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Wind and wave climate in the vicinity of Bozcaada

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Abstract

One of the most important subjects of coastal engineering is determining the effect of waves on coastal areas. There are different types of marine structures constructed for different purposes such as berths and breakwaters for ports, seawalls for coastal protection, offshore breakwaters and groins. The basic design tools in planning and designing coastal structures and determining the shoreline changing are wave parameters.
Wind and wave climate studies were carried out in Bozcaada coastal region. The wind data used in the wave prediction is obtained from the General Directorate of State Meteorology Affairs. The data includes the hourly wind data for the 30-year period covering the period January 1980-July 2010 for Station number 17111. By evaluating the data, hourly wind distribution percentages, frequency distributions considering direction of wind speeds and direction weighted speed averages were obtained between the years 1980 and 2010. Wave parameters belonging to this region are determined by SMB method which is one of empirical wave estimation methodsWind and wave roses were obtained by using numerical model Mike 21 SW in the thesis comprehensiveness. Wind data required for this model is obtained from ECMWF (European Centre Medium-Range Weather Forecasts) ERA Interim data set. For the calibration of wind – wave models, data is used which was recorded for Bozcaada buoy stations under NATO TU- WAVES project at the coast of Turkey between 21 November 1994- 30 September 1995. When examining the results received from model according to ECMWF data, it has been observed that waves are usually more effective at Bozcaada in south and south east direction.

Keywords: *SMB wave model, wave height, wave climate, Mike 21 SW, ECMWF.*

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Bozcaada çevresinde rüzgar ve dalga iklimi

Özet

Kıyı mühendisliğinin en önemli konularından biri dalgaların kıyı alanına olan etkisinin belirlenmesidir. Kıyı alanlarında birçok tipte deniz yapıları inşa edilmektedir. Bu yapılardan bazıları limanlar için yanaşma yerleri ve dalgakıranlar, kıyı koruma için kıyı duvarları, açık deniz dalgakıranları ve mahmuzlardır. Bu yapıların planlanmasında, tasarımında, inşasında ve kıyı çizgisi değişiminin belirlenmesinde dikkate alınacak ana faktör dalga parametreleridir.
Bozcaada kıyı bölgesinde rüzgar ve dalga iklimi çalışması yapılmıştır. Dalga tahmininde kullanılan rüzgar verileri Devlet Meteoroloji İşleri Genel Müdürlüğü'den temin edilmiştir. Veriler 17111 nolu istasyonun Ocak 1980- Temmuz 2010 dönemini kapsayan 30 yıllık döneme ait saatlik rüzgar verilerini içermektedir. Veriler değerlendirilerek 1980-2010 yılları arasında saatlik rüzgar dağılım yüzdeleri, rüzgar hızlarının yönlere göre frekans dağılımı ve yönsel ağırlıklı hız ortalamaları elde edilmiştir. Ampirik dalga tahmin yöntemlerinden SMB yöntemi ile bu bölgeleye ait dalga parametreleri belirlenmiştir. Ayrıca çalışma kapsamında MIKE 21 SW numerik modeli kullanılarak rüzgar ve dalga gülleri elde edilmiştir. Model için gerekli olan rüzgar verileri ECMWF (Avrupa Orta Vadeli Hava Tahmin Merkezi) ERA Interim veri setinden elde edilmiştir. Rüzgar-dalga modelinin kalibrasyonu için Türkiye kıyılarında NATO TU-WAVES projesi kapsamında Bozcaada şamandıra istasyonu için 21 Kasım 1994-30 Eylül 1995 tarihleri arasında kaydedilen veriler kullanılmıştır. ECMWF verilerine göre modelden elde dilen sonuçlara bakıldığında dalgaların genellikle Bozcaada için Güney ve Güney doğu yönlerinde daha etkili olduğu görülmüştür.

Anahtar kelimeler: *SMB wave model, wave height, wave climate, Mike 21 SW,ECMWF*

1. Introduction

One of the most important issues of coastal engineering is the determination of the impacts of waves on the coastal regions. Many types of marine structures can be constructed in coastal areas. Among these structures, the rubble-mound breakwaters withstand the wave impacts by using the block weights employed in the protective layers. The block weight related to this protective layer is directly proportional to the cube of the wave height. In this instance, incorrect characterization of the wave height will bring about incorrect detection of the stone weight composing the protective layer as well. Hence, accurate determination of parameters pertaining to the wave is rather essential during the design of coastal structures.

In this study, 30-year hourly wind data of Bozcaada meteorological station operated by Turkish State Meteorological Services were used and then the wave parameters concerning these regions were determined through SMB method that is one of the empirical wave estimation methods. The wind and wave roses were plotted for Bozcaada by providing ECMWF's ERA Interim data as wind data. Additionally, in the modeling phase, MIKE 21 SW program was utilized.

2. Wave prediction methods

2.1. SMB method

In order to determine the fetch length in the SMB method, the point of interest on the shore is considered within a band of ± 45º from the direction of the main wave, and the length of the fetches is measured at intervals of 7.5º. Effective fetch is computed with the given equation [1].

$$F = \frac{\sum xi.\cos \propto^2}{\sum \cos \propto_i} \tag{1}$$

This method is the first method for determining design values using wind data and has been developed by Sverdrup and Munk [2]. Wave prediction curves given by Sverdrup and Munk have been updated by Bretschneider using empirical data set Bretschneider [3,4]. Therefore, this method is often termed as Sverdrup-Munk-Bretschneider (SMB) method.

$$\frac{gH_s}{U^2} = 0.283 \tanh\left[0.0125\left(\frac{gF}{U^2}\right)^{0.42}\right] \tag{2}$$

$$\frac{gT_s}{U} = 7.54 \tanh\left[0.077\left(\frac{gF}{U^2}\right)^{0.25}\right] \tag{3}$$

$$\frac{gt}{U} = \mathrm{K}\exp\left\{\left[\mathrm{A}\left(\ln\left(\frac{\mathrm{gF}}{\mathrm{U}^2}\right)\right)^2 - \mathrm{B}\ln\left(\frac{\mathrm{gF}}{\mathrm{U}^2}\right) + \mathrm{C}\right]^{1/2} + \mathrm{D}\ln\left(\frac{\mathrm{gF}}{\mathrm{U}^2}\right)\right\} \tag{4}$$

where U is wind velocity, Hs is significant wave height, Ts, is wave period, t is wind duration and g is gravitational accelaration (K = 6.5882, A = 0.0161, B = 0.3692, C = 2.2024, and D = 0.8798). In these expressions, gF / U^2 is known as the fetch parameter and is denoted by ϕ, which is given as graphically in Figure 1. While the duration limited waves control the wind blowing time and fetch can be taken infinitely, the fetch limited waves controls the fetch distance and the wind blowing time is insignificant [5].

$$\phi = gF/U^2 \tag{5}$$

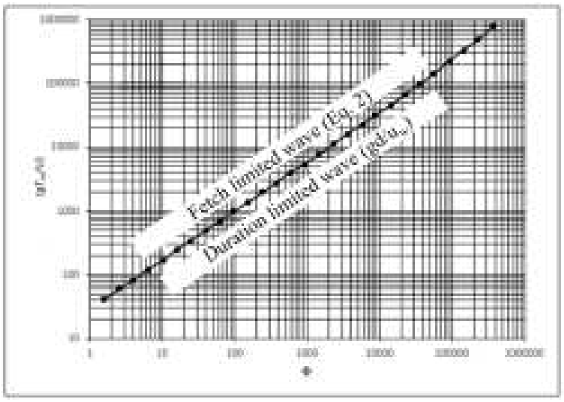


Figure 1. ϕ Fetch parameters.

In case the equations are employed,

(a) t, U and F are determined using the current wind data.

(b) ϕ is determined by the equation (5)
(c) gt/U parameter is calculated
(d) If the value found by using steps (b) and (c) remains on the curve in Fig. 1, the wave height is determined by the fetch and the fetch parameter defined in step (b) is preferred. If the mentioned value remains below the curve, the wave height can be calculated from the wind blow duration and the smaller value of ϕ, determined from the curve, is taken into account using the time parameter gt / U.
(e) From the determined value of ϕ, H_s and T_s can be calculated using the equations of (2) and (3), respectively [5].

2.2. Numerical model

MIKE 21 SW software is a new generation wind wave model based upon an unstructured network system. In offshore and coastal areas, it simulates the development of wind-generated wave and swell wave, its transformation and its energy-driven change.

MIKE 21 SW contains two different equations which are namely directional decoupled parametric formula and fully spectrum formula.

The directional decupled parametric formula is based upon parameterization of the wave action conservation equation. Parametrization is carried out in the frequency domain. In other words, the zeroth and first moments of the wave spectrum are designated. On the other hand, the fully spectrum formula is based upon the direct wave motion conservation equation, where the directional wave-spectral formulation is a dependent variable. The fundamental conservation equations were formulated within cartesian coordinates for small-scale studies, and polar spherical coordinates for large-scale studies [6].

MIKE 21 SW contains the following physical events:

- Wave growth originated from wind,
- Nonlinear wave-wave interaction,
- Wave energy loss originated from white-capping,
- Wave energy loss originated from bottom,
- Energy loss originated from depth-induced wave breaking,
- Refraction and shoaling originated from depth alteration,
- Wave-flow interaction,
- The impact of impermanent water level

The discretization of the basic equations in both geographic and spectral area is performed by the method of cell centered finite volumes. In the geographical area, unstructured mesh technique is utilized. Time integration is realized with fractional step approach, in which the explicit method with multi-sequence is implemented for wave propagation.

MIKE 21 SW is preferred for prediction of wave climate in offshore and coastal regions. One of the most crucial applications is the sensitive evaluation of wavelengths in offshore, coastal and harbour areas. It provides the safe and economical design of structures in such areas mentioned above. In long period durations, in an extreme sea state, there is usually no environment available to obtain sufficiently sensitive data. In this phase, during the storm, the observed data can be supported by an estimation method related with wave conditions using MIKE 21 SW [6].

The MIKE 21 SW method can be implemented in simultaneous estimation and analysis for especially large scale (west coast of Jutland's, Denmark) and regional scale (the North Sea). Coarse spatial and temporal resolution is utilized for regional parts of mesh, and high-resolution boundary- and depth-adaptive mesh junction defines the shallow water parts located at the shorelines.

3. Determining wind and wave climate

3.1. Study area

In order to be able to perform a reliable wave climate study, long-term wave measurements are required. As this is both exhaustive and time-consuming process, wave parameters are determined using empirical wave prediction methods by concerning long-term wind data only. In this study, wave parameters are designated by using wind data representing Bozcaada which is the input of SMB method that is one of empirical wave prediction methods.

Bozcaada is an island in the north-east of the Aegean Sea and twelve sea miles south of the Dardanelles (Fig. 2). The area of Bozcaada, which is 38 km in perimeter, is calculated as 36.67 km². It has an area of 37.6 km² with 17 small islets around it. It is generally low and flat in terms of the land forms. The inner zones of the island frequently comprise large plains. The coves and capes are unique to the island. There are twelve capes and coves on the island and sand dunes on the north coast. It can be said that it is under the influence of Mediterranean climate. The wind is existent for every month of the year, while it attains higher velocities in winter months. Because of its location at the outlet of the Strait of Dardanelles, the region is highly exposed to southern winds and especially northern winds [7].

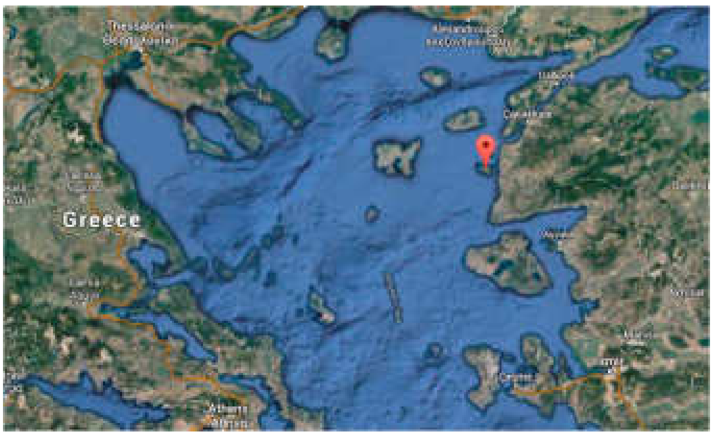


Figure 2. Study area [8].

3.2. Evaluation of wind and wave climate

3.2.1. Evaluation of obtained wind data from Turkish State Meteorological Service

Bozcaada meteorology station having 17111 code number is located at $39^{0}49'$ north latitude and $26^{0}04'$ east longitude. Hourly average wind speed and direction values at 10 m height covering January 1980 - August 2010 period were used in the study. For the study region, the occurrence percentages related to wind directions data of 1980-2010 period are given in Table 1. When this table is evaluated, it can be attained that the winds prevailed in the NE, NNE and NNW directions in Bozcaada comprise nearly half of the total wind direction. Frequency distributions and directional weighted values of the mean hourly wind speeds according to the directions are also summarized in Table 2.

Table 1. The occurrence percentages related to wind directions acc. to TSMS data between1980-2010 for Bozcaada (1980-2010) [9].

DIRECTIONS	E	ENE	ESE	N	NE	NNE	NNW	NW
BOZCAADA	2,51%	7,56%	4,76%	7,94%	12,12%	23,11%	12,50%	1,86%
DIRECTIONS	S	SE	SSE	SSW	SW	W	WNW	WSW
BOZCAADA	4,78%	2,54%	6,36%	7,45%	1,92%	0,76%	1,85%	1,98%

In Table 3, it was determined that winds in the north-north east direction under 0-2 hour blowing duration are effective at 1.72% for 0-2 m/sec speeds. Likewise, at speeds of 2-4 m/s, 4-6 m /s, 6-9 m / sec, 9-12 m/s and greater than 12 m/s, 3.24%, 3.61%, 5.46%, 4.42% and 1,97%, respectively efficiency percentages are available. The maximum wind speed in this direction is calculated as 27.7 m / s.

Table 2. Frequency distributions and directional weighted values of the mean hourly wind speeds according to the directions [9].

SPEED (m/s)	DIRECTIONS															
	E	ENE	ESE	N	NE	NNE	NNW	NW	S	SE	SSE	SSW	SW	W	WNW	WSW
1	678	1034	1220	531	650	976	727	302	557	694	1080	748	144	145	202	266
2	1213	2150	1508	842	1229	7980	1824	389	571	1517	2102	1918	202	383	430	381
3	1066	2084	2247	656	1234	5587	2505	369	782	982	1324	1559	560	279	540	233
4	990	2270	1920	1272	1844	8053	1334	460	1157	566	1062	1530	592	240	640	637
5	284	1978	1328	1672	2328	4136	1528	598	1293	476	964	1708	548	215	382	653
6	320	1673	617	1880	2059	4412	1961	613	1101	243	1010	1649	433	140	324	429
7	206	1480	160	1974	2017	4044	1265	528	1056	213	1003	1539	269	62	402	153
8	152	1330	141	2101	3086	5915	2090	330	970	177	1103	1425	204	50	221	133
9	140	879	56	1805	2498	4560	2064	202	741	138	903	645	179	36	160	45
10	62	608	27	1383	2279	4435	1454	150	612	106	577	495	146	18	42	37
11	32	380	15	1009	1946	3915	852	103	470	69	624	546	95	9	40	18
12	22	725	13	938	1373	7232	586	71	456	48	340	259	62	7	21	17
13	15	143	5	420	935	1282	257	73	318	33	440	401	33	1	3	10
14	5	97	2	253	563	1117	177	15	187	20	204	274	24	1	4	5
15	5	20	1	151	415	671	102	9	120	14	175	202	32	0	4	2
16	1	17	0	86	234	366	86	2	80	0	120	136	3	0	1	0
17	0	4	0	73	180	150	36	0	53	3	78	130	4	0	0	0
18	0	0	0	45	136	169	20	0	50	1	35	53	7	0	0	0
19	0	0	0	36	73	74	23	1	35	0	13	38	1	0	0	0
20	0	0	0	16	42	41	9	0	10	0	14	17	0	0	0	0
21	0	0	0	8	13	35	6	0	5	0	7	4	1	0	0	0
22	0	0	0	9	10	15	13	0	3	0	3	2	0	0	0	0
23	0	0	0	13	3	4	4	0	1	0	3	0	0	0	0	0
24	0	0	0	10	3	7	3	0	0	0	0	0	0	0	0	0
25	0	0	0	6	3	4	0	0	0	0	0	0	0	0	0	0
26	0	0	0	9	1	2	0	0	0	0	0	0	0	0	0	0
27	0	0	0	4	1	2	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	5412	10964	10317	17306	36653	59690	32707	4094	10150	5103	13772	10332	4361	1653	3498	4201
Weigh. Ave. Speed	3,838	5,244	3,251	7,380	7,708	7,974	6,200	5,597	7,036	3,397	6,294003	6,907	5,480	3,079	4,570	4,108

Table 3. Distribution of wind durations for 1980-2010 period [9].

DIRECTION	Wind Speed (m/s)	0-2 hours	2-4 hours	4-6 hours	6-8 hours	8-12 hours	12<	DIRECTION	Wind Speed (m/s)	0-2 hours	2-4 hours	4-6 hours	6-8 hours	8-12 hours	12<
E	0-2	0,81%	0,04%	0,01%	0,01%	0,00%	0,00%	NE	0-2	0,81%	0,03%	0,03%	0,03%	0,00%	0,00%
	2-4	0,82%	0,03%	0,01%	0,00%	0,00%	0,00%		2-4	1,34%	0,08%	0,01%	0,03%	0,00%	0,00%
	4-6	0,39%	0,02%	0,03%	0,00%	0,00%	0,00%		4-6	2,13%	0,12%	0,03%	0,01%	0,00%	0,00%
	6-8	0,24%	0,02%	0,03%	0,00%	0,00%	0,00%		6-8	2,49%	0,28%	0,08%	0,03%	0,02%	0,01%
	8-12	0,06%	0,02%	0,02%	0,00%	0,00%	0,00%		8-12	2,18%	0,17%	0,04%	0,03%	0,01%	0,01%
	12<	0,01%	0,02%	0,02%	0,00%	0,00%	0,00%		12<	1,18%	0,06%	0,02%	0,01%	0,01%	0,01%
ENE	0-2	1,38%	0,08%	0,01%	0,01%	0,00%	0,00%	NNE	0-2	1,72%	0,09%	0,02%	0,03%	0,00%	0,00%
	2-4	1,37%	0,12%	0,03%	0,01%	0,00%	0,00%		2-4	3,28%	0,18%	0,04%	0,01%	0,00%	0,00%
	4-6	1,44%	0,11%	0,03%	0,01%	0,00%	0,00%		4-6	3,61%	0,18%	0,06%	0,02%	0,00%	0,00%
	6-8	1,42%	0,13%	0,04%	0,02%	0,00%	0,00%		6-8	3,46%	0,73%	0,17%	0,12%	0,04%	0,03%
	8-12	0,49%	0,04%	0,01%	0,01%	0,00%	0,00%		8-12	4,42%	0,14%	0,14%	0,08%	0,03%	0,01%
	12<	0,15%	0,01%	0,03%	0,00%	0,00%	0,00%		12<	1,97%	0,03%	0,08%	0,09%	0,02%	0,01%
ESE	0-2	1,72%	0,14%	0,04%	0,01%	0,00%	0,00%	SE	0-2	0,96%	0,04%	0,01%	0,01%	0,00%	0,00%
	2-4	1,03%	0,11%	0,03%	0,02%	0,00%	0,00%		2-4	0,73%	0,04%	0,02%	0,02%	0,00%	0,00%
	4-6	0,48%	0,03%	0,01%	0,01%	0,00%	0,00%		4-6	0,36%	0,02%	0,01%	0,03%	0,00%	0,00%
	6-8	0,23%	0,01%	0,03%	0,00%	0,00%	0,00%		6-8	0,12%	0,02%	0,03%	0,03%	0,00%	0,00%
	8-12	0,02%	0,03%	0,03%	0,00%	0,00%	0,00%		8-12	0,09%	0,01%	0,03%	0,03%	0,00%	0,00%
	12<	0,02%	0,02%	0,02%	0,00%	0,00%	0,00%		12<	0,23%	0,02%	0,02%	0,02%	0,00%	0,00%
N	0-2	0,42%	0,02%	0,01%	0,00%	0,00%	0,00%	SSE	0-2	1,37%	0,07%	0,02%	0,01%	0,00%	0,00%
	2-4	0,97%	0,04%	0,01%	0,00%	0,00%	0,00%		2-4	1,30%	0,03%	0,01%	0,03%	0,00%	0,00%
	0,41%	1,38%	0,11%	0,02%	0,01%	0,00%	0,00%		4-6	0,25%	0,04%	0,01%	0,02%	0,00%	0,00%
	6-8	2,42%	0,18%	0,07%	0,03%	0,01%	0,01%		6-8	1,23%	0,02%	0,03%	0,02%	0,00%	0,00%
	8-12	1,54%	0,12%	0,04%	0,02%	0,01%	0,00%		8-12	0,79%	0,02%	0,03%	0,02%	0,00%	0,00%
	12<	0,47%	0,02%	0,01%	0,01%	0,00%	0,00%		12<	0,44%	0,02%	0,01%	0,01%	0,00%	0,00%

3.2.2. Evaluation of wind data set provided from ECMWF

Another wind data set representing study area is acquired from the ECMWF. Data is available in 0.25 x 0.25 resolution from the ERA Interim database on the ECMWF website. Wind speeds measured at 10 meters altitude for 6-hour intervals were provided from the GRIB format site for 2007-2009 period. In order to use GRIB type data in MIKE21 program interface, it was first converted to txt file with PanoplyWin program. Then, these text files were pre-processed with the help of Microsoft Excel and could be analyzed. The seasonal and annual wind roses prepared utilizing the WRPLOTView (Version 7.0.0) program developed by Lakes Environmental Software are shown in Figure 3 [10].

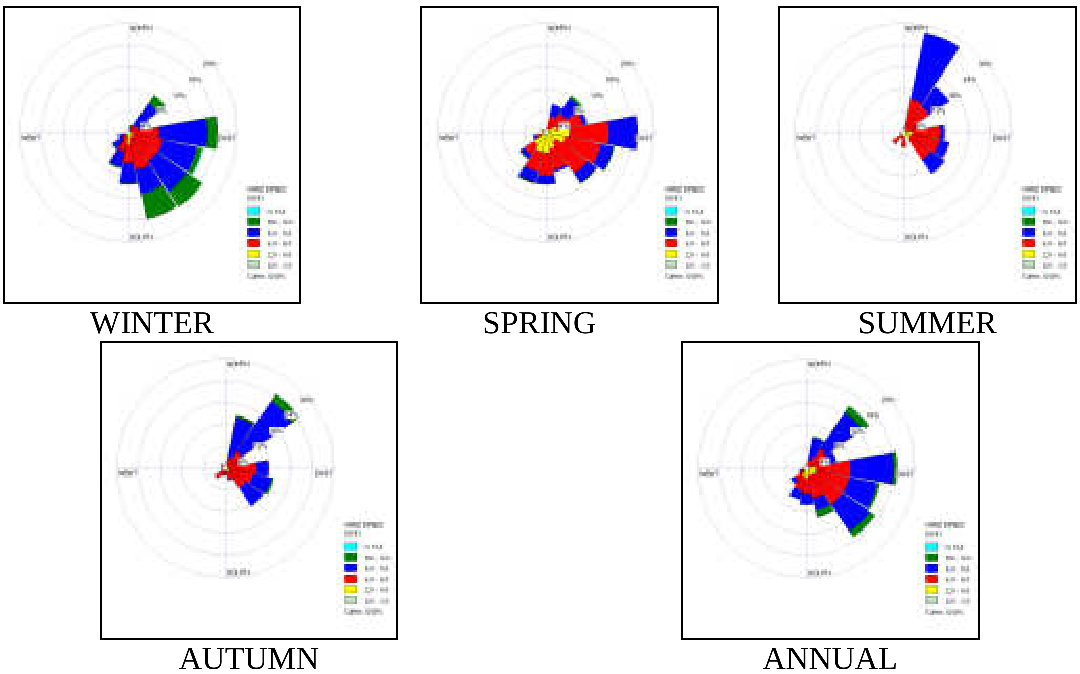


Figure 3. Wind roses representing Bozcaada [9].

3.3. Application of SMB method to study area

Using Equation 1, the fetch lengths for Bozcaada were calculated and the fetch directions are shown in Figure 4. In this study, SMB empirical wave prediction method is used so as to determine both wave height and period of related region. To realize this, wind data from March-August-August 2010 taken from the meteorological stations were used. In the estimation phase concerning wave height and its period, other directions outside the dominant wind direction were not taken into account.

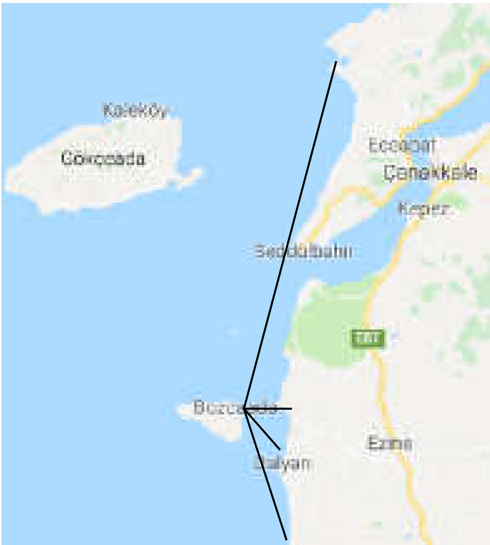


Figure 4. Fetch direction of Bozcaada [11]

3.4. Wave Modeling and Analysis

To prepare the wave model in the MIKE 21 SW program, the bathymetry data is required within the digital environment. Bathymetry data of the Aegean Sea were obtained from the European Marine Observation and Data Network [12]. The obtained data were compared with the maps published by Turkish Naval Forces Office of Navigation, Hydrography and Oceanography (ONHO). Coordinates of the Aegean and Marmara Sea are given in Table 4, model mesh system and bathymetry are shown in Fig 5 and Fig. 6.

Table 4. Study area coordinates.

		Latitude	Longitude
Aegean	Mak.	41	26.94
	Min.	39.02	24.4

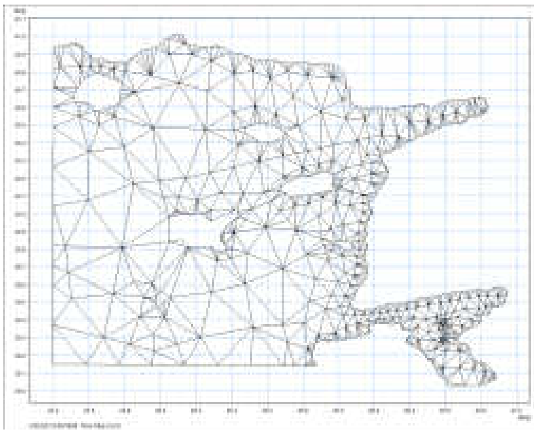


Figure 5. Aegean Sea computational mesh [9].

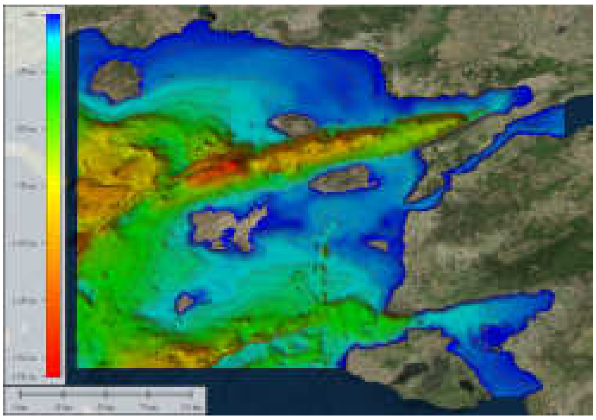


Figure 6. Aegean Sea bathymetry [9].

Wind areas, which are one of the model inputs, have been extracted from ECMWF's Era-Interim data set. In this phase, u and v wind components were used at a 10-meter-high interval of 6 hours. For the calibration of the wind-wave model prepared, the data recorded in the station of Bozcaada were used within the scope of the NATO TU-WAVES project that was sponsored by a NATO unit termed "Science for Peace". The mentioned data were recorded from November 21, 1994 to December 10, 1994, from January 1, 1995 to January 31, 1995, and from August 11, 1995 to September 30, 1995. The apparent wave height values of the Bozcaada station and the data simulated in [13] were also compared in Figure 7. Analyzing the results obtained from the model according to ECMWF data, both seasonal and annual wind roses were shown in Figure 8. When this graph is analyzed, it is seen that winds are more dominant in south and south east directions.

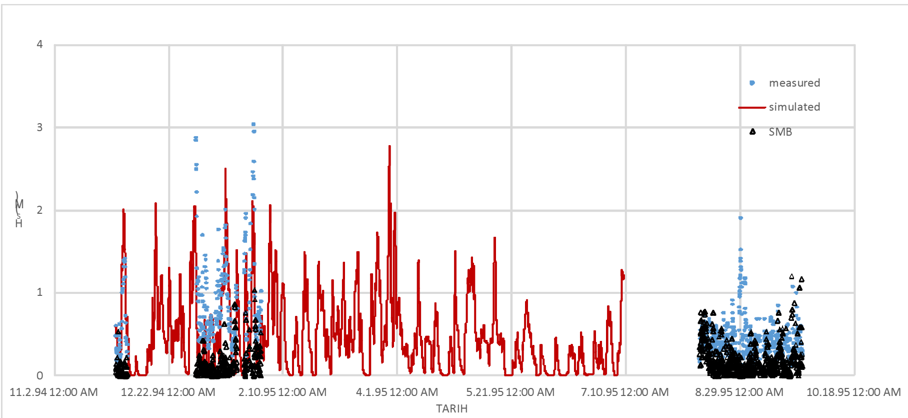
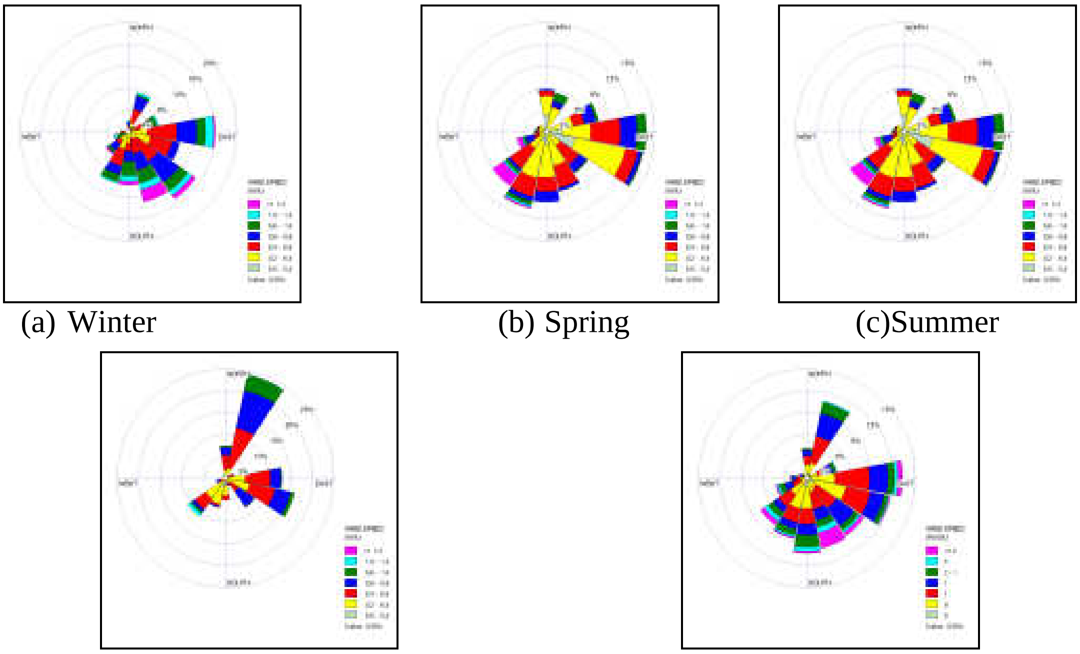


Figure 7. Comparison of wave height data for Bozcaada [9].



(a) Winter (b) Spring (c)Summer

(d) Autumn (e) Annual

Figure 8. Wind roses for Bozcaada [9].

4. Result

Wind and wave climate in the vicinity of Bozcaada is planned to be undertaken in this study. Wind data used in the wave forecasts have been obtained from meteorological station having 17111 code number which belong to Turkish State Meteorological Service between the period of 30 years January 1980- July 2010. For this region, the percentages of occurrence according to the wind directions that existed for 30-year period are given and it is seen that the winds are more dominant in the directions of NE, NEE and NNW in Bozcaada. Besides, the frequency distribution and directional weighted speeds of the study area are given based upon the direction of the hourly average wind speeds. In Bozcaada, when the winds in the north-northeast direction were considered with regard to 2-hour duration, it was determined that the temporal efficiency rates of 0-2, 2-4, 4-6, 6-9, 9-12 m/s, and above 12 m/s wind speeds were found to be 1.72%, 3.24%, 3.61%, 5.46%, 4.42% and 1.97%, respectively. The maximum wind speed in this direction is determined as 27.7 m/s. The wave parameters representing the region are obtained by SMB method which is one of empirical wave estimation methods. It is observed that the highest wave height has a value of 2.22 m for NE direction.

Wind and wave roses were obtained by using numerical model Mike 21 SW in the study comprehensiveness. The wind areas generating wind input of the model were compiled from the ERA-Interim data set of the ECMWF (European Centre for Medium-Range Weather Forecasts). In the study, u and v wind components having 10-meter height with a 6-hour interval were used at a spatial resolution of 0.25^0 x 0.25^0 for the period of 2007-2009. In the phase of the calibration of the prepared wind-wave model, the data of the Bozcaada station, which is located at 39^o 42' 14" N and 26^o 02' 57" E coordinates, served under the NATO TU-WAVES project sponsored by NATO's "Science for Peace" unit were evaluated in the study content pertaining the records from 21 November 1994 to 10 December 1994, from 1 January 1995 to 31 January 1995, and from 11 August 1995 to 30 September 1995. The significant wave height measured at Bozcaada Station and the data obtained in [13] were compared. According to ECMWF data, the results derived from the modeling study were analyzed and both seasonal and annual wind roses were achieved and found to be more impressive in the south and south east directions.

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