Improved satellite altimeter mapped sea level anomalies in the Mediterranean Sea: a comparison with tide gauges

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Abstract.

The new gridded Mediterranean sea level anomaly product recently released by AVISO (DT14) is evaluated and compared with the earlier version (DT10) at which it is aimed to substitute. Differences between the two products are found along coastal regions, where the new version captures more variability (up to 10% more) and trends locally differ by up to 1 mm/yr for the altimetric period. Coastal tide gauge observations have therefore been used as the basis for quantifying changes in DT14. Correlation and variance reduction in available monthly tide gauge time series are improved in more than 80% of the selected sites by up to 0.2 and 5 cm^2, respectively. This resulted in an overall higher skill to recover coastal low frequency (with periods larger than a few months) sea level signals. Results for higher/lower order percentiles were also explored and showed different performances depending on the site, although with a slight overall improvement. A comparison with tide gauges on a daily basis using wavelet analysis reveals that altimetry gridded products are not capable of recovering higher frequency (a few days) coastal sea level signals despite some advances have been achieved thanks to the daily temporal sampling of DT14.

Keywords: Mediterranean Sea; sea level; satellite altimetry; tide gauges;

1. Introduction

Since the early nineties, satellite altimetry has become an essential tool in oceanographic research, with applications in sea level changes, mesoscale variability or propagating ocean Rossby waves, among others (Cazenave and Llovel, 2010 ; Le Traon et al., 2013, Cipollini et al. 2010 ; Calafat and Marcos, 2012). During the last 20 years, many efforts have been devoted to data processing and development of geophysical corrections that allowed reaching the current maturity of the sea surface height observations with 1-2 cm accuracy. The use of multiple satellites has furthermore permitted merging sea level measurements into interpolated products, thus facilitating the investigation of ocean mesoscale variability (Ducet et al. 2000, Pascual et al. 2009). Regional altimetric gridded sea surface height products deserve special attention, as they have been developed using processing adapted to areas of particular oceanographic interest with higher spatial resolution than the global products. This is the case of the Mediterranean Sea, where products are developed with a resolution of 1/8 of degree and that is considered a reduced scale ocean laboratory, where processes can be studied at smaller scales than in other oceanic regions (Internal Rossby Radius is 10-15 km) including deep convection, shelf-slope exchanges, thermohaline circulation, water mass interaction and mesoscale and sub- mesoscale dynamics (Robinson et al. 2001; Hermann et al. 2009; Bouffard et al. 2012).

Dedicated altimetric gridded fields for the Mediterranean Sea produced and delivered by the Archiving, Validation and Interpretation of Satellite Oceanographic Data (AVISO) have provided access to realistic sea surface circulation variability (e.g. Larnicol et al., 2002; Pujol and Larnicol 2005; Pascual et al. 2007; Mason and Pascual 2013). It must be remarked though that, as evidenced by previous in situ experiments (e.g., Nencioli et al., 2011, Escudier et al. 2013), altimetric maps have limited capabilities in detecting small and coastal features (~10–100km). Indeed, Nencioli et al., (2011) showed that in comparison with in situ experiments the altimetry maps for the Mediterranean Sea lack the resolution required to detect small and coastal features. In this context, Escudier et al., (2013) has developed innovative strategies to attempt to improve existing satellite altimetry products to better resolve mesoscale eddies. It is shown that this improvement is possible but at the cost of the homogeneity of the fields;

the resolution can only be improved at times and locations where altimetric observations are densely distributed.

The objective of the present work is to assess the changes and quantify the improvements in the new gridded Mediterranean sea level anomalies product recently released by AVISO. New reprocessing and updated geophysical corrections have been developed within the framework of MyOcean Project (User Handbook Ssalto/Duacs, 2014). This assessment will be based on comparisons with tide gauge data.

2. Data and methods

2.1 Sea Level Anomalies from altimetry

Two different satellite altimetric regional products on the Mediterranean Sea have been compared. Both consist of gridded Sea Level Anomaly (SLA) observations generated by AVISO and available at its web site (http://www.aviso.altimetry.fr/). The first product, hereinafter referred to as DT10, corresponds to the former altimeter gridded fields, i.e. SLA interpolated onto a 1/8ºx1/8º regular grid and weekly sampling, using satellite observations available since October 1992 (User Handbook Ssalto/Duacs, 2014).

The second product, hereinafter refer to as DT14 and released by AVISO in April 2014, correspond to SLA spanning the period 1993-2012, interpolated with the same spatial resolution (for the specific product of the Mediterranean Sea) and with daily temporal sampling. The process is the same as for DT10 products except that some parameters were adjusted (see below for details) and that a map is produced for every day instead of one map per week as for the DT10 product. The daily maps in DT14 are obtained by optimal interpolation (OI) as are the weekly maps in DT10. In both the datasets, each map produced use data selected in a temporal window of ±49 days. This windows is larger than the temporal correlation scale considered (10 days in the Mediterranean Sea) in order to allow an optimal correction of the long-wavelength errors that need to be accounted for (i.e. reduction of large scale bias between the different altimeter tracks). The main differences between DT14 and DT10 are induced by the use of:

- a new reference field and SLA bias convention: the SLA DT10 were referenced to the mean sea surface MSS_CNES_CLS_2001 (or equivalent precise mean profile for repetitive missions), representative of the 7-year [1993, 1999] period. The SLA DT14 are referenced to the MSS_CNES_CLS_2011 2001 (or equivalent precise mean profile for repetitive missions) corrected to be representative of the 20-year [1993, 2012] period. Mean SLA over year 1993 are fixed to 0 by convention.
- updated sensor-specific standards for geophysical and atmospheric corrections, and a new ocean tidal component. The details of the standards used in DT14 are given in (User Handbook Ssalto/Duacs, 2014)
- revised inter-calibration (reduction of the bias between the missions): in DT14, Jason-2 is used as reference. The previous missions Topex/Poseidon and Jason-1 were corrected from a global and regional bias is order to ensure the consistency of the mean sea level over all the altimeter period. In DT10 this calibration was done using Topex-Poseidon as reference.
- improved error budget: The variance characteristic of the uncorrelated noise measurement and long wavelength correlated errors, that are involved in the covariance matrix definition (OI process) were reviewed taking into account the characteristics the different altimeters that can impact the measurement errors (i.e. no radiometer; mono-frequency measurements, non repetitive orbit)
- the inclusion of Cryosat since 2011 in DT14.

We refer to CNES (2014) for further details. Additionally the use of new mean profiles (precise mean sea surface height along the tracks of the different altimeters required to derive SLA) has enabled a gain of measurements in coastal areas, compared to previous mean profiles. Another change consists in the extension of the gridded product up to 6ºW, improving the representation of the Alboran Sea. The contribution of the atmospheric pressure and wind forcing is removed in both DT10 and DT14 datasets using a dynamic atmospheric correction applied to the along-track data prior to the objective analysis. This correction combines the high frequencies output of the barotropic ocean model MOG2D (Modèle d'Onde de Gravité à 2 Dimensions) forced by pressure and wind from the European Centre for Medium-Range Weather Forecasts (ECMWF) analysis with the low frequencies of the inverted barometer (IB) correction (Carrère and Lyard, 2003; Pascual et al. 2009). It has been shown that using this correction rather than the static IB improves the representation of the high frequency atmospheric forcing on sea level (Volkov et al, 2007; Pascual et al., 2008). Note that in DT14 the Dynamic Atmospheric Correction solution has been also upgraded for the missions ERS-1, ERS-2 and Topex/Poseidon (i.e. over the end1992-end2005 period) while taking into account the more accurate ERA-Interim forcing instead of ECMWF operational analysis.

In this study, we use the "all-sat" or "upd" (in AVISO nomenclature) gridded SLA fields that consider all available altimeters and therefore have higher quality levels, although not homogeneous in time due to the time-varying mission configuration. DT10 corresponds to the last version of the products delivered in the AVISO+ ftp directories /regional-mfstep/regional-mfstep/dt/upd/msla/merged/h (no more existing on AVISO+ ftp since April 2015); DT14 corresponds to the first version of the product delivered in the AVISO+ ftp directories regional-mediterranean/delayed-time/grids/msla/all-sat-merged/h (more information can be found at http://www.aviso.altimetry.fr/fr/donnees/information-sur-les-produits/updates-and-reprocessing/ssaltoduacs-delayed-time-reprocessing.html). During the 20 years considered, the number of altimeters available generally varies between 2 and 4. The common period 1993-2012 of DT10 and DT14 was selected for the analyses. When stated, monthly values of SLA were computed at each grid point if at least 3 weeks of measurements were available (a monthly product is also available for DT14, simply computed as the monthly means of daily fields). Seasonal cycle and linear trends were estimated based on monthly observations at each grid point. The time-mean seasonal cycle was obtained by fitting an annual and a semi-annual signal using harmonic analysis. Linear trends were then computed over deseasoned time series using a robust linear regression.

2.2 Tide gauge records

Monthly mean sea level records from the Permanent Service for Mean Sea Level (www.psmsl.org) tide gauge data repository along the Mediterranean coasts and with datum control were used (Holgate et al, 2013). All tide gauge records with at least 10 years of valid observations during the period 1993-2012 were selected, resulting in 70 stations. In addition, the two Mediterranean daily tide gauge records available at the University of Hawaii Sea Level Center (http://uhslc.soest.hawaii.edu/), namely Marseille and Ceuta, were also included. The stations and their information are listed in Table 1 and mapped in Figure 1. Note that the stations in the list have been sorted with increasing longitude and these were then grouped into five regions: Western Mediterranean, Central Mediterranean, Adriatic Sea, Aegean Sea and Eastern Mediterranean (see Table for classification).

The atmospherically-induced sea level caused by the action of atmospheric pressure and wind was removed from the tide gauge records. The same dynamic atmospheric correction as for altimetry was applied for the sake of consistency. To do so, 6-hourly fields of this correction, available at AVISO web site, were downloaded and converted into daily and monthly fields. Then, for each tide gauge site, the closest grid point was selected and used to remove the atmospherically-induced sea level from observations.

The comparison between tide gauge and SLA time series was based on a particular grid point selected for each tide gauge location as follows: first, correlations between each tide gauge record and SLA corresponding to grid points within a radius of 2º were computed, using detrended and deseasoned monthly time series. Second, the most correlated grid point was selected and all the grid points within the area whose correlations were statistically the same at the 90% confidence level were identified. Finally, the grid point among this set with the smallest distance to the tide gauge was chosen. The equivalence between the correlations corresponding to all the grid points was tested according to the Fisher Z transformation of each correlation R, which is defined as:

$$Z_f = \frac{1}{2} ln \frac{1+R}{1-R}$$

While the distribution of correlations is generally skewed, the distribution of the Z-transformed correlations is close to normal and, therefore, confidence intervals can be estimated. Given two SLA time series at grid points with correlations of values R_1 and R_2 with the tide gauge, the difference of their Z-transformed values is defined as:

$$Z = \frac{Z_{f1} - Z_{f2}}{\sqrt{\frac{2}{N-3}}}$$

Where N is the length of the time series. As Z is normally distributed, its confidence intervals can be estimated using a t-test. The value of Z was then used to determine the level of significance of the difference between R_1 and R_2 (90% in our choice). Once the grid point was selected, the corresponding SLA time series was used for comparison with tide gauges.

3. Evaluating differences between gridded SLA

SLA from DT10 and DT14 products and their differences were first assessed. Variances at each grid point were computed using weekly and daily data for DT10 and DT14, respectively. The latter is mapped in Figure 1 (top) together with the difference between DT14 and DT10 (bottom). A positive difference implies that variance of DT14 is higher than that of DT10. The map of variability matches the well-known mesoscale activity structures in the Mediterranean Sea with the Alboran gyres, Algerian eddies and Ierapetra eddy (Pujol and Larnicol, 2005). Differences between the two products ranged between -5 and 10 cm^2 and were, on average, about 1.3 cm^2 (~2% of the averaged variance within the basin). Therefore, the new product adds little value to the total variability captured by SLA averaged over the entire basin. However, locally and especially along the coasts, the increase in variance can represent a significant part of the total variance. It is likely that the new mean profiles providing more coastal sea level anomalies are partly responsible for this improvement. The Northern Adriatic Sea is one of the examples where changes in the variance reached about 10%. When both products were compared on a weekly basis the average difference in variance showed the same spatial pattern but was reduced to 0.45 cm^2.

Monthly time series were deseasoned and the mean annual and semi-annual cycles were computed. The differences in the mean amplitudes and phases of the seasonal cycles between the two products lied within the uncertainty range of the parameters (not shown). Thus no changes in the ability of estimating the mean seasonal sea level cycle can be reported in the new version DT14. Linear trends and their difference were then computed for deseasoned DT10 and DT14 SLA (Figure 2). Linear trends were spatially heterogeneous, varying between -5 and 6 mm/yr for the period 1993-2012 (Figure 2, top). Trends of their differences ranged between ±1 mm/yr (Figure 2, bottom), a value which was smaller than the standard error (SE) of the linear trend over most parts of the basin. These areas, shadowed in Figure 2, represented about 92% of the total surface and corresponded to the region where no changes in the trends can be reported in the new version. The rest of the basin where changes in trends are statistically significant in DT14, were mostly concentrated close to the coasts, which was indeed where higher improvements of SLA were expected after the increase in variance reported above. In these cases, positive values of about 1 mm/yr dominated over negative values.

4. Validation with coastal tide gauges

The distances between the selected SLA grid points and the tide gauge sites were first explored, as these are considered indicative of the performance of altimetric products in regions close to the coast. Indeed, the location of the grid points that were found to be closest and most correlated with the coastal record generally differed between DT10 and DT14, with DT14 showing smaller values in most cases. The median distance of DT10 was 96 km whereas for DT14 was 78 km, implying thus that DT14 is generally improved in areas close to the coast. These relatively long distances respond to the fact that changes along the coasts are essentially barotropic and highly coherent along the Mediterranean coasts (Marcos, 2015).

The ability of SLA to recover coastal sea level variability was also evaluated using tide gauge observations. The correlations between coastal and altimetric time series and the differences in the variance reduction are plotted in Figure 3. Correlations were higher for DT14 at most of the selected tide gauge sites (87%), with a maximum value of 0.2 in the Alboran Sea. The median of the correlations were 0.77 for DT10 in front of 0.79 for DT14. Two examples of these comparisons are plotted in Figure 4, for the stations of Imperia (correlation of 0.9) in the western basin and Erdek (correlation of 0.6) in the eastern basin. This figure reveals the high coherence between intra- and inter-annual sea level variability as measured by the coastal tide gauges and the selected altimetric observations. Accordingly, the reduction in the variance, defined as the variance of the tide gauge record minus the variance of the difference between the tide gauge and the SLA time series, was higher (up to 5 cm^2) for DT14. Figure 3b illustrates the difference in this variance reduction: positive values indicate that such reduction at the tide gauge is greater for DT14. This was found to be the case for more than 84% of coastal sites, reinforcing the improvement of the new product DT14 in areas close to the coast. The histogram represented in the inset plot (Figure 3b) also highlights this distribution skewed towards positive values of the difference. When linear trends were explored it was found that median differences with DT14 (0.23 mm/yr) were significantly smaller than those with DT10 (0.95 mm/yr), and this despite SLA and tide gauge trends are the same only in absence of vertical land movements. The improvement at coastal tide gauges is generalized, without any areas particularly enhanced.

A comparison between sea level percentiles at coastal tide gauges and altimetric grid points was conducted using quantile-quantile (qq) plots generated at each tide gauge with DT10 and DT14 SLA. Percentiles between 1^{st} and 99^{th} (in integer steps) computed for the entire time series of tide gauge and SLA were used. This kind of comparison using high and low order percentiles provides more information than a direct comparison of the time series, as that in figure 4; the latter essentially reflects the mean sea level (i.e. 50^{th} percentile) behaviour. The root mean square error (rmse) of the regression between the tide gauge and the SLA was chosen to measure the goodness of the fit. The smaller the rmse the larger similarity between high and low values of SLA and tide gauges. The results (Figure 5a) are in line with above results, with median (for all tide gauges) rmse slightly smaller for DT14 (0.27 cm) than for DT10 (0.29 cm), indicating that the fit of SLA when higher and lower order percentiles were accounted for was improved in the new product. It is evident that the correspondence between tide gauges and SLA for the highest and lowest sea level values is poorer than for the mean sea level (Figure 5). This is likely due to the different original sampling of the tide gauges, typically hourly, in front of that of SLA, much longer, which implies that it may not capture the highest/lowest sea level events. It is worth noting that there are cases for which the fit worsens significantly when DT14 is used. The two cases for which the fit is most worsened and most improved are marked in Figure 5a with blue dots and their qq-plots are represented in Figures 5b and 5c, respectively. In the case of the station 374, corresponding to Piraievs in the Aegean Sea (Figure 5b), the fit for DT10 was found to be very good even for the highest and lowest order percentiles. In the case of the highest improvement in station 788, corresponding to Monaco in the Western Mediterranean, the fitting is very similar for both products. This is indeed the case of most of the stations, for which the reported reduction in rmse for DT14 cannot be attributed to a general feature such as a better match of the higher or lower sea levels.

4.1 Comparison with daily coastal sea level

The two daily tide gauge records at Marseille and Ceuta have been checked against the high frequency altimetry. With the aim of exploring the energy content at different frequency bands, a wavelet analysis was performed onto the tide gauge and SLA time series. The mother function used was Morlet. Energy contents in the range from 1 to 500 days were represented for the tide gauge and SLA DT14 time series and from 7 to 500 days for SLA DT10 (Figure 6). Results for both stations revealed that the energy at the coastal tide gauge was greater than that of the altimetry for all frequencies, with the only exception of the annual cycle. Differences between DT10 and DT14 were small for periods shorter than 20 days, after which the energy content decreased rapidly. This represents an important difference with the tide gauge measurements and points at the fact that none of these products is able to capture daily sea level variability despite its temporal sampling. For periods longer than about 20 days there were clear differences between SLA DT10 and DT14. The new product displayed higher energy content than the former in a wide frequency band. Despite the energy was still lower than observed by the tide gauge, it represents an improvement with respect to the SLA DT10. It seems reasonable to attribute the energy contents partly to the different grid points selected in DT10 and DT14, the latter being closer to the coast. Likewise, the lesser number of profiles near the coast in DT10 is expected to smooth the signal in the optimal interpolation procedure.

5. Discussion and conclusions

A new gridded SLA regional altimetric product for the Mediterranean Sea, recently released by AVISO, has been evaluated and the differences with the former version at which it is aimed to substitute have been assessed. The new SLA DT14 is distributed with daily temporal sampling compared to the weekly resolution of DT10 product. It has been shown that the recent improvements have a significant local impact, especially along the coasts, where differences between the two products were found both in terms of variance and linear trends. The comparison with coastal tide gauges has overall improved: correlations with SLA DT14 were higher than with DT10 at almost all the selected tide gauges (87%). Consequently, the variance reduction at the tide gauge sites was greater. The improvement is especially large in the area close to the Strait of Gibraltar, because of the short tracks in this area, often discarded in the previous version and due to the extension of the DT14 products up to 6ºW. When linear trends from the selected grid points were compared to those from tide gauges, it was found that DT14 reduced the overall difference too.

The way in which tide gauge and SLA time series are compared is also a subject of discussion. Along the coast and over continental shelves, sea level changes are essentially barotropic. This fact results in a high coherence in terms of sea level variability that can reach long distances following the coast, whereas the correlation rapidly decreases in the cross-shore direction with increasing water depth (see e.g. Marcos, 2015, for a Mediterranean study). This is why the closest grid point to the tide gauge is not necessarily the most correlated, as it likely will lie in an area which may not be representative of coastal sea level. In addition to this it may also happened that the quality of the altimetric signal differs from one site to another simply due to the amount of raw data used to generate the interpolated product. But even in the case that the quality is exactly the same the topographic features of the area under study also have an impact. When the comparison between altimetry and tide gauges is simply based on the most correlated SLA grid point it may happen that this selected point is located at a remote distance from the station. Therefore, a commitment must be reached between the maximum distance allowed and the choice of the most correlated grid point to ensure that the comparisons are not biased and that different regions are indeed not being explored. In this paper we have selected a maximum distance within a radius of 2º in latitude and longitude, but this choice is certainly dependent on the region investigated.

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Figure Captions

Figure 1. a) Variance of SLA DT14 and locations of tide gauges used in this study (black dots identify the two stations with daily sea level observations) and b) difference in the variances between DT14 and DT10 SLA.

Figure 2. a) Linear trends of DT14 SLA and b) trends of differences between DT10 and DT14. Areas where differences were smaller than the standard error of the trend of DT14 SLA have been shaded.

Figure 3. a) Correlation of DT10 and DT14 monthly SLA for the selected grid points with monthly tide gauge records and b) difference in variance reduction between DT14 and DT10 at each tide gauge site. Inset plot represents the histogram of these latter values. Vertical lines denote regions as in Figure 3 (see Table 1 for number and region correspondence).

Figure 4. Comparison of tide gauge records and altimetric time series from DT14 SLA for two selected stations

Figure 5. a) Rmse of quantile-quantile (qq) plots for all tide gauge locations. All qq-plots have been computed using percentiles from 1st to 99th. Vertical lines denote regions as in Figure 3. The qq-plots of the stations where rmse is most increased (reduced) with respect to DT10 are plotted in b (c). These two stations are marked with a blue dot in a).

Figure 6a. Wavelet analysis of the tide gauge time series at Marseille (bottom) and of the two SLA most correlated grid points for DT14 (middle) and DT10 (top).

Figure 6b. As in Figure 6a but for the tide gauge at Ceuta.

Tables

	Region	PSMSL Code	Station Name	Lat(ºN)	Lon(ºE)	Period	% gaps
1	Western Mediterranean	488	TARIFA	36.00	-5.60	1993-2012	1
2		498	CEUTA	35.90	-5.31	1993-2012	2
3		496	MALAGA	36.71	-4.41	1993-2012	0
4		1810	MALAGA II	36.71	-4.41	1993-2012	2
5		1813	VALENCIA	39.46	-0.33	1994-2012	8
6		1811	BARCELONA	41.35	2.16	1993-2012	5
7		1892	P. DE MALLORCA	39.55	2.63	1997-2010	35
8		1764	L''ESTARTIT	42.05	3.20	1993-2012	0
9		958	SETE	43.39	3.69	1996-2012	28
10		61	MARSEILLE	43.27	5.35	1993-2012	15
11		980	TOULON	43.12	5.91	1993-2012	8
12		1468	NICE	43.69	7.28	1993-2012	21
13		788	MONACO	43.72	7.42	2001-2012	40
14		2078	IMPERIA	43.87	8.01	2001-2012	40
15		2076	CARLOFORTE	39.14	8.30	2001-2012	40
16		2084	PORTO TORRES	40.84	8.40	2001-2012	42
17		2090	GENOVA II	44.41	8.92	2001-2012	42
18		2089	CAGLIARI II	39.21	9.11	2001-2012	40
19		2080	LIVORNO II	43.54	10.29	20012012	40
20	Central Mediterranean	2079	LAMPEDUSA	35.49	12.60	2001-2012	40
21		2093	PALERMO II	38.12	13.37	2001-2012	40
22		2083	PORTO EMPEDOCLE	37.28	13.52	2001-2012	42
23		2092	NAPOLI II	40.84	14.26	2001-2012	41
24		1735	MARSAXLOKK	35.82	14.53	1993-2011	12
25		2086	SALERNO	40.67	14.75	2001-2012	40
26		2094	CATANIA II	37.49	15.09	2001-2012	40

27		2082	PALINURO	40.02	15.27	2001-2012	40
28		2142	REG. CALABRIA II	38.12	15.64	2001-2012	40
29		2095	TARANTO II	40.47	17.22	2001-2012	40
30		1239	LEVKAS	38.83	20.71	1993-2012	12
31		410	PREVEZA	38.95	20.75	1993-2012	14
32		1240	KATAKOLON	37.64	21.31	1993-2012	8
33		1250	PATRAI	38.41	21.72	1993-2006	33
34		411	KALAMAI	37.02	22.11	1993-2012	11
35	Adriatic	2100	VENEZIA II	45.41	12.42	2001-2012	41
36		2098	ANCONA II	43.62	13.50	2001-2012	40
37		761	ROVINJ	45.08	13.62	1993-2011	5
38		1817	LUKA KOPER	45.56	13.75	1993-2003	50
39		2099	TRIESTE II	45.64	13.75	2001-2012	41
40		154	TRIESTE	45.64	13.75	1993-2012	0
41		2097	ORTONA II	42.35	14.41	2001-2012	41
42		353	BAKAR	45.30	14.53	1993-2011	5
43		1859	ZADAR	44.12	15.23	1994-2011	13
44		2087	VIESTE	41.88	16.17	2001-2012	41
45		685	SPLIT RT MARJANA	43.50	16.39	1993-2011	8
46		352	SPLIT – G. LUKA	43.50	16.44	1993-2011	5
47		2075	BARI	41.14	16.86	2001-2012	40
48		1706	SUCURAJ	43.13	17.20	1993-2005	38
49		760	DUBROVNIK	42.65	18.06	1993-2009	15
50		2096	OTRANTO II	40.14	18.49	2001-2012	40
51	Aegean	373	THESSALONIKI	40.63	22.93	1993-2012	7
52		409	POSIDHONIA	37.95	22.96	1993-2012	38
53		1441	KHALKIS SOUTH	38.46	23.58	1993-2012	23
54		1237	KHALKIS NORTH	38.47	23.59	1993-2012	7
55		374	PIRAIEVS	37.93	23.62	1993-2012	17

56		1232	SOUDHAS	35.48	24.08	1993-2011	8
57		375	KAVALLA	40.93	24.41	1993-2010	23
58		1234	SIROS	37.43	24.94	1993-2012	5
59		634	IRAKLION	35.34	25.15	1993-2011	35
60		1238	ALEXANDROUPOLIS	40.84	25.87	1993-2012	6
61		408	KHIOS	38.37	26.14	1993-2012	7
62		1679	MENTES/IZMIR	38.43	26.71	1993-2009	25
63		1233	LEROS	37.12	26.84	1993-2012	9
64		1680	BODRUM II	37.03	27.41	1993-2009	29
65		1598	ERDEK	40.38	27.85	1993-2009	34
67	Eastern Mediterranean	1243	RHODOS	36.44	28.23	1993-2012	31
68		503	ALEXANDRIA	31.21	29.91	1993-2006	33
69		1681	ANTALYA II	36.83	30.61	1993-2009	30
70		1880	TEL AVIV	32.08	34.76	1996-2010	36
71		1797	HADERA	32.47	34.86	1993-2012	14
		UHSLC Code					
		824	Marseille	43.27	5.35		
		207	Ceuta	35.90	-5.31		

Table 1. List of tide gauge records with their PSMSL ID code, location, period of operation and percentage of data gaps during the period 1993-2012.