 June – 2 July, 2010.

EARSeL 2010: Gómez-Enri J., López-León P., Vignudelli S**.**, Cipollini P., Gommenginger C., Gleason S., Benveniste J., Villares P., Coastal Envisat RA-2 data validation in the Gulf of Cadiz (Spain), *30th European Association of Remote SEnsing Laboratories (EARSEL) Symposium*, Paris, France, 31 May – 3 June, 2010.

Ocean from Space Venice 2010: Cipollini P., and COASTALT Team, The COASTALT project for coastal altimetry and its contribution to the monitoring of coastal sea level, *4th Oceans from Space Symposium*, Venice, Italy, 26-30 April, 2010.

AGU FM 2009: Vignudelli S**.**, Cipollini P., Gommenginger C., Snaith H., Coelho H., Fernandes J., Gómez-Enri J., Martin-Puig C., Woodworth P., Dinardo S., Benveniste J., The COASTALT project: towards an operational use of satellite altimetry in the coastal zone, *American Geophysical Union Fall Meeting*, San Francisco, United States, 14-18 December, 2009.

MTS/IEEE OCEANS2009: S. Vignudelli, P. Cipollini, C. Gommenginger, H.M. Snaith, H. Coelho, J. Fernandes, J. Gómez-Enri, C. Martin-Puig, P. Woodworth, S. Dinardo, J. Benveniste, The COASTALT Project: Towards an Operational Use of Satellite Altimetry in the Coastal Zone, *presented at OCEANS 2009 MTS/IEEE Biloxi Conference*, Biloxi, Mississippi, USA, 26-29 October 2009 (paper in proceedings)

3CA-WS: S. M. Barbosa, M. J. Fernandes, C. Lazaro, P. Leitao, A. L. Nunes, N. Pires, P. Cipollini, Wavelet-Based Comparison of Coastal Altimetry Data and In-situ Tide Gauge Measurements Along the West Iberian Coast, *presented at 3rd Coastal Altimetry Workshop*, ESA/ESRIN, Frascati, Italy, 17-18 September 2009. (abstract in abstract book)

3CA-WS: M. J. Fernandes, C. Lazaro, A. L. Nunes, N. Pires, L. Bastos, V. B. Mendes, S. Barbosa, P. Cipollini, GNSS-Derived Path Delay: A Method to Compute the Wet Tropospheric Correction for Coastal Altimetry, *presented at 3rd Coastal Altimetry Workshop*, ESA/ESRIN, Frascati, Italy, 17-18 September 2009. (abstract in abstract book)

3CA-WS: J. Gómez-Enri, G. Quartly, S. Vignudelli, C. Gommenginger, P. Cipollini, P. Challenor, J. Benveniste, P. Lopez-Leon, P. Villares, Coastal Altimery: Case-Studies of Ocean Waveform Contamination, *presented at 3rd Coastal Altimetry Workshop*, ESA/ESRIN, Frascati, Italy, 17-18 September 2009. (abstract in abstract book)

SPIE 2009: J. Gómez-Enri, P. Cipollini, C. Gommenginger, C. Martin-Puig, S. Vignudelli, P. Woodworth, J. Benveniste, P. Villares, Improving coastal altimeter products by a new retracking approach, *Presented at SPIE Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2009*, Berlin, Germany, 31 August 2009, doi:10.1117/12.831080

ACCESS WS: P. Cipollini and the COASTALT crew, Coastal Altimetry: on the 'wish list' for a Southern African OOS, *presented at the ACCESS Workshop on Designing, planning and implementing an Oceanography System for Southern Africa* , Cape Town, South Africa, 20-22 July 2009.

IGARSS 2009: P. Cipollini and the COASTALT crew, Advances in coastal altimetry: the COASTALT Project outlook, *presented at IEEE IGARSS 2009*, Cape Town (South Africa), 13-17 July 2009.

OSTST 2009: G. Quartly, J. Gómez-Enri, S. Vignudelli, P. Cipollini, P. Challenor, C. Gommenginger and J. Benveniste, Singular reflections on the Golfo della Botte, *presented by G. Quartly at 2009 Ocean Surface Topography Science Team meeting*, Seattle, Usa, 22-24 June 2009. Abstract in Abstracts & Program, p. 64.

EGU 2009: P. Cipollini, C. Gommenginger, H. Coelho, J. Fernandes, J. Gómez-Enri, C. Martin-Puig, S. Vignudelli, P. Woodworth, S. Dinardo, J. Benveniste, Progress in Coastal Altimetry: the experience of the COASTALT Project, *presented at EGU 2009 General Assembly*, Vienna, Austria, 20-24 April 2009. Abstract in Geophysical Research Abstracts, Vol. 11, EGU2009-12862, 2009

Kiel 2009: P. Cipollini, Coastal Altimetry: recent developments and proposed use in the Agulhas region, *presented at the Workshop on the SW Indian Ocean*, IFM GEOMAR Kiel, Germany, 2-3 March 2009

AGU FM 2008: J. Benveniste, N. Picot, S. Vignudelli, P. Cipollini, Progress in Observing the Coastal Zone by Radar Altimetry, *presented at AGU 2008 Fall Meeting*, S. Francisco, USA, 15-19 December 2008. Abstract in Eos Trans. AGU, 89(53), Fall Meet. Suppl., Abstract OS41B-1227

OSTST 2008: P. Cipollini, Take home messages from the 2nd Coastal Altimetry Workshop, *plenary talk at OSTST Nice*, France, 10-12 November 2008.

2CA-WS: C. Dufau, C. Martin-Puig, User Requirements (for coastal altimetry), *presented at the 2nd Coastal Altimetry Workshop*, Pisa (Italy), 6-7 November 2008. [joint PISTACH/COASTALT contribution]

2CA-WS: J. Gómez-Enri, C. Gommenginger, P. Challenor, S. Vignudelli, P. Cipollini, P. Villares, P. Woodworth, J. Benveniste, Envisat RA-2 Coastal Waveform Analysis in the Western Mediterranean Sea and West Britain during the ESA COASTALT Project, *presented at the 2nd Coastal Altimetry Workshop*, Pisa (Italy), 6-7 November 2008.

2CA-WS: M.J. Fernandes, A.L. Nunes, C. Lázaro, N. Pires, L. Bastos, V.B. Mendes, Wet Tropospheric Correction for Coastal Altimetry based on GNSS path delay measurements , *presented at the 2nd Coastal Altimetry Workshop*, Pisa (Italy), 6-7 November 2008.

2CA-WS: C.Gommenginger, S. Gleason, H. Snaith, P. Challenor, G. Quartly, H. Snaith, J. Gómez-Enri, The COASTALT prototype processor & products, *presented at the 2nd Coastal Altimetry Workshop*, Pisa (Italy), 6-7 November 2008.

2CA-WS: J. Benveniste, European Effort in Coastal Zone Altimetry, *presented at the 2nd Coastal Altimetry Workshop*, Pisa (Italy), 6-7 November 2008.

IGARSS 2008: P. Cipollini, H. Coelho, J. Fernandes, J. Gomez-Enri, C. Gommenginger, C. Martin-Puig, S. Vignudelli, P. Woodworth, J. Benveniste, Developing radar altimetry in the oceanic coastal zone: the COASTALT project, *presented at IEEE IGARSS 2008*, Boston, USA, 6-11 July 2008.

ESEAS 2008: P. Cipollini, M. Tsimplis and the COASTALT Partners, Developing radar altimetry in the oceanic coastal zone: the COASTALT project, *presented by Mikis Tsimplis at the ESEAS Meeting*, Paris, 6-7 May 2008

ALTICORE-Africa WS: P. Cipollini, S. Vignudelli, Coastal Altimetry: a brief introduction, *presented at the ALTICORE-Africa Workshop*, Cape Town (South Africa), 21 April 2008.

ALTICORE-Africa WS: P. Cipollini, M. Tsimplis, C. Martin-Puig, L. Moreno, A. Pi Figueroa, S. Vignudelli, C Dufau, F Mercier, Product requirements in coastal zone: results from the COASTALT and PISTACH projects, *presented at the ALTICORE-Africa Workshop*, Cape Town (South Africa), 21 April 2008.

ALTICORE-Africa WS: P. Cipollini, Validation in Coastal Altimetry, *presented at the ALTICORE-Africa Workshop*, Cape Town (South Africa), 21 April 2008

EGU 2008: P. Cipollini, J. Gómez-Enri, C. Gommenginger, C. Martin-Puig, S. Vignudelli, P. Woodworth, J. Benveniste, Developing radar altimetry in the oceanic coastal zone: the COASTALT project, *presented at EGU General Assembly 2008*, Vienna, Austria, 13-18 April 2008. Abstract in Geophysical Research Abstracts, Vol. 10, EGU2008-A-09805, 2008.

A.7. Posters (total = 28)

(most recent first)

EGU2012: P. Cipollini, J. Benveniste, and the COASTALT Team, "COASTALT Project's contribution to the development and dissemination of coastal altimetry", *poster at EGU General Assembly 2012*, Vienna, 22-27 April 2012.

EGU2012: S. M. Barbosa and M. J. Fernandes, "Space-time variability of geophysical corrections from the COASTALT coastal altimetry product in the west Iberia region", *poster at EGU General Assembly 2012*, Vienna, 22-27 April 2012.

MOMAR Workshop: P Cipollini, S.Vignudelli, A Scozzari, J Benveniste and the COASTALT Team, COASTALT: Coastal Altimetry contributes to regional sea level monitoring, *poster at MOMAR final Workshop "Coastal Observing and Forecasting Systems, Today & Tomorrow"* Livorno, Italy, 18-19 April 2012

GLOSS Surge WS: Paolo Cipollini, J. Benveniste, et al., “The Role of Altimetry in Coastal Observing Systems”, *poster at GLOSS Workshop on Storm Surge Monitoring and Extreme Sea Levels*, UNESCO Paris, France, 7-8 November 2011

GLOSS Surge WS: P. Cipollini, P. Woodworth, J. Benveniste and the COASTALT team, COASTALT: coastal altimetry contributes to regional sea level monitoring, *poster at GLOSS Workshop on Storm Surge Monitoring and Extreme Sea Levels*, UNESCO Paris, France, 7-8 November 2011.

OSTST 2011: Peter Challenor, Luke West, Paolo Cipollini, Bayes Linear, *poster at the Ocean Surface Topography Science Team (OSTST) meeting*, San Diego, USA, 19-21 October 2011.

OSTST 2011: Joana Fernandes, Clara Lázaro, Alexandra Nunes, Paolo Cipollini, Global comparison of microwave radiometer, GNSS and ECMWF derived path delays, *poster at the Ocean Surface Topography Science Team (OSTST) meeting*, San Diego, USA, 19-21 October 2011.

OSTST 2011: Paolo Cipollini and the COASTALT Team, Technical Achievements, Data and Recommendations from the COASTALT Project, *poster at the Ocean Surface Topography Science Team (OSTST) meeting*, San Diego, USA, 19-21 October 2011.

OSTST 2011: Graham Quartly, Hyperbolic pretracker: a means to filter waveform data, *poster at the Ocean Surface Topography Science Team (OSTST) meeting*, San Diego, USA, 19-21 October 2011.

5CA-WS: S. M. Barbosa, M. J. Fernandes, P. Cipollini, COASTALT Product Validation at the Cascais Tide Gauge, *poster at 5th Coastal Altimetry Workshop*, San Diego, USA, 16–18 October 2011.

5CA-WS: Peter Challenor, Luke West, Paolo Cipollini, Bayes Linear Retracking in the Coastal Zone, *poster at 5th Coastal Altimetry Workshop*, San Diego, USA, 16–18 October 2011.

5CA-WS: Graham Quartly, Hyperbolic pretracker: a means to filter waveform data, *poster at 5th Coastal Altimetry Workshop*, San Diego, USA, 16–18 October 2011.

IUGG 2011: Cipollini P., Woodworth P., Benveniste J., Vignudelli S**.**, and COASTALT team, COASTALT: coastal altimetry contributes to regional sea level monitoring, *XXIV International Union of Geodesy and Geophysics (IUGG) General Assembly*, Melbourne, Australia, 27 June – 8 July, 2011.

NURC MREA 2010: Cipollini P., and COASTALT team, A summary of the COASTALT Project and its contribution to the monitoring of coastal sea level, *NATO Undersea Research Centre (NURC) Rapid Environmental Assessment (REA) Conference* – “Quantifying, Predicting and Exploiting uncertainties in the marine environment”, Lerici, La Spezia, Italy, 18-22 October, 2010.

Hydrology Workshop Lisbon 2010: Gomez-Enri J., Scozzari A., Quartly G., Vignudelli S., Cipollini P., Benveniste J., and COASTALT team: Envisat RA-2 Satellite Altimetry in Coastal and Inland Waters: A comparison of Retrackers, *Towards High-Resolution of Ocean Dynamics and Terrestrial Surface Waters from Space Workshop*, Lisbon, Portugal, 21-22 October, 2010.

OSTST Lisbon 2010: Cipollini P., Vignudelli S., and COASTALT team, Coastal Altimetry moving: an update on the COASTALT Project, *Ocean Surface Topography Science Team Meeting (OSTST)*, Lisbon, Portugal, 18-20 October, 2010.

4CA-WS: Gomez-Enri J., Vignudelli S., Cipollini P., Tejedor B., Villares P., Some Advances in the Coastal Envisat RA-2 Data Validation in the Gulf of Cadiz (Spain), *4th Coastal Altimetry Workshop*, University of Porto, Porto, Portugal, 14-15 October, 2010.

4CA-WS: S. Gleason S., C. Gommenginger, H. Snaith, P. Cipollini : The COASTALT Processor for Coastal Altimetry, *4th Coastal Altimetry Workshop*, University of Porto, Porto, Portugal, 14-15 October, 2010.

4CA-WS: Gomez-Enri J., Scozzari A., Quartly G., Vignudelli S., Cipollini P., Benveniste J., and COASTALT team, Quality Checking and Validation of Coastal Altimetry: Strategy and Preliminary Results, *4th Coastal Altimetry Workshop*, University of Porto, Porto, Portugal, 14-15 October, 2010

ESA Living Planet 2010: G. D. Quartly, Hyperbolic Retracker: Removing Bright Target Artefacts from Altimetric Waveform Data, *European Space Agency ENVISAT Living Planet Symposium*, Bergen, Norway, 28 June – 2 July, 2010.

EGU 2010: Cipollini P., Barbosa S., Coelho H., Fernandes J., Gomez-Enri J., Gommenginger G., Martin-Puig C. Vignudelli S., Woodworth P., Benveniste J., and COASTALT team, A summary of the COASTALT project and its contribution to the monitoring of coastal sea level, *European Geosciences Union (EGU) General Assembly*, Vienna, Austria, 2-7 May, 2010, Vol. 12, EGU2010-9859, 2010.

EGU 2010: S. Barbosa**,** M. J. Fernandes, C. Lázaro, A. Nunes, N. Pires, P. Cipollini, Comparison of coastal altimetry and tide gauge data along the west Iberian coast *European Geosciences Union (EGU) General Assembly*, Vienna, Austria, 2-7 May, 2010, Vol. 12, EGU2010-13395, 2010.

OceanObs'09: P. Cipollini, C. Gommenginger, H.M. Snaith, H. Coelho, J. Fernandes, J. Gómez-Enri, C. Martin-Puig, S. Vignudelli, P. Woodworth, S. Dinardo, J. Benveniste, Making Coastal Altimetry Happen: a Prototype Envisat Processor From the COASTALT Project, *poster presented at the OceanObs'09 Conference*, Venice (Italy), 21-25 September 2009.

3CA-WS: P. Cipollini, C. Gommenginger, H.M. Snaith, H. Coelho, J. Fernandes, J. Gómez-Enri, C. Martin-Puig, S. Vignudelli, P. Woodworth, S. Dinardo, J. Benveniste, Making Coastal Altimetry Happen: a Prototype Envisat Processor From the COASTALT Project, *poster presented at 3rd Coastal Altimetry Workshop*, ESA/ESRIN, Frascati, Italy, 17-18 September 2009.

3CA-WS: V. Byfield, P. Cipollini, H. M. Snaith, P. G. Challenor, S. Vignudelli, P. L. Woodworth, Coastal Altimetry Education: Case Studies and Lessons, *poster presented at 3rd Coastal Altimetry Workshop*, ESA/ESRIN, Frascati, Italy, 17-18 September 2009

3CA-WS: P. López-León, J. Gómez-Enri, S. Vignudelli, C. Gommenginger, P. Cipollini, H. Snaith, B. Tejedor, P. Villares, J.

Benveniste, Assessment of Envisat COASTALT altimetry processor in the Gulf of Cadiz (Spain), *poster presented at 3rd Coastal Altimetry Workshop*, ESA/ESRIN, Frascati, Italy, 17-18 September 2009

OSTST 2009: Joana Fernandes, Alexandra Nunes, Clara Lázaro, Nelson Pires, Luisa Bastos,Virgílio Mendes, Paolo Cipollini, GNSS-derived path delay (GPD) – a method to obtain the Wet Tropospheric correction for coastal altimetry, *poster at 2009 Ocean Surface Topography Science Team meeting*, Seattle, Usa, 22-24 June 2009. Abstract in Abstracts & Program, p. 69-70.

AGU 2008: P. Cipollini, C. Gommenginger, H.M. Snaith, H. Coelho, J. Fernandes, J. Gómez-Enri, C. Martin-Puig, S. Vignudelli, P. Woodworth, S. Dinardo, J. Benveniste, Making Coastal Altimetry Happen: a Prototype Envisat Processor From the COASTALT Project, *poster at AGU 2008 Fall Meeting*, S. Francisco, USA, 15-19 December 2008. Abstract in Eos Trans. AGU, 89(53), Fall Meet. Suppl., Abstract IN51B-1153

A.8. Teaching/Outreach (total = 4)

P. Cipollini, “A short course on altimetry”, *4 lectures at ESA 2nd Advanced Training on Ocean Remote Sensing*, VilVite Bergen, Norway, 29 September 2009. (~60 students) [includes material on coastal altimetry and COASTALT]

P. Cipollini, lecture on "Satellite altimetry: a powerful way to observe the oceans" (4h) at the *Univ. of Sannio Summer School on "Ocean Observation with Remote Sensing Satellites",* Benevento, Italy, 18-19 June 2010. (~25 students) [includes material on coastal altimetry and COASTALT]

P. Cipollini, 2-h lecture on “Remote Sensing, with Applications to the Mediterranean Sea”, at the “Environmental impacts know no boundaries” school, La Spezia, Italy, 6 June 2011 [includes material on coastal altimetry and COASTALT]

H. Snaith “A short course on altimetry”, lectures at EAMNET workshop Cape Town, June 2011, [includes material on coastal altimetry and COASTALT]