EXPERIMENTAL COASTAL ALTIMETRY DATA FROM THE COASTALT PROJECT

Paolo Cipollini(1), Christine Gommenginger(1), Henrique Coelho(2), Joana Fernandes(3), Jesus Gomez-Enri(4), Cristina Martin-Puig(5), Helen Snaith (1), Stefano Vignudelli(6), Philip Woodworth(7), Salvatore Dinardo(8), Jérôme Benveniste(9)

(1) Ocean Observing and Climate, National Oceanography Centre, Southampton, U.K. (cipo@noc.soton.ac.uk), (2) Hidromod, Lisbon, Portugal, (3) Faculdade de Ciências, Universidade do Porto, Portugal, (4) Universidad de Cádiz, Spain, (5) Starlab Barcelona S.L., Barcelona, Spain, (6) Istituto di Biofisica, Consiglio Nazionale delle Ricerche, Pisa, Italy, (7) Proudman Oceanographic Laboratory, Liverpool, U.K., (8) Serco/ESRIN, Frascati, Italy, (9) European Space Agency/ESRIN, Frascati, Italy

The coastal zone is one of the new frontiers for satellite altimetry. It is primarily in this zone that the effects of rising sea levels, storm surges and changing coastal ocean dynamics are suffered by humans and nature. The ensuing impact on environment, society and economy is so significant that it calls for a large observational and modeling effort, so that our ability to *observe* and *predict* coastal dynamics and *mitigate* the effects of coastal hazards is sustained and increased. Any observing system that can deliver useful information in this crucial region must be exploited, even more so if it allows reprocessing of long time series of archived data and helps to establish long-term trends and climatologies. Such is the case of altimetry, a success story over the open ocean, but still profoundly underexploited in the coastal area where processing and data correction issues have so far resulted in systematic flagging and rejection of 17 years of data. Having recognized the importance of recovering those measurements, the major Space Agencies are now sustaining coastal altimetry research through projects such as COASTALT (funded by ESA, the European Space Agency), PISTACH (funded by CNES, the Centre National d'Etudes Spatiales in France) and some initiatives jointly funded by CNES and the U.S. National Aeronautics and Space Administration (NASA) within the OST-ST (Ocean Surface Topography Science Team) framework. It is now clear that by overcoming the technological problems and extending the capabilities of current and future altimeters to the coastal zone, the altimeter-derived measurements of sea level, wind speed and significant wave height can play an obvious role in coastal ocean observing systems (Cipollini et al., 2009).

The COASTALT project, which we present here, aims at defining, developing and testing a prototype software processor for ESA's Envisat RA-2 radar altimeter. COASTALT is essentially a scientific study leading to experimental RA-2 products over just a few pilot coastal areas surrounding Europe. However the techniques developed in COASTALT are a first step towards a full reprocessing of Envisat coastal altimetry products globally, also in preparation for exploitation of data from the future altimetry missions, CryoSat and Sentinel-3. These missions will have inherently improved coastal zone capabilities by virtue of the adoption of a Delay-Doppler instrument, also known as SAR altimeter (Raney, 1998).

The initial phase of the project consisted of an evaluation of the requirements for the new coastal product by means of a survey within the community of potential users. This provided valuable recommendations, for instance on:

- desired quantities – there is widespread interest not only in sea surface height (SSH), but also in significant wave height (SWH) and to a lesser extent in wind speed;
- domain and posting rate – users asked for along-track data as close as possible to the coast, with the maximum posting rate compatible with an acceptable signal-to-noise-ratio, which may depend on the application. This, in practice, implies that data should be processed at the maximum posting rate available in the raw altimetric records (18Hz for

RA-2), leaving to the user to decide the level of average most suited to their particular application;

- level of detail – a significant part of users asked for the fields to be provided with individual corrections (HF dynamics for example) to facilitate their use in synergy with 2D and 3D models, plus quality flags, error budget and some clear documentation on the characteristics and limitations of the products;
- data formats– NetCDF being the preferred format.

Despite COASTALT being an experimental (i.e. not operational) project, the above recommendations have helped to design a prototype product already in line with the users' needs, facilitating its future extension and further development.

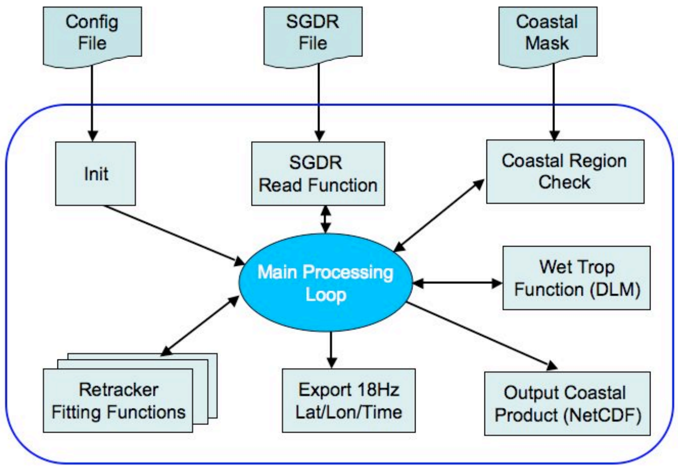
In parallel to the user requirement survey, the geophysical corrections were also assessed. The main contributions to the SSH error budget in the coastal zone remain those from the path delay induced by tropospheric water vapour ('wet tropospheric' correction) and from the tides. The wet tropospheric correction in the COASTALT product is generated by dynamic extrapolation of the open-ocean correction (which in turn is derived by onboard microwave radiometer measurements and very accurate, but failing within ~20km from the coast as land enters the radiometer footprint) by using the ECMWF atmospheric model. This is called the "Dynamically Linked Model" (DLM) correction. The project, however, also investigated a different approach, namely the use of of ZTD (Zenith Total Delay) estimates derived from Global Navigation Satellite System (GNSS) measurements, and their meteorological correction to ZWD – Zenith Wet Delay. This technique requires careful mathematical mapping of the 'slant' GNSS-derived measurements into the corresponding vertical (zenith) quantities; results are extremely promising and we recommend that this correction be further explored and possibly included in future versions of the product.

In all those applications needing the removal of tides and high-frequency (HF) oceanic and atmospheric signals, large errors in tidal models and in the models used to obtain high-frequency and inverse barometer corrections remain a problem. In the COASTALT prototype product we duplicated the global tidal model already present in the RA-2 Sensor Geophysical Data Records (SGDRs) that are input to the coastal processor. We leave to the user the option of adding one or more regional tidal and HF models (using the UCGC module as explained below), which may be more accurate.

The central task in COASTALT is the design and coding of the prototype software processor, i.e. the software code that generates the improved coastal altimetry data (which we refer to as Coastal Geophysical Data Records, or CGDRs) by fitting a parametric model to the raw hi-rate ocean return signals (waveforms), a process known as *waveform retracking*. This code also generates some improved corrections. In more detail, the COASTALT processor consists of two functional units, which are both run as stand-alone applications:

A) the baseline COASTALT Processor. The processing options of the baseline processor are controlled by the user at run-time through an editable configuration file. The baseline processor components, interfaces and data flow are shown in Figure 1.

The Main Processing Loop (MPL) controls all other system blocks. Which ones are called is determined using the information and flags in the configuration file, read in immediately after the start of execution by the Init module. The MPL reads through the entire SGDR data file, processing the individual entries if they belong to the coastal region mask (this mask is customizable by the user). Then, for each waveform in both the Ku and S bands, the MPL calls three different waveform retrackers (one based on the Brown waveform model, one based on a specular waveform shape, and a mixed Brown+specular one). Subsequently – and for each retracker output – the processor computes the new 18Hz corrections and the wet tropospheric correction with the DLM algorithm. Finally, the processor outputs the retracked parameters (from all three retrackers) plus all the corrections to the CGDR NetCDF file.



- **Figure 1: Process and data flow in the COASTALT Baseline processor**

B) the User-defined Coastal Geophysical Corrections (UCGC) module. The UCGC module is an optional add-on for users interested in ingesting their own user-defined geophysical corrections into the COASTALT product.

From the point of view of data structure, the CGDRs can be seen as an evolution of the RA-2 level 2 SGDRs, as defined in the Envisat product handbook and product specification documents. Not all records from the Envisat SGDR data are copied to the COASTALT CGDR though – instead, only those data considered necessary for processing of the output data, or useful for direct comparison with the new fields, are included. The NetCDF (network Common Data Form) data format was chosen as suggested by the user community and as it is extremely flexible, self-describing, platform-independent and has been adopted as a de-facto standard for many operational oceanography systems. Although the latest version of NetCDF (v. 4) has advantages in terms of data compression, COASTALT CGDRs are being produced in NetCDF v. 3 format, to retain maximum compatibility with existing software and for simplicity of installation, as it does not require the additional HDF 5 and compression libraries.

The final phase of the COASTALT project is now dealing with the validation of the CGDRs over the pilot sites, by comparison with tide gauges and other in situ measurements and models. At the same time the project is producing a user handbook and a selection of case study examples to be implemented into a tutorial module for BRAT (http://earth.esa.int/brat/). Further information on the project is available at http://www.coastalt.eu .

References

Cipollini, P. and 19 co-authors (2009), The Role of Altimetry in Coastal Observing Systems, *OceanObs09 Community White Paper*.
Raney, R. K. (1998) "The delay Doppler radar altimeter," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 36, pp. 1578-1588.