An improved of Satellite Altimetry Data Processing along the Algerian Coast

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Abstract: In coastal systems, shorter spatial and temporal scales make ocean dynamics particularly complex, so the coastal domain represents a challenging target for processing of satellite altimetry data.

The main objectives of this paper are to improve the altimetric measurement in coastal areas by analyzing the main problems related to atmospheric corrections that must be applied to this measurement to obtain a precise surface height.

The processing of Saral/AltiKa Geophysical Data Records with in-house developed algorithms, including: re-tracking which is important for the last 7 km next to the coast; a more accurate wet troposphere correction (decontaminated correction) and better modelling of atmospheric effects permit us to determination the sea surface height over the Algerian coast.

Key Words: Coastal Altimetry; Saral/AltiKa; Sea Surface Height; Ionosphere; Wet Troposphere; Dry Troposphere.

1. Introduction

Satellite altimetry, one of the most successful applications of remote sensing at the service of earth science and climate studies, is based on a simple radar principle. The fundamentals of satellite altimetry are comprehensively described in Chelton, Ries, Haines, Fu, and Callahan (2001).
The acquisition depends on the functioning of the on-board tracker, which adjusts the altimeter observation window in time in order to keep the reflected signal coming from the Earth within the window (Passaro et al., 2014).
Several studies have been made for the mean sea level determination along the Algerian Mediterranean coasts based on spatial altimetry which allows us to have the sea level to the geodetic reference system 1980 (GRS80) ellipsoid (Kahlouche et al., 2003), (Rami and Kahlouche, 2005) and (Rami et al., 2011). The calculation of the parameters affecting the altimetry measurements with a best precision have been applied to improve the determination of the sea surface height on the coastal area (Desportes et al., 2007), (Obligis et al., 2011) and (Wöppelmann and Marcos, 2012).
Saral/AltiKa is a joint cooperative mission of ISRO and CNES, focussing on environmental monitoring. One of its primary objectives is to monitor mesoscale variability with an innovative radar altimeter (Verron et al., 2015). Indeed, the so-called AltiKa altimeter is the first to use the Ka-band and it has a very high along-track resolution and small footprint (5.7 km as opposed to 9.6 km for Jason-2 altimeter) (Vincent et al., 2006).
The exploitation of altimetric measurement over ocean relies on the capability to correct the altimeter range from all external perturbations. Two of them are related to the troposphere characteristics and should be estimated to properly correct the altimeter range: the wet and the dry corrections.
Near the coast, altimetric observations are affected by a number of factors including footprint land contaminations (altimeter and radiometer), inaccurate tidal corrections and incorrect removal of atmospheric (wind and pressure) effects at the sea surface.
So, in coastal areas, specific studies are needed to assess the quality of the standard products and to propose specific processing if necessary.
As a first initiative aiming at improving coastal altimetry over the Mediterranean Sea, Manzella et al. (1997) proposed a customised wet tropospheric correction more suited to the coastal zone. The first one consisted of retracking the altimetric waveforms, this strategy proposed reprocessing the single waveforms using a nonstandard waveform model in an attempt to recover the ocean surface parameters, it is usually defined as a “preprocessing” approach, the second strategy lies in a “post-processing” approach, discarding over-conservative flags, using local models for tides and atmospheric effects, filling gaps and filtering out noise in some of the corrections, this strategy was adopted by the ALBICOCCA initiative (ALtimeter-Based Investigations in Corsica, Capraia and Contiguous Area) (Vignudelli et al., 2005), which made a major contribution to the coastal altimetry data post-processing.
In this study, we will briefly present some techniques for improving the processing of ALES (Adaptive Leading Edge Subwave form retracker) Saral/Altika satellite altimetric data and will provide diagnostic evaluations of the different methods used.
For coastal altimetry, the wet tropospheric correction consists to corrected the measured brightness temperatures in order to remove the contamination coming from the surrounding land, the dry tropospheric correction is proportional to the sea level pressure and is not the largest correction to be applied to the altimeter range.
The analysis of the main issues related with the atmospheric

corrections that need to be applied to the altimeter range. Thus, the main purpose of this work is to present and validate improved coastal altimetric data, which can be used to determinate a precise sea surface height along the Mediterranean Algerian coast.

2. Materiel and methodes

The sea surface height above a reference ellipsoid is obtained as (Bronner et al., 2013):

SSH=Altitude-Range corr-Tides (1)

Range corr=Range+corr+SSB (2)

corr=DTC+WTC+IC+DAC (3)

Where Altitude is the computed satellite height above a reference ellipsoid provided by a precise orbit solution, referred to an International Terrestrial Reference Frame (ITRF), Range is the observed altimeter range corrected for all instrument effects and Range corr is the altimeter range corrected for all atmospheric effects. The term corr includes range corrections required to account for the interaction of the radar signal with the atmosphere mainly those concerning the effects of the dry troposphere (DTC), wet troposphere (WTC), the ionosphere (IC) and dynamic atmospheric correction (DAC). SSB is the sea state bias correction that is responsible due to the local sea states. Tides Are geophysical phenomena, which must be accounted in order to separate them from the signals of interest.

In this section we discuss the most important parameters affecting Saral/AltiKa measurements in coastal area which is the atmospheric effect (ionosphere, wet troposphere and dry troposphere) and give the different models to correct them.

The quality of Saral/AltiKa radiometer antenna patterns is characterized by very good directivity (0.84° angular with at -3dB for channel 23.8 GHz and 0.58° for 37 GHz) for both channels, and low-level amplitude of the secondary side lobes. Combined with an altitude of almost 800 km, the AltiKa radiometer is considered to be the instrument with the best resolution for altimetry missions (12km for the 23.8 GHz channel and 8km for the 37 GHz channel) (Valladeau et al., 2015).

2.1 Ionospheric Correction

Correction for the path delay in the radar return signal due to the atmosphere's electron content (TEC) (Rummel and Sansò, 1993):

$$IC = -40.3 \frac{TEC}{{f_{Ka}}^2} \quad (4)$$

f_{Ka} is the frequency of Altika altimeter (Hz);

The map of TEC used in this study is interpolated at different altitudes based on measurements of the smoothed code of 100 International Geodetic System (IGS) stations and 28 GPS permanent stations in Algeria; this map has provided by space geodesy division (Centre of space technique).

2.2. Dry Tropospheric Correction

Correction for the path delay in the radar return signal due to the dry gases in atmosphere (Bronner et al., 2013).

$$DTC = -2.277\, P_{atm}[1 + 0.0026\, cos(2\varphi)] \quad (5)$$

Where $P_{\_atm}$ is sea level atmospheric pressure (in mb) and φ is latitude.

Sea Level Pressure is computed by linear interpolation over time between two consecutive ECMWF re-analysis model data files six hour intervals, and by bilinear interpolation in the space from the four nearby model grids.

2.3 Wet Tropospheric Correction

One major source of error affecting the SSH determination is the wet troposphere correction derived from microwave radiometers on-board altimetric satellites. Indeed, this correction is potentially contaminated in thge coastal area.

The amount of water vapour present along the path length contributes to the index of refraction of the Earth's atmosphere. Over open ocean surfaces, its contribution to the delay of the radio pulse, the wet tropospheric delay, can be estimated by measuring the atmospheric brightness near the water vapour line (Mercier et al., 2010).

In order to restore the wet tropospheric correction, a brightness temperature measured at a frequency sensitive to the content integrated in water vapour is necessary, but not only, since it would not be possible, with a single channel, to separate the contributions from the surface and the atmosphere.

A log-linear relationship between brightness temperatures at 23.8 GHz ($BT_{23.8}$), brightness temperatures at 36.5 GHz ($BT_{36.5}$), back scattering coefficient of Ku (σ_0) band and wet tropospheric correction was developed using one year of Envisat dataset as shown in eq. (6) (Desportes, 2008).

$$WTC = a_0 + a_1 * log(280 - BT_{23.8}) + a_2 * log(280 - BT_{36.5}) + a_3 * \frac{1}{\sigma_0^2} \quad (6)$$

On coastal approach, the measured brightness temperature (BT) results from a mix between oceanic and land emissions (figure 1). Since the retrieval algorithms are tuned only for ocean surface, this leads to a contamination of the wet troposphere correction (WTC) distances from the coast of the order of the radiometer spatial resolution (Valladeau et al., 2015).

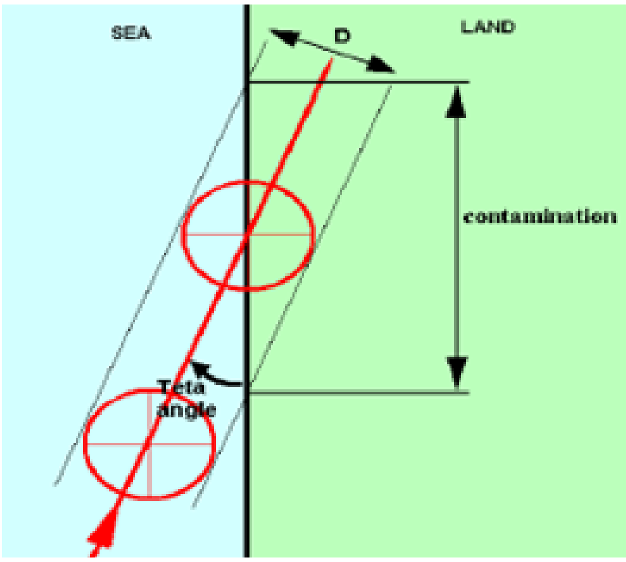

Fig.1. The contamination of the measurement by the land at the approach of a coast (Obligis et al., 2011).

There are two alternative solutions to the wet tropospheric correction for coastal areas, the decontaminated correction and the composite correction (Mercier et al., 2010). In this study we have used the first correction.

The decontaminated wet tropospheric correction (Obligis et al., 2011) aims at removing the contamination of land within the brightness temperatures (BT) measured by the radiometer, taking into account the antenna 400pattern of each channel:

$$BT_{corr(f)} = BT_f - Cor(p, f) \quad (7)$$

$$Cor(p, f) = (BT_{land} - BT_{sea})p(f) \quad (8)$$

Where:

$p(f)$ is land proportion in the pixel for 36.5 and23.8 frequency.

BT_{land} and BT_{sea} sea are estimated along the satellite track. For a complete sea-land transition, BT_{sea} sea is the last uncontaminated BT ($p(f) = 0$) and BT_{land} is the and is the first uncontaminated BT (p(f)=1).

DATA USED

For this application, we have used ten (10) cycles of ALES (Adaptive Leading-Edge Subwave form retracker) Saral/AltiKa dataset containing 40Hz values which represent cycle (12, 13, 14, 15, 16, 17, 18, 19, 20 and 21) over the Western Mediterranean Sea.

The ALES data were obtained from JPL Physical Oceanography DAAC and developed by the UK National Oceanography Centre, Southampton UK. The fundamentals of ALES retraker are described and detailed in Passaro et al. (Passaro et al., 2014).

Our interest area is defined by the following coordinates: 35°N-45°N, 3°W-11°E. To select the right track, we used a pass locator using Google Earth available through Aviso. Figure 2 represents the selected Saral/AltiKa tracks over the Western Mediterranean Sea.

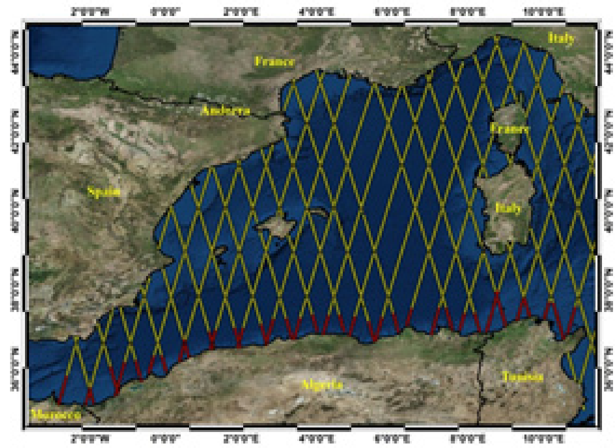

Fig.2 The used Saral/AltiKa data over the Algerian coast, points in red are less than 50 km from the coast.

3. Result and Analysis

The distance between the nadir of each altimeter data point to the closest shoreline point is computed using coastline position information from the GMT (Generic Mapping Tools) software Full-Resolution coastline database (Bronner et al., 2013). The calculated distance between the used altimeter data to the closet shoreline is represented in figure 2.

As an example; table 1 exhibits, for pass #773 cycle 20 of Saral/AltiKa satellite data, the mean of calculated ionospheric correction, dry and wet topospheric corrections based on the models described in the methodology part, less than 50 km from the coast.

Tab 01 . Mean of Ionospheric, dry and wet tropospheric correction, Passage 773 cycle20.

Parameters	IC	DTC	WTC
Mean (cm)	0.6	216.5	8.8

To validate our results, we compare the WTC obtained (decontaminated) and the WTC retrieved from radiometer brightness temperatures (contaminated) to the WTC correction resulting from ECMWF model.
The ECMWF model provides global fields every 6 hours, at a resolution of 0.5 °. The WTC of this model is available in altimetric products, interpolated to the point of the altimetric measurement. This method consists in replacing, in the coastal area, the simulated WTC by the WTC of the model (https://www.ecmwf.int/en/forecasts).

Tab 2. Mean of WTC less than 50 km from the coast depending on the used method, Passage 773 cycle20.

Method	Mean (cm)	Standard deviation (cm)
Standard model (Radiometer WTC)	13.5	4.8
ECMWF WTC	10.2	1.9
Decontaminated WTC	8.8	1.7

The wet tropospheric correction retrieved from radiometer brightness temperatures is given from S-GDR Saral/AltiKa data set.

The application of all correction affecting the altimetric measurement, we can determinate the sea surface along the Algerian coast (Rami and Benkouider, 2018).

All of the geophysical corrections to the altimeter range were applied to the SSH including, Inverse barometer using Computed from ECMWF atmospheric pressures (Pascual et al., 2008); Dynamic atmospheric correction which is the combination of the high frequencies fluctuation implemented using a MOG2D model (Carrère and Lyard, 2003) forced by pressure and wind (from ECMWF analysis), with the low frequencies of the Inverse Barometer correction based on atmospheric pressure over the oceans (Foucher, 2013); Sea State Bias correction based on Gasper and Florens method (Gaspar et al., 1994) which is function of recent wind speed models developed for the AltiKa altimeter (Lillibridge et al., 2014) and (Abdalla, 2014); Ocean Tide correction computed with diurnal and semidiurnal ocean and load tide values predicted by the GOT4.8 (Global Ocean Tide) (Ray, 2013) and FES2012 (Finite Element Solution) (Carrere et al., 2015) models, respectively (Andersen and Scharroo, 2011); Solid tide computed as described by Cartwright and Edden (Cartwright and Edden, 1973), pole tide easily computed as described in (Wahr, 1985),

The mean sea surface height is a geometrical description of the mean sea surface height; the obtained surface is represented in figure 3.

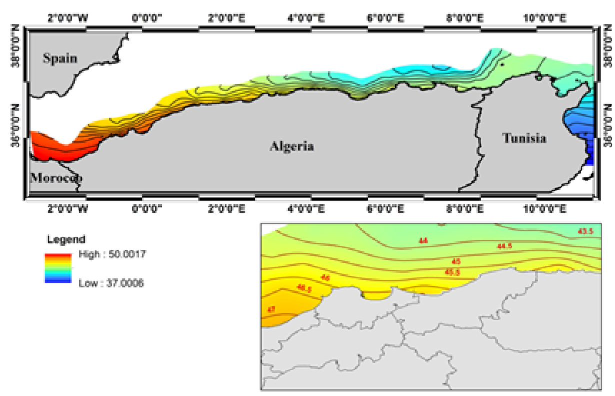

Fig. 3 Mean sea surface (in meter) over the Algerian coast.

We note that the mean sea surface over the coast varies between 41.4 m in the East and 49.8 m in the West, with an average of 44.9 m.

4. Conclusion

Satellite altimetry offers an important measurement source over the coastal studies. We have shown that basing of specific processing on coastal area; it is possible to improve the quantity and quality of data in those regions

The major issues associated with the atmospheric and geophysics corrections were analyzed in detail that need to be applied to satellite altimeter range measurements, often requiring range improvement, to get centimeter precision of sea surface height.

In the case of the wet tropospheric correction which is the most important effect on coastal area, different studies have been conducted recently and the first results are encouraging. The use of external information to describe more accurately the atmospheric humidity in the coastal band should allow a significant improvement in the quality of the altimeter products. In this study, the correction of brightness temperatures using the land proportion has been used and gives us good results.

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