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A Comparison between Coastal Altimetry Data and Tidal Gauge Measurements in the Gulf of Genoa (NW Mediterranean Sea)

Paola Picco [1,*], Stefano Vignudelli [2,*] and Luca Repetti [1]

[1] Istituto Idrografico della Marina, passo dell'Osservatorio, 4, 16135 Genova, Italy; luca_repetii@marina.difesa.it
[2] Institute of Biophysics, National Research Council, CNR, via Moruzzi 1, 56124 Pisa, Italy
* Correspondence: paola.picco@persociv.difesa.it (P.P.); stefano.vignudelli@pi.ibf.cnr.it (S.V.)

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Abstract: Satellite altimetry data from X-TRACK products were analyzed for an overall assessment of their capability to detect coastal sea level variability in the Ligurian Sea. Near-coastal altimetry data, collected from 2009 to 2016 along track n.044, were compared with simultaneous high frequency sampled data at the tidal station in Genoa (NW Mediterranean Sea). The two time series show a very good agreement: correlation between total sea level elevation from the altimeter and sea level variation from the tidal gauge is 0.92 and root mean square difference is 4.5 cm. Some relevant mismatches can be ascribed to the local high frequency coastal variability due to shelf and harbor oscillation detected at the tidal station, which might not be observed at the location of the altimetry points of measurement. The analysis evidences discrepancies (root mean square difference of 4.7 cm) between model results for open sea tides and harmonic analysis at the tidal station, mainly occurring at the annual and semiannual period. On the contrary, the important part of dynamic atmospheric correction due to the inverse barometer effect, well agrees with that computed at the tidal station.

Keywords: ligurian sea; satellite altimetry; sea level variations; tide gauge measurements

1. Introduction

Measures of sea level vertical displacements in harbors or close to coastal structures are among the oldest oceanographic observations available. In some of the Mediterranean Sea harbors such as Marseille, Genoa, Trieste and Venice, regular mareographic measurements date back to the end of the 19th century [1–3]. Sea level elevation measurements in the open sea area were later obtained by bottom pressure sensors, while estimation of sea surface topography at the regional and global scale is performed by computing the steric level from sea water density profiles or by means of numerical model simulation. Since 1970 sea level topography from onboard satellite altimeters has opened new perspectives to the investigation of mesoscale dynamics, in particular in those remote areas where direct observations were rarely available [4]. This has made it possible to follow the spatial and seasonal evolution of oceanographic structures well identified by relative sea surface elevations such as gyres and important current systems [5]. In the Mediterranean Sea first investigations based on altimetry observations addressed mesoscale dynamics, [6–9], the estimation of water exchange between Tyrrhenian and Ligurian Sea [10].

Due to the improved the accuracy of the altimetric measurements and the availability of more than two decades of data we can now study long term sea level variability in wide areas, also in the Mediterranean Sea [11,12].

The investigations of the sea level trend from long-term tidal gauge observations and from satellite altimetry pose the problem of how two so different measurement systems can be combined. Satellite altimetry measures geocentric changes, i.e., the change in the local mean sea level (MSL) relative to a terrestrial reference frame [13,14] and therefore independent of land changes, while tide gauges measure the sea level vertical displacements against a fixed land benchmark, thus requiring to eliminate the vertical land movements contribution. Moreover, local topography and environmental conditions strongly modify the coastal sea level variability in respect to the open sea, in particular at high frequencies. This occurs mainly because of the amplification of tides and meteotsunamis, shelf and harbor oscillations and a dynamic response to a wind storm. That is why several recent investigations [15–18] focus on the comparison between altimetry and tidal gauge data, aiming at evaluating how reliable it is to extend satellite altimetry data close to the coastal areas.

The main objective of this work is to compare sea level data obtained from satellite altimetry close to the coast with simultaneous tidal gauge measurements in the Port of Genoa for an overall assessment of the dataset. This is the first time such a comparison has been made in this region, which is an important maritime hub in Italy. Direct comparisons between the two datasets relied on basic statistics [19]. Previous results from oceanographic studies in the region helped for a more comprehensive evaluation of the dataset.

An important part of this study addresses the estimation of the coastal variability in the Gulf of Genoa, considering phenomena occurring in a wide range of time scales: from a few minutes period of meteotsunamis and shelf oscillations to the seasonal and annual cycle.

This will also contribute to a better and reliable exploitation of altimetry data for the assessment of sea level variability in the Ligurian Sea.

2. Datasets

2.1. Altimetry Data

The improvements in altimetry data processing over the last ten years have made available experimental and operational products dedicated to the monitoring of regional and coastal areas. Compared to standard products, these products can include higher along track resolution, new/improved retrackers, new/improved corrections, refined preprocessing and/or post-processing. The Centre for Topographic Studies of the Oceans and Hydrosphere (CTOH), a French observation service dedicated to satellite altimetry studies, maintains homogeneous altimetry databases (L2/L3) for the long-term monitoring of the sea level. The reprocessing involves an 'ad hoc' editing strategy of the data records and a careful extrapolation/interpolation of missing or imperfect corrections of the altimetry measurement in the coastal strip. The product called X-TRACK was developed for different altimetry missions and regions. It is essentially a standard product at an along track resolution of 7 km, assembled on nominal tracks in the form of a sea level anomaly (SLA) time series, and extended to the coastal zone with improved editing and post-processing [20]. Altimetric measurements accuracy has increased from 4.2 cm of TOPEX/Poseidon to an expected 2.5 cm of Jason-3.

The track considered in this study was n. 044, which crosses the Western Mediterranean Sea from the North of Sicily to the Ligurian coast. Data covered the period from 22 March 1993 to 24 September 2016. There were 869 repeated tracks at a time interval of about 10 days, each containing 250 points at an average distance of about 6.17 km (std 144 m). The dataset also includes computed sea surface elevation due to tides, atmospheric pressure and wind effects, (so called dynamic atmospheric correction, DAC), which can be analyzed separately. Tides are computed by means of the global tidal model FES2012 [21] using 93 harmonic components obtained by the analysis of the altimetry data. DAC includes the static inverted barometer correction at a low frequency ($T > 20$ days), while higher frequency ocean variability is obtained by MOG2D-G, a barotropic model [22] forced by atmospheric pressure and wind from ERA-Interim reanalysis data (https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-interim).

The five points closest to the Ligurian Sea coast were selected for this analysis (Figure 1). Details are reported in Table 1. This small part of track 044 was about 24 km long, between 9 and 24 km from the coast. It crosses the two deep canyons and, unfortunately, no points were in correspondence of the narrow shelf. This assessment was based on data starting from 2009.

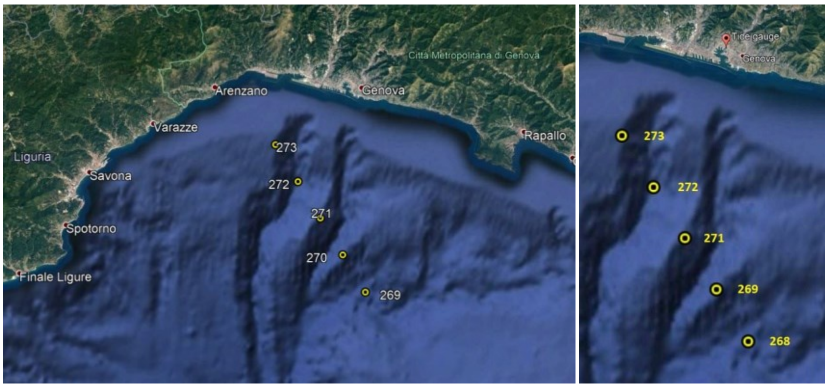


Figure 1. The Ligurian Sea with the ground position of the five selected satellite measurements points along track 044 and the location of the tidal station.

Table 1. For each point (first column) the table indicates the position (latitude and longitude), the sea depth, the distance to the tidal station of Genoa, the distance to the coast, the first and last available data and the number of valid data from 2009. (*) indicates the number of available measurements from 2009 covering at least one point.

Point	Lat (°E)	Lon (°N)	Sea-Depth	Dist-TG (m)	Dist-Coast (m)	Start dd/mm/yyyy	Stop dd/mm/yyyy	N Data 2009
269	44.1481	8.9542	988	29,445	24,444	8/8/1993	24/9/2016	220
270	44.1951	8.9143	1259	24,137	21,935	8/8/1993	24/9/2016	222
271	44.2416	8.8745	704	19,375	17,379	20/5/1993	24/9/2016	228
272	44.2876	8.8349	1046	15,577	13,312	20/5/1993	24/9/2016	222
273	44.3342	8.7950	293	13,472	9167	3/1/1994	24/9/2016	180
mean	44.24	8.87		20,401	17,247			274*

2.2. Tidal Gauge Data

The sea level dataset used for this investigation consisted of a time series recorded in the Port of Genoa (Ligurian Sea, Western Mediterranean) from 1993 to 31 December 2019. The tidal station (44°24′43.3″ N–08°55′32.2″ E), managed by the Italian Hydrographic Institute [23], is now composed of an OTT Thalimedes float operated shaft encoder level sensor and of an external OTT RLS 24 GHz radar level sensor, which started to operate in 2010. The float of the tidal gauge oscillated along a 22 cm diameter duct in a 55 cm wide and 3 m high stilling well. Its accuracy was 2 mm, the radar's was 3 mm. Atmospheric pressure data were collected every five minutes by an OTT barometer located in the tidal station and having an accuracy of 0.1 hPa. For this analysis, data from the float gauge were used, since the stilling well filters out small disturbances. Data from 1993 were obtained by analog registrations digitized at a one-hour time step. In 2000 the shaft encoder started to operate providing digital data at a 10 min time step until 2008 and then at a 5 min interval. From August 2008, the time step was increased to 1 min. This investigation was performed by using a 1-min sampled time series (from 1 January 2009), which can be considered quite synchronous with the altimeter passages. This would also avoid uncertainties due to low temporal sampling with respect to the local variability. Data were checked for spikes and bad data, which were removed. On the average, the missing data were only about 0.3% of the entire time series (Table 2). To obtain the continuity of time series to facilitate some analysis, small gaps were filled with spline-interpolated data. The long gap occurred from 4 to 8 June 2011 was filled in using radar data after checking the consistency of the two time series. This was not possible for the missing data from 18 to 25 October 2009. For this reason altimetry data of 20 October 2009 were discarded from the time series.

Vertical land movements (VLMs) may affect tidal measurements as they are referred to a benchmark fixed on land. This knowledge is important for investigations of sea level long-term variability. Very recent estimations of VLM by means of GPS measurements close to the tidal station of Genoa during 1998–2018 [24] indicate an average subsidence of 0.12 mm/y. Due to the short time interval considered, from 2009 to 2016, the expected effects on the sea level variation would be negligible, so no correction due to VLM was applied to the tidal gauge data. Moreover, the focus of the paper was a comparison between coastal altimetry and tidal gauge measurements based on the analysis of relative variations and did not include any consideration about trends. For the same reasons, and as we are not treating absolute values, it was not necessary to take into consideration vertical datum unification [25].

Table 2. Number of missing data on a total of 525,600 for each year of measurements in the period 2009–2019.

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
13,703	273	6887	2380	709	2262	870	0	743	3675	2381

3. Coastal Sea Level Variability

3.1. Tidal and Infragravity Variability

Coastal sea level variability is the sum of the effects of a variety of processes occurring at different time scales. In many cases, the ocean response is characterized by oscillations having a well-defined frequency band, which can help to identify the involved process.

Tidal variability is the best-known and predictable contribution. Tidal regime in the Gulf of Genoa is mixed semidiurnal dominant having the tidal form factor F = 0.44 [26]. Time series of tidal predictions were computed by using the Foreman [27] method as described in Caldwell [28] by using 67 components recently computed over a 12-year period, from 2004 to 2018. These newly computed components were compared with those reported in the Italian Hydrographic Institute tide tables [29] and obtained from the data collected in the fifties [30], finding only negligible differences, well below the standard deviation. The tidal range (difference between annual maximum and minimum) was below 35 cm; M2 was the largest component with 8.5 cm amplitude, S2 was 3.3 cm and K1, the highest diurnal component, was 3.5 cm. Among the longer period components, Mf and Mm were only 1.3 cm.

The basin response to ocean dynamics and atmospheric forcing explains an important part of subtidal variability. This is mainly due to seiches, meteotsunami and shelf oscillations [31,32]. The principal seiches of the Ligurian Sea was identified in the sixties [33] and later modeled by Papa [34,35]. Its occurrence over the last 10 years was analyzed by Picco et al. [36]. The principal oscillation period of the Ligurian Sea, whose amplitude can reach about 5 cm, was 3.6 h. Seiches did not occur very often but can last a few days. Spectral analysis also identified secondary seiches at 2.6 h and 2.1 h (Figure 2). Meteotsunamis detected in the Ligurian Sea are mainly generated by atmospheric pressure jumps or travelling perturbations [37] and are characterized by 26–30 min oscillations. The most frequently detected in the time series had an amplitude of about 10 cm. In a few cases, they reached amplitudes higher than 30 cm and persisted for several hours. The highest meteotsunamis were those registered on 29 October 2018 and on 16 October 2016 because of different but particularly severe weather conditions [38–40]. Even though seiches and meteotsunamis were both a response to atmospheric forcing, no relation between the occurrences of these phenomena was observed. Oscillations having a period of 10 min and an amplitude of a few centimeters were also an almost constant presence in the sea level signal. This period was consistent with the shelf oscillation period computed using the Merian formula for an open system [41].

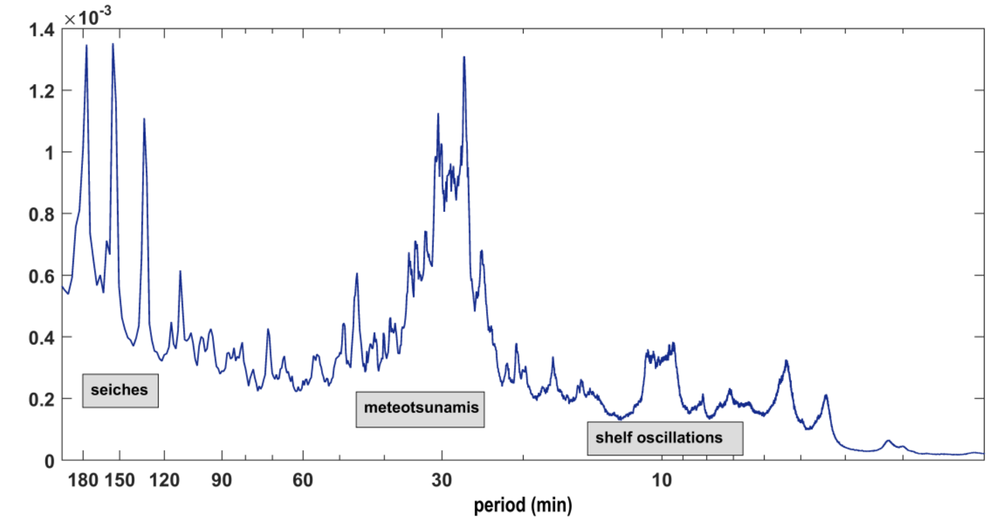


Figure 2. Power spectral analysis of sea level data from the tidal station focusing in the 0–200 min period band.

3.2. Long Period Variability

Annual (SA) and semi-annual (SSA) tidal components computed with Foreman [27] were 4.95 cm and 3.5 cm respectively. They both had a high standard deviation (2.7 and 1.6 cm), as they also include the uncertainness on the inverse barometric pressure effect and the steric level variation. The same computation on pressure gave SA 2.85 hPa and SSA 2.06 hPa, standard deviations being respectively 1.6 hPa and 0.95 hPa.

In order to distinguish between the energy from the astronomical tide and from the atmospheric pressure effect was made by recalculating harmonic constants on a five-year wide moving window, from 2003 to 2016, based on the assumption that the random characteristics of the atmospheric phenomena could reduce their effect on a larger time series. A significant difference was obtained for the semiannual component, which was reduced to 2.4 cm and std 0.7 cm, while the computed annual component was 4.25 cm and std 2.4. These estimations were also consistent with the spectral analysis reported below (Figure 3).

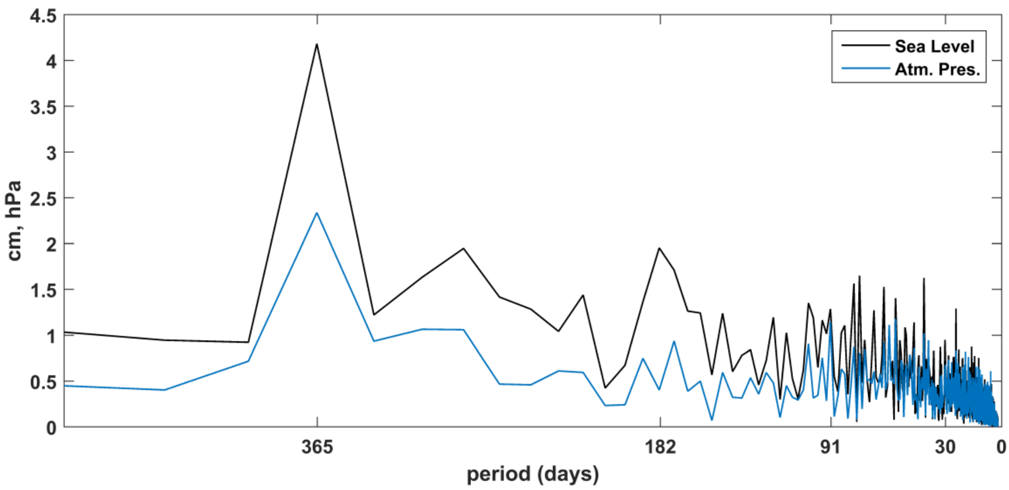


Figure 3. Spectralanalysis of sea level and inverse atmospheric pressure time series of daily mean data.

Due to the limited amplitude of tides, the effects of atmospheric pressure on the sea level explain a huge part of the observed sea level variability, in particular at a few days period.

If we just apply the rule of thumb of the inverse barometer effect, which considers a sea level variation of 1 cm for 1 hPa variation of atmospheric pressure, we can assess the range of sea level variability that can be ascribed to the atmospheric pressure. During the eleven-year period (2009–2019) of observations, the minimum pressure values was 978.5 hPa (5 March 2009), the maximum was 1040.3 hPa and occurred on 30 December 2016. We could thus estimate 80 cm as the range of sea level variation due to the atmospheric pressure effect (Table 3). Even if this simple relation is routinely used to correct sea level observation data for tidal components computation, it is well known that it is not really verified. That is why the help of numerical models simulating the barotropic response of the ocean to the atmospheric forcing is needed to better estimate this contribution [42,43]. The correlation coefficient between daily averaged data of atmospheric pressure and sea level time series was −0.7. This value can be as low as −0.3 if we consider the annual cycle obtained by averaging the eleven subsamples of each annual time series (Figure 4). Both signals were characterized by having the lowest variability from May to late September and the highest in winter. The pressure annual cycle was well fitted by a sinusoidal curve having an amplitude of 3.2 hPa and the maximum at the end of December. The same results could not be obtained with the sea level as evidenced by the spectral characteristics. The semiannual component is more important and the annual component phase has a shift resulting from other contributions such as the annual tidal component and the steric level [44]. Moreover, during the autumn months the two signal trend diverged.

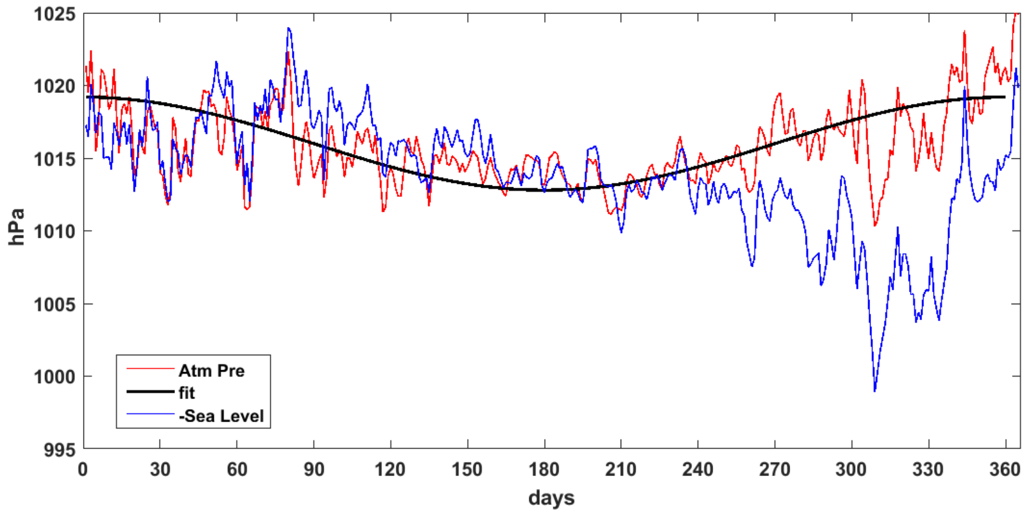


Figure 4. Mean annual cycle of the inverse of the sea level and atmospheric pressure obtained as the average of eleven daily mean data for each year from 2009 to 2019 and a fit with a sinusoidal wave having an amplitude of 3.2 cm/hPa, 365 days period and 90 days phase. Sea level data variations must be converted into cm (1 cm/1 hPa).

Table 3. Basic statistics of yearly subsets of sea level and atmospheric pressure measured at the tidal station of Genoa.

		SEA	LEVEL	(m)		ATM	PRES	(hPA)
	mean	**max**	**min**	**std**	**mean**	**max**	**min**	**std**
2009	0.119	0.662	−0.295	0.126	1014.2	1032.6	978.5	7.12
2010	0.167	0.689	−0.201	0.128	1013.3	1034.7	983.2	7.26
2011	0.087	0.525	−0.250	0.108	1017.8	1038.8	990.8	6.50
2012	0.096	0.666	−0.319	0.132	1016.3	1035.5	985.5	7.35
2013	0.117	0.538	−0.238	0.116	1015.2	1037.9	985.7	7.86
2014	0.144	0.629	−0.220	0.117	1015.1	1037.7	993.5	6.22

2015	0.083	0.515	−0.330	0.116	1018.1	1038.1	980.5	8.48
2016	0.097	0.557	−0.297	0.112	1016.7	1040.3	993.4	7.93
2017	0.064	0.512	−0.266	0.109	1017.2	1037.8	987.6	6.69
2018	0.124	0.854	−0.374	0.115	1015.1	1038.0	981.8	6.61
2019	0.118	0.770	−0.302	0.135	1015.2	1038.3	984.9	7.66
Average 2009/19	0.111				1015.9			

Steric level is the variation of seawater volume due to seasonal changes in temperature and salinity of the water column and can be considered as a significant contributor to the annual sea level variation. Annual variation of the steric level for the Ligurian Sea was estimated using two temperature and salinity profiles taken in the centre of this basin (43°47.770 N; 9°02.850 E) on 13 September 2003 and 26 April 2004 and described in [45]. These two profiles represent well enough the summer maximum and winter minimum in the Ligurian Sea, even some surface warming can be observed in the upper 25 m at the end of April. Computation over 250 m depth provided a variation of 7 cm. Similar estimations of annual cycle of steric level amplitude from the ECCO model results for the period of 2001−2005 were reported in [46]. On the other hand, due to the narrow shelf and high depth of the basin, the wind effects on the coastal sea level can be considered as negligible.

The range of coastal sea level variations in the Ligurian Sea due to the main contributions and disregarding their time scale can be roughly summed up as follows:

- Atmospheric pressure as an inverted barometer effect: 80 cm.
- Tsunamis/meteotsunamis, seiches and shelf oscillations: 50 cm.
- Tides: 35 cm.
- Steric level: 10 cm.

4. Comparison between Altimetry and Tidal Gauge Data

4.1. Tidal and Atmospheric Corrections

The altimetry product provides tidal correction computed from FES12 model for each ground point. The spatial resolution of this finite element hydrostatic model was 1/16°, 6.95 km at our latitude, close to the distance between the altimeter points of measurement along the track. The tidal components used for the simulation were the main components at the daily and sub-daily period. An assessment of the capability to reproduce tidal elevation in the world's oceans against that of other common models was provided by Stammer [47]. They found this model's performance among the highest and results reported for the European shelf waters, considering the principal tidal component M2, gave the root mean square difference (RMSD) of 6.58 cm against bottom pressure sensors and 3.7 cm against the tidal station.

Tidal corrections in the five selected points were almost the same, as the difference among them was below 1 mm. This allowed us to consider the average value of the five points as representative of the coastal altimetry value, thus obtaining a higher number of data for the comparison and reducing the variability. Tidal prediction at the tidal station versus the correspondent values used to correct the altimeter data, and their difference, are shown in Figure 5. The time series were well correlated (correlation coefficient was 0.83), average difference was only −0.1 cm and RMSD was 4.7 cm. The difference between them shows a clear annual cycle with the highest negative difference of about −10 cm occurring during winter months. As above discussed, this was mainly due to the annual and semiannual components, which were not included in the tidal model, and to the contribution of the steric level.

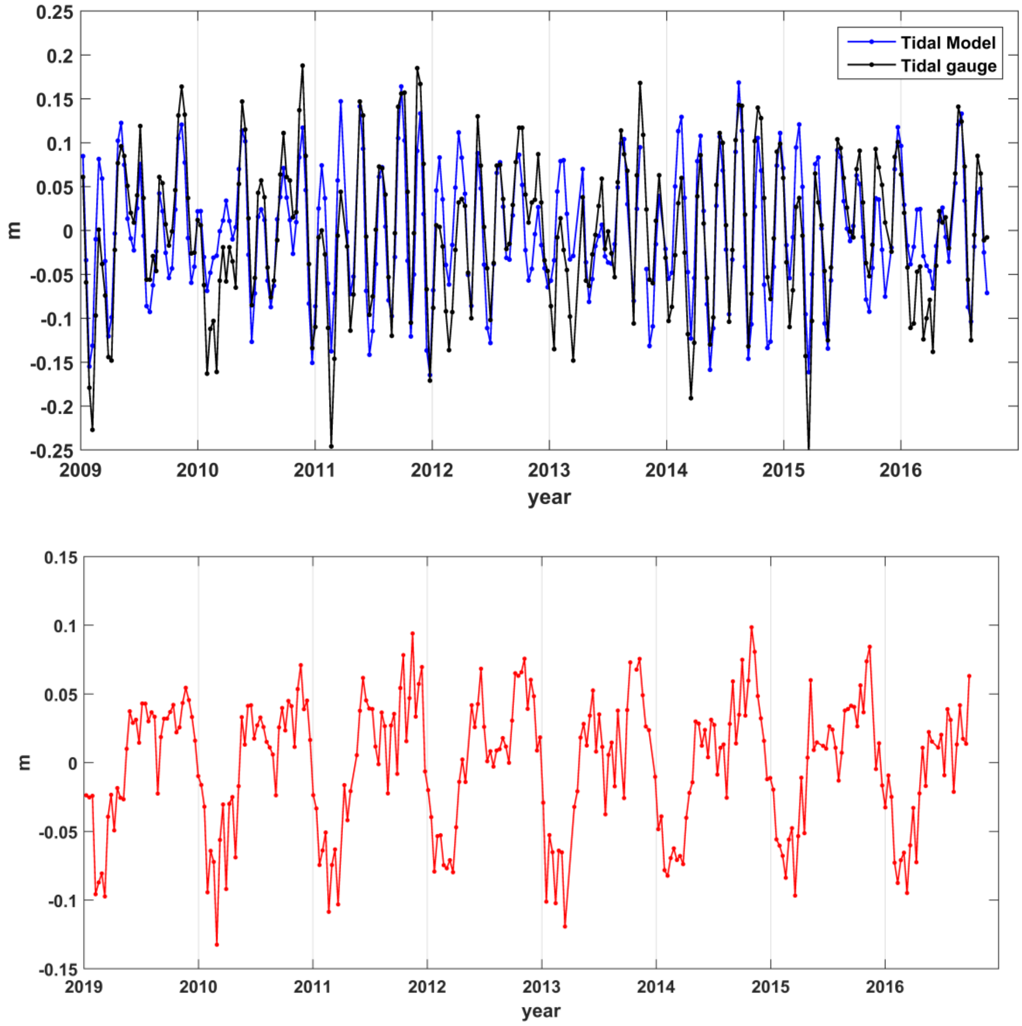


Figure 5. Time series of altimetry correction from the tidal model and tidal prediction at the tidal station of Genoa and their difference (red line).

Global dynamic atmospheric correction (DAC) is the computed sea level variation due to the pure inverse barometer effect and to higher frequency variation of atmospheric pressure and surface wind. It accounts for a variability spanning from −20 to 23 cm, mean and standard deviation being 1.6 cm and 7.1 cm respectively. The inverse barometer effect computed at the tidal station as the difference from the average pressure values converted into centimeters has a variation between −27 and 19.7 cm and a standard deviation being 7.3 cm (Figure 6). Most of the DAC correction seems due to the inverse barometer effect on the sea level, as these time series were very highly correlated: the correlation coefficient was 0.91 and RMSD was 3.5 cm. The observed differences can be mainly ascribed to the dynamic response of the sea level and to local topographic effects. In the Mediterranean Sea, deviations from the pure inverse barometer response were related to the semienclosed characteristics of the basin and of the sub-basin that it includes, as evidenced by numerical simulation [42,48]. The balance between the water exchange at Gibraltar and the water budget at the surface due to evaporation, precipitation and river runoff, also played an important role in the determination of low frequency sea level variations [49].

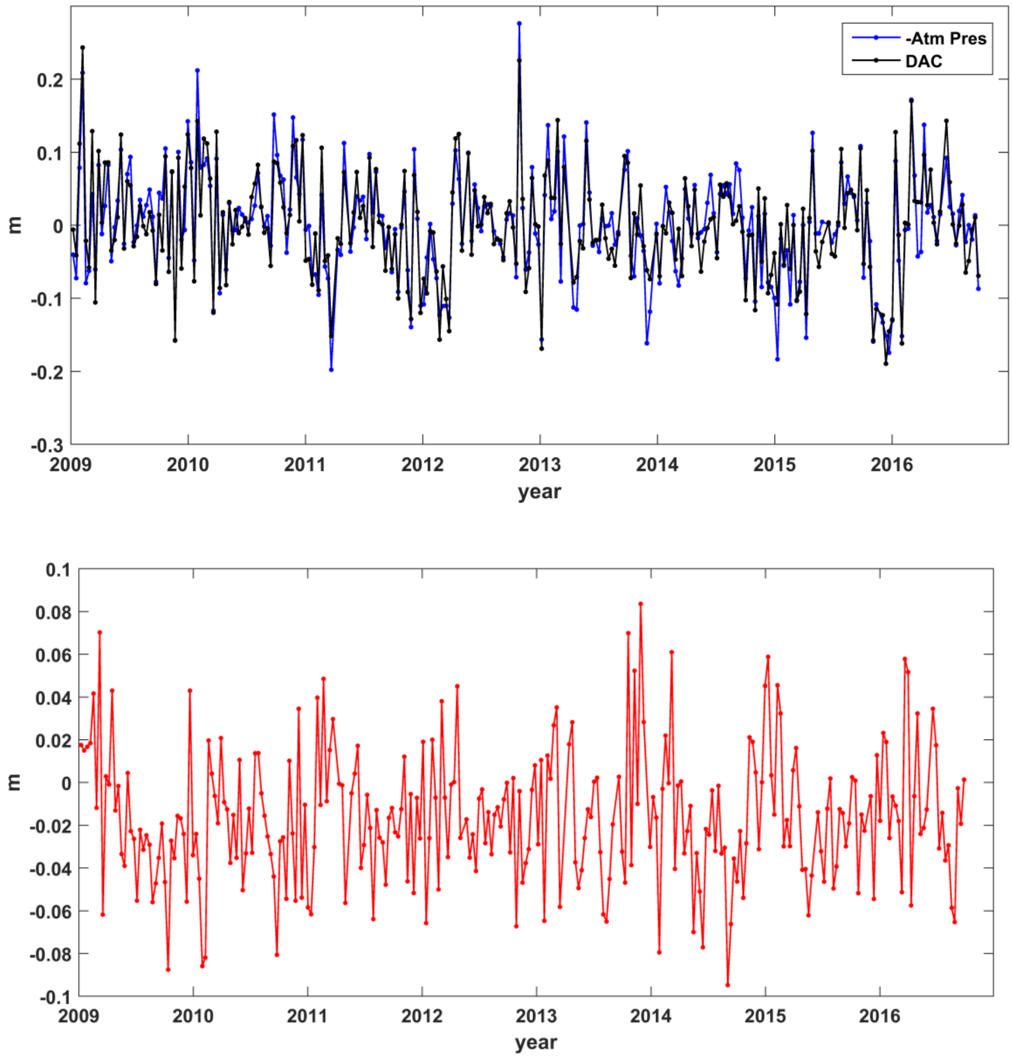


Figure 6. Inverse barometer effect from atmospheric pressure measurements at the tidal station and dynamic atmospheric correction (DAC) and their difference (red line). Reported time series are referred to their mean value.

4.2. Total Water Level Elevation

Total water level elevation (TWLE) data are the sum of sea level anomalies (SLAs), tidal and DAC correction, thus including both the barotropic and baroclinic contribution to sea level variations. They were used for an overall comparison with the correspondent tidal gauge data as they are not affected by the uncertainties introduced by model corrections as in SLA. It can be noted from Table 1 that not all the five points had the same temporal coverage. There were 180 values for point 273, the one closest to the coast, and 288 for point 271, the one in the middle. Considering the number of passages covering at least one of the points, there were 274 data available for the comparison.

Before the analysis, the five time series of altimetry data were checked for errors and consistency. Three outliers found in the time-series at point 273 were removed.

Mean values decreased with the distance from the coast, but differences remained well below the accuracy of the measurements; standard deviations were all about 12 cm, very close to that of the sea level measured from the tidal gauge. Correlation coefficients were high, from 0.88 to 0.92, and were decreasing with the distance from each other, and the root mean square differences, which were in the range between 4.3 and 6.3 cm. Moreover, all the points were located just outside the narrow shelf, so they could be considered to have the same dynamic response and none of them was expected to be affected by the local shelf variability occurring at the coast. For the comparison with tidal gauge data, we considered the average over the five points time series. The two time series were in very good agreement (Figure 7), were highly correlated (correlation coefficient was 0.92) and RMSD was 4.5 cm. There was no bias between them, the mean of the differences was closed to zero. Absolute difference was higher than for 10 cm in 13 cases (Figure 8).

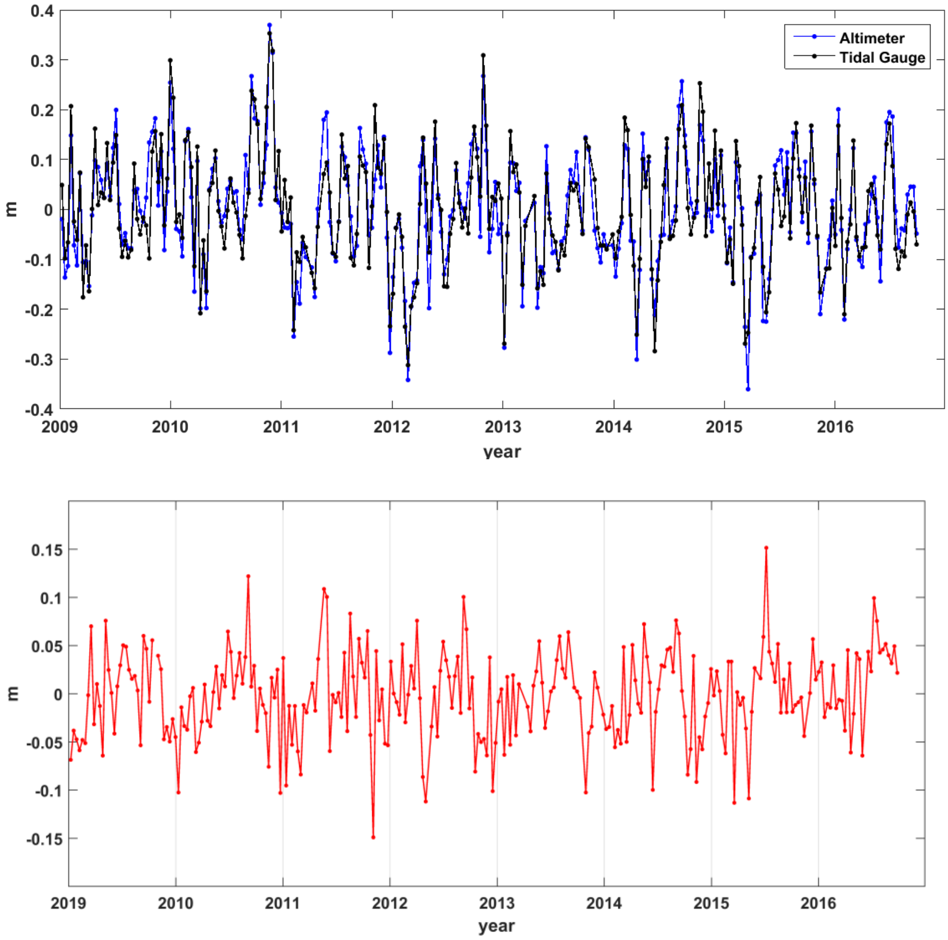


Figure 7. Point-to-point comparison between altimeter total water level elevation (TWLE) and tidal gauge data and their difference (red line).

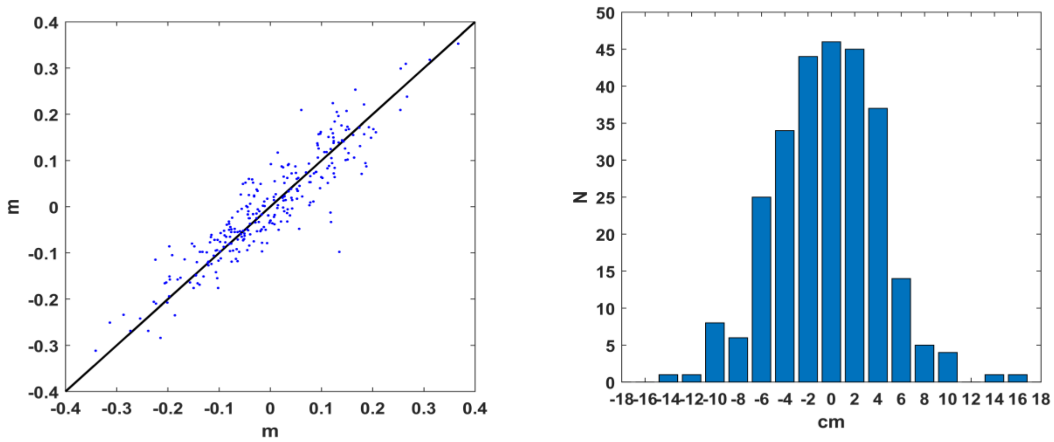


Figure 8. Plot of altimeter versus tidal gauge data (**left**) and distribution of their differences in classes of 2 cm each (**right**).

5. Discussion

The comparison between coastal altimetry and the tidal gauge sea level data collected in the Port of Genoa during the period 2009–2016 shows remarkably good agreement. Correlation was very high (0.92) and RMSD was 4.5 cm. This result was quite satisfactory if we considered that the comparison was done between raw data and the mean values of five points of altimetric measurements from track n.044 at an average distance of 20 km from the coast.

An estimation of RMSD between altimetry and tidal gauge data during the period 1993–2012 in Marseille and Toulon, which can be considered as having similar characteristics as the Gulf of Genoa, was provided by Bonaduce [50]. He reported 2.98 cm and 2.6 cm but these lower values resulted from a comparison based on monthly mean data.

In addition, when comparing performances, several difficulties arose to the different accuracies (3.5–2.5 cm for the altimeter and up to 0.2 cm for the tidal gauge). Sea level altimeter data may degrade approaching the land, so it can be doubtful whether the point closest to the coast could be considered as the most representative for such an assessment. On the contrary, moving too far from the coast might result in missing a huge part of the sea level signal due to very local coastal processes such as shelf and harbor oscillations, which are detected by the tidal gauge.

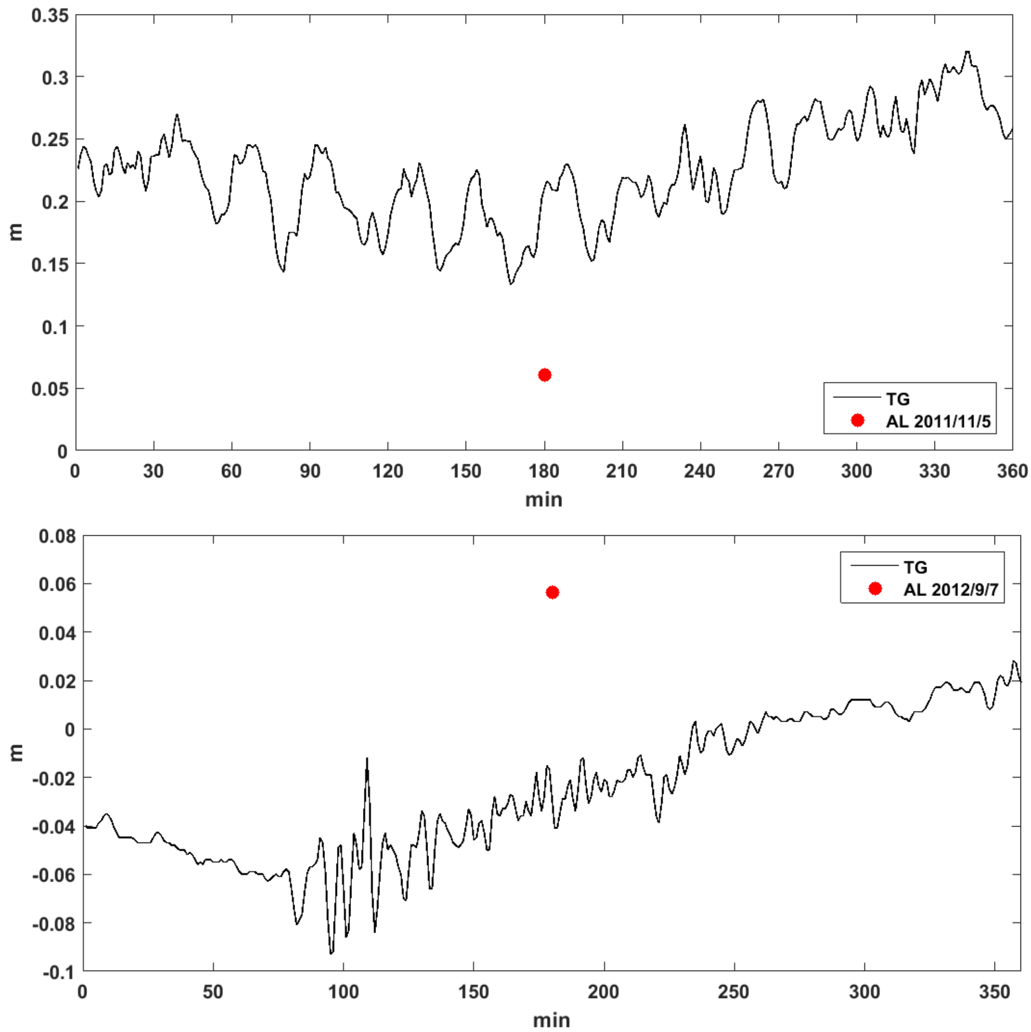
Out of the 243 analyzed data, 13 had differences higher than 10 cm. Discrepancies between observation methods can be also related to the coastal topography of the region. Due to the narrow shelf, even the altimetric measurements closest to the coast might not well resolve the coastal dynamics or might be differently affected by the infra-gravity variability detected at the tidal station. Events of significant mismatch between altimetry and tidal gauge observations occurred during periods characterized by high frequency variability phenomena (meteotsunamis and rapid atmospheric pressure variations) were "caught" in the altimeter time series as shown in Figure 9.

In particular, the first example shows well-developed and persistent meteotsunami oscillations, even though of relative small amplitude. As meteotsunamis reach their highest amplitude in the shelf, it is likely that the amplitude at the site of the altimetry measurements, at a higher sea depth, was negligible. Moreover, the low frequency of satellite passages and the lack of additional observations prevent one from understanding if and how the sea level perturbations detected at the tidal gauge can be the only factor responsible for the observed mismatches.

An additional assessment of the consistency and quality of the altimetry dataset for applications to coastal oceanographic studies in the region is the computation of the geostrophic currents by means of sea level anomaly (SLA) data averaged over the whole period. SLAs are generally used to describe the barotropic contribution to sea level variations, thus allowing one to investigate geostrophic currents and large eddies [51,52]. The elevation between the two points at the edge of the track was 1.6 cm and the distance was 24.27 km, about twice the internal Rossby radius for the Ligurian Sea [53]. This drives small surface geostrophic currents of about 6 cm/s orthogonal to the track and mainly directed eastward. This direction does not seem consistent with the general circulation of the Ligurian Sea, characterized by a cyclonic circulation with intense coastal current directed westward. Nevertheless, it can be pointed out that this evaluation could not be reliable for the small amplitude of SLA in respect to the accuracy of the altimetric measurements.

An analysis of tidal and DAC corrections used to obtain SLA is necessary for a better interpretation of altimetry data, even if the different observation methods and the location of altimetry points of measurements (just far from the shelf) in respect to the tidal station located inside a harbor does not allow a proper direct comparison. Tide prediction at the tidal stations is very precise as tidal components are obtained from long temporal series and harmonic analysis. Due to the need of computing offshore tidal elevations, corrections applied to satellite data require a different approach (generally a 2D hydrostatic model). Moreover, tidal elevation is amplified along the coasts, so that the two signals are hardly comparable. In the analyzed time series, RMSD was 4.7 cm, and most of the differences were related to the long period components, which apparently were not taken into account in the model. Regarding the DAC, it was well correlated with the inverse barometer effect computed from the atmospheric pressure measurements at the tidal station. The remaining part of the correction, which was mainly due to wind forcing and other dynamic processes, could not be estimated for the tidal measurements.

Despite the significant and impressive improvements in altimetric measurements of the sea surface elevation, a lot of care is still required when handling altimetry data to approach investigations on coastal dynamics and its variability. Future studies will benefit from the reprocessing of archived data and improved native observations from modern altimetry. The results of this study highlight and quantify the difference between coastal tides and altimetry data in the Gulf of Genoa. Tide gauges provide a time series of sea level changes in a single point with frequent sampling. However, they are essentially located in protected environments that might not be representative of offshore conditions. With the advent of satellite altimetry, we had also sea level measurements in open ocean along tracks, although with lower temporal sampling (at the moment ≥ 10 days); however we could densify them by merging multiple missions. The added value of altimetry is that a unique and homogenous long term observational dataset will permit to characterize how sea level variability evolves from the open ocean to the coastal zone, thus filling the gap between open ocean and tide gauges. The integrated use of altimetry and tide gauges, as demonstrated in this study, contributes to a better understanding of the sea level processes occurring at the various scales.



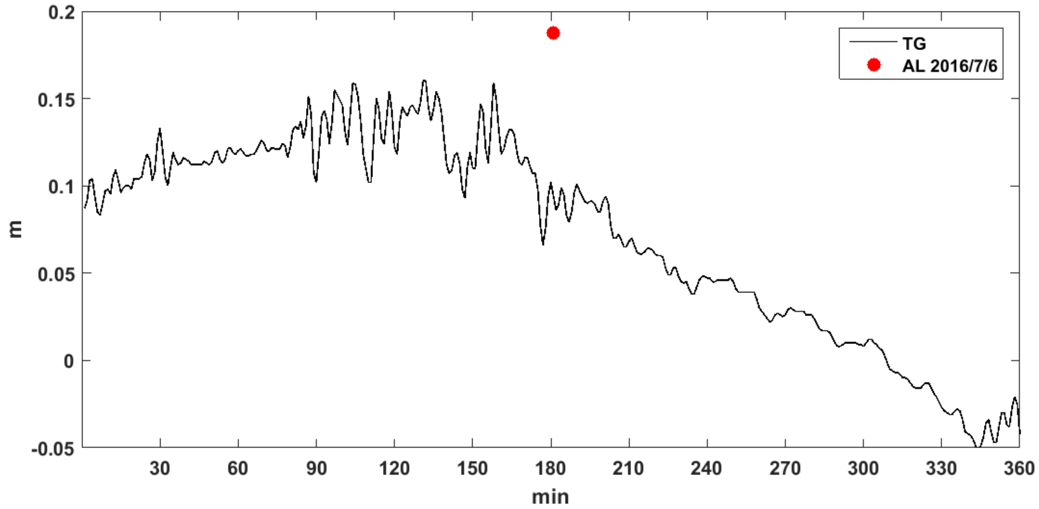


Figure 9. Time series of sea level data from the tidal gauge (black line) 3 h before and after the passage of the altimeter and the TWLE values detected by the altimeter (red dot).

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