OIL SPILL ALONG THE TURKISH STRAITS SEA AREA; ACCIDENTS, ENVIRONMENTAL POLLUTION, SOCIO-ECONOMIC IMPACTS AND PROTECTION

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WAVE CLIMATE IN THE SEA OF MARMARA

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1. Introduction

The Sea of Marmara (SM) is located at one of the busiest shipping lanes in the world and the surrounding area is an important industrial region. The industrial and commercial investment in the region constitutes more than half of the entire Turkish enterprise. Despite the significant importance of the region in economy, commerce, tourism and transportation, coastal engineering applications are relatively lagging behind. For instance, while in coastal and offshore activities accurate prediction of wind induced waves is quite an important aspect, presently wave measurements are very scare for the SM. Lack of such essential data adversely affects the reliability of engineering works. In this work, estimation of wave heights and periods in the SM are reviewed.

The SM is a small enclosed water body situated roughly between 40°20'N and 41°00'N latitudes and 27°00'E and 29°20'E longitudes. It serves as a connecting basin between Black Sea and Aegean Sea through the Bosphorus and Dardanelles. The SM is an actively used seaway with high navigation traffic and important coastal constructions. The surface area is approximately 11,350 km² with a 240 km length and a 70 km width. The deepest point of the SM is in Çınarcık trough in the east and its depth is 1270 m. The area covering the SM with the location of TPIC buoy is given in Figure 1 while the bathymetry of the SM is shown in Figure 2.

Accurate prediction of wind wave characteristics is of vital importance in ocean and coastal engineering practice. Despite this importance, the literature on wave climate is quite limited because long-term wave measurements are difficult and expensive. Lack of essential data decrease the reliability of coastal and offshore engineering designs. In many engineering applications in the region, it is therefore necessary to employ simplified wave prediction approaches for wave hindcasting. Although such approaches greatly reduce the cost of estimation these methods should be used with caution. Etemad-Shahidi et al. (2009) compared three simplified wave prediction methods and tested their performance using data from Lake Ontario and Lake Erie (North America). The results indicate that the simplified methods typically underestimate the wave parameters. Similar findings are also reported by Saçu et al. (2018) and Akpınar et al. (2011).

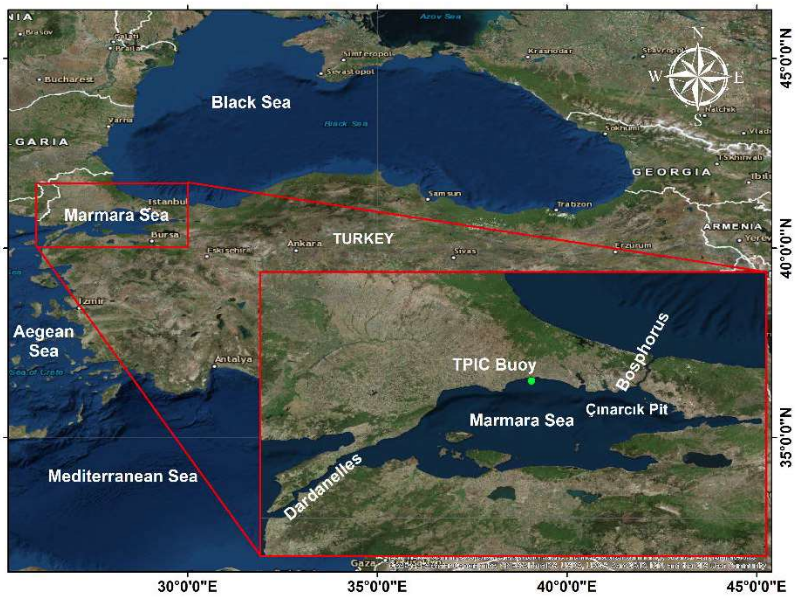


Figure 1. Map of the SM and location of TPIC buoy

Erdik and Beji (2018) analyzed wave height and wind velocity distributions for the SM using the wave and wind measurements collected by Turkish Petroleum International Company (TPIC). This work is among the few studies that statistically analyze the quite valuable one-year-duration data for wind, wave height and energy conditions in the SM.

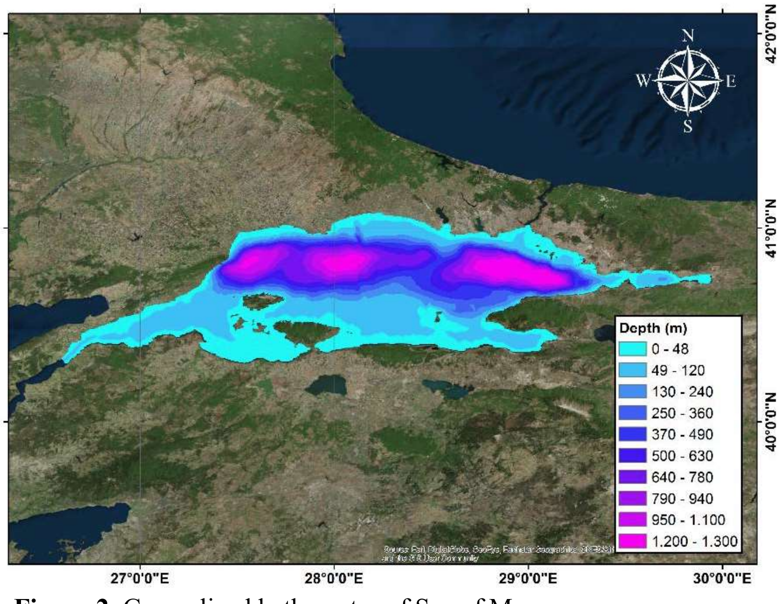


Figure 2. Generalized bathymetry of Sea of Marmara.

The measurements reveal that wave heights are relatively low due to the inland characteristics of the SM. Saçu et al. (2018) tested the performance of simplified wave prediction methods in the SM and compared the results with those given in the literature by using error statistics. Widely used CEM, Wilson, JONSWAP and SMB methods are used to predict the hourly significant wave height.

Abdollahzadehmoradi et al. (2014) computed wave energy potential of the SM for the year 2012 by using MIKE 21 SW, forced with ECMWF wind data with a resolution of 0.125° in longitude and latitude. The model was calibrated by using the wave measurements collected by TPIC for 2 months. According to this study, wave energy in the SM was classified in the lower energy category. The highest rate estimated was for Çınarcık pit zone as 0.84kW m^{-1} for the year 2012.

Kutupoğlu et al. (2016), who employed a SWAN model to predict wave conditions, carried out computations for the SM. The model results were calibrated by the use of one-year-long wave measurements at TPIC location. Short-term wave data measurements performed in 1990 and 2003 at Marmara Ereğli and Ambarlı regions were also employed for validation purposes.

Some researchers investigated tsunami generation and propagation in the SM. Beji and Aldoğan (2001) developed a new Boussinesq-type wave model for the simulation of long water waves generated by a possible fault movement in the Çınarcık Basin in the northeast region of the SM. Later, using the same model Beji (2004) presented the results of various seaquake scenarios for the SM. Güler et al. (2018) investigated tsunami wave attack on Haydarpaşa breakwater by using Volume-Averaged Reynolds-Averaged Navier-Stokes solver, IHFOAM, developed in OpenFOAM® environment.

2. Study area and description of wave parameters

Majority of studies to estimate wave climate in the SM have employ one-year wave data of TPIC, which is collected quite close to the northern shores of İstanbul depicted in Figure 1. The dataset consists of "spectrally based significant wave height H_{m0}, maximum wave height H_{max}, mean wave direction, peak period T_p, mean wave period based on the first moment T_{01}, wave period based on the second moment T_{02}, wind speed, wind direction". The wave parameters are described in terms of the spectral moments m_i of the energy density spectrum $S(f)$:

$$m_i = \int_{fmin}^{fmax} f^i S(f) df \quad (1)$$

where, $H_{m0} = 4\sqrt{m_0}$, where $m_0 = \int S(f) df$ represents to the zeroth-order moment in equation (1). The spectral wave periods are defined by

$$T_{ij} = \left(\frac{m_i}{m_j}\right)^{\frac{1}{j-i}} \qquad i < j \quad (2)$$

According to equation (2) the mean wave period based on the first moment is given by $T_{01} = m_0/m_1$; likewise, the mean wave period based on the second moment is $T_{02} = \sqrt{m_0/m_2}$.

3. Wind and wave climate analysis in the SM

Erdik and Beji (2018) examined the wind data collected from TPIC buoy for a period of approximately one year between February 2013 and January 2014. As is seen in Figure 3, 56% of the winds predominantly blow from the NE. Wave rose graph containing all waves at TPIC buoy is plotted in Figure 4. Majority of waves are observed to come from the SE band. From all available data collected by TPIC, 90% of the measured wave heights are equal or less than 0.55 m whereas only 1% of the wave data measured is higher than 1 m. 68% of the total collected time period waves propagate from the SE band. The highest waves were observed to come from the S-SSW directions. The meaningful wave heights were taken into account only for winds blowing from the band between 101.25°-258.75°, considering the location of the measurement buoy and the associated fetch lengths in Figure 5. Based on the meaningful wave sector (101.25°-258.75°), wave rose graph for the frequency of wave direction is plotted in Figure 6. According to the meaningful wave heights, 86% of the measured wave heights are equal or less than 0.50 m whereas only 2% of the wave data measured is higher than 1 m.

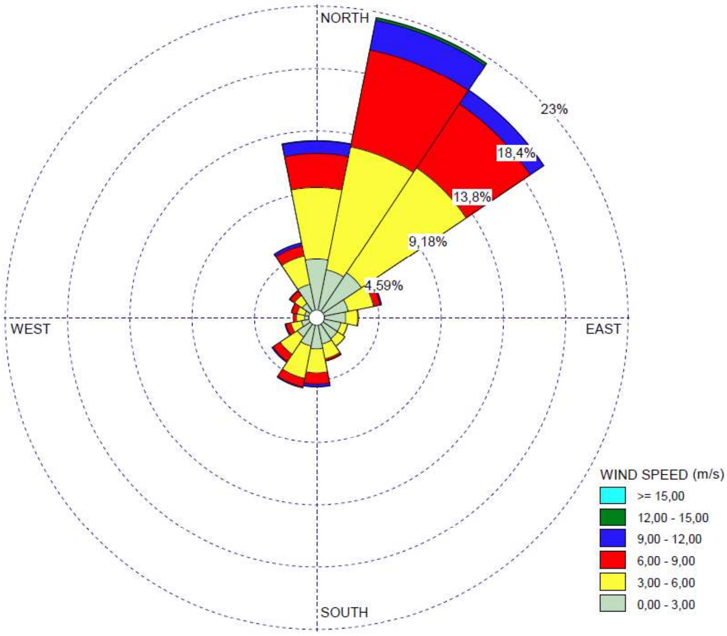


Figure 3. Wind rose diagram for TPIC buoy.

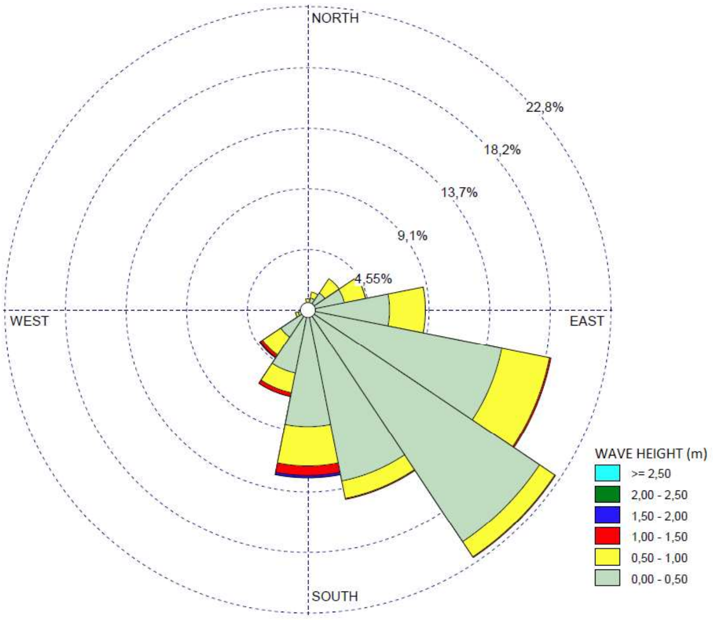


Figure 4. Wave rose diagram for 16 cardinal wave directions at TPIC buoy.

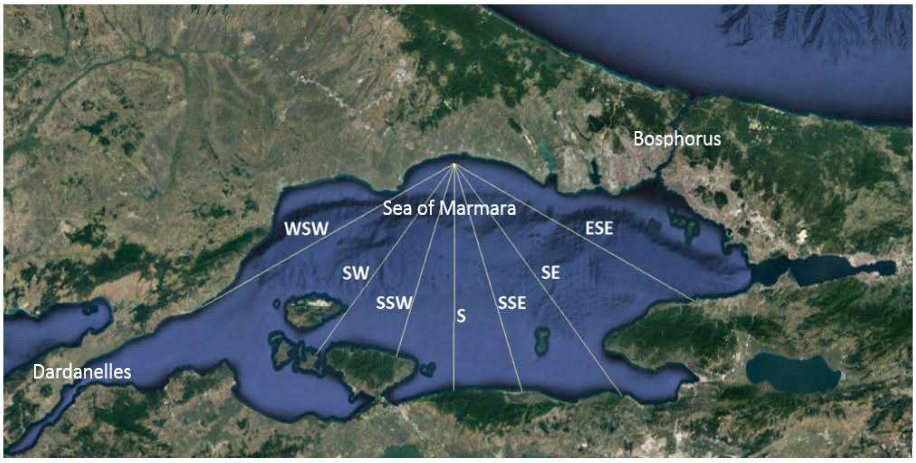


Figure 5. Fetch lengths for TPIC buoy.

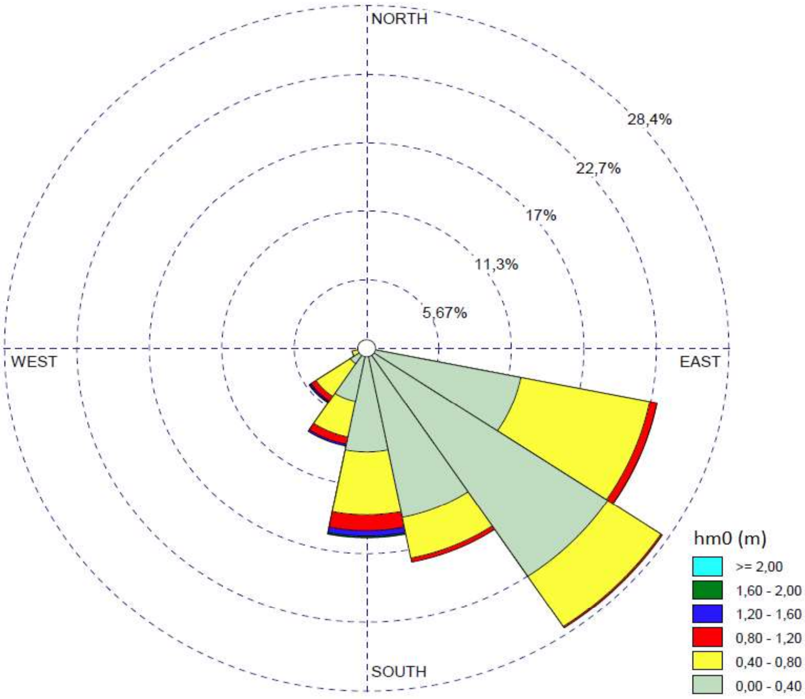


Figure 6. Wave rose diagram for TPIC buoy.

Figure 7 shows the relationship between the risks level and wave height amounts on the horizontal axis. The risk level is defined as the exceedance probability for a given wave height. It is obvious from this figure that as the risk level increases wave height amounts decrease. For practical risk level ranges, say 1% and 10%, wave heights correspond to 1.13m and 0.55m, respectively.

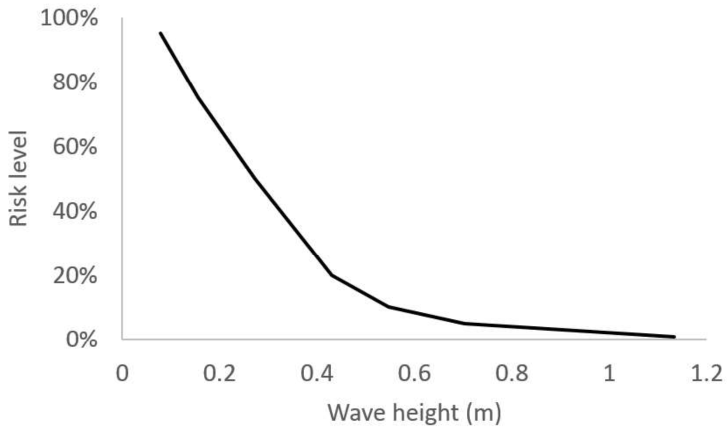


Figure 7. Wave height-risk level relationships at TPIC buoy for sector 101.25°-258.75°.

Joint probability density function of the significant wave height H_{m0} and mean wave period T_{02} are calculated and plotted in Figure 8 for the meaningful wave measurement sector taken between 101.25° and 258.75°, where the frequency of occurrence is scaled to 1:10000. The solid lines represent constant wave steepness, $H_{m0}/L_{m0} = 2\pi H_{m0}/gT_{02}^2$ for 1/20 (blue) and 1/40 (red). Herein, $gT_{02}^2/2\pi$ represents wavelength computed for deep-water waves. Battjes (1972) indicates that limiting wave steepness range from 1/16 to 1/20 in random waves. Similarly, all waves measured fall below wave steepness of 1/20. The most frequent wave has $H_{m0} = 0.25$ m and $T_{02} = 4$ s. The highest waves occur for $H_{m0} = 2$ m and $T_{02} = 5$ s and for a total duration of 13 hours per year.

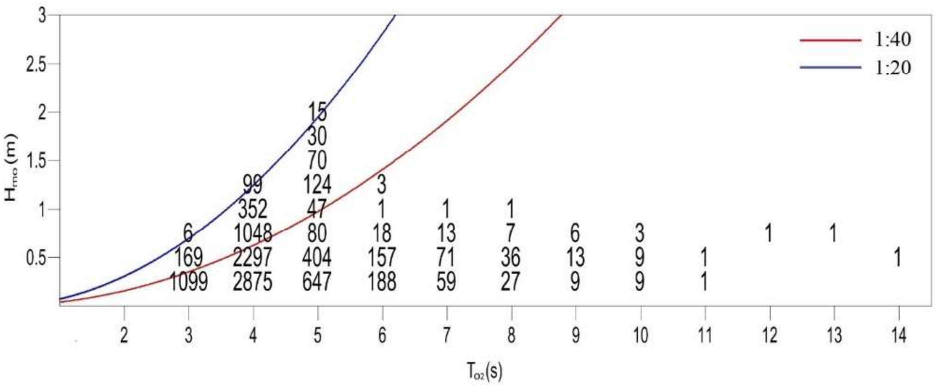
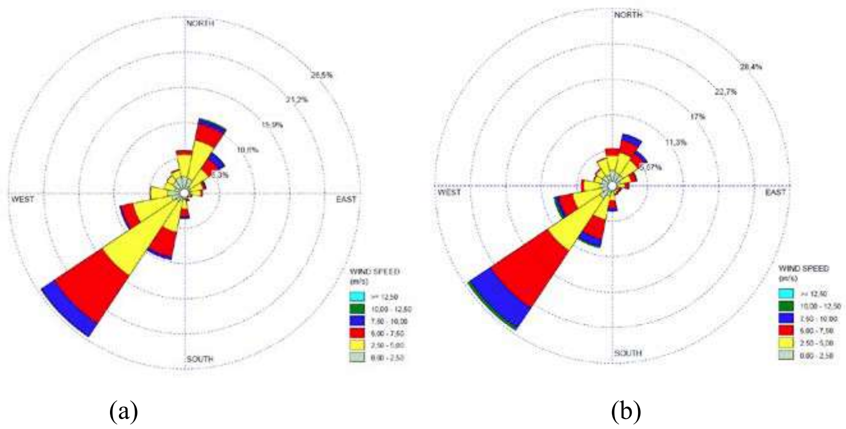


Figure 8. Joint distribution of H_{mo} and T_{02}.

Saçu et al. (2018) compared the measured wind data at TPIC buoy with ERA Interim and Cera-Sat data for the closest location to the TPIC buoy for the same period (Figure 9). ERA Interim and Cera-Sat data yield similar results; however, the direction is basically opposite of that given in Figure 3 for the TPIC buoy.



(a) (b)

Figure 9. Predicted wind data for (a) ERA Interim (b) Cera-Sat.

Saçu et al. (2018) also estimated the wave heights at TPIC location by using simplified wave prediction methods as CEM, Wilson, JONSWAP and SMB. They later compared the predicted wave heights with observed ones of TPIC and concluded that simplified wave methods tend to underpredict the significant wave heights. Similar findings were also reported by Etemad-Shahidi et al. (2009) and Akpınar et al. (2011). Comparison of the methods shows that the WILSON method is more accurate than the others in predicting wave heights at TPIC location in the SM.

Kutupoğlu et al. (2016) employed a SWAN model to predict wave conditions in the SM. In this study, the ERA Interim winds from the ECMWF and the CFSR winds from the NCEP are employed as wind forcing for comparison purposes. ERA Interim data set has a spatial resolution of 0.100°x 0.100° and a 6-hour temporal resolution while CFSR dataset a has spatial resolution of 0.2045° x 0.2045° and a 1-hour temporal resolution. They concluded that the peaks of the winds were underestimated by both CFSR and ERA Interim wind datasets although the CFSR predicts much better than with the ERA Interim. Similarly, SWAN model using the CFSR winds has better prediction performance in the wave height peaks; although both of the wind sources underestimated the wave-height peaks during the storms.

4. Conclusion

Wave climate for the Sea of Marmara (SM) has been reviewed. Based on one-year-long measurements collected by Turkish Petroleum International Company (TPIC) in the SM, for the most frequent wave the wave height and period are $H_{m0} = 0.25$ m and $T_{02} = 4$ s while for the highest waves $H_{m0} = 2$ m and $T_{02} = 5$ s. Total duration of highest waves is 13 hours per year. These results are in agreement with Abdollahzadehmoradi et al. (2014) who have computed that the wave energy in the SM is very low.

Simplified wave prediction methods tend to underpredict the significant wave heights in the SM (Saçu et al., 2018). The highest rates are calculated around Çınarcık trough zone as 0.84kW m^{-1} for the year 2012. The peak values for wind speeds are also underestimated by both CFSR and ERA data sources, although the CFSR wind data set gives better results compared to ERA (Kutupoğlu et al., 2016). As these sources underestimate the peak wind speeds, the SWAN model used for the SM likewise underestimated the wave height peaks during the storm conditions. Nevertheless, use of the CFSR wind data provides somewhat better prediction performance for the wave height peaks.

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