COASTAL ALTIMETRY, FROM DATA PROCESSING TO INDUSTRIAL APPLICATIONS: SOME ILLUSTRATIONS

M. Cancet[(1)], E. Jeansou[(1)], J. Lamouroux[(1)], F. Crespon[(1)], F. Birol[(2)], F. Lyard[(3)], R. Morrow[(2)], E. Bronner[(4)], J. Benveniste[(5)]

[(1)] NOVELTIS, 153 rue du Lac, 31670 Labège (France), Email:Mathilde.Cancet@noveltis.fr
[(2)] CTOH/LEGOS/OMP/UPS, 14 Avenue Edouard Belin, 31400 Toulouse (France)
[(3)] LEGOS/OMP/UPS, 14 Avenue Edouard Belin, 31400 Toulouse (France)
[(4)] CNES, 18 Avenue Edouard Belin, 31400 Toulouse (France)
[(5)] ESA/ESRIN, Via Galileo Galilei, Casella Postale 64, 00044 Frascati (Italy)

ABSTRACT

During the last ten years, many efforts were made to develop corrections and processing strategies dedicated to the coastal altimetry observations. Ever since, the coastal altimetry data has proved to be of high value in many scientific and industrial applications. This paper gives an overview of some of NOVELTIS recent projects related to coastal altimetry, from the products improvement and assessment to the promotion of coastal altimetry through the development of new added-value products.

1. INTRODUCTION

For more than 20 years, the satellite altimetry missions have been providing sea surface height information all over the global ocean with a precision at the centimetre level in the open ocean. In the coastal zones, the quality of the measurements is degraded because of the land proximity, which affects the signals of the radar altimeter and the contingent on-board microwave radiometer. The knowledge of the coastal ocean dynamics is of prime importance due to the large populations that live on the shores and the social and economic stakes it represents (environment, fisheries, sea transport, marine energy resources, etc…). During the last ten years, many efforts were made by different groups to develop corrections and processing strategies dedicated to the coastal altimetry observations ([1]; [2]; [3]; [4]). Ever since, the coastal altimetry data has proved to be of high value in many scientific and industrial applications. This paper presents some of the coastal altimetry projects in which NOVELTIS was involved these last years. The first section illustrates some examples of regional corrections implemented for the ocean tide and the ionosphere path delay. Then, some illustrations of our studies for product assessment are presented, based on the PISTACH coastal altimetry products. The last section concerns our activities to promote coastal altimetry through the development of new products for coastal engineering or industrial applications, such as tidal energy resource assessment.

2. IMPROVING COASTAL ALTIMETRY

Retrieving reliable altimetry measurements in the coastal zones is challenging in more than one way. Not only are the radar altimeter measurements as well as some corrections (e.g. wet tropospheric correction) and parameters (e.g. mean sea surface) degraded by the proximity of the land, but the ocean dynamics is also more complex than in the open ocean, with smaller structures and more interactions that require high resolution models especially for the tide and the DAC corrections.

2.1. Regional tide correction

With amplitudes ranging from a few centimetres to several meters in some continental shelf regions, the ocean tides contribute strongly to the ocean topography variability observed by the satellite altimeters, and more particularly in the coastal areas. In most scientific applications using altimetry data, global models are used to correct the altimeter sea surface heights from the tide in order to focus on other signals of the ocean dynamics. The accuracy of these models is generally at the centimetre level in the open ocean [5]. The main error sources are principally located in the coastal areas and in the high latitudes, where the tidal signal is amplified and more difficult to comprehend because of the complex and often not well-documented bathymetry. In addition, the dynamics of the tide is generally strongly non-linear in the shelf seas.

A global tidal model must provide an accurate tidal solution all over the world despite the constraints inherent to its coverage. In the case of a tidal atlas based on an assimilated hydrodynamic model solution, the model grid resolution and the number of assimilated observations are limited by the computing resources. The global tidal modelling is necessarily a compromise to provide a good tidal solution everywhere, and a best-effort solution in the coastal regions, where the tidal

Proc. 'ESA Living Planet Symposium 2013', Edinburgh, UK
9–13 September 2013 (ESA SP-722, December 2013)

dynamics is more complex and consequently needs more resolution and more assimilated observations.

The improvements in the coastal altimeter data processing have naturally led to the implementation of regional high resolution tidal models with the objective to more properly correct the altimeter data by increasing the models accuracy and extending the prediction spectrum, in particular with non-linear and minor constituents. Since 2008, NOVELTIS, in collaboration with LEGOS and CTOH, has developed high resolution regional and local tidal models, such as the COMAPI tidal atlases (CNES project) over the North East Atlantic (NEA) and the Mediterranean Sea.

These regional atlases benefit from many improvements, compared to global models [6]: better bathymetry, higher resolution of the mesh, regional tuning of the model parameters, larger number of assimilated observations, extended tidal wave spectrum…

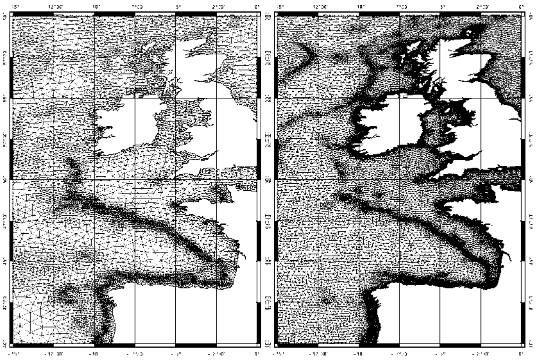

Figure 1. Extracts of the FES2012 model mesh (left) and the regional tidal model mesh (right) in the NEA region.

Fig. 1 illustrates the refinement of a regional model mesh in the North East Atlantic ocean (NEA) compared to the FES2012 model mesh [7]. In this case, the size of the finite elements ranges between 500 m and 25 km for the regional model, whereas the FES2012 model mesh ranges between 75 km in the deep ocean and 7.5 km in the shallow waters. With such a fine grid resolution, a regional model is able to model the non-linear structures with an accuracy of a few centimetres.

2.2. High resolution ionospheric correction

In some cases, the proximity of the land can be of benefit for the altimetry data corrections as it gives the possibility to take advantage of more independent observations, such as GPS networks in the case of the ionospheric correction. In 2004, NOVELTIS developed the SPECTRE operational service, which, since then, has provided Total Electron Content (TEC) maps over Europe, based on dense GPS networks (Fig.2, [8]). This service was initially implemented in order to detect the ionosphere variations due to the seismic activity. However, the TEC maps can also be used for many other applications such as the monitoring of land deformation in the SAR interferometry images, the telecommunication disruptions due to ionospheric perturbations and the construction of a high resolution ionospheric correction for the altimetry data.

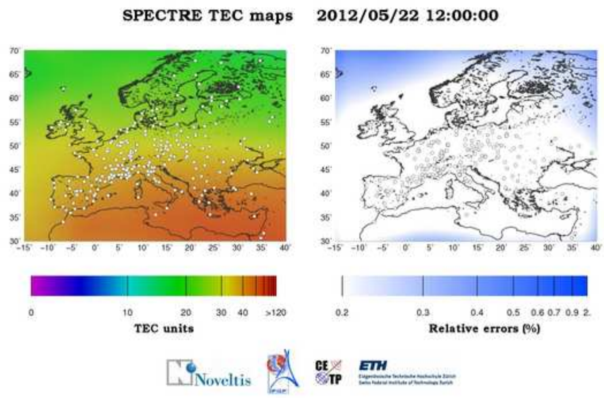

Figure 2. TEC and RMS (in percentage) maps estimated by the SPECTRE service from the GPS receivers (white dots) of the European network

The space resolution of the SPECTRE-TEC maps is 2.5° x 2.5°, while the GIM (Global Ionosphere Map) products have a longitudinal resolution of 5°. However the best improvement concerns the time resolution, as the SPECTRE products are updated every 30 seconds, whereas it is done every 2 hours for the GIM products. The increase of the space and time resolutions allows estimations of the ionospheric perturbations at smaller space and time scales. This is of particular interest in the high latitudes, where the ionosphere is affected by sudden and extreme increases of the TEC due to the occurrence of geomagnetic storms. Moreover, the space and time scales of ionization patterns during storms are smaller (time spans of 10-15 minutes) than the ionosphere dynamics patterns at mid and low latitudes. Therefore, ionosphere maps with increased space and time resolutions may significantly improve the accuracy of the ionospheric correction for satellite altimeters, in particular those reaching the high latitudes (ERS-1/2, Envisat, CryoSat, SARAL/AltiKa…). A regional ionospheric correction derived from the SPECTRE maps will be assessed over Europe for the CryoSat mission in the frame of the ESA project CryoSat Plus for Ocean (CP4O).

3. ASSESSING COASTAL ALTIMETRY

Each time a new global correction or parameter is released, an extensive global validation is performed. However, this kind of validation generally considers the data in boxes of several degrees of latitude and longitude, which can hide some local behaviour, especially near the coasts. This is why an in-depth local or regional validation is also necessary, in order to assess the new products in all kinds of geographic configurations (open ocean, coastal zones, proximity of islands…). This complementary validation can not only be applied to the corrections but also to the retracking strategies and the post-processing of the data (editing, filtering, etc…).

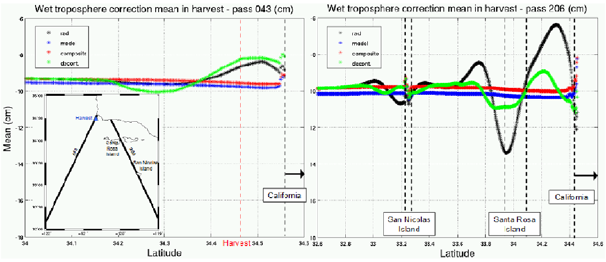

Figure 3. Local analysis of the wet tropospheric corrections available in the PISTACH coastal products.

Fig. 3 provides an illustration of the very different mean behaviours of the various wet tropospheric corrections available in the PISTACH coastal products. This kind of along-track local analysis provides additional information concerning the quality of the corrections. It also gives some complementary material to the users and highlights what kind of patterns they can encounter with these products.

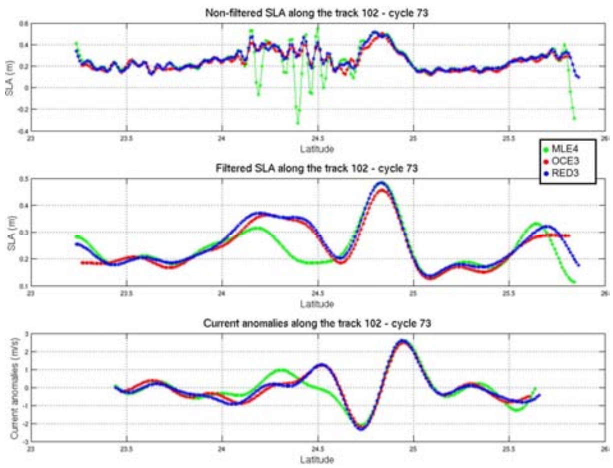

Figure 4. Analysis of the retracking strategies in the SLA (raw and filtered) and derived current anomalies along the track 102 and for cycle 73, level 3 PISTACH coastal products in the Florida Strait.

Some rather simple diagnostics performed on the sea level anomalies (SLA) such as the computation of the standard deviation over all the available cycles, along the track, can help the users to identify potential suspect behaviours in the data. Fig. 4 illustrates how some unrealistic variations in the SLA, probably due to some rain cell not well managed by the MLE4 retracker, can lead to large errors once the SLA are filtered, and then in the derived geostrophic current anomalies. The verification of the coastal altimetry data via simple statistics is consequently highly recommended before using them for any scientific applications.

Comparisons with independent data such as tide gauges, current-meters, other satellite observations (sea surface temperature, ocean colour) or even model outputs, also help to assess the altimetry data near the coasts ([9], [10]). Even if the physical contents are not always similar from one source of data to the other, some patterns are generally comparable (coastal current position, eddies, fronts).

Providing some of these diagnostics, as well as the global validation results, increases the confidence in the products and gives some local elements of comparison to the users, who can reproduce the same analysis easily. In addition, it can be of help for the selection of the most appropriate combination of corrections or data processing for local scientific applications.

4. DEVELOPING ADDED-VALUE PRODUCTS

Most of the coastal altimetry data users are altimetry experts, scientists from oceanography centres and labs or ocean modellers. Most of the studies using coastal altimetry data are academic. The altimetry data, and *a fortiori* the coastal altimetry data, are rarely known of the industrial world. However, potential end-users exist, often without knowing it. Indeed, there are many under-exploited possibilities to use altimetry data in their fields, such as coastal engineering (surge model validation, assimilation, regional high resolution mean sea surface and currents maps…) and marine energy resource assessment (e.g. tidal models and wave models).

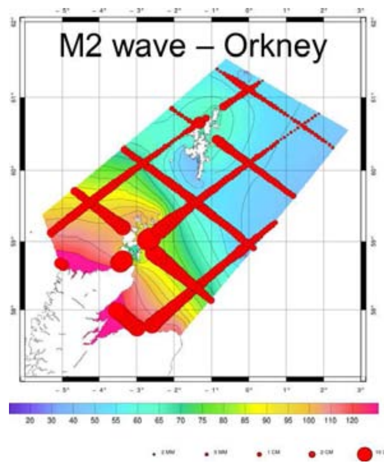

Figure 5: Comparison between the local tidal model developed by Noveltis in the Orkney islands region and the CTOH coastal altimetry harmonic constituents for the M2 wave, superimposed to the amplitude (in cm) of the model M2 wave. The size of the red dots is proportional to the vector differences between the model and the altimetry observations.

For several years, NOVELTIS has been promoting coastal altimetry through its industrial projects. For example, a local tidal model was recently developed in the Orkney (and Shetland) islands region (Fig. 5), where the European Marine Energy Centre (EMEC) settled ten years ago. In particular, this centre holds a tidal test site where the marine energy companies can test their marine turbine in real conditions. For this kind of applications, high resolution tidal models are required for the elevations and the currents, and coastal altimetry is a powerful tool that can be used as boundary conditions, for assimilation and for validation. Indeed, the coastal altimetry observations can dramatically complete the generally small tide gauge networks, in order to better constrain the models.

Then, some added-value products can be derived from these regional and local tidal models which benefit from coastal altimetry. In particular, tidal currents are a key parameter for the settlement and maintenance of offshore infrastructures such as platforms, rigs, wind-farms and submarine turbines. For example, it is possible to compute some tidal energy diagnostics with these high resolution tidal currents (main tidal current directions, average power density…), which are of high interest for the selection of tidal energy sites. For these kinds of applications, the use of high resolution tidal models is absolutely crucial, as energy efficiency and economic issues are at stake.

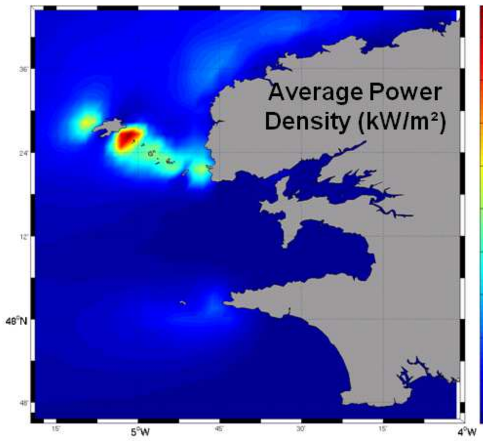

Figure 6. Average power density of the tide in the Ushant Sea, computed from the TIPS regional tidal currents.

Finally, in order to promote high resolution regional and local tidal modelling for academic and industrial applications, NOVELTIS developed a service, TIPS (TIdal Prediction Service, www.tips.noveltis.fr), which provides tidal elevations and currents predictions on demand, as well as some tidal energy diagnostics (Fig. 6). All these activities help to promote coastal altimetry, via derived and added-value products dedicated to both academic and engineering activities.

5. CONCLUSIONS AND PERSPECTIVES

Coastal altimetry is an under-development field, with still many improvements and adjustments to be done. In particular, new challenges are foreseen. The performances of the new missions equipped with SAR mode (CryoSat, Sentinel-3, Jason-CS…) are very promising and may lead to improvements in the conventional radar altimetry processing strategies. The polar regions become more and more strategic and high accuracy corrections for altimetry are needed in these zones, especially for the tides. The high performances of the new altimetry missions in the coastal zones (SARAL/AltiKa) also raise a need for high accuracy mean sea surface profiles and surfaces near the coasts.

All these new corrections, parameters, processing strategies and products need some independent assessment involving the users. The users' feedback is essential to the services that process and provide the data, as it helps them to define and deliver products that really suit the needs of the end-users.

Finally, the successful promotion of coastal altimetry derived products towards engineering activities demonstrates the usefulness of today's products and helps to prepare the next and future missions, by providing new end-users with new applications.

6. REFERENCES

1. Vignudelli, S., Cipollini, P., Roblou, L., Lyard, F.,Gasparini, G.P., Manzella, G. & Astraldi, M. (2005). Improved satellite altimetry in coastal systems: case study of the Corsica Channel (Mediterranean Sea), *Geophysical Research Letters* 32, L07608. Doi: 10.1029/2005GL022602

2. Deng, X. & Featherstone, W.E. (2006). A coastal retracking system for satellite radar altimeter wave forms: application to ERS-2 around Australia. *Journal of Geophysical Research* 111, C06012. doi: 10.1029/2005JC 003039.

3. Bouffard, J., Vignudelli, S., Herrmann, M., Lyard, F., Marsaleix, P., Ménard, Y. & Cipollini, P. (2008). Comparison of ocean dynamics with a regional circulation model and improved altimetry in the North-Western Mediterranean, *Terr. Atmos. Ocean. Sci.* 19, 117–133. doi: 10.3319/TAO.2008.19.1-2.117(SA).

4. Roblou, L., Lamouroux, J., Bouffard, J., Lyard, F., LeHénaff, M., Lombard, A., Marsaleix, P., DeMey, P. & Birol, F. (2011). Post-processing altimeter data toward coastal applications and integration into coastal models, S. Vignudelli et al. (edc), *Coastal Altimetry*, doi: 10.1007/978-3-642-12796-0_9, Springer-Verlag Berlin Heidelberg

5. Ray, R., Egbert, G.D. & Erofeeva, S.Y. (2011). Tide predictions in Shelf and Coastal Waters: Status and Prospects, S. Vignudelli et al. (eds.), *Coastal Altimetry,* doi:10.1007/978-3-642-12796-0_8, Springer-Verlag Berlin Heidelberg

6. Cancet, M., Lyard, F., Birol, F., Roblou, L., Lamouroux, J., Lux, M., Jeansou, E., Boulze, D. & Bronner, E. (2012). Latest Improvements in Tidal Regional Modelling: A Regional Approach, Proceeding of the 20 Years of Progress in Radar Altimetry Symposium, Venice, Italy

7. Carrère, L., Lyard, F., Cancet, M., Guillot, A., & Roblou, L. (2012). FES2012: A new global tidal model taking advantage of nearly twenty years of altimetry, Proceeding of the 20 Years of Progress in Radar Altimetry Symposium, Venice, Italy

8. Crespon F., Jeansou, E., Helbert, J., Moreaux, G., Lognonné, P., Godet, P.E. & Garcia, R. (2007). SPECTRE (www.noveltis.fr/spectre): a web Service for Ionospheric Products, Proceeding of the 1st Colloquium Scientific and Fundamental Aspects of the Galileo Programme, Toulouse, France

9. Cancet, M., Kourafalou, V., Le Hénaff, M., Dufau, C., Birol, F., Labroue, S., Johns, E., Smith, R., Jeansou, E., Morrow, R., Picot, N., Guillot, A., Dibarboure, G. & Bronner, E. (2011). Comparing in situ current data with current anomalies derived from the PISTACH products: the Loop Current case, Presented at the 5th Coastal Altimetry Workshop, San Diego, USA

10. Cancet, M., Labroue, S., Birol, F., Beal, L.M., Dufau, C., Jeansou, E., Morrow, R., Guillot, A. & Picot, N. (2012). Comparing in situ current data with current anomalies derived from the PISTACH products: the Agulhas Current, Presented at the 6th Coastal Altimetry Workshop, Riva del Garda, Italy