COASTAL ALTIMETRY: RECENT PROGRESS AND APPLICATION TO STORM SURGE RESEARCH

Paolo Cipollini[1], Jérôme Benveniste[2], Craig Donlon[3]

[1] National Oceanography Centre, Southampton, U.K.
[2] ESA/ESRIN, Frascati (Rome), Italy
[3] ESA/ESTEC, Noordwjik, The Netherlands

1. INTRODUCTION

Satellite altimeters have been monitoring the global ocean for 20 years, with an excellent degree of accuracy; but in the coastal strip the data are normally flagged as bad for a number of technical problems, and therefore rejected. However this situation is rapidly changing: prompted by the tantalizing prospect of recovering 20 years of data over the coastal ocean, and encouraged by the improved suitability for coastal applications of new and future altimeters (like those on Cryosat-2, AltiKa and Sentinel-3), a lively community of researchers in coastal altimetry has coalesced in the last few years, and is developing techniques to recover useful measurements of sea level and significant wave height in the coastal strip, as well as implementing and promoting new applications (for an overview of the entire discipline see [1]). The major space agencies are strongly supporting R&D in this new field with initiatives like ESA's COASTALT (for Envisat) and CNES' PISTACH (for Jason-2). The coastal altimetry community holds regular workshops (see http://www.coastalt.eu/community) where the science and techniques of coastal altimetry are reviewed and the various applications are showcased and discussed. The present contribution revisits briefly the many recent technical improvements that are contributing to the steady progress of this new field and presents a new project supported by the European Space Agency where coastal altimetry data are expected to give a significant contribution to the monitoring and forecasting of storm surges, one of the deadliest natural phenomena.

2. METHODS OF COASTAL ALTIMETRY

Two classes of problems are encountered when trying to recover meaningful estimates of geophysical parameters (sea level, significant wave height and wind speed) from altimeter data in the coastal zone. First, there are problems due to the modification of the altimetric echoes (waveforms) when land enters the footprint of the instrument. Then there are problems due to the unavailability or inaccuracy of some of the corrections that need to be applied to the raw altimetric measurements to account for instrumental, atmospheric or other geophysical effects (for instance tides). Both these classes of problems are described below.

2.1. Need for improved Retracking

The first class of problems impact on the shape of the waveforms and affect the retrieval of parameters which is normally carried out by fitting a waveform model to the waveforms, a process known as *retracking*. While waveforms over the open ocean are well fitted by the Brown model [2], in close proximity to the coast (0–10km) more sophisticated retracking approaches are needed [3]. The impact of land on waveforms will not only depend on crude 'distance from coast' but also on the coastal topography; in the coastal zone waveforms will normally suffer an attenuation due to missing ocean surface elements in the altimetric footprint (as land returns are normally weaker then those from the ocean), but their shape is also modified by returns from land elements close to the coastline at an elevation different from zero. An effort is underway within the ESA-funded Sea Level Climate Change Initiative (SL-CCI) Project to quantify these effects of land proximity and morphology on the waveforms, by defining a *coastal proximity parameter* that can then be used to screen the coastal altimetry data to see whether the data are amenable to derive climate-level time series allowing a significant assessment of the rate of sea level rise. Figure 1 shows an example of coastal proximity parameter in the area of Elba Island, Tuscan Archipelago. The parameter is designed to vary between –1 (corresponding to the open ocean i.e. where there are no effects of land on the waveforms) to + 1 (corresponding to far inland, were there is virtually no recoverable information from the sea). Note how, for given distance from the coastline, the parameter tends to be lower (indicating higher chances of a successful retracking) in the adjacency of a tip or peninsula, and higher (indicating a more difficult retracking) in recessed bays.

Several retracking schemes optimized for the coastal environment have been devised in recent years, for instance to account for the peaky waveforms due to quasi-specular reflections from calm waters [4], and within the COASTALT and PISTACH Projects. Both projects are also investigating techniques to treat each waveform not in isolation, but using the information from the previous and following ones: this is an area of very active ongoing research that will hopefully pave the way for the next generation of altimeter retrackers.

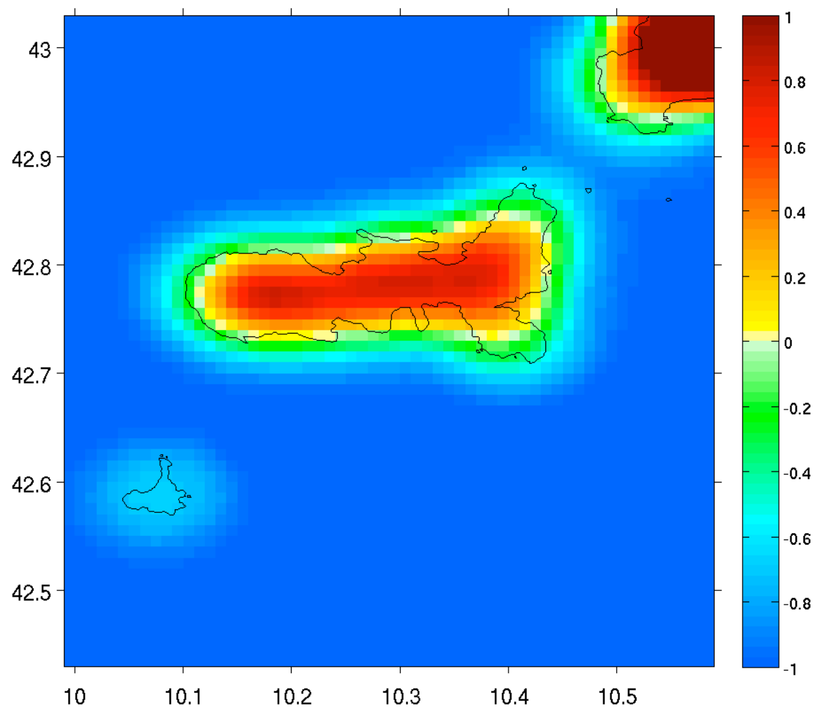

Fig. 1: example of coastal proximity parameter derived for the ESA SL-CCI Project

2.2. Need for optimized corrections

The most critical corrections in the coastal zone are ocean tides, water vapour, and the sea state bias (SSB). The SSB, i.e. the bias on the range estimate dependent on the sea state and due to the shape of the sea surface not being perfectly sinusoidal, is in need of further investigation to migrate from the actual empirical correction models towards physically–based ones, a difficult task even over the open ocean, let alone in the coastal zone. However the largest uncertainty in the coastal altimetry data comes from inaccurate removal of the tides (the global tidal models improve at every new release but still do not perform well in many coastal and shelf locations) and from the inaccurate correction of the path delay due to water vapour, known as 'wet tropospheric correction'. As far as tides are concerned, the obvious solution is to develop accurate local tidal models, which then need to be merged with the global models. Notably, some applications do not require the application of this correction – a case in point is the study of storm surges, where the contribution due to tides must be included in the measured water level. The wet tropospheric correction is normally estimated from a multi-channel passive microwave radiometer on the same platform as the altimeter, but this estimate gets quickly corrupted as soon as land enters the radiometer footprint, i.e. 20–50 Km from the coast. Alternative corrections have been devised and appear to be successful at least in some conditions [5],[6]. A very promising scheme is the one attempting to estimate the wet tropospheric path delay from GPS measurements, known as GPD (GNSS-derived Path Delay) and developed within COASTALT [7].

Some of the techniques described above have been implemented in software processors used to routinely reprocess coastal altimetry data, like the Jason-2 data generated by PISTACH and made available by AVISO.

3. APPLICATION TO STORM SURGES

Many possible applications of coastal altimetry were presented and discussed at the recent 5th Coastal Altimetry workshop (October 2010). All presentations and posters from the workshop are available at http://www.coastalt.eu/sandiegoworkshop11. One of the most promising applications is the one to the study of storm surges. The understanding and realistic modelling of surges supports both preparation and mitigation activities and should eventually bring enormous societal benefits, especially to some of the world's poorest countries (like Bangladesh). Earth Observation data have an important role to play in storm surge monitoring and forecasting, but the full uptake of these data by the users (such as environmental agencies and tidal prediction centres) must be first encouraged by showcasing their usefulness, and then supported by providing easy access.

Having recognized the above needs, ESA has recently launched a Data User Element (DUE) project called *eSurge***.** The main purposes of eSurge are a) to contribute through Earth Observation to an integrated approach to storm surge, wave, sea-level and flood forecasting as part of a wider optimal strategy for building an improved forecast and warning capability for coastal inundation; and b) to increase the use of the advanced capabilities of ESA and other satellite data for storm surge applications. The project is led by Logica UK, with NOC (UK), DMI (Denmark), CMRC (Ireland) and KNMI (Netherlands) as scientific partners.

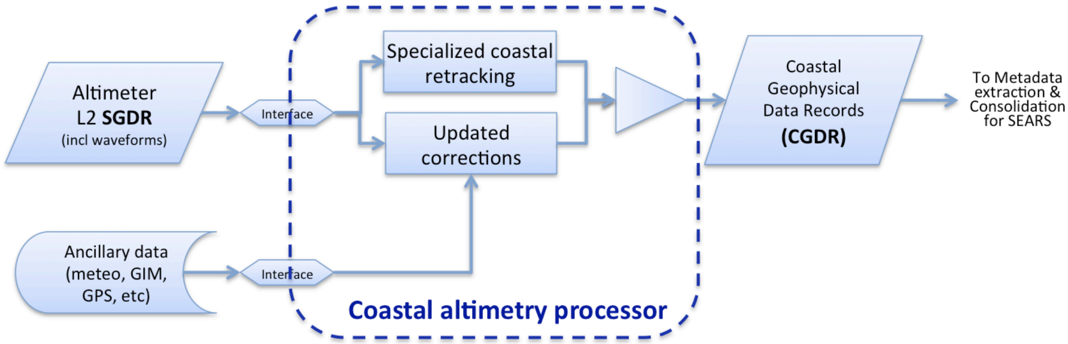

Fig. 2: schematic of the coastal altimetry processor for the ESA eSurge Project

A very important component of eSurge is the development, validation and provision of dedicated coastal altimetry products. Coastal altimetry has a prominent role to play as it measures directly the total water level envelope (TWLE), i.e. one of the key quantities required by storm surge applications and services. But it can also provide important information on the wave field in the coastal strip, which helps the development of more realistic wave models that in turn can be used to improve the forecast of wave setup and overtopping processes. We will present examples of how altimetry has captured a few significant surge events in European Seas, and we will describe how a multi-mission coastal altimetry processor is going to be integrated in the eSurge system. The delayed-time reprocessed coastal altimetry data will be blended with tide gauge data to extract the main modes of variability in the coastal regions. Then data from the tide gauges can be used to estimate the water level in real time, based on the modes of variability found.

In a later phase of the project, the eSurge coastal altimetry processor (fig.2) will be extended to be able to ingest NRT raw altimetric waveforms and generate the relevant NRT products, a definite first for coastal altimetry. The pilot regions for this application will be the European Seas and the North Indian Ocean. In summary, we expect eSurge to be one of the first pre-operational applications of coastal altimetry and a proof of the benefits to society that can be brought by this relatively new branch of marine remote sensing.

4. REFERENCES

[1] Vignudelli, S., A. Kostianoy, P. Cipollini and J. Benveniste (eds.), *Coastal Altimetry*, Springer, Berlin Heidelberg, 578 pp, 2011. doi:10.1007/978-3-642-12796-0

[2] Brown, G. S., The average impulse response of a rough surface and its applications. *IEEE J. Oceanic Eng*., OE-2, 67-74, 1977.

[3] Gommenginger, C., 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.

[4] Deng, X., Featherstone, W., A coastal retracking system for satellite radar altimeter waveforms: application to ERS-2 around Australia. *Journal of Geophysical Research,* 111, C06012. doi:10.1029/2005JC003039, 2006.

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

[6] Brown, S., A Novel Near-Land Radiometer Wet Path-Delay Retrieval Algorithm: Application to the Jason-2/OSTM Advanced Microwave Radiometer, *IEEE Trans. On Geoscience and Remote Sensing*, 48, 1986-1992, doi: 10.1109/TGRS.2009.2037220, 2010.

[7] Fernandes, M. J. , 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., 2010