SVEUČILIŠTE U SPLITU
POMORSKI FAKULTET U SPLITU

ILGIN OZGUL

SEA LEVEL VARIATIONS AND THEIR INTERACTIONS BETWEEN THE BLACK SEA AND THE AEGEAN SEA

SEMINAR WORK

SPLIT, December 2020.

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STUDIJ: MARITIME METEOROLOGY AND OCEANOLOGY

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MENTOR:
Assist. Prof. Nenad Leder, PhD

STUDENT:
Ilgin Ozgul

(MB:017----)

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ABSTRACT

In this study, tide gauge measurements and tide gauges around the Black Sea and the Aegean Sea were investigated and compared with satellite altimeter data. Six original pieces of research investigated amplitudes of oscillations in the Black Sea and the Aegean Sea. According to investigated researches, the primary source of water level changes in the Black Sea and the Aegean Sea has been observed as seasonal. The seasonal water change in the Southwestern Black Sea was measured as an average of 19 cm. Tidal characteristic in the South of the Black Sea was determined as semi-diurnal. Tide amplitudes for the Northern Black Sea were measured as 1.3-3.0 cm and the main tide pattern was observed as semi-diurnal. The seasonal water change in the Northeast Aegean Sea was measured as 12 cm. The tidal pattern of the North Mediterranean Sea and South Aegean Sea was determined as mixed, mostly diurnal. The tidal amplitude of the Aegean Sea was observed to be higher than the Black Sea. The reason for this difference may be that the Aegean Sea is the continuation of the Mediterranean and the water bodies it relates to are larger.

Keywords: sea level, Black Sea, Aegean Sea, Turkish straits

CONTENT

1. INTRODUCTION

The Black Sea is a body of water located between the Eastern end of Europe and the Western end of Asia. The Black Sea, the world's largest inland sea with 547,000 m^3 of water after the Caspian Sea, is fed by 17 rivers and more streams, including the Danube River from Central Europe, the Dnieper River from Eastern Europe, and the Don River (Wikipedia, 2020) Bulgaria, Romania, Russia, Turkey, and Ukraine located on borders with the Black Sea, an average of 300,000 m^3 of water annually is discharged to the Aegean Sea over Bosporus and Dardanelles. A geographical map of the Black Sea and nearby cities are given in Figure 1. Bosporus is the natural way that connects the Sea of Marmara and the Black Sea. The Aegean Sea forms the northern tip of the Mediterranean Sea, located between the Balkan peninsula and the Anatolian peninsula, with a sea area of 214,000 m^2 (Wikipedia, 2020). The Marmara Sea and the Aegean Sea are connected by the Dardanelles natural waterway. Bosporus forms the Turkish Straits System with Dardanelles and Sea of Marmara. The water exchange between the Black Sea and the Aegean Sea takes place in a versatile way through these two natural waterways. The Bosporus, which has a length of 29.9 km, constitutes the most complex structure of the Turkish Straits System. Because of the terrestrial structure, which expands from place to place (3.6 km maximum width) and shrinks (698 m minimum width), its depth (120 m maximum) although it is 60 m on average, different current characteristics are encountered. Since the Black Sea is 40 cm higher than Marmara, there is a surface current varying in intensity from the Black Sea to the Marmara at 3-7 knots (Wikipedia, 2020). A geographical map of the Aegean Sea Region is given in Figure 2. However, the salinity rate of the Sea of Marmara - although it varies- is about 2 times the Black Sea. (Average salinity of the Black Sea is 1.8%; average salinity of the Marmara is 2.95%) The specific gravity formed because the difference in salinity is higher in the Sea of Marmara. From the Marmara Sea, which is heavier in terms of specific gravity, to the Black Sea; there is a deep current of the Bosporus that progresses from a depth of 15-45 m from the surface. Orkoz currents unique to the Bosporus are formed by the effect of projecting terrestrial structure in the Bosporus and strong Southern winds such as southwestern winds (Alpar & Yüce, 1998). Orkoz can reach speeds of 6-7 knots from time to time. A geographical map of the Sea of Marmara, Bosporus Strait, and Dardanelles Strait is given in Figure 3. Studies above sea level have a very rich story. Even prehistoric societies tried to associate regular changes in sea level with the movements of the Moon and the Sun. There are more than 37 distinct factors affecting tides today (Trujillo & Thurman, 2015). However, it is known that the Sun and the Moon, two of them, are the primary factors in tidal forces. Today, sea level research is vital for fishing technologies, ponding, navigation safety, and the construction of coastal structures. Sea level measurements have been carried out by mareograph (or known as tide gauge, marigraph, sea-level recorder, limnimeter) stations that have been established on seacoasts and islands for a hundred years. The first mareograph systems comprised scaled pieces of rock or wall.

Figure 1. Geographical map of the Black Sea and nearby cities (Britannica, 2021).

In many European ports, low and high-water levels were collected in this way. The first quantitative observation of ocean tides was started by Laplace in 1775 and continued by Kelvin in 1868. The first mechanical mareograph systems that detect high-frequency variations in still water with float mechanism and clock graphing recorder emerged in the 1830s. In the last century, with the advancement of technology, acoustic, pressurized, and RADAR-type tide gauges were established. These gauges were generally created by revising old stations. Local sea research in Turkey was realized with the float mareograph systems until 1998. In the past 22 years, these systems were replaced by pressure, acoustic, and RADAR systems (Turkey General Directorate of Mapping, 2020). Usually, mareograph stations use multiple gauges to minimize the margin of error associated with the gauge. In the last 50 years, height differences can be determined by measuring from space with satellite-assisted methods. To increase accuracy in research; The measurements obtained from GPS satellites that measure the movement of observation satellites, tide gauges, and tide gauges relative to the earth are evaluated. The goal of this seminar work is to examine the sea-level changes in the Black Sea and the Aegean Sea by explaining the reasons for sea-level change and the measurement of sea-level change and to reveal the amplitudes of these changes.

Figure 2. Geographical map of Aegean Sea Region (U.S. Central Intelligence Agency, 2021).

Figure 3. Geographical map of Sea of Marmara, Bosporus Strait, and Dardanelles Strait (WorldAtlas, 2021).

2. TIDE GAUGE MEASUREMENTS

2.1 Importance and Purpose of Tide Gauge

Considering that more than 200 million people live on the seashore (Milne et al., 2009), changes in sea level directly affect many sectors from daily life to sea trade, from fishing to construction. The areas where water level observations are used can be summarized as oceanographic modeling and simulation studies (tide, ocean current system, etc.), satellite observations (altimetric observations) calibration, hydrographic measurements, determination of territorial waters and continental shelf, climate change research, and disaster early warning systems. Average sea level on coasts; is defined as the average of sea level elevation measured relative to a fixed benchmark on land for a period (one month or year) that is long enough to substantially eliminate the effects of waves and tides. The recommended period for the calculation of the mean sea level (and other vertical dates) is 18.6 years.

2.2 Tolerance of Mareographs

Average sea-level changes measured at tide gauge are referred to as relative sea-level changes as the sea surface is moving relative to the mainland on which the station was built. Measurements at tide gauge are affected by waves, winds and currents, tides, and atmospheric pressure. These measurements also include tectonic movement on the mainland. Heavy tectonic land movements caused by sudden displacements due to earthquakes, precipitation, or sedimentation contribute significantly to local sea-level change. These effects are separated from sea level measurements by geodetic measurements made from tide gauges and absolute sea level is obtained. Earth landforms are expressed in various models. The equilibrium surface where the sea level is supposed to continue under land is called the geoid. The average sea level obtained from long-term sea level data at tide gauges has been used as a vertical datum (reference point for sea altitude) for many years assuming that it coincides with the geoid. With geodetic measurements made at tide gauges, the effects of tectonic land movements are separated from sea level measurements and absolute sea level is obtained. Long-term sea-level records can be used to detect long-term trends at sea level (Yıldız et al., 2003).

2.3 Types of Tide Gauges

2.3.1 Tide Pole (Tide Staff) Gauges

This system is the simplest and lowest cost measurement system used for many years (Woodworth). It consists of a rod with markings to read the sea level or a coastal structure with a measuring scale on it. With advancing technology, it has ceased to be the primary source for research. However, it is still found in tide gauges together with other measuring instruments. Tide pole gauge is given in Figure 4.

2.3.2 Float Gauges

Today, they are the most used measurement tool on a global scale (Woodworth). They replaced Tide Pole from the 1830s. Unlike Tide Pole, Float stations were able to automatically save data on a sheet of paper when it was first introduced. With the advancing technology, they started to record data digitally, not analog.

Figure 4. Tide pole gauge (Cali, 2012).

Float stations, although they have been renewed with acoustic, pressure, or radar stations, they are the information source for many studies. With the computerization and automation of the stations, the measurement time is determined by the Geostationary Operational Environmental Satellite (GOES) system instead of mechanical timers. Besides measuring tide heights more accurately, modern water level stations can show real-time meteorological data such as wind speed and direction, air and seawater temperature, barometric pressure, humidity, precipitation, soil temperature, and snow height. Meteorological offices such as NOAA use this information for purposes such as providing secure voyage information and annual tide forecasts (U.S. National Ocean Service, 2020). The basic float tide gauge system and chart recording drum are given in Figure 5.

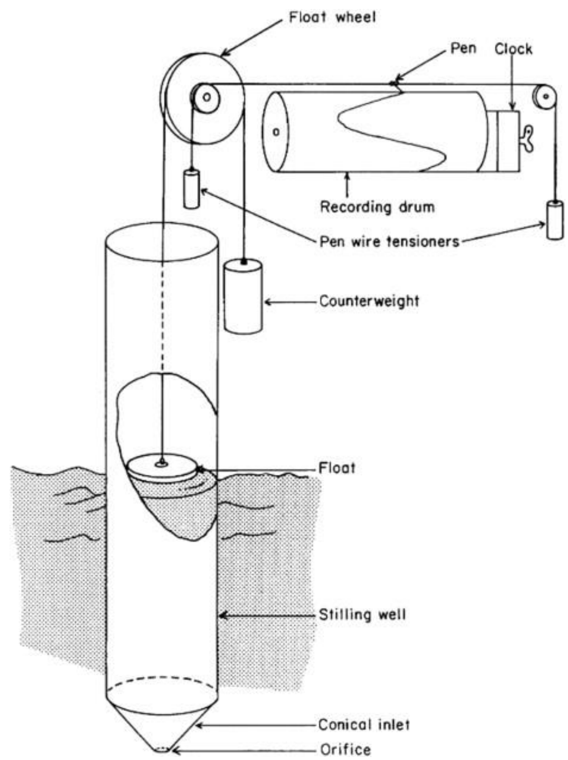

Figure 5. Basic float tide gauge system and chart recording drum (Bradshaw et al., 2015).

2.3.3 Acoustic Systems

Acoustic systems, which are a cheap method, contain a tube and a transceiver system (Woodworth). It sends an audio signal into the tube and measures the return time of the signal. Since it knows the datum point, it monitors it by calculating how high the water is at that moment. The acoustic tide gauge station is given in Figure 6.

Figure 6. Acoustic tide gauge station (Zacharia et al., 2017).

2.3.4 Pressure Gauges

Pressure measurement stations are usually measured with a sensitive pressure gauge placed on the seabed. As the seawater mass on the sensor increases, it automatically calculates how many centimeters the water level rises, based on the density information of the water and the instantaneous atmospheric pressure. It must be positioned so that it does not remain above the water surface even during low tide (REFMAR, 2012). The pressure tide gauge is given in Figure 7.

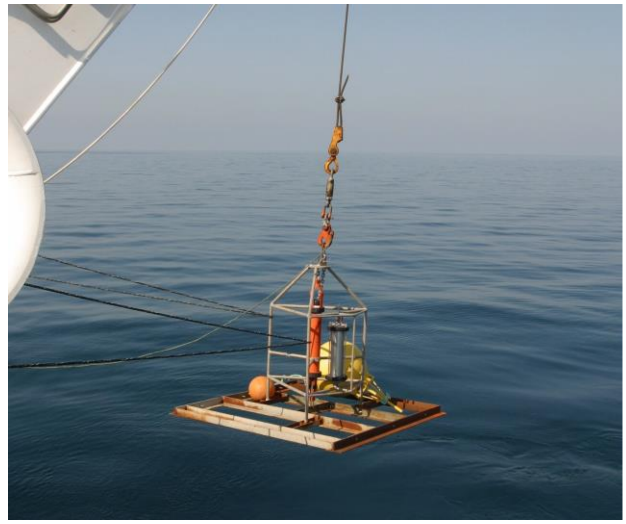

Figure 7. A pressure tide gauge (REFMAR, 2012).

2.3.5 RADAR Gauges

RADAR (Radio Detection and Ranging) systems are preferred because of speed setup, instant data monitoring, and the prevalence of RADAR technology in many industries. These expensive but easily procured, fast, and reliable measurement systems have been installed on the Black Sea and Mediterranean coasts in recent years (Turkey General Directorate of Mapping, 2020). There are two types of RADARs: Frequency Modulated - Continuous Wave (FACT) RADARs and pulse RADARs (Intergovernmental Oceanographic Commission, 2016). The RADAR tide gauge is given in Figure 8.

2.3.5.1 FMCW RADARs

In continuous wave (CW) RADAR, an electromagnetic beam with a continuous unmodulated frequency is transmitted towards a target, with echoes reflected by

Figure 8. RADAR gauge (Turkey General Directorate of Mapping, 2020).

the target and received back at the transmitter. If the target is not moving, the frequency of the return echoes will be the same as that transmitted. However, for a moving target, the frequency of the return signal depends on its speed toward or away from the transmitter. This is the well-known Doppler Effect. In this case, while the speed of the target can be estimated readily from the frequency shift, the range from the transmitter to the target cannot be determined (Intergovernmental Oceanographic Commission, 2016).

2.3.5.2 Pulse RADARs

In pulse, RADAR one measures the time of flight of short pulses (typically measured in nanoseconds to microseconds) between the transmitter and target and back. Correction for the speed of light and division by 2 gives the range. The pulses take the form of short pockets of waves. The number of waves and length of pulse depend on pulse duration and the carrier frequency that is used. A relatively long delay between pulses is imposed to allow the return echo to be received before the next pulse is transmitted. For our purposes, the target can be considered stationary. In a variant of the method, the Doppler-shifted frequency of the return pulse is also measured, enabling both the range and speed of the target to be estimated (Intergovernmental Oceanographic Commission, 2016).

2.4 Satellite Altimeter

Satellite altimeter systems, which are special subjects of oceanography other than sea level determination and whose distances from orbit to the sea surface can be determined with an accuracy of 0.01 m today, provide great support to sea level determination studies. The first satellite altimeter is Skylab S-193 and was launched into space in 1973 (Gürdal, 2002).

3. SEA LEVEL CHANGE MAIN CAUSES

It is known that sea level is generally not stagnant but constantly variable. The values of the sea level are periodically shaped under the influence of the periodic gravitational forces created by the Moon and the Sun on the Earth, as well as under the influence of meteorological parameters such as pressure and wind. Sea level shows non-periodic and long-term (secular) changes due to intra-sea earthquakes and vertical movements of the earth's crust. Long periods of sea-level changes have significant effects on coastal settlement and climate change (Alpar & Yüce, 1998).

3.1 Tidal Effects

The tides are one of the main causes of the periodic change in sea level. As the sea level rises or falls, the sea horizon slowly retracts towards the sea or rises towards the land. The tides are essentially very long and regular shallow-water waves. Due to the tide, the most variation normally occurs near the equator and at large ones up to 0.5 meters. However, 2 m in oceans; Occasionally, sea-level changes of around 10 m can occur on the oceanic coasts. For example, sea level variation was observed as 12.9 m along the Atlantic Ocean coast of Canada and up to 15 m in the Bay of Fundy. There are more than 37 independent factors in creating tidal patterns, but the Moon and Sun effects are the most important. However, there are also affects such as terrestrial effects and orbital effects (Trujillo & Thurman, 2015)

3.2 Tide-Generation Force of The Moon

Every atom in the universe exerts a force of attraction against each other. This is called Newton's Universal Law of Gravity. According to gravity, the force of attraction between two substances is directly proportional to the mass of the substances in question and inversely proportional to the square of their distance. However, it is known that the tide-generation force is inversely proportional to the cube of the distance. Every point on Earth is gravity by the Moon. As the Moon rotates over the Earth, the waters in the oceans follow it. Due to this gravitational effect, a tidal bulge is formed on the face of the Earth that sees the Moon. At the same time, there is a centripetal force created by the rotation of the Earth around its axis. Oceans in the part of the Earth that does not see the Moon are directed towards the opposite direction of the Moon with the effect of this centripetal force. To be more specific, the tides are the two forces acting on the oceans; It arises from the inequality between centripetal force and gravitational force. On the face of the Earth-facing the Moon, the gravitational force of the Moon overcomes the centripetal force, creating a tidal bulge. On the face of the Earth that does not see the Moon, the centripetal force overcomes the gravitational force applied by the Moon, creating another tidal bulge. The elevations created by the moon are also known as lunar bulges. The monthly tidal cycle is 29.5 days as the Moon completes a full orbit around the Earth in 29.5 days. In this cycle, when the Moon is aligned between the Sun and the Earth, the lunar bulges and the solar bulges align, and the wave amplitudes converge. In this case, high tides appear higher and are called Spring Tides. When the moon is in the position of the first quarter or the last quarter, lower high tides appear and are called the neap tide. Springtide is strong as solar bulges and lunar bulges are a sum, but the neap tide is weak. At the time of spring tide, the tidal range (distance between high and low tides) is large because there is constructive interference between lunar bulges and solar bulges during this time. Neap tide instant tidal range is small because there is destructive interference between lunar bulges and solar bulges. The time between consecutive spring tides (full moon and new moon) or consecutive neap tides (first quarter and fourth quarter) corresponds to a "half" lunar calendar. The time between spring tide and neap tide corresponds to a "quarter" lunar calendar, which is about 1 week. In addition to the monthly calendar, The Moon completes one complete revolution in 24 hours and 50 minutes, which means: It takes 24 hours and 50 minutes for any point on Earth to align with the same point on the Moon. This is called lunar day. Therefore, the Moon rises 50 minutes late every day and sets 50 minutes late. In many parts of the world, high tides occur every 12 hours and 25 minutes. This is called the tidal period. If you stand in the Equator, you will experience high tides twice a day. The time between high tides is called the tidal period. If you move from the equator towards North or South latitudes you will experience the same period, but the higher tides will be lower because you are on the lower part of the bulges (Trujillo & Thurman, 2015).

3.1.2 Tide-Generation Force of The Sun

The Sun also creates two tidal elevations just like the Moon on Earth. These elevations are also called solar bulges. The Sun's mass is 27 times greater than the Moon's mass, but its tide-generation force is not as great as the Moon. Because the Sun is 390 times farther from the Earth than the Moon. The Sun's tidal-forming force on Earth is 46% of that of the Moon. As a result, solar bulges are 46% smaller than lunar bulges. Even though its size is much smaller than the Sun, the reason the Moon has a more gravitational effect is that the Moon is about 400 times closer to the Earth than the Sun (Trujillo & Thurman, 2015).

3.1.3 Rotation Effect of The Earth

The tides appear to move in the water towards the land (flood tide) and towards the sea (ebb tide). Variable high and low tides are caused by the rotation of the Earth around its axis in the body of water drawn by the Sun and Moon. The rise of waters on the face of the Earth that does not see the Moon is due to the centripetal force (Trujillo & Thurman, 2015).

3.1.4 Effects of Continents

Tidal waves that want to travel across the ocean are blocked by the shores. At this point, the most important factors that determine what pattern a tide will follow along the shore are the coastal structure and the ocean depth off the shore. When the tides enter shallow water, they undergo physical changes such as slowing down or rising. These changes tend to increase the tidal range on the shore compared to oceans where the maximum tidal change is 45 cm. Theoretically, the Earth should experience 4 different tides a day, 2 high and 2 low. In practice the situation is different. Different tidal patterns are observed due to varying depths and dimensions, especially the effect of land. These can be diurnal, semi-diurnal, or mixed patterns (Trujillo & Thurman, 2015).

3.1.4.1 Diurnal Pattern

In the diurnal tide pattern, one high tide and one low tide occur per lunar day. These tides are common in shallow inland waters (such as the Gulf of Mexico and Southeast Asia). Their periods are 24 hours and 50 minutes (Trujillo & Thurman).

3.1.4.2 Semi-Diurnal Pattern

In the semi-diurnal tide pattern, two high and two low tides occur per lunar day. The height of successive low and high tides is on average the same. Half-day tides are common along the Atlantic coast of the USA. The period is 12 hours and 25 minutes (Trujillo & Thurman, 2015).

3.1.4.3 Mixed Pattern

The mixed pattern features both diurnal and semi-diurnal tide patterns. There is a considerable height difference between successive high and/or low tides. Their periods are usually 12 hours and 25 minutes, but they can also have a daily period. Mixed tides are the most common tides in the world. Occurs in Pacific coasts and North America (Trujillo & Thurman, 2015).

3.2 Effects of Meteorological Elements

The sea-level change caused by meteorological effects is not regular but occurs because of changes in air pressure and changes in wind direction and strength. Due to meteorological effects, variations up to 0.03-0.25 m are observed between the measured sea-level values and the predicted sea-level values (Gürdal, 2002).

3.2.1 Effects of Atmospheric Pressure and Temperature

Increasing atmospheric pressure causes a decrease in sea level; a decrease causes an increase in sea level. Theoretically, a change of 1 mbar in atmospheric pressure causes a change of about 1 cm in sea level. Changes in air temperature depend on latitude and often cause sea surfaces to tilt from the poles to the equator. As the temperature increases, the density of the sea decreases and the sea level rises. When the temperature drops, the density of the sea increases, and the sea level decreases. According to tide gauge stations located on Turkey's the Mediterranean and the Aegean Sea coasts (Antalya, Bodrum, Menteş, Erdek), sea level rises by an average 1 cm per 0.679 degrees Celsius (Yıldız, et. al., 2003).

3.2.2 Wind Direction and Intensity

The drift effect of the wind on the sea surface is an effect that the atmosphere exerts on the sea surface, and this force increases in direct proportion to the square of the wind speed. With a wind-drift effect, the seawater starts to move. The amount of water entrained by the wind; drifts in the direction of the wind blowing in shallow sea waters, to the right in the Northern Hemisphere in deep waters, and to the left in the Southern Hemisphere (Coriolis effect). Seawater carried by the wind rises suddenly when it reaches land and can cause changes in meter dimensions in extreme conditions.

3.3 Climate Change

Climate change is related to the continuation of the amount of carbon dioxide in the atmosphere with the carbon dioxide gas that is ejected due to industrialization. The earth absorbs some of the short-wave radiation emitted by the Sun and re-emits some of the energy it receives as long-wave radiation back into the atmosphere. Carbon dioxide with water vapor in the atmosphere; absorbs some of these radiations from the earth and emits some of them back to the earth, this is called the "greenhouse effect". During the circulation of energy between the atmosphere and the earth, the atmosphere and the earth get warmer. The continuous increase in the amount of carbon dioxide in the atmosphere causes an increase in the annual average temperature in the atmosphere and therefore climate change. As the annual average temperature increases, the ice sheets in the South and the North Pole melt. Thus, the average global sea level rises. Between 1993 and 2003, the mean sea level change with the global altimeter was determined as +2.4±0.4 mm/year (Cezenave & Nerem, 2004). It was observed that the average sea level for the Eastern Mediterranean coasts increased at a rate of +4-7 mm/year (Simav et al., 2008). If these predictions, which are higher than the global sea-level rise predictions, continue in the coming years, it will be inevitable to create economic and social problems, especially in coastal areas.

3.4 Vertical Earth Crust Movement

One of the most important factors that change the sea level is vertical earth crust movements. Local and regional vertical movements of the earth's crust cause significant changes in sea level. Sea level is measured relative to a benchmark on land. If land collapses over time, sea level rises, on the contrary, if the land rises over time, the sea level decreases relatively. Vertical earth crust movements appear as tectonic movements at the borders of the plates occur due to sedimentation, collapse due to the withdrawal of water or oil, and reaching isostatic equilibrium, etc. When these movements occur on or near the seacoast, they distort sea level data, creating very distinct long-term trends (Yıldız et al., 2003).

4. AMPLITUDES OF SEA LEVEL OSCILLATIONS IN THE BLACK SEA AND THE AEGEAN SEA

In this part of the study, the sea-level changes in the Black Sea and the Aegean Sea were examined separately. For the Black Sea, the (Alpar & Yüce, 1998) study including the observations for 1993 and 1994, respectively, the (Avşar et al., 2016) study including the observations between 1993 and 2014, and the (Medvedev et al., 2016) study examining the tidal characteristics in the closed seas including the Black Sea were used. For the Aegean Sea, the (Alpar & Yüce, 1998) study, which includes observations for 1993 and 1994, respectively, the (Yıldız, et al., 2003) study that includes the observations of 1984-2002, and the (Simav et al., 2010) study, which includes observations from 1985-2001 were used.

4.1 The Black Sea

All three studies (Alpar & Yüce, 1998) (Avşar et al., 2016) (Medvedev et al., 2016) indicate that sea-level observations in the Black Sea are not clear enough due to insufficient measurement stations and low stability satellite data. Investigated tide gauges are given in Figure 9. In the first study dated 1998, sea-level measurements were observed from the Karadeniz Ereğli (1996) tide gauge in the Southwest of the Black Sea and from Anadolukavak (4-23 May 1993, 5 April-3 June 1994) at the Northern entrance of the Bosporus, further southwest. Wind and pressure observations were taken from meteorological stations along the Southern shores of the Black Sea. In the Black Sea, short-term winds arising from two specific seasonal climate regime

Figure 9. Investigated tide gauges in the Black Sea.

are effective. During the winter, the weather is almost completely dominated by cyclonic systems. During the summer, the Southwest Black Sea is dominated by the Northeastern winds. While there is no Northeastern wind, there are usually the Southwestern winds. The winds towards the land generally increase the sea level. Therefore, Northeast winds are expected to increase the water level on the Southern coasts of the Black Sea. Wind-induced water level changes can be observed as 10-20 cm in places. Sea level changes up to 20 cm have been observed at the northern entrance of the Bosporus with the strong northern winds. However, besides the prevailing winds, the local weather conditions where the measurement station is located have an undeniable contribution to the water level. Tidal effects are minor along the Marmara and Aegean Sea, including the Southern coasts of the Black Sea. The tides in this area are hidden by wind, sea breeze, and strong current from the Black Sea to the Aegean Sea. A semi-diurnal tidal pattern originating from the Black Sea was observed at the northern entrance of the Bosporus. Semi-diurnal tides of the Black Sea lose their effect along the Bosporus and are observed at the southern end of the Bosporus with a tidal range (amplitude) of 2.5 cm. Seasonal changes are of great importance along the Southern shores of the Black Sea. At Anadolukavak station, a maximum change of 34 cm was detected in the measurements made over a 2-year period. Seasonal high water at the Northern entrance of the Bosporus is experienced in May-June, seasonal low water is experienced in October-November. The difference between the two seasons in terms of mean sea level was observed to be 19 cm. Southwest Black Sea is under the influence of low tide amplitude. When the percent energy distribution is analyzed according to different frequency bands obtained from Karadeniz Ereğli and Anadolukavak stations, the biggest share of the distribution points to the low frequency [Table 1]. Detailed tide data measured from Karadeniz Ereğli and Anadolukavak stations are given in Table 2. In the South of the Black Sea, there are regular sea-level changes caused by meteorological effects throughout the year.

Table 1. Energy distribution percentages in the sea-level records over different frequency bands in Karadeniz Ereğli and Anadolukavak tide gauges (Alpar & Yüce, 1998).

Station Name	Low	Diurnal	Semi-Duirnal	Other
Karadeniz Ereğli	42.4	23.5	23.8	10.3
Anadolukavak	50.8	10.1	6.7	32.4

Table 2. Detailed data measure from Karadeniz Ereğli and Anadolukavak stations. Amplitudes and ranges in cm; M2, S2, K1, and O1 principal components semi-diurnal lunar, semi-diurnal solar, soli-lunar diurnal, and main lunar diurnal, respectively (Alpar & Yüce, 1998).

Tide Gauge Station and Period	M_2 Amplitude	S_2 Amplitude	K_1 Amplitude	O_1 Amplitude	Mean Spring Range	Mean Neap Range
Karadeniz Ereğli 12/2-20/1996	1.12	0.51	0.97	0.52	3.3	1.2
Anadolukavak 1987-89, 1996	1.26	0.52	1.0	0.63	3.6	1.5

The range of seasonal variations reaches its maximum from May to July; Between October and November, minimum levels are seen. The seasonal change at the northern end of the Bosphorus is like the model in the Black Sea, with a maximum value in June and a minimum value in November. In the study written in 2016 (Avşar et al., 2016), sea-level changes along the Black Sea coast were observed by satellite altimeter, tide gauge, and GPS (Global Positioning System). Linear trend and seasonal variation in sea level were measured with the data obtained from Amasra, İğneada, Trabzon-II, Sinop, Şile, Poti, Tuapse and Batumi stations located on the Black Sea coast and altimeter data obtained from the grid point at a maximum distance of 10 km to those stations. Since the end of 1992, satellite altimetry has become widespread in the world and its use for precise sea and lake level measurements has increased. Because tidal stations measure at a specific point on land, precise sea level data is hidden in tide measurement data. If terrestrial vertical movement is present at the tidal station, sea level data includes water level change and vertical ground motion. Data for accurate sea-level change measurements should be processed with GPS data linked to the tidal station. Such that, the accuracy rate of the data obtained from Trabzon-II, Sinop, and Şile stations increased more than 2 times with the addition of GPS vertical movement data. With satellite altimeter data from January 1993 to December 2014, it was observed that the Black Sea basin had a 0-5 mm/year trend. Besides, according to the data of the 1992-2005 period, terrestrial areas of the Black Sea Basin have a trend of 8-9 mm/year due to the cyclonic rim flow, which is twice the offshore trend (3.5-6 mm/year). All the 8-station data analyzed in this study were taken in different periods. However, satellite measurement periods are equal for the same station. Measurements of Poti, Tuapse, Batumi, Amasra, İğneada, Trabzon-II, Sinop, and Şile stations are given in Table 3. Satellite measurements have been corrected for atmospheric effects (ionospheric delay and dry/wet tropospheric effects) and geophysical effects (solid ocean, and pole tides, loading effect of the ocean tides, sea state bias, and the inverted barometer response of the ocean). Moreover, 3 of the tide gauge stations (Trabzon-II, Sinop, and Şile) have been corrected by GPS data. These GPS stations are used from January 1st, 2010 to December 31st of 2014 (TRBN, SINP, and SLEE). This study does not include measurements of the North of the Black Sea. Since the Glacial Isostatic Adjustment (GIA) effect is minimal in the Black Sea region, it is negligible in this study. Long-term observation results such as Poti and Tuapse in Table 3 are in line with the general results. However, there is inconsistency with altimeter data at some stations such as Amasra. The reason for this may be the short period or data loss. It has also been stated that changing sea levels in periods of less than 50-60 years may lead to uncertainties. However, short-term coastal sea-level changes differ much more than global sea-level changes. Moreover, seasonal variation also affects sea level variation. Seasonal components of the sea-level change along the Black Sea coast are given in Table 4. It is known that the satellite altimeter can lose its accuracy as it approaches land. Furthermore, although the GIA vertical displacement along the Black Sea coast is minimal, the uncertainty of the GIA model is still an error source of the trend estimations from the GPS and tide gauges. Tides are the main cause of sea-level changes in the world's oceans, according to (Medvedev et al., 2016) study that examined tides in closed seas, including the Black Sea. However, oceanic tides show little or no penetration in closed basins such as the Baltic Sea, Black Sea, Caspian Sea. Semi-diurnal tides in harmony with the local resonance were observed in the northwest of the Black Sea. In 100 years of observations, the maximum tide height in the Black Sea has been recorded as 18 cm. The Black Sea has a limited water exchange through the Mediterranean and Turkish Straits. Tidal amplitudes in the Black Sea have been investigated for 100 years, but there is still no clear data. Tidal observations in the Black Sea are generally less than 1 year. It is based on short series and has limited accuracy because the tidal signal coincides with the background noise. In this study, data from 23 stations located in the borders of Russia, Ukraine, and Georgia were used. Semi-diurnal tides prevail in the main part of the Black Sea. In the northwest, semi-diurnal tide amplitudes are 2.8-3 cm, and diurnal tidal amplitudes are 1.3-1.7 cm. Diurnal tides up to 4 cm have been observed from time to time. The 18 cm maximum tide was also observed in the Northwest. The radiational tides associated with solar radiational forcing on the sea surface were found to play an important role in the general tidal regime in this sea. Maximum tidal heights and the energy factor in the Black sea are shown in Figure 10.

Table 3. Long-term observation results of the sea-level change along the Black Sea coast (Avşar et al., 2016).

Tide Gauge Station	Time Span	Satellite Altimetry	Tide Gauge
Poti	Jan. 1993-Dec. 2013	3.45 ± 0.78	4.13 ± 0.78
Tuapse	Jan. 1993-Dec. 2011	3.42 ± 0.86	4.30 ± 0.88
Batumi	Sep. 2003-Dec. 2013	1.38 ± 2.29	3.47 ± 2.56
Amasra	June 2001-Dec. 2012	0.95 ± 1.72	0.07 ± 1.45
İğneada	July 2002-Dec. 2014	2.19 ± 1.66	6.74 ± 2.08
Trabzon-II (TD+GPS)	July 2002-Dec. 2014	-0.38 ± 1.65	1.21 ± 1.76
Sinop (TD+GPS)	June 2005-Dec. 2014	7.05 ± 2.48	6.63 ± 2.88
Şile (TD+GPS)	July 2008-Dec. 2014	3.61 ± 4.57	4.44 ± 4.84

Table 4. Seasonal components of the sea-level change along the Black Sea coast (Avşar et al., 2016).

Tide Gauge Station	Satellite Altimetry Annual Amplitude Change (mm)	Satellite Altimetry Semi-Annual Amplitude Change (mm)	Tide Gauge Annual Amplitude Change (mm)	Tide Gauge Semi Annual Amplitude Change (mm)
Poti	30.70 ± 6.68	23.65 ± 6.68	45.97 ± 6.86	17.22 ± 6.87
Tuapse	42.76 ± 6.71	19.50 ± 6.70	55.75 ± 6.85	26.80 ± 6.83
Batumi	43.52 ± 9.62	26.24 ± 9.62	90.08 ± 10.87	14.37 ± 10.75
Amasra	24.59 ± 8.15	20.44 ± 8.11	27.40 ± 6.78	9.30 ± 6.57
İğneada	23.16 ± 8.59	11.54 ± 8.50	52.11 ± 10.89	22.54 ± 10.88
Trabzon-II	22.46 ± 8.44	22.46 ± 8.43	62.65 ± 8.99	22.27 ± 9.01
Sinop	33.41 ± 9.73	26.50 ± 9.68	49.04 ± 11.26	29.52 ± 11.27
Şile	62.92 ± 12.84	22.90 ± 12.84	62.74 ± 12.66	22.84 ± 12.66

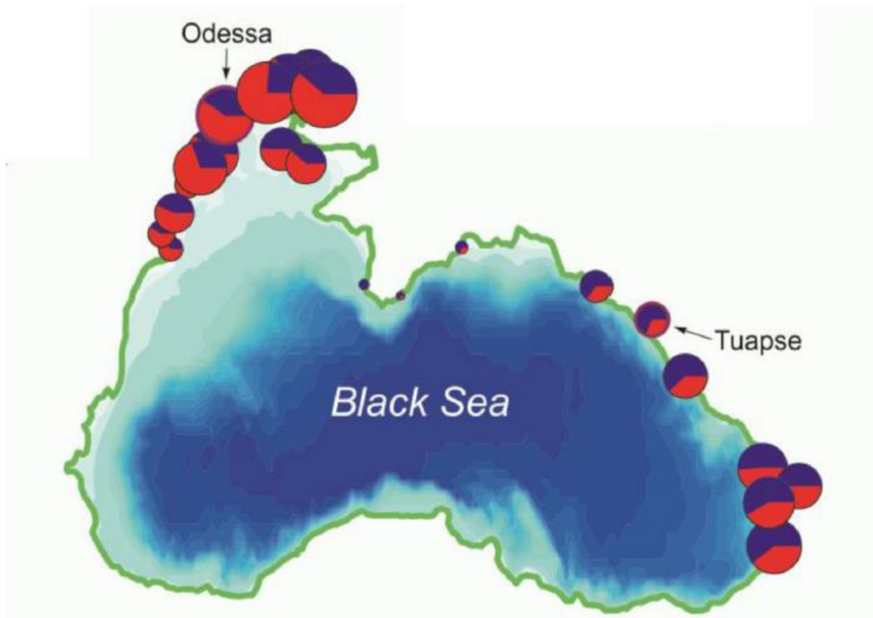

Figure 10. Maximum tidal heights and the energy factor in the Black Sea. Blue colors indicate diurnal; red colors indicate a semi-diurnal tidal pattern. The biggest circle represents 20 cm of tidal height, the smallest circle represents 5 cm of tidal high. It is proportional (Medvedev et al., 2016).

4.2 The Aegean Sea

In the first study dated 1998 (Alpar & Yüce, 1998), Gökçeada and Nara stations for the Aegean Sea were observed between 4-23 May 1993 and 5 April-3 July 1994. Also, historical information about Gelibolu (1966-71) and Bozcaada (1988-92) stations was used. For pressure corrections, data collected between April 5th and July 3rd from Göztepe station. Investigated tide gauges are given in Figure 11 and Figure 12. According to the results of this study, similar to the Black Sea, the eastern shores of the Aegean Sea and the southern entrance to the Dardanelles are under the influence of low amplitude tidal waves. The observed characteristic is mostly diurnal, but the minor, semi-diurnal character is also observed. Long-period observations are dominated by barometric pressure. Higher half-diurnal tidal amplitudes were observed at Nara and Gökçeada stations compared to Bozcaada and Gelibolu stations. Energy distribution percentages observed from four stations are given in Table 5. In the Dardanelles and the Northeast Aegean Sea, the tides are semi-diurnal. Amplitude data obtained from Gelibolu, Nara, Gökçeada, and Bozcaada stations are given in Table 6. Therefore, along the Strait of Canakkale towards the Aegean Sea, the mean ranges at spring tide increase rapidly. The seasonal sea-level patterns for the North-Eastern Aegean have maxima in late summer-early spring and minima in winter. These seasonal changes are significant throughout the Aegean Sea. For the Northeast Aegean, seasonal high water was observed in October and seasonal low water was observed in January.

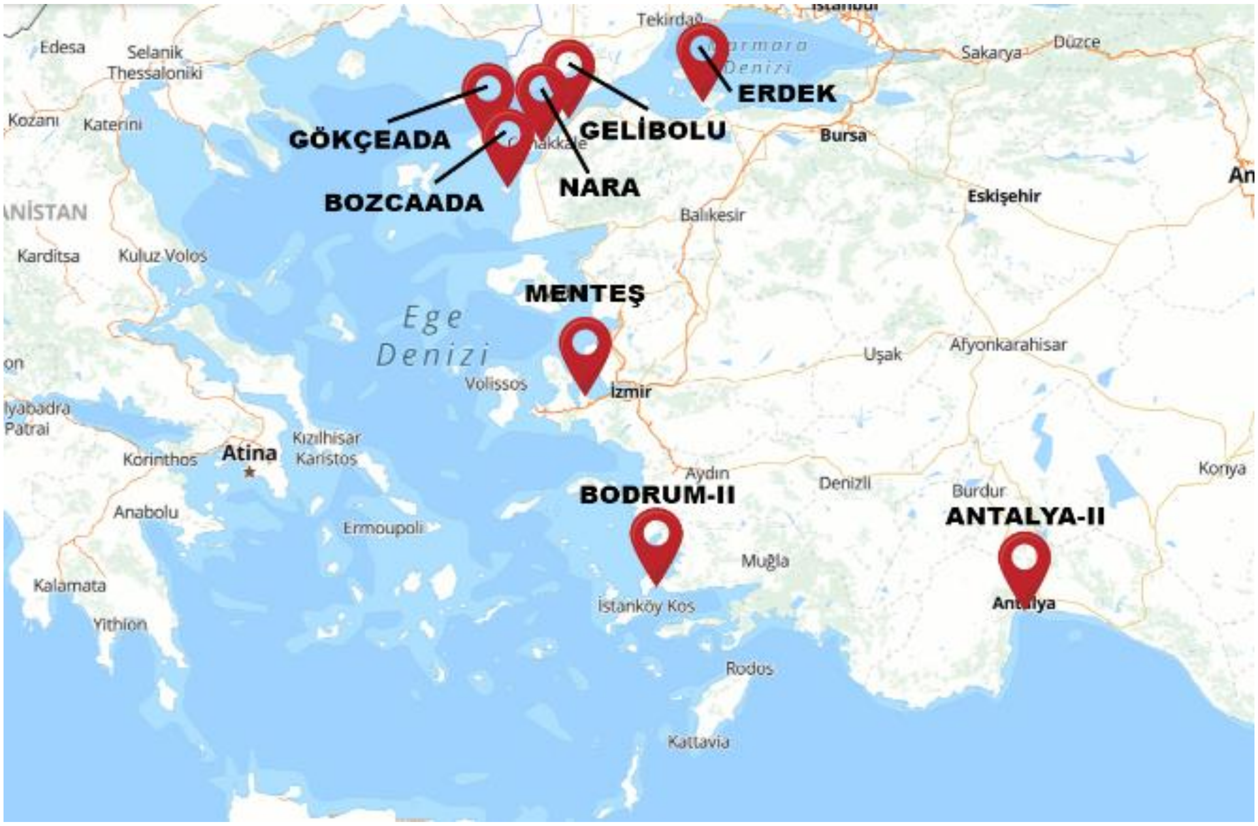

Figure 11. Investigated tide gauges in the Aegean Sea, Mediterranean Sea, and the Sea of Marmara.

Figure 12. Investigated tide gauges near Dardanelles and in the Sea of Marmara.

The difference between the two seasons is 12 cm. The changes are important throughout the Aegean Sea. The tidal stations and their periods used in the second study dated 2003 (Yıldız et al., 2003), are as follows: Antalya-II, Bodrum-II, and Menteş, 1985-2002; Erdek, 1984-2002. Periods of selected tidal components are more than 1 month and less than 18 years. As a result of the analyzes, the average sea level variation was determined to be 8.7±0.8 mm/year in Antalya-II, 3.3±1.1 mm/year in Bodrum-II, 6.8±0.9 mm/year in Menteş, and 9.6±0.9 mm/year in Erdek. The mentioned analysis results are shown in Table 7. Average sea-level changes calculated at tide gauges are higher than global sea-level changes of 1-2 mm/year. This situation reveals that the average sea level at the tide gauges increased significantly compared to the land where the stations are located. Tidal amplitudes and tidal types of each station were calculated with the same measurement data. Tidal amplitudes are given in Table 8. The tide patterns of Antalya-II, Bodrum-II, Menteş stations are mixed, mostly semi-diurnal. The tidal type of Erdek station is mixed, mostly diurnal. In the repeated GPS measurements carried out in 2002, it was determined that Antalya and Erdek mareograph benchmarks collapsed at -5.3±1.8 mm/year and -8.4±3.0 mm/year, respectively. It is considered that the relative sea-level changes at Antalya-II and Erdek stations are caused by the local or regional collapse of the land where the tide gauges are located. The relative change of mean sea level (3.3±1.1 mm/year) at Bodrum-II station is very close to global sea-level rise estimates. It is consistent with the absence of significant vertical movement in repeated GPS measurements. It was determined that the mean sea level of the Menteş tide gauges rose at a speed of 6.9±0.9 mm/year, but no significant vertical movement could be determined with repeated GPS measurements.

Table 5. Energy distribution percentages in the sea-level records over different frequency bands in Gelibolu, Nara, Gökçeada, and Bozcaada tide gauges (Alpar & Yüce, 1998).

Station Name	Low	Diurnal	Semi-Diurnal	Other
Gelibolu	75.3	6.9	10.3	7.6
Nara	28.6	4.8	59.9	6.7
Gökçeada	5.4	2.9	89.3	2.4
Bozcaada	34.8	11.7	35.5	18.1

Table 6. Amplitudes and ranges in cm; M2, S2, K1 and O1 principal components semi-diurnal lunar, semi-diurnal solar, soli-lunar diurnal, and main lunar diurnal, respectively (Alpar & Yüce, 1998).

Tide Gauge Station and Period	M_2 Amplitude	S_2 Amplitude	K_1 Amplitude	O_1 Amplitude	Mean Spring Range	Mean Neap Range
Gelibolu 2-21/12/1969	1.78	1.69	0.97	0.98	6.9	0.2
Nara 22/4-31/7/1994	5.50	2.10	1.17	0.85	15.2	6.8
Gökçeada 21/2-3/7/1994	6.58	4.92	2.10	0.96	23.0	3.3
Bozcaada 1988-92	6.30	3.90	2.40	1.30	20.4	4.8

Table 7. Monthly and annual average sea level change trends of four tide gauges (Yıldız et al., 2003).

Tide Gauge Station	Period	Number of average monthly sea level measurements	Monthly trend (mm/month)	Yearly trend (mm/year)
Antalya-II	11/1985-12/2002	176	0.72 ± 0.07	8.7 ± 0.8
Bodrum-II	12/1985-12/2002	144	0.27 ± 0.09	3.3 ± 1.1
Menteş	12/1985-12/2002	176	0.57 ± 0.08	6.8 ± 0.9
Erdek	2/1984-12/2002	199	0.77 ± 0.99	9.6 ± 0.9

Table 8. The tidal amplitudes of the four geography stations over the respective periods. K1, solar diurnal; O1, lunar diurnal; M2, lunar semi-diurnal, S2, solar semi-diurnal (Yıldız et al., 2003).

Tide Gauge Station	Period	K_1 (cm)	O_1 (cm)	M_2 (cm)	S_2 (cm)
Antalya-II	10.12.1998-31.12.1999	2.15	1.28	6.97	4.27
Bodrum-II	10.12.1998-31.12.1999	2.15	1.11	3.96	2.66
Menteş	01.01.2000-31.12.2000	2.54	1.30	5.77	4.04
Erdek	01.01.2000-26.12.2000	1.21	0.84	0.48	0.29

In this study, meteorological and oceanographic parameters are not included in the analysis model, and if these parameters have a long-term trend, they will affect the accuracy and magnitude of the change in mean sea level. Although it is caused by local or regional vertical crustal movements at Antalya-II and Erdek geography stations at all four geography stations, a local (relative) 3-10 mm/year sea level rise trend was found. In another study conducted in the Aegean Sea in 2010, trends and interannual variability based on 1985-2001 sea level measurements at two tide gauge stations on the Aegean and Eastern Mediterranean coasts of Turkey have been analyzed to determine the possible forcing mechanisms: in particular, the levels of contributions by atmospheric, steric and land motion. During the period 1985-2001 the sea level trends in Antalya and Menteş are found to be 7.9±0.8 mm/year and 5.5±1.0 mm/year, respectively. The atmospheric contribution only accounts for 0.6-0.9 mm/year of a trend, while the steric contribution is greater, accounting for 2.5±0.4 mm/year and 6.4±0.7 mm/year respectively in Antalya and Menteş. Almost half of the interannual sea level variance is due to the combined atmospheric and steric effects. Significant local land subsidence is detected in Antalya with a rate of -3.2±0.5 mm/year based on EGPS data, and a trend of smaller magnitude -1.3±0.5 mm/year is recorded in Menteş. After removing the GPS estimated VLM rates, and the steric and atmospheric sea-level trends, there remain unexplained trends of 1.3 mm/year and -4.5 mm/year respectively in Antalya and Menteş. Two distinct periods, 1985-1993 and 1993-2001, apparent in the sea level time series of both tide gauges are studied to better understand the largely different residual trends at these two stations. In the 1985-1993 period, the observed sea level in Menteş decreases at a rate of -14 mm/year, about 3.5 times faster than Antalya. The same downward trend is also found at the Khios tide gauge located 50 km away from Menteş. On the other hand, positive sea level trends up to 12 mm/year are found in both tide gauges for the 1993-2001 period mainly attributed to steric effect accounting for 80% of the sea-level trends. The results indicate that the primary source of the discrepancy between the residual sea level trends of Antalya and Menteş over the 1985-2001 period is the highly negative trend observed at Menteş during the 1985-1993 period, the source of which could not be resolved with the available data sets.

5. CONCLUSIONS

The primary source of sea-level changes in the Black Sea and the Aegean Sea has been observed as seasonal (annual and semi-annual) changes. According to the (Alpar & Yüce, 1998) study examined for the Black Sea, the seasonal (semi-annual) water change in the Southwestern Black Sea was measured as an average of 19 cm, this value was measured at the stations on the shores of the South Black Sea, mainly Şile (22.84±12.66) and İğneada (22.54±10.88) (except Trabzon-II station). Again, in the (Alpar & Yüce, 1998) study, the tidal characteristic in the South of the Black Sea was determined as semi-diurnal and the tidal range originating from the Black Sea in the Bosporus was measured as 2.5 cm. In the study of closed seas tides (Medmedev et al., 2016), tide amplitudes for the Northern Black Sea were measured as 1.3-3.0 cm and the main semi-diurnal tide pattern was observed. It has been noticed that the tidal pattern changes diurnally as one moves towards the Eastern Black Sea. However, the common point emphasized by all 3 studies examined is that the tidal effect in the Black Sea is small. According to the study dated 2016 (Medvedev et al., 2016), a tidal effect of a maximum of 18 cm has been observed in the Black Sea in the last 100 years. It has been stated that the Black Sea has an average sea level trend of 8-9 mm/year on the land and 3.5-6 mm/year in the open, and it has been realized that this is not valid for all stations and coasts. Thus, the annual trend for the Trabzon-II station was given as 1.21±1.76, but for the Sinop station, this value was recorded as 6.63±2.88. Both measurements are corrected for vertical ground motion and are compatible with satellite altimeter data. In the 1998 study (Alpar & Yüce, 1998) for the Northeast Aegean Sea, it was stated that the seasonal difference was 12 cm, and the low water time was January, and the high-water time was October. In the 2003 study (Yıldız et al., 2003), the annual trend of Antalya-II station (1985-2002) was 8.7±0.8 and the annual trend of Menteş station (1985-2002) was 6.8±0.9. In the 2010 study (Simav et al., 2010), Antalya station (1985-2001) was measured as 7.9 ± 0.8 mm/year, and Menteş station (1985-2001) was measured as having a trend of 5. ±1.0 mm/year. The fact that both stations yield 1 mm different results in similar observation periods may be due to the analysis method and other factors (wind, pressure, ground motion) included in the data. In the (Yıldız et al., 2003) study, the tidal type of the Antalya-II, Bodrum-II and Menteş stations was mixed, mostly semi-diurnal; The tide pattern of Erdek station was found to be mixed, mostly diurnal. The largest tidal components of these stations are 6.97 cm, 3.96 cm, 5.77 cm, and 1.21 cm, respectively. According to these results, the tidal amplitudes in the Aegean Sea are greater than those in the Black Sea. The reason for this difference may be that the Aegean Sea is the continuation of the Mediterranean and the water bodies it relates to are larger. On the other hand, the Black Sea has connections to other seas only through two narrow waterways, the Bosporus, and the Dardanelles. The Black Sea and Aegean tides lose their influence after passing through these bottlenecks and, according to some studies, they are not affected by each other. However, in the (Alpar & Yüce, 1998) study, very low-frequency interactions were reported.

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