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Estimates of vertical land motion along the southwestern coasts of Turkey from coastal altimetry and tide gauge data ☆

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Abstract

The differences between coastal altimetry and sea level time series of tide gauges in between March 1993 and December 2009 are used to estimate the rates of vertical land motion at three tide gauge locations along the southwestern coasts of Turkey. The CTOH/LEGOS along-track coastal altimetry retrieves altimetric sea level anomalies closer to the coast than the standard along-track altimetry products. However, the use of altimetry very close to the coast is not found to improve the results. On the contrary, the gridded and interpolated AVISO merged product exhibits the best agreement with tide gauge data as it provides the smoothest variability both in space and time compared with along track altimetry data. The Antalya gauge to the south (in the Mediterranean Sea) and the Mentes/Izmir gauge to the west (in the Aegean Sea) both show subsidence while the Bodrum tide gauge to the south (in the Aegean Sea) shows no significant vertical land motion. The results are compared and assessed with three independent geophysical vertical land motion estimates like from GPS. The GIA effect in the region is negligible. The VLM estimates from altimetry and tide gauge data are in good agreement both with GPS derived vertical velocity estimates and those inferred from geological and archaeological investigations.

Keywords: Vertical land motion; Coastal altimetry; Standard altimetry; Tide gauge; GPS; Southwestern coasts of Turkey

1. Introduction

Tide gauge records provide important information for detecting coastal sea level change. However, for interpretation of the changes, it is necessary that true sea level variations can be differentiated from the vertical land movement (VLM) signals which are inherently present in the same record. While it is possible to make VLM corrections based on glacial isostatic adjustment (GIA) models, these models do not often fully explain the VLM component (Teferle et al., 2006). Woodworth (2006) emphasizes the need for VLM corrections of the tide gauge sea level records from reliable geodetic measurements of the total VLM rather than for GIA effect alone. The value of the geodetic measurement approach to correct the tide gauge derived relative sea level trends has recently been demonstrated using Global Positioning System (GPS)-derived vertical velocities (Bouin and Wöppelmann, 2010). As an independent method, satellite altimetry data have been used in comparison with tide gauge data to estimate the rate of VLM at tide gauges assuming that the VLM is the leading cause of the difference between the altimetry and tide gauge sea level time series (Cazenave et al., 1999; Ray et al., 2010; Nerem and Mitchum, 2002; Kuo et al., 2004).

Several previous studies have applied altimetry and tide gauge data to the problem of VLM in southern Turkey. Fenoglio-Marc et al. (2004) and Garcia et al. (2007)

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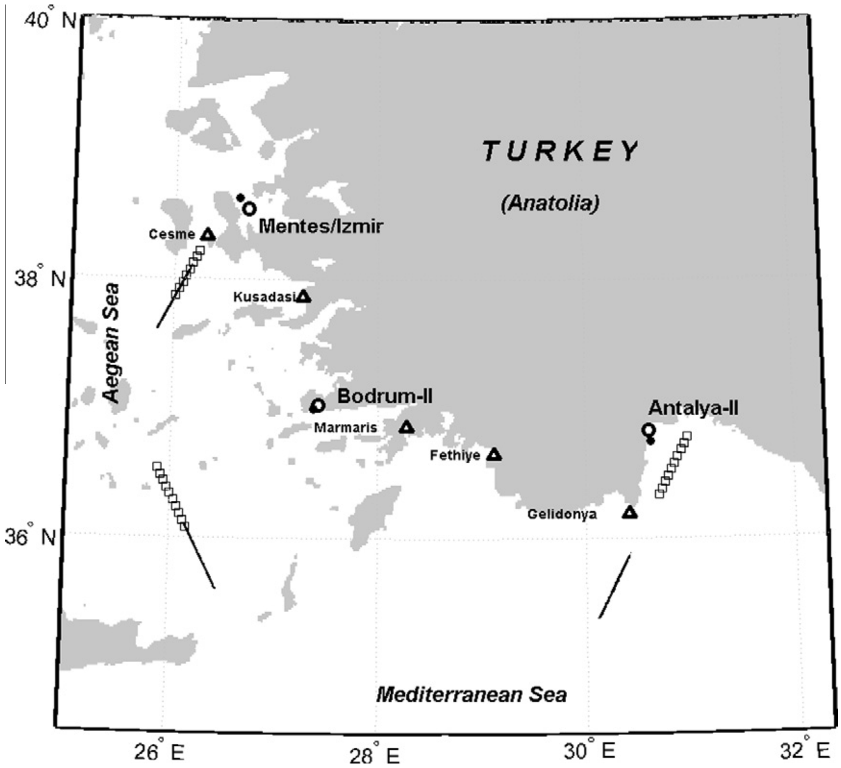

Fig. 1. Location of tide gauge stations (open circles) along the southwestern coasts of Turkey and the positions of the CTOH/LEGOS along-track coastal altimetry data (open squares), RADS standard along-track altimetry data (dots) and the nearest grid points of merged AVISO gridded altimetry data (dark circles) used to construct altimetric sea level time series for the comparison with each tide gauge. Triangles show archaeology stations used by Flemming (1978).

analyzed the differences between altimetry and tide gauge sea level time series over the period 1993–2001 to estimate the rates of VLM at several tide gauges in the Mediterranean Sea. For the Antalya-II Turkish tide gauge (Fig. 1), Fenoglio-Marc et al. (2004) found a land subsidence rate of -3.0 ± 1.6 mm/yr from TOPEX/Poseidon altimetric sea level anomalies (SLA) and the quality checked tide gauge sea level records provided by the General Command of Mapping of Turkey (GCM). They also reported an inconsistency between the tide gauge data of Antalya-II provided by GCM and similar data available in the Permanent Service for Mean Sea Level (PSMSL) at that time suggesting problems with the quality of the PSMSL data. Garcia et al. (2007) found land subsidence rates of -17.6 ± 4.0 mm/yr and -12.8 ± 3.8 mm/yr at Antalya-II and Menteş tide gauges (Fig. 1), respectively, using PSMSL data as well as a land uplift rate of 21.6 ± 5.6 mm/yr at the Bodrum-II tide gauge (Fig. 1). Garcia et al. (2007) interpreted these rates of VLM as suspicious. In the meantime, the GCM corrected and replaced the existing records in the PSMSL in 2010.

Fenoglio-Marc et al. (2004) and Garcia et al. (2007) used gridded satellite altimetry data obtained with the standard altimetry processing. However, the standard gridded maps of SLA derived from multiple satellite radar altimeter missions or standard along-track SLA are known to suffer from various biases and additional noise while getting closer to the coast (Anzenhofer et al., 1999). The radar altimeter and the radiometer data are potentially contaminated by the signals from land and islands within their footprints (Bouffard et al., 2011; Andersen and Scharroo, 2011). The tides are much more complex near the shores than in the open ocean and require a precise knowledge of the coastal geography of the study area. The wet tropospheric corrections computed from radiometer measurements are also less precise or not present at all near the coasts. Vignudelli et al. (2005) has shown that improved post-processing strategies can provide along-track SLA closer to the coast than is currently available from standard along-track altimetry products. It could be interesting to investigate if the altimetry data very close to the coast could produce new and interesting findings. We therefore decide to use CTOH/LEGOS post-processed coastal altimetry data, available at http://ctoh.legos.obs-mip.fr/, for the Mediterranean Sea.

This study aims to estimate the VLM along the southwestern coasts of Turkey using CTOH/LEGOS coastal altimetry and tide gauge data and to compare these data with the standard altimetry products. The comparison of the altimetry data with the tide gauge data is carried out in terms of distance to the tide gauges, the correlation and the root mean square (RMS) of the differences between the altimeter and the tide gauge time series. Consequently, coastal and standard altimetry data combined with quality checked tide gauge data are used to estimate the rates of VLM at tide gauge locations along the southwestern coasts of Turkey providing a comparison with GPS-derived vertical velocities, GIA model uplift predictions and VLM estimates from geological and archaeological investigations.

2. Data

2.1. Tide gauge data

Turkish tide gauge data are downloaded from the PSMSL (Woodworth and Player, 2003; Permanent Service for Mean Sea Level (PSMSL), 2012). Revised Local Reference (RLR) monthly sea level records from Antalya-II and Mentes/Izmir tide gauges (Fig. 1) are used for the March 1993 to December 2009 period. For the Bodrum-II tide gauge (Fig. 1), only data from September 1994 to December 2009 are available due to data gaps.

2.2. Satellite altimetry data

Coastal altimetry data set made available by the CTOH/LEGOS and preprocessed using the X-TRACK software (Roblou et al., 2011). Geophysical Data Records (GDRs) for the joint TOPEX/Poseidon (T/P hereinafter) Jason-1 and Jason-2 missions have been reprocessed at 1 Hz rate (6–7 km). The objectives of the X-TRACK are to improve both the quantity and quality of altimeter estimates in coastal regions by reprocessing aposteriori the GDRs. Data processed with X-TRACK provides improved SLA closer to the coast with an improved quality which is suitable for the comparison with coastal sea level variations observed by tide gauges (Roblou et al., 2011).

The CTOH/LEGOS along-track coastal satellite altimetry observations (Fig. 1) close to the Antalya-II, Bodrum-II and Mentes/Izmir tide gauges within a radius of 0.5° are averaged into monthly means. Note that the inverse barometer correction has not been applied to CTOH/LEGOS coastal altimetry data.

In order to compare the CTOH/LEGOS with standard along-track altimetry data, data from Radar Altimetry Data System (RADS: http://rads.tudelft.nl/rads/rads.shtml) as well as gridded altimetry data from Archiving Validation and Interpretation of Satellite Oceanographic data (AVISO) are used. Similar joint TOPEX, Jason-1 and Jason-2 data period of March 1993 to December 2009 has been extracted for the area of study using version 3.1 of default settings in the RADS database as described by Scharroo (2010), except for the DAC correction which is not applied to the altimeter data. From the RADS database, using standard corrections and selection criteria, altimetry data could be obtained close to the Antalya-II and Bodrum-II tide gauges (Fig. 1), but not for the Mentes station, because the radar altimeter and the radiometer data are contaminated by signals from land and islands within their footprints (Bouffard et al., 2011; Andersen and Scharroo, 2011). Data from the ERS-2 satellite were also extracted from RADS but these did not improve the analysis. Consequently the ‘radiometer land flag’ were ignored for Mentes. The RADS along-track satellite altimetry records (Fig. 1) close to the Antalya-II, Bodrum-II and Mentes tide gauges within a radius of 0.5° are averaged into monthly means to produce RADS altimetric sea level time series.

Finally, the “updated series” of weekly altimetry data grids based on the AVISO regional solution for the Mediterranean Sea, covering the period from March 1993 to December 2009 was used. Monthly averages were computed from the weekly sea level anomaly data. All standard corrections were applied, and DAC is added back to AVISO altimetry data to make it comparable with tide gauge observations.

The minimum distances between the altimetric sea level points to the tide gauges are given in Table 1 for the three different altimetry data sources. The distances from CTOH/LEGOS coastal along-track altimetry data to the tide gauges are smaller than those of the RADS standard along track altimetry data. However, the closest distance to tide gauges is obtained with the interpolated AVISO merged product (Fig. 1).

2.3. GPS data

The GCM has performed episodic GPS (EGPS) campaigns at 2–3 year intervals since 1992 at tide gauges along the southwestern coasts of Turkey in order to place sea level records in a well-defined global reference system and to monitor the VLM at tide gauges. Over the period from 1992 to 2009 several GPS campaigns have been performed at Antalya-II, Bodrum-II and Mentes/Izmir tide gauges each covering 2–8 independent occupations with the observation session lengths of about 5–7 h. Continuous GPS (CGPS) stations were established at Antalya in December 2003 and at Mentes/Izmir in August 2003 within less than 300 m distance to the tide gauges to continuously monitor VLM at the tide gauges. Although, these CGPS stations now provide sufficient observation lengths to minimize the influence of the seasonal signals on the estimated velocities (Blewitt and Lavallée, 2002), their time spans do not entirely coincide with the 1993–2009 altimetry–tide gauge sea level period whereas EGPS data period coincides with the altimetry–tide gauge sea level period. In order to get VLM at these tide gauges we combined the long time span of EGPS observations and the shorter but continuous GPS data following Sanli and Blewitt (2001).

The GPS data of episodic and CGPS sites used in the study are processed using GAMIT/GLOBK (v.10.3) software (Herring et al., 2006a,b). All corrections except atmospheric pressure loading are applied in accordance with International GNSS Service (IGS; Dow et al., 2009) and International Earth Rotation and Reference Systems Service (IERS) conventions (IERS Conventions, 2010). We use absolute azimuth and elevation dependent antenna

Table 1
The minimum distance between (km) locations of altimetry data and tide gauges and CTOH/LEGOS, RADS and AVISO represents along-track coastal altimetry data, standard along-track altimetry data and standard gridded merged altimetry data, respectively.

Tide gauge	Altimetry analysis centre	Minimum distance between tide gauge and along-track or gridded altimetry data (km)
Antalya-II	CTOH/LEGOS	32
	RADS	106
	AVISO	9
Menteş/ Izmir	CTOH/LEGOS	55
	RADS	68
	AVISO	13
Bodrum-II	CTOH/LEGOS	148
	RADS	153
	AVISO	6

phase center corrections for receivers, elevation dependent antenna phase center corrections for satellites and apply solid Earth and polar tide corrections following the IERS conventions (IERS Conventions, 2010) and FES2004 model (Lyard et al., 2006) for ocean tide loading corrections. Tropospheric parameters are estimated for 2 h intervals including horizontal tropospheric gradients with the use of global mapping functions of Boehm et al. (2006).

14 IGS core stations surrounding Turkey are included in the process where a series of loosely constrained daily GPS network solutions are obtained for episodic GPS and CGPS sites. Loosely constrained daily GPS solutions and Scripps Orbit and Permanent Array Center (SOPAC) loosely constrained solutions (hfiles) which include all IGS stations coordinates in the world, orbit parameters and variance–covariance matrix are directly combined. Combined solutions are then transformed into daily EGPS and CGPS coordinate time series by using 3-D seven parameter Helmert transformation (three translations, three rotations and one scale parameter) and 59 globally distributed IGS stations (Fig. 2) of which positions and velocities are defined in ITRF2005 (Altamimi et al., 2007). Because of the relatively lower accuracy of the vertical coordinates with respect to horizontal ones, the weights of the vertical coordinates of the IGS core sites used for datum realization are reduced by a factor of 10 in the transformation.

Vertical velocities from the combined EGPS–CGPS coordinate time series are estimated using the Maximum Likelihood Estimation method in Create and Analyze Time Series (CATS) software (Williams, 2008) simultaneously estimating the spectral indices for the time series. For the analysis of the combined time series, a mathematical model was employed which includes the velocity along with the annual component. As the GPS-derived velocities are all reference frame dependent, the uncertainties of the origin and the scale rates of the ITRF2005 reference frame were propagated to the uncertainties of the GPS derived vertical velocities using the transfer function derived by Collilieux and Wöppelmann (2011) applying 0.5 mm/yr for the scale rate and 1.0 mm/year for the rate of the Z component of the origin.

3. Results and discussion

The rates of VLM are computed from the series of monthly sea level differences built for the longest common periods between the altimetry and tide gauge data. Prior to the computations of these series of differences, the seasonal signals are removed from the original monthly altimetry and tide gauge time series by subtracting the estimates obtained from the least squares adjustment of seasonal sinusoids with annual and semiannual periods (Wöppelmann and Marcos, 2012). The rates of VLM are determined from these series of differences using CATS software employing a mathematical model including the velocity component. Furthermore, the significance of the rates of VLM is assessed at the 95% confidence level by applying the t-test to the ratio between the estimated VLM rate and its uncertainty (Fenoglio-Marc et al., 2012). The results and the RMS difference and correlation coefficient between the three different altimetry data sets

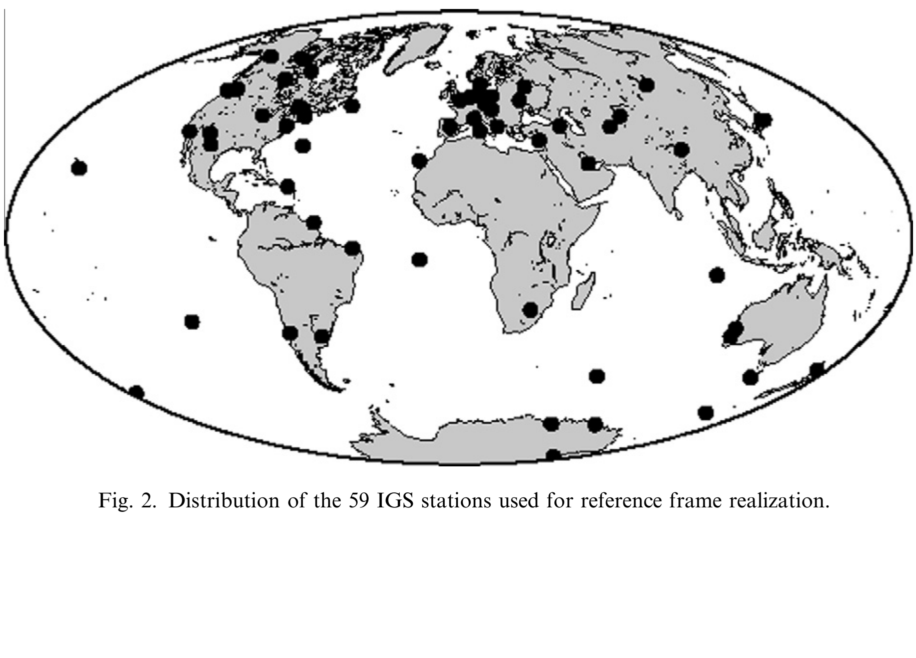

Fig. 2. Distribution of the 59 IGS stations used for reference frame realization.

and tide gauge data are given Table 2. The best agreement with the tide gauge data is obtained by using AVISO gridded data both in terms of RMS difference and correlation (Table 2). This is because AVISO merged product provides the smoothest variability both in space and time with respect to the along-track altimetry data.

3.1. Antalya-II

In Fig. 3, the results for Antalya-II tide gauge from CTOH/LEGOS coastal altimetry and tide gauge are shown. The RMS difference between the coastal altimetry and tide gauge is 3.9 cm and the correlation coefficient is 0.89 (Table 2). These results show better statistics than those given by Fenoglio-Marc et al. (2004) who found a correlation coefficient of 0.82 and an RMS of 4.5 cm between monthly altimetry and tide gauge data at Antalya-II tide gauge. Furthermore, the CTOH/LEGOS coastal altimetry data give better agreement with the Antalya-II tide gauge than the RADS data both in terms of RMS and correlation (Table 2). We estimate a statistically significant VLM rate of -2.9 ± 0.8 mm/yr from the differences between the CTOH/LEGOS coastal altimetry and tide gauge sea level time series which agrees well with Fenoglio-Marc et al. (2004). Furthermore, we analyzed the differences between the CTOH/LEGOS coastal altimetry and tide gauge sea level over the 1993–2001 period which was used by Fenoglio-Marc et al. (2004). We found the correlation coefficient as 0.87, the RMS as 4.0 cm and the VLM as -2.9 ± 1.5 mm/yr over the 1993–2001 period. The coastal altimetry data showed slightly better statistics than Fenoglio-Marc et al. (2004), although we found exactly the same VLM estimate as Fenoglio-Marc et al. (2004) over this period.

The altimetry–tide gauge derived estimates and the GPS derived VLM rates both indicate land subsidence (Table 3). Altimetry from RADS shows a rate of VLM in the order of -2.5 ± 3.2 mm/yr (not statistically significant) whereas the gridded AVISO data show statistically significant land subsidence with a rate of -3.4 ± 0.6 mm/yr in agreement with the VLM rate from the CTOH/LEGOS coastal altimetry data within their uncertainties.

Table 2
Comparisons of the sea level anomalies (SLA) from CTOH/LEGOS coastal altimetry data, standard altimetry products from RADS and AVISO in terms of number of altimetric data in common with the tide gauge (TG) time series correlation and root mean square (RMS) of the differences between altimeter and TG time series.

Tide gauge	Altimetry analysis centre	Number of altimetric data in common with the TG time series	RMS (cm)	Correlation
Antalya-II	CTOH/LEGOS	167	3.9	0.89
	RADS	165	6.2	0.72
	AVISO	167	3.6	0.92
Menteş/Izmir	CTOH/LEGOS	178	4.9	0.78
	RADS	175	5.2	0.74
	AVISO	178	3.8	0.86
Bodrum-II	CTOH/LEGOS	162	4.7	0.74
	RADS	162	5.2	0.72
	AVISO	162	3.7	0.84

3.2. Mentes/Izmir

Mentes/Izmir tide gauge shows a correlation coefficient of 0.78 and an RMS difference of 4.9 cm with CTOH/LEGOS coastal altimetry data (Fig. 4). Although the RMS values of the difference between the altimetry and

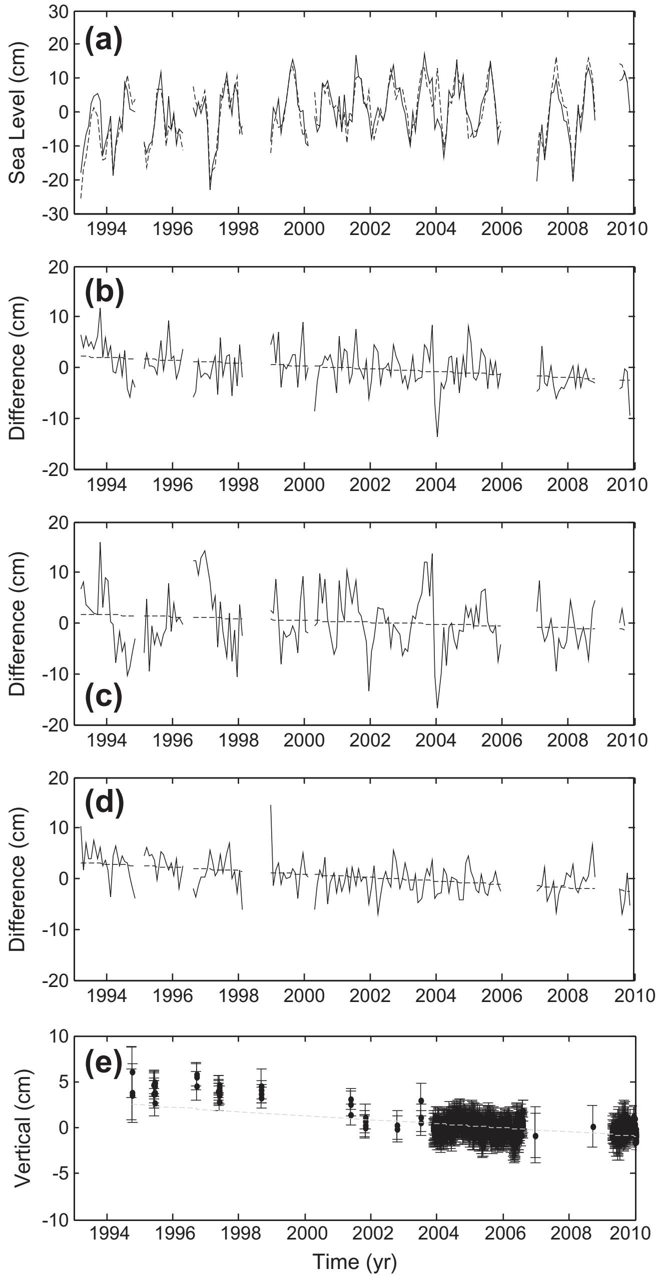

Fig. 3. (a) Monthly CTOH/LEGOS coastal altimetry (solid line) and tide gauge (dashed line) sea level time series at Antalya-II. The differences between altimetry and tide gauges using (b) CTOH/LEGOS (c) RADS (d) AVISO altimetry data (e) GPS vertical coordinate time series.

Table 3
Vertical land motion (VLM) comparison. All numbers shown are in mm/yr. All uncertainties are computed by using CATS software (Williams, 2008) estimating the spectral index for each time series to obtain realistic estimates of uncertainties of VLM.

Tide gauge/comparison period	Altimetry analysis centre	ALT-TG derived VLM	GPS derived VLM (Period)	GIA (mm/yr)
Antalya-II (1993–2009)	CTOH/LEGOS	-2.9 ± 0.8	-3.6 ± 1.7 (1994–2009)	-0.01
	RADS	-2.5 ± 3.2		
	AVISO	-3.4 ± 0.6		
Menteş/Izmir (1993–2009)	CTOH/LEGOS	-1.2 ± 0.5	-1.4 ± 1.3 (1992–2009)	-0.04
	RADS	-0.6 ± 0.8		
	AVISO	-2.4 ± 0.7		
Bodrum-II (1994–2009)	CTOH/LEGOS	0.5 ± 1.6	0.4 ± 1.4 (1994–2007)	-0.16
	RADS	0.6 ± 1.4		
	AVISO	-0.8 ± 1.9		

the tide gauge time series are almost equal for CTOH/LEGOS and standard along track altimetry data, the CTOH/LEGOS data gives a slightly higher correlation with the Mentes/Izmir tide gauge (Table 2). RADS data shows a VLM rate of -0.6 ± 0.8 (not statistically significant) whereas the VLM rate derived from the coastal altimetry data suggest statistically significant land subsidence in the order of -1.2 ± 0.5 mm/yr (Table 3), in agreement with GPS derived VLM rate. However the VLM rate obtained using the AVISO merged data shows a land subsidence in the order of -2.4 ± 0.7 mm/yr that is twice the rate computed using the along track altimetry data.

3.3. Bodrum-II

Bodrum-II tide gauge (Fig. 5) shows agreement between the CTOH/LEGOS coastal altimetry and tide gauge sea level time series, with a correlation coefficient of 0.74 and an RMS difference of 4.7 cm. When the CTOH/LEGOS data are considered, we find the smallest correlation coefficient and the largest RMS difference for the Bodrum-II tide gauge among the three tide gauges. Using the CTOH/LEGOS coastal altimetry, AVISO merged product and RADS standard altimetry data in combination with Bodrum-II tide gauge does not give statistically significant VLM rates in agreement with the GPS data (Table 3).

It is also noteworthy that using quality checked tide gauge data in combination with altimetry data provided more realistic and better estimates of VLM estimates at Bodrum-II and Mentes/Izmir tide gauge than that found by Garcia et al. (2007) indicating that they had problems with the tide gauge data.

The VLM estimates at Antalya-II and Mentes/Izmir tide gauges inferred from the differences between the CTOH/LEGOS coastal altimetry and tide gauge sea level time series which are validated by the GPS measurements, are considered to be the combination of vertical tectonics and glacio–hydro-isostatic signals associated with the last glacial cycle. The subsidence arising from the compaction of sediments or from the extraction of ground water is considered to be negligible and the dominant contributions considered here are tectonic and isostatic factors. We used ICE-5G uplift rates v1.3f (Peltier, 2004, http://www.atmosp.physics.utoronto.ca/~peltier/data.php) to predict the GIA induced VLM at each tide gauge, predicting land uplift rates for Antalya-II, Mentes/Izmir and Bodrum-II of -0.01, -0.04, -0.16 mm/year, respectively (Table 3). These results show that the estimates from the GIA model are much smaller than estimated VLM rates in Table 3 suggesting that that tectonic motion may be the dominant factor responsible for the estimated rates. Therefore, we investigate geological and archaeological evidence to explain the observed VLM rates at these three tide gauges.

Flemming (1978) studied the southwestern coasts of Turkey in terms of coastal vertical land movements based on archaeological data and separated these coasts into several active and passive zones depending on the tectonic trends along the southwestern coasts of Turkey: an active zone of subsidence over the Çeşme peninsula, a passive zone from Kuşadası to Bodrum, an active zone in Marmaris–Fethiye area and a region of rapid subsidence from Fethiye to Gelidonya in the east (Fig. 1). In this study, we found land subsidence of ~1 mm/yr at Mentes/Izmir tide gauge located in the Çeşme peninsula and Bodrum-II tide gauge to be stable in agreement with Flemming (1978). The subsidence rate observed at Mentes/Izmir is also in good agreement with the Izmir coastal subsidence rate which was estimated to be 1 m/1000 yrs over geological time (Aksu et al., 1987).

Recently, Anzidei et al. (2011) studied the archaeological evidence for the late Holocene relative sea level change along the southwestern coasts of Turkey using eight archaeological sites located along the Gulf of Fethiye. They found that these sites yielded consistent rates of subsidence in the order of -1.5 ± 0.3 mm/yr considered to be the primary cause of dramatic relative sea level rise for this part of the coast inferred from the rising sea level trend recorded by the Antalya-II tide gauge (6.8 ± 2.0 mm/yr during 1985–2005 period) which is the nearest available tide gauge to the Gulf of Fethiye. Our VLM estimates at Antalya-II station are in agreement with land subsidence rate estimate of the Anzidei et al. (2011) for the region.

4. Conclusion

The rates of VLM at three tide gauge locations along the southwestern coasts of Turkey are estimated using CTOH/LEGOS coastal altimetry. It is shown that CTOH/LEGOS

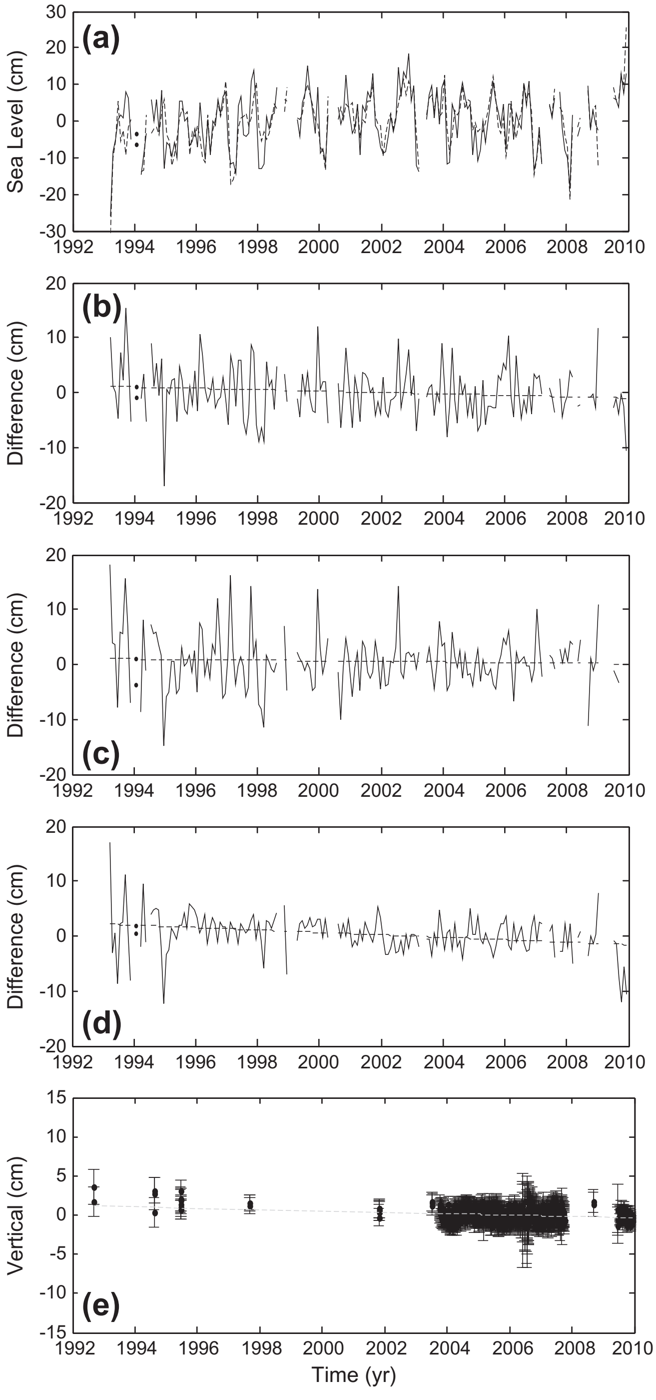

Fig. 4. (a) Monthly CTOH/LEGOS coastal altimetry (solid line) and tide gauge (dashed line) sea level time series at Mentes/Izmir. The differences between altimetry and tide gauges using (b) CTOH/LEGOS (c) RADS (d) AVISO altimetry data (e) GPS vertical coordinate time series.

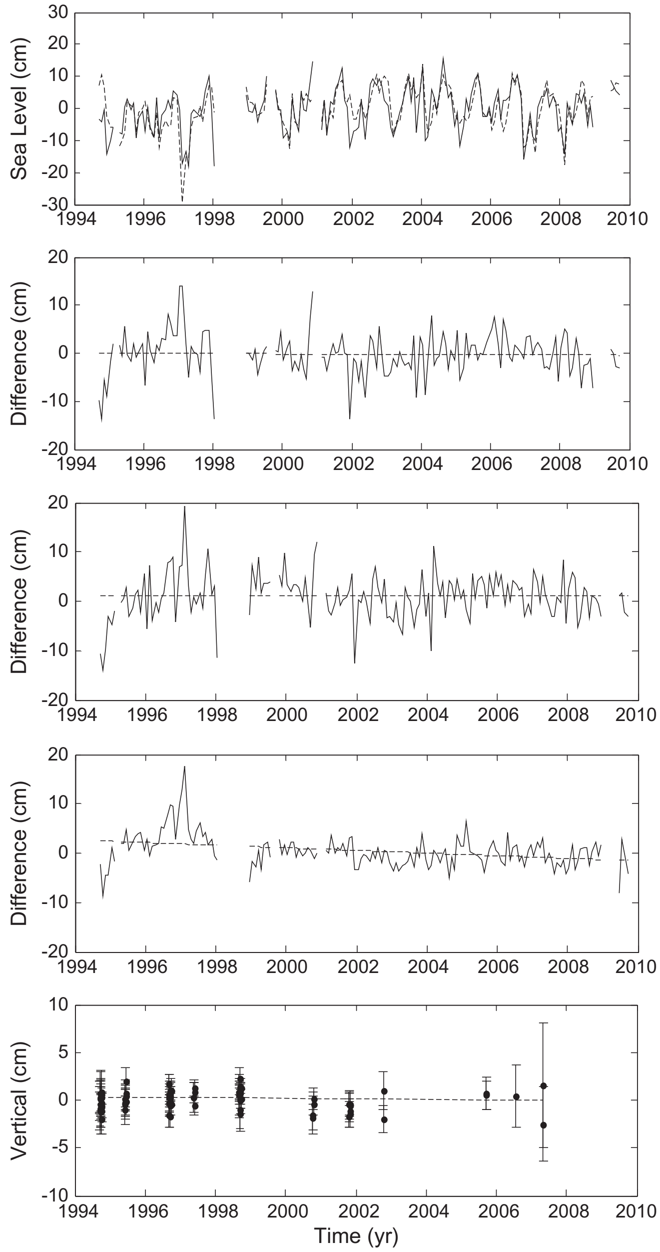

Fig. 5. (a) Monthly CTOH/LEGOS coastal altimetry (solid line) and tide gauge (dashed line) sea level time series at Bodrum-II. The differences between altimetry and tide gauges using (b) CTOH/LEGOS (c) RADS (d) AVISO altimetry data (e) GPS vertical coordinate time series.

coastal altimetry data enabled the retrieval of altimetric sea level anomalies closer to the coast than the standard RADS along-track altimetry products. The best agreements with the tide gauge data for all three tide gauges are obtained using AVISO merged product both in terms of RMS difference and correlation, as the AVISO merged product provides the smoothest variability both in space and time with respect to the along track altimetry data.

At Antalya-II tide gauge the CTOH/LEGOS coastal altimetry data gives better agreement with the Antalya-II tide gauge than the RADS standard along track data both in terms of RMS and correlation, whereas at Bodrum-II and Mentes tide gauges the CTOH/LEGOS and RADS altimetry data show almost the same RMS difference and correlation values. These results show that the use of altimetry very close to the coast data does not improve the results importantly with respect to using the standard along track altimetry data.

At all three tide gauges, the VLM rates from the CTOH/LEGOS coastal altimetry and from standard RADS and

AVISO products agree with each other within their uncertainties.

No statistically significant VLM is found at the Bodrum-II tide gauge (Aegean Sea). At Antalya-II to the south (in Mediterranean Sea) and Mentes/Izmir (in the Aegean Sea) we find statistically significant VLM rates of -2.9 ± 0.8 mm/year and -1.2 ± 0.5 mm/year suggesting land subsidence. These VLM estimates are compared with those inferred from GPS measurements and with the predictions from a GIA model. The comparison with the estimates from GPS measurements shows a good consistency. GIA effect in the region is found to be negligible. We found that the VLM rates estimated from the differences between the altimetry and tide gauge sea level time series and from GPS measurements correlate well with those inferred from archaeological data.

Correcting tide gauge sea level records for estimated vertical land movements is essential to enable them to be useful for measuring the climate related component of changes in sea level. It is suggested that the local scenarios of sea-level rise and vulnerability assessment plans for the southwestern coasts of Turkey need to be improved taking into account the better understanding of relative sea level change and its component from vertical land motion.

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