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# Sea Level Changes in Izmir Bay

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***ABSTRACT.*** *The semi-diurnal tidal range is small along the Turkish coastline, being in the order of 30 cm. Therefore, sea level changes, are largely influenced by changes in air pressure and wind parameters. In this study, meteorological changes are related to seawater level changes. İzmir Bay located in the Aegean Sea of Turkey is chosen as the application area. Sea level, wind speed and direction, and pressure data of 1999-2016 measured at Menteş Station in the Bay have been analyzed. Hourly wind speed and direction measurements at nearby meteorological station have been used as well in the long term wind analyses. The twenty-five-hour moving average filter is applied to eliminate the tidal effects on the sea level measurements. The reverse barometer effect that is the one cm sea level drop corresponding to the one mb pressure increase, is calculated, and the barometric pressure effect from the sea level data has also been eliminated. For the remaining data, wind surge has been performed. It has been observed the local meteorological contribution appears to be the most important in regional sea level variations. In İzmir Bay, the observed sea level variations result mainly from the combination of two elevations: astronomical tides and surges. While the former is of minor importance; being ±15 cm, the latter may reach up to 1.0 m elevation under the effect of the meteorological factors.*

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## I. INTRODUCTION

The tidallevel change shave little effect onse alevelalong Turkish coastline.Therefore, sealevel changes in Turkey, largelyin fluenced by changes in airpres sure andwind parameters. Tidal cyclesaredividedmainlyinto three groups: diurnaltides, semi-diurnaltides, and mixed semi-diurnaltides.The lunarday is the time it takesfor a specific site on the Earth torotatefrom an exactpointunderthemoontothe samepoint.A solar day is 24-hours, and a lunarday is24 hoursand 50 minutes. The daily tidalcy cleconsists of a highand a low tide everylunarday.Thelunardiurnaltidal constituentis termed as $O_1$. A semi-diurnaltidal cycle consists of two high and two low tides, almost equal in size every solarday[1].

The tidal components differ with location. The dominant diurnaltidalconstituentsare K1(lunar), O1(lunar), P1(solar), Q1 (larger lunare lliptic), and S1(solar), with periods of 23.93, 25.82, 24.07, 26.87, and 24.0 h, respectively. The semidiurnaltidal constituentsare M2 (principallunar), S2 (principalsolar), N2 (larger lunarelliptic), andK2(lunisolar), withperiods of 12.42, 12.00, 12.66, and 11.97 h, respectively. Thesum of thesetidalsinusoidal wave shaving different periods results in a spring-neaptidal range. Ifthetidal range is lessthantwometers, theregion is classified as microtidal (tidal range< 2 m), if it is in betweent woand four meters, region is classified as mesotidal (2 m <tidalrange< 4 m), if it is in between four and six meters, region is classified as macrotidal (4 m <tidal range< 6 m), and if it is more than six meters, region is classified as hypertidal (tidalrange> 6 m)[2].

IntheMediterraneanSea, the four most significant tidal constituents recordedare $M_2$, $S_2$, $K_1$, and $O_1$ [3]. The usually mixed semi-diurnaltidal cycle is effective along the Turkish coast line. There occurt wohighandt wolowtides of different sizes every solarday. İzmir Bay is located with in a microtidal Eastern Mediterranean Seaen vironment, with a semi-diurnal tide. The means pringtidal range is approximately 17cm, where as the mean neaptidal range does not exceed3.8 cm maximumaccordingtothemeasurements of Menteş Tidal Gauge Station [4] [5]. The location of Menteş Station is shown in Figure 1.

**Figure 1.** Location of Menteş Station in İzmir Bay.

It is known that the impact of global warming on the world and the Mediterranean region is undeniable. Many studies show that with the melting of the poles, there is a significant increase in the global average sea water level. The water level rise in the Mediterranean occurs at a low rate. However, the projections show that between 2021 and 2050, sea level increase is expected between 7 and 12 cm [6].

In order to serve the needs related to sea level changes, General Command of Mapping (HGK) recordslong-term sea level changes on Turkish coastline. Turkish National Sea Level Monitoring System(TUDES) has been established by a tidal gauge networkin accordance with the Global Sea Level Observing System Standards(GLOSS). HGK is the coordinator of a regional early warning system in Turkey, providing support with real-time sea level data from the tidal gauge stations. TUDES consists of a total of 20 stations located at Turkish coastline [6] .

## II. MATERIAL AND METHOD

In this study, sea level, wind speed, wind direction,andbarometric pressure data between 1999-2016 of HGK's Menteş station (Figure 1) were used in order to investigate the effect of meteorological parameters on the sea level changes. The sea level changes obtained from the measurements of the Menteş tidal gauge station include the tidal sea level constituents by the movements of the Moon and the Sun. As an example of mixed tidal constituents effects on sea level, annual investigation in 2010 of Menteştidal gauge station is presented in Figure 2. Therefore, in order to examine the sea level changes where meteorological parameters are effective, first of all, tidal data should be filtered from the measurements. There are a few common filters like the walking weighted average filter, the Lanczos-window cosine filter, the Butterworth filter and the Kaiser-Bessel filters applied in coastal data analyses[7]. In this study, the twenty-five-hour moving average filter is applied to eliminate the diurnal and semi-diurnal tidal effects from the sea level measurements[8]. Raw data and tidal effects eliminated sea level changes measured at Menteş station are given in Figure 3 for 2010 as an example. A similar procedure has been applied to all of the data annually between 1999-2016.

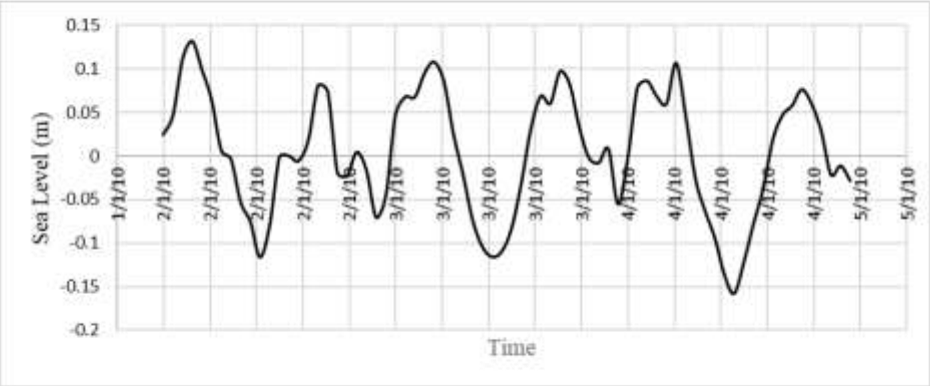


**Figure 2.** Menteştidal gauge station mixed semidiurnal tidal effects on sea level in 2010.

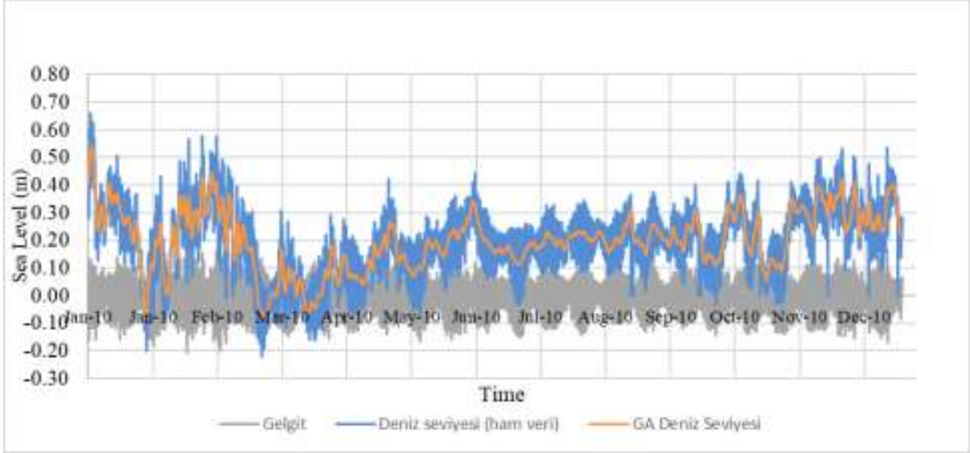


**Figure 3.** Menteştidal gauge station sea level changes in 2010

The changes in barometric pressure, wind speed and direction are also quite effective on the sea level changes.Changes in atmospheri e caus e in the nd longer time scales, the sea level is expected to react as an inverted barometer (IB) to changes in atmospheric pressure, so as the atmospheric pressure rises, the sea level drops.Such isostatic response is described simply by

$$\eta = -\frac{\Delta \mathbf{p}}{\mathbf{g}\rho} \#\#(\mathbf{1})\#$$

where Δp is change in atmospheric pressure, g is gravitational acceleration and ρ is the density of sea surface.Therefore, one millibarincrease in atmospheric pressure results in anearlyone centimeter sea level decrease.

Tidal constituents eliminated sea level changes according to atmospheric pressures in 2010at Menteştidal gauge station is given as example in Figure 4.Similar analyseshave been performed to all of the data annually between 1999-2016.

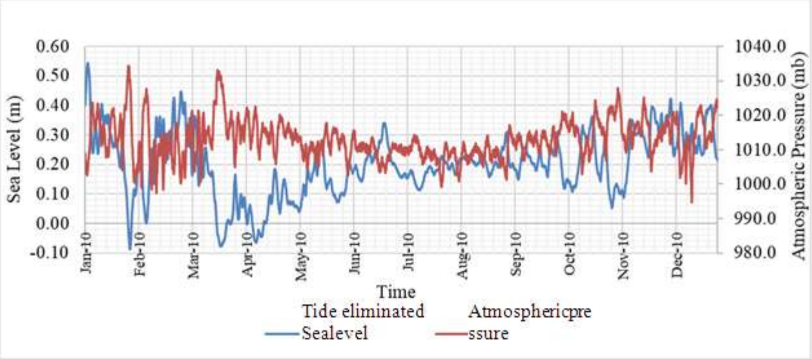


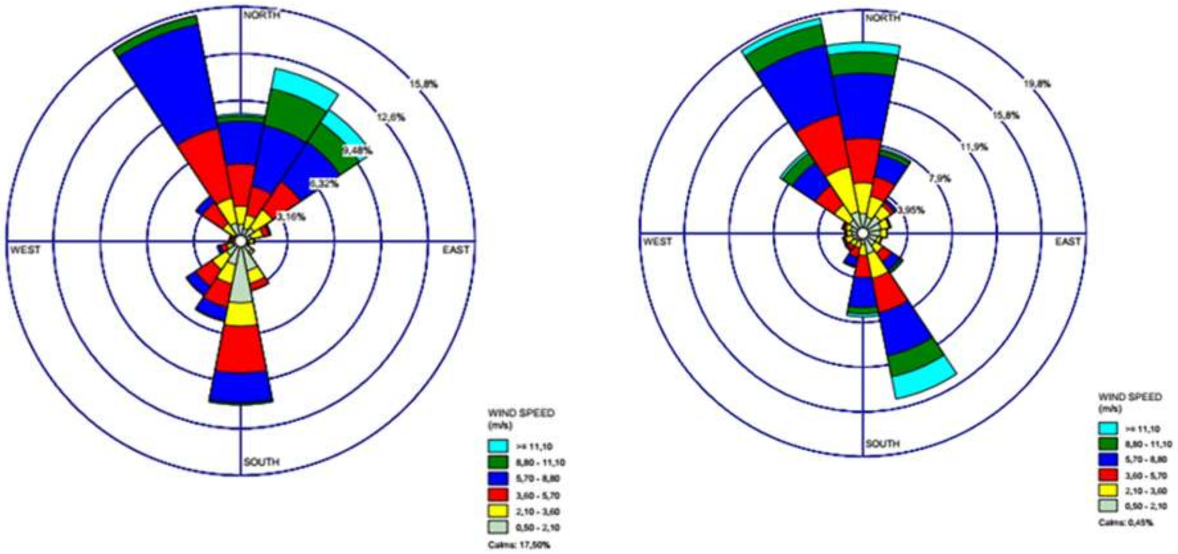
**Figure 4.** Tidal constituents eliminated sea level changes according to atmospheric pressures in 2010at Menteştidal gauge station

It has been seen that, as an example, in mid-March 2010, the pressure was higher than 1030 mb, while the sea level decreased nearly to -0.07 m. While the pressure tended to decrease, sea level tended to increase. Again in late January 2010, the pressure increased to 1035 mb and sea level decreased nearly to -0.09 m.

The average of all pressure datain between 1999-2016 at Menteş station was calculated to be 1015.08 mb. Therefore, in order to remove the pressure effect from the tidal influence eliminated sea level values, each pressure value was subtracted from the mean value of 1015.08 mb and the inverted effects on the sea level were calculated [9]. In this way, the pressure effect was removed from thetidal influence eliminated sea level measurements as well and therefore the sea level changes free of tidal and pressureeffects were obtained to analyze the wind shear responses.

The wind drag force on the sea surface is an important effect that causes the sea levelchanges. The wind drag force increases in direct proportion to the square of the wind speed. With this drag effect, surface sea water starts to move in the direction of the blowing wind in the shallower waters and in the deep waters to the right in the northern hemisphere and in the southern hemisphere to the left at a right angle[10].Therefore, the sea level decreases as the wind blows from the land to the sea, while the sea level tends to increase with the drifting effect as the wind blows from the sea to the land. Therefore, land-sea breezes affect sea level in daily or short periods of time.

Wind speed measurements between 1999 and 2016 at Menteş station obtained at four meters above the mean sea level, were increased to a level of ten meters by logarithmic wind profile law. Then wind measurements of Menteş Tidal Gauge Station were compared to the coincident hourly measurements of nearest Urla Meteorological Station (Figure 1) in between 2012 and 2016. Windroses and wind speeds of Mentes and Urla Stations were compared in Figure 5 and Figure 6, respectively.



**(a)** **(b)**

**Figure 5.** Windrose of a) MenteşTidal Gauge Station b) Urla Meteorological Station

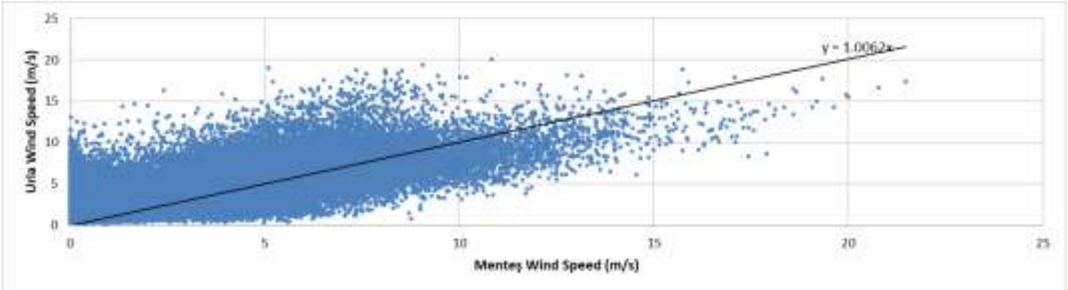


**Figure 6.** Wind speed comparison ofMenteşTidal Gauge Station to Urla Meteorological Station

It has been observed that the dominant wind direction for MenteşStation measurements is NorthNorthWest(NNW) with an occurrence probability of nearly 17%. Likewise,Urla Meteorological Station measurements indicate the same dominant wind direction with an occurrence probability of nearly 20%. Wind speed comparisons of two measurement stations were supported each other.

To analyze the effects of the local wind on the sea level changes, wind measurements were decomposed into the North (positive)-South (negative) direction and the East (positive)-West (negative) direction components and all the Menteş Station wind data in between 1999 and 2016 have been analyzed.The sea level changes free of tidal and pressureeffects were plotted against the wind speed components in N-S and E-W directions, and the analyses belonging to 2015 is presented in Figure 7 and Figure 8, respectively.

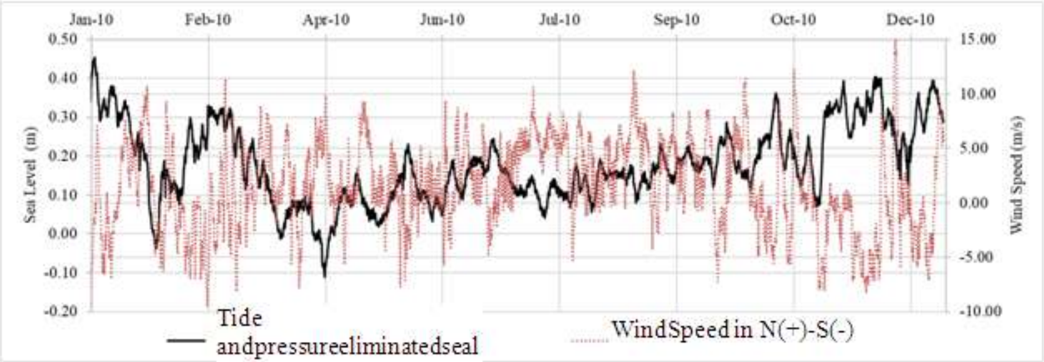


**Figure7.** Effect of wind speed in N-S direction on sea level changes in 2010 atMenteşTidal Gauge Station

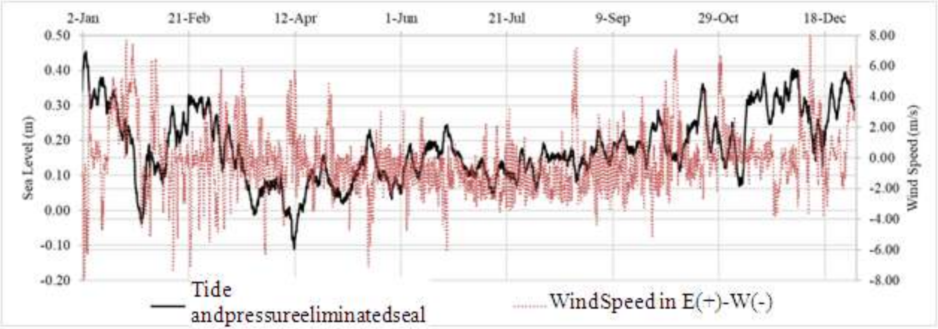


**Figure8.** Effect of wind speed in E-W direction on sea level changes in 2010 atMenteşTidal Gauge Station

It has been observed generally that as the wind is blowing strongly from North to South clockwise directions, there occurs a sea level increase. With the effect of strong winds blowing from the east, sea level decrease has been observed generally.Analyses of all sea level data have shown that sea level increased in time on the average by an amount of 11 cm in between 1999-2016 based on the Menteş Tidal Gauge Station sea level measurements.

## III. CONCLUSIONS

In this study, the effects of tidal constituents, air pressure, wind speed and direction parameters on sea level changes have been investigated by using the measurements in between 1999-2016 at Menteş Tidal Gauge Station operated by General Command of Mapping and located in İzmir Bay. The wind data measured at a level of four meters at the Menteş Station was increased to 10 meters using the logarithmic wind profile law and wind speed and directions were compared with the nearest Meteorological station located at Urla. Measured datasetswere supported each other regarding the magnitudes of the wind speeds and wind directions werealso consistent. In order to eliminate the tidal effects at sea level measurements, a twenty-five-hour walking filter was applied. The one cm sea level drop corresponding to the onemb pressure increase called as the reverse barometer effect was also considered and the pressure effect from the sea level data was also eliminated together with the tidal constituents. Theeffects of the wind shear on the sea level measurements have been analyzed for the remaining data. It is seen from the wind climate of the Mentes Station that North-easterly winds are dominant causing the sea level increase at the location to be dominant during the investigated period of time. It has been observed the local meteorological contribution appears to be the most important in regional sea level variations. In İzmir Bay, the sea level variations result mainly from the combination of tides and surges. While the former is of minor importance; being ±15 cm, the latter may reach up to 1.0 m elevation under the effect of the meteorological factors.Analyses of all measured sea level data in between 1999-2016 have shown that sea level increased in time on the average by an amount of 11 cm.

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