CONTRIBUTION OF IMPROVED ALTIMETRY TO A STUDY OF COASTAL OCEAN DYNAMICS IN THE NW MEDITERRANEAN SEA (MARINA PROJECT)

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ABSTRACT

Monitoring the dynamics of marginal oceanic systems raises complex and challenging issues, owing to the wide spectrum of spatial and temporal scales of the oceanic processes occurring there (Cipollini *et al.*, 2008). Sustained in situ observation programs are not yet adequate to give the necessary information with the expected coverage. Similarly, remote sensing techniques for routinely monitoring of the sea surface (e.g. radar altimetry, SST, ocean color) encounter intrinsic limitations when moving near coasts. The current altimeter systems are designed with open ocean in mind and in most cases do not account for specificities of the coastal zone (presence of land, of clouds, inappropriate processing, etc.). Recovering the data in the coastal zone requires an integrated approach through the merging of in situ, remote sensing and model data; the setting and exploitation of an improved (reprocessed) coastal altimeter dataset with this approach is one of the central objectives of the MARINA (MARgin INtegrated Approach) project funded by CNES within the Ocean Surface Topography Science Team research program framework.

A data integration pilot study in the area of Corsica and Sardinia islands in the NW Mediterranean Sea is reported here. Met-ocean parameters have been collected and processed to be compared and merged with high resolution, optimized coastal altimetry products from the X-TRACK processor. The results of this study are illustrated, highlighting the potential and limitations of such data sets.

MARINA OBJECTIVES

There is an increasing consensus that coastal management requires a holistic view, based on better quality and more integrated geospatial and environmental information on which a scientifically sound policy can be built. As for deep ocean, coastal operational oceanography will be made possible only in an integrated approach, merging process-oriented studies, remote-sensed and in situ observing systems, ocean modeling and data assimilation.

In this framework, our research program is intended to pursue two central objectives:
1) to enhance the satellite altimetry coverage and quality in the marginal ocean by using a multi-satellite approach and coastal-oriented altimetry processor X-TRACK (Roblou *et al.*, 2007);
2) to exploit satellite altimetry in the context of regional hydrodynamic modeling of shelves and coastal circulation, with focus in the NWMED.

CASE STUDY OF THE BONIFACIO STRAIT (SARDINIA AND CORSICA)

The Bonifacio strait constitutes a very interesting case study, as both ends of the strait are equippedequipped with permanent, quality-controlled tide gauges and where TOPEX/POSEIDON plus Jason-1 (and now Jason-2) and ENVISAT altimeter missions overflight in a multi-crossover configuration. Land contamination issues and complex coastal dynamics make altimetry processing particularly challenging in the area.

Altimeter data set:

-TOPEX/POSEIDON + JASON-1,
- -passes 222 and 085
- -original GDR made available by CTOH
- -processed with X-TRACK processor
- -time sampling: nearly 10 days
- -high rate data streams (10Hz/20Hz)
- -starts 15/11/1992, finishes 30/12/2007

-ENVISAT,
- -passes 887 and 130
- -original GDR made available by CTOH
- -processed with X-TRACK processor
- -time sampling: 35 days
- -1Hz data streams
- -starts 1/ 1/2002, finishes 8/ 1/2007

In situ data set:

-Tide gauge of Sénétosa (M3),
- -provided by CNES/NOVELTIS/GEMINI
- - time sampling: 5 minutes
- -starts 12/ 5/1998, finishes 9/ 7/2006
- - tides are removed by harmonic analysis

-Tide gauge of Porto Torres,
- -courtesy of APAT and made available by ESA
- - time sampling: 1 hour
- -starts 1/ 1/2002, finishes 8/ 1/2007
- - tides are removed by harmonic analysis

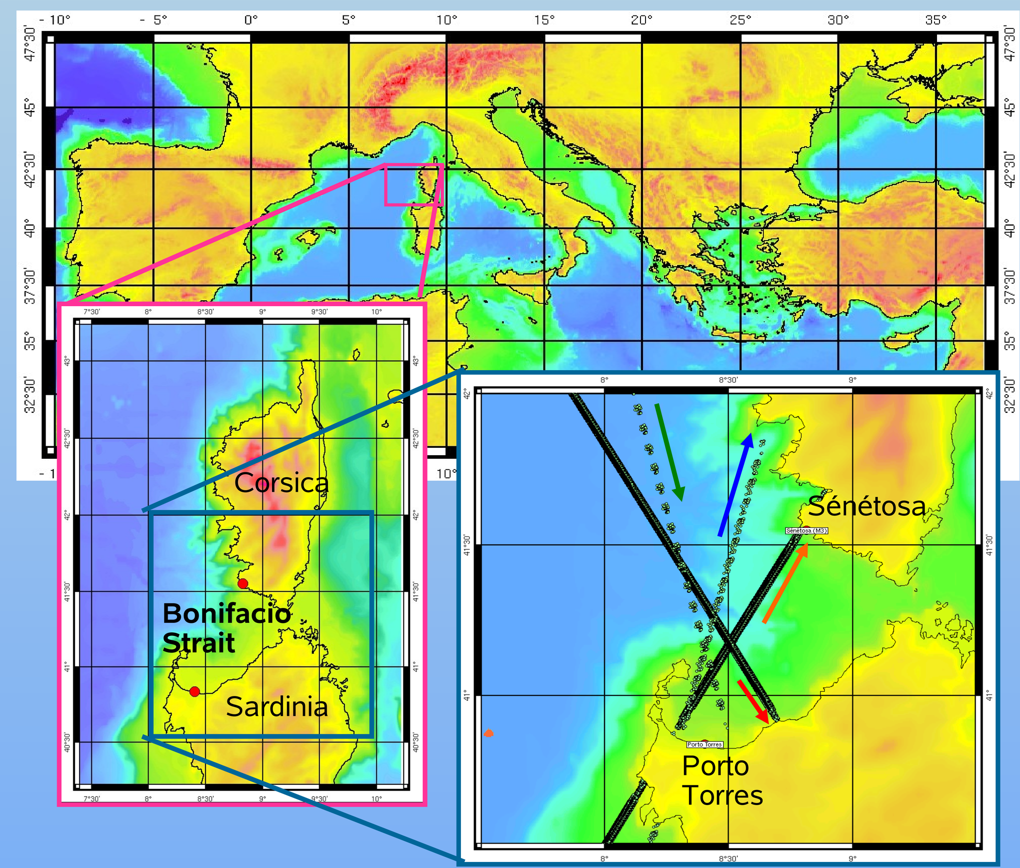

Fig. 1: the Bonifacio Strait in the NW Mediterranean Sea and data sets available. Background map is local bathymetry.

DE-ALIASING CORRECTION PREFERENCE

The goal of this validation phase is to check the relevance of the strategy defined for the whole Med Sea for de-aliasing tides and atmospheric loading effects within the X-TRACK processor and check whether it is applicable in the Bonifacio Strait.
So, the different corrections available within X-TRACK product, namely Mog2D-Medsea regional spectrum, FES2004 and GOT4.7 global charts for tidal correction, and IB, Mog2D-G and Mog2D-medsea models solutions for atmospheric effects correction are assessed in comparison to in situ measurements (Tables 1 and 2).

TIDES

Sénétosa	Mog2D-Medsea	FES2004	GOT4.7
M2	3.6	3.3	4.0
K1	1.2	1.7	1.5
S2	1.8	2.2	1.7

Porto Torres	Mog2D-Medsea	FES2004	GOT4.7
M2	0.6	1.2	0.8
K1	1.7	1.2	0.7
S2	0.6	1.1	0.4

Tab. 1: modulus of the complex difference between significant tidal constituent at both tide gauges and in from the model availables. Units are cm.

ATMOSPHERIC EFFECTS

	observations	IB	Mog2D-G	Mog2D-Medsea
Sénétosa	4.57	3.71	2.81	2.94
Porto Torres	5.54	4.22	3.49	3.44

Tab. 2: Standard deviation reduction at tide gauges (periods shorter than 20 days), for the different corrections available. Units are cm.

As previously suggested by Vignudelli et al., 2005 and Bouffard et al., 2008, no single model outperforms the others for all constituents in this area. Hence, a composite spectrum should to be implemented to optimize the tidal correction.
This validation highlights also very close performances for the global or regional configuration of Mog2D model, now T-UGOm 2D model, in the area (as also observed in the Corsica Channel by Vignudelli et al., 2005).

DATA SET ANALYSIS

A **tidal analysis exercise** of the X-TRACK SLA products for T/P plus Jason-1 overall mission is performed in order to assess the potential of the data set for studies of tides in the Strait of Bonifacio. Altimeter data are sampled every 0.7km (e.e. what would be 10Hz over the whole mission) on a reference track. Several de-aliasing strategies have been tested, whether one use Mog2D-G or Mog2D-medsea for correcting meteorologically-induced motion and Mog2D-Medsea regional spectrum, FES2004 global atlas or no prior model for removing tides. Results are compared to available tidal models (Table 3) and in situ data (Figure 2).
NB: Due to the very few samples of ENVISAT data exploitable (~40-45 cycles), a similar harmonic analysis is not possible as yet.
As noticed on the comparisons at tide gauges (and once K1 is upgraded in a composite tidal spectrum), tidal analysis of X-TRACK SLA product shows very close performances when compared to the tidal models available. Of course, FES2004 and GOT4.7 models are integrating altimetry. However, the Mog2D-Medsea model, which is purely hydrodynamic, shows results very close to the GOT4.7 solution. Surprisingly, K1 analysis is very close to the (erroneous) Mog2D-Medsea K1.
Another remarkable feature is that this high rate data set performs in a consistent way every 0.7km, with good performances very close to the coast with a very low signal/noise ratio, making us confident on the quality of the SLA.
Differences in S2 amplitudes between analyses of ascending and descending passes illustrate a residual alias at this period from an improper correction of meteo effects in altimetry. Actually, the 6-hour time resolution of the meteorological forcing fields is highly suspected to be responsible of these differences and a higher time resolution would probably help a lot in reducing these discrepancies. This assumption would be also verified with respect to the various meteo stations available in the area.

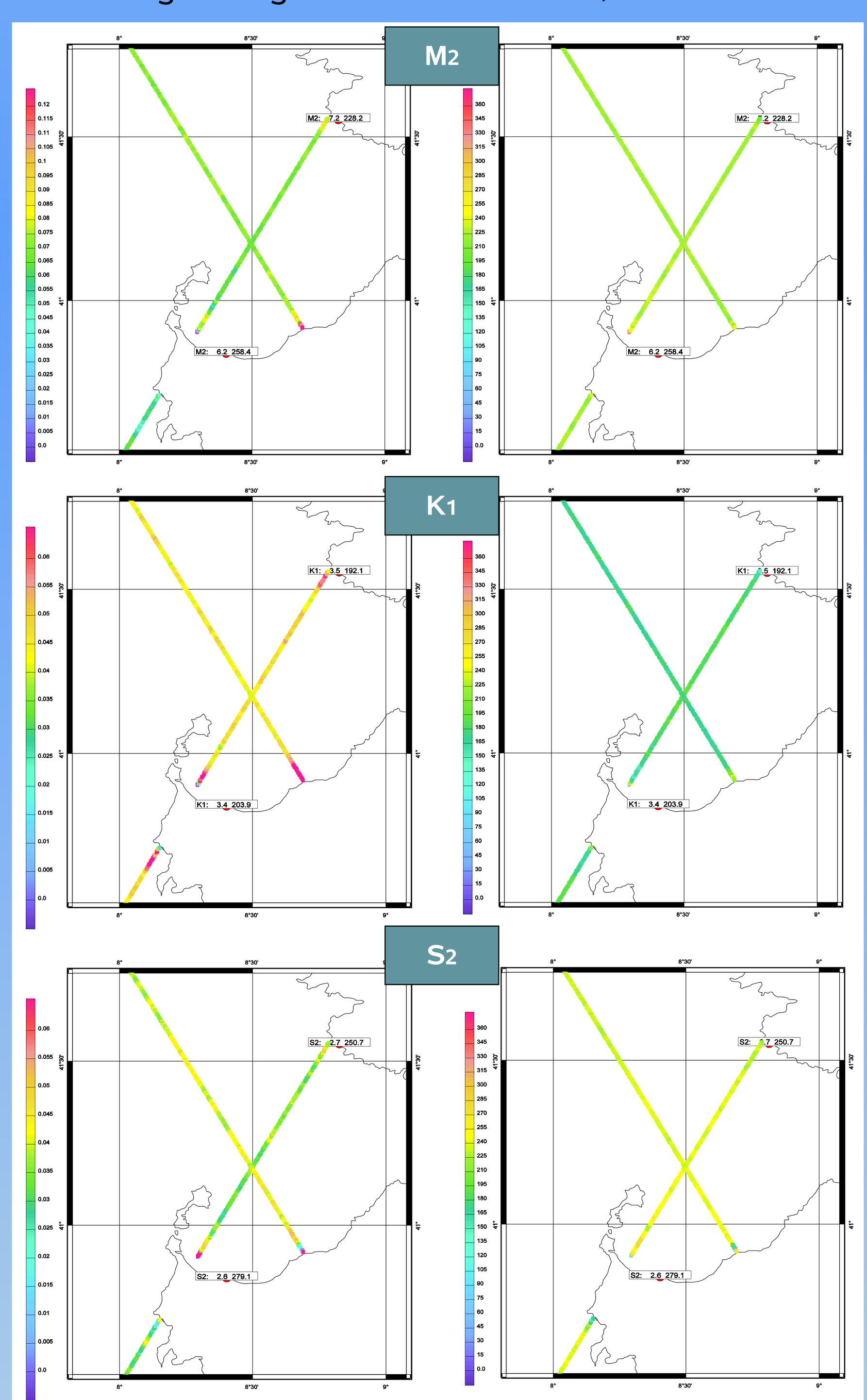

Fig. 2: Amplitude (metres) and phase lag (degrees) of M_2, K_1 an S_2 from 15 years of altimetry (X-TRACK reference SLA at high rate) versus tide gauges. Altimeter data are corrected from Mog2D-Medsea for atmospheric effets and a prior composite spectrum for tides.

Meteo. Effects	Mog2D-G	Mog2D-G	Mog2D-G	Mog2D-medsea	Mog2D-medsea	Mog2D-medsea
Tides effects	Ø	FES2004	composite	Ø	FES2004	composite
M2						
FES2004	1.2 +/- 1.4 cm	1.2 +/- 1.4 cm	1.2 +/- 1.5 cm	1.2 +/- 1.4 cm	1.2 +/- 1.4 cm	1.2 +/- 1.5 cm
GOT4.7	0.5 +/- 0.9 cm	0.5 +/- 0.9 cm	0.5 +/- 0.9 cm	0.5 +/- 0.8 cm	0.5 +/- 0.9 cm	0.5 +/- 0.9 cm
Mog2D-Medsea	0.8 +/- 1.1 cm	0.8 +/- 1.1 cm	0.8 +/- 1.1 cm	0.8 +/- 1.1 cm	0.8 +/- 1.1 cm	0.8 +/- 1.1 cm
K1						
FES2004	0.5 +/- 1.2 cm	0.5 +/- 1.1 cm	1.3 +/- 1.7 cm	0.5 +/- 1.2 cm	0.5 +/- 1.1 cm	1.3 +/- 1.6 cm
GOT4.7	0.6 +/- 1.2 cm	0.6 +/- 1.2 cm	1.5 +/- 1.8 cm	0.6 +/- 1.2 cm	0.6 +/- 1.2 cm	1.5 +/- 1.8 cm
Mog2D-Medsea	1.8 +/- 2.1 cm	1.8 +/- 2.1 cm	0.2 +/- 1.0 cm	1.8 +/- 2.1 cm	1.8 +/- 2.1 cm	0.1 +/- 1.0 cm
S2						
FES2004	0.9 +/- 1.2 cm	0.9 +/- 1.2 cm	0.9 +/- 1.4 cm	0.9 +/- 1.4 cm	0.9 +/- 1.2 cm	0.9 +/- 1.2 cm
GOT4.7	0.6 +/- 1.0 cm	0.6 +/- 1.0 cm	0.6 +/- 1.2 cm	0.6 +/- 1.2 cm	0.6 +/- 1.0 cm	0.6 +/- 1.0 cm
Mog2D-Medsea	0.5 +/- 0.9 cm	0.5 +/- 0.9 cm	0.5 +/- 0.9 cm	0.5 +/- 0.9 cm	0.5 +/- 0.9 cm	0.5 +/- 0.9 cm

Tab. 3: Mean (modulus) and standard deviation of differences between tides infered from improved altimeter data set (high rate, T/P plus Jason-1 SLA) and available tidal models.

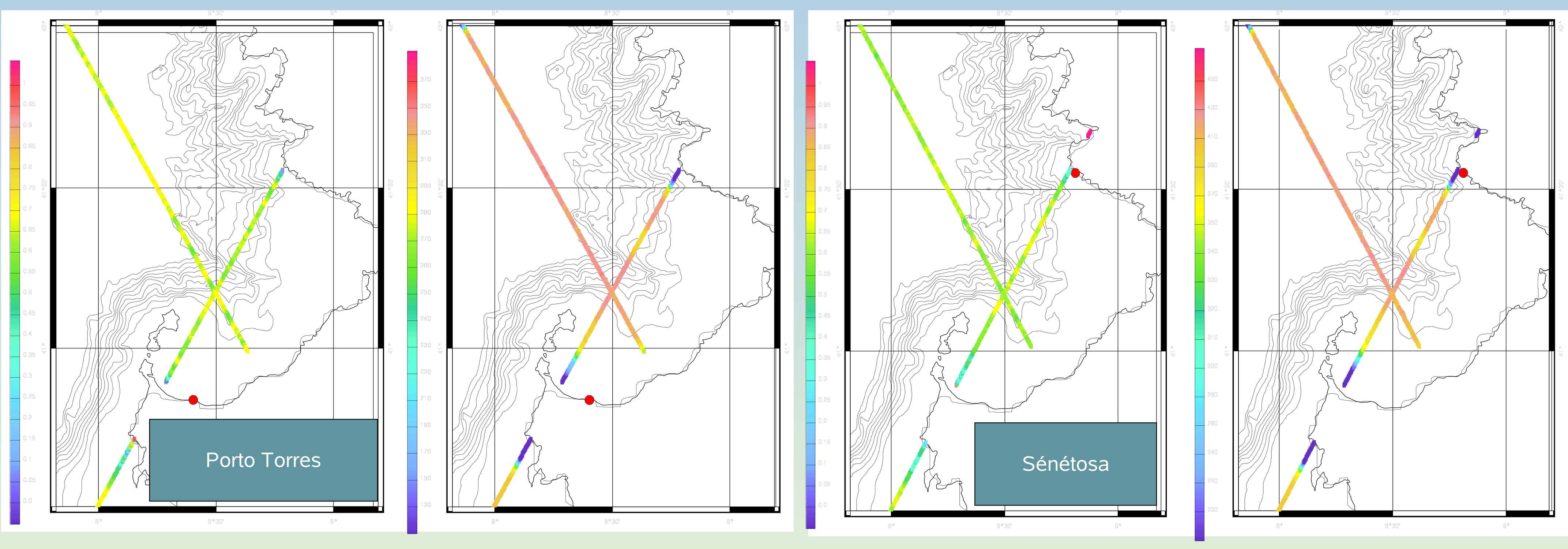

Fig. 3: Correlation and number of samples between SLA signal recorded at Porto Torres and Sénétosa tide gauges and X-TRACK SLA time series along the reference tracks 222 and 085 (0.7km sampling). Red dot is the tide gauges location and bathymetry isocontours ranges from sea surface to -2000m every 200m.

The along track altimeter-derived estimates of sea level every 0.7 km are compared with the Porto Torres and Sénétosa tide gauges over a common recording period. Tide gauge sea level records are sub-sampled to the exact times of overpass of each altimeter pass. The **Mog2D-Medsea+composite** combination is applied to dealiase high frequency dynamics whereas only Mog2D-Medsea is applied to tide gauge records as tides had already been removed by harmonic analysis. Figure 3 shows that **along-track correlations** with Porto Torres (left side) and Sénétosa (right side) range between 0.6 and 0.7. The lower number of data along the coasts (which also impacts correlation) may be due to the land effect.
We expect to get more usable data in this coastal strip with specialized re-tracking techniques and improved wet tropospheric path delay corrections.

CONCLUDING REMARKS

X-TRACK post-processing strategy has been assessed over the Strait of Bonifacio, for high rate data from the combination of T/P plus Jason-1 missions. This 16-year enhanced SLA data set is validated and ready for investigations of coastal dynamics of the Strait.
Our investigations will include absolute current comparisons featuring regional geoid and MSS model and integration approach with in situ data and other remote sensing data set (e.g. SST, ocean color, …). Synergies with circulation models will also be investigated.

In a next future, we will also set up and validate an 18Hz , ENVISAT data set and make intercomparison experiments with COASTALT data set (including retracked SSH, new wet troposhere correction, …), extending then our data set in the Strait.

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