IMPROVING SEA SURFACE HEIGHT OVER THE PATAGONIAN CONTINENTAL SHELF

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ABSTRACT

Sea Surface Height (SSH) as measured by satellites has become a powerful tool for oceanographic and climate related studies. Whether in the open ocean a good accuracy has been achieved, a more energetic dynamics and a number of calibration problems have limited applications over continental shelves and near the coast. Tide amplitudes in the Patagonian shelf are among the highest in the world ocean, reaching up to 12 m at specific locations. This fact highlights the relevance of the accuracy of the tidal correction that must be applied to the satellite data to be useful in the region. In this work, five global tide models and two regional models are compared to available tide-gauges distributed along the Argentinean coast. The seven models shown that the root-sum-square of the misfit of the five main tidal components (M_2, S_2, N_2, O_1 and K_1) is higher than 58 cm. In particular it is shown that all the models considered have a poor representation of N_2. A better accuracy is needed to estimate non-tidal currents from satellite altimetry in the region, which are on the order of 10 cm/s or less. Comparison and discussion of the origin of the differences obtained within the tide models are presented.

1. INTRODUCTION

Since the launch of the TOPEX/Poseidon satellite mission on August 1992 high quality global sea level data are available. Fitting altimetry data to empirical functions derived from numerical hydrodynamic models deep ocean tides have been estimated with unprecedent precision and accuracy [1, 2, 3, 4]. This success has been achieved thanks to (i) TOPEX design which allowed to separate tidal aliases [5], (ii) precise satellite orbiter and tracking determination and (iii) advances in modeling and data assimilation. At present, deep ocean sea levels can be estimated with a Root Mean Square (RMS) precision of 2 cm, a result that exceed in some cases the precision of conventional tide gauges measurements. However, in marginal seas and near the coast the results are not that good. Coastal processes are more difficult to resolve with altimeter data, due to two types of problems. First, and most importantly, intrinsic difficulties affect the corrections applied to the altimeter data near the coast (e.g. the wet tropospheric component, high frequency oceanographic signals, tidal corrections, etc.). Thus, data are usually flagged as unreliable within some distance of the coast. Second, the interpolation of along-track data collected by just one or two satellites provides only marginal resolution of mesoscale and smaller-scale structures in ocean circulation [6, 7, 8], which are dominant in the coastal region.

Several approaches are available to address the problems described above. References [9, 10] showed that increasing the number of satellites used to produce gridded maps of sea surface height to four greatly increases the accuracy of the mesoscale surface circulation estimated. Reference [11] showed that improvements in tidal and high frequency models used to produce the data distributed by the AVISO Project (Archiving Validation and Interpretation of Satellite Data in Oceanography) also improve the quality of the altimeter SSH fields over wide continental shelves. Other efforts to correct the altimeter signal near the coast include re-computing the wet tropospheric correction [12, 13, 14], the use of customized tidal modeling [15, 11], the use of higher rate data [16] and/or retracking [17, 18]. Algorithms to correct for these and other atmospheric and surface effects in coastal regions are the subject of several international initiatives, including ALTICORE [19, 20, 21], COASTALT [22, 23] and PISTACH [24, 25]. Reference [26] demonstrated that inclusion of more realistic SSH data (from tide gauges, altimeter tracks or other sources) in producing gridded SSH fields will result in improved estimates of surface currents in the 50 km closest to the coast.

The region of study, the Argentinean continental shelf, or Patagonian shelf, has a mean width that ranges between 300 and 800 km (Fig. 1). Roughly extends from 35ºS to 55ºS and from the coastline to the 300m isobath, where a pronounced shelf-break clearly divides the continental waters from open waters. Two main problems limit the approaches described above to improve the satellite SSH. First, the scarcity of in situ data. Only few well calibrated tide gauges and relatively short time series of current meters are present along more than 3000 km of coast and over the shelf. Second, tidal amplitudes are among the highest of the world ocean: values as high as 12 m were recorded at Bahía Grande [27].

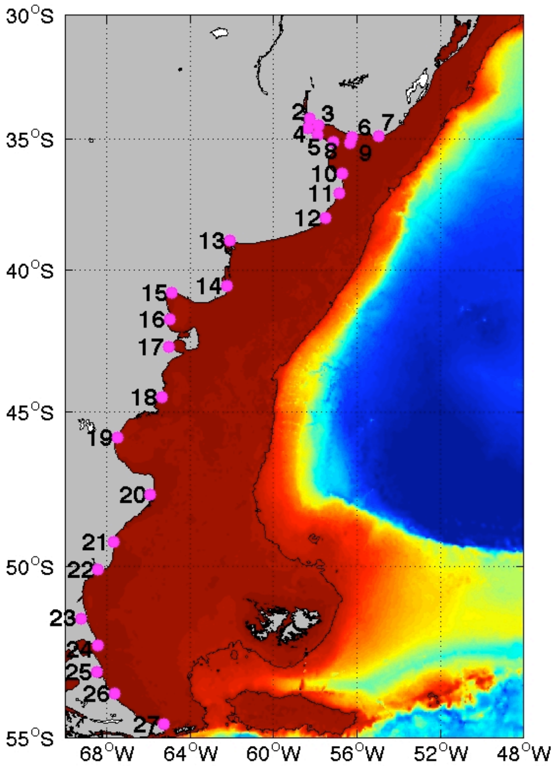

Figure 1. Bathymetry of the region and position of the tide gauges. Dark blue is deeper than 5000m. The shelf is characterized by shallow waters delimited by the 300m (black line) isobath.

2. HYPOTHESIS AND OBJECTIVES

The tide model used by AVISO to produce the widely used gridded maps of SSH is GOT00 [28]. The hypothesis of this work is that there are tide models that perform better than GOT00 over the Patagonian shelf. In others regions of the ocean where important tides exist as well, it has been shown that regional models can be more accurate to correct the altimeter data than global ones [29, 30, 31, 32]. The objective of this work is to evaluate which tide model works better in the Patagonian shelf. The evaluation will be carried out through the comparison of the five major tidal constituents (M_2, N_2, S_2, O_1 and K_1) estimated by the models with those estimated from harmonic analysis of several tide-gauges distributed along the Argentinean coast (Fig. 1).

3. DATA AND METHODOLOGY

3.1. Tide Gauges

Tide gauge tidal constants used in this work are the same used for the publication of the official Argentinean Tidal Tables [27]. The harmonic analysis of the tide gauges has been carried out using the least squares method by the Naval Hydrographic Service of Argentina (E. D'Onofrio, personal communication). The location of the tide gauges is indicated in Fig. 1 where the index used are those used by [33]. A table providing location, type of device and length in days of each time series is found also in [33]. Only four stations have been collecting more data and therefore they length is different than that provided by [33]. Because data are obtained from different type of devices and time series are very different in length we worked with four different subsets of the data (Table 1). The first set include all the stations; the second set exclude stations 2-4 which are too inside the mouth of Rio de La Plata and thus respond more to the dynamics of the river than to the dynamics of the ocean; the third set excludes stations 2-4 and those measured by tide poles which are shorter than 140 days (i.e. stations 14, 15, 18, 21, 24, 25 and 27); set four includes the four tide gauges which kept collecting data: stations 12, 17, 20 and 23 which correspond to the longest (over 10 years of data) time series over the Patagonian shelf.

Table 1. subsets used for the comparison with the altimetry data

SET	station index	selection criterium
1	2-27	all
2	5-27	without Rio de La Plata
3	5-13, 16, 17, 19, 20, 22, 23, 26	without Rio de La Plata and tide poles
4	12, 17, 20, 23	over 10 years of data

We will use data sets 1-4 to compare the M_2 component and data set 4 to compare N_2, S_2, K_1 and O_1.

3.2. Tide Models

We used five global and two regional tide models. The two regional models use boundary conditions from global ones but do not assimilate any data inside their domain. On the other hand, the five global tide models do assimilate in-situ and/or remote sense data. The seven models are listed in Table 2 where the type of data assimilated is specified. The reader is referred to the reference cited in the table for further details on each model.

Table 2. Tide models used

	data assimilated	Coverage	Resolution (x, y) deg	reference
FES04	TG+altimetry	Global	1/8, 1/8	[34]
Simionato	none	SWA	1/3, 1/4	[33]
Palma	none	SWA	1/10, 1/10	[35]
GOT4.7	altimetry	Global	1/2, 1/2	[28]
GOT00	altimetry	Global	1/2, 1/2	[28]
TPXO6.0	altimetry	Global	1/4, 1/4	[36]
EOT08a	TG+altimetry	global	1/8, 1/8	[37]

3.3. Methodology

To quantify the misfit between the models and tide gauges estimate, the following formula will be used for each constituent:

$$RMS_{misfit} = \left(\frac{1}{N} \sum_{N} \frac{1}{2} [[H_1 \cos(g_1) - H_2 \cos(g_2)]^2 + [H_1 \sin(g_1) - H_2 \sin(g_2)]^2 \right)^{1/2} \quad (1)$$

where N is the number of tide gauges used, H_1 and g_1 are the amplitude and Greenwich phase lag, and H_2 and g_2 are the observed amplitude and Greenwich phase lag measured by the TGs.

4. RESULTS

Considering all the TGs, EOT08a is the model that obtains the best agreement for M_2 (Figure 2 and Table 2). Considering data sets 2 and 3, FES04 is the one that get the best results for M_2, closely followed by EOT08a.

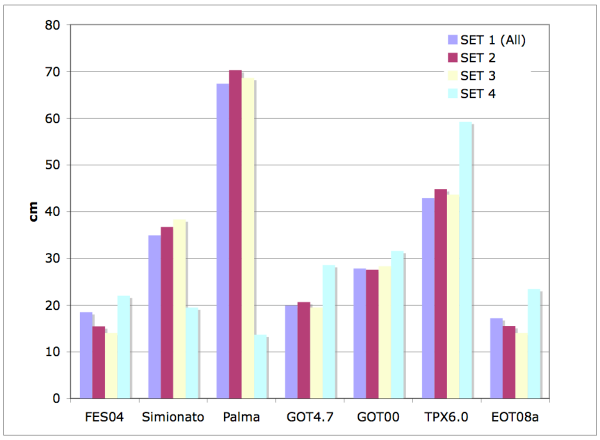

Figure 2. Comparison of the RMS misfit (cm) obtained for each model and for each data set for the M_2 tidal component.

The above results suggest that models which perform data assimilation have a better agreement with in-situ data. However, if only the longest time series are considered (data set 4) the two regional models, which do not assimilate in-situ data, produce more realistic results for M2, leaded by Palma's model. The apparent contradiction could be explained considering that FES04 and EOT08a assimilated most of the TGs amplitude and phases along the Patagonian shelf [34,37]. However for most of the TGs only the M2 component should be assimilated, due to the shortness and ubiquitous quality of the measures (E. D'Onofrio, personal communication). Consequently, a high resolution model without data assimilation (e.g. Palma) produces better results in most cases. Nevertheless, inspection of the spatial distribution of the RMS misfit for M_2 (not shown) reveals that Palma's model has the largest errors for stations 13-16, which probably explain the poor result of this model for data set 1-3 (Table 3).

Table 3. RMS misfit (cm) obtained for the different subsets of data for the M2 component

DATA SET	SET 1 (All)	SET 2	SET 3	SET 4
FES04	18.51	15.46	14.04	21.99
Simionato	34.90	36.72	38.31	19.45
Palma	67.41	70.31	68.65	13.65
GOT4.7	19.88	20.66	19.49	28.57
GOT00	27.84	27.54	28.29	31.61
TPXO6.0	42.93	44.83	43.67	59.22
EOT08a	17.20	15.52	14.03	23.42

The Root Sum Square (RSS) of the main five tidal components (Table 4) for all the models considered is above 58 cm. This is an order of magnitude higher than what is obtained in shallow waters in other regions of the world (e.g. [38]). Most of the error arises from a poor representation of the N2 component (Table 4). If N2 is not considered, Palma's model produces the best agreement with the TGs (RSS of 32 cm) followed by FES04 (RSS of 38 cm). In set 4, the RSS of these five tidal components doubles for the southern stations (20 and 23) compared to the northern ones (12 and 17). The tidal amplitude is much larger in southern Patagonia than in the northern section (eg. [35]). Thus, it is clear that tidal models need to be improved in regions where large tidal amplitudes exist.

Table 4. RMS misfit (cm) for the five main tidal components considering data set 4. The Root Sum Square (cm) of the five components is indicated in the last column.

SET 4	M_2	S_2	N_2	K_1	O_1	RSS
FES04	21.99	20.25	46.90	11.11	20.62	60.35
Simionato	19.45	21.92	43.26	11.53	23.93	58.62
Palma	13.65	16.82	53.50	14.38	18.66	62.34
GOT4.7	28.57	18.88	46.21	11.08	20.75	62.14
GOT00	31.61	19.60	45.84	11.30	21.05	63.67
TPXO6.0	59.22	18.68	42.70	10.72	19.49	78.58
EOT08a	23.42	20.88	47.20	10.85	20.59	61.26

5. CONCLUSIONS

The Root Sum Square (RSS) of the misfit between TG and models for the main five tidal components is above 58 cm in the Patagonian shelf. Non-tidal currents in the region are of the order of 10 cm/s or less [39]. Therefore, improved tidal models are needed to estimate geostrophic currents from satellite altimetry in the region. It should be stressed that only coastal TG have been considered. A companion paper will extend the comparison made here to the shelf, using available in-situ data and the analysis of the altimeter data at the cross-over of ascending and descending paths.

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