EVALUATION AND COMPARISON OF THE WAVE ENERGY POTENTIAL IN SELECTED COASTAL REGIONS IN TURKEY

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ABSTRACT

EVALUATION AND COMPARISON OF THE WAVE ENERGY POTENTIAL IN SELECTED COASTAL REGIONS IN TURKEY

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In order to meet energy needs in world, studies on wave energy, alternative energy, are becoming more and more important with each passing day. The purpose of this study is to identify the wave energy potential along the coastline of Turkey. For this purpose, the data of wind speed and direction, swell and wind wave height, period and direction for certain duration with the six hours time intervals are obtained from ECMWF for the wind and wave climate computations. In order to compute the wind and wave climate at any selected coastal location, software is developed by Serhan Aldoğan in his MSc thesis. By the help of the specifically developed software, for every location, by utilizing existing wind data, depending on geographical location of station, in the direction of energy thought to produce, by using calculated average wind speed of storm which is above the selected wind speed u_0, characteristics (Hs; Tm) of the waves of this storm and power (P, W/m) per unit length will be calculated. The duration curves for power, Hs and T, can be obtained. The duration curve represents the occurrence of the parameter (wave height, wave period, wave energy or wave power). It can also be called occurrence curve or availability curve. From these curves, for various percentages of the total storm duration, P, Hs and T's values can be determined. Also, in the analysis, the shapes of these curves can provide important information about the available wave energy for the selected coasts.

Keywords: Swell, Wind Wave, Wave Power, Wave Energy, Renewable Energy

ÖZ

TÜRKİYEDE SEÇİLMİŞ KIYI BÖLGELERİNDE DALGA ENERJİSİ POTANSİYELİNİN DEĞERLENDİRMESİ VE KARŞILAŞTIRILMASI

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Dünyadaki enerji ihtiyacının karşılanması için, alternatif enerji dalga enerjisi çalışmaları her geçen gün daha da önem kazanmaktadır. Bu çalışmanın amacı Türkiye kıyılarında dalga enerjisi potansiyelini belirlemektir. Bu amaçla, rüzgar ve dalga iklimi hesaplamaları için, rüzgar hızı, solugan ve rüzgar dalgası yüksekliği, periyodu ve yönü verileri belli bir süre için altı saat aralıklarla ECMWF'den sağlanmıştır. Elde edilen veriler, Serhan Aldoğan tarafından geliştirilmiş olan özel bir yazılım aracılığıyla Türkiye'nin kıyıları boyunca seçilen çeşitli bölgelerdeki rüzgar ve dalga iklimi istatistiksel olarak hesaplanmıştır. Özel olarak geliştirilmiş yazılım yardımıyla, mevcut rüzgar verilerinden yararlanılarak, istasyonun yer aldığı kıyının coğrafi konumuna bağlı olarak, enerji üretilebileceği düşünülen yönlerde seçilen bir u_0 rüzgar hızının üzerindeki fırtınalara ait hesaplanan ortalama rüzgar hızı kullanılarak, bu fırtınaların oluşturacağı dalgaların karakteristikleri (Hs; Tm) ve birim boya karşı gelen güç (P, W/m) hesaplanacaktır. Hs, T, P süreklilik eğrileri elde edilecektir. Bu eğrilerden toplam fırtına süresinin çeşitli yüzdeleri için P, Hs ve T'nin aldığı değer belirlenebilir. Eğrilerin şekilleri de incelenen büyüklüklerin analizinde o kıyı için önemli bilgi verecektir.

Anahtar Kelimeler: Soluğan Dalga, Rüzgar Dalgası, Dalga Gücü, Dalga Enerjisi, Yenilenebilir Enerji

To My Family

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Abbreviations and Acronyms

DSİ	State Hydraulic Works
E	Wave energy (kWh/m)
EİE	General Directorate of Electrical Power Resources Survey and Development Administration
GRIB	Gridded binary
J	Wave power (kW/m)
MARS	Mainly Meteorological Archival and Retrieval System
MDPS	Mean direction of primary swell (degrees)
MDWW	Mean direction of wind wave (degrees)
MPPS	Mean period of primary swell (s)
MPWW	Mean period of wind wave (s)
NOAA	National Oceanic and Atmospheric Administration of U.S. Department of Commerce
OWC	Oscillating water column
OWSC	Oscillating wave surge converters
SHPS	Significant height of primary swells (m)
SHWW	Significant height of wind wave (m)
T	Wave period (s)
WEC	Wave energy converter

WIND	10 meter wind speed (m/s)
WWIA-SIM 2.2	Wind and Wave Interpreter and Analyzer-Simulation 2.2

CHAPTER 1

INTRODUCTION

1.1. HISTORY OF ENERGY PRODUCTION

Energy production has undergone several major transitions throughout history as it transforms from wood to coal, coal to petroleum, petroleum to nuclear. But new methods applied to produce the energy caused to new sources of pollution. Studying the history of energy reveals that use of new energy sources has done irreparable damages on natural environment. We have to learn from our past experiences but in this way society's energy requirement may be balanced in sense of responsibility to protect the natural environment in the time to come.

Earliest colonies would use wood in two ways: as a fuel and building material. Fuelwood was a very important heating and cooking means. For these purposes wood had become increasingly scarce. Both in the North and South, human beings destroyed the forests surrounding their places for agriculture and cultivated the land for food production.

In 1709 coal was an important resource in the sope of energy. Since successive developments in industrial and metallurgical processes occurred, this circumstance caused to an increase in coal demand. Coal-burning steam engine invented in 1769 and thus coal started to occupy a very important place in industry and to be used in railroads.

But today, coal is one of the dirtiest sources of energy. Coal production had negative results both for workers and environmental. Due to touching of coal with air and establishment of mines near major rivers, toxic substances spread outside and seeped human water, rivers and lakes. Emerging wastes had a lot of sulfur compounds and other detrimental materials polluting wildlife, human health and environmental.

In consequence of improvement of the Industrial Revolution, coal had progressively important. At the end of the century cities were rapidly developing and accordingly countries were well into the process of industrialization. To produce steel was required for making of buildings and machines and coal had a very important role in the production of steel. The use of coal was tremendously important in the generation of electricity. As steam turbines lights the country, thanks to the combustion of coal the necessary energy was provided for producing the steam. But coal's combustion led to various problems such as the toxic smog and soot. Intensive air pollution descended over like a nightmare on city streets and buildings, humans suffered from lung disease, and industrial melanism emerged in animals living in and around urban areas.

Prior to potential of petroleum was found as a fuel source it was accepted that it was a disaster contaminating clear water due to its penetrating to the water. But, as the whale oil industry deteriorated (mainly due to over-hunting) new energy sources were needed. Miners discovered the kerosene, a byproduct of petroleum production, as the alternative for oil being a fuel source and they used it to light their way in the coal mines. By the turn of the century, gasoline was started to use in the first internal combustion engines. When Henry Ford invented the assembly line production in 1913 and manufactured the Model-T, the automobile became more usable according to previous conditions. Due to the low-cost cars, suburban expansion made possible, it necessitated owning a car; cycle of fuel permanently changed the landscape and sharply increased the amount of energy consumed per capita.

Benefiting from petroleum as a reliable energy source expended the automobile use and unfortunately this accompanied many problems. It has been estimated that approximately seven times as much carbon dioxide resides in untapped fossil fuels as exists in the atmosphere today. Because of consuming as fossil fuels such as petroleum and coal, carbon dioxide is released into the atmosphere and causes to global warming. Acording to a theory suggested by scientists, carbon dioxide and other gasses such as methane trap the longest wavelengths of infrared light in the atmosphere and they maintaine a blanket of heated air over the Earth's surface. To some extent this "greenhouse effect" is necessary to the permanent balance of the global climate. However, by reason of carbon dioxide emissions exponentially on the rise, the amount of heat trapped in the atmosphere has reached a point of unbalance within the past century. A lot of scientists are worried that increasing of global warming will cause to climate changes and will wreak havoc on ecosystems and will permanently chang weather conditions and lead to drought in some regions and flood disasters in others.

Years after the release of the Model-T, many changes in the energy consumption were seen out of increasing reliance on petroleum. During these years power grid reached to the most remote areas of the country as a reaction to the Great Depression and this expansion radically increased the consumed energy. Expansion of grid provided a great deal of interest; In the other words electric light and heating working hours increase and quality of life is generally improved. Today it is impoosible for many humans to accept a life without the conveniences of electricity. Unfortunately, for such a life increasing of energy production was necessary and for this purpose coal and gas power plants were established numerously and thus the environmental impact of energy production remained on the agenda permanently.

Atomic weaponry was used on Hiroshima and Nagasaki at the end of World War II and the world stepped in the nuclear age. After the war, governments requested to use the power of the atom for peaceful purposes. The use of nuclear fission to generate electricity committed great expectations for the future. Although building and maintaining nuclear power plants are expensive, the uranium required for the production of nuclear power is incredibly common in the Earth's crust. Extracting and locating of fossils fuels were very expensive and therefore nuclear energy could be used as an alternate and plentiful source of energy. Nuclear plants were constructed during the 1950s, 60s, and 70s to fulfill this promise.

But excitement felt for nuclear energy was somewhat misevaluated. The production of nuclear power causes to a byproduct of radioactive waste. These wastes are dangerous for hundreds of thousands and this dangerous remains for years. To store them safely is both odious and expensive. In addition the decommissioning of reactors that have outlived their productive lives is a very important problem. For example 40 nuclear power plants in the United States have reached 25 years of age, it was commonly accepted age that they should stop production due to outliving their productive lives and safety reasons. Worst of all however is the danger of nuclear meltdown.

Many accidents occur in the nuclear plants. In such a case an uncontrolled fission reaction can lead to an explosion. This explosion releases massive amounts of radiation and exposes the material inside a nuclear power plant to the outside world. Such an accident occurred at the Chernobyl power plant in 1986. That explosion released over 100 megacuries of radioactivity in a five kilometer high plume of steam, uranium dioxide fuel and fission products. Winds carried this radioactivity throughout Europe and contaminated thousands of square kilometers of land and induced radiation sickness and cancer in thousands of victims. A much smaller incident at Three Mile Island in 1979 caused the American public to lose its taste for nuclear energy. Since that incident, a single nuclear reactor has not been constructed within the United States.

In 1973, all world faced with oil crisis because of fight between Israel and Arab nations. The price of petroleum products sharply increased. In addition coming to power of Ayatollah Khomeini in Iran created another crisis in 1979. Due to these crises industrialized countries started to seek new energy resources and desired to develop renewable energy sources. Energy conservation became an important matter. Accordingly these efforts proved fruitful of environmentally friendly technologies such as wind, solar and geothermal energy.

Consequently each major transition in energy production led to very important damages on natural environment, human health and natural resources.

Recent events have encouraged energy conservation and the production of alternative energy sources for strategic reasons. If the technology of alternative energy sources were implemented widely and the efficiency of energy use increased, it could have a great impact on the health of the natural environment and on human well-being.

1.2. PURPOSE AND SCOPE

The main purpose of this study is to evaluate and compare the wave energy potential between different regions of Turkey by using available wind and wave model data. Five different coastal regions are selected along the coastline of Black and Mediterranean Sea. Until now wind wave and swell wave climate are collectively studied. This study focuses on swell wave energy and wind wave energy potential along the Turkish coasts. By the help of the software WWIA-SIM 2.2 developed by Serhan ALDOĞAN (Aldoğan, 2008), all parameters for swell and wind wave data are extracted from ECMWF database for any given coastal and offshore location. Moreover statistical analyses for the extracted data can easily be performed by the user friendly interface.

The results are provided separately for selected locations and entirely for the region in scope.

The term wind wave refers to sea waves caused by winds over sea surface. Nevertheless, in this study the term "Wind Wave" is used for wind-generated waves, encountered in their generation zone.

The scope of this study is to evaluate and compare the wave energy potential at selected locations (Figure 1.2.1) along the Turkish coastline. For the purpose of the study, data is obtained from ECMWF [ECMWF, 2008] for the whole Basin. Five locations are identified along the Black and Mediterranean Sea for the simulation of software. The obtained data is analyzed in detail for these locations. The results are presented separately for locations in scope. These five locations are identified as İğneada, Sinop, Hopa, Alanya, Karataş (Figure 1.2.1).

Figure 1.2.1 The Layout of The 5 Regions

1.3. METHOD OF STUDY

The method of this study is carried in the following steps; the data gathering, re-arrangement and refining of data, analysis of data in scope and presentation of findings. Data used in this study is obtained from the ECMWF Data Server. [ECMWF, 2008] The data is obtained for the area bounded by throughout 10 E to 43 E and 30 N and 46 N geographical coordinates which includes the coastline of Turkey. The data period is between 01.01.1996 to 31.12.2008, totally 156 months in length. Data for the five selected regions are extracted from the whole data group considering at least three separate (30 arc min = 55.5 km apart) locations for each region. The extracted data of each location in any region is separately analyzed. In the analysis the long term distribution of swell and wind waves are computed. The following relations are presented graphically. They are

(i) The joint distribution of significant height of swell wave and mean period,

(ii) The joint distribution of significant height of wind wave and mean period,

(iii) Duration curve for significant height of swell wave and mean period,

(iv) Duration curve for significant height of wind wave and mean period,

(v) Duration curve for the swell wave power,

(vi) Duration curve for the wind wave power,

The subsequent sections of this study are as follows. Chapter 2 presents a summary of theoretical considerations on swell and wind waves energy and previous works related to this study. Detailed methodology of evaluation and comparation of wave energy are presented in Chapter 3, followed by results of evaluation and comparation for the twenty locations in Chapter 4. Summaries and comparisons of the results are given in Chapter 5. Finally conclusion of the study is given in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

In this chapter general information on wave energy and previous works on wave energy researches are given. In section 2.2 information about wave energy and importance are given in general. In section 2.3 previous works on wave energy researches are given.

2.1. RENEWABLE ENERGY SOURCES

Energy is an indispensable necessity to meet the basic needs and improve social and economical prosperity of a nation. There are many methods for generating energy according to available natural sources. Many countries use fossil fuels for energy needs. The countries which have to import raw materials for generating energy will force to develop new strategies. The coal power plant, where coal is turned into energy is the a major sources of electricity. These are extremely damaging to the environment. Gas emissions derived form fossil fuels make greenhouse effect and it is known that this event cause climate change all over the world (Gleick,1986). Renewable energy is derived from natural processes that are renewed constantly. In its various forms, it is derived from directly from the sun, or from heat generated intensively within the earth. It is possible to include in the definition; the electricity and heat generated from solar, wind, wave, hydropower, biomass, geothermal resources, and bio fuels and hydrogen which is possible to be derived from renewable resources.

In Kyoto Protocol, the decision, 10% of develop and developing country's energy consumption until 2010 must be meet by clean energy sources, was taken (Şen, 2003). Lately, technological point of view, there are developments in use of renewable energy types. This issue has been point of attraction by many researchers.

The most important indicator of economic development and social welfare is also the electrical energy consumption. In a country, electricity production and / or consumption per capita is used as a criterion in that country as it reflects the level of prosperity (Şen, 2003).

At the beginning of 2004, in Turkey, although gross electricity consumption per capita has reached 2090 kWh, in Europe it is approximately 6500 kWh/person and world average is 2350 kWh/person.

2.1.1. Solar Energy

Sun is the ultimate source of energy on this planet. All other sources of energy owe their origin to the Sun. Actually, when we mention the solar energy; we will refer to utilizing the heat and light energy of the Sun directly. Electricity is generated from the solar energy using photo- voltaic cells and heat engines. Solar energy is important on our planet in many different ways, both in the sense of commercial power production as well as the energy that it provides both us and other living organisms to survive daily and go about our lives. Solar energy typically is characterized in four primary forms: light, heat, wind and hydro power.

The use of solar radiation as energy has recently seen a very great interest. This energy type varies according to time and location is natural. In the northern hemisphere, solar radiation in summer months when maximum amount of energy produced, is more than in the winter months. Moreover, duration of solar radiation in equatorial regions is the most, toward the poles it decreases. In different regions of the world, by selecting the appropriate region, where solar radiation could be utilized from the most optimal way, collecting solar energy farms are established. The biggest problem as in other energy sources is unavailability of storing energy and consuming energy when wanted (Şen, 2003, Faiman, and others 2007). The studies related with this topic continue. Tendency to run out of fossil fuels and because of the negative effects on the environment, this type of energy has gained considerable importance (Sorensen, 2000).

Today, there are various methods of solar energy production, with them being either direct or indirect, with active and passive components. For instance, the solar thermal method utilizes the sun's energy to directly generate heat. This process works by using solar panels to collect the heat from the sun. This heat is kept and then transferred to water tanks for distribution and heating through the rest of the house.

By now, this is the most popular form of solar panel available on the market, with may building designs harnessing this technology.

The photovoltaic method directly transfers the sun's power into electricity. This process utilizes solar cells, or photovoltaic cells to trap the sun's heat. They are often silicon-based with wide surface area for maximum heat absorption from the sun's rays. Through this method electricity is directly trapped, instead of using the warmth created from the sun in the thermal method. The number of these cells contained in one panel changes depending on the size of the panel, but these cells can be also interlinked and combined for a greater production power. The disadvantage part of this production method is that it is DC, or direct current electricity, and actually it is not available to be utilized in most of the households. Fort his reason, an inverter is needed to transform the direct current power into AC, or alternating current power. This transformation causes a minor loss of energy, but it means the electricity is ready to use in household appliances at night time and during times when the sunlight is diminished. With the assistance of this method, in case a home is connected to the power grid, it will be possible to feed any excess energy which your batteries cannot contain, back into the grid. With this method, you will be producing your own energy.

Solar energy is responsible for generating wind currents. Solar energy is even responsible in part for the generation of waves and currents. Indirect solar energy involves more than one process in order to obtain usable solar energy. Hydroelectric dams and wind turbines also function through indirect solar means, as water and wind can be sun powered. All ocean thermal energy is an indirect result of solar power, because the sun warms the ocean and causes different wave movements with the assistance of the wind.

After the water, that is evaporated by the sun as the energy source of hydrological cycle, concentrates on the air, again it falls down to earth as rain. Hence, the stored water and flow and in high places can be used as potential energy. Due to differences in temperature, the flow of air from the high pressure center to low pressure center is the source of wind and wave energy (McCormick, 1998). Moreover, in the oceans, the currents occurred due to differences in seawater temperature also is used as energy source (McCormick, 1998).

Every day, the earth receives a huge capacity of solar energy in the form of radiations sourcing from the sun. However, most of this energy is reflected by our upper atmosphere. Further large layer of the energy received by the sun is absorbed by the land masses, oceans and clouds. However, using only about 1% of the total energy that reaches the surface of the earth is able to offer a solution against our energy crisis. Earth gets the energy necessary for the continuation of life in a way that is balanced and continuous. For Calculations for solar energy, solar radiation is measured by an instrument called solarimetre. The solar radiation energy coming from the sun on earth each year is about 160 times as much as fossil fuel reservoir (Şen, 2003). To utilize a lot of solar energy in a region, the climate of that region must be known. There are three ways for heat Exchange of solar radiation with Inner and outer surfaces of device

1) Conduction

2) Convection

3) Radiation

The world gets power constantly from the sun about 10.000 times of energy which is consumed by the world annually (Şen, 2003). It should be kept in mind that this energy is constant, inexhaustible, renewable and environmentally friendly. In calculations of solar radiation, there are two important factors such as solar radiation and sunshine duration. For the estimation of the amount of solar radiation

1) degrees of latitude and longitude and height of that place,

2) geometric and microhydrologic properties of clouds and the positions of clouds from earth in terms of height

3) at various times of the day, fair, cloudly and partly cloudly weather conditions are required.

If these variables are correctly predicted, the amount of energy can be calculated precisely. For these calculations, at first, Angstrom (1924) has presented a linear relationship. Later, many researchers have made several approaches (Şahin and Şen, 1998; Şen 2001, 2004).

Our country has a huge potential in terms of solar energy. In case of making the necessary investments, on average, 1500 kWh/m2 solar energy can be produced yearly in Turkey (Şen, 2003). Most favorable regions of Turkey in terms of solar energy are the Southeastern Anatolia and Mediterranean regions.

2.1.2. Wind Energy

The Earth is heated unequally by the sun because of its shape. Whilst the equator gets maximum heat, the poles get the least. Along with this, land heats up more quickly than the seas and oceans. This differential heating creates an atmospheric convection system between the surface of the earth and stratosphere; moreover the energy of the system is stored in the wind movement.

The energy from the wind can be harnessed by a wind turbine. As there shall be some changes in the wind pressure, the blades of the turbine move. This results in the conversion of the kinetic energy of the wind into mechanical energy. The latter is carried through the shaft of the turbine to the generator where it is converted into electrical energy and used for different purposes.

Wind power is inherently one of the cleanest sources of power available at earth. It neither contributes to global warming, nor produces any form of harmful waste. This means that; if we used wind power for more of our energy needs we would be doing the earth a very big favor. This is through not only a reduction in the amount of carbon dioxide (CO_2) produced but also of sulfur dioxide (SO_2) which raises the acidity of the moisture in the air causing "acid rain". Wind turbines also do not require the use of non-renewable fuels such as coal, as wind energy is generated by earth heating and cooling every day due to the sun. You should consider this fact that wind farms require very small amounts of land and can be integrated into farm land, and you can also see that they are environmentally friendly energy source.

"Currently, there are around 68,000 wind turbines operating around the world, and several countries have achieved relatively high levels of wind power penetration, such as 20% of stationary electricity production in Denmark, 14% in Ireland and Portugal, 11% in Spain, and 8% in Germany in 2009" (World Wind Energy Report, 2009). "At the end of 2009, worldwide nameplate capacity of wind-powered generators was 159.2 gigawatts, which is about 1.5% of worldwide electricity usage; and is growing rapidly, having doubled in the three years between 2005 and 2008" (World Wind Energy Report, 2009). Although manufacturing capacity of wind turbine up to several megawatts, the turbine capacity, which is widely used nowadays, is between 600 kW and 1200 kW. Since 2005, wind energy has successfully provided around 1% of the world's energy requirements, where United States is the third largest wind energy producing country in the world whereas Germany has been leader in renewable energy sources.

To understand the distribution of wind energy potential with time and location, the study on air movement, periodically occurred and various size, is useful. Because the wind occur due to conversion of different types of energy in the atmosphere, to understand of physic behind the event is useful. Wind occur due to occurence of physical events such as dynamic, thermodynamic and radiation

The strength of wind differs, and an average value for a given location does not indicate alone the amount of energy which can be produced by a wind turbine there. In order to assess and check the frequency of wind speeds at a particular location, a probability distribution function is often fit to the observed data. In order to determine the potential of wind energy, it is necessary to have long-term wind measurements. The wind speed measured at a weather station includes temporal oscillations. It is divided into two as the significant (static) part which represents the arithmetic average and the part which makes undefinite oscillations around the average. The wind loads on the wind turbine also are divided into two groups. First of these is average wind load so that it is called as time-mean loading or if-static loading. The random oscillations also correspond to turbulent and it is also called dynamic loads of wind. The average of these is equal to zero. Characteristics of static and turbulent winds depend on the scale kept in mind. While static part is important in large-scale regime, turbulences become important in small-scale point measurements by anemometer. Variation of Significant portion with time is as low as it can be neglected. This part is important for the determination of wind energy potential. Oscillation of the wind speed is important for turbine control and stability. For the calculation of the potential of wind energy, two parameters obtained in wind speed are important.

2.1.3. Hydropower

Hydropower plants, especially small scale hydropower plants, are getting more important in renewable energy technologies (Dragu et al., 2001).

Hydropower provides majority of power generation in 55 countries and contributes 20 percent of the world's power generation (Altınbilek, 2005 and Dragu et al., 2001). In developed countries, this rate is up to 40%. The efficiencies of hydropower plant are several times more than conventional power plants. With these plants, obtaining energy can be possible by reliable, efficient and sustainable way. Flows in rivers vary from season to season and from year to year. During the seasons with high flow, extra flow can be stored in a reservoir that is located at the upstream of a hydropower facility. The stored water in the reservoir is used during low flow seasons. This control of flow is called flow regulation. The optimization of flow regulation requires reservoir operation studies. Large storage capacity may bring some environmental problems. Recently, through micro-turbines, without storage capacity, it is possible to obtain electrical energy directly in the river. Turkey has been generating electricity from small hydropower plants since 1902 (Balat, 2007).

In terms of technology, hydropower plant development has almost reached to the end point. Today, it is among the major energy sources of up to approximately 35 countries in the world. As a result of the developments that occurred over the years, energy production efficiency has been increased to 90%.

The generation of electricity from hydropower could be explained with the same simple fact of nature, conservation of energy. Potential energy of water, gained by hydrologic cycle, turns into mechanical energy by turbines then into electrical energy by generators of hydropower plants.

"Water constantly moves through a vast global cycle, in which it evaporates from lakes and oceans, forms clouds, precipitates as rain or snow, then flows back to the ocean known as hydrologic cycle. The energy of this water cycle that is driven by the sun can be evaluated most efficiently with hydropower." (INL, 2007).

Parameters which affect the amount of hydroelectric power are net head, flow and turbine efficiency. Obtained energy is proportional to the net head and flow. The potential energy of water turning into power by means of turbine is given by the following formula:

$$P = \eta .\ \rho . g . Q . H \qquad (2.1.3.1)$$

where;

P is the power in Watts

η is the multiplication of the turbine, generator and transformer efficiencies

ρ is the density of water in kg/m^3

g is the gravitational acceleration in m/s^2

Q is the flow passing through the turbine in m^3/s

H is pressure head of water in meters

In dams, the potential energy is converted to kinetic energy by falling water down, and finally electrical energy produced by using generators. Of course, during this transformation, an amount of energy is lost. The pressure head and planned to produce energy is two important decision variables used for turbine selection

Hydropower potential of a basin is defined in three important terms that are gross theoretical potential, technically available potential and economic potential. Gross theoretical hydropower potential of a basin is calculated by taking all natural flows in that basin from the beginning to the sea level to generate electricity with 100% efficiency (η = 1). As a function of topography and hydrology, the gross hydropower potential is about 433 billion kWh for our country (EİE).

Technically available potential is the applicable amount of gross theoretical potential that is limited by the current technology (in which losses due to friction, turbine and generator efficiencies (η) are taken into consideration).

Economic hydropower potential of the Republic of Turkey has been calculated by State Hydraulic Works (DSI) and General Directorate of Electrical Power Resources Survey and Development Administration (EIE) from the master plan studies of basins. In these studies, benefits of hydropower developments are compared with other possible alternative sources of electricity generation. The reason for this comparison is to find the cheapest solution to supply a specific amount of energy at a given time (Goldsmith, 1993).

2.1.4. Wave Energy

"The world energy consumption is estimated to rise considerably over the next decades and in the same period the energy consumption in the European Union will increase by almost a similar amount." (CRES, 2002).

Traditional energy resources such as oil, gas, and coal are non-renewable. They also create pollution by releasing huge quantities of carbon dioxide and other pollutants into the atmosphere. On the contrary waves are a renewable source of energy that doesn't cause pollution.

"The energy sector was forced through a renovating process, which sees its opening towards renewable energy. In the dynamic evolution of the renewable energy industry a wave energy industry is emerging. Although the technology is relatively new and currently not economically competitive with more mature technologies such as wind energy, the interest from governments and industry is steadily increasing. An important feature of sea waves is their high energy density, which is the highest among the renewable energy sources. The idea of converting the energy of sea surface waves into useful energy forms is not new."(CRES, 2002). Many wave energy converter are designed and models are tested (McCormick, 1981).

“The intensive research and development study of wave energy conversion began however after the dramatic increase in oil prices in 1973. Different European countries with exploitable wave power resources considered wave energy as a possible source of power supply and introduced support measures and related programs for wave energy. Several research programs with government and private support started thenceforth, mainly in Denmark, Ireland, Norway, Portugal, Sweden and the United Kingdom, aiming at developing industrially exploitable wave power conversion technologies in the medium and long term. The amount of the R&D work on wave energy is very large and extensive reviews have been made e.g. by Salter (1988), Ross (1995), and others. The efforts in research and development in wave energy conversion have met the support of the European Commission, which has been since 1986 observing the evolution in the wave energy field. The research programs of the Commission on wave energy effectively started with the 4th Framework Programme in 1994 following successful completion of related studies and preparatory RTD work.” (CRES, 2002).

“From 1993 the Commission supported a series of international conferences on wave energy (Edinburgh, UK, 1993, Lisbon, Portugal, 1995, Patras, Greece, 1998 and Aalborg, Denmark, 2000), which significantly contributed to the stimulation and coordination of the activities carried out throughout Europe within universities, national research centers and industry.” (CRES, 2002).

“In the last twenty-five years wave energy has gone through a cyclic process of phases of enthusiasm, disappointment and reconsideration. However, the persistent efforts in R&D and the experience accumulated during the past years have constantly improved the performance of wave power techniques and have led today wave energy closer to commercial exploitation than ever before. Different schemes have proven their applicability in large scale under hard operational conditions, and a number of commercial plants are currently being built in Europe, Asia, Australia and elsewhere. Other devices are in the final stage of their R&D phase with certain prospects for successful implementation. Nevertheless, extensive R&D work is continuously required, at both fundamental and application level, in order to improve steadily the performance of wave power conversion technologies and to establish their competitiveness in the global energy market." (CRES, 2002).

Waves are created by the wind as it blows across the open water, the gravitational pull from the sun and moon, and differs in atmospheric pressure, earthquakes etc. Waves caused by the wind are the most common waves and the waves relevant for most wave energy technology. Wave energy conversion takes advantage of the waves caused primarily by the interaction of winds with the sea surface. When created, wind waves can travel thousands of kilometers with little energy losses, unless they face up head winds. For example, waves on the American side of the Atlantic Ocean also with the effect of westerly winds, approaches to the west coast of Europe. The energy flow in the deep sea is quite grate. The power in a wave is proportional to the square of the amplitude and to the period of the motion. "Long period (~7-10 s), large amplitude (~2 m) waves have energy fluxes commonly exceeding 40-70 kW per meter width of oncoming wave." (McCormick, 1981). Nearer the coastline the wave energy intensity decreases due to interaction with the seabed. The wave energy is less on the shoreline but this can be partly compensated by the concentration of wave energy that occurs naturally at some locations by refraction and/or defraction.

"Situated at the end of the long fetch of the Atlantic, the wave climate along the western coast of Europe is highly energetic. Higher wave power levels are found only in 8 the southern parts of South America and in the Antipodes. Recent studies assign for the area of the north-eastern Atlantic (including the North Sea) available wave power resource of about 290 GW." (CRES, 2002).

“The long-term annual wave power level increases from about 25 kW/m of the southernmost part of Europe's Atlantic coastline (Canary Islands) up to 75 kW/m off Ireland and Scotland. In the North Sea, the resource changes significantly, varying from 21 kW/m in the most exposed (northern) area to about the half of that value in the more sheltered (southern) area. In the Mediterranean basin, the annual power level off the coasts of the European countries varies between 4 and 11 kW/m, the highest values occurring for the area of the south-western Aegean Sea. The entire annual deep-water resource along the European coasts in the Mediterranean is of the order of 30 GW, the total wave energy resource for Europe resulting thus to 320 GW.” (CRES, 2002).

“It is important to appreciate the difficulties facing wave power developments, the most important of which are:

• Irregularity in wave amplitude, phase and direction; it is difficult to obtain maximum efficiency of a device over the entire range of excitation frequencies

• The structural loading in the event of extreme weather conditions, such as hurricanes, may be as high as 100 times the average loading

• The coupling of the irregular, slow motion (frequency ~0.1 Hz) of a wave to electrical generators requires typically ~500 times greater frequency.

Obviously the design of a wave power converter has to be highly sophisticated to be operationally efficient and reliable on the one hand, and economically feasible on the other. As with all renewables, the available resource and variability at the installation site have to be determined first.” (CRES, 2002).

The current technology in medium size are supported about 1.5-2 MW or smaller devices are supported 5-20 kW power. Into a number of them can be established for the production of more energy.

“On the other hand, the advantages of wave energy are obvious, the development of which is in line with sustainable development as it combines crucial economic, environmental and social factors. Wave energy is generally considered to provide a clean source of renewable energy, with limited negative environmental impacts. In particular, wave power is seen as a large source of energy not involving large CO emissions.” (CRES, 2002). The effects of this technology to the environment were ranked by Thorpe (1992).

The biggest problem of sizing of wave energy converters is prediction of exposed and common encountered wave characteristics. Furthermore, the determination of peak values is required. For all these, we need to have the long-term wave records. For determining the wave that is 50-year recurrence interval, regularly wave measurements for several years are not enough. As a result, exposed charges of designed device will either under or over the expectations. While the structural damage occurs partially or totally in the first case, in the latter case, it will lose competitiveness with others due to high structural costs and thus increasing energy production costs. With these restrictions, providing information incorrectly and lack of understanding by the public, industry and administration of the country on wave energy technology has slowed the development of wave energy. On the other hand, in terms of sustainable development, there are obvious benefits of wave energy with the economical, environmental, ethical, and social factors. The ample resource and the high-energy fluxes of wave power prescribe – at appropriate design of the devices - economically viable energy production. Specific benefits of wave energy are the limited environmental impact, the natural seasonal variability of wave energy, which follows the electricity demand in temperate climates, and the introduction of synchronous generators for reactive power control. The negligible demand of land use is also an important aspect, followed by the current trends of offshore wind energy exploitation. As for most renewable, the in-situ exploitation of wave energy implies diversification of employment and security of energy supply in remote regions. Furthermore, the large-scale implementation of wave power technologies will stimulate declining industries, as e.g. shipbuilding, and promote labor opportunities in small and medium-sized enterprises.

Offshore Wave Energy

Offshore Wave energy is kept directly from surface waves or from pressure fluctuations below the surface.

Waves are caused by the wind blowing over the surface of the sea. In many areas of the world, the wind blows with adequate consistency and force which shall provide continuous waves. There is huge energy in the sea waves. Wave power devices extract energy directly from the surface motion of sea waves or from pressure fluctuations below the surface.

Wave power differs to a great extent in various parts of the world, and wave energy can't be harnessed effectively everywhere. Wave-power rich areas of the world involve the western coasts of Scotland, northern Canada, southern Africa, Australia, and the northwestern coasts of the United States.

2.2. GENERAL INFORMATION ON WAVE ENERGY

Wave energy can be expressed in the literature under different definitions. The simplest version of the energy flux in terms of the concepts in physics can be described as follows,

$$\text{Energy Flux} = \Phi = \text{Power} / \text{Area} = \text{Energy} / (\text{Time} \times \text{Area}) \qquad (2.2.1)$$

Energy is,

$$E = \text{Force} \times \text{Distance} \qquad (2.2.2)$$

According to the theory of small amplitude waves, the average energy, on unit area, transmitted by sinusoidal waves is,

$$E = 1/8 \times \rho \times g \times H^2 \qquad (2.2.3)$$

where H is wave height, ρ is the density of sea water and g is acceleration of gravity (Kabdaşlı, S., 1992). In case of irregular wave, significant wave height derived from wave energy spectrum is used.

If Eq. 2.2.3 is multiplied by the wave propagation velocity C=L/T, then

the average power per unit crest length will be found. (Uygur, I, vd., 2004)

$$P=1 / 8 \times \rho \times g \times H^2 \times C_g \qquad (2.2.4)$$

As known, in open-sea conditions, wave propagation speed and wave height can be written as follows:

$$C_g = C / 2 \qquad (2.2.5)$$

$$C = L / T \qquad (2.2.6)$$

$$L = (g \times T^2) / (2 \times \pi) \qquad (2.2.7)$$

Accordingly, if the fourth expression are rearranged;

$$P = 1 / (32 \times \pi) \times \rho \times g^2 \times H^2 \times T \qquad \text{in (W/m)} \qquad \text{and}$$

if $k = 1 / (32 \times \pi) \times \rho \times g^2$

then $P = k \times H^2 \times T$ in (W/m) (2.2.8)

Eq. 2.2.8 is the new form of average wave power per unit crest length (Kabdaşlı S., Önöz B. and Yeğen B., 2007).

For sinusoidal waves, coefficient k is calculated as 976 W/s.m^3. In case of irregular waves in real sea conditions, different values for k are given in the literature and in general, it is indicated in between 300 and 500 W/s.m^3 (Innova, I,A, vd., 2005), (Hagerman G., and Bedard R., 2003). In this study, coefficient k is selected as 420 W/s.m^3 (Hagerman G., and Bedard R., 2003).

2.2.1. Duration Curves of Wave and Wave Power

The duration curve represents the occurrence of the parameter (wave height, wave period, wave energy or wave power). It can also be called occurrence curve or availability curve. From these curves, for various percentages of the total storm duration, P, Hs and T's values can be determined. Also, in the analysis, the shapes of these curves can provide important information about the available wave energy for the selected coast.

By utilizing existing wind data, depending on geographical location of station, in the direction of energy thought to produce, by using calculated average wind speed of storm which is above the selected wind speed u_0, characteristics (Hs, Tm) of the waves of this storm and power (P, W/m) per unit length can be calculated.

By analyzing wave characteristics obtained for each storm and power values, for those coast, Hs, T, P duration curves can be obtained. For example, for storm, P values obtained (P1≥P2≥P3≥.....≥Pi≥........≥Pm) are ranked from highest to lowest order and using with corresponding value for each storm, the percentage of time P values equal or greater can be calculated. For this purpose, the percentage of time (exceedance probability, A (P_i)) is determined as a percentage of the total storm duration (tt_m). As $A(P_i)=tt_i/tt_m$, $tt_i=\sum_{k=1}^{i} t_k$ and $tt_m=\sum_{k=1}^{m} t_m$. "t" is the duration of each storm (time) and "m" is the total number of storms. Thus, the obtained percentages of time (exceedance probability, A (P_i)) in horizontal axis and P (W/m) values corresponding to these percentages in the vertical axis would be pointed, power duration curve is obtained. Similarly, for Hs and T, the duration curve can be obtained. From these curves, for various percentages of the total storm duration, P, Hs and T's values can be determined. Also, in the analysis of examined size, the shapes of the curves are provided important information for those coasts. Furthermore, the directions of the storms can be determined as the average. According to type of plant to produce energy, this issue is important. In this way, by classifying the storms for different directions, duration curves described above can be obtained for different directions.

2.3. LITERATURE SURVEY

The study "Özhan, E. and Abdalla, S.: "Turkish Coast Wind and Deep Water Wave Atlas" 1999" is an atlas of Wind and wave climate prepared for Turkey and comprise wind and wave climate of Black Sea along Turkish coast. Principle elements for wind and wave climate are given in 30 kilometer intervals for Black Sea, Aegean Sea, and Mediterranean and in 10 kilometer intervals for Marmara Sea. The following elements of climate were given for every location for surface wind speeds and significant wave heights; yearly and seasonal wind and wave roses, monthly means and extreme values, extreme value statistics and also significant wave height vs. mean wave period relations. In this work (Özhan, 1999) meteorological and wave models were prepared and used in addition to existing models. The meteorological and wave models uses wind fields as input, and wind fields were obtained from ECMWF (European Centre for Medium Range Weather Forecast) and Synoptic Maps. The atlas used continuous data with 3 hours sampling duration for an 8 years span for the long-term statistics. For extreme value statistics, 20 years' (1976-1995) yearly maximums of wind speed and significant wave height were used for Black Sea.

In the TU-WAVES Project, the wave climate has been studied in four regions in TURKEY;

* Black Sea Coastal sites,

* Marmara Sea Coastal sites,

* Aegean Sea Coastal sites,

* Mediterranean Sea Coastal sites.

At the end of this project, the team constructed a “Wind and Wave Atlas for the Black Sea and the other Turkish Coasts” with detailed statistical information on wind and wave climate in it. (Özhan, E., Abdalla S., 2002)

The book “Ocean Wave Energy” (Cruz, J., 2007), compiles a number of contributions prepared with the aim of providing the reader with an updated and global view on ocean wave energy conversion. Given the topics covered and the link between of all them, it can be considered one of the first textbooks (or handbooks) related to this field. The authors are recognized individuals within the wave energy community with different backgrounds, and their contributions attempt to deliver an overall perspective of the state of the art of different technologies. The book does not intend to specify a specific technology; the market will be responsible for that. The main motivation here is to provide, to a wide engineering audience, a first contact with the current status of wave energy conversion technologies, which is hoped to affect and inspire the next generation of engineers and scientists.

The assembly of the experiences from a panel who has knowledge about the design and operation of such machines enhances the practical nature of the textbook, filling a gap in the available literature.

The book “Wave Energy Conversion” (Bhattacharyya, R., McCormick, M.E., 2003), explores the potential of the ocean’s energy from waves.

In METU, Civil Engineering Department Coastal and Ocean Engineering Division, Five thesis have been completed by Berkun (2006), Çaban (2007), Derebay (2007), Aldoğan (2008) and Kışlakçı (2008) on the analysis of ECMWF data for some selected coastal regions of Turkey.

The paper “Wave Energy and Technical Potential of Turkey” (Sağlam M., Sulukan E., Uyar T.S., 2010), presents author’s assessment on whether it is feasible to integrate the wave energy systems into the current Turkish Energy Program. The data required for calculating the approximate wave energy densities at many sites along the Turkish coasts have been derived from "Wind and Deep Water Wave Atlas of the Turkish Coast", MEDCOAST Publications, have been used in a wave energy project analysis, which has been conducted by using RETScreen® International, "Small Hydro" in order to find out the cost effectiveness of a wave power converter system to harness the sea power from Turkish waters having a mild climate.

In the paper "Wave Energy and Technical Potential of Turkey" (Sağlam M., Sulukan E., Uyar T.S., 2010), authors consider a reservoir type offshore converter with the aim of comparing the previous studies made in seas having similar climates. From this point, the low energy flux of 6.6 kW/m of Kalkan wave climate has been scaled according to the parameters of Wave Dragon test area. With the average wave height of 1.21 m and a wave reservoir of 1375 m3 of water and up to 6.09 s of wave period, if it is assumed it is all available power, one system can harness about 9.368 GWh annually from the sea waves. The total initial costs have been estimated by converting from the small hydro such as subtracting the land costs and adding the carrying costs. The total initial costs are the sum of the estimated feasibility study, development, engineering, energy equipment, balance of plant and miscellaneous costs and are the inputs of this calculation (Sağlam M., Sulukan E., Uyar T.S., 2010).

"Results of the paper Wave Energy and Technical Potential of Turkey

Initial Cost: 4 426 735 $

Feasibility study: 234 500 $ Development : 313 000 $

Engineering : 277 500 $ Miscellaneous : 1 052 119 $

Annual Cost : 406 659 $

Maintenance Costs : 406 659 $

Periodical Costs : 1 500 000 $

Other Values:

Electricity production cost : 0.0679 $/kWh

To meet the cost of investment : 8.1 years

Distributed renewable energy : 9.368 MWh/years" (Sağlam M., Sulukan E., Uyar T.S., 2010).

In the conclusion of this paper, it is stated that the regions in the west of the Black Sea in the north of Istanbul Straits and off the southwestern and western coasts of Aegean Region have been suggested as the best sites to harness the wave energy.

CHAPTER 3

WAVE ENERGY CONVERSION AND TECHNOLOGIES

3.1. WAVE ENERGY TECHNOLOGIES

The technology which will exploit Wave Energy has now reached the initial phase of demonstration after 30 years of Research and Development. However, contrarily to wind energy, there still exist a large amount of concepts competing in wave energy. Wave technologies have been designed to be installed in nearshore, offshore, and far offshore locations. Offshore systems are located in deep water of more than 40 meters.

While all wave energy technologies are purposed to be installed at or near the water's surface, they differ in their orientation to the waves with which they are interacting and in the manner in which they convert the energy of the waves into other energy forms, usually electricity. The following wave technologies have been the target of recent development.

3.1.1. Tests on Sea of Pilot Plants and Prototypes

Different wave energy exploitation systems have been tested at sea, both pilot plants and prototypes: Wave Star (Wave Star Energy/Denmark), WaveRoller (AW-Energy Oy/Finland), FO3 (Fobox/ Norway), WaveBob (Wavebob Ltd/Ireland), OEbuoy (Ocean Energy Ltd/Ireland), AquaBuOY (Finavera Renewables/Canada), Parabolic OWC Plant with Deniss-Auld turbine (Oceanlinx/Australia), Powerbuoy (Ocean Power Technologies/ USA), Pelamis (Ocean Power Delivery Ltd/United Kingdom), Wave Dragon (Wave Dragon ApS/Denmark), AWS (Teamwork Technology, 2004/ The Netherlands), OWC LIMPET Plant (Wavegen, United Kingdom) and OWC Pico Plant (WavEC, Portugal).

Other systems exist on a less developed phase, however they may be tested at sea in the coming years.

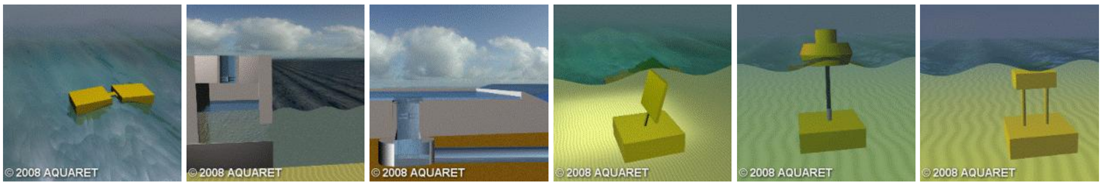
3.1.2. Pre-Commercial State of Technology

"Some of these companies have already plans to install the next units in other countries. Two projects for which commercial contract are executed are at their final stage to start deploying the wave energy units. One project has been already installed at the end of 2008 namely three Pelamis units of the Scottish company Pelamis Wave Power (former OPD) at the western coast of Portugal (total power of 2.25 MW) based on a contract with the Portuguese ENERSIS company. Another project promoted by Ente Vasco de la Energía (EVE) has the intention to integrate 16 OWC chambers of the Scottish company Wavegen into the new breakwater of Mutriky at the Bask Region (total power of 296 kW). The third project is the installation of 10 devices of the American Powerbuoy in Cantábria, Spain (total power of 1.4 MW), a contract with the multination Iberdrola Renewables." (Wavec.org, 2010)

Nowadays we witness a fast growing of industry interested in wave energy with new participants in this sector and some of them are multinational companies.

On the other hand new mechanisms have been established in the last years in several countries. For the investors it is important to acknowledge the technology, the several teams responsible for the development of the technology, expected capital costs for the first farm, i.e. and to obtain a global vision of the sector in order to make decisions for a possible involvement.

3.2. Wave Technology Types



Attenuator	Oscillating Water Column (OWC)	Overtopping Device	Oscillating Wave Surge Converters (OWSC)	(Axisymmetrical) Point Absorber	Submerged Pressure Differential

Figure 3.2.1 Wave technology types

Attenuators are long multisegment floating structures oriented parallel to the direction of the waves. The differing heights of waves along the length of the device causes flexing where the segments connect, and this flexing is connected to hydraulic pumps or other converters.

Terminator devices extend perpendicular to the direction of wave movement and capture or reflect the power of the wave. These devices are typically onshore or nearshore; however, floating versions have been designed for offshore applications. The oscillating water column is a form of terminator in which water enters through a subsurface opening into a chamber with air trapped above it. The wave action causes the captured water column to move up and down like a piston to force the air though an opening connected to a turbine.

Overtopping devices have reservoirs and they are filled by incoming waves to levels above the average surrounding ocean. The water is then released, and gravity causes it to fall back toward the ocean surface. The energy of the falling water is used to turn hydro turbines. Vessels which are especially for designed seagoing travels can also capture the energy of offshore waves. These floating platforms create electricity by funneling waves through internal turbines and then back into the sea.

A point absorber is a floating structure having components and these components move relative to each other due to wave action (e.g., a floating buoy inside a fixed cylinder). The relative motion is used to drive electromechanical or hydraulic energy converters.

Animations developed for AquaRET project, a network of 7 European partners and coordinated by AquaTT (Ireland).

Table 3.2.1 List of current main Wave Energy Devices

Device Name	Main promotor	Device type	Country of origin
Aegir Dynamo™	Ocean Navitas Ltd	Near- & Offshore	United Kingdom
AquaBuOY	Aquaenergy group	Offshore	Canada (originally Ireland; Aquaenergy group: USA; technologies developed in Sweden)
AWS (Archimedes Wave Swing)	AWS Ocean Energy Ltd	Offshore submerged	The Netherlands
BioWAVE™	BioPower Systems Pty. Ltd	Nearshore	Australia
Brandl Generator	Brandl Motor	Near- & Offshore	Germany
CETO	Seapower Pacific Pty Ltd	Nearshore	Australia
C-Wave	C-Wave Limited	Near-& Offshore	United Kingdom
Direct Drive Permanent Magnet Linear Generator Buoy / Permanent Magnet Rack and Pinion Generator Buoy / Contact-less Force Transmission Generator Buoy	Columbia Power Technologies	Near- & Offshore	USA
EGWAP (Electricity Generated Wave Pipe)	Able Technologies	Nearshore	USA

Table 3.2.1 Cont'd

FO3	Fobox AS	Offshore	Norway
FWEPS (Float Wave Electric Power Station)	Applied Technologies Company, Ltd	Offshore	Russia
FWPV (Floating Wave Power Vessel)	Sea Power International AB	Near- & Offshore	Sweden
Generator utilizing patented electroactive polymer artificial muscle (EPAM™) technology	SRI International	Offshore	USA
Langlee System	Langlee Wave Power	Nearshore	Norway
Lever Operated Pivoting Float	Swell Fuel	Offshore	USA
Linear generator (Islandsberg project)	Seabased AB	Near- & Offshore	Sweden
Manchester Bobber	University of Manchester Intellectual Property Ltd (UMIP)	Offshore	United Kingdom
Martifer device	Martifer	Offshore	Portugal
McCabe Wave Pump (MWP)	Hydam Technology Ltd	Near- & Offshore	Ireland
MHD Neptune	Neptune Systems	Offshore submerged	The Netherlands
MHD Wave Energy Conversion (MWEC)	Sara Ltd	Near- & Offshore	USA
Multi Absorbing Wave Energy Converter (MAWEC)	Leancon Wave Energy	Multi Absorbing Wave Energy Converter (MAWEC) / Near- & Offshore	Denmark
Multi Resonant Chamber (MRC) wave energy converter - MRC 1000	ORECon Ltd	Near- & Offshore	United Kingdom
Ocean Energy Buoy (OE Buoy)	Ocean Energy Ldt.	Near- & Offshore	Ireland
OceanStar ocean power system	Bourne Energy	Unclear	USA
OMI Combined Energy System (OMI CES)	Ocean Motion International LLC	Near- & Offshore	USA
OWEC (Ocean Wave Energy Converter)	Ocean Wave Energy Company	Offshore	USA

Table 3.2.1 Cont'd

OWEL Wave Energy Converter (the Grampus)	Offshore Wave Energy Limited	Near- & Offshore	United Kingdom
Oyster	Aquamarine Power Ltd	Nearshore submerged but surface-piercing	United Kingdom
PelagicPower	Pelagic Power AS	Nearshore	Norway
Pelamis	Pelamis Wave Power	Offshore	United Kingdom
Pico plant	Wave Energy Centre (WaVEC)	Onshore	Portugal
Poseidon's Organ	Floating Power Plant ApS (F.P.P.)	Near- & Offshore	Denmark
PowerBuoyTM	Ocean Power Technologies Inc. (OPT)	Offshore	USA
PS FROG	Lancaster University		
S.D.E.	SDE Energy Ltd.	Onshore; structure-mounted	Israel
Salter's Duck	University of Edinburgh		
SEADOG	Independent Natural Resources, Inc (INRI)	Nearshore	USA
Seaheart	Oceanic Power		Spain
Seawave Slot-Cone Generator (SSG)	WAVEenergy AS	Onshore	Norway
Shoreline OWC	Wavegen (wholly owned subsidiary of Voith Siemens Hydro Power Generation)	Shoreline OWC	United Kingdom
SPERBOY	Embley Energy Limited	Near- & Offshore	United Kingdom
SurfPower	Seawood Designs Inc	Near- & Offshore	Canada
SyncWave	SyncWave™ Energy Inc.	Near- & Offshore	Canada
Système Autonome Electrique de Récupération de l'Energie des Vagues (SEAREV)	SeaRev (Consortium being built, starting from Ecole Centrale de Nantes)	Offshore	France
TETRON	Joules Energy Efficiency	Offshore; details unclear	Ireland

Table 3.2.1 Cont'd

	Services Ltd		
The Linear Generator	Trident Energy Limited	Near- & Offshore; ideally structure-mounted	United Kingdom
Wave Catcher	Offshore Islands Limited	Offshore structure-mounted	USA
Wave Dragon	Wave Dragon Aps	Near- & Offshore	Denmark
Wave Rider	SeaVolt Ltd	Near- & Offshore	USA
Wave Rotor (Darrieus Wave Rotor)	Ecofys BV	Near- & Offshore; ideally structure-mounted	The Netherlands
Wave Star	Wave Star Energy ApS	Near- & Offshore	Denmark
Waveberg	Waveberg™ Development Limited	Nearshore	USA
WaveBlanket	Wind Waves And Sun	Near- & Offshore	USA
Wavebob	Wavebob Ltd.	Offshore	Ireland
WaveEnergySystem	Oceanlinx Ltd.	Onshore & Nearshore	Australia
WaveMaster	Ocean WaveMaster Limited	Near- & Offshore	United Kingdom
Wavemill	Wavemill Energy Corporation	Onshore	Canada
WavePlane	WavePlane Production A/S – (now) WPP A/S	Near- & Offshore	Denmark
WaveRoller	AW Energy Oy	Nearshore submerged	Finland
WECA – PDP500	DAEDALUS Informatics Ltd	Near- & Offshore	Greece
WET EnGen™	Wave Energy Technologies Inc.	Near- & Offshore	Canada
WET-NZ device	WET-NZ	Near- & Offshore	New Zealand

3.2.1. Oscillating Water Column

An oscillating water column (OWC) consists of a partially submerged, hollow structure and it is opened to the sea below the water line (Figure 3.2.1.1). This structure encloses a column of air on top of a column of water. As waves impinge upon the device, they will cause the water column to rise and fall, which alternatively compresses and depressurizes the air column. If this trapped air is allowed to flow to and from the atmosphere through a turbine, energy can be extracted from the system and used to generate electricity. Energy is usually extracted from the reversing air flow by Wells' turbines having the property of rotating in the same direction regardless of the direction to the airflow.

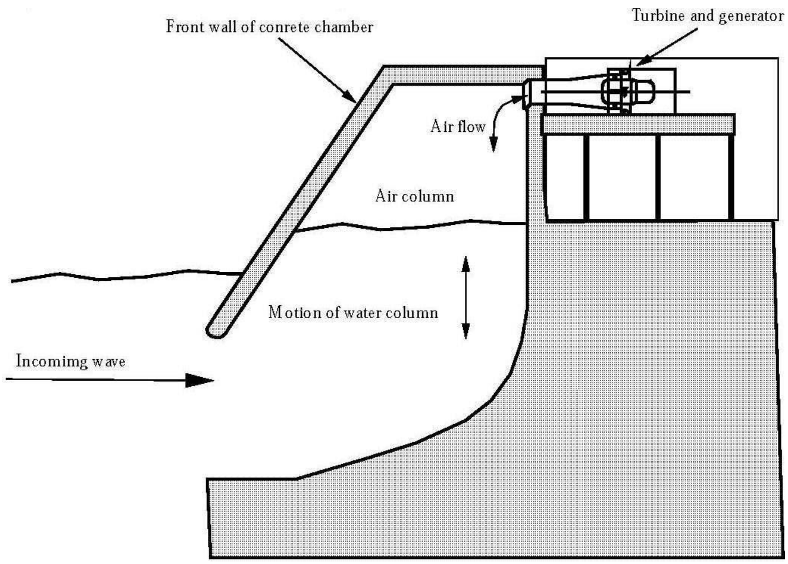


Figure 3.2.1.1 Outline of an Oscillating Water Column (OWC)

Wave tank tests have shown that the inclined slope increases the capture efficiency, whilst the dog leg on the front wall inhibits outflow and so helps to prevent exposure of the lower lip to air.

There are turbines placed behind the OWC chambers and the associated electrical equipment is situated behind the turbines and so it is protected from sea water splashes by a rock bund. Each set of turbines is protected by a sluice gate, which can prevent the turbines being subjected to green water in stormy seas. The turbines also have flywheels to smooth out energy supply, as well as blow out valves.

The air chamber within the OWC housing must be planned with the wave period, significant wave height and wave length characteristics of the local sea climate in mind. If the housing does not have correct size, waves can resonate within the air chamber. This resonating effect causes a net zero passage of air through the turbine. Ideally, the air chamber dimensions will be designed to maximize energy capture in the local wave climate while research has shown that the generator design (generator size and generator coefficient) is almost completely independent of wave climate such that only areas of extreme wave energy benefit from larger generators and only marginally so.

In addition to sizing the air chamber related with the wave climate, the air chamber must also be suitable to air flow through the turbine. This is best achieved with a funnel shaped design such that the chamber narrows from the water surface level to the turbine. This will concentrate the air flow through the turbine.

OWC devices are placed on the shoreline or near the shore. The shoreline devices are situated to places where the waves break on the beach and are known to be noisy. The near shore devices are fixed to the ocean bottom in such that same manner as offshore wind turbines or slack moored so as to respond to changes in mean water level i.e. tides. The housing is placed just above the water surface.

Near shore and shoreline placements have their advantages and dezadvantages. First concern is that the wave energy is greater offshore than at the shoreline, in this way more energy is available for capture in a near shore OWC. Wave energy concentration near shore through natural phenomena such as refraction or reflection can compensate for some or all of this energy dissipation, but there are few areas where this occurs. The con to being offshore is that installation and maintenance costs increase. Both the near shore and shoreline OWCs are seamy as they are visible over the ocean surface, therefore both will experience public resistance to their installation. Then again, the shoreline device will interfere with beachgoers more directly and will therefore be met with the most public resistance. If public support and and decent available energy are provided, one may conclude that the near shore OWC is the better device.

The changing mean ocean surface level accompanying tides may pose problems for a fixedly moored OWC. Nonetheless, a fixedly moored device maintains its position better than a slack moored device so as to provide more resistance to incoming waves and therefore produce more energy. Another tradeoff between the fixedly and slack moored OWC is that while the fixedly moored OWC collects more energy, the slack moored OWC provides some flexibility in rough seas which might damage a fixedly moored device. Also, the installation costs of a slack moored device are less than a fixedly moored device because a rigid foundation does not need to be constructed.

3.2.2. Overtopping Wave Energy Converter

The overtopping wave energy converter functions similar as a hydroelectric dam works. Waves roll into a collector which funnels the water into a hydro turbine as seen in Figure 3.2.2.1. The turbines are coupled to generators which produce electricity. After the waves flow through the turbines, they continue through the ocean. A mesh grid is used to extract trash and marine debris before the waves pour into the turbine. The overtopping WEC can be placed on the shoreline or near shore but it is more commonly placed at a near shore location. As with the OWC, the overtopping WEC may be slack moored or fixedly moored to the ocean bottom, and the issues associated with these mooring options are very similar with the OWC. It should be considered that overtopping wave energy converters are not as common as OWCs.

"The offshore devices include the Wave Dragon™ (Wave Dragon 2005), whose design includes wave reflectors that concentrate the waves toward it and thus raises the effective wave height. Wave Dragon development includes a 7-MW demonstration project off the coast of Wales and a precommercial prototype project performing long-term and real sea tests on hydraulic behavior, turbine strategy, and power production to the grid in Denmark. The Wave Dragon design has been scaled to 11 MW, but larger systems are feasible since the overtopping devices do not need to be in resonance with the waves as is the case for point absorbing devices." (Renewable Energy and Alternate use Program, 2006)

The WavePlane™ (WavePlane Production 2009) overtopping device has a smaller reservoir. The waves are fed directly into a chamber that flows the water to a turbine or other conversion device.

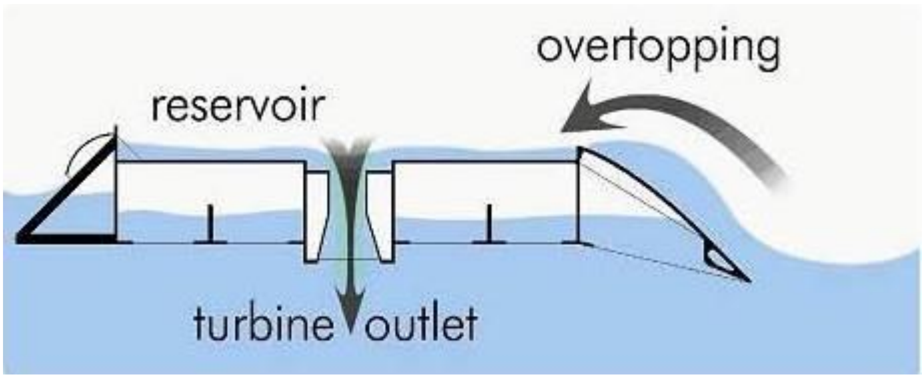


Figure 3.2.2.1 Overtopping WEC

3.2.3. Point Absorber

Point absorbers have a small horizontal dimension compared with the vertical dimension and utilize the rise and fall of the wave height at a single point for WEC.

3.2.3.1. Buoy Type

The buoy type wave energy converter is further known as a "point absorber" as it harvests energy from all directions at one point in the ocean. These devices are installed at or near the ocean surface away from the shoreline. They may occupy a variety of ocean depths ranging from shallow to very deep water depending on the WEC design and the type of mooring utilized. There are several types of point absorbers with the most common being the hollow tube type and the float type, although there are some further forms.

3.2.3.2. Tube Type

This type of WEC consists of a vertically submerged, neutrally buoyant (relative to its position just below the mean ocean surface level) hollow tube. The tube allows water to pass through it, driving either a piston or a hydro turbine. The piston power take-off method is appropriate for this application because the rate of water flowing through the tube is not rapid. There are two tube arrangements in which one end may be closed and the other open or they are commonly open. With both ends closed, no water flow is possible and the device becomes the float type.

The hollow tube type WEC works on the concept that waves cause pressure differentiations at the surface of the ocean. The long, cylindrical tube experiences a pressure difference between its top and bottom which causes water to flow into and out of the open end(s) of the tube. When a wave crest passes above a tube, water will flow down the tube, and when a wave trough passes above the tube, water will flow up the tube. This flow will push a piston which may either power a drive belt, a hydraulic system, or a linear generator. In the case of the drive belt, the piston is connected to a belt which turns at least one gear. The gear may be connected to a gear box to increase the speed of rotation of the shaft which turns the rotor of an electric generator. With a hydraulic system, the piston pumps hydraulic fluid through a hydraulic motor which is coupled to an electric generator. The hydraulic system is preferred over the drive belt due to maintenance issues. Moreover, multiple WECs may be connected to one electric generator through a hydraulic system. When the piston is connected to a linear generator, it bypasses the hydraulics process and a drive belt's gear box.

Power take-off with this method is a consequence of the up and down movement of the linear generator's translator (in the case of linear generators, the rotor is referred to as a translator), which is directly coupled to the piston.

3.2.3.3. Float Type

As referred above, the float-type WEC is some sort of sealed tube or other type of cavity. It will most likely be filled with air or water or a mix of the two. In order to make the sealed cavity positively buoyant so that it floats on top of the ocean surface, it is required to contain some air. If the cavity is to be just below the surface, it is required to contain water at the pressure of the depth it is placed thus making it neutrally buoyant with respect to its depth. The behavior of the float may be altered by changing the pressure within the cavity.

The float type WEC in Figure 3.2.3.3.1 functions with several different power take-off methods. The floater will move in different directions, relative to wave motion which depends on its location and which is above or below the water. If the floater is on the surface, it will move up and down with the wave. This results in control problems because the wave height may exceed the WEC's stroke length (how far up and down the floater is permitted to move by design). The worst possible outcome could be damage which might be occurred to the WEC during a storm when wave heights are extreme. The solution to this problem of limited stroke length is to place the tube under water as referred above.

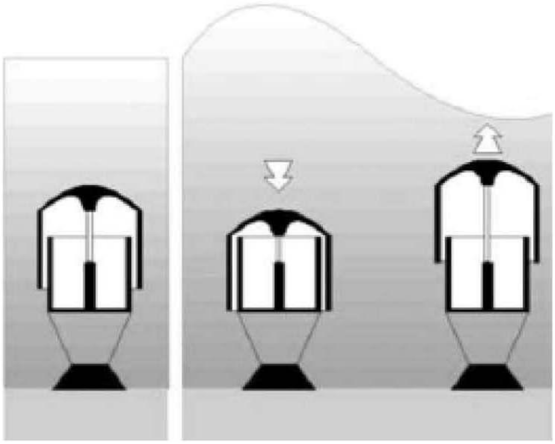


Figure 3.2.3.3.1 Below Surface Point Absorber

Figure 3.2.3.3.1 shows the motion of a below surface point absorber relative to wave motion. When a wave crest passes overhead, the extra water mass will push the float down, and when a wave trough passes, the absence of water mass will pull the float up because it becomes lighter than the water overhead. A control system can pump water and/or air into the float to vary buoyancy and thus restrain the float if large wave heights are experienced. Furthermore, in case a rough storm exists, the entire system will be underwater and out of harm's way.

As with the tube type point absorber, the up and down motion of the floater relative to some stationary foundation will operate on a piston. This piston can be connected to a generator using any of the methods which was described in previous sections. With a float instead of a tube, other conversion mechanisms may be used.

Rather than a piston, the float may operate on what is called a "hose pump" as seen in the Figure 3.2.3.3.2. It is similar to a hydraulic system in that the hose pressurizes seawater driving a generator. The method of pressurization creates the difference with a horse pump system. A long flexible hose is connected to a float and a stationary reaction plate. The float moves relative to the reaction plate, stretching and constricting the hose. When the hose is stretched, it will pull in seawater, and when the hose is constricted, pressurized water will be pushed out to a generator.

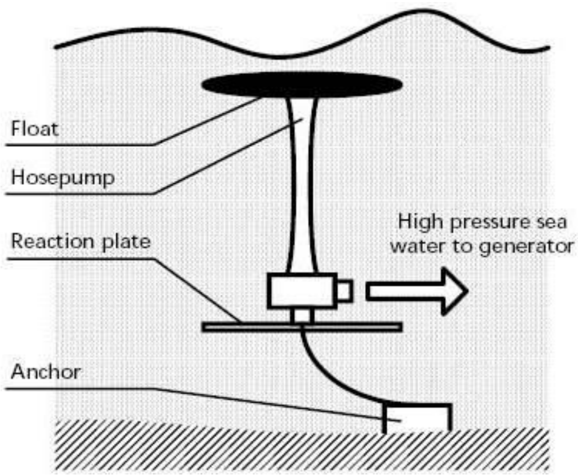


Figure 3.2.3.3.2 Hose Pump

3.2.4. Attenuators

Attenuators are long multi - segment floating structures oriented parallel to the direction of the wave travel. The varying heights of waves along the length of the device result flexing where the segments connect, and this flexing is connected to hydraulic pumps or other converters. The attenuators with the most advanced development are the McCabe wave pump and the Pelamis by Ocean Power Delivery, Ltd. (2006).

The McCabe wave pump (Figure 3.2.4.1) has three pontoons linearly hinged together and pointed parallel to the wave direction. The center pontoon is connected to a submerged damper plate causing it to remain still relative to fore and aft pontoons.

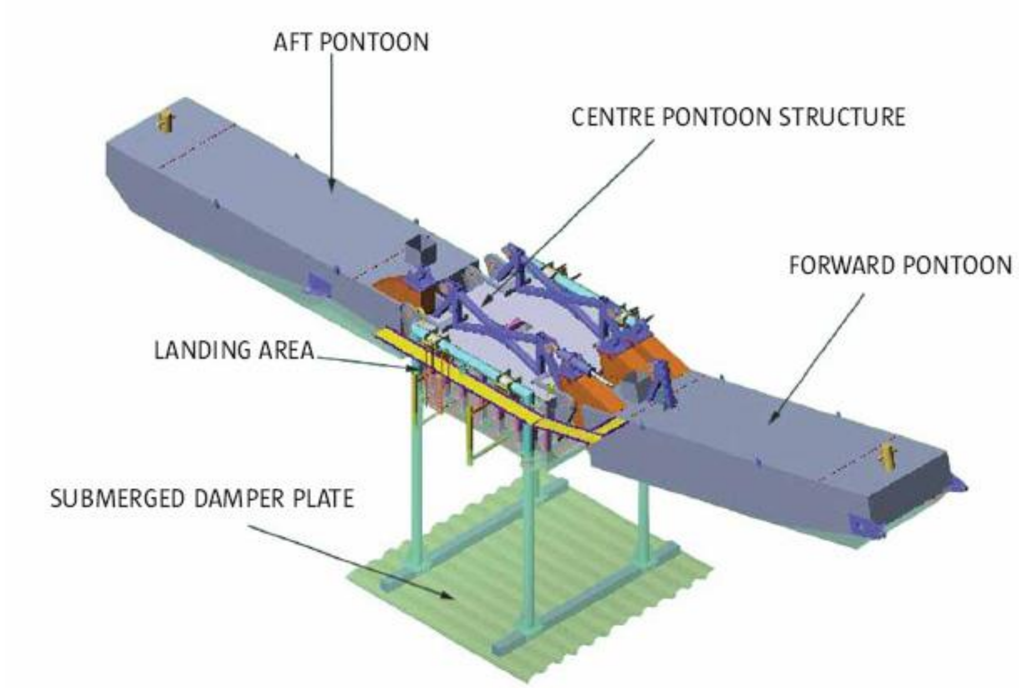


Figure 3.2.4.1 McCabe Wave Pump

A corresponding concept is used by the Pelamis (designed by Ocean Power Delivery Ltd. [2006]), which has four 30-m long by 3.5-m diameter floating cylindrical pontoons connected by three hinged joints (Figure 2.6).

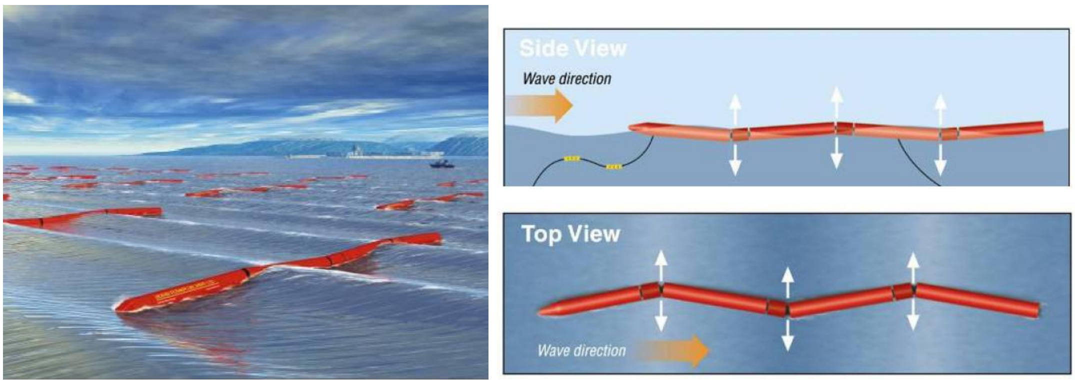


Figure 3.2.4.2 Pelamis Wave Energy Converter (Source: Ocean Power Delivery Ltd. 2006)

CHAPTER 4

WAVE DATA, WAVE ENERGY AND DURATION CURVES OF SELECTED COASTAL REGIONS IN TURKEY

In this chapter information about the data that is used in the analyses are given and analyses steps are explained. In section 4.1 the details of data source and download procedure are explained. In section 4.2, information about the data gathered from ECMWF database and the rearrangement of the data are discussed. In section 4.3 the analysis procedures and presentation steps are given. Finally, in section 4.4 results of the analysis for each location are given. As described in detail in the Chapter 4.2.1, there are 5 regions along Turkish coasts. Firstly a brief description of region is given for each region and following this description, the analysis results which are based on graphics provided, are discussed.

The results of each region are given in a sub-chapter Geographical coordinates of the locations and they are also indicated in Chapter 4.2.1. In addition, the location is approximately shown by a ring on the Black Sea and the Mediterranean Sea map given with the graphs. Inside the sub-chapters, the graphics provided from analysis results are given in the following order; the joint distribution of significant height of swell wave and mean period, the joint distribution of significant height of wind wave and mean period, duration curve for significant height of swell wave and mean period, duration curve for significant height of wind wave and mean period, duration curve for the swell wave power, duration curve for the wind wave power. Detailed descriptions of generation of these graphs are explained in section 4.3 Data Analysis and Presentation.

4.1 DATA SOURCE AND OBTAINING DATA

4.1.1 The Data Source

The data source for this study is the European Centre for Medium-Range Weather Forecasts (ECMWF in short). ECMWF, the Centre is an independent international organization established in 1975 and is currently supported by 31 States. [ECMWF, 2008] The organization has co-operation agreements with several other international organizations. Turkey, being a member of this organization, does assist ECMWF and has access to ECMWF data by the Turkish State Meteorological Service. The ECMWF runs atmosphere global forecasts, ocean wave forecasts and seasonal forecast, stores the data obtained from observations, analyses, forecasts and research experiments, provides an ensemble prediction system and carries a range of research programs, which are available to its member states and co-operatives. The ECMWF Operational data, used in this study have been obtained from the ECMWF Data Server by special permission from General Directorate of Turkish State Meteorological Service and ECMWF.

The data archiving services of ECMWF is used to download the data. In the archive service, there are three sets of data available, which are Operational Archive, ERA-15 and ERA-40. ERA-15 and ERA-40 are archives of re-analysis of global and short range forecasts of relevant weather parameters for 15 and 40 years duration respectively. The operational archive of ECMWF is used in this study, which in turn is divided into six classes of data sets. The data sets; atmospheric and wave models are used to gather data. Atmospheric model is the richest data set from the space resolution and time duration point of view. The atmospheric model supports thirteen separate data sets. From these data sets, surface analysis data set is used and wind data are obtained from this set. In a similar manner, the wave model is divided into four data sets, namely sets of Global and Mediterranean wave analysis and forecasts. For the purpose of this study, the Global wave analysis set is selected. The parameters to be ordered are selected from parameter list of the data sets. Two parameters from surface analysis data set and seven parameters from Global wave analysis data set are selected and these parameters are given as a list in Section 3.2.1.

4.1.2 Obtaining Data

In this section, data obtaining procedure is explained in brief. Ordering of data from ECMWF can be made in different ways. Ordering data online is an easy way for selective parameters. Mainly Meteorological Archival and Retrieval System (MARS) is used for downloading bulk data with its own script language. However, for small amount of data, data can be ordered directly from data services. In this study, data is directly ordered from the Mediterranean Wave model of Operational archive. In this way, the interactive web environment directs user through the ordering process. After the selection of the data set, pages for selection of the data time range, available daily times, parameters and finally the area and grid spacing selection pages are opened. The request is evaluated and prepared by ECMWF for download. Afterwards the requested data is downloaded in GRIB file format. A single file for every month is downloaded for wind and wave data.

4.2 INFORMATION ON DATA AND DATA RE-ARRANGEMENT

4.2.1 Information on Obtained Data

The data to be used in the analysis are ordered from two data sets. Wind data is ordered from surface analysis data set and wave data is ordered from global wave analysis data set. The parameters ordered form the wind data set of the atmospheric model is listed in the following;

- 10U - 10 meter U wind component (m/s)
- 10V - 10 meter V wind component (m/s)

The parameters ordered from the Global wave data set of Analysis wave model is listed in the following;

- TIME – Observation Time (Year, Month, Day, Hour)
- WIND - 10 meter wind speed (m/s)
- MDPS - Mean direction of primary swell (degrees)
- MDWW - Mean direction of wind wave (degrees)
- MPPS - Mean period of primary swell (s)
- MPWW - Mean period of wind wave (s)
- SHPS - Significant height of primary swell (m)
- SHWW - Significant height of wind wave (m)

These parameters can also be attained from the parameter catalogue of ECMWF. The 10-meter wind components, which are downloaded from wind data set, refer to wind speeds 10 meter above surface given in meters/seconds units. They are abbreviated as 10U and 10V. The abbreviation U specifies that the component is along the latitude and similarly V specifies that the component be along the longitude. The positive direction for the U component is towards east and for the V component, it is towards north. The resolution of the wind components are selected as 0.50°x0.50°.

In the wave data set, four parameters are ordered with a resolution of 0.50°x0.50°. The wind-abbreviated parameter gives only speed at 10 meters above water surface in meters/seconds units.

Parameters defined as MDPS, MPPS and SHPS are complementary parameters in defining swell waves. MDPS is an abbreviation for Mean Direction of Primary Swell, given in degrees measured clockwise starting from north. MDPS indicates the direction of incoming swells. MPPS is an abbreviation for Mean Period of Primary swell, given in seconds. Significant Height of Primary Swell is abbreviated as SHPS and is given in meters units. Other parameters defined as MDWW, MPWW and SHWW are complementary parameters in defining wind waves. MDWW is an abbreviation for Mean Direction of Wind Wave, given in degrees measured clockwise starting from north. MDWW indicates the direction of incoming waves. MPWW is an abbreviation for Mean Period of Wind Wave, given in seconds. Significant Height of Wind Wave is abbreviated as SHWW and is given in meters units. Due to recent changes in ECMWF data service, these parameters are being served as regard to total wind replacing primary wind applicable by November 2006.

For the purpose of this study, the study area is selected as 10 E to 43 E and 30 N to 46 N which is enough to cover whole Mediterranean region. The spatial resolution is selected as 0.50°x0.50° for all parameters which are stated above. This way a 65x33 matrix is formed over where every cell indicates a location. And the naming of locations was made due to this matrix, e.g. 04-03 refers to 4th column, 3rd row of this matrix counted from left to right and bottom to top. The wind and wave data is obtained for a 156 months period starting from 01.01.1996 to 31.12.2008 with 6 hour data record interval covering whole Mediterranean basin. Totally 194150 data records for all locations inside the matrix are acquired, providing data elements which are the wind components 10 meter above sea level, the mean direction of primary swell, the mean direction of wind wave, the mean period of primary swell, the mean period of wind wave, the significant height of primary swell and the significant height of wind wave.

Table 4.2.1.1 Location Indices

LOCATION INDEX	REGION NAME	LAT	LON
38x24 38x25 39x24 39x25	İĞNEADA	41,385 41,885 41,385 41,885	28,676 28,676 29,176 29,176
49x26 50x26 51x26	SİNOP	42,202 42,202 42,202	34,528 35,028 35,528
61x24 61x25 62x24 62x25 63x25	HOPA	41,215 41,715 41,215 41,715 41,715	40,161 40,161 40,661 40,661 41,161
44x13 44x14 45x13 46x13	ALANYA	35,93 36,43 35,93 35,93	31,775 31,775 32,275 32,775
50x13 50x14 51x13 51x14	KARATAŞ	35,968 36,468 35,968 36,468	34,80 34,80 35,30 35,30

4.2.2 The GRIB File Format

The source data are obtained in GRIB format as explained in Section 4.1.2. The GRIB is an abbreviation for “Gridded Binary”. The GRIB file format is a bit-oriented data exchange and storage format. In GRIB form the data is efficiently packed and compacted and this way storage and transmission of data is made efficiently. However GRIB files cannot be opened and/or viewed in conventional software before extraction. Special software is needed to unpack the GRIB files. Few programs exist for this purpose and unfortunately it is hard to find satisfactory documentation for any of them. In this study free software named WGRIB is used. But also the ECMWF serves another free software product, named GRIBEX for handling GRIB files which is available for UNIX systems [ECMWF, 2008]. WGRIB runs in DOS environment and is well established and usage is quite simple and straightforward once commands are understood. The program is available from National Oceanic & Atmospheric Administration (NOAA) of U.S. Department of Commerce [NOAA, 2006]. The decoding process is carried out by using WGRIB program and the decoded GRIB files are saved as text files. Every GRIB file contained data for a month period, and so text files for every month was produced for wind and wave data totaling in 166 separate text files. The usage of WGRIB and links to detailed help files are given in the appendix. Although the extracted text files can be viewed in conventional software at this level, they are still not meaningful. The data in text files had to be re-arranged for processing the data as described in the following section.

4.2.3 Re-arrangement of Data

In this section, the re-arrangement of text files obtained from the decoding of GRIB files is described. The text files are composed of one column data and header information included in GRIB files does not exist. Inside the text files, in the first row total row and column counts are given for the start of each day, i.e. the matrix dimensions. In the following rows all data, covering whole region is listed, where the region is the total of locations. The data is listed starting from the upper right corner of the matrix and flowing in left-to-right and top-to-bottom order. For every location there is a data group listed. That is, for wind data the wind parameters 10U and 10V is listed in an alternating order. In addition, for wave data the parameters wind, MDWW, MPWW and SHWW are listed in an alternating order. In the file, the parameter group is given for a date and time value for all locations following the flow direction, and then the date and time value is incremented and the data flow continues in this way. The text files are re-arranged by a user-friendly software called as Wind and Wave Interpreter and Analyzer – Simulation 2.1 (WWIA-SIM 2.2) written for especially re-arrangement of these files.

Briefly, WWIA-SIM 2.2 takes the text files as input and extracts the parameters, and stores the monthly values of the parameter in a matrix form covering whole area. In addition, the programs are made to extract data for a single location in a tabular format as a data file (*.txt), indicating date and time of measurement and parameters in the following columns. This text file forming the base for all analysis can be viewed in a spreadsheet. These files are named as location-data type e.g. 33-17-Wave.txt or 34-19-Wind.txt. After extraction of data values from both model results, WWIA-SIM 2.2 combines them hour by hour. If one of the model values is missing for that hour, software can either pass the hour or writes high values for the missing parts so that analyze routines simply denies such values. These combined files are later modified and necessary calculations made directly on them as needed.

4.3 DATA ANALYSIS AND PRESENTATION

In this section the analysis procedure and presentation steps are given. Before starting any analysis the data files that have been divided according to locations and obtained for every month of every year, are combined. Thus, one single data file for every location is produced. For each location one wave file and one wind file is prepared. For wind data, the wind vector that is given as U and V components are converted to polar coordinates. So wind speed and angle from North direction measured clockwise is computed along with the geographical bearing. Also for both wind and wave, data the year, month, day, and hour values of every measurement is extracted and placed on different columns merely for analysis purposes by the help of WWIA-SIM 2.2 (Aldoğan, 2008).

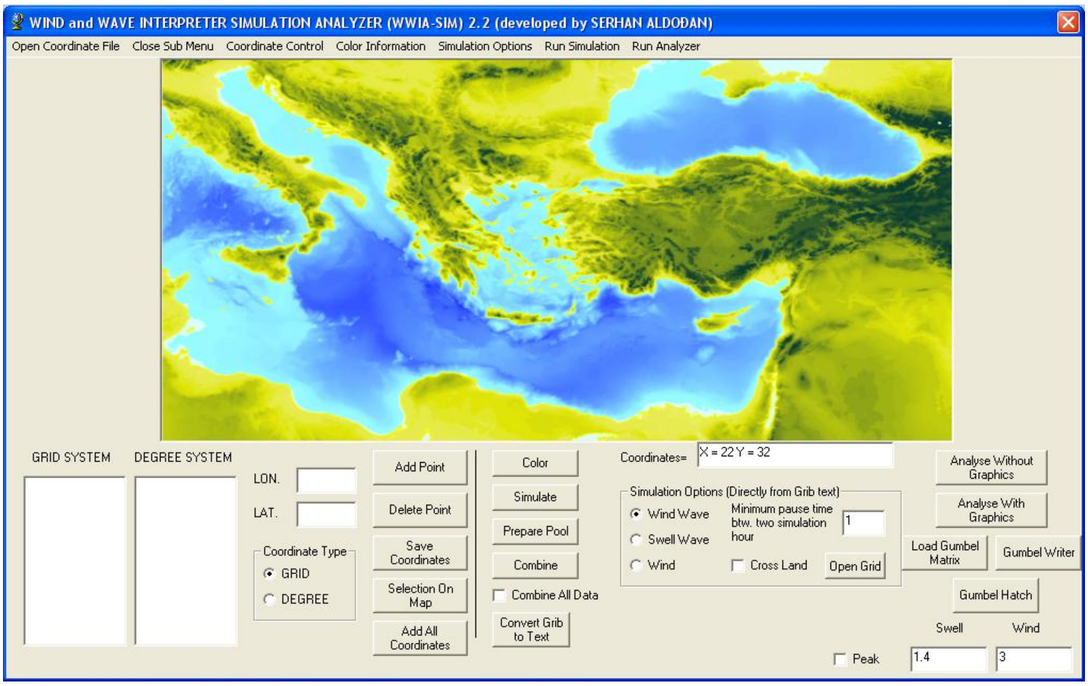


Figure 4.3.1 General View of the WWIA-SIM2.2 (Aldoğan, 2008)

4.3.1 H_s vs. T_m Relation Graphs

The graphs of significant wind wave height versus mean period of swell and wind waves, as will be shortly expressed as H_s vs. T_m relations thereafter, are the plot of every data point according to its significant height and mean period. The horizontal axis of the graph is mean period of waves (T_m) in meters and the vertical axis is significant wave height (H_s) in seconds. In the H_s vs. T_m relations, all data points are plotted. These graphs effectively represent the relation between H_s vs. T_m and the maxima. The H_s vs. T_m relations are given for different bearings and one relation covering all directions.

The axis maximum and minimum values are kept constant through the locations to make the comparisons easier.

4.4 REGION – İĞNEADA

In this region four different locations are selected for the statistical analysis and given in the following sections.

İğneada Region - Location 1 (GRID 38x24 ; 28.676°E - 41.385°N)

A point at the offshore location near İğneada is selected at the coordinates 28.676° E - 41.385° N (at 38x24 grid nodes). The point is approximately 76 km south-east of İğneada Cape and about 4.3 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.1. Several data points, exceeding 10 second periods and few data points exceeding 3.0 m of swell wave heights are observed with a maximum wave height of 3.58 m. Swell waves having more than 12 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.2. Throughout the observation period wind waves are observed to be less than 5.46 m at offshore İğneada. Maximum significant wave height is observed to be 5.46 meters. The corresponding wave period is 9.79 s.

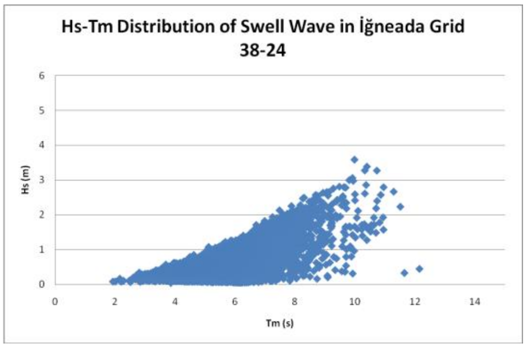


Figure 4.4.1 Relationship between Mean Period & Significant Height of Swell Wave in İğneada Grid 38-24

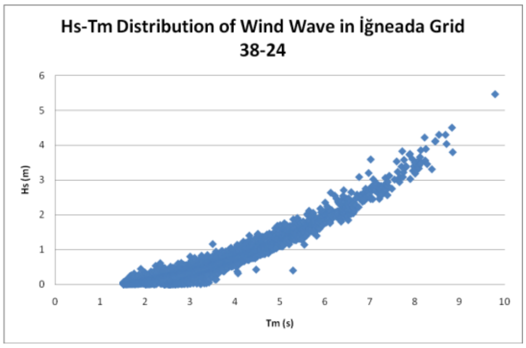


Figure 4.4.2 Relationship between Mean Period & Significant Height of Wind Wave in İğneada Grid 38-24

İğneada Region - Location 2 (GRID 38x25 ; 28.676°E - 41.885°N)

A point at the offshore location near İğneada is selected at the coordinates 28.676° E - 41.885° N (at 38x25 grid nodes). The point is approximately 51 km east of İğneada Cape and about 51 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.3. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 3.27 m. Swell waves having more than 12 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.4. Throughout the observation period wind waves are observed to be less than 5.43 m at offshore İğneada. Maximum significant wave height is observed to be 5.43 meters. The corresponding wave period is 9.46 s.

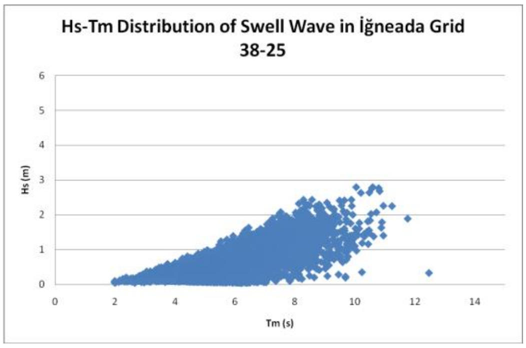


Figure 4.4.3 Relationship between Mean Period & Significant Height of Swell Wave in İğneada Grid 38-25

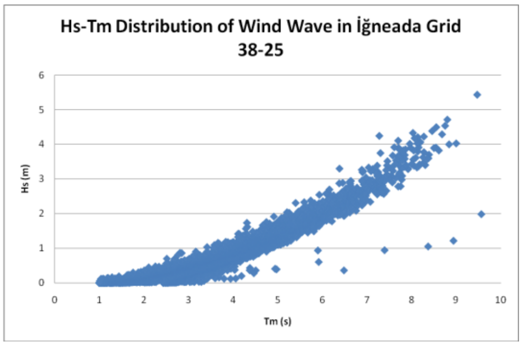


Figure 4.4.4 Relationship between Mean Period & Significant Height of Wind Wave in İğneada Grid 38-25

İğneada Region - Location 3 (GRID 39x24 ; 29.176°E - 41.385°N)

A point at the offshore location near İğneada is selected at the coordinates 29.176° E - 41.385° N (at 39x24 grid nodes). The point is approximately 108 km south-east of İğneada Cape and about 17 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.5. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 3.85 m. Swell waves having more than 12 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.6. Throughout the observation period wind waves are observed to be less than 4.88 m at offshore İğneada. Maximum significant wave height is observed to be 4.88 meters. The corresponding wave period is 8.89 s.

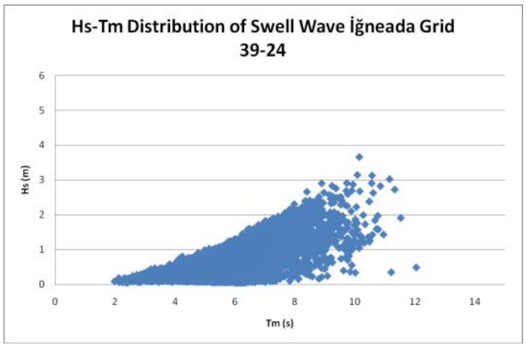


Figure 4.4.5 Relationship between Mean Period & Significant Height of Swell Wave in İğneada Grid 39-24

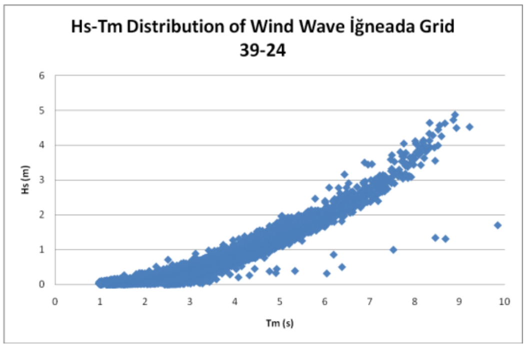


Figure 4.4.6 Relationship between Mean Period & Significant Height of Wind Wave in İğneada Grid 39-24

İğneada Region - Location 4 (GRID 39x25 ; 29.176°E - 41.885°N)

A point at the offshore location near İğneada is selected at the coordinates 29.176° E - 41.885° N (at 39x25 grid nodes). The point is approximately 93 km east of İğneada Cape and about 70 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.7. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 3.95 m. Swell waves having more than 12 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.8. Throughout the observation period wind waves are observed to be less than 6.92 m at offshore İğneada. Maximum significant wave height is observed to be 6.92 meters. The corresponding wave period is 9.78 s.

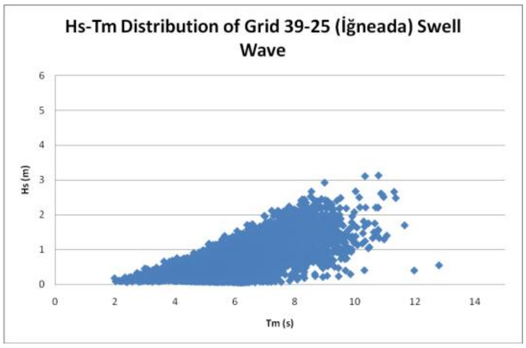


Figure 4.4.7 Relationship between Mean Period & Significant Height of Swell Wave in İğneada Grid 39-25

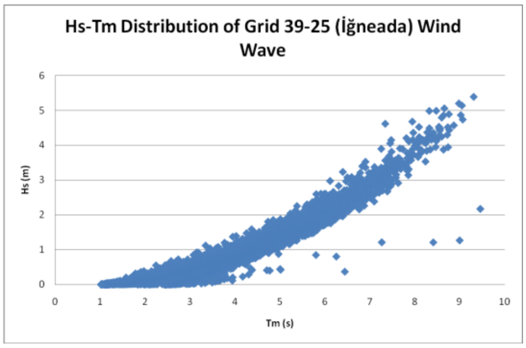


Figure 4.4.8 Relationship between Mean Period & Significant Height of Wind Wave in İğneada Grid 39-25

The results of the statistical analysis of swell wave and wind wave power for these locations of İğneada region are given in Figures 4.4.9 , 4.4.10 , 4.4.11 , 4.4.12 , 4.4.13 and 4.4.14 .

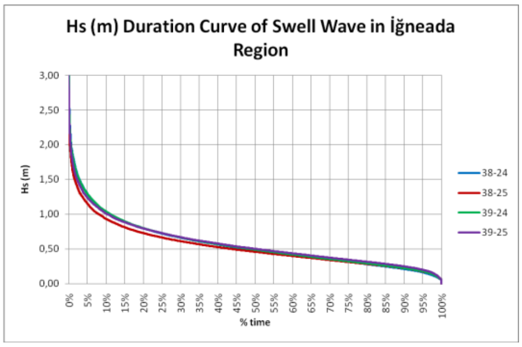


Figure 4.4.9 Significant Wave Height Duration Curve of Swell Wave at İğneada Region

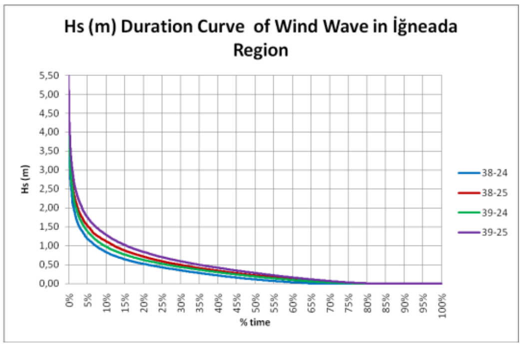


Figure 4.4.10 Significant Wave Height Duration Curve of Wind Wave at İğneada Region

When Figure 4.4.9 is examined, wave heights are higher than 0.5 m for 50% of the total storm duration, they are higher than 1 m for 10% of the total storm duration and they are higher than 2 m for 0.47% of the total storm duration. All curves are nearly same.

When Figure 4.4.10 is examined, wave heights at 39x25 grid node are higher than wave heights at other grid nodes. Wave heights at 39x25 grid node are higher than 0.5 m for 34.76% of the total storm duration, they are higher than 1 m for 15.3% of the total storm duration and they are higher than 2 m for 3.57% of the total storm duration.

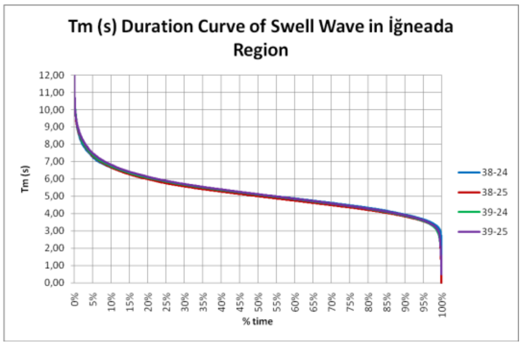


Figure 4.4.11 Mean Period Duration Curve of Swell Wave at İğneada Region

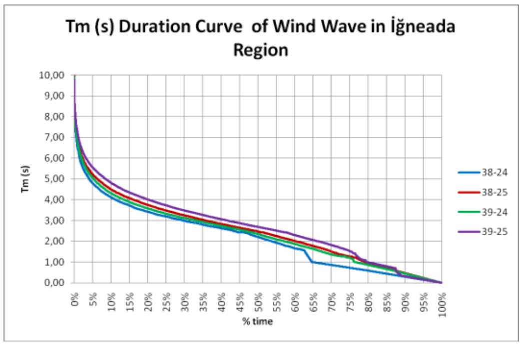


Figure 4.4.12 Mean Period Duration Curve of Wind Wave at İğneada Region

When Figure 4.4.11 is examined, mean periods are higher than 4 s for 88% of the total storm duration, they are higher than 6 s for 22.63% of the total storm duration and they are higher than 8 s for 3% of the total storm duration. All curves are nearly same.

When Figure 4.4.12 is examined, mean periods at 39x25 grid node are higher than mean periods at other grid nodes. Mean periods at 39x25 grid node are higher than 2 s for 66.16% of the total storm duration, they are higher than 4 s for 20.16% of the total storm duration and they are higher than 6 s for 3.18% of the total storm duration.

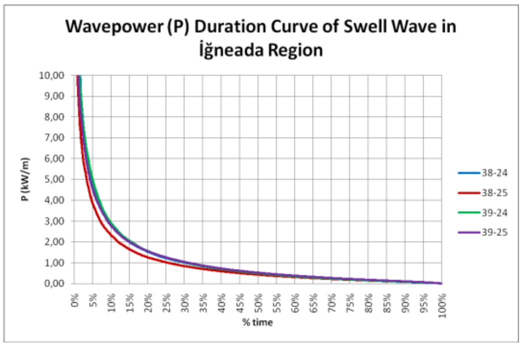


Figure 4.4.13 Wave Power Duration Curve of Swell Wave at İğneada Region

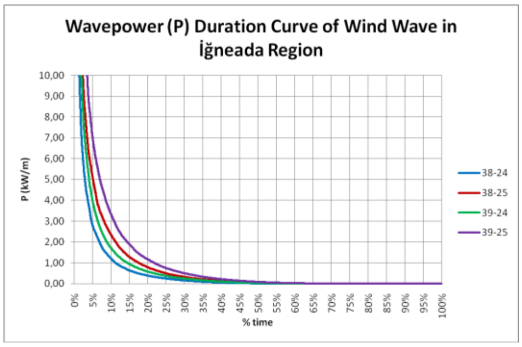


Figure 4.4.14 Wave Power Duration Curve of Wind Wave at İğneada Region

When Figure 4.4.13 is examined, wave power are higher than 1 kW/m for 31.21% of the total storm duration, they are higher than 3 kW/m for 9.61% of the total storm duration and they are higher than 5 kW/m for 5.02% of the total storm duration. All curves are nearly same.

When Figure 4.4.14 is examined, wave powers at 39x25 grid node are higher than wave powers at other nearby grid nodes. Wave powers at 39x25 grid node are higher than 1 kW/m for 21.69% of the total storm duration, they are higher than 3 kW/m for 10.85% of the total storm duration and they are higher than 5 kW/m for 6.98% of the total storm duration.

4.5 REGION – SİNOP

In this region three different locations are selected for the statistical analysis and given in the following sections.

Sinop Region - Location 1 (GRID 49x26 ; 34.528°E - 42.202°N)

A point at the offshore location near Sinop is selected at the coordinates 34.528° E - 42.202° N (at 49x26 grid nodes). The point is approximately 56 km north-west of Sinop Cape and about 25.2 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.15. Several data points, exceeding 10 second periods and few data points exceeding 3.0 m of swell wave heights are observed with a maximum wave height of 3.76 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.16. Throughout the observation period wind waves are observed to be less than 6.32 m at offshore Sinop. Maximum significant wave height is observed to be 6.32 meters. The corresponding wave period is 9.18 s.

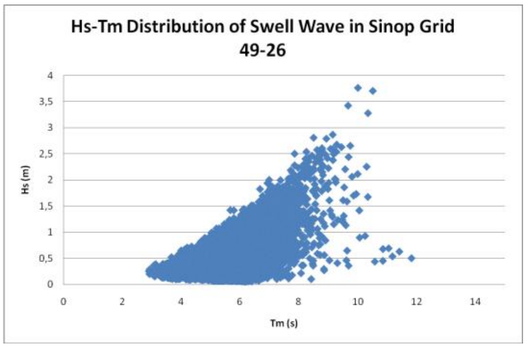


Figure 4.4.15 Relationship between Mean Period & Significant Height of Swell Wave in Sinop Grid 49-26

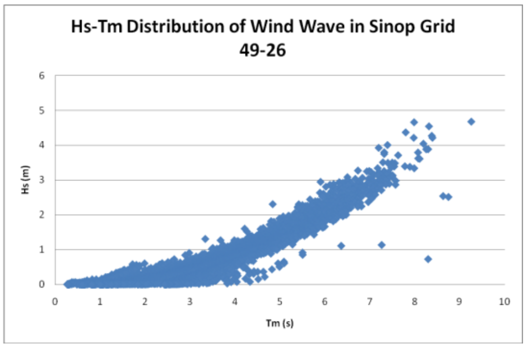


Figure 4.4.16 Relationship between Mean Period & Significant Height of Wind Wave in Sinop Grid 49-26

Sinop Region - Location 2 (GRID 50x26 ; 35.028°E - 42.202°N)

A point at the offshore location near Sinop is selected at the coordinates 35.028° E - 42.202° N (at 50x26 grid nodes). The point is approximately 21 km north of Sinop Cape and about 12.2 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.17. Several data points, exceeding 10 second periods and few data points exceeding 3 m of swell wave heights are observed with a maximum wave height of 3.76 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.18. Throughout the observation period wind waves are observed to be less than 6.75 m at offshore Sinop. Maximum significant wave height is observed to be 6.75 meters. The corresponding wave period is 9.81 s.

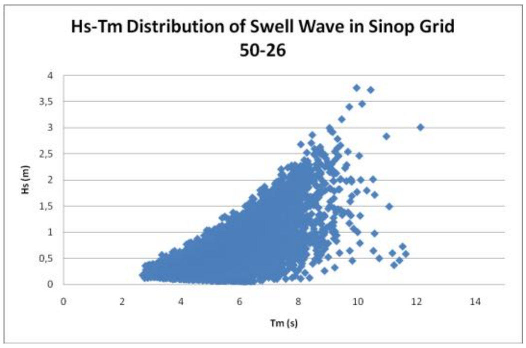


Figure 4.4.17 Relationship between Mean Period & Significant Height of Swell Wave in Sinop Grid 50-26

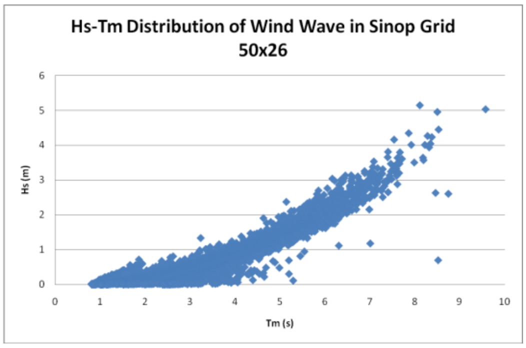


Figure 4.4.18 Relationship between Mean Period & Significant Height of Wind Wave in Sinop Grid 50-26

Sinop Region - Location 3 (GRID 51x26 ; 35.528°E - 42.202°N)

A point at the offshore location near Sinop is selected at coordinates 35.528° E - 42.202° N (at 51x26 grid nodes). The point is approximately 33.2 km north-east of Sinop Cape and about 33.2 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.19. Several data points, exceeding 10 second periods and few data points exceeding 3 m of swell wave heights are observed with a maximum wave height of 6.52 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.20. Throughout the observation period wind waves are observed to be less than 5.77 m at offshore Sinop. Maximum significant wave height is observed to be 5.77 meters. The corresponding wave period is 8.75 s.

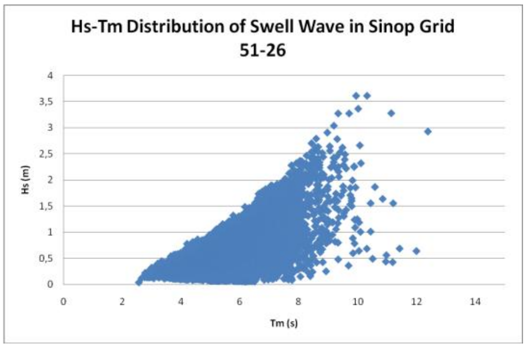


Figure 4.4.19 Relationship between Mean Period & Significant Height of Swell Wave in Sinop Grid 51-26

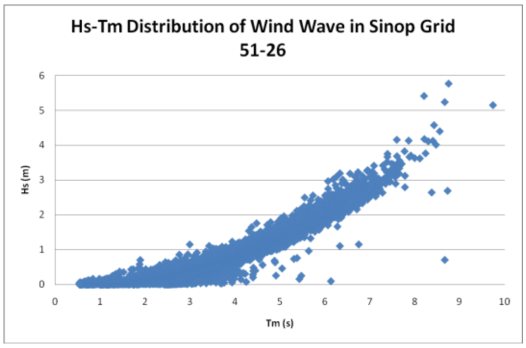


Figure 4.4.20 Relationship between Mean Period & Significant Height of Wind Wave in Sinop Grid 51-26

The results of the statistical analysis of swell wave and wind wave power for these locations of Sinop region are given in Figures 4.4.21 , 4.4.22 , 4.4.23 , 4.4.24 , 4.4.25 and 4.4.26.

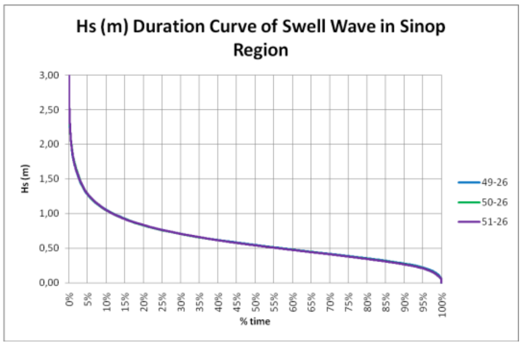


Figure 4.4.21 Significant Wave Height Duration Curve of Swell Wave at Sinop Region

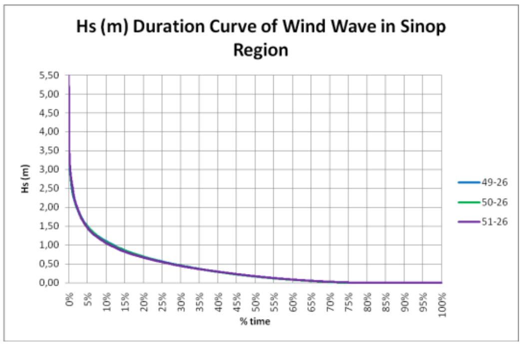


Figure 4.4.22 Significant Wave Height Duration Curve of Wind Wave at Sinop Region

When Figure 4.4.21 is examined, wave heights are higher than 0.5 m for 56.9 % of the total storm duration, they are higher than 1 m for 11.86 % of the total storm duration and they are higher than 2 m for 0.73 % of the total storm duration. All curves are nearly same.

When Figure 4.4.22 is examined, wave heights at 49x26 grid node are higher than wave heights at other grid nodes. Wave heights at 49x26 grid node are higher than 0.5 m for 27.8 % of the total storm duration, they are higher than 1 m for 11.97 % of the total storm duration and they are higher than 2 m for 2.10 % of the total storm duration.

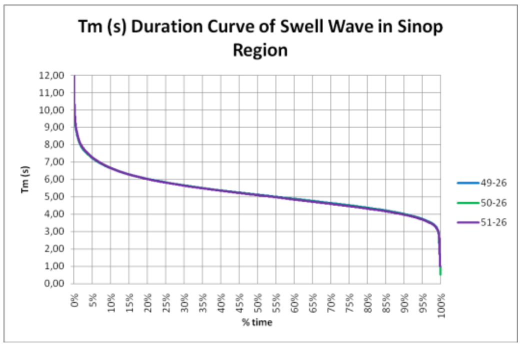


Figure 4.4.23 Mean Period Duration Curve of Swell Wave at Sinop Region

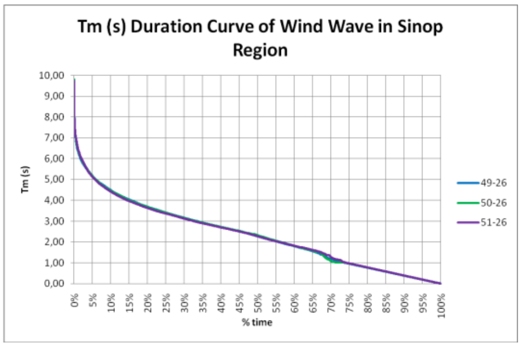


Figure 4.4.24 Mean Period Duration Curve of Wind Wave at Sinop Region

When Figure 4.4.23 is examined, mean periods are higher than 4 s for 90.26 % of the total storm duration, they are higher than 6 s for 20.80 % of the total storm duration and they are higher than 8 s for 1.87 % of the total storm duration. All curves are nearly same.

When Figure 4.4.24 is examined, mean periods at 49x26 grid node are higher than mean periods at other grid nodes. Mean periods at 49x26 grid node are higher than 2 s for 55.74 % of the total storm duration, they are higher than 4 s for 15.57 % of the total storm duration and they are higher than 6 s for 1.76 % of the total storm duration.

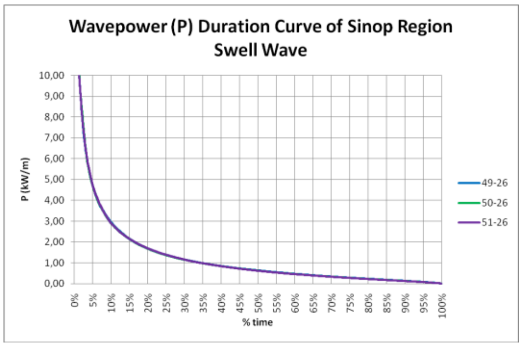


Figure 4.4.25 Wave Power Duration Curve of Swell Wave at Sinop Region

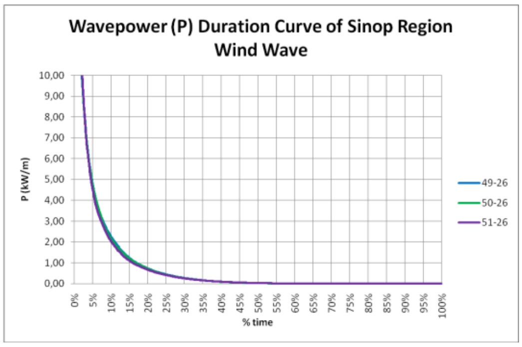


Figure 4.4.26 Wave Power Duration Curve of Wind Wave at Sinop Region

When Figure 4.4.25 is examined, wave power are higher than 1 kW/m for 34.47 % of the total storm duration, they are higher than 3 kW/m for 9.78 % of

the total storm duration and they are higher than 5 kW/m for 4.58 % of the total storm duration. All curves are nearly same.

When Figure 4.4.26 is examined, wave powers at 49x26 grid node are higher than wave powers at other nearby grid nodes. Wave powers at 49x26 grid node are higher than 1 kW/m for 16.92 % of the total storm duration, they are higher than 3 kW/m for 7.82 % of the total storm duration and they are higher than 5 kW/m for 4.82 % of the total storm duration.

4.6 REGION – HOPA

In this region five different locations are selected for the statistical analysis and given in the following sections.

Hopa Region - Location 1 (GRID 61x24 ; 40.161°E - 41.215°N)

A point at the offshore location near Hopa is selected at the coordinates 40.161° E - 41.215° N (at 61x24 grid nodes). The point is approximately 106,8 km west of Hopa and about 27.75 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.27. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 3.31 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.28. Throughout the observation period wind waves are observed to be less than 4.36 m at offshore Hopa. Maximum significant wave height is observed to be 4.36 meters. The corresponding wave period is 8.85 s.

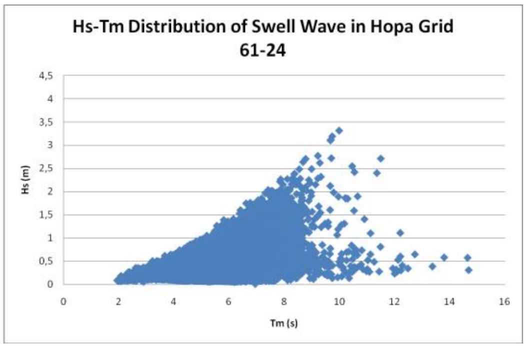


Figure 4.4.27 Relationship between Mean Period & Significant Height of Swell Wave in Hopa Grid 61-24

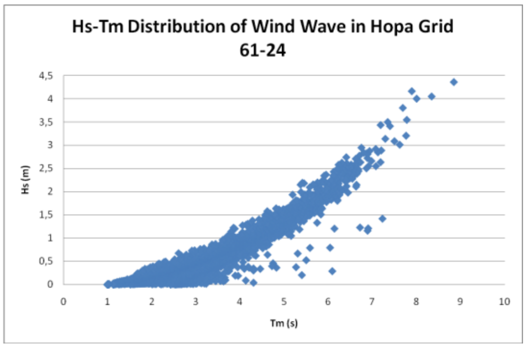


Figure 4.4.28 Relationship between Mean Period & Significant Height of Wind Wave in Hopa Grid 61-24

Hopa Region - Location 2 (GRID 61x25 ; 40.161°E - 41.715°N)

A point at the offshore location near Hopa is selected at the coordinates 40.161° E - 41.715° N (at 61x25 grid nodes). The point is approximately 110.5 km west of Hopa and about 78.8 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.29. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 3.48 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.30. Throughout the observation period wind waves are observed to be less than 4.83 m at offshore Hopa. Maximum significant wave height is observed to be 4.83 meters. The corresponding wave period is 9.21 s.

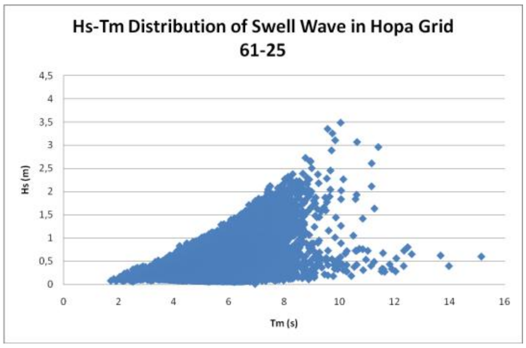


Figure 4.4.29 Relationship between Mean Period & Significant Height of Swell Wave in Hopa Grid 61-25

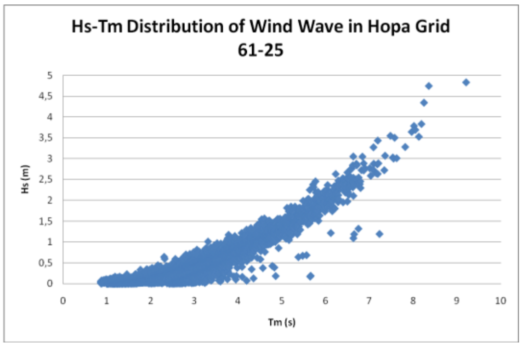


Figure 4.4.30 Relationship between Mean Period & Significant Height of Wind Wave in Hopa Grid 61-25

Hopa Region - Location 3 (GRID 62x24 ; 40.661°E - 41.215°N)

A point at the offshore location near Hopa is selected at coordinates 40.661° E - 41.215° N (at 62x24 grid nodes). The point is approximately 66.1 km west of Hopa and about 12.5 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.31. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 3.31 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.32. Throughout the observation period wind waves are observed to be less than 4.20 m at offshore Hopa. Maximum significant wave height is observed to be 4.20 meters. The corresponding wave period is 8.44 s.

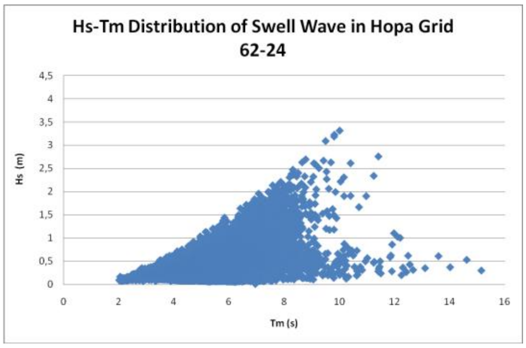


Figure 4.4.31 Relationship between Mean Period & Significant Height of Swell Wave in Hopa Grid 62-24

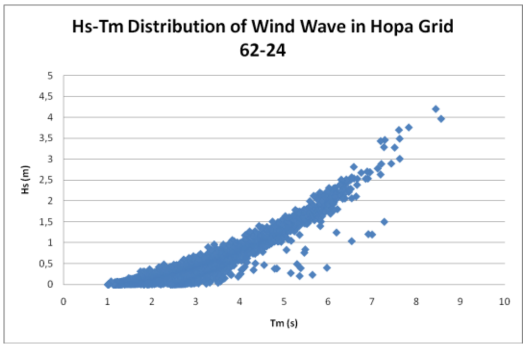


Figure 4.4.32 Relationship between Mean Period & Significant Height of Wind Wave in Hopa Grid 62-24

Hopa Region - Location 4 (GRID 62x25 ; 40.661°E - 41.715°N)

A point at the offshore location near Hopa is selected at coordinates 40.661° E - 41.715° N (at 62x25 grid nodes). The point is approximately 72.34 km north-west of Hopa and about 62 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.33. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 3.72 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.34. Throughout the observation period wind waves are observed to be less than 4.65 m at offshore Hopa. Maximum significant wave height is observed to be 4.65 meters. The corresponding wave period is 9.14 s.

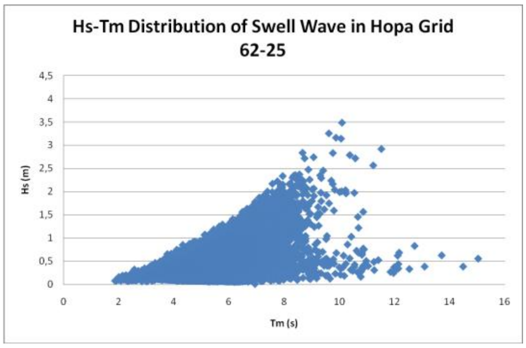


Figure 4.4.33 Relationship between Mean Period & Significant Height of Swell Wave in Hopa Grid 62-25

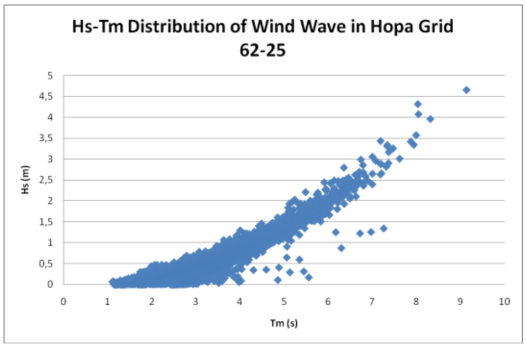


Figure 4.4.34 Relationship between Mean Period & Significant Height of Wind Wave in Hopa Grid 62-25

Hopa Region - Location 5 (GRID 63x25 ; 41.161°E - 41.715°N)

A point at the offshore location near Hopa is selected at coordinates 41.161° E - 41.715° N (at 63x25 grid nodes). The point is approximately 41,63 km north-west of Hopa and about 36.4 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.35. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 3.40 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.36. Throughout the observation period wind waves are observed to be less than 4.19 m at offshore Hopa. Maximum significant wave height is observed to be 4.19 meters. The corresponding wave period is 8.46 s.

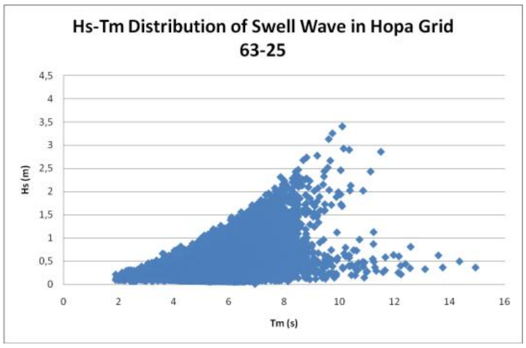


Figure 4.4.35 Relationship between Mean Period & Significant Height of Swell Wave in Hopa Grid 63-25

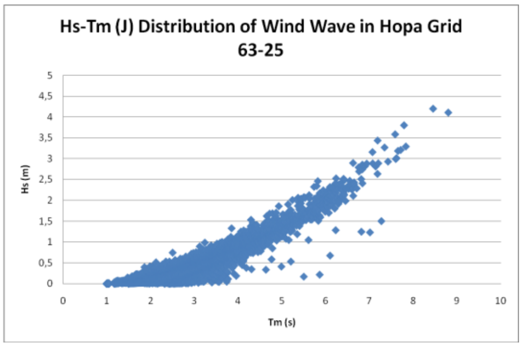


Figure 4.4.36 Relationship between Mean Period & Significant Height of Wind Wave in Hopa Grid 63-25

The results of the statistical analysis of swell wave and wind wave power for these locations of Hopa region are given in Figures 4.4.37 , 4.4.38 , 4.4.39 , 4.4.40 , 4.4.41 and 4.4.42.

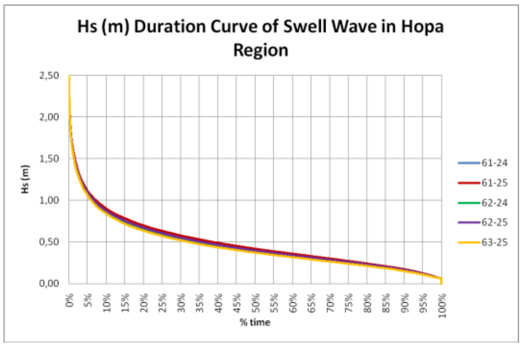


Figure 4.4.37 Significant Wave Height Duration Curve of Swell Wave at Hopa Region

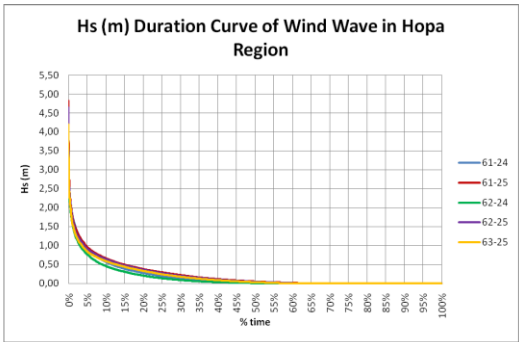
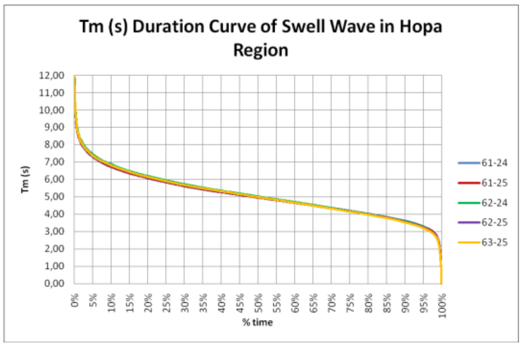


Figure 4.4.38 Significant Wave Height Duration Curve of Wind Wave at Hopa Region

When Figure 4.4.37 is examined, wave heights are higher than 0.5 m for 38.44 % of the total storm duration, they are higher than 1 m for 7.32 % of the total storm duration and they are higher than 2 m for 0.33 % of the total storm duration. All curves are nearly same.

When Figure 4.4.38 is examined, wave heights at 61x25 grid node are higher than wave heights at other grid nodes. Wave heights at 61x25 grid node are higher than 0.5 m for 14.61 % of the total storm duration, they are higher than 1 m for 4.63 % of the total storm duration and they are higher than 2 m for 0.68 % of the total storm duration.



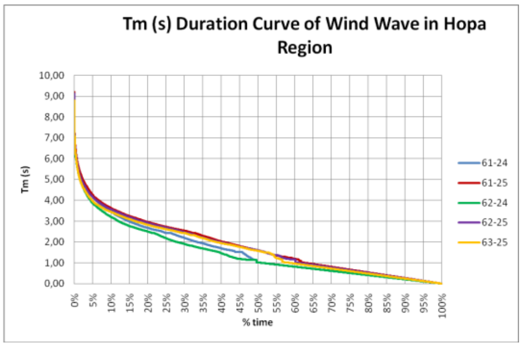
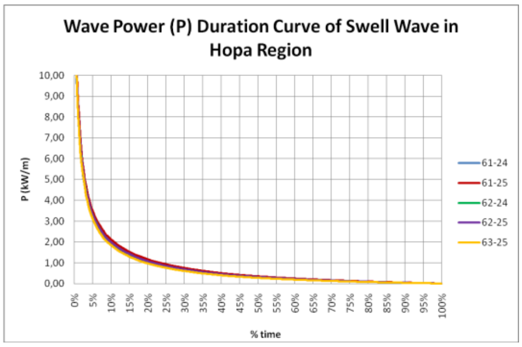


Figure 4.4.39 Mean Period Duration Curve of Swell Wave at Hopa Region

Figure 4.4.40 Mean Period Duration Curve of Wind Wave at Hopa Region

When Figure 4.4.39 is examined, mean periods are higher than 4 s for 80.65 % of the total storm duration, they are higher than 6 s for 23.86 % of the total storm duration and they are higher than 8 s for 2.51 % of the total storm duration. All curves are nearly same.

When Figure 4.4.40 is examined, mean periods at 61x25 grid node are higher than mean periods at other grid nodes. Mean periods at 61x25 grid node are higher than 2 s for 40.61 % of the total storm duration, they are higher than 4 s for 6.61 % of the total storm duration and they are higher than 6 s for 0.70 % of the total storm duration.



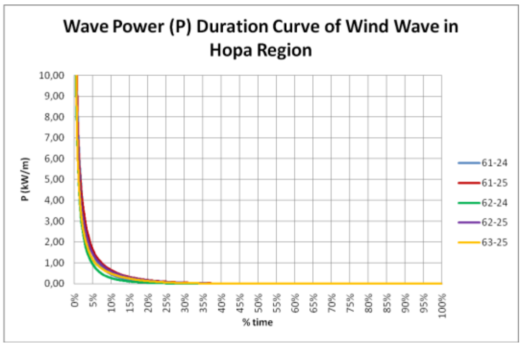


Figure 4.4.41 Wave Power Duration Curve of Swell Wave at Hopa Region

Figure 4.4.42 Wave Power Duration Curve of Wind Wave at Hopa Region

When Figure 4.4.41 is examined, wave power are higher than 1 kW/m for 23.17 % of the total storm duration, they are higher than 3 kW/m for 6.20 % of

the total storm duration and they are higher than 5 kW/m for 2.83 % of the total storm duration. All curves are nearly same.

When Figure 4.4.42 is examined, wave powers at 61x25 grid node are higher than wave powers at other nearby grid nodes. Wave powers at 61x25 grid node are higher than 1 kW/m for 7.36 % of the total storm duration, they are higher than 3 kW/m for 2.95 % of the total storm duration and they are higher than 5 kW/m for 1.64 % of the total storm duration.

4.7 REGION – ALANYA

In this region four different locations are selected for the statistical analysis and given in the following sections.

Alanya Region - Location 1 (GRID 44x13 ; 31.775°E - 35.93°N)

A point at the offshore location near Alanya is selected at the coordinates 31.775° E - 35.93° N (at 44x13 grid nodes). The point is approximately 72,75 km south-west of Alanya and about 58 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.43. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 3.65 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.44. Throughout the observation period wind waves are observed to be less than 4.80 m at offshore Alanya. Maximum significant wave height is observed to be 4.80 meters. The corresponding wave period is 9.33 s.

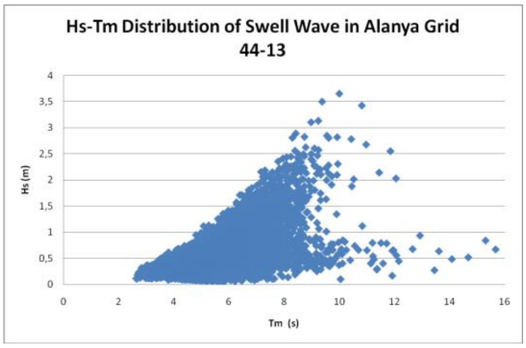


Figure 4.4.43 Relationship between Mean Period & Significant Height of Swell Wave in Alanya Grid 44-13

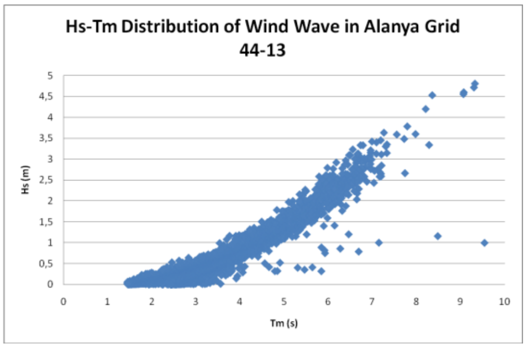


Figure 4.4.44 Relationship between Mean Period & Significant Height of Wind Wave in Alanya Grid 44-13

Alanya Region - Location 2 (GRID 44x14 ; 31.775ᴼE - 36.43ᴼN)

A point at the offshore location near Alanya is selected at the coordinates 31.775° E - 36.43° N (at 44x14 grid nodes). The point is approximately 24.75 km south-west of Alanya and about 18.5 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.45. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 4.04 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.46. Throughout the observation period wind waves are observed to be less than 3.94 m at offshore Alanya. Maximum significant wave height is observed to be 3.94 meters. The corresponding wave period is 8 s.

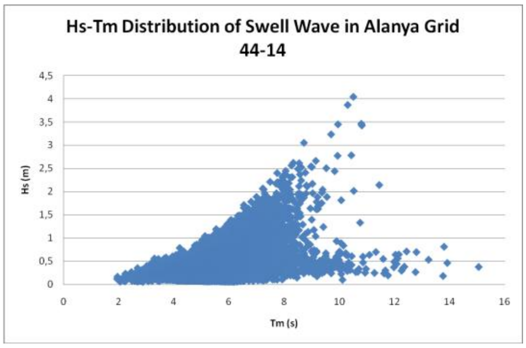


Figure 4.4.45 Relationship between Mean Period & Significant Height of Swell Wave in Alanya Grid 44-14

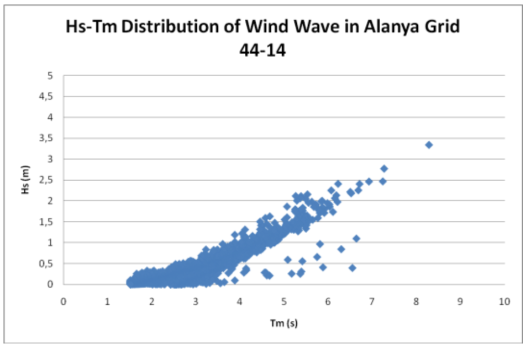


Figure 4.4.46 Relationship between Mean Period & Significant Height of Wind Wave in Alanya Grid 44-14

Alanya Region - Location 3 (GRID 45x13 ; 32.275°E - 35.93°N)

A point at the offshore location near Alanya is selected at coordinates 32.275° E - 35.93° N (at 45x13 grid nodes). The point is approximately 74 km south of Alanya and about 27.5 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.47. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 3.88 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.48. Throughout the observation period wind waves are observed to be less than 4.39 m at offshore Alanya. Maximum significant wave height is observed to be 4.39 meters. The corresponding wave period is 9.05 s.

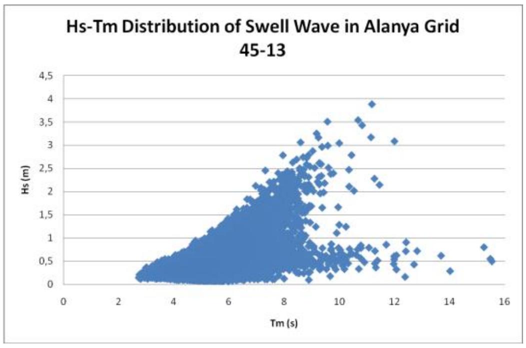


Figure 4.4.47 Relationship between Mean Period & Significant Height of Swell Wave in Alanya Grid 45-13

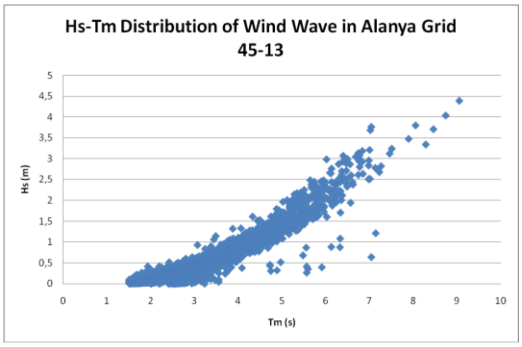


Figure 4.4.48 Relationship between Mean Period & Significant Height of Wind Wave in Alanya Grid 45-13

Alanya Region - Location 4 (GRID 46x13 ; 32.775°E - 35.93°N)

A point at the offshore location near Alanya is selected at coordinates 32.775° E - 35.93° N (at 46x13 grid nodes). The point is approximately 98.25 km south-east of Alanya and about 9.9 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.49. Several data points, exceeding 10 second periods and few data points exceeding 2.5 m of swell wave heights are observed with a maximum wave height of 3.62 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.50. Throughout the observation period wind waves are observed to be less than 4.85 m at offshore Alanya. Maximum significant wave height is observed to be 4.85 meters. The corresponding wave period is 8.70 s.

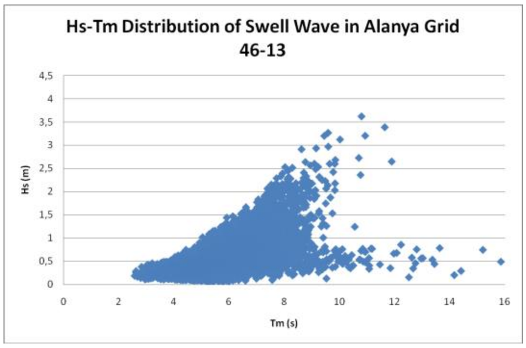


Figure 4.4.49 Relationship between Mean Period & Significant Height of Swell Wave in Alanya Grid 46-13

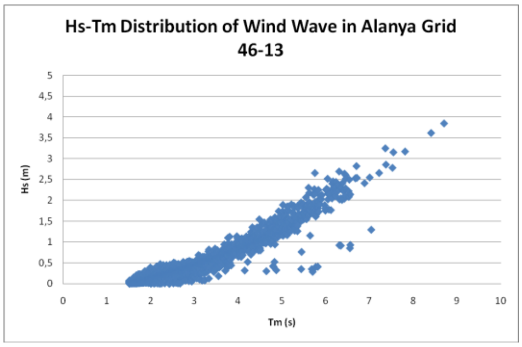


Figure 4.4.50 Relationship between Mean Period & Significant Height of Wind Wave in Alanya Grid 46-13

The results of the statistical analysis of swell wave and wind wave power for these locations of Alanya region are given in Figures 4.4.51 , 4.4.52 , 4.4.53 , 4.4.54 , 4.4.55 and 4.4.56.

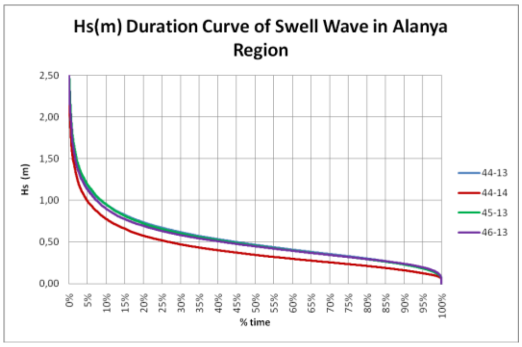


Figure 4.4.51 Significant Wave Height Duration Curve of Swell Wave at Alanya Region

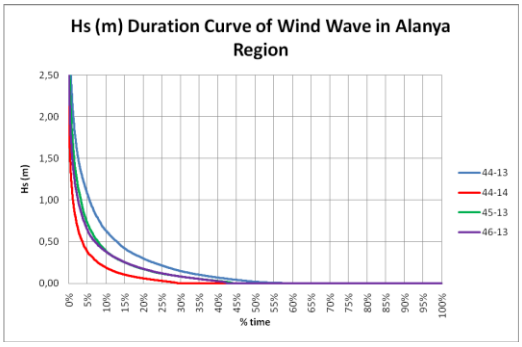


Figure 4.4.52 Significant Wave Height Duration Curve of Wind Wave at Alanya Region

When Figure 4.4.51 is examined, wave heights are higher than 0.5 m for 44.76 % of the total storm duration, they are higher than 1 m for 8.68 % of the total storm duration and they are higher than 2 m for 0.63 % of the total storm duration. All curves are nearly same.

When Figure 4.4.52 is examined, wave heights at 44x13 grid node are higher than wave heights at other grid nodes. Wave heights at 44x13 grid node are higher than 0.5 m for 12.94 % of the total storm duration, they are higher than 1 m for 5.62 % of the total storm duration and they are higher than 2 m for 1.26 % of the total storm duration.

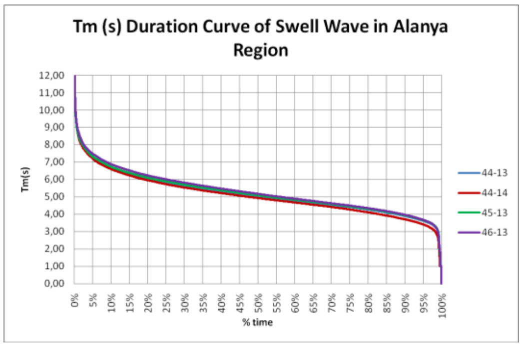


Figure 4.4.53 Mean Period Duration Curve of Swell Wave at Alanya Region

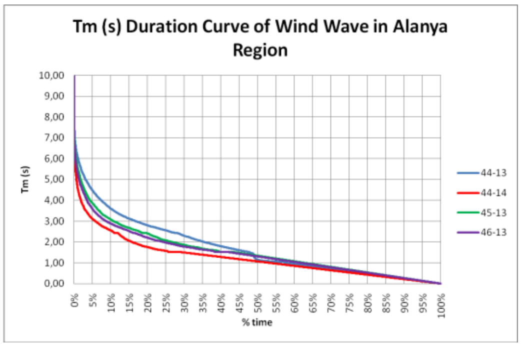


Figure 4.4.54 Mean Period Duration Curve of Wind Wave at Alanya Region

When Figure 4.4.53 is examined, mean periods are higher than 4 s for 89.37 % of the total storm duration, they are higher than 6 s for 23.12 % of the total storm duration and they are higher than 8 s for 2.56 % of the total storm duration. All curves are nearly same.

When Figure 4.4.54 is examined, mean periods at 44x13 grid node are higher than mean periods at other grid nodes. Mean periods at 44x13 grid node are higher than 2 s for 35.45 % of the total storm duration, they are higher than 4 s for 7.30 % of the total storm duration and they are higher than 6 s for 1.05 % of the total storm duration.

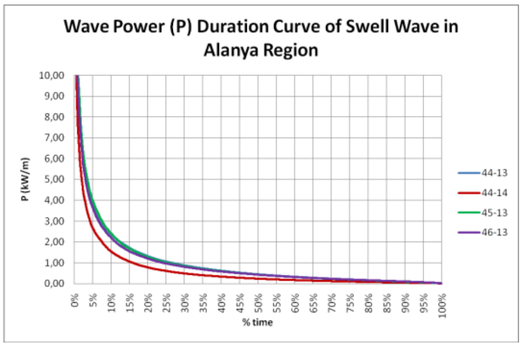


Figure 4.4.55 Wave Power Duration Curve of Swell Wave at Alanya Region

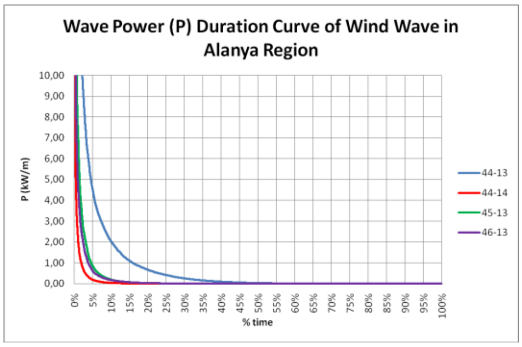


Figure 4.4.56 Wave Power Duration Curve of Wind Wave at Alanya Region

When Figure 4.4.55 is examined, wave power are higher than 1 kW/m for 26.45 % of the total storm duration, they are higher than 3 kW/m for 7.57 % of

the total storm duration and they are higher than 5 kW/m for 3.56 % of the total storm duration. All curves are nearly same.

When Figure 4.4.56 is examined, wave powers at 44x13 grid node are higher than wave powers at other nearby grid nodes. Wave powers at 44x13 grid node are higher than 1 kW/m for 15.88 % of the total storm duration, they are higher than 3 kW/m for 7.32 % of the total storm duration and they are higher than 5 kW/m for 4.52 % of the total storm duration.

4.8 REGION – KARATAŞ

In this region four different locations are selected for the statistical analysis and given in the following sections.

Karataş Region - Location 1 (GRID 50x13 ; 34.80°E - 35.968°N)

A point at the offshore location near Karataş is selected at the coordinates 34.80° E - 35.968° N (at 50x13 grid nodes). The point is approximately 79,7 km south-west of Karataş and about 76 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.57. Several data points, exceeding 10 second periods and few data points exceeding 2 m of swell wave heights are observed with a maximum wave height of 3.6 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.58. Throughout the observation period wind waves are observed to be less than 4.06 m at offshore Karataş. Maximum significant wave height is observed to be 4.06 meters. The corresponding wave period is 8.91 s.

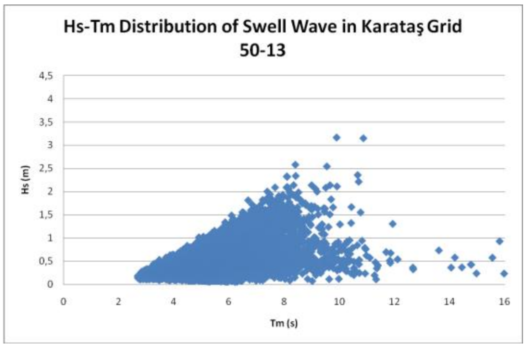


Figure 4.4.57 Relationship between Mean Period & Significant Height of Swell Wave in Karataş Grid 50-13

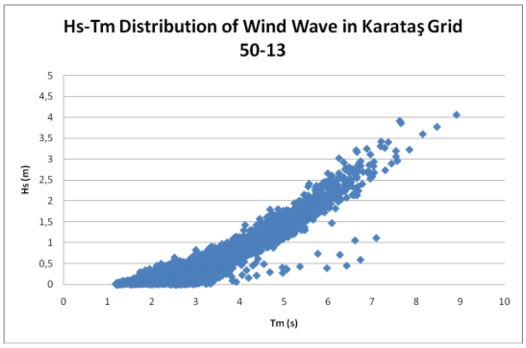


Figure 4.4.58 Relationship between Mean Period & Significant Height of Wind Wave in Karataş Grid 50-13

Karataş Region - Location 2 (GRID 50x14 ; 34.80°E - 36.468°N)

A point at the offshore location near Karataş is selected at the coordinates 34.80° E - 36.468° N (at 50x14 grid nodes). The point is approximately 48.90 km west of Karataş and about 30 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.59. Several data points, exceeding 9 second periods and few data points exceeding 1.5 m of swell wave heights are observed with a maximum wave height of 3.95 m. Swell waves having more than 9 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.60. Throughout the observation period wind waves are observed to be less than 4.39 m at offshore Karataş. Maximum significant wave height is observed to be 4.39 meters. The corresponding wave period is 6,78 s.

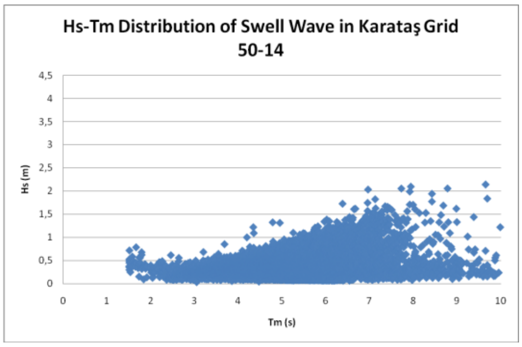


Figure 4.4.59 Relationship between Mean Period & Significant Height of Swell Wave in Karataş Grid 50-14

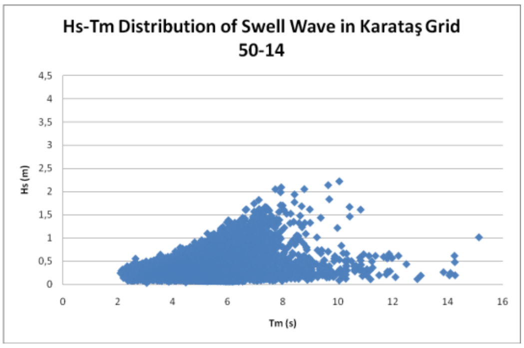


Figure 4.4.60 Relationship between Mean Period & Significant Height of Wind Wave in Karataş Grid 50-14

Karataş Region - Location 3 (GRID 51x13 ; 35.30°E - 35.968°N)

A point at the offshore location near Karataş is selected at coordinates 35.30° E - 35.968° N (at 51x13 grid nodes). The point is approximately 63.35 km south of Karataş and about 46.8 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.61. Several data points, exceeding 10 second periods and few data points exceeding 2 m of swell wave heights are observed with a maximum wave height of 3.40 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.62. Throughout the observation period wind waves are observed to be less than 5.11 m at offshore Karataş. Maximum significant wave height is observed to be 5.11 meters. The corresponding wave period is 9.40 s.

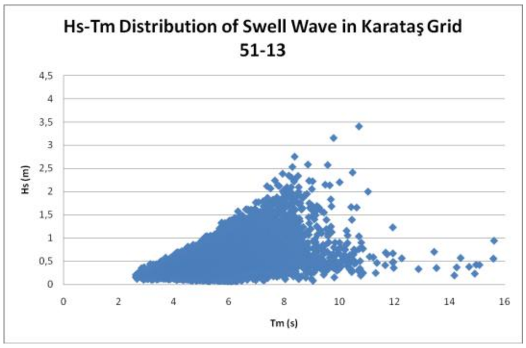


Figure 4.4.61 Relationship between Mean Period & Significant Height of Swell Wave in Karataş Grid 51-13

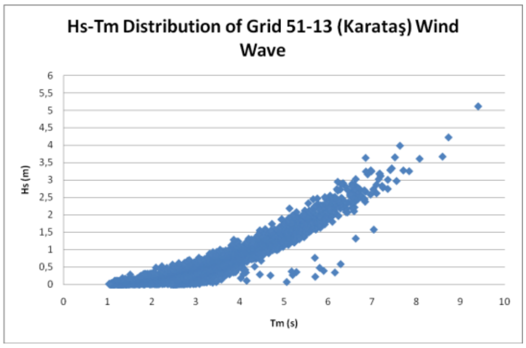


Figure 4.4.62 Relationship between Mean Period & Significant Height of Wind Wave in Karataş Grid 51-13

Karataş Region - Location 4 (GRID 51x14 ; 35.30°E - 36.468°N)

A point at the offshore location near Karataş is selected at coordinates 35.30° E - 36.468° N (at 51x14 grid nodes). The point is approximately 8.63 km south of Karataş and about 8.63 km away from the shoreline.

The relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.63. Several data points, exceeding 10 second periods and few data points exceeding 1.5 m of swell wave heights are observed with a maximum wave height of 3.77 m. Swell waves having more than 10 seconds periods can be observed.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.64. Throughout the observation period wind waves are observed to be less than 4.00 m at offshore Karataş. Maximum significant wave height is observed to be 4.00 meters. The corresponding wave period is 8.21 s.

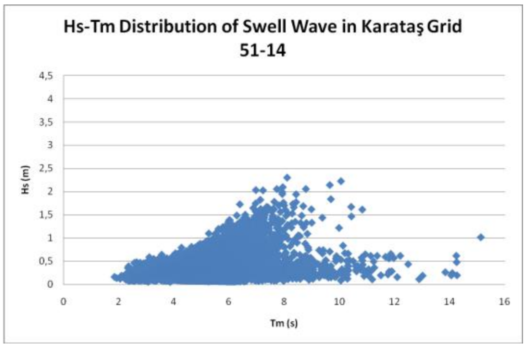


Figure 4.4.63 Relationship between Mean Period & Significant Height of Swell Wave in Karataş Grid 51-14

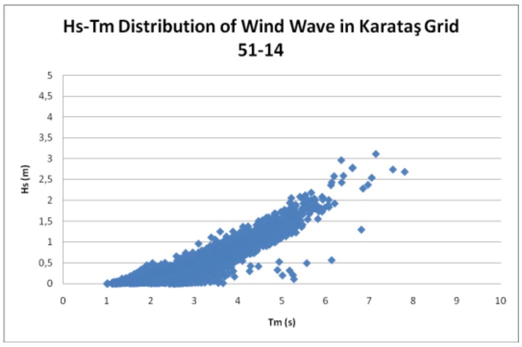


Figure 4.4.64 Relationship between Mean Period & Significant Height of Wind Wave in Karataş Grid 51-14

The results of the statistical analysis of swell wave and wind wave power for these locations of Karataş region are given in Figures 4.4.65 , 4.4.66 , 4.4.67 , 4.4.68 , 4.4.69 and 4.4.70.

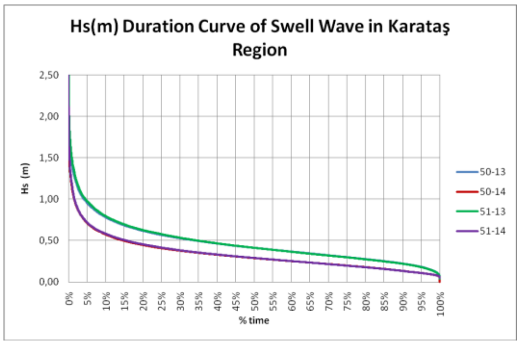


Figure 4.4.65 Significant Wave Height Duration Curve of Swell Wave at Karataş Region

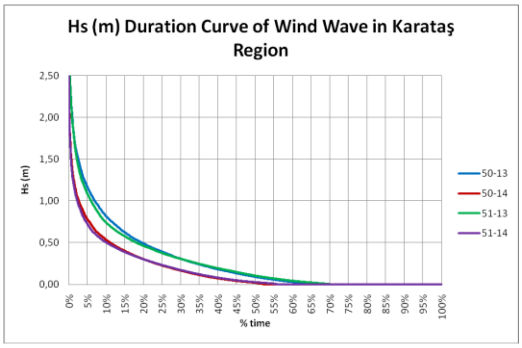


Figure 4.4.66 Significant Wave Height Duration Curve of Wind Wave at Karataş Region

When Figure 4.4.65 is examined, wave heights are higher than 0.5 m for 34.68 % of the total storm duration, they are higher than 1 m for 4.58 % of the total storm duration and they are higher than 2 m for 0.17 % of the total storm duration. All curves are nearly same.

When Figure 4.4.66 is examined, wave heights at 50x13 grid node are higher than wave heights at other grid nodes. Wave heights at 50x13 grid node are higher than 0.5 m for 19.63 % of the total storm duration, they are higher than 1 m for 7.02 % of the total storm duration and they are higher than 2 m for 0.97 % of the total storm duration.

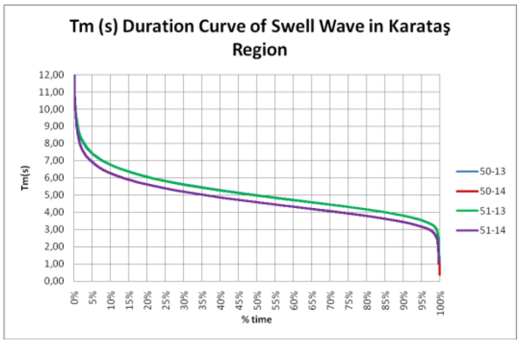


Figure 4.4.67 Mean Period Duration Curve of Swell Wave at Karataş Region

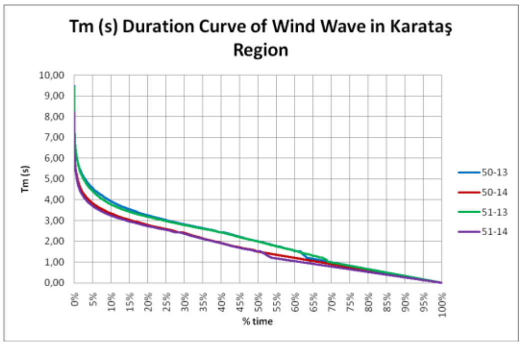


Figure 4.4.68 Mean Period Duration Curve of Wind Wave at Karataş Region

When Figure 4.4.67 is examined, mean periods are higher than 4 s for 85.12 % of the total storm duration, they are higher than 6 s for 21.20 % of the total storm duration and they are higher than 8 s for 2.79 % of the total storm duration. All curves are nearly same.

When Figure 4.4.68 is examined, mean periods at 50x13 grid node are higher than mean periods at other grid nodes. Mean periods at 50x13 grid node are higher than 2 s for 50.01 % of the total storm duration, they are higher than 4 s for 9.38 % of the total storm duration and they are higher than 6 s for 0.70 % of the total storm duration.

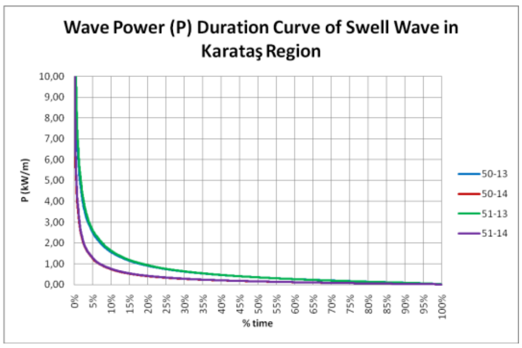


Figure 4.4.69 Wave Power Duration Curve of Swell Wave at Karataş Region

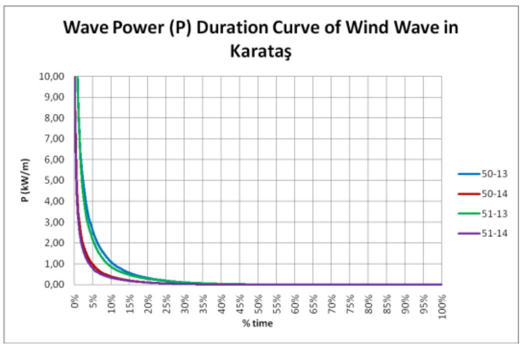


Figure 4.4.70 Wave Power Duration Curve of Wind Wave at Karataş Region

When Figure 4.4.69 is examined, wave power are higher than 1 kW/m for 18.54 % of the total storm duration, they are higher than 3 kW/m for 4.01 % of the total storm duration and they are higher than 5 kW/m for 1.77 % of the total storm duration. All curves are nearly same.

When Figure 4.4.70 is examined, wave powers at 50x13 grid node are higher than wave powers at other nearby grid nodes. Wave powers at 50x13 grid node are higher than 1 kW/m for 10.57 % of the total storm duration, they are higher than 3 kW/m for 4.28 % of the total storm duration and they are higher than 5 kW/m for 2.39 % of the total storm duration.

CHAPTER 5

COMPARISON AND DISCUSSION OF RESULTS

In this thesis, the complete analysis of the power of swell and wind waves is performed by using ECMWF data. In the statistical analysis of wind and swell waves the software, developed by Serhan Aldoğan, is used to extract data from ECMWF, combine wave and atmosphere model data and analyze data.

The results of analysis are given in Chapter 4 for selected five regions around Turkey. In this chapter a general comparison and discussion of the results are given. The data are obtained for 156 months duration in 6-hour intervals and the results are based on only this duration of data.

The graph of the swell wave power duration curves for all best locations (out of five selected regions) of all regions is given in Figure 5.1 for comparison. When Figure 5.1 is examined, wave powers at 49x26 grid node (near Sinop) are higher than wave powers at other grid nodes. However, swell wave power curve of 49x26 (Sinop) and 39x25 (İğneada) are almost same.

The graph of the wind wave power duration curves for all best locations of all selected five regions is given in Figure 5.2 for comparison. When Figure 5.2 is examined, wave powers at 39x25 grid node (İğneada) are higher than wave powers at other grid nodes.

In order to make a full comparison of combined level of the wind wave and swell wave power of the selected regions, the swell and wind wave power curves are accumulated for each location and a single combined curve representing swell and wind power together for each location is obtained. 5 single curves of 5 selected regions are plotted in Figure 5.3 for comparison. When Figure 5.3 is examined, wave powers at 39x25 (İğneada) grid node are higher than wave powers at other grid nodes. In other words, the west of the Black Sea in the north of Istanbul Straits can be suggested as the best sites to harness the wave energy comparing to other selected sites in this study.

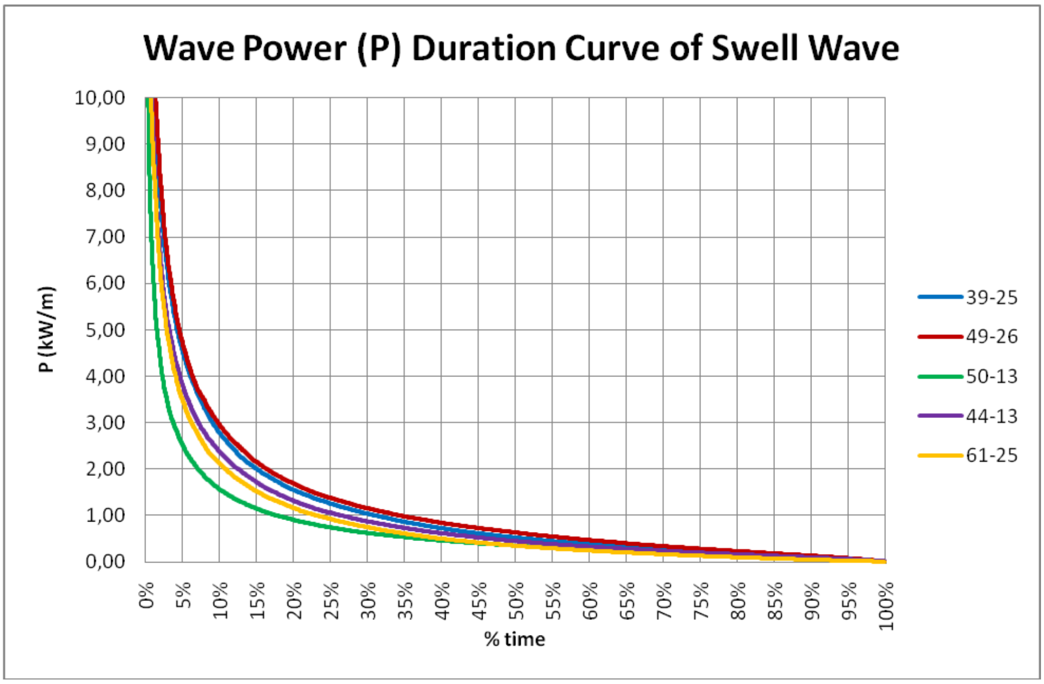


Figure 5.1 Wave Power Duration Curves of Swell Wave at All Regions

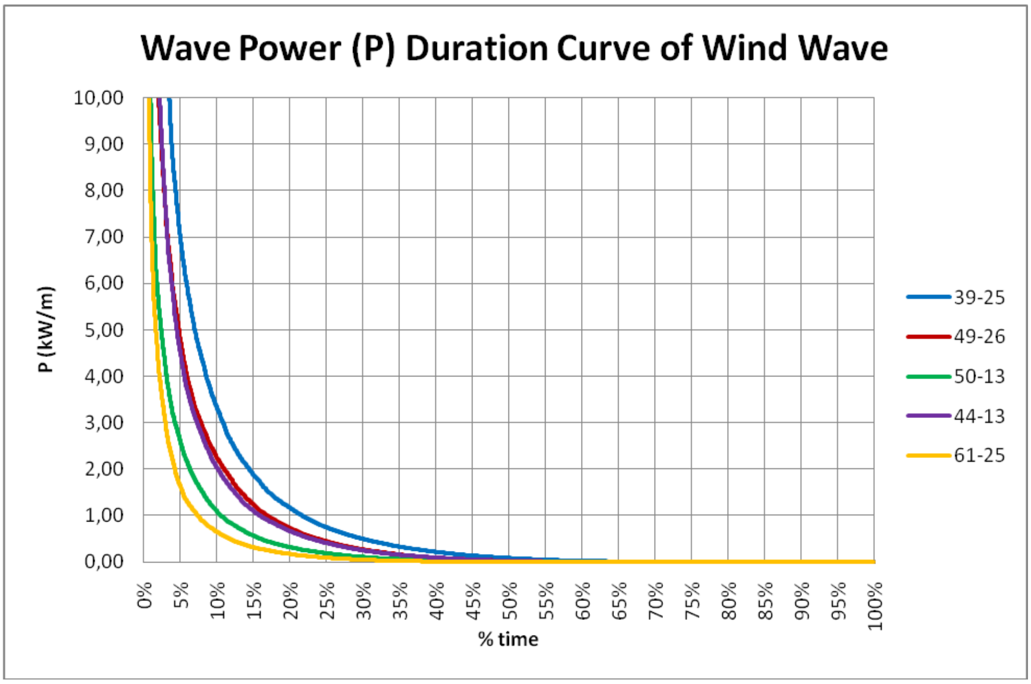


Figure 5.2 Wave Power Duration Curves of Wind Wave at All Regions

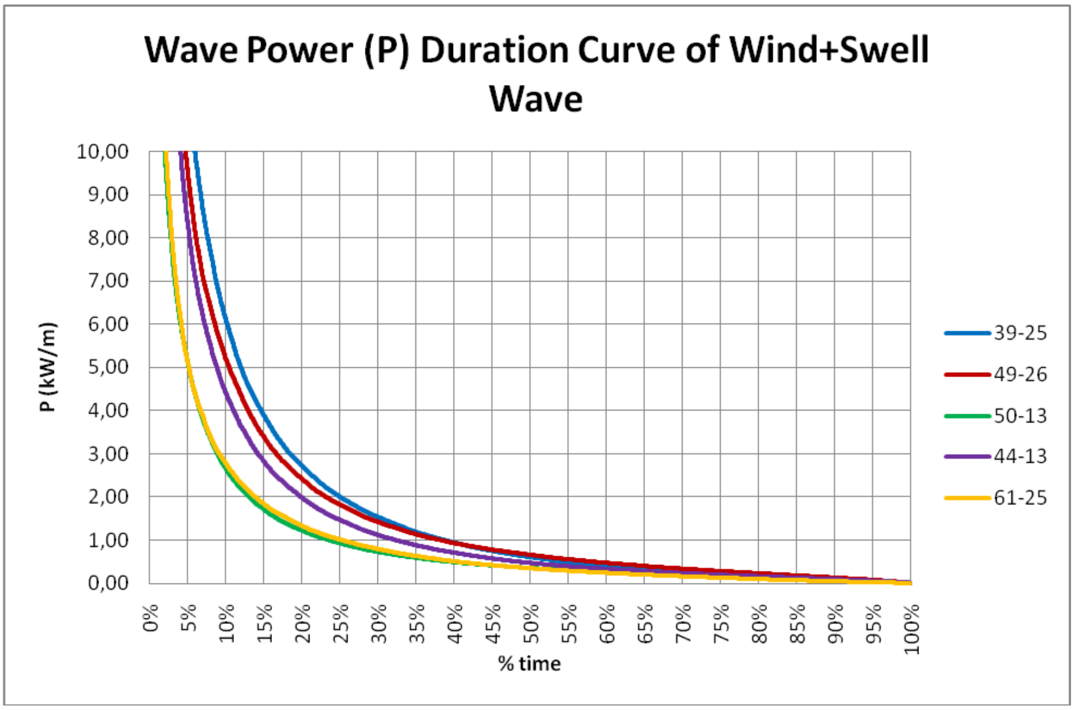


Figure 5.3 Wave Power Duration Curves of Swell and Wind Wave at All Regions

The bar chart of number of swell waves according to directions at 39x25 grid node in İğneada region is given in Figure 5.4. It is seen from Figure 5.4 that, the number of swell waves, coming from north-east direction, is 7480 and more than the other directions. North and East directions are the secondary important directions of swell waves in İğneada region.

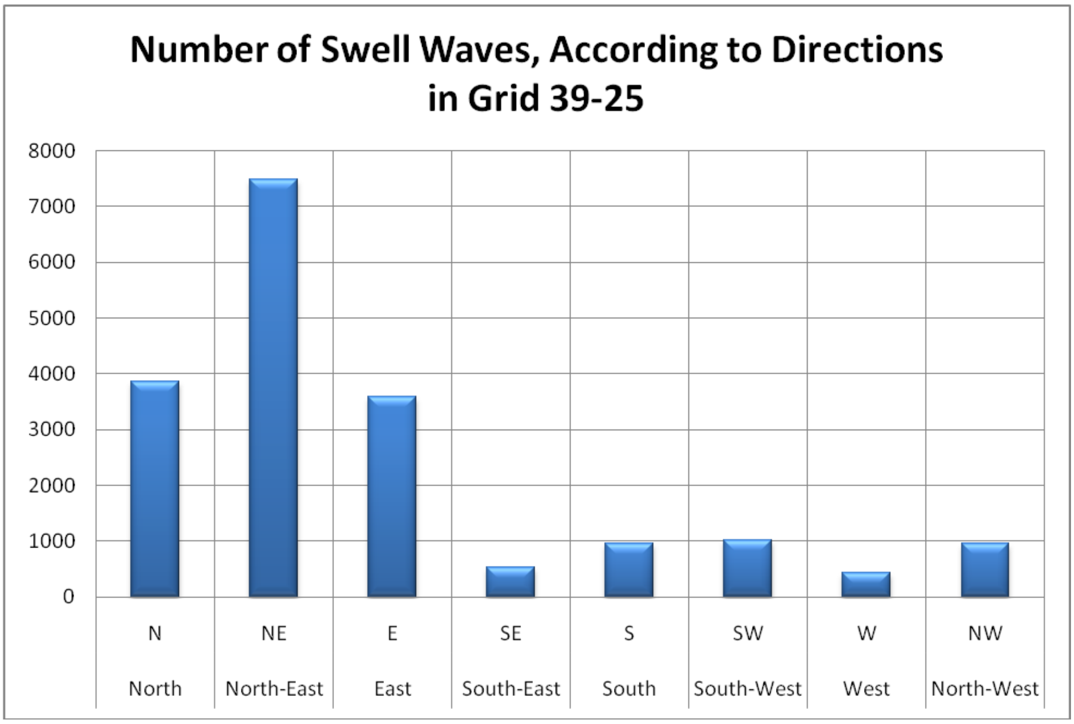


Figure 5.4 Number of Swell Waves According to Directions in Grid 39x25 (İğneada)

The rose diagram of number of swell waves according to 15^0 intervals of directions at 39x25 grid node in İğneada region is given in Figure 5.5. It is seen from Figure that, the number of swell waves, coming from the direction between 60^0 and 75^0, is more than the other directions.

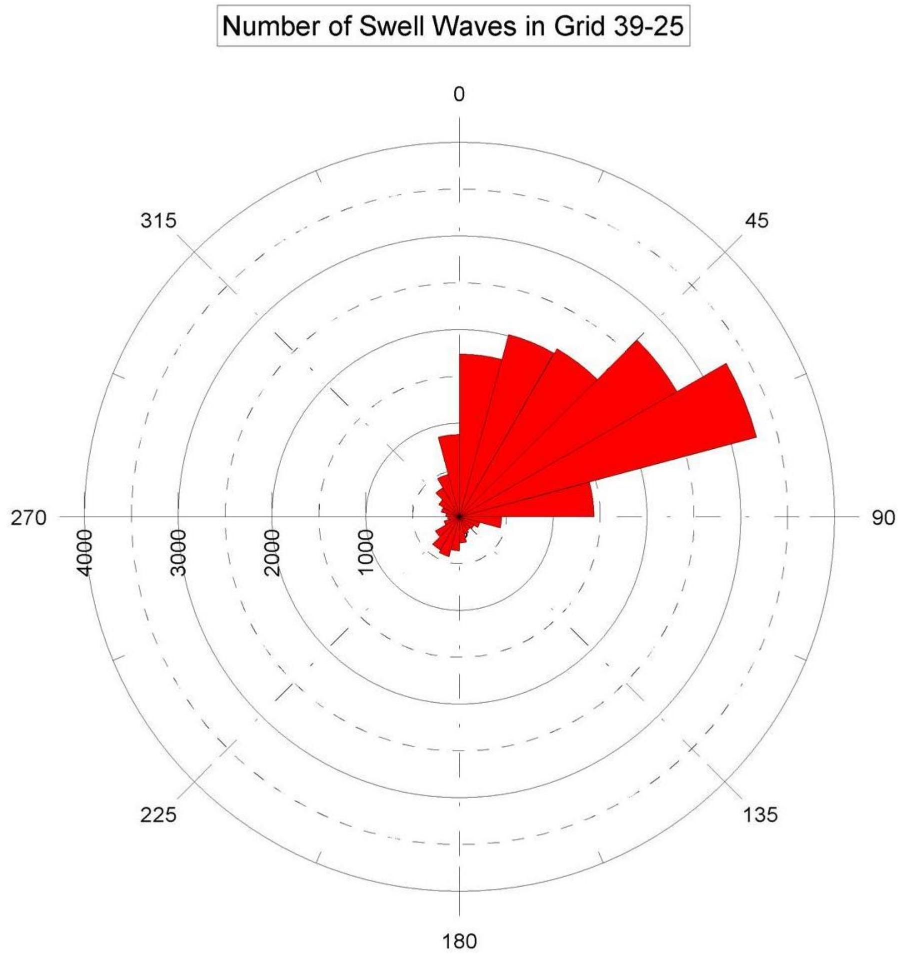


Figure 5.5 The Rose Diagram of Number of Swell Waves According to 15^0 Intervals of Directions at 39x25 Grid Node in İğneada Region

The polar bar chart of distribution of average wave powers according to directions of each swell wave at 39x25 grid node in İğneada region is given in Figures 5.6. It is seen from the Figure that, almost all power of swell waves, comes from the directions between 0^0 and 90^0 in İğneada.

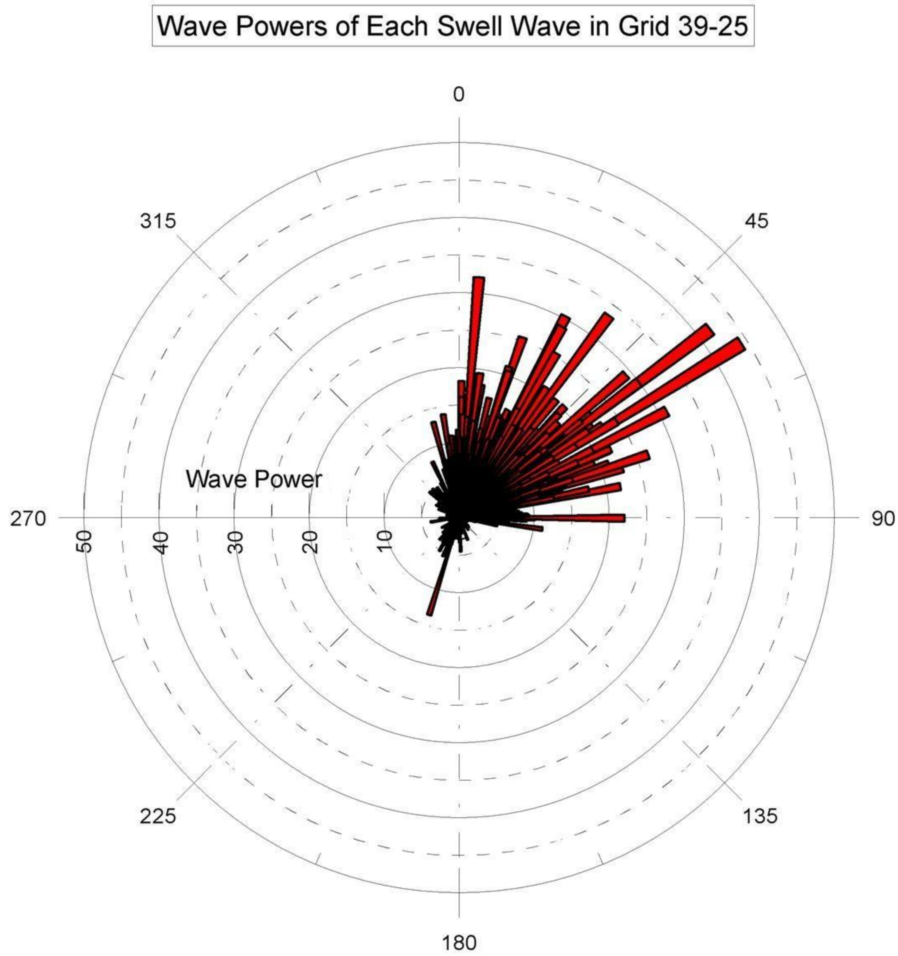


Figure 5.6 The Distribution of Average Wave Powers According to Directions of Each Swell Wave in Grid 39x25 (İğneada)

The graph of the directional wave power duration curves of swell wave at 39x25 grid node in İğneada region is given in Figure 5.7. When Figure 5.7 is examined, wave power duration curve of north-east direction is higher than wave power duration curves of other directions. In other words, north-east direction suggested as the best direction to harness the swell wave energy.

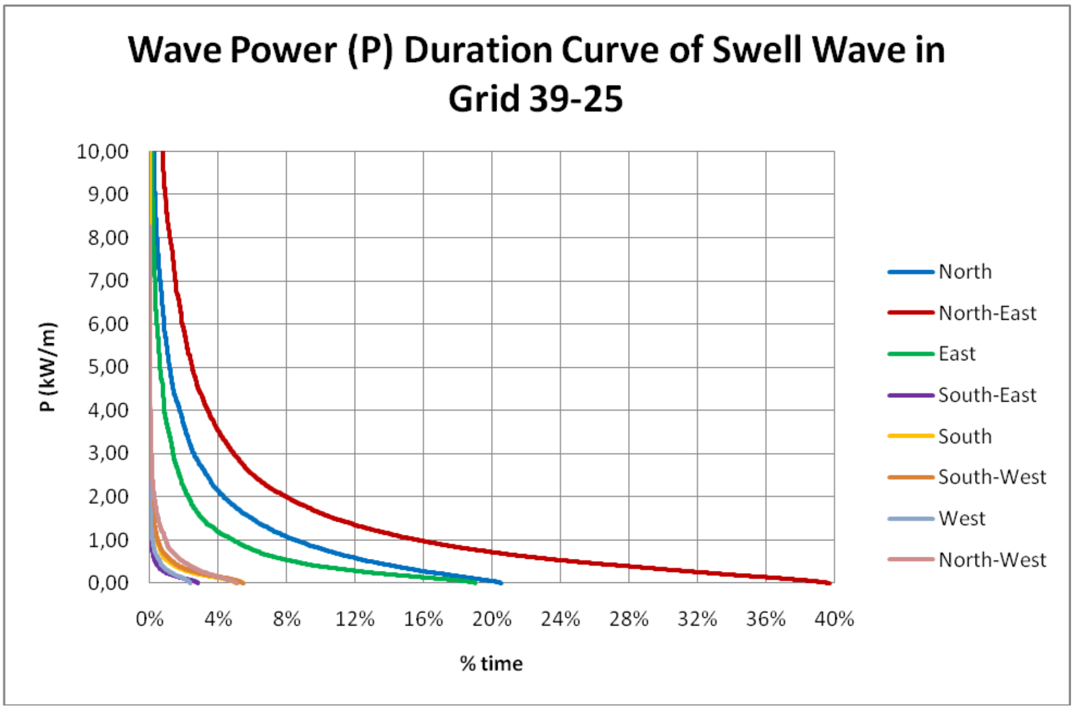


Figure 5.7 Directional Wave Power Duration Curves of Swell Waves in Grid 39x25 (İğneada)

The chart of directional distribution of wave power of swell waves at 39x25 grid node in İğneada region is given in Figures 5.8. When Figure 5.8 is examined, wave powers of swell waves, coming from north-east direction, are more than the others.

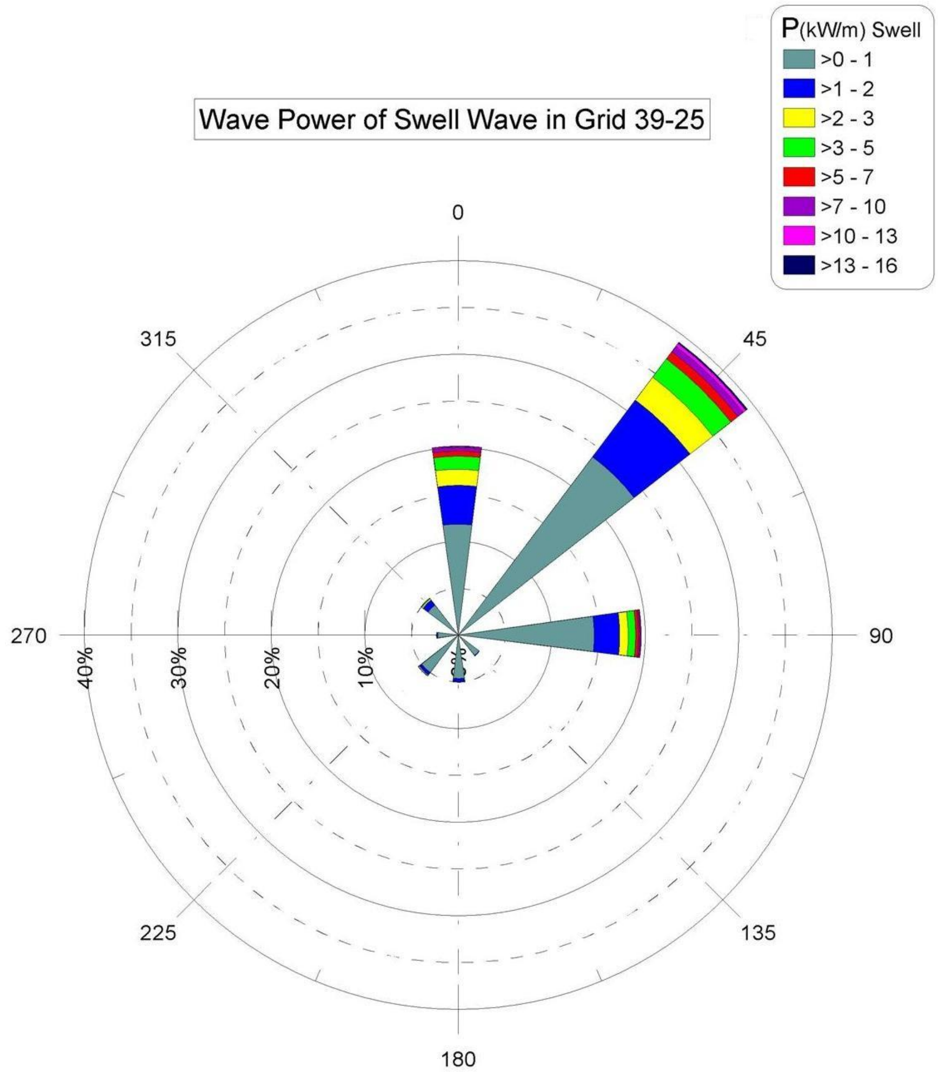


Figure 5.8 Directional Distribution of Wave Power of Swell Waves in Grid 39x25 (İğneada)

The bar chart showing the number of wind waves according to directions at 39x25 grid node in İğneada region is given in Figures 5.9. When Figure 5.9 is examined, number of swell waves, coming from north-east direction, is 4609 and more than the others.

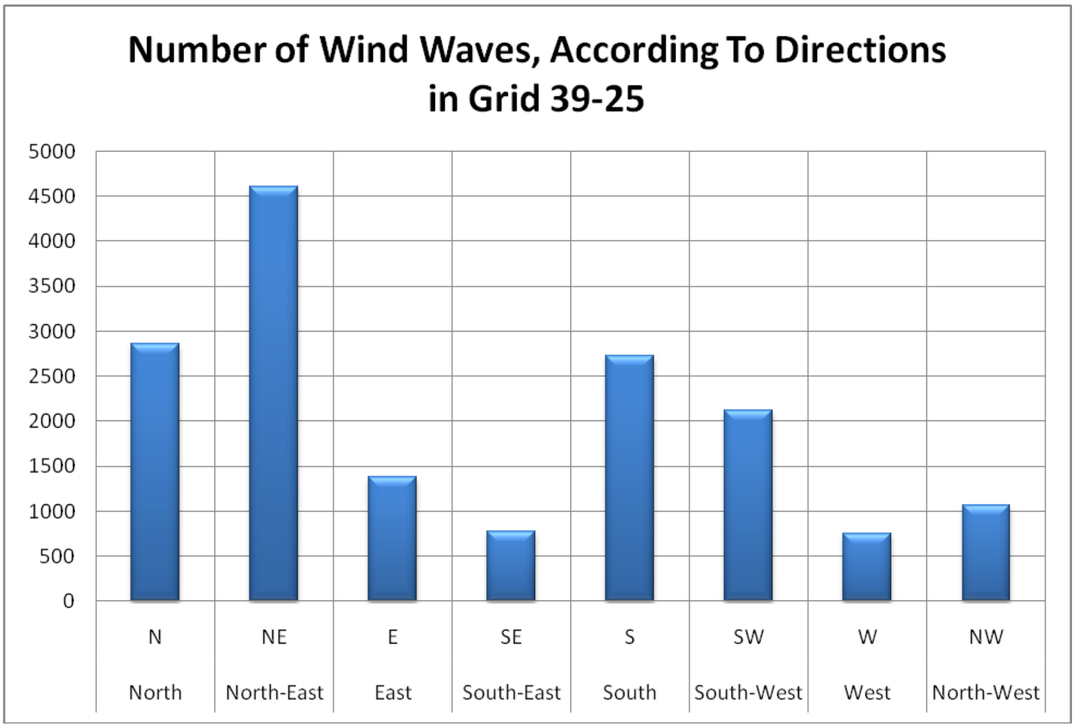


Figure 5.9 Number of Wind Waves According to Directions in Grid 39x25 (İğneada)

The rose diagram of number of wind waves according to 15^0 intervals of directions at 39x25 grid node in İğneada region is given in Figure 5.10. When Figure 5.10 is examined, the number of wind waves, coming from the direction between 45^0 and 60^0, is more than the others.

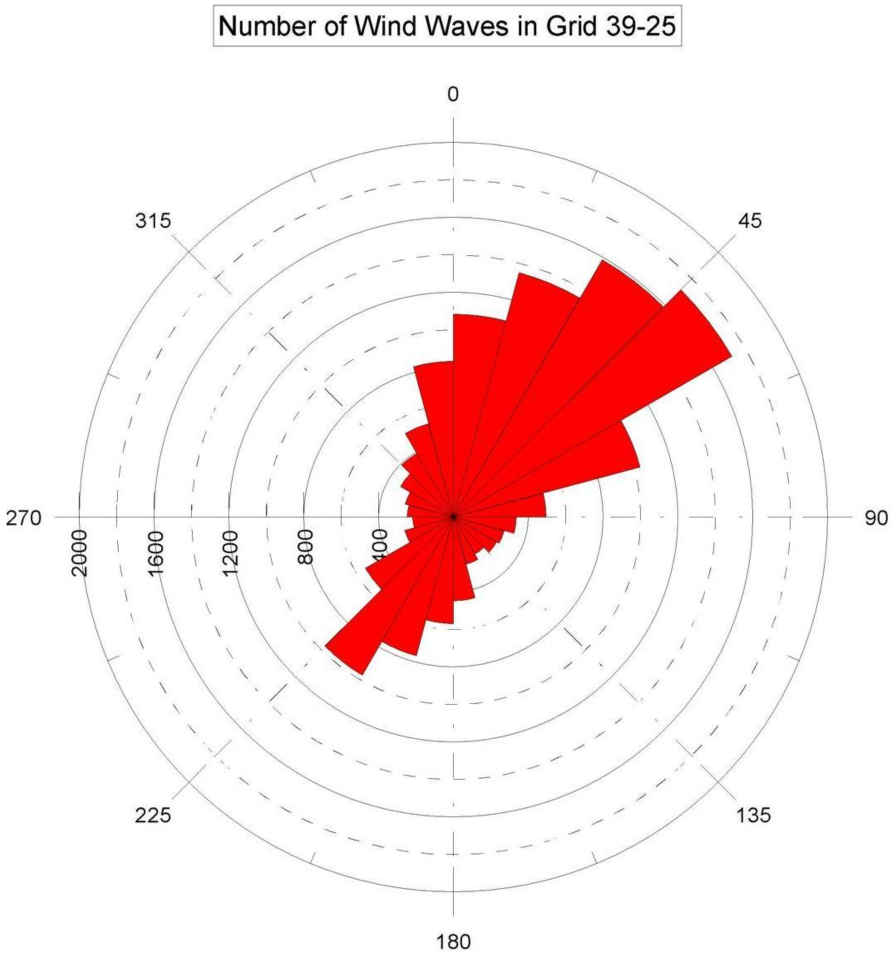


Figure 5.10 The Rose Diagram of Number of Wind Waves According to 15^0 Intervals of Directions at 39x25 Grid Node in İğneada Region

The polar bar chart of distribution of average wave powers according to directions of each wind wave at 39x25 grid node in İğneada region is given in Figure 5.11. When Figure 5.11 is examined, almost all power of wind waves comes from the directions between 0^0 and 90^0 in İğneada.

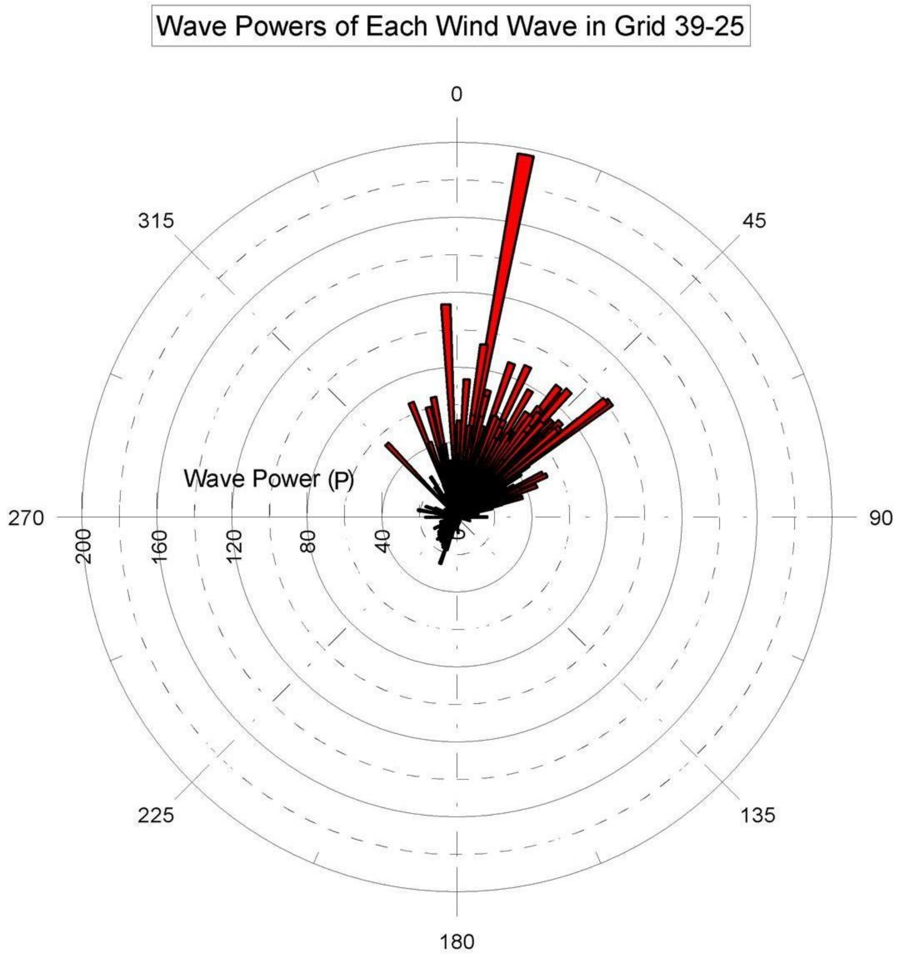


Figure 5.11 The Distribution of Average Wave Powers According to Directions of Each Wind Wave in Grid 39x25 (İğneada)

The graph of the directional wave power duration curves of wind wave at 39x25 grid node in İğneada region is given in Figure 5.12. It is seen from the Figure that, wave power duration curve of north-east direction is higher than wave power duration curves of other directions. In other words, north-east direction suggested as the best direction to harness the wind wave energy.

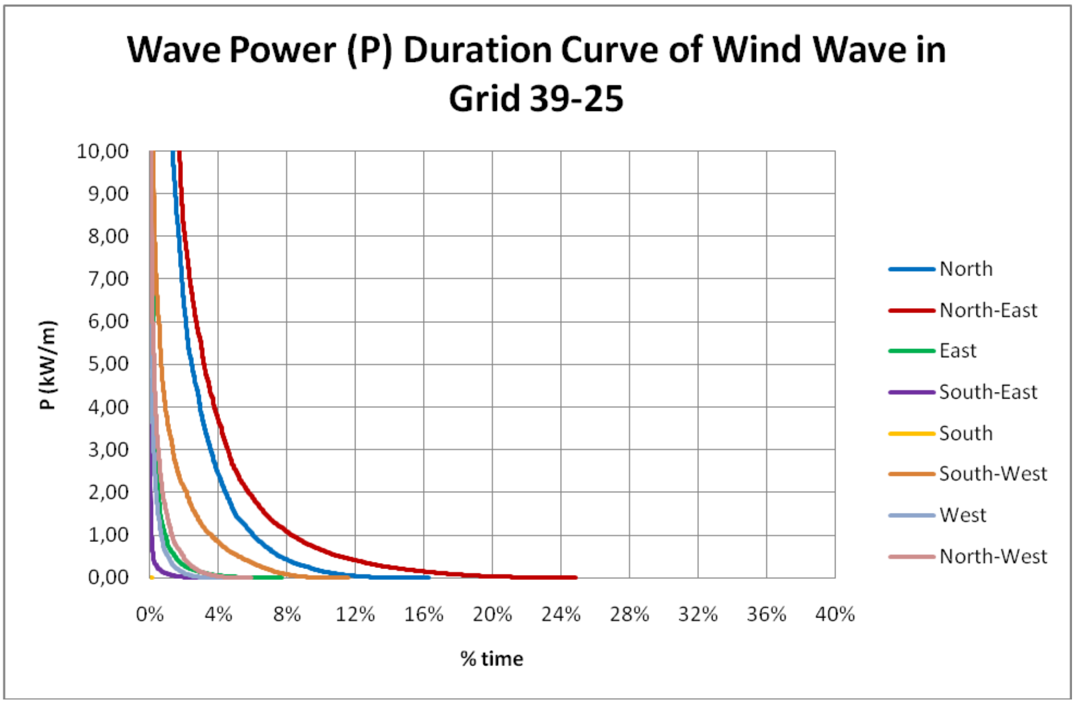


Figure 5.12 Directional Wave Power Duration Curves of Wind Waves in Grid 39x25 (İğneada)

The chart of directional distribution of wave power of wind waves at 39x25 grid node in İğneada region is given in Figure 5.13. It is seen from the Figure that, wave powers of wind waves, coming from north-east direction, are more than the others.

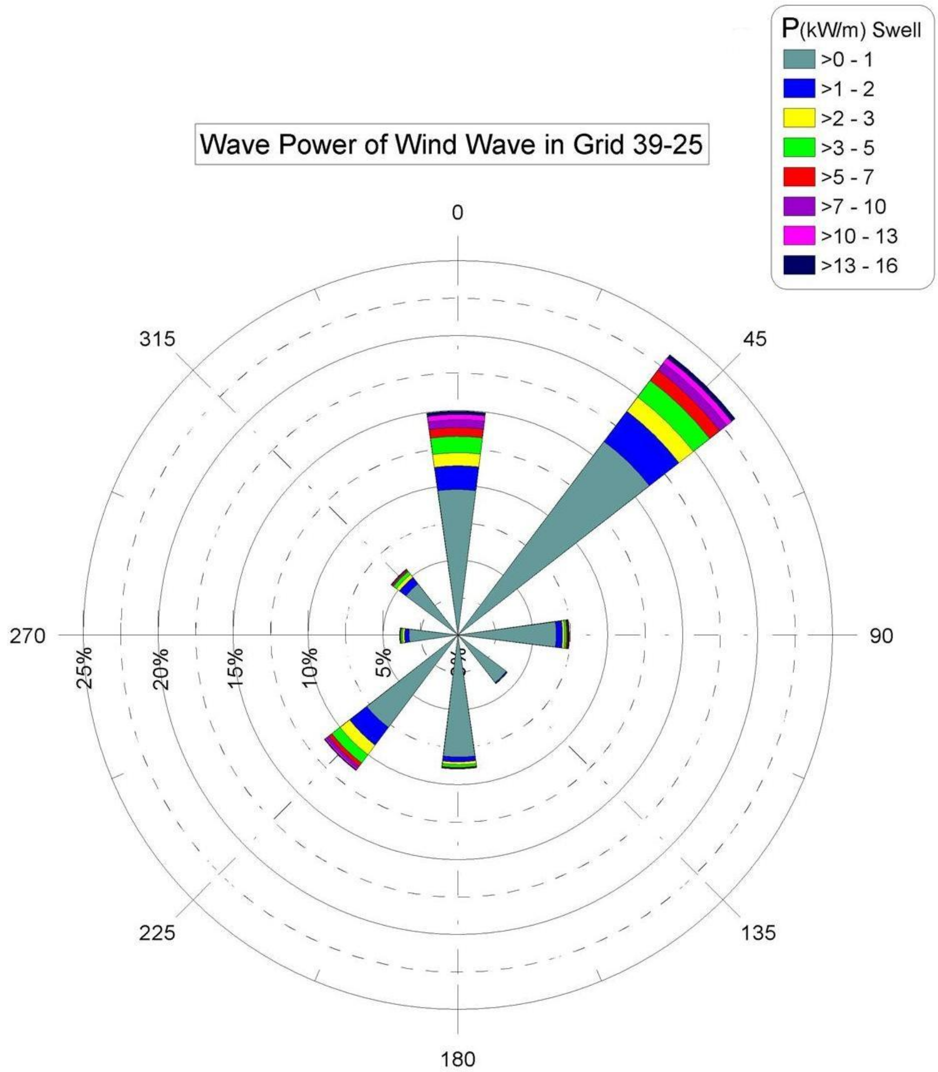


Figure 5.13 Directional Distribution of Wave Power of Wind Waves in 39x25 (İğneada)

The swell wave energy at 39x25 grid node in İğneada region is 10 406 kWh/m/year.

The rose diagram of swell wave energy (kWh/m/year) according to 45^0 intervals of directions at 39x25 grid node in İğneada region is given in Figure 5.14. When Figure 5.14 is examined, swell wave energy, coming from north-east direction, is 5 335 kWh/m/year and more than the others. Swell wave energy, coming from north, is 2 640 kWh/m/year and swell wave energy, coming from east, is 1 631 kWh/m/year.

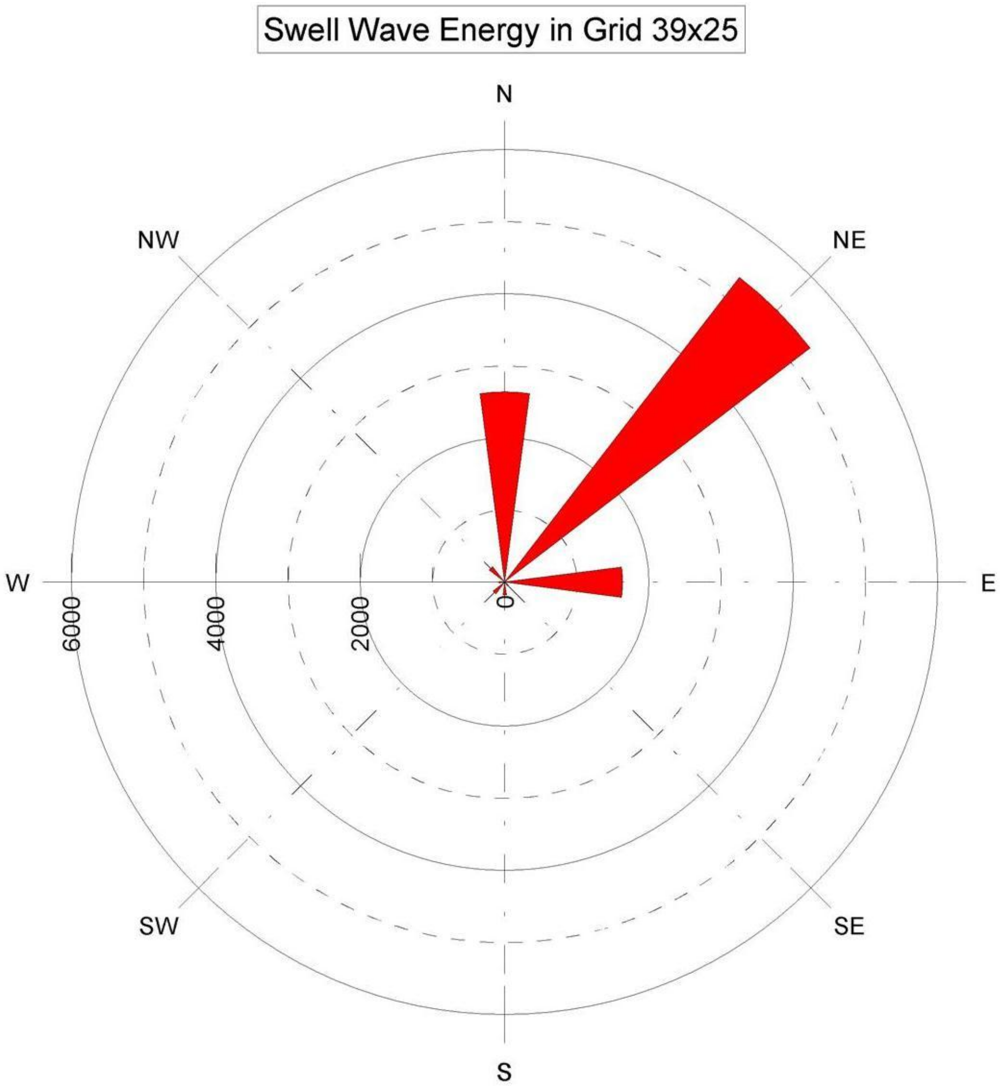


Figure 5.14 The Rose Diagram of Swell Wave Energy (kWh/m/year) According to 45^0 Intervals of Directions at 39x25 Grid Node in İğneada Region

The wind wave energy at 39x25 grid node in İğneada region is 13 311 kWh/m/year.

The rose diagram of wind wave energy (kWh/m/year) according to 45^0 intervals of directions at 39x25 grid node in İğneada region is given in Figure 5.15. When Figure 5.15 is examined, wind wave energy, coming from north-east direction, is 6 230 kWh/m/year and more than the others. Wind wave energy, coming from north, is 4 319 kWh/m/year and wind wave energy, coming from south-west, is 1 227 kWh/m/year.

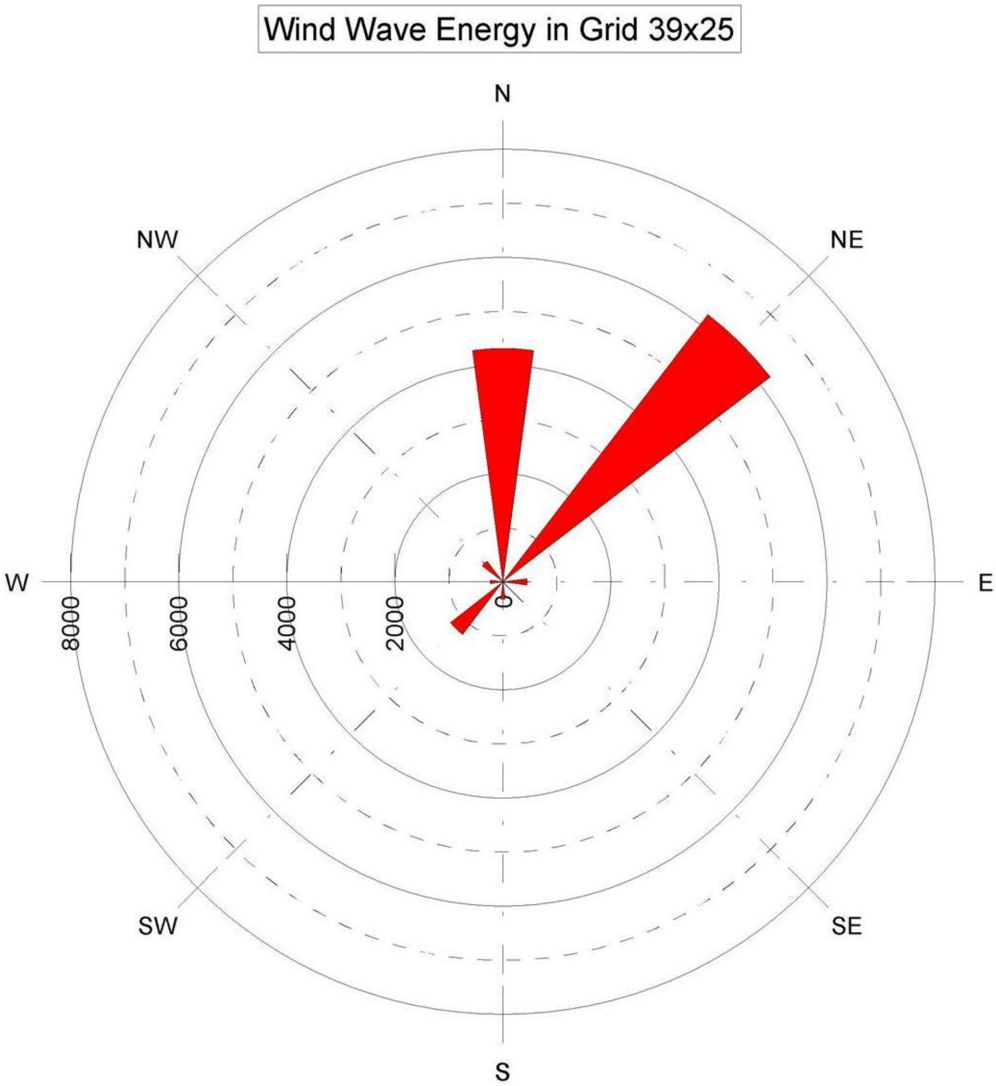


Figure 5.15 The Rose Diagram of Wind Wave Energy (kWh/m/year) According to 45^0 Intervals of Directions at 39x25 Grid Node in İğneada Region

The total wave energy at 39x25 grid node in İğneada region is 23 717 kWh/m/year.

The rose diagram of total energy (kWh/m/year) of swell and wind waves according to 45^0 intervals of directions at 39x25 grid node in İğneada region is given in Figure 5.16. When Figure 5.16 is examined, wave energy, coming from north-east direction, is 11 545 kW/m/year and more than the others. Wave energy, coming from north, is 6 959 kW/m/year and wave energy, coming from east, is 2 078 kW/m/year.

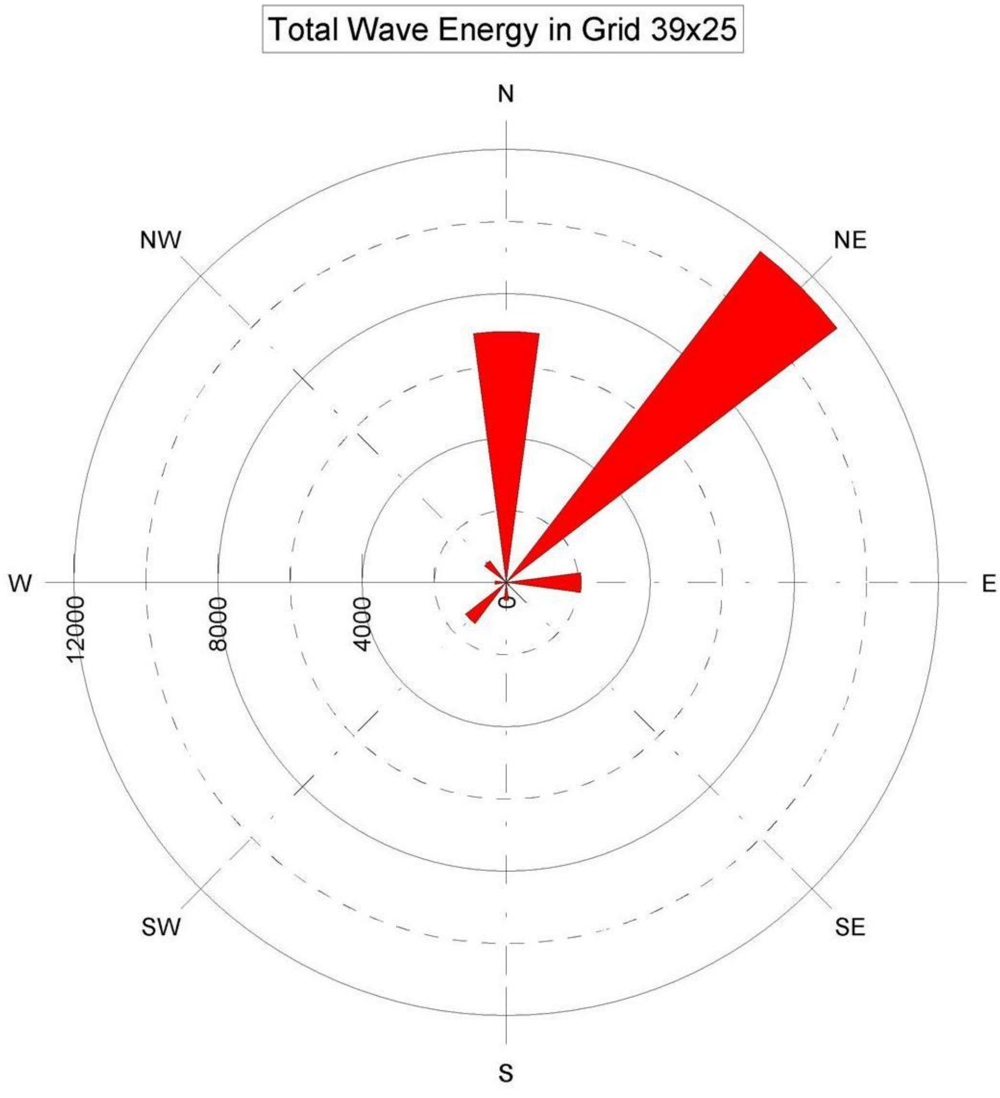


Figure 5.16 Total Energy (kWh/m/year) of Swell and Wind Waves According to Directions in Grid 39x25 (İğneada)

The total wave energy at 39x25 grid node in İğneada region is 23 717 kWh/m/year. Current wave energy converter's (WEC) efficiencies are accepted to be around 50 % (Hagerman G. and Bedard R., 2004). If an energy conversion plant, 100 meters wide, is established in İğneada region to harness the wave energy with 50 % efficiency, then it can produce (23 717,22 x 100 x 50 %) 1 185 861 kWh/year. In 2009, according to TEDAŞ, annual electricity consumption per capita is about 2 162 kWh in Turkey. Thus, if the annual electricity consumption in 2009 is taken into account, then the electricity need of the population equivalent of about (1 185 861 / 2 162) 548 persons can be meet with the wave energy converter plant (WEC) which has 100 meter width.

CHAPTER 6

CONCLUSION

In this study swell and wind wave energy in Black and Mediterranean Sea is attempted to be enlightened by analysis of certain swell wave, wind and wave data. The data used in this study is obtained from the ECMWF Data Server. [ECMWF, 2008] The data is obtained for the whole Black and Mediterranean Sea basin. The data period is between 01.01.1996 to 31.12.2008, totally 156 months in length. Analyses were made for five regions (20 grid node) along the Black Mediterranean Sea coastline of Turkey.

In this study the five regions (20 grid node) are analyzed separately and for every location results are presented graphically via software used in this thesis study called WWIA-SIM 2.2. The joint distribution of significant height of swell wave and mean period, the joint distribution of significant height of wind wave and mean period, duration curve for significant height of swell wave and mean period, duration curve for significant height of wind wave and mean period, duration curve for the swell wave power and duration curve for the wind wave power are provided for the regions and are presented in the 4th chapter. The 4th chapter thus presents the swell and wind wave energy for the coast of the Black Sea, the Mediterranean Sea. In the 5th chapter, comparison of the results is given.

In this thesis, the wind data is used to determine the wave energy potential. When the obtained datas are processed and edited, corrupted datas inside them were observed. Because of these errors are not used in calculations, the obtained numbers of storms and the powers of these storms are expected to be larger in reality. In addition, in this study, wind waves and also swell waves are taken into account. When these factors are taken into consideration, to make a long-term wave measurements in the selected regions is necessary for determining the true potential of wave energy in the selected regions.

Although the technology is relatively new and currently not economically competitive with more mature technologies such as wind energy, the interest from governments and industry is steadily increasing. An important feature of sea waves is their high energy density, which is the highest among the renewable energy sources. The idea of converting the energy of sea surface waves into useful energy forms is not new. Many wave energy converters are designed and models are tested. Wave energy converter (WEC) technology is still at the R&D phase. Without the subsidies, the electricity production cost still is not as low as the cost of electricity produced by thermal fuels. New technologies still can be developed to add wave energy to the other sources of energy in Turkey.

As set forth in this thesis, in certain coastal areas, wave energy can be generated at usable scale. The regions in the west of the Black Sea in the north of Istanbul Straits have been suggested as the best sites to harness the wave energy. Wave farms can be set up at two main regions north-west (İğneada region) and north (Sinop region) among selected five regions in this study.

The results of this study are based on the ECMWF data for academic purposes. The comparison and verification of ECMWF Data with the measurement and other methods are necessary in order to come to more precise estimations of wave energy potential around Turkey. It is highly recommended and emphasized that these results cannot be applied to any application or project without the consent and approval of the author and supervisor of this thesis.

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