EVALUATION OF EXTREME WAVE STATISTICS BY USING TWO WIND DATA SETS FOR WESTERN BLACK SEA REGION IN TURKEY

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ABSTRACT

EVALUATION OF EXTREME WAVE STATISTICS BY USING TWO WIND DATA SETS FOR WESTERN BLACK SEA REGION IN TURKEY

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Design of coastal structures in Turkey depends on wind measurements since on-site wave measurements either do not exist or very limited. Two of the most commonly used wind data sets, meteorology and ECMWF, are decided to be compared and analyzed in terms of extreme wave characteristics to see their effects on design process when different data sets are utilized. For this purpose, seven points are selected along western coast of Black Sea in Turkey and both data sets are acquired from their respective sources. These data are re-arranged and organized to make them compatible with programs necessary for analysis, namely wind.exe and W61. For each location, graphical and numerical comparisons are made by plotting scatter graphs and wind roses for visualization and extreme analysis for numeric calculations. Obtained results and previous studies around selected regions are compared and results are presented. Also, an additional research on historical storm events based on online sources of local and national media is presented and results are compared with available data sets.

Keywords: Western Black Sea, Meteorology, ECMWF, Wind Data, Extreme Wave Statistics

ÖZ

TÜRKİYE’NİN BATI KARADENİZ BÖLGESİ İÇİN İKİ RÜZGAR VERİ SETİ KULLANILARAK EN YÜKSEK DALGA DEĞERLERİNİN HESAPLANMASI

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Yerinde yapılan dalga ölçümleri kısıtlı veya var olmadığından dolayı Türkiye’deki kıyı yapılarının tasarımları rüzgar ölçümlerine dayanmaktadır. Farklı rüzgar veri setleri kullanıldığı takdirde, bu setlerin tasarıma olan etkilerini görebilmek amacıyla Türkiye kıyılarında en çok kullanılan veri setleri olan meteoroloji ve ECMWF veri setleri analiz edilip en yüksek değerler istatistiği bakımından karşılaştırılmıştır. Bu amaçla, Türkiye’nin Karadeniz’in batısında kalan kıyılarından yedi adet nokta seçilip, noktalardaki veri setleri kendi kaynaklarından elde edilmiştir. Bu veriler analiz için gerekli olan wind.exe ve W61 programlarına uyumlu hale getirilebilmek için tekrardan düzenlenmiştir. Her bir bölge için dağılım grafiği ve rüzgar gülleri kullanılarak görsel karşılaştırmalar ve en yüksek değerler istatistiği kullanılarak sayısal karşılaştırılmalar yapılmıştır. Elde edilen sonuçlar geçmiş çalışmalar da kullanılarak değerlendirilmiş ve sonuçlar sunulmuştur. Ayrıca, yerel ve ulusal medya haber siteleri ve bunların arşivlerinden elde edilen geçmiş fırtınalara ait bilgiler ışığında mevcut veri setleri bu araştırma ile de karşılaştırılmıştır.

Anahtar Kelimeler: Batı Karadeniz, Meteoroloji, ECMWF, Rüzgar Verileri, En Yüksek Dalga İstatistiği

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CHAPTER 1

INTRODUCTION

Accurately predicting design wave height for coastal structures is one of the most important aspects in coastal engineering field. Due to inaccurate designs, construction cost can yield too high values which can easily turn an appealing investment option into a financial black hole or it can also mean loss of lives because of defective designs. In Turkey, this prediction solely depends on available wind data since on site measurements are very limited or non-existent on many of the locations. Although there exists several data sets covering the Turkish coastlines, the most commonly used ones are the meteorology data set, obtained from meteorology stations of Turkish State Meteorological Service and wind data provided by The European Centre for Medium-Range Weather Forecasts (ECMWF).

These two data sets are fundamentally different than each other when their measurement methods and measurement points are considered. These differences should affect the design waves calculated from both data sets thus, an extensive comparison is necessary between two data sets focusing not only wind measurements but also wave characteristics so that most useful data set can be found for different regions and more precise designs can be performed.

For study area, coasts of Turkey have been investigated and Black Sea region, where the most powerful and highest number of storms occurred, is found suitable. Since the amount of data for whole region is tremendous, it is decided to narrow down the study area. From previous investigation, it is found that generally, most intense storms periodically occur at western part of Black Sea each year and damage inflicted on infrastructures and properties is substantial. Also, it should be kept in mind that many economically invaluable structures are located in west coast like Sinop, Şile and Karasu Ports, as well as future projects like Filyos Port in Zonguldak. So, the study area is confined with western part only. Several points have been selected along west coast and comparison and analysis of both data sets is performed.

This study aims to:

- Compare the two data sets used in design of coastal structures to determine the level of discrepancy.
- Determine the impact of selection of data set to be used in the design to calculate the significant wave height.
- Determine the reliability of the representation of different wind data sets (Meteorology and ECMWF) in Black Sea coast of Turkey by using information on historical storm events.

Although comparison of these data sets with on-site buoy measurements is necessary for an accurate validation, any significant discrepancies and/or good fit of both data sets would strengthen the reliability of the overall design of structures. This information will determine the uncertainty related to the input data for a design problem.

For these purposes;

- In chapter 2, a literature review covering most common wind data sets is performed as well as an investigation on previous studies on Black Sea region containing wind and/or wave comparisons.
- In chapter 3, data sets, programs and methodology are explained. As previously stated before, two types of data sets are used in this study. This chapter presents the general view of these data sets and differences between

them, stating their measurement points and methods. Selected points for analysis and comparison along west coast are also presented in this chapter. In addition, methodology is presented in which used programs and corrections performed are explained in detail.

- In chapter 4, results of the analysis showing graphical and numerical comparison and extreme statistics are presented. Comparison and analysis are performed for all selected points on west coast and results and discussions are presented in detail. Also, possible reasons for the differences are investigated and additional research on past events around selected points is also implemented.
- In chapter 5, conclusions and future recommendations are given based on the results and discussions on chapter 4.

CHAPTER 2

LITERATURE REVIEW

In this chapter, general view on wind measurements by the most commonly used wind data sets in Turkey and previous studies on Black Sea coast of Turkey concerning wind and wave characteristics are presented.

2.1 WIND MEASUREMENTS

Wind data sets of ECMWF and Turkish State Meteorological Service's meteorology stations are included in this study. These two sources measure wind velocities in different ways and their measurement ways are explained in the following sections.

2.1.1. ECMWF

The European Centre for Medium-Range Weather Forecasts (ECMWF) is an international independent organization founded in 1975 with 28 current members. It is based in London, United Kingdom. The organization develops and operates global models and data assimilation systems as well as storing resultant data which is available to all of its members.

ECMWF stores 4 different types of archives. These are Operational Archive, ERA-15, ERA-40 and ERA-Interim. ERA (ECMWF Re-Analysis) archives contain global re-analysis and short range forecasts of weather parameters. In this study, only operational archive is used. This archive is divided into eight classes and from these classes atmospheric model is used in this study. In terms of space resolution and time duration, atmospheric model is the most resourceful model and best fitting one for case studies. Also, this model contains thirteen different data sets. From these sets, surface analysis data set is used for wind data for this study. This data set contains 6-hour forecasts for each day.

(http://old.ecmwf.int/products/data/archive/descriptions/od/oper/index.html)

2.1.2. Meteorology Stations

The most commonly used wind data set in Turkey belongs to Turkish State Meteorological Service’s meteorology stations. These stations utilize several measurement methods like ground and ship observations, radar and satellite images but majority of their data come from automatic meteorological observation stations, otomatik meteoroloji gözlem istasyonu (OMGİ). There are total 861 OMGİ stations along coastal regions in Turkey. These stations automatically measures wind velocities and directions on land at 10 m. height and these data are transmitted to related departments with minimal error margin. Acquired data is analyzed and used in forecast models. (www.mgm.gov.tr)

2.2. PREVIOUS STUDIES ON BLACK SEA COAST OF TURKEY

There exist several studies concerning Black Sea region of Turkey but these studies are very limited and none of them utilized both data sets for Black Sea region. In this section these previous studies are summarized.

“Özhan, E and Abdalla, S.: Turkish Coast Wind and Deep Water Wave Atlas, 1999” is one of the important studies on wind and wave climate on Turkish coasts, mainly because continuous data collection is achieved and wave data is presented. It covers not only Black Sea coasts but also Aegean Sea, Marmara Sea and Mediterranean coasts. Yearly and seasonal wind and wave roses, extreme value analyses and significant wave height vs. mean wave period relations are presented for each location for wind velocities and significant wave heights. 8 years of continuous data for every 3 hours are used in Özhan, E and Abdalla, S., 1999 study for long term analysis. Also, for Black Sea, 20 years of maximum wind velocity and wave height data (1976-1995) is used for extreme analysis.

“K. E. Saraçoğlu: The wave modeling and analysis of the Black Sea and the Sea of Marmara, 2011” is a wave modeling and comparison study on Black Sea and Sea of Marmara. Third generation Mike 21 SW wave model is utilized to find out wave characteristics like significant wave height and mean wave period, as well as extreme significant wave heights for 8 year analysis period by using ECMWF data set as input. In addition, results of this model are compared with previously stated Özhan, E and Abdalla, S., 1999 research. Study concludes that both sources seem to be compatible for Black Sea region, whereas they are not consistent for Sea of Marmara.

“Ergin, A. and Özhan, E.: 15 Deniz Yöresi İçin Dalga Tahminleri ve Tasarım Dalgası Özelliklerinin Belirlenmesi, 1986” is a research to find wave parameters by using wave hindcast methods for 15 regions. For this purpose, wind data and synoptic maps are acquired from meteorology stations. Both wind data and synoptic maps are analyzed by using extreme analysis methodology. Gumbel distribution model is selected as the best fitting model and significant wave height vs. return period graphs are plotted for 15 regions on probability distribution papers for the results of wind data and synoptic maps of meteorology stations.

“Berkün, U.: Wind and Swell Wave Climate for the Southern Part of Black Sea, 2007” is a research on south of Black Sea focusing on swell waves. In Berkün, U. (2007) study, 65 months of ECMWF data between 01.10.2000 and 28.02.2006 were used. Wind and swell wave data were extracted from ECMWF archives and used for log-linear cumulative probability distributions, and to find out return periods from extreme analysis. Also, significant wave height vs. mean wave period graphs were plotted and wind and wave roses were presented and compared with Özhan, E and Abdalla, S., 1999 study and showed good correlation in general. However, all of the selected points for analysis aligned along 42^0 N latitude, which means that these points were selected just to cover entire Black Sea region without considering geography of the region itself. Also, duration of used data is very limited which may create unreliable results (Goda, 2000).

“Çaban, S.: Wind and Wind Wave Climate Research along the Southern Part of Black Sea, 2007” is another research based on Berkün, U. (2007). Only difference of Çaban, S. (2007) study is that wind waves are used instead of swell waves. Same exact procedure and same points were analyzed in Çaban, S. (2007) thesis. Like swell waves, wind waves for 65 months between 01.10.2000 and 28.02.2006 were also extracted from ECMWF archives, from Mediterranean wave model data set. Results are again in good correlation with Özhan, E and Abdalla, S., 1999 study in general. Çaban, S. (2007) study is compared with extreme analysis results in this study rather than Berkün,U. (2007) since it utilizes wind waves rather than swell waves.

“Bilyay, E., Ünal A., Özbahçeci, B.O. and Yalçıner, A.C.: Extreme Waves at Filyos, Southern Black Sea, 2010” is an extensive study on surrounding area of Filyos Harbor. Two years of wave data were used. Statistical and spectral analyses on extreme waves were performed in detail. Bilyay, E. et al., 2010 research is important not only because it is a fully detailed research but also continuous wave data measurements were made for two consecutive years which is quite rare for Turkish coasts.

“Özyurt, G. and Özbahçeci, B.Ö.: Tasarım Dalgasının Bulunmasında Dağılım Modelinin Etkisi, 2008” is a study dedicated to find the best distribution model for Black Sea region. It uses the results of the Özhan, E and Abdalla, S., 1999 study which assumes that the data follow Gumbel distribution. Study utilizes a unique numbering system for different distribution models to find out the best fitting model for each study region and significant wave heights are also calculated and compared with Özhan, E and Abdalla, S., 1999 study results. It is found out that assuming Gumbel distribution as the correct one yields significantly different results for certain areas.

Since there are only handful of studies made on south of Black Sea, four more studies are also presented here which are loosely related to this study.

First study is “Şahin,C.: Parametric Wind Wave Modeling and Western Black Sea Case Study, 2007”. Aim of Şahin, C., 2007 study is to develop a wave hindcast model by utilizing available wave data to envisage wave parameters. For this purpose a model has been prepared by using CERC (1984) equations. This model has been tested with 8 months of available data for Black Sea region and results were compatible.

Another study is “Akbaşoğlu, S.: Short Term Statistics of Wind Waves around the Turkish Coast, 2004” which is based on wind wave records on three locations one of which is Artvin, Hopa. Probability distributions of individual wave characteristics were found and comparisons were made with the model distribution. Also joint probability distributions were performed and presented as well as a comparison with found results and statistical wave parameters.

Third study is “Akpınar, A.: Wave Modeling and Wave Power Potential Determination in the Black Sea, 2012”. By using ECMWF ERA Interim wind fields, wave parameters are hindcasted by using SWAN wave prediction model. Also wave parameters are estimated by using 4 models and 2 wind sources at Hopa and Sinop buoy stations where wave data is available. Results of SWAN, models and hindcasted ECMWF wave data are compared with available wave data at Hopa and Sinop. It is concluded that SWAN model gives the best results. SWAN model is used for entire Black Sea region to find out wave power differences for different regions. It is concluded that western Black Sea region in Turkey has the largest potential wave power.

Last study presented in this chapter is “Yılmaz,N.: Spectral Characteristics of Wind Waves in the Eastern Black Sea, 2007”. In Yılmaz, N., 2007 study, spectral characteristics were investigated by using three sets of wave data which were collected from deployed buoys at Sinop, Hopa and Gelendzhik. Single peaked spectra were investigated. By utilizing a least square error method, model parameters of JONSWAP and PM were estimated for calculated spectra.

CHAPTER 3

DATA SETS, PROGRAMS AND METHODOLOGY

3.1. DATA SETS

Seven points have been selected for comparison and analysis. For this purpose, two available types of data sets are used. These are meteorology data acquired from Turkish State Meteorological Service and ECMWF data acquired from its website (http://data-portal.ecmwf.int). These data sets are explained in detail in the sections 3.1.1. and 3.1.2.

3.1.1. Meteorology Data Sets

Wind velocities and directions are hourly measured by dozens of meteorology stations on the coasts of Turkey. These measurements are performed on land and at 10 m height.

For this study, west coast of Black Sea region is selected and as a start, meteorology stations have been selected for this region. All data from all of the stations have been acquired from Turkish State Meteorological Service. Some stations are found to be too inland and some stations have long period of data missing, so seven stations are found to be suitable for comparison and analysis on western coast. These stations and their station numbers are listed at Table 1.

Also, it is found that each data set from these stations has different start and end measurement dates. Moreover, there are certain gaps in each measurement. For example for Sinop data set, measurement starts at 1.11.1958 and there is no measurement for entire 1959 year. And for Zonguldak data set, measurement starts at 1.1.1975 and there is no measurement for 4 months between 01.02.2000-01.07.2000. Start and end dates of measurements for each station are summarized at Table 1.

Table 1 – General Information on Meteorology Stations

Station Name	Station Number	Measurement Start Date	Measurement End Date
İstanbul - Kilyos	17059	01.12.1966	31.03.2009
İstanbul - Şile	17610	01.09.1972	31.03.2009
Düzce - Akçakoca	17612	01.10.1970	31.03.2009
Zonguldak	17022	01.01.1975	31.12.2006
Bartın - Amasra	17602	01.10.1982	31.03.2009
Kastamonu - İnebolu	17024	01.01.1975	31.12.2006
Sinop	17026	01.11.1958	29.12.2006

The information provided by Meteorology is a text document with information on station number, year, month, day, hour, wind velocity and wind direction. General view of data set is shown at Figure 1.

```
17602;1982;10;1;0;6.3;ENE
17602;1982;10;1;1;6.6;ENE
17602;1982;10;1;2;6.5;ENE
17602;1982;10;1;3;4.4;E
17602;1982;10;1;4;3.8;E
17602;1982;10;1;5;3.4;E
17602;1982;10;1;6;3.3;ESE
17602;1982;10;1;7;4.2;E
17602;1982;10;1;8;4.2;ENE
17602;1982;10;1;9;4.8;NE
17602;1982;10;1;10;5.8;NNE
17602;1982;10;1;11;6.1;NNE
17602;1982;10;1;12;6.8;NE
17602;1982;10;1;13;7.2;NNE
17602;1982;10;1;14;7.8;NNE
17602;1982;10;1;15;8.9;NNE
17602;1982;10;1;16;9.9;NNE
17602;1982;10;1;17;9.2;ENE
```

Figure 1 – General View of Meteorology Data Set

Certain calculations are performed to make the meteorology data set compatible with various programs and for comparison and analysis which are explained in sections 3.3.1 and 3.3.2.

3.1.2. ECMWF Data Sets

ECMWF utilizes pressure data acquired from satellites and by means of numerical models, wind velocities in every six hours are calculated on sea at 10 m height. While meteorology stations have representative numbers, ECMWF data points are stored as coordinates.

For this study, seven points have already been selected for available meteorology stations. So, seven closest and available ECMWF data points have been selected for comparison and analysis. It should also be noted that, each ECMWF data point is representative for 0.1 degree grids (30.00 N and 30.00 E data point represents all the data between 29.95 N and 30.05 N and between 29.95 E and 30.05 E) and the measurements are for the sea only, so, the closest point to a meteorology station should be selected such that there is no land effect on the respective grid. Each closest point has been checked one by one and the ones that are too close to land are substituted with a further but next closest coordinate.

Selected coordinates are listed below;

- 41.30 N – 29.00 E (İstanbul - Kilyos data)
- 41.30 N – 29.60 E (İstanbul - Şile data)
- 41.20 N – 31.10 E (Düzce - Akçakoca data)
- 41.60 N – 31.80 E (Zonguldak data)
- 41.80 N – 32.40 E (Bartın – Amasra data)
- 42.10 N – 33.80 E (Kastamonu – İnebolu data)
- 42.00 N – 35.20 E (Sinop data)

All of these data sets start at 1.1.1983 and end at 31.10.2013.

ECMWF provides wind data into two columns only. First column is horizontal u component of wind velocity and second column is vertical v component of wind velocity. There are plus and minus signs for each velocity value. These signs indicate the directions. For example, 0.00 and -3.00 means 3 m/s wind from north direction.

Locations of both data sets are presented in the following figures from Figure 2 to Figure 8.

Selected coordinate for İstanbul – Kilyos is approximately 6 km away from selected meteorology station in NW direction.

Figure 2 – Layout of İstanbul – Kilyos Measurement Points

Selected coordinate for İstanbul – Şile is approximately 14 km away from selected meteorology station in N direction.

Figure 3 – Layout of İstanbul – Şile Measurement Points

Selected coordinate for Düzce – Akçakoca is approximately 13 km away from selected meteorology station in NNW direction.

Figure 4 – Layout of Düzce – Akçakoca Measurement Points

Selected coordinate for Zonguldak is approximately 17 km away from selected meteorology station in NNE direction.

Figure 5 – Layout of Zonguldak Measurement Points

Selected coordinate for Bartın – Amasra is approximately 5 km away from selected meteorology station in NNE direction.

Figure 6 – Layout of Bartın – Amasra Measurement Points

Selected coordinate for Kastamonu – İnebolu is approximately 14 km away from selected meteorology station in NNE direction.

Figure 7 – Layout of Kastamonu – İnebolu Measurement Points

Selected coordinate for Sinop is approximately 5 km away from selected meteorology station in SE direction.

Figure 8 – Layout of Sinop Measurement Points

Certain calculations are performed to make the ECMWF data set compatible with various programs and for comparison and analysis which are explained in sections 3.3.1 and 3.3.2.

3.2. PROGRAMS

Two different programs have been used for comparison and analysis. These programs are wind.exe and w61. These two programs should be used successively in order to create waves with provided wind data.

3.2.1. Wind.exe

This program has been supplied by METU, Coastal Engineering Department and used as a standard program for wind data. Basically, this program is used prior to w61 and it uses meteorology data as a standard format and performs various calculations to organize wind data and to find out storm durations.

Only file it requires as input is .dat file of wind data set. All columns and rows should be in the same format with meteorology data set. It also requires three different parameters, namely, minimum storm velocity, wave height group interval and period group interval. It also requires fetch distances for further use in w61.

Output files are txt files for each year, containing storm durations, wind velocities for each storm and start and end dates of storms. As an example, only a portion of storms for Bartın – Amasra data set is presented at Figure 9.

```
   18    2    1 1983   19    2    1 1983    1
 24 95
    6    6    1 1983   10    6    1 1983    4
 23125 23119 23103 23105
   12   16    1 1983   14   16    1 1983    2
 23108 23 97
    1   21    1 1983    8   21    1 1983    7
 13131 13126 13127 13166 13136 13136 13133
    2   24    1 1983   12   24    1 1983   10
 22138 23143 23162 23163 23164 23164 23135 23123 25 97 12 97
   14   24    1 1983    1   25    1 1983   11
 26100 26 97 26 99 26109 26130 25126 26136 26111 26106 26 97 26 98
    7    4    2 1983    8    4    2 1983    1
 22139
   13    4    2 1983    0    5    2 1983   11
 23185 23174 23158 23164 23161 23156 23164 23149 23125 23144 23117
    2   13    2 1983    5   13    2 1983    3
 22141 22148 22103
    3   16    2 1983    8   16    2 1983    5
 23118 22142 22112 22122 22117
   21   16    2 1983   22   16    2 1983    1
 11 95
```

Figure 9 – Example Output of Wind.exe Program

First row shows the first storm which is 1 hour storm only and started at 1.2.1983 at 18^{th} hour and ended at 19^{th} hour at the same day. Second row is the direction and magnitude of storm velocities for each hour. North direction is taken as 11 and rest of the directions continue clockwise, so 24 is WNW direction of a wind with 95 dm/s velocity.

In this study, only storm data is compared and analyzed, so, minimum value for storm velocity is chosen as 10m/s. But, since wind data are irregular in nature, hours of important data could be missed due to this threshold value so an error margin of 0.5 m/s is decided to be included. Thus, threshold is decided to be chosen as 9.5 m/s for both data sets.

Since the study is to compare the closest but different data sets, same fetch distances have been used for both data sets which are taken from closest shoreline for each meteorology station and its closest ECMWF data point.

Also, since the study area is black sea coast of Turkey, all southern wind data is excluded from analysis for both data sets. For this reason, all presented storm and wave data lack southern directions.

As an example, İnebolu station's parameters have been shown at Figure 10. For all stations and coordinates, 0.4 has been chosen as an interval parameter.

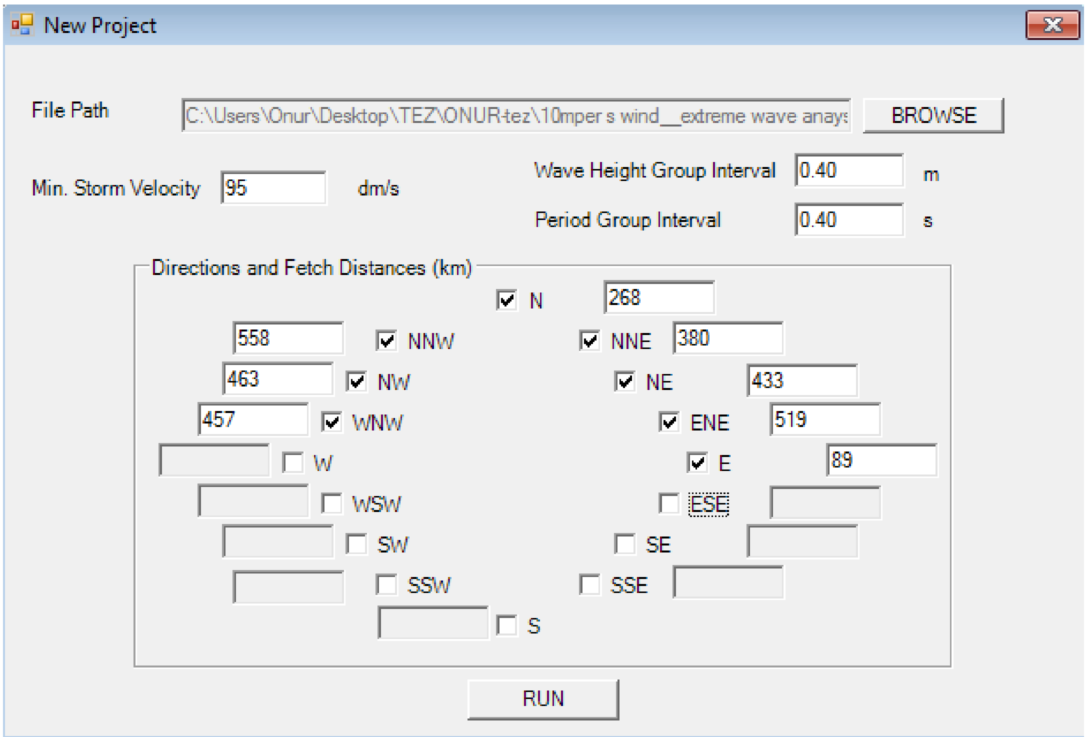


Figure 10 – Wind.exe Parameters for İnebolu Region

3.2.2. W61

This program is a FORTRAN code developed and used as a standard program for wind to wave transformations by METU, Coastal Engineering Department. It uses output of wind.exe program as input for each separate year. It uses various numerical and empirical equations to transform given wind velocities into wave data. Five output files are created with each runned input. These files are individual Hs and Ts values for each wave (program considers each wave as an output of 1 hour storm and creates Hs and Ts accordingly), average storm velocities, dates and durations of each storm, Hs and Ts values for each storm (unlike individual Hs and Ts file which gives 10 output for 10 hour storm, this file gives 1 output, which is the max Hs and corresponding Ts value in a 10 hour storm) and last file is the cumulative table for the number of the waves for each year, grouped by directions.

As explained before, meteorology stations measure wind velocity on land whereas ECMWF measures on sea. Since the boundary conditions differ at sea and land, wind velocities can also be different for sea and land measurements. In order to include this land effect, below empirical equation (Hsu, 1980) is implemented in the code for land measurements (meteorology data set), so that land measurements can be turned into sea measurements.

$$U_{sea} = 3(U_{land})^{2/3} \tag{1}$$

By using acquired wave data, comparison and analysis have been made in terms of extreme characteristics which are explained in Chapter 4.

3.3. METHODOLOGY

After data sets and programs are acquired, the following methodology has been implemented in this study.

1- Acquired data sets are re-arranged to make them suitable for graphical comparison which is explained in detail in section 3.3.1. In addition, certain calculations are performed on both data sets to make them compatible with programs which are explained in section 3.3.2.
2- For visualization, graphical comparisons are made in section 4.1. by using new arranged data sets.
3- Wind.exe program is used first. Output of this program is entered as input for w61.
4- Results of w61 program are used to find yearly maximum values of significant wave height for each selected point for entire analysis period.
5- An Excel sheet has been prepared for extreme analysis. This analysis has been performed on each point by using yearly maximum values.
6- Results have been found for each point and discussions are presented in section 4.2.3.

7- An additional research has been conducted based on recorded or observed historical storms and these storms are compared with found results in section 4.4.

3.3.1. Re-Arrangement for Data Sets

In this subsection re-arrangement for data sets are explained in detail.

Start and end dates of both data sets are different for all stations. Although all of ECMWF data sets start at 1983 and end at 2013 for all coordinates, these dates change for meteorology data sets. For example Sinop data set starts at 1958 and ends at 2006 while Kilyos data set starts at 1966 and ends at 2009. To make a proper comparison, both data sets are made compatible with each other first. All data before 1983 for all meteorology data sets are trimmed and all ECMWF data after relevant meteorology stations' end date are also deleted.

3.3.2. Corrections for Data Sets

In this part, certain calculations and corrections performed on data sets to make them compatible with programs are presented.

3.3.2.1. Meteorology Data Set

Since wind.exe program uses meteorology data format as standard, no major corrections is required for this data set. First change made on this data set is delimiter change. All data before 2006 uses comma as delimiter but program requires point delimiter, so a minor delimiter change is done to all station data.

As stated before, meteorology data sets have certain gaps due to malfunction of measurement devices. These gaps can be as small as a few hours but for certain years, months of missing data are detected. For this reason, a MatLAB code is developed by the author to properly fill these gaps. Wind velocity for these gaps is determined as minus 1 (-1) to distinguish missing data from measured zero values.

3.3.2.2. ECMWF Data Set

Many major changes have been made on this data set. First of all, data acquired is for every six hours but program requires hourly data. To make the data suitable for use, spline method is used to turn six hour data into hourly data. A MatLAB code is created by Coastal Engineering Department, METU and this code is further developed for this purpose.

Second step is to determine directions. ECMWF data does not present any directions, neither letter nor number format but it does give directions with plus and minus signs on u and v components of wind velocity. By using arctan method on MatLAB, all directions have been found for each data as degrees. Since wind.exe program requires wind directions as letters, those degrees are turned into letter format by using simple formulas for each direction (e.g. degrees between 11.25 and 33.75 are taken as NNE direction).

Last change made on the data is to combine u and v components with simple $U = \sqrt{(u^2 + v^2)}$ formula since program requires only wind velocity and its direction.

An example of the output of final ECMWF data that is ready to use in wind.exe program is presented in Figure 11. As it can be seen, to make the data fully compatible, coordinates of the data set is entered at first column where station number is written on meteorology data set.

```
42003520;1983;1;1;0;4.579;NNW
42003520;1983;1;1;1;4.409917535;NNW
42003520;1983;1;1;2;4.280130364;NNW
42003520;1983;1;1;3;4.14088105;NNW
42003520;1983;1;1;4;3.97476288;N
42003520;1983;1;1;5;3.785748588;N
42003520;1983;1;1;6;3.591;NNW
42003520;1983;1;1;7;3.414269622;NNW
42003520;1983;1;1;8;3.279583415;NNW
42003520;1983;1;1;9;3.204852481;NNW
42003520;1983;1;1;10;3.197258034;NNW
42003520;1983;1;1;11;3.253613404;NNW
42003520;1983;1;1;12;3.367;NNW
42003520;1983;1;1;13;3.530838533;NNW
42003520;1983;1;1;14;3.723680324;NNW
42003520;1983;1;1;15;3.917106188;NNW
42003520;1983;1;1;16;4.074738111;NNW
42003520;1983;1;1;17;4.152565538;NNW
42003520;1983;1;1;18;4.103;NNW
42003520;1983;1;1;19;3.896759777;NNW
42003520;1983;1;1;20;3.575519971;NNW
42003520;1983;1;1;21;3.204483525;NNW
```

Figure 11 – Final ECMWF Data After Re-Arrangement and Corrections

CHAPTER 4

COMPARISON AND ANALYSIS

In this chapter, both graphical and numerical comparisons and analyses have been conducted and discussions on their results are presented. Also, an additional research on historical storm events is performed and results of both data sets are compared with this research.

4.1. GRAPHICAL COMPARISON AND DISCUSSION

4.1.1. Comparison and Discussion on Time Series

Before using any program, scatter graphs are drawn by using corrected wind data for visualization.

As stated before, 7 points have been selected for comparison. 7 graphs have been presented below from Figure 12 to Figure 18. All graphs include 1 hour meteorology data, 1 hour ECMWF data, 6 hour ECMWF data and three threshold values, 3 m/s, 5 m/s and 10 m/s.

Since there are huge amount of measurements for both data sets, only one month of data are selected for proper comparison. All presented graphs are for January, 2000 simply because more storms are expected during winter.

In these data sets directions are not considered. Only wind velocity vs time is presented. In the section 4.1.2., wind roses are also plotted and discussions are presented. Since south directions are excluded from analysis, they are also excluded in graphical comparisons.

İstanbul – Kilyos:

Wind data for both data sets in January, 2000 are plotted and presented below. From scatter plot at Figure 12 it is observed that ECMWF and meteorology data sets are in good agreement between 3-10 m/s thresholds but above 10 m/s, meteorology data set determines the peak values and it creates around seven peak points and ECMWF data set comes close to 3 of them, including the highest peak. If the rest of the data follow this pattern, it can be expected that meteorology data set will provide larger wave height in extreme analysis.

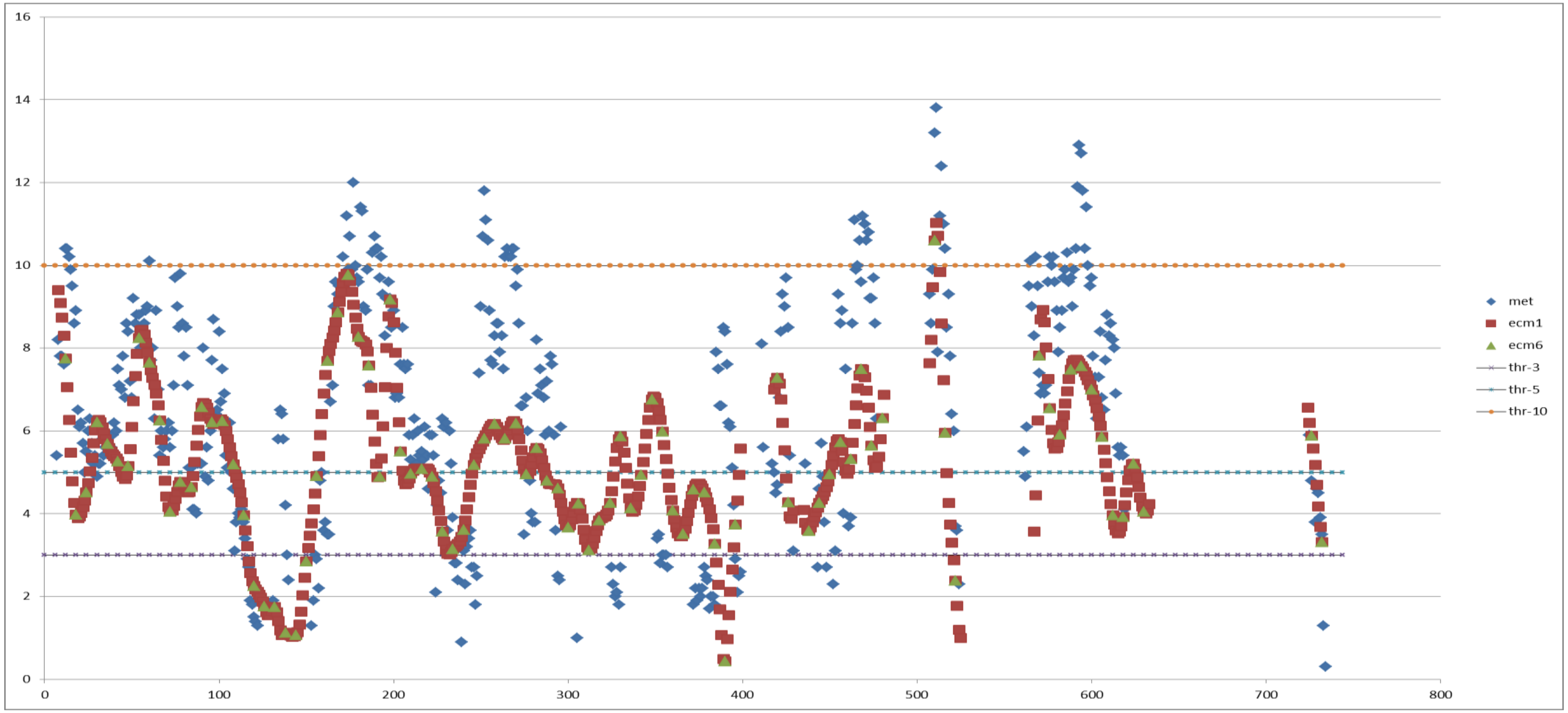


Figure 12 – Time Series for İstanbul - Kilyos

İstanbul – Şile:

Wind data for both data sets in January, 2000 are plotted and presented below. From scatter plot at Figure 13, it is observed that for this case ECMWF data create three peaks above 10 m/s threshold and meteorology data set can only come close to one of them but the difference between the peak values is high. It is clearly seen that bulk of meteorology data are piled up below 5 m/s threshold value whereas ECMWF data are mainly accumulated between 5 and 10 m/s thresholds. Nevertheless, it can be concluded that both data sets are in good agreement for this point.

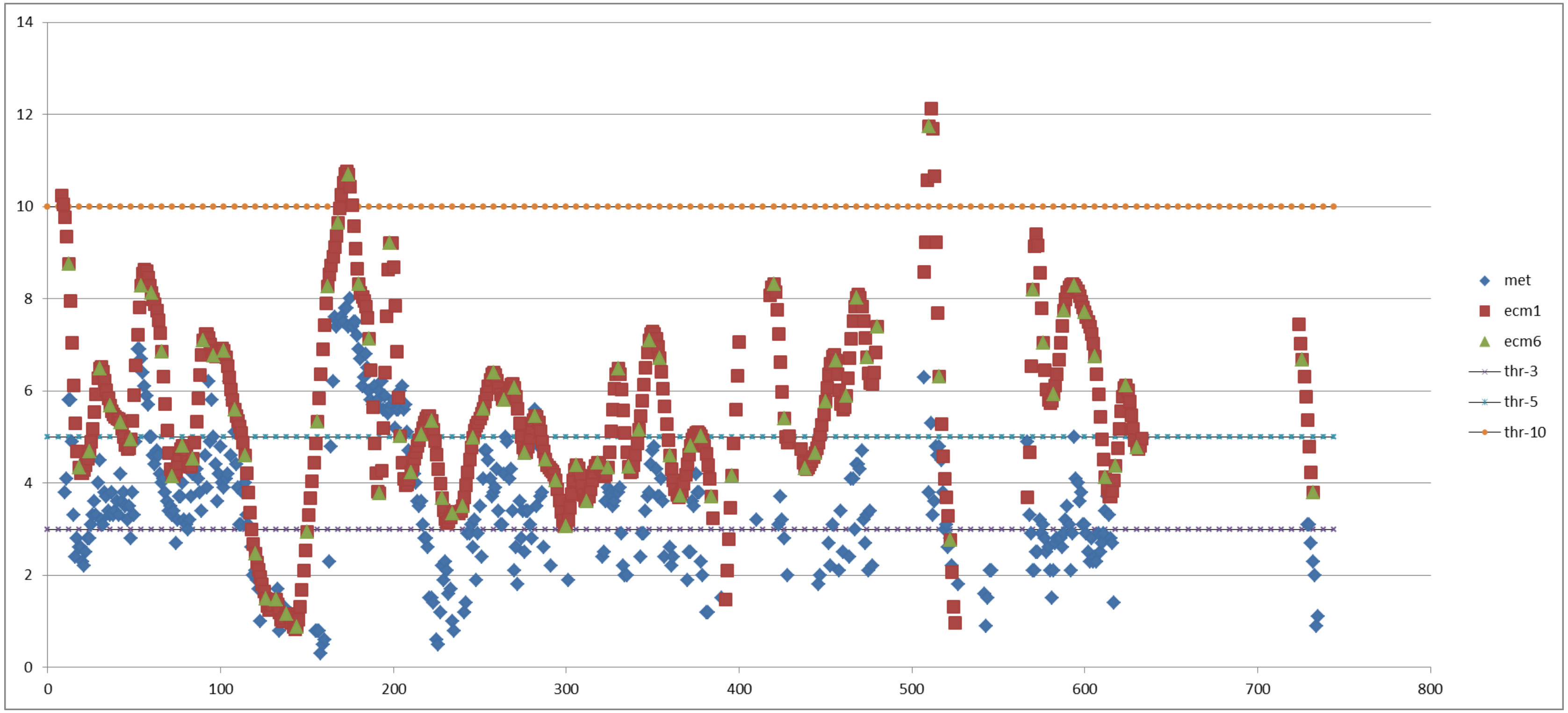


Figure 13 – Time Series for İstanbul - Şile

Düzce – Akçakoca:

Wind data for both data sets in January, 2000 are plotted and presented below. From scatter plot at Figure 14, it is clear that ECMWF data set gives a lot higher wind velocities than meteorology data set. There is no peak point above 10 m/s threshold but ECMWF data set clearly dominates all high values and almost all of the meteorology data are below 5 m/s threshold and they are mainly accumulated under 3 m/s threshold. On the other hand, ECMWF data varies between thresholds. If the rest of the data follows this pattern, it should be expected that ECMWF's extreme wave height should be larger than meteorology's.

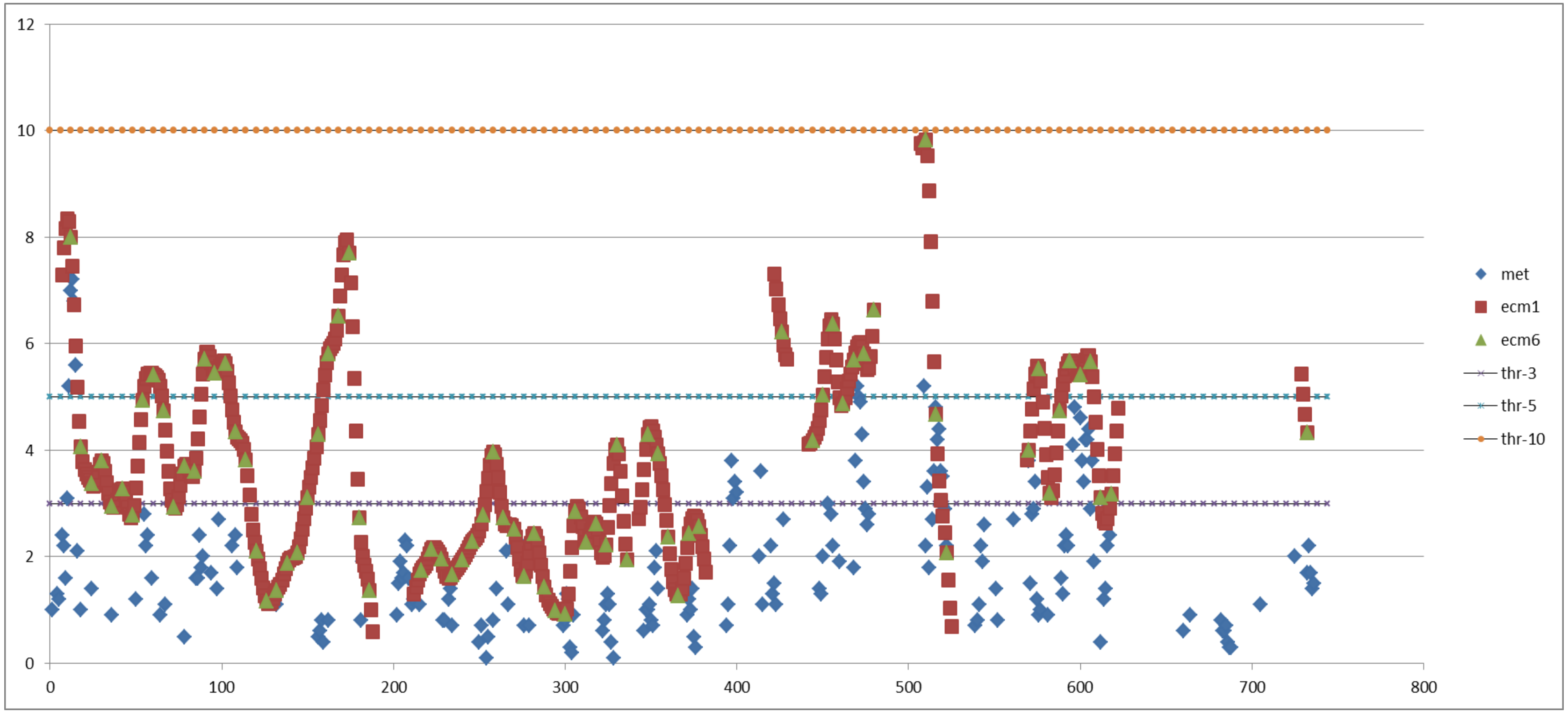


Figure 14 – Time Series for Düzce – Akçakoca

Zonguldak:

Wind data for both data sets in January, 2000 are plotted and presented below. From scatter plot at Figure 15, it can be seen that it is generally the same with Düzce – Akçakoca point except the fact that this time meteorology data are mainly accumulated under 5 m/s threshold value. And again, ECMWF data govern all peak values and should create higher extreme wave height value.

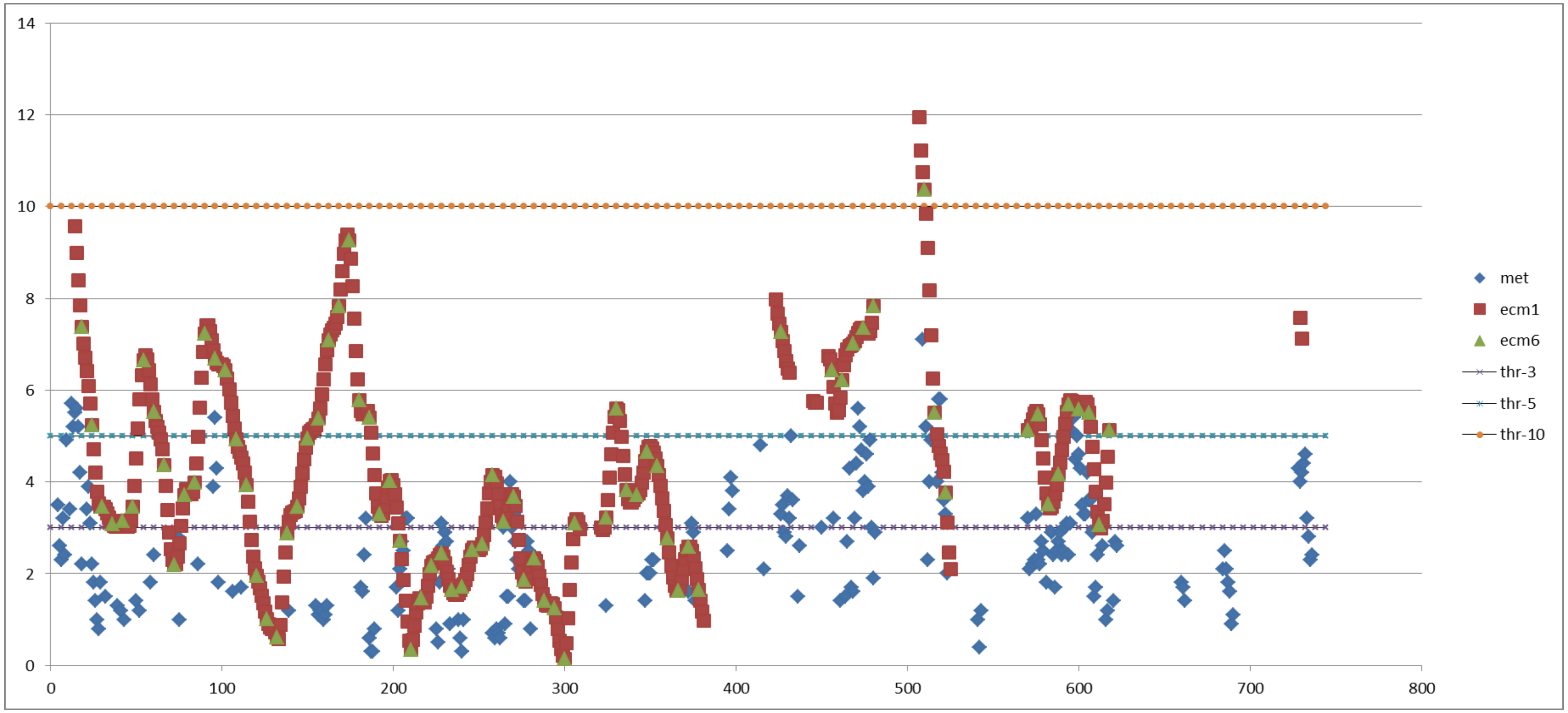


Figure 15 – Time Series for Zonguldak

Bartın – Amasra:

Wind data for both data sets in January, 2000 are plotted and presented below. From scatter plot at Figure 16, it is seen that this case is almost the opposite of two previous cases. Meteorology data set dominate all peak values and measure wind velocities as high as 20 m/s where ECMWF data are mainly piled up below 5 m/s threshold value. This set can barely measure one value above 10 m/s threshold where meteorology data set measure at least seven peaks.

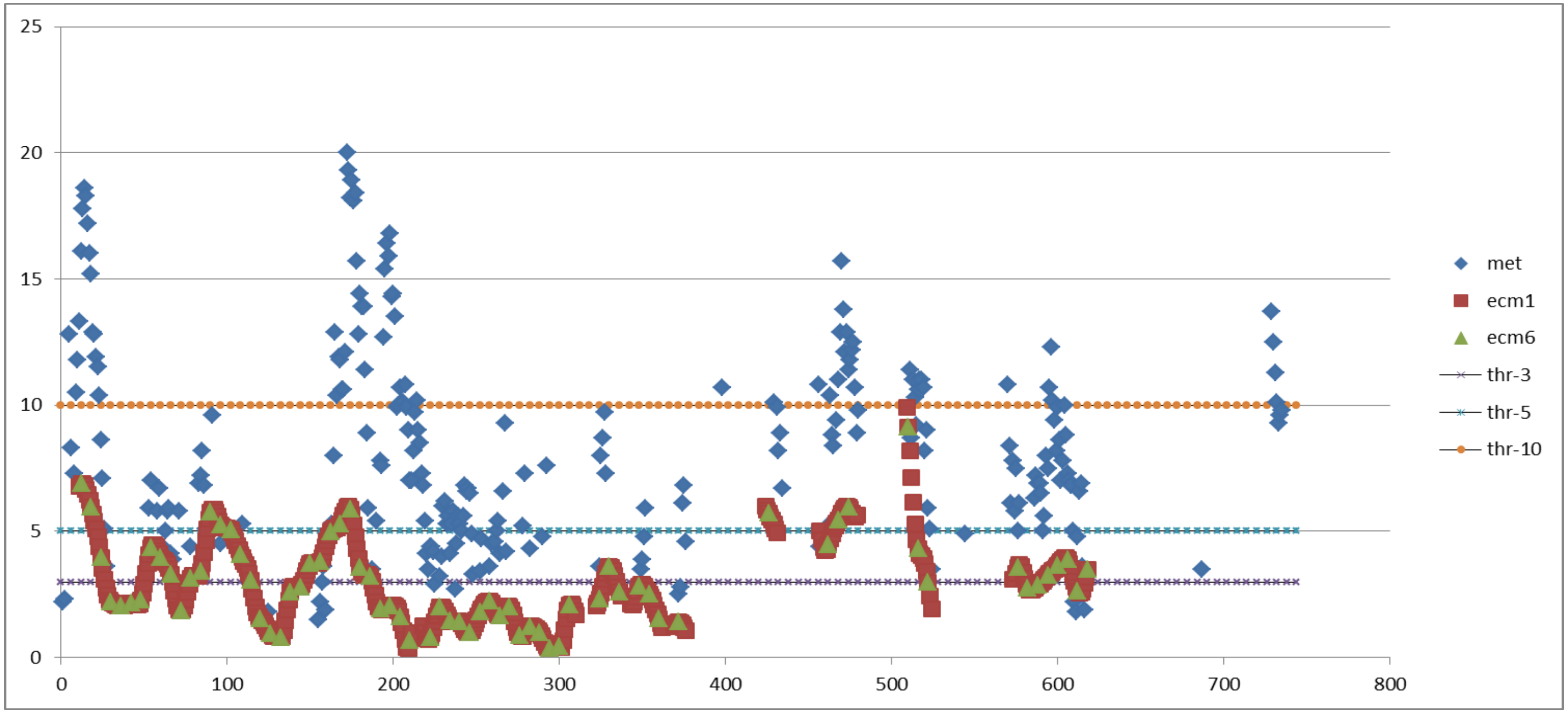


Figure 16 – Time Series for Bartın - Amasra

Kastamonu – İnebolu:

Wind data for both data sets in January, 2000 are plotted and presented below. From scatter plot at Figure 17, it can be seen that this point is the most balanced one so far. For both data sets, there is no piling up below a specific threshold value. There are 3 different peak values above 10 m/s. All of them are measured by ECMWF but meteorology measured very close to the biggest peak. If this pattern continues throughout the data sets, a higher value from ECMWF data set can be expected but difference should be lower than previous three cases.

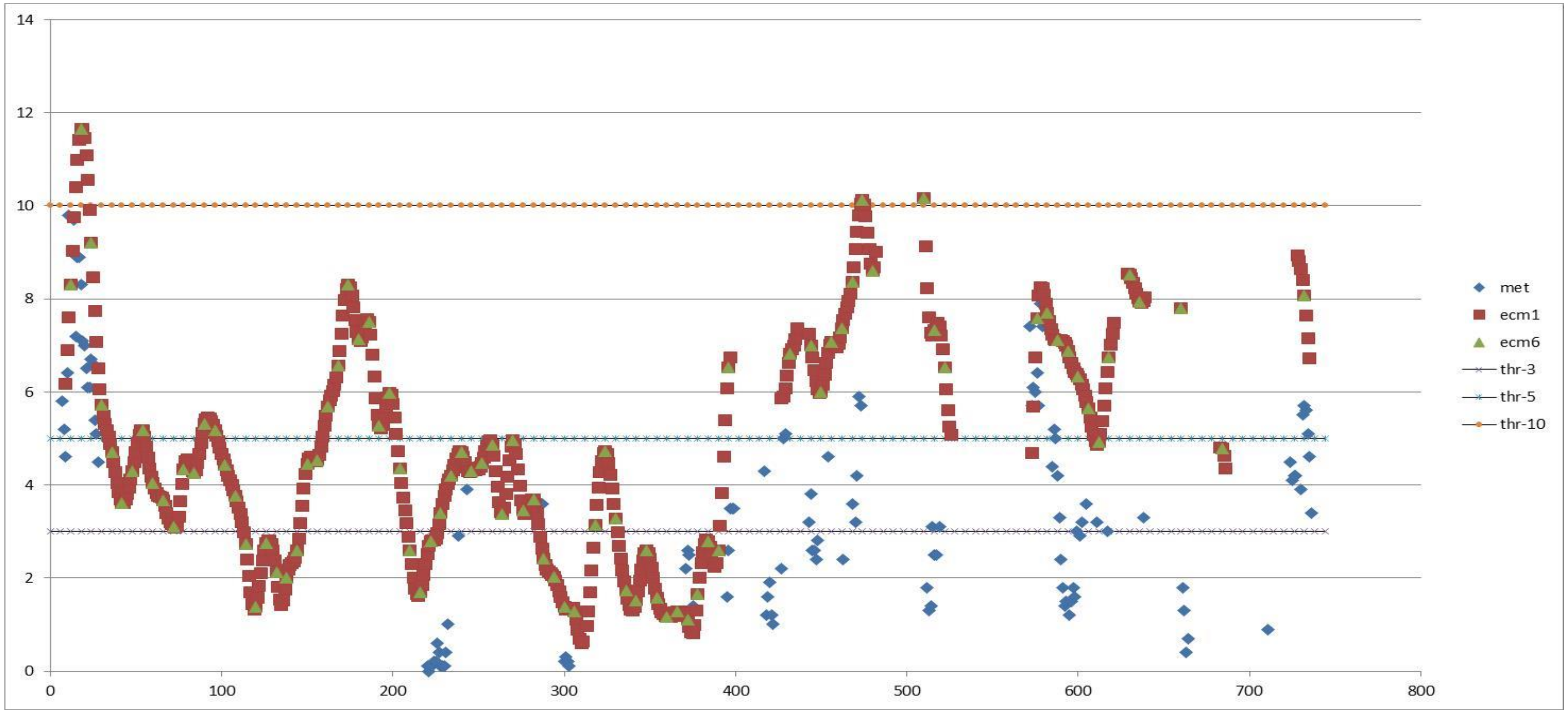


Figure 17 – Time Series for Kastamonu - İnebolu

Sinop:

Wind data for both data sets in January, 2000 are plotted and presented below. This is a similar case to Kastamonu – İnebolu. Again, data points are scattered at Figure 18, and there is no specific piling up. This time, meteorology data set determine the three peak values above 10 m/s. Although ECMWF data set measures close but lower peaks for two of them, it measures a lot lower value for the first peak meteorology measured.

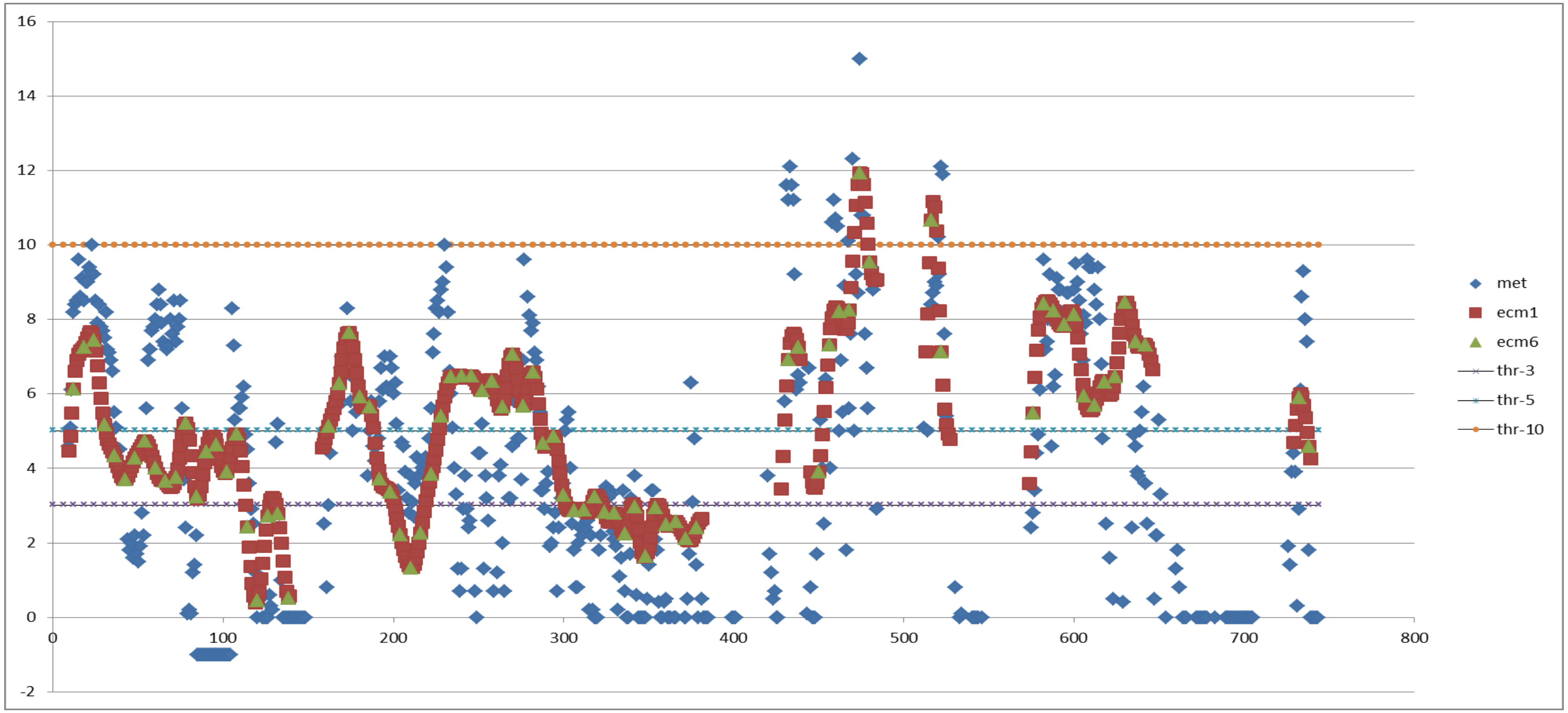


Figure 18 – Time Series for Sinop

4.1.2. Comparison and Discussion on Wind Roses

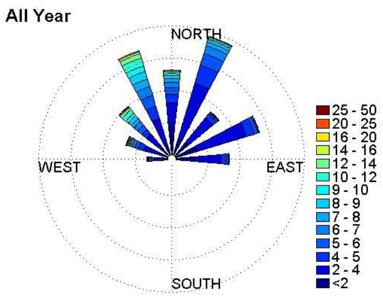
As previously stated, wind roses are prepared for all points. 5 wind roses are plotted four of which are seasonal plots and one of which is for all years. South directions are omitted and wind roses are for analysis periods only.

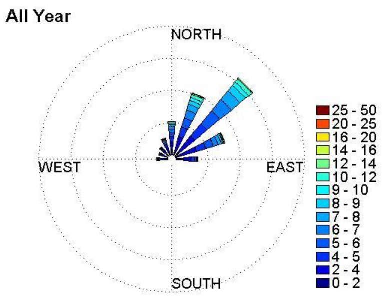
Discussions on wind roses are also presented in this section. In addition, previous wind rose study of Berkün, U., 2007 which uses ECMWF data set for Black Sea coast is compared with the results of ECMWF data in this study.

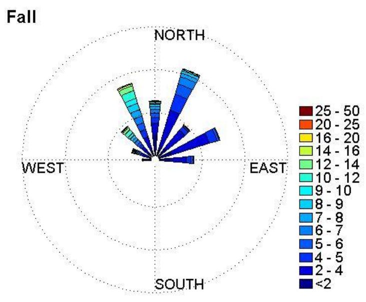
İstanbul – Kilyos:

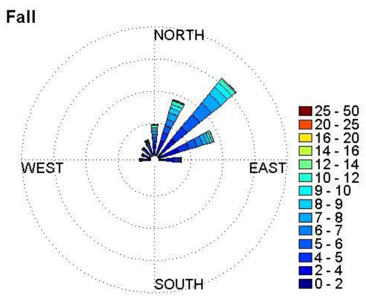
Wind roses are plotted for İstanbul – Kilyos region for wind data between 1983 – 2009.

Meteorology: **ECMWF:**









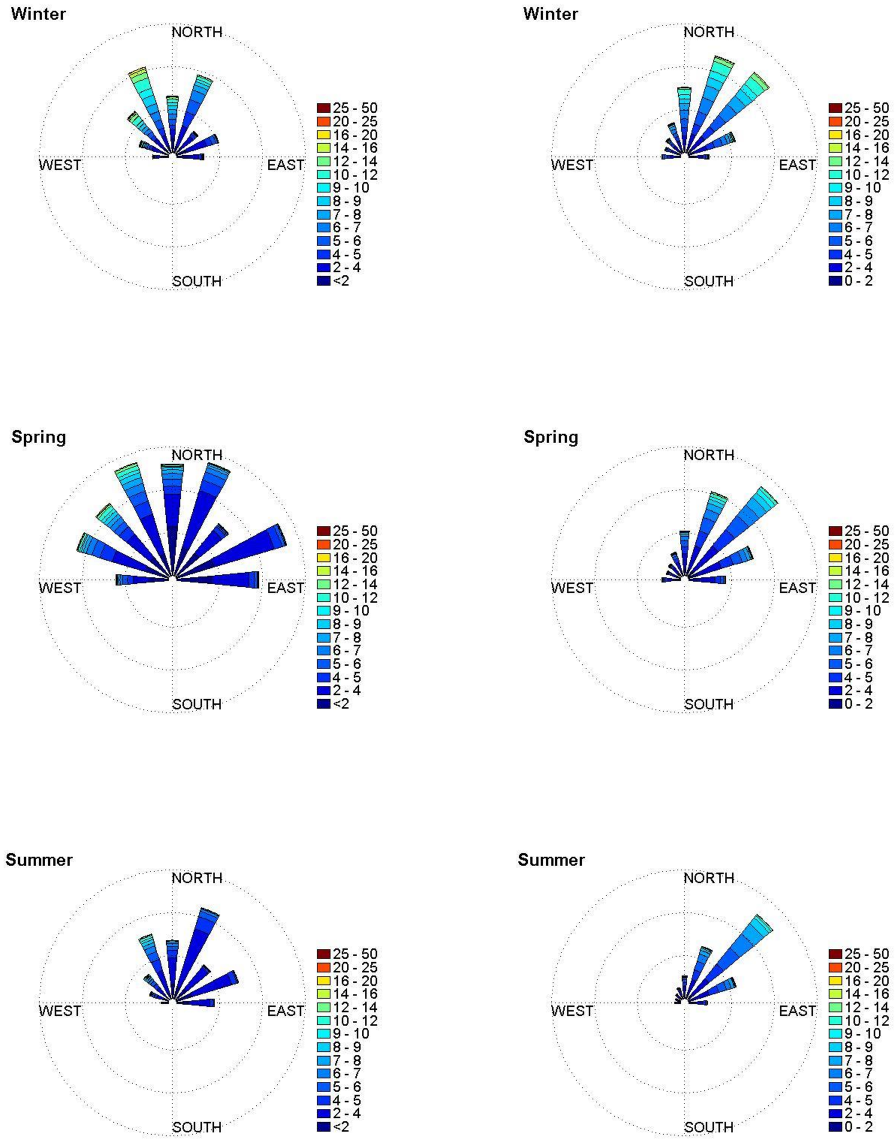


Figure 19 – Wind Roses for İstanbul – Kilyos Region

From wind roses at Figure 19, it can be seen that maximum wind velocities for all years are similar but meteorology data set created more winds at higher velocities. Dominant wave direction for meteorology data is NNW direction where the biggest winds are stacked. For ECMWF data set however, dominant direction is NE direction.

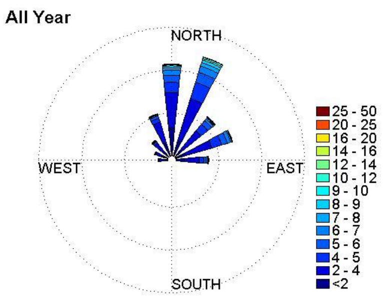
From seasonal plotting, general pattern does not change during fall and summer for both data sets. During winter, higher wind velocities are observed for meteorology data and another dominant direction, NNE is observed for ECMWF data and there is no major change during spring except lower wind velocities are measured from NNE direction when compared to winter season. For meteorology data, however, spring season is somehow different than the rest of the seasons. 6 of the northern directions out of 9, WNW, NW, NNW, N, NNE and ENE, can be considered as dominant directions. Biggest winds come from NNW direction as expected but distribution of the winds between directions is quite unusual.

When Berkün, U., 2007 study is checked, results are found to be a lot similar. Only winter season there is a minor difference. In Berkün, U., 2007 study during winter season wind velocities from north direction are higher than our study. This difference can be tolerated due to the fact that studied coordinate is approximately 90 km away from Kilyos and study period is for 65 months only.

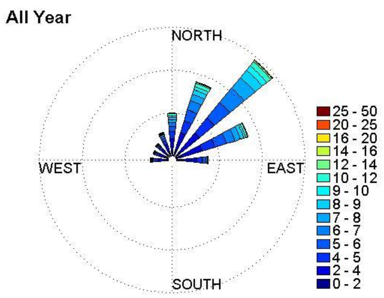
İstanbul – Şile:

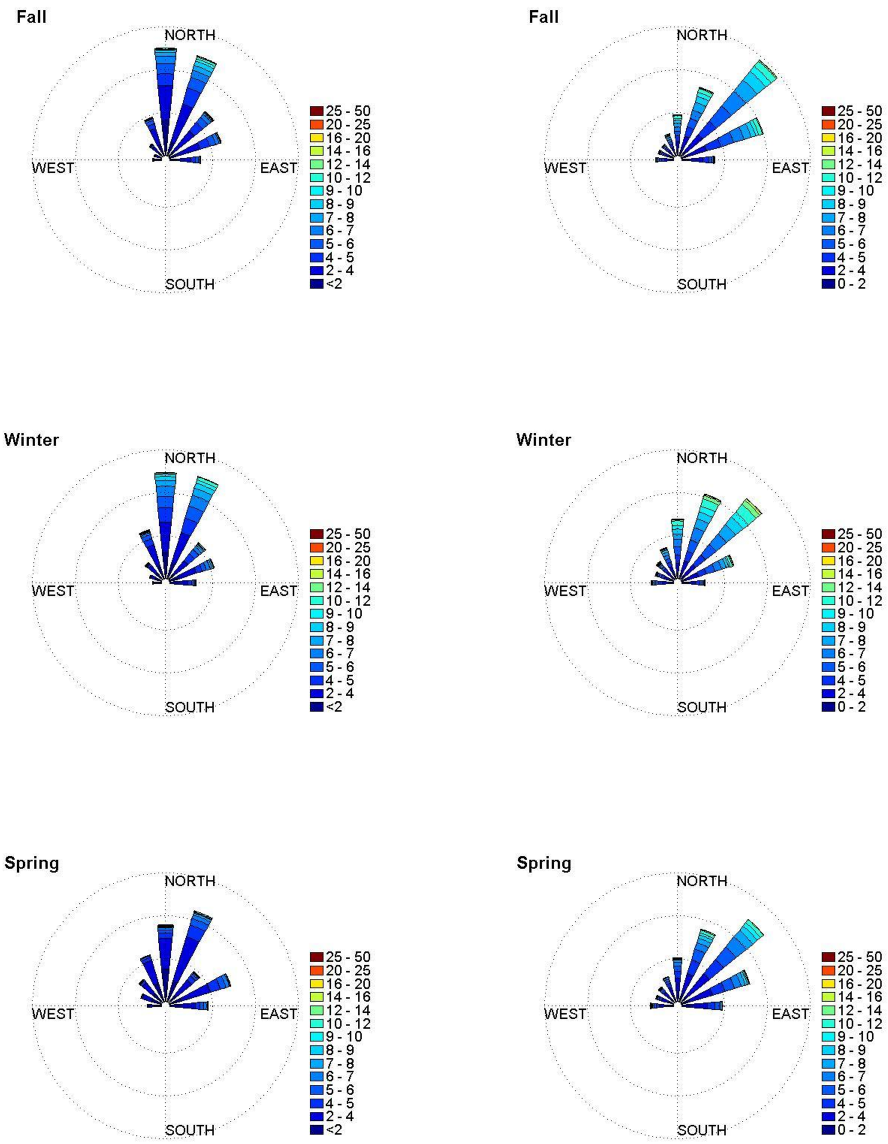
Wind roses are plotted for İstanbul – Şile region for wind data between 1983 – 2009.

Meteorology:



ECMWF:





Fall
NORTH
WEST
EAST
SOUTH
25 - 50
20 - 25
16 - 20
14 - 16
12 - 14
10 - 12
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
<2
Fall
NORTH
WEST
EAST
SOUTH
25 - 50
20 - 25
16 - 20
14 - 16
12 - 14
10 - 12
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
0 - 2
Winter
NORTH
WEST
EAST
SOUTH
25 - 50
20 - 25
16 - 20
14 - 16
12 - 14
10 - 12
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
<2
Winter
NORTH
WEST
EAST
SOUTH
25 - 50
20 - 25
16 - 20
14 - 16
12 - 14
10 - 12
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
0 - 2
Spring
NORTH
WEST
EAST
SOUTH
25 - 50
20 - 25
16 - 20
14 - 16
12 - 14
10 - 12
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
<2
Spring
NORTH
WEST
EAST
SOUTH
25 - 50
20 - 25
16 - 20
14 - 16
12 - 14
10 - 12
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
0 - 2

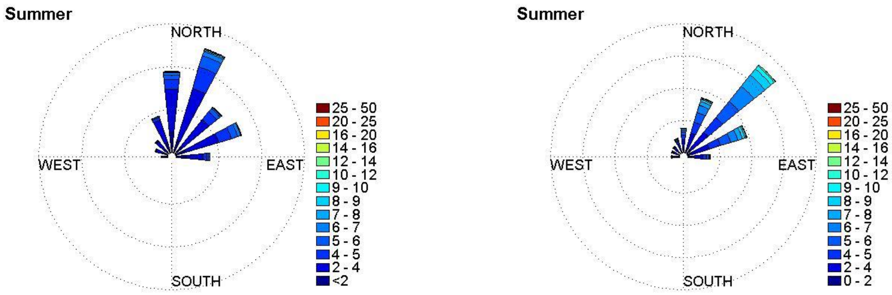


Figure 20 – Wind Roses for İstanbul – Şile Region

From wind roses at Figure 20, it is observed that ECMWF generally created higher wind velocities for almost all directions. Most dominant direction for ECMWF is NE whereas for meteorology data these directions are N and NNE.

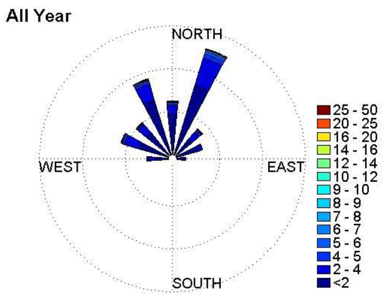
From seasonal plotting for meteorology data, summer and spring seasons follows the pattern for all years. Fall season is similar too but there are more winds coming from N direction. For ECMWF data, fall and summer seasons are a lot similar with all year plot. Spring season is also similar but weaker winds are coming from NE direction. For winter however, there are considerable amount of strong winds coming from N and NNE directions.

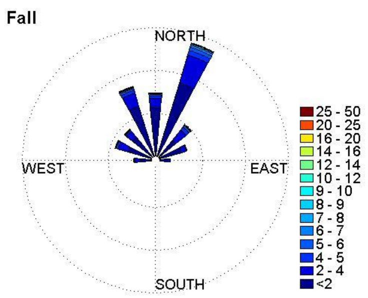
No closer points are found in previous studies to compare with. A loosely related point in Berkün, U. (2007) is Kefken, Kocaeli. It is located between İstanbul – Şile point and Düzce – Akçakoca point and closer to Şile. Location of selected coordinate is approximately 120 km away in northeast direction. Results are again in good agreement. Generally there are more winds observed for Şile region from NNE direction whereas in Berkün, U., 2007 study summer winds are observed a lot more intensely from ENE direction.

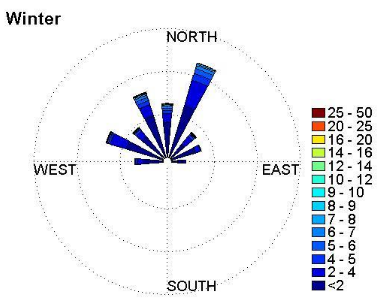
Düzce – Akçakoca:

Wind roses are plotted for Düzce – Akçakoca region for wind data between 1983 – 2009.

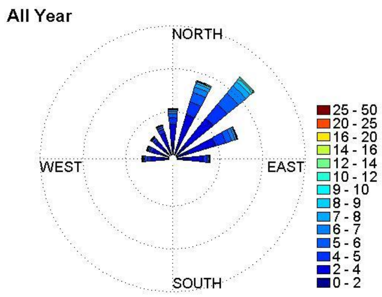
Meteorology:

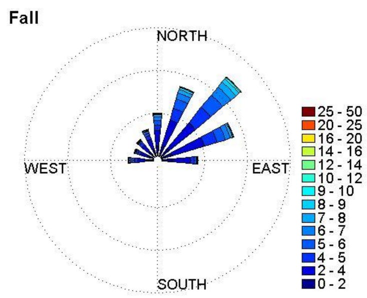


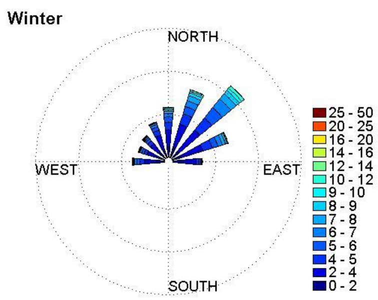




ECMWF:







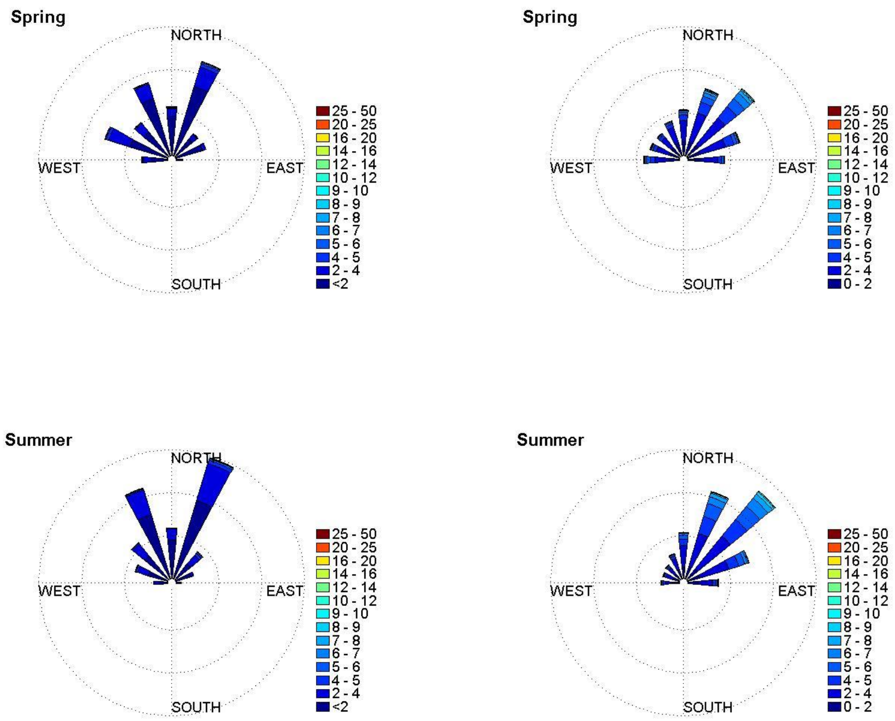


Figure 21 – Wind Roses for Düzce – Akçakoca Region

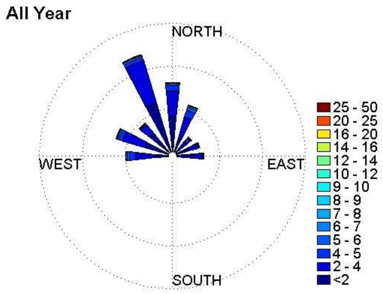
From wind roses at Figure 21, observed difference is a lot higher than previous cases. ECMWF data present denser and higher number of storms for all years plot. Dominant direction is NE for ECMWF whereas it is NNE for meteorology data. There is no major difference for meteorology and ECMWF data from seasonal plots. ECMWF's most prominent directions are NNE, NE and ENE from which winds come stronger than meteorology data.

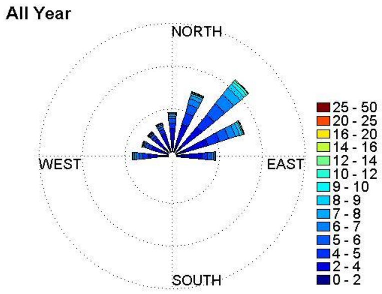
No close point is detected from previous studies to make a reliable comparison.

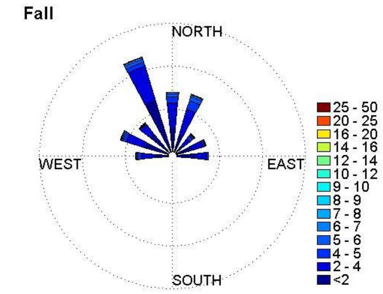
Zonguldak:

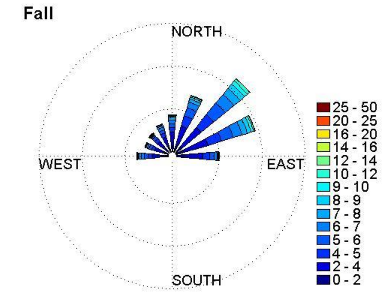
Wind roses are plotted for Zonguldak region for wind data between 1983 – 2006.

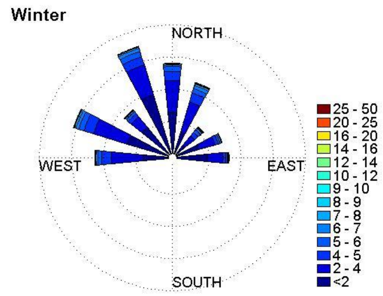
Meteorology: **ECMWF:**

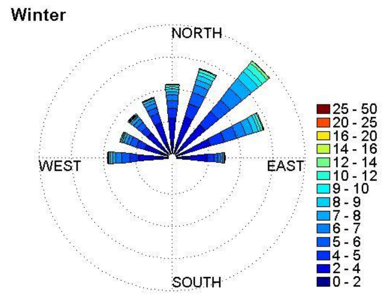












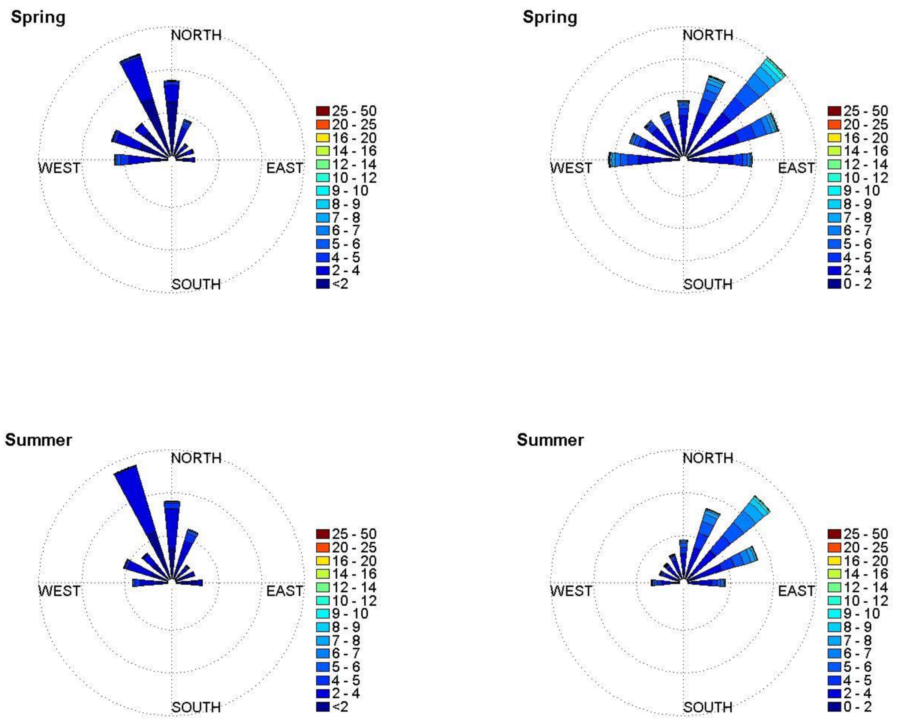


Figure 22 – Wind Roses for Zonguldak Region

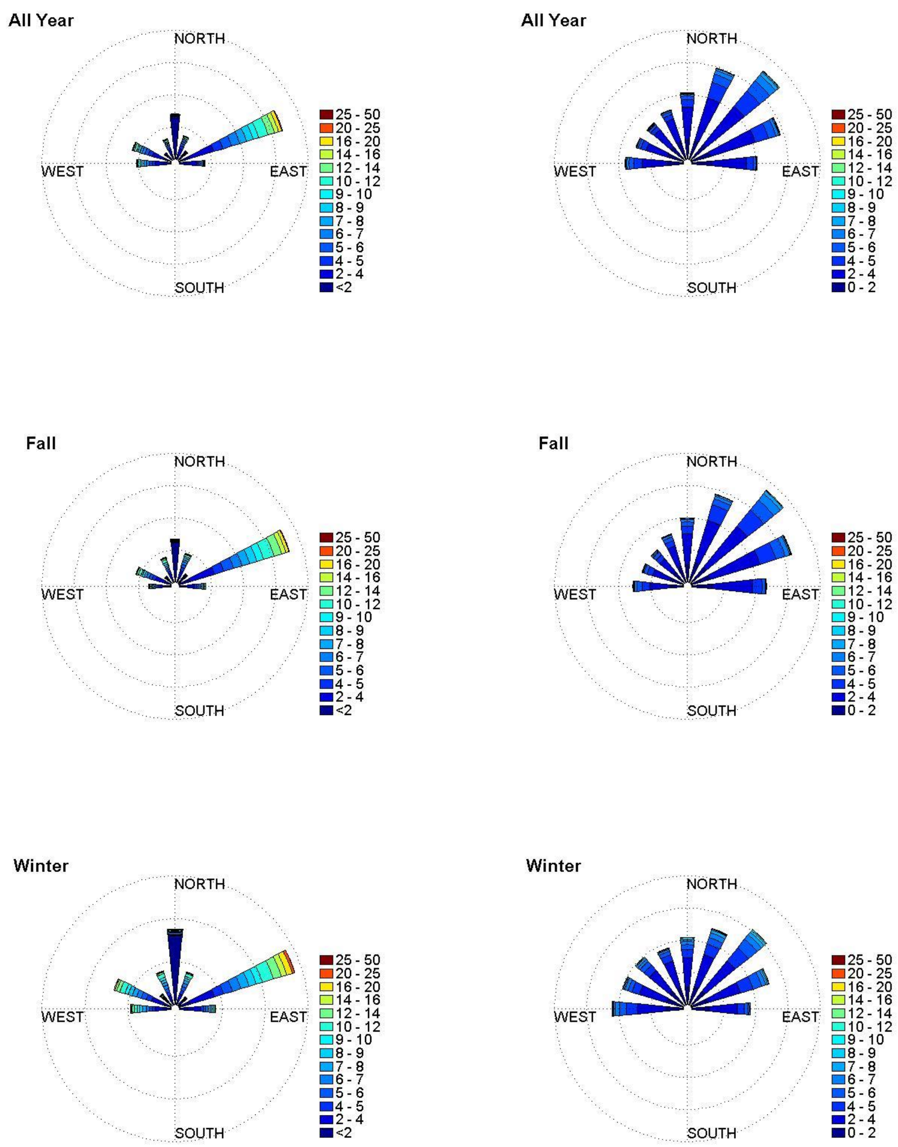
From wind roses at Figure 22, general behavior of scatter plot coincides with wind roses. Again ECMWF data set provides bigger winds than meteorology data set. For all directions dominant direction for ECMWF data is NE whereas it is NNW for meteorology data. There is no major change from seasonal plots expect winter. It appears the biggest winds can be expected during winter season for this region. Both data sets present biggest winds during this season from almost all directions.

Berkün, U. (2007) has studied a similar coordinate. It only uses ECMWF data set and the closest point selected is approximately 70 km northeast of Zonguldak. General behavior of both data sets is similar. More winds are observed from ENE direction for Berkün, U., 2007 study and fewer winds are observed from NNE direction. Biggest difference is at summer season. Berkün, U., 2007 study shows that for that coordinate, there are a lot more winds measurements from same directions but they are also a lot weaker.

Bartın – Amasra:

Wind roses are plotted for Bartın – Amasra region for wind data between 1983 – 2009.

Meteorology: **ECMWF:**



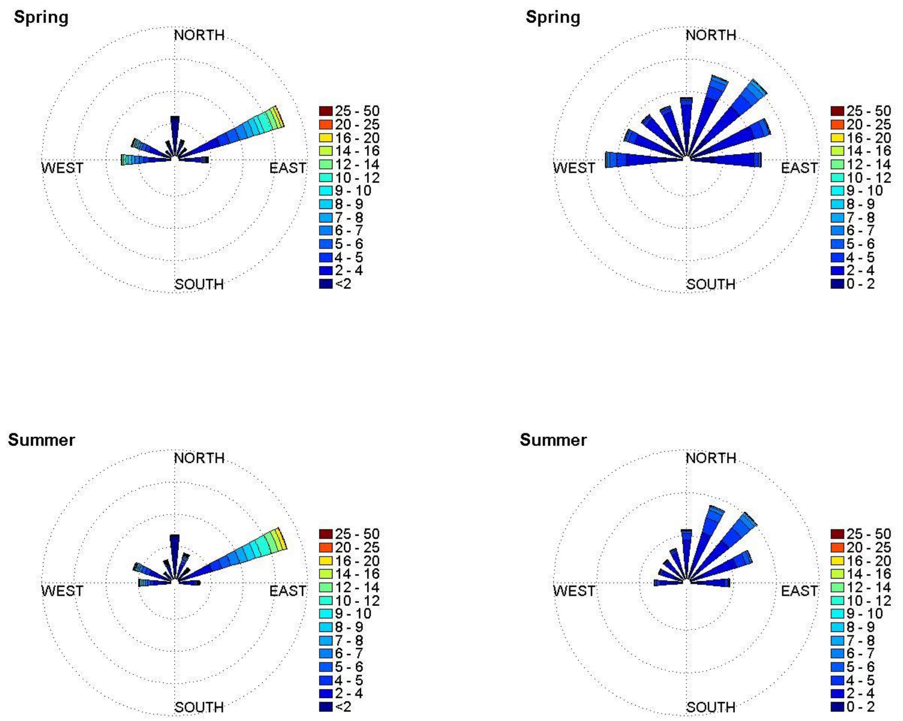


Figure 23 – Wind Roses for Bartın – Amasra Region

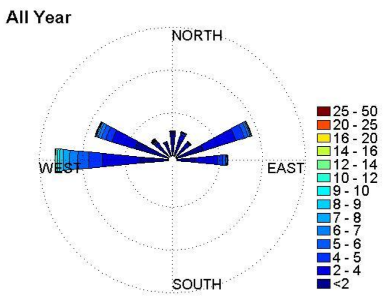
From wind roses at Figure 23, it is observed that for meteorology data set pattern provided from one month’s worth scatter plot does not change for all years. Most dominant direction for meteorology data set is clearly ENE direction where some of the most intense storms are accumulated so far. Also its pattern does not change much during seasons except for winter when N direction also provides high number of winds. For ECMWF data set, most dominant direction seems to be the NE direction but NNE and ENE directions are also contributed to the plot.

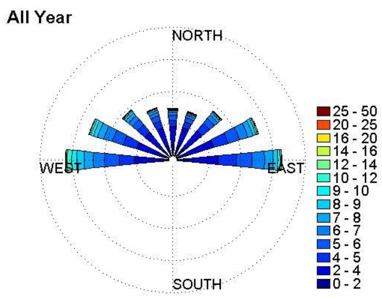
Berkün, U. (2007) has studied a similar coordinate. The closest point selected is approximately 35 km northeast of Amasra. For dominant directions, results are in good agreement but in Berkün, U., 2007 study it is found that more winds are observed between W and NNE directions even though selected coordinates are really close. Extreme analysis will provide a better comparison to see the effects of these less dominant directions.

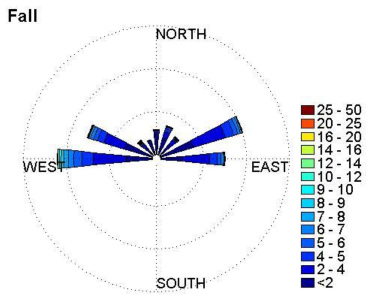
Kastamonu – İnebolu:

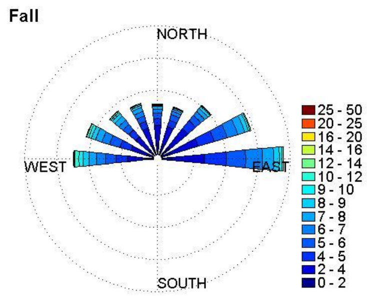
Wind roses are plotted for Kastamonu – İnebolu region for wind data between 1983 – 2006.

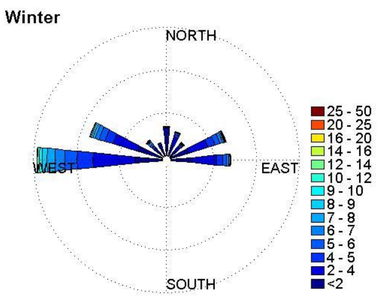
Meteorology: **ECMWF:**

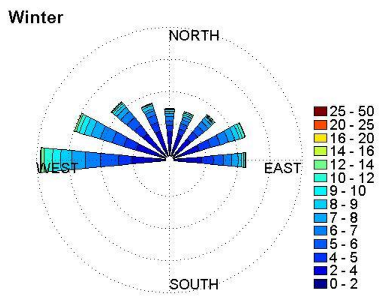












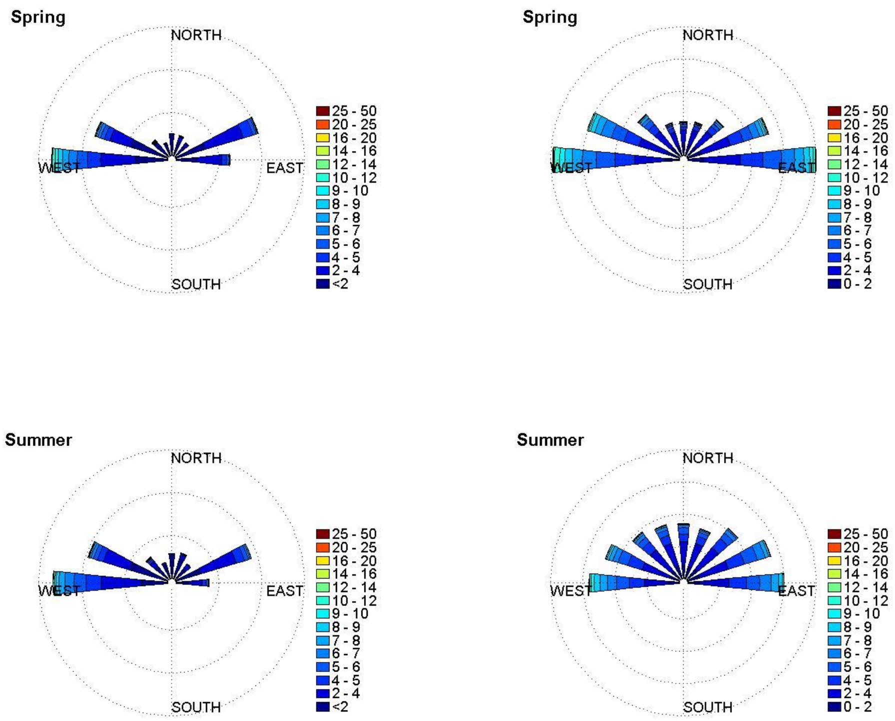


Figure 24 – Wind Roses for Kastamonu – İnebolu Region

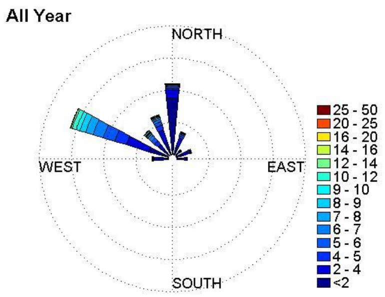
From wind roses at Figure 24, it is observed that for this region ECMWF data set dominates over meteorology data set. It presented stronger winds from W, WNW, E and ENE directions. Most dominant direction for meteorology data is west and there is no major change during different seasons. Only winds from east direction during summer season are lower than general pattern. For ECMWF data set west direction seems to be the most dominant one but east direction is also as nearly strong as west direction. During fall season dominant direction shifts to east and most unexpected results is that summer season seems to present more brutal storms than former regions. Unlike the results of scatter plot, it is expected to have a higher extreme value difference than previously assumed but it should still be less than three prior cases.

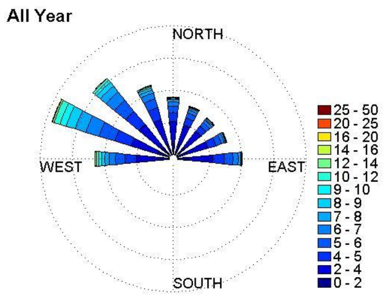
Berkün, U. (2007) has studied an almost identical coordinate. The closest point selected is approximately 10 km northwest of İnebolu. Results are generally in good agreement. In this study, it is seen that there are more winds between NW and NE directions than Berkün, U., 2007 study. Also, spring season seems to be the one of the most effective seasons.

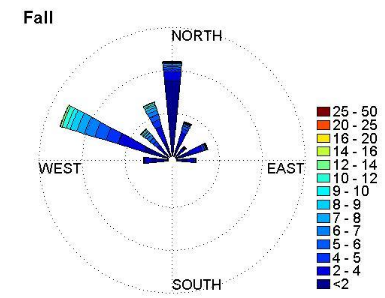
Sinop:

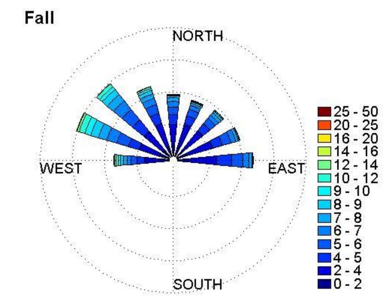
Wind roses are plotted for Sinop region for wind data between 1983 – 2006.

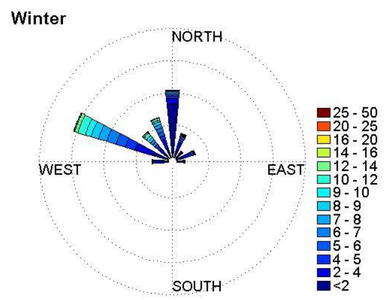
Meteorology: **ECMWF:**

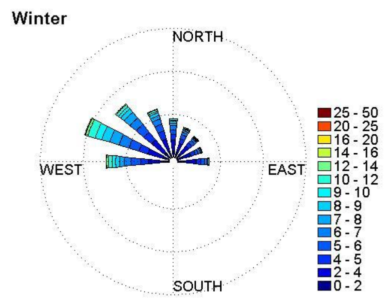












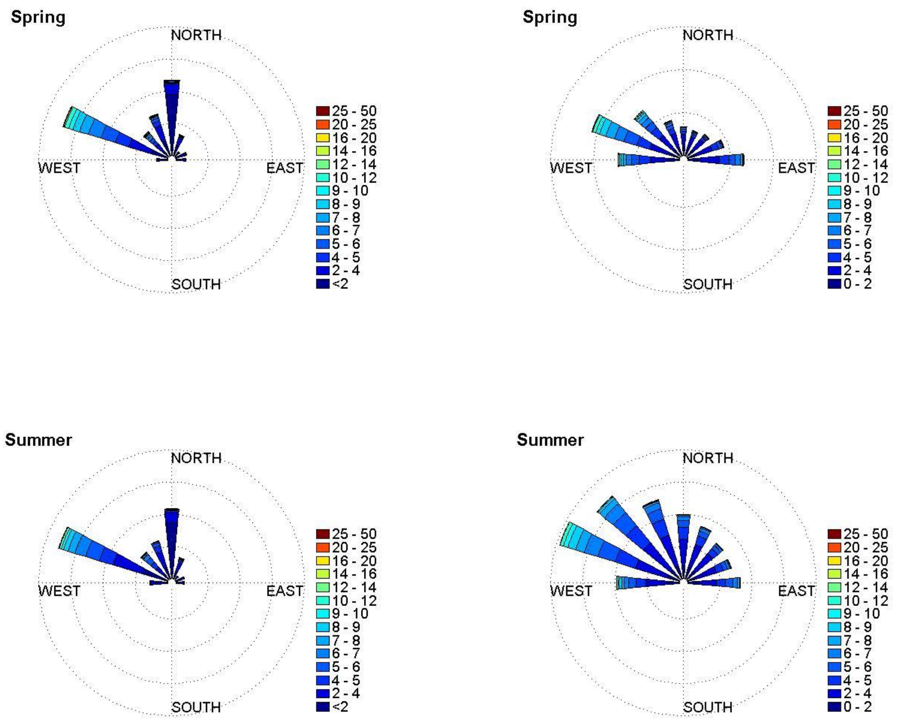


Figure 25 – Wind Roses of Meteorology Data for Sinop Region

From wind roses at Figure 25, it is seen that meteorology data set measure winds from WNW direction almost exclusively. Nevertheless, it also measures decent amount of winds from north direction. Also, there is almost no difference between seasons. Only during winter stronger winds are observed from secondary directions. On the other hand, ECMWF data set measures stronger winds from western directions but again dominant direction seems to be the WNW. Their peak values are seemed to be close. For that reason extreme analysis between two data sets will determine effects of these secondary directions.

Berkün, U. (2007) has studied an almost identical coordinate. The closest point selected is approximately 28 km west-northwest of Sinop. Results are generally in good agreement. Same dominant direction is found and peak values seem to be close. Results for lesser directions between NW and ENE differ greatly between two studies but their effects on end results are predicted to be negligible.

4.2. NUMERICAL COMPARISON

From graphical comparison, it can be concluded that there is no significant pattern in terms of comparison between two data sets. It appears which data set gives higher wind velocities changes depending on the area. But, since the graphical comparison is not informative enough, a numerical comparison is made based on extreme wave height values created by these two data sets, for all selected points. This way, impact of these differences can also be seen on design process.

For this purpose, all of southern directions are excluded from the study as explained before. Southern fetch distances are also selected as zero but it is decided to make a minor storm comparison by using northern directions only, so south directions are also filtered out. Also, as previously decided, 9.5 m/s threshold value is used for extreme analysis.

It should also be stated that, this study does not include any storm by storm comparison, since during storm comparison process, it is seen that due to lack of any measurements to validate either data sets, it is near impossible to determine any recorded storm in any of these data sets. Also, in majority of the cases, start and end dates of measured storms are different for each data set. Also, their durations are different as well. So, even if one data set is chosen as correct one and checking other data set's storms to see whether their results match with other data set's results in terms of start and end dates and durations, such a study is impractical and highly unreliable since there are hundreds of storms for each year for both data sets.

When new arranged data sets are created by using above limitations, wind.exe and w61 programs are used to ultimately create individual wave heights and periods. By using this data, maximum wave heights and their corresponding wave periods are found out for each year and for each direction.

Used fetch distances for all points are presented at Table 2.

Table 2 – Fetch Distances

SELECTED POINTS	FETCH DISTANCES (km)								
	N	NNE	NE	ENE	E	W	WNW	NW	NNW
İstanbul - Kilyos	385	598	517	896	199	-	52	117	230
İstanbul - Şile	416	593	592	864	51	-	136	228	270
Düzce - Akçakoca	614	489	650	21	-	28	274	353	434
Zonguldak	529	365	584	-	-	278	365	366	438
Bartın - Amasra	483	320	529	629	-	355	395	416	482
Kastamonu - İnebolu	268	380	433	519	89	-	457	463	558
Sinop	305	366	373	430	563	8	555	576	296

An example output of maximum wave heights and their periods is shown at Table 3.

Table 3 – Example Output of Maximum Wave Heights and Corresponding Periods

Year:1983			Year:1984		
Hmax(m.)	Tmax(sec.)	Direction	Hmax(m.)	Tmax(sec.)	Direction
3.19	6.73	NNE	3.55	3.7	NNE
2.96	6.43	NE	0	0	NE
2.93	6.16	ENE	0	0	ENE
0	0	E	0	0	E
0	0	ESE	0	0	ESE
0	0	SE	0	0	SE
0	0	SSE	0	0	SSE
0	0	S	0	0	S
0	0	SSW	0	0	SSW
0	0	SW	0	0	SW
0	0	WSW	0	0	WSW
0	0	W	0	0	W
2.12	5.22	WNW	2.52	5.74	WNW
3.95	7.12	NW	3.61	6.85	NW
4.47	7.94	NNW	3.82	7.36	NNW
3.3	6.85	N	0	0	N
4.47	7.94	All Directions	3.82	7.36	All Directions
4.47	7.94	All Directions	3.82	7.36	All Directions

It can be seen that, since there are no fetch distances from south directions, neither meteorology data set nor ECMWF data set create any wave from southern directions. Also, due to high threshold value, at certain years, no wave is created from certain northern directions as well which means there is no wind measured from that direction entire year which is higher than the threshold value.

4.2.1. Non – Directional Analysis

First of all, extreme analysis is performed without considering any direction, e.g. all directions values are used. Highest value from any direction is selected for each year.

For analysis, 10 different distribution methods have been used. These are Gumbel, Fisher-Tipper II (k=2.5, 3.33, 5.0, 10.0), Weibull (k= 0.75, 1.0, 1.4, 2.0) and Lognormal distributions (Goda, 2000). Also 7 different return periods are found for extreme waves which are 5, 10, 20, 50, 100, 500 and 1000.

To find the best fitting method to the data sets, below criteria are considered.

Coefficient of correlation, *r*: It gives the correlation between ordered Hs data and its corresponding probability in a distribution model. When *r* value is closer to 1, it indicates a better fit to the data set.

Residue of correlation coefficient, Δr (REC criterion): Residue of correlation coefficient is defined as $\Delta r = 1 - r$. By using Δr, Goda and Kobune (1990) proposed a criterion for rejection of candidate distribution. This criterion is defined as the below empirical equation.

$$\Delta r_{\%95} = \exp(a + b\ln N + c(\ln N)^2) \quad (2)$$

N is the number of data and a, b and c are the empirical parameters given in Goda (2000). If the Δr value of the data is higher than $\Delta r_{95\%}$, model is rejected.

Minimum ratio of residual correlation coefficient $\Delta r / \Delta r_{mean}$ (MIR criterion): This criterion was proposed by Goda and Kobune (1990) to find the best fitting model by using ratio between the residue of correlation coefficient and mean residue of correlation coefficient. For this purpose a, b and c parameters are provided in Goda (2000) and used in the equation (2) and Δr_{mean} is calculated. The model with the smallest ratio is selected as the best fit by this criterion.

Deviation of outlier (DOL criterion): Sometimes an extreme data set contains a data much larger than the rest of the data. And in some cases, the largest data can be slightly larger than the second largest data and can be plotted below the distribution curve. These data are called outliers. DOL criterion is proposed by Goda and Kobune (1990) to detect outliers. For this purpose the following dimensionless deviation ξ is calculated for the biggest data:

$$\xi = \frac{(H_1 - \bar{H})}{s} \tag{3}$$

Where H_1 is the biggest data, $\bar{H}$ is the mean Hs and s is the standard deviation. $\xi_{\%5}$ and $\xi_{\%95}$ are calculated by using the equation (4). If ξ_{data} satisfies $\xi_{\%5} < \xi_{data} < \xi_{\%95}$ limitation, model is accepted.

$$\xi_{\%5} \; or \; \xi_{\%95} = a + blnN + c(lnN)^2 \tag{4}$$

Where N is the number of data and a, b and c are the parameters provided in Goda (2000).

Above criteria have been checked one by one and best distribution method has been found out for all selected points. When different criteria determine different best distributions or if there is no study on that study area about the selection of distribution models, *r* criterion is selected as defining criterion to determine the best distribution for all comparisons. Reason for this is that from Özyurt, G. and Özbahçeci, B.Ö (2008) study it is found out that none of these distribution models are the best fitting model for whole Black Sea region. Instead, selecting best distribution model depends on the study area. It is also presented that using different distribution models create approximately 10% difference for Hs_{50} and Hs_{100} values. Study regions for both studies are checked and for majority of the study regions it is seen that the best distribution models for Özyurt, G. and Özbahçeci, B.Ö (2008) study coincide with *r* criterion in this study. So, for other regions where no study exists, *r* is also selected as the decisive criterion.

It should also be noted that, at some results, same criterion shows more than one best distribution, which means all of these distributions are between required limits.

Results for non-directional analysis for İstanbul – Kilyos are presented at Table 4 and Table 5. Rest of the regions are also presented at Appendix - A.

İstanbul – Kilyos:

Meteorology data set:

Table 4 – Extreme Analysis Results of İstanbul – Kilyos for Meteorology Data Set

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	6.38	7.22	8.03	9.08	9.87	11.69	12.47	-	Best Distr.	-	-
FT 2 (k1=2.5)	5.67	6.35	7.22	8.78	10.40	16.44	20.49	-	-	-	-
FT 2 (k2=3.33)	5.86	6.63	7.56	9.11	10.58	15.45	18.39	-	-	-	-
FT 2 (k3=5.0)	6.04	6.89	7.82	9.25	10.51	14.19	16.18	-	-	-	-
FT 2 (k4=10.0)	6.22	7.08	7.98	9.23	10.25	12.89	14.16	-	-	-	-
Weibull (k1=0.75)	5.86	6.75	7.74	9.16	10.32	13.22	14.56	-	-	-	-
Weibull (k2=1.0)	6.13	7.04	7.96	9.16	10.08	12.20	13.11	-	-	-	-
Weibull (k3=1.4)	6.37	7.23	8.03	9.00	9.69	11.19	11.81	-	-	-	-
Weibull (k4=2.0)	6.52	7.30	7.98	8.75	9.28	10.37	10.80	Best Distr	-	-	-
LogNormal	6.74	7.87	8.94	10.32	11.35	13.78	14.85	-	-	Best Distr	-

Meteorology data set yields 9.28 m extreme wave height for 100 year return period when Weibull (k4 = 2.0) is selected as best distribution.

ECMWF data set:

Table 5 – Extreme Analysis Results of İstanbul – Kilyos for ECMWF Data Set

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	6.31	6.97	7.60	8.41	9.02	10.43	11.04	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	5.79	6.37	7.12	8.46	9.86	15.04	18.52	-	-	Best Distr	-
FT 2 (k2=3.33)	5.94	6.59	7.37	8.66	9.89	13.96	16.42	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	6.08	6.77	7.53	8.69	9.72	12.72	14.34	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	6.21	6.89	7.60	8.60	9.41	11.51	12.52	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	5.96	6.72	7.57	8.79	9.78	12.28	13.42	-	-	Best Distr	-
Weibull (k2=1.0)	6.16	6.91	7.67	8.67	9.43	11.18	11.94	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	6.32	7.01	7.64	8.41	8.96	10.16	10.64	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	6.41	7.01	7.52	8.12	8.52	9.35	9.68	Best Distr	-	Best Distr	Best Distr.
LogNormal	6.39	6.99	7.53	8.18	8.65	9.68	10.11	-	-	Best Distr	Best Distr.

ECMWF data set yields 8.52 m extreme wave height for 100 year return period when Weibull (k4 = 2.0) is selected as best distribution.

4.2.2. Direction – Wise Analysis

In addition to non-directional analysis, direction-wise extreme wave calculations are conducted. Main problem considering these calculations is that not all data sets create similar amount of data for same direction. Performing an extreme analysis with such low amount of measurements will create unreliable results (Goda, 2000). For example, for Kastamonu – İnebolu point, both data sets are re-arranged and they start from 1983 and end at 2006 (24 years of analysis period) but ECMWF data set can create maximum wave heights from east direction for 18 years whereas meteorology data set can create only for 4 years for the same direction. This means that, for 6 years, ECMWF data set does not have wind velocities higher than threshold value so no waves are created from east direction. But for meteorology data set, no wind above threshold exists from east direction for 20 years. So, making an extreme analysis and comparing results for east direction would create unreliability. Directions that have similar amount of data, which is decided as 60% of analysis period for both data sets, have been selected for comparison which also differs for each point. Results of direction-wise analysis for İstanbul – Kilyos are presented from Table 6 through Table 11. Rest of the regions are also presented at Appendix - B.

İstanbul – Kilyos:

For this point, three directions are selected. These are NNE, NNW and N directions.

Meteorology data set:

NNE:

Table 6 – Extreme Analysis of NNE Direction for İstanbul – Kilyos for Meteorology Data Set

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	4.31	5.17	6.00	7.07	7.87	9.73	10.53	-	Best Distr.	-	Best Distr.
FT 2 (k1=2.5)	3.61	4.34	5.28	6.97	8.73	15.27	19.66	-	-	-	-
FT 2 (k2=3.33)	3.80	4.63	5.62	7.27	8.84	14.04	17.17	-	-	-	-
FT 2 (k3=5.0)	3.99	4.87	5.86	7.36	8.68	12.55	14.64	-	-	-	-
FT 2 (k4=10.0)	4.16	5.06	5.98	7.28	8.33	11.07	12.39	-	-	-	Best Distr.
Weibull (k1=0.75)	3.82	4.79	5.87	7.43	8.70	11.88	13.34	-	-	-	-
Weibull (k2=1.0)	4.09	5.07	6.06	7.35	8.34	10.62	11.60	-	-	-	-
Weibull (k3=1.4)	4.32	5.23	6.06	7.08	7.80	9.37	10.02	-	-	-	Best Distr.
Weibull (k4=2.0)	4.45	5.25	5.93	6.72	7.26	8.37	8.80	Best Distr.	-	Best Distr	Best Distr.
LogNormal	4.46	5.61	6.79	8.42	9.71	12.98	14.50	-	-	Best Distr	Best Distr.

Meteorology data set yields 7.26 m extreme wave height for 100 year return period when Weibull (k4 = 2.0) is selected as best distribution for NNE direction.

NNW:

Table 7 – Extreme Analysis of NNW Direction for İstanbul – Kilyos for Meteorology Data Set

Return Period	5	10	20	50	100	500	1000	r	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	6.45	7.09	7.69	8.48	9.07	10.44	11.03	-	-	Best Distr	Best Distr.
FT 2 (k1=2.5)	5.95	6.50	7.22	8.51	9.84	14.82	18.16	-	-	-	-
FT 2 (k2=3.33)	6.09	6.71	7.46	8.70	9.89	13.80	16.16	-	-	-	Best Distr.
FT 2 (k3=5.0)	6.22	6.88	7.62	8.74	9.73	12.62	14.18	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	6.35	7.01	7.69	8.66	9.44	11.47	12.45	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	6.10	6.84	7.65	8.83	9.78	12.18	13.28	-	-	-	-
Weibull (k2=1.0)	6.30	7.03	7.76	8.72	9.45	11.14	11.87	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	6.46	7.12	7.73	8.48	9.01	10.16	10.63	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	6.55	7.13	7.62	8.20	8.59	9.40	9.71	-	-	Best Distr	Best Distr.
LogNormal	6.54	7.13	7.64	8.27	8.72	9.71	10.11	Best Distr.	Best Distr.	Best Distr	Best Distr.

Meteorology data set yields 8.72 m extreme wave height for 100 year return period when Lognormal is selected as best distribution for NNW direction.

N:

Table 8 – Extreme Analysis of N Direction for İstanbul – Kilyos for Meteorology Data Set

Return Period	5	10	20	50	100	500	1000	r	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	4.59	5.57	6.50	7.71	8.62	10.71	11.61	-	Best Distr.	-	Best Distr.
FT 2 (k1=2.5)	3.80	4.63	5.70	7.63	9.63	17.07	22.07	-	-	-	-
FT 2 (k2=3.33)	4.02	4.96	6.08	7.95	9.73	15.62	19.17	-	-	-	-
FT 2 (k3=5.0)	4.23	5.23	6.34	8.04	9.54	13.92	16.28	-	-	-	-
FT 2 (k4=10.0)	4.43	5.44	6.48	7.95	9.14	12.23	13.72	-	-	-	Best Distr.
Weibull (k1=0.75)	4.04	5.14	6.36	8.12	9.55	13.15	14.80	-	-	-	-
Weibull (k2=1.0)	4.35	5.46	6.56	8.03	9.14	11.71	12.82	-	-	-	-
Weibull (k3=1.4)	4.60	5.63	6.56	7.71	8.53	10.31	11.03	-	-	-	Best Distr.
Weibull (k4=2.0)	4.75	5.65	6.42	7.31	7.92	9.17	9.66	Best Distr.	-	Best Distr	Best Distr.
LogNormal	4.77	6.17	7.64	9.72	11.40	15.77	17.86	-	-	Best Distr	Best Distr.

Meteorology data set yields 7.92 m extreme wave height for 100 year return period when Weibull (k4 = 2.0) is selected as best distribution for N direction.

ECMWF data set:

NNE:

Table 9 – Extreme Analysis of NNE Direction for İstanbul – Kilyos for ECMWF Data Set

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	5.78	6.87	7.92	9.28	10.30	12.66	13.67	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	4.89	5.82	7.01	9.16	11.38	19.66	25.23	-	-	-	-
FT 2 (k2=3.33)	5.13	6.18	7.44	9.53	11.52	18.10	22.07	-	-	-	-
FT 2 (k3=5.0)	5.37	6.49	7.74	9.64	11.32	16.22	18.87	-	-	-	-
FT 2 (k4=10.0)	5.59	6.72	7.89	9.54	10.88	14.35	16.02	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	5.15	6.38	7.74	9.70	11.29	15.29	17.13	-	-	-	-
Weibull (k2=1.0)	5.50	6.73	7.97	9.60	10.83	13.70	14.93	-	-	-	-
Weibull (k3=1.4)	5.79	6.93	7.98	9.26	10.17	12.15	12.96	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	5.96	6.96	7.83	8.83	9.51	10.91	11.46	Best Distr.	-	Best Distr	Best Distr.
LogNormal	6.06	7.58	9.12	11.23	12.90	17.08	19.03	-	-	Best Distr	-

ECMWF data set yields 9.51 m extreme wave height for 100 year return period when Weibull (k4 = 2.0) is selected as best distribution for NNE direction.

NNW:

Table 10 – Extreme Analysis of NNW Direction for İstanbul – Kilyos for ECMWF Data Set

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	2.97	3.76	4.51	5.48	6.21	7.89	8.62	-	-	Best Distr	Best Distr.
FT 2 (k1=2.5)	2.39	3.15	4.14	5.92	7.76	14.62	19.23	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	2.56	3.40	4.39	6.05	7.63	12.85	16.00	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	2.73	3.58	4.53	5.99	7.27	11.01	13.03	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	2.87	3.70	4.57	5.78	6.77	9.33	10.56	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	2.59	3.59	4.69	6.28	7.57	10.82	12.31	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	2.82	3.77	4.72	5.97	6.92	9.12	10.07	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	2.99	3.82	4.59	5.52	6.19	7.63	8.22	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	3.07	3.77	4.37	5.07	5.55	6.53	6.91	-	-	Best Distr	Best Distr.
LogNormal	2.85	3.81	4.84	6.34	7.59	10.92	12.56	Best Distr.	Best Distr.	Best Distr	Best Distr.

ECMWF data set yields 7.59 m extreme wave height for 100 year return period when Lognormal is selected as best distribution for NNW direction.

N:

Table 11 – Extreme Analysis of N Direction for İstanbul – Kilyos for ECMWF Data Set

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	4.53	5.26	5.96	6.86	7.53	9.10	9.77	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	3.96	4.59	5.40	6.87	8.39	14.04	17.85	-	-	Best Distr	-
FT 2 (k2=3.33)	4.11	4.82	5.67	7.08	8.43	12.87	15.55	-	-	Best Distr	-
FT 2 (k3=5.0)	4.27	5.02	5.86	7.13	8.25	11.54	13.31	-	-	Best Distr	-
FT 2 (k4=10.0)	4.41	5.17	5.95	7.04	7.93	10.24	11.36	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	4.12	4.94	5.85	7.16	8.23	10.90	12.13	-	-	Best Distr	-
Weibull (k2=1.0)	4.35	5.16	5.98	7.06	7.88	9.78	10.60	-	-	Best Distr	-
Weibull (k3=1.4)	4.53	5.29	5.98	6.83	7.43	8.74	9.27	-	-	Best Distr	-
Weibull (k4=2.0)	4.65	5.31	5.88	6.54	6.99	7.92	8.28	Best Distr.	-	Best Distr	Best Distr.
LogNormal	4.70	5.59	6.44	7.55	8.40	10.43	11.33	-	-	Best Distr	-

ECMWF data set yields 6.99 m extreme wave height for 100 year return period when Weibull (k4 = 2.0) is selected as best distribution for N direction.

4.2.3. Summary and Discussion on the Results of Numerical Analysis

Extreme analysis is performed to all data sets for all points. As stated before, *r* criterion is selected as decisive criterion to find out best distribution among ten distributions. Detailed results for all points are presented in Appendix – A and B.

Direction – wise differences between two data sets are also calculated. It should be noted that meteorology data set is considered as accurate data set due to the fact that meteorology stations make measurements on hourly basis and they are used only for Turkish coasts.

Also, previous studies are compared with the calculated results. These studies are Çaban, S. (2007), Bilyay, E. et al. (2010), Ergin, A. and Özhan, E. (1986) and Özhan, E. and Abdalla, S. (1999).

Çaban, S. (2007) study includes ECMWF data for 65 months only and selected analysis points differ for each region. Moreover, in Çaban, S. (2007) study it is assumed that Gumbel distribution is the correct one and its results are presented accordingly. But in this study, best distribution is different for each point depending on the *r* criterion. For this reason results for Gumbel distribution for ECMWF data set are also presented during comparison with Çaban, S. (2007) study to see the discrepancy more clearly.

Bilyay, E. et al. (2010) study is on Filyos region near Zonguldak study area. Although study period is for two years only, direct wave measurements are performed. For this reason, a validation can be performed for both data sets.

Ergin, A. and Özhan, E. (1986) study is for 15 regions along Turkish coasts. For these regions, wind data and synoptic maps are acquired from various meteorology stations and extreme analysis is performed. Results of two regions, namely Amasra and Çatalzeytin, are compared with results in this study. It is expected that wind data results in Ergin, A. and Özhan, E. (1986) study will be in good agreement with results of meteorology data set in our study since same data sets are used in analysis. Also, it is expected that synoptic map results in Ergin, A. and Özhan, E. (1986) study will be in good agreement with the results of ECMWF data set since both of them use pressure data. In Ergin, A. and Özhan, E. (1986) study, for Amasra region, Zonguldak meteorology station data is used and for Çatalzeytin region, Sinop meteorology station data is used.

Extreme wave results from the closest Özhan, E and Abdalla, S. (1999) study point is also compared and again a validation can be performed for both data sets. Özhan, E and Abdalla, S. (1999) also uses Gumbel distribution for all points. For this reason, results for Gumbel distribution are also presented for proper comparison.

İstanbul – Kilyos:

Results for this region are summarized at Table 12.

Table 12 – Comparison of Numerical Analysis for İstanbul – Kilyos Region

	MET		BEST DIST	ECM		BEST DIST	H_{50} DIFF (%)	H_{100} DIFF (%)
	H_{50}	H_{100}		H_{50}	H_{100}			
ALL DIRECTIONS	8.75	9.28	Weibull(k4=2.0)	8.12	8.52	Weibull(k4=2.0)	-7.26%	-8.19%
NNE	6.72	7.26	Weibull(k4=2.0)	8.83	9.51	Weibull(k4=2.0)	31.38%	31.02%
NNW	8.27	8.72	LogNormal	6.34	7.59	LogNormal	-23.38%	-13.00%
N	7.31	7.92	Weibull(k4=2.0)	6.54	6.99	Weibull(k4=2.0)	-10.51%	-11.70%

For this point, results for all directions are in good agreement. ECMWF data set give only 8% less Hs_{100} than meteorology data set which also tallies with initial assessment from graphical comparison. On the other hand, NNE comparison gives very different result than expected. It shows 30% higher Hs_{100} value than meteorology data set. When results of both data sets are inspected, it is seen that NNE direction is the most dominant direction for ECMWF data set but for meteorology data set, NNW and N directions are the most dominant ones.

Çaban, S. (2007) has yielded similar results. The closest point selected is approximately 90 km north of Kilyos and Hs_{100} is found as 8.5 m. In this study, Hs_{100} is found as 8.52 m. for best distribution and 9.02 m. for Gumbel distribution for ECMWF data set.

41.25 N and 29.00 E coordinate is selected for comparison for Özhan, E and Abdalla, S. (1999) study (Wave Atlas). Results for both best distribution and Gumbel Distribution for all data sets are shown at Table 13.

Table 13 – Comparison of Results with Wave Atlas for İstanbul – Kilyos Region

	Wave Atlas	Meteorology		ECMWF	
	Gumbel	Best Distribution	Gumbel	Best Distribution	Gumbel
Hs_{50} (m)	8.75	8.75	9.08	8.12	8.41
Hs_{100} (m)	9.50	9.28	9.87	8.52	9.02

From the comparison, it is found that meteorology data set is in very good agreement with Wave Atlas when best distribution is used. Whereas, ECMWF data set is in good agreement with Gumbel distribution.

İstanbul – Şile:

Results for this region are summarized at Table 14**.**

Table 14 – Comparison of Numerical Analysis for İstanbul – Şile Region

	MET		BEST DIST	ECM		BEST DIST	H_{50} DIFF (%)	H_{100} DIFF (%)
	H_{50}	H_{100}		H_{50}	H_{100}			
ALL DIRECTIONS	7.44	7.97	Weibull(k4=2.0)	8.03	8.39	Weibull(k4=2.0)	7.94%	5.34%
NNE	7.52	8.07	Weibull(k4=2.0)	8.21	8.81	Weibull(k4=2.0)	9.19%	9.12%
N	6.98	7.84	Gumbel	6.73	7.21	Weibull(k4=2.0)	-3.66%	-8.09%

Although graphical comparison suggested that ECMWF data set gives higher wind velocity peaks, it seen from extreme analysis that end results are in very good agreement with each other but still ECMWF data set overestimates Hs_{100} value around 5%.

From inspection of the results, it is seen that, although end result is less than ECMWF, NNE direction is the most dominant direction for meteorology data set for almost all years. But for ECMWF data set, peak values of wave heights for each year varies between different directions but only two directions could be compared due to less number of data provided from meteorology data set.

No closer points are found in previous studies to compare with. A loosely related point in Çaban, S. (2007) is Kefken, Kocaeli. It is located between İstanbul – Şile and Düzce – Akçakoca but closer to Şile. Location of selected coordinate is approximately 120 km away in northeast direction from Şile point. Extreme wave height is found as 8.2 m for Hs_{100}. In this study, Hs_{100} is found as 8.39 m. for best distribution and 8.84 m. for Gumbel distribution for ECMWF data set.

41.25 N and 29.60 E coordinate is selected for comparison for Özhan, E and Abdalla, S. (1999) study (Wave Atlas). Results for both best distribution and Gumbel Distribution for both data sets are shown at Table 15.

Table 15 – Comparison of Results with Wave Atlas for İstanbul – Şile Region

	Wave Atlas	Meteorology		ECMWF	
	Gumbel	Best Distribution	Gumbel	Best Distribution	Gumbel
Hs_{50} (m)	9.25	7.44	7.84	8.03	8.30
Hs_{100} (m)	10.00	7.97	8.63	8.39	8.84

From the comparison, it is found that although Gumbel distribution creates higher wave heights, both data sets still underestimate for this region. But it should be noted that ECMWF data set is in better agreement with Wave Atlas.

Düzce – Akçakoca:

Results for this region are summarized at Table 16**.**

Table 16 – Comparison of Numerical Analysis for Düzce - Akçakoca Region

	MET		BEST DIST	ECM		BEST DIST	H_{50} DIFF (%)	H_{100} DIFF (%)
	H_{50}	H_{100}		H_{50}	H_{100}			
ALL DIRECTIONS	3.78	4.18	Gumbel	6.33	7.07	Gumbel	67.47%	68.95%
NNE	2.68	2.92	Weibull(k3=1.4)	4.63	4.98	Weibull(k4=2.0)	72.69%	70.59%
N	3.3	3.63	Weibull(k3=1.4)	4.15	4.47	Weibull(k4=2.0)	25.67%	23.20%

Although from graphical comparison, it is expected that ECMWF data set would give larger extreme wave height value, it is still a lot larger than expected.

When results are checked for both data sets, it is seen that the most dominant direction is NE direction for ECMWF data set. But meteorology data set provides only three values from that direction. Also, for 7 years out of 27 years of analysis period, meteorology data set does not provide any wave data from any directions. In addition, ECMWF's maximum wave height is at 2008 and 6.25m, whereas meteorology's value at that year is 2.07m, which is almost 1/3 of former one's.

No closer points are found in previous studies to compare with for Çaban, S. (2007) study.

41.25 N and 31.10 E coordinate is selected for comparison for Özhan, E and Abdalla, S. (1999) study (Wave Atlas). Results for best distribution which is also Gumbel distribution for both data sets are shown at Table 17.

Table 17 – Comparison of Results with Wave Atlas for Düzce – Akçakoca Region

	Wave Atlas	Meteorology	ECMWF
	Gumbel	**Best Distribution**	**Best Distribution**
Hs_{50} (m)	8.00	3.78	6.33
Hs_{100} (m)	8.75	4.18	7.07

From the comparison, it is found that although Gumbel distribution creates higher wave heights, both data sets still underestimate for this region. But it should be noted that ECMWF data set is in better agreement with Wave Atlas.

Zonguldak:

Results for this region are summarized at Table 18.

Table 18 – Comparison of Numerical Analysis for Zonguldak Region

	MET		BEST DIST	ECM		BEST DIST	H_{50} DIFF (%)	H_{100} DIFF (%)
	H_{50}	H_{100}		H_{50}	H_{100}			
ALL DIRECTIONS	3.4	3.66	Weibull(k4=2.0)	6.47	6.88	Weibull(k4=2.0)	90.49%	88.09%

Results for this point are highly unexpected. As seen above, results of two data sets are hugely different, almost 90% for Hs_{100}. Possible reasons for such difference will be investigated in the section 4.3., yet first inspection shows that the main problem is with meteorology data set. Considering that analysis point is on Black Sea region of Turkey where the biggest storms are recorded, meteorology data set provides with wave heights only for 10 years for a 24 year analysis period whereas ECMWF data set can provide 24 maximum wave heights for same period.

Çaban, S. (2007) has yielded similar results. The closest point selected is approximately 70 km northeast of Zonguldak and Hs_{100} is found as 7.2 m. In this study, Hs_{100} is found as 6.88 m. for best distribution and 7.37 m. for Gumbel distribution for ECMWF data set.

Another study around this region is "Bilyay, E., Ünal A., Özbahçeci, B.O. and Yalçıner, A.C.: Extreme Waves at Filyos, Southern Black Sea, 2010". Considering the proximity, Bilyay, E. et al. (2010) study's results are also investigated. For Bilyay, E. (2010) study, 1995 and 1996 wave records were used. For these two years, maximum significant wave height was found as 5.0 m. For these years meteorology data set gives no value for Hs and ECMWF data set gives Hs values of 3.03 and 2.78 m., for 1995 and 1996, respectively. As for the Hs_{max} in ECMWF data set, it is found as 5.82 m. in 2006. When it is considered that direct wave measurements were performed for Bilyay, E. et al. (2010) and including the fact that measurement area is only 25 km away from study area, it can be concluded that ECMWF underestimates wave parameters for Zonguldak region. As for meteorology station data, measurements are far below than expected.

Results of Ergin, A. and Özhan, E. (1986) study are also used for validation and comparison. Amasra study point is selected for comparison for which Zonguldak meteorology data is used. Although same data set and similar methodologies are used in Ergin, A. and Özhan, E. (1986) study and our study in terms of wave prediction, different programs are used for wind to wave transformations. For this reason, minor differences between two studies are expected. Gathered data for Ergin, A. and Özhan, E. (1986) study is for 16 years, between 1969 and 1984. In our study, analysis period is for 24 years, between 1983 and 2006. Synoptic maps are for 9 years, between 1976 and 1984. Since results for 1983 and 1984 coincide in both studies, they are also presented in comparison. But it should be noted that for Zonguldak region meteorology data set in our study cannot present any values for both years if threshold value is kept as 9.5 m/s. For this reason, threshold is lowered to 3 m/s for this instance. Results are shown at Table 19.

Table 19 – Comparison of Results with Wind Data and Synoptic Maps for Zonguldak Region

	1983	**1984**	**Gumbel**			
	Hs_{max}	**Hs_{max}**	**Hs_{50}**	**Hs_{100}**		
Wind Data	2.21	2.21	4.09	4.37		
Synoptic Maps	1.98	2.83	5.29	5.84		
	1983	**1984**	**Gumbel**		**Best Distr.**	
	Hs_{max}	**Hs_{max}**	**Hs_{50}**	**Hs_{100}**	**Hs_{50}**	**Hs_{100}**
Met	2.54	2.18	3.74	3.99	3.63	3.80
ECMWF	4.36	4.83	7.04	7.52	6.82	7.13

It can be concluded that although there are minor differences, results of meteorology data set are in good agreement with wind data results of Ergin, A. and Özhan, E. (1986) study when Gumbel distribution is considered. On the other hand, ECMWF overestimated all values when compared with Ergin, A. and Özhan, E. (1986) study.

41.50 N and 31.70 E coordinate is selected for comparison for Özhan, E and Abdalla, S. (1999) study (Wave Atlas). Results for both best distribution and Gumbel Distribution for both data sets are shown at Table 20.

Table 20 – Comparison of Results with Wave Atlas for Zonguldak Region

	Wave Atlas	Meteorology		ECMWF	
	Gumbel	Best Distribution	Gumbel	Best Distribution	Gumbel
Hs_{50} (m)	8.00	3.40	3.60	6.47	6.75
Hs_{100} (m)	8.50	3.66	4.00	6.88	7.37

From the comparison, it is found that although Gumbel distribution creates higher wave heights, both data sets still underestimate for this region. But it should be noted that ECMWF data set is in better agreement with Wave Atlas. Considering that there is a direct wave measurement exists for this region, it is possible that Wave Atlas is actually overestimated the results.

Bartın – Amasra:

Results for this region are summarized at Table 21.

Table 21 – Comparison of Numerical Analysis for Bartın - Amasra Region

	MET		BEST DIST	ECM		BEST DIST	H_{50} DIFF (%)	H_{100} DIFF (%)
	H_{50}	H_{100}		H_{50}	H_{100}			
ALL DIRECTIONS	12.8	13.54	LogNormal	4.73	6.15	FT 2(k1=2.5)	-63.08%	-54.27%
NE	10.53	11.97	FT 2(k4=10.0)	6.99	9.31	FT 2(k1=2.5)	-33.67%	-22.21%

This case is almost the opposite of Düzce – Akçakoca. This time, meteorology data set gives higher results. Meteorology data set creates waves for almost all direction for almost all years but as it is observed from wind roses, the most dominant direction is ENE, on the other hand, ECMWF data provides nearly not enough data for analysis. When all directions are considered, meteorology data set shows that lowest value of the maximum wave heights is at 2007 and 4.98m whereas ECMWF data set's maximum value is 4.65m. For 2007, it gives 0.82 m wave height from west direction.

Çaban, S. (2007) has yielded similar results. The closest point selected is approximately 40 km northeast of Bartın - Amasra and Hs_{100} is found as 6.50 m. In this study, Hs_{100} is found as 6.15 m. for best distribution and 4.61 m. for Gumbel distribution for ECMWF data set.

41.75 N and 32.30 E coordinate is selected for comparison for Özhan, E and Abdalla, S. (1999) study (Wave Atlas). Results for both best distribution and Gumbel Distribution for both data sets are shown at Table 22.

Table 22 – Comparison of Results with Wave Atlas for Bartın – Amasra Region

	Wave Atlas	Meteorology		ECMWF	
	Gumbel	Best Distribution	Gumbel	Best Distribution	Gumbel
Hs_{50} (m)	8.25	12.80	12.76	4.73	4.11
Hs_{100} (m)	8.50	13.54	13.65	6.15	4.61

From the comparison, it is found that this region is unusual when compared to other points. Meteorology data set overestimates more than 50% whereas ECMWF data set underestimates around 30%. It appears it is impossible to determine the correct data set without on-site buoy measurements.

Kastamonu – İnebolu:

Results for this region are summarized at Table 23.

Table 23 – Comparison of Numerical Analysis for Kastamonu - İnebolu Region

	MET		BEST DIST	ECM		BEST DIST	H_{50} DIFF (%)	H_{100} DIFF (%)
	H_{50}	H_{100}		H_{50}	H_{100}			
ALL DIRECTIONS	5.33	6.04	LogNormal	6.93	7.44	Weibull(k4=2.0)	29.84%	23.16%
WNW	4.96	5.63	LogNormal	6.08	6.59	Weibull(k4=2.0)	22.59%	17.08%

Considering the last three cases, this point gives more reasonable results. Nevertheless, results are still more than anticipated. Main reason why there is only one direction that is compared is that unlike meteorology data set, ECMWF provides more waves from different directions but meteorology data set cannot.

Çaban, S. (2007) includes a study on a similar region. The closest point selected is approximately 10 km northwest of Kastamonu – İnebolu. But no extreme analysis is performed for that region due to lack of data for selected coordinate and analysis period.

42.00 N and 33.80 E coordinate is selected for comparison for Özhan, E and Abdalla, S. (1999) study (Wave Atlas). Results for both best distribution and Gumbel Distribution for both data sets are shown at Table 24.

Table 24 – Comparison of Results with Wave Atlas for Kastamonu – İnebolu Region

	Wave Atlas	Meteorology		ECMWF	
	Gumbel	Best Distribution	Gumbel	Best Distribution	Gumbel
Hs_{50} (m)	8.5	5.33	4.91	6.93	7.25
Hs_{100} (m)	8.75	6.04	5.46	7.44	8.02

From the comparison, it is found that although Gumbel distribution creates higher wave heights, both data sets still underestimate for this region. But it should be noted that ECMWF data set is in better agreement with Wave Atlas.

Sinop:

Results for this region are summarized at Table 25.

Table 25 – Comparison of Numerical Analysis for Sinop Region

	MET		BEST DIST	ECM		BEST DIST	H_{50} DIFF (%)	H_{100} DIFF (%)
	H_{50}	H_{100}		H_{50}	H_{100}			
ALL DIRECTIONS	7.15	7.46	LogNormal	7.19	7.70	LogNormal	0.63%	3.14%
WNW	7.34	7.69	Weibull(k4=2.0)	7.62	8.23	Weibull(k4=2.0)	3.90%	6.96%
NW	6.60	7.03	LogNormal	5.63	6.20	LogNormal	-14.76%	-11.83%
NNW	6.02	6.39	Weibull(k4=2.0)	5.18	5.57	Weibull(k4=2.0)	-14.00%	-12.92%
N	5.48	5.91	Weibull(k4=2.0)	4.64	5.03	Weibull(k4=2.0)	-15.24%	-14.88%

Unlike all other cases, data sets for this point give almost same results when all directions are considered which is also not expected. It somehow contradicts with initial visual assessment since ECMWF data set creates larger extreme wave heights but as it stated before, pattern deducted from one month's data is not enough to cover entire analysis period.

Çaban, S. (2007) includes a study on a similar region. It only uses ECMWF data set and the closest point selected is approximately 28 km west-northwest of Sinop. But no extreme analysis is performed for that region due to lack of data for selected coordinate and analysis period.

Results of Ergin, A. and Özhan, E. (1986) study are also used for validation and comparison. Çatalzeytin study point is selected for comparison for which Sinop meteorology data is used. Although same data set and similar methodologies are used in Ergin, A. and Özhan, E. (1986) study and our study in terms of wave prediction, different programs are used for wind to wave transformations. For this reason, minor differences between two studies are expected. Gathered wind data for Ergin, A. and Özhan, E. (1986) study is for 16 years, between 1969 and 1984. In our study, analysis period is for 24 years, between 1983 and 2006. Synoptic maps are for 9 years, between 1976 and 1984. Since results for 1983 and 1984 coincide in both studies, they are also presented in comparison. Results are shown at Table 26.

Table 26 – Comparison of Results with Wind Data and Synoptic Maps for Sinop Region

	1983	**1984**	**Gumbel**	
	Hs_{max}	**Hs_{max}**	**Hs_{50}**	**Hs_{100}**
Wind Data	5.34	5.68	7.46	7.85
Synoptic Maps	2.40	2.84	4.62	5.03

	1983	**1984**	**Gumbel**		**Best Distr.**	
	Hs_{max}	**Hs_{max}**	**Hs_{50}**	**Hs_{100}**	**Hs_{50}**	**Hs_{100}**
Met	5.67	5.75	7.26	7.69	7.15	7.45
ECMWF	2.68	3.06	7.26	7.85	7.19	7.70

It can be concluded that although there are minor differences, results of meteorology data set are in very good agreement with wind data results of Ergin, A. and Özhan, E. (1986) study when Gumbel distribution is considered. On the other hand, although Hs_{max} values of 1983 and 1984 are in very good agreement with synoptic map results, ECMWF overestimated Hs_{50} and Hs_{100} values when compared with Ergin, A. and Özhan, E. (1986) study.

42.00 N and 35.30 E coordinate is selected for comparison for Özhan, E and Abdalla, S. (1999) study (Wave Atlas). Results for both best distribution and Gumbel Distribution for both data sets are shown at Table 27.

Table 27 – Comparison of Results with Wave Atlas for Sinop Region

	Wave Atlas	Meteorology		ECMWF	
	Gumbel	Best Distribution	Gumbel	Best Distribution	Gumbel
Hs_{50} (m)	8.20	7.15	7.26	7.19	7.26
Hs_{100} (m)	8.75	7.46	7.69	7.70	7.85

From the comparison, it is found that although Gumbel distribution creates higher wave heights, both data sets still underestimate for this region.

4.3. DISCUSSION ON GRAPHICAL AND NUMERICAL ANALYSIS

From above analyses, it can be concluded that ECMWF data set generally gives higher results than meteorology data set but the difference is a lot higher than previously expected. In this section, possible reasons are investigated for such differences. Zonguldak region is selected for analysis since its results yielded the biggest difference in favor of ECMWF.

4.3.1 Calculation Error and Code Validation

First thing that is checked is calculation errors and the computation codes. Both of them are double checked and compared with similar codes and programs. Additionally, a validation study has been performed using the design report of a real life coastal project, Ordu – Giresun Airport (Yüksel Proje Uluslararası A. Ş., 2011). The inputs used in the design of the project are analyzed and same output results are found by the extreme analysis method used in this study.

4.3.2 All Directions Study

Although it is highly unlikely, another graphical comparison has been made based on all directions instead of only northern directions to see whether omitting southern directions have any impact on storms peaks that is above threshold value in which case it can be concluded that there is a direction-wise mismeasurement on data sets. Naturally, only wind velocities are checked since it is impossible to perform wave analysis without any fetch distances from south. Again, January 2000 data are drawn to agree with previous graphs in section 4.1. But as it can be seen at Figure 26, there is almost no difference for Zonguldak region. Also, graphs for the rest of the regions are presented in Appendix – C.

Since the graphical comparison is only for one month, number of storms above 9.5 m/s threshold are also obtained for both data sets for all directions and for northern directions only. Results are shown below.

Meteorology – All Directions: 182

Meteorology – Northern Directions: 71

ECMWF – All Directions: 5280

ECMWF – Northern Directions: 3037

It is concluded that although more than half of the storms for meteorology data set are measured from southern directions, considering the difference between data sets, effect of the storms from southern directions for meteorology data set is assumed to be negligible.

Effect of number of measurements between data sets is investigated in section 4.3.5. for all regions.

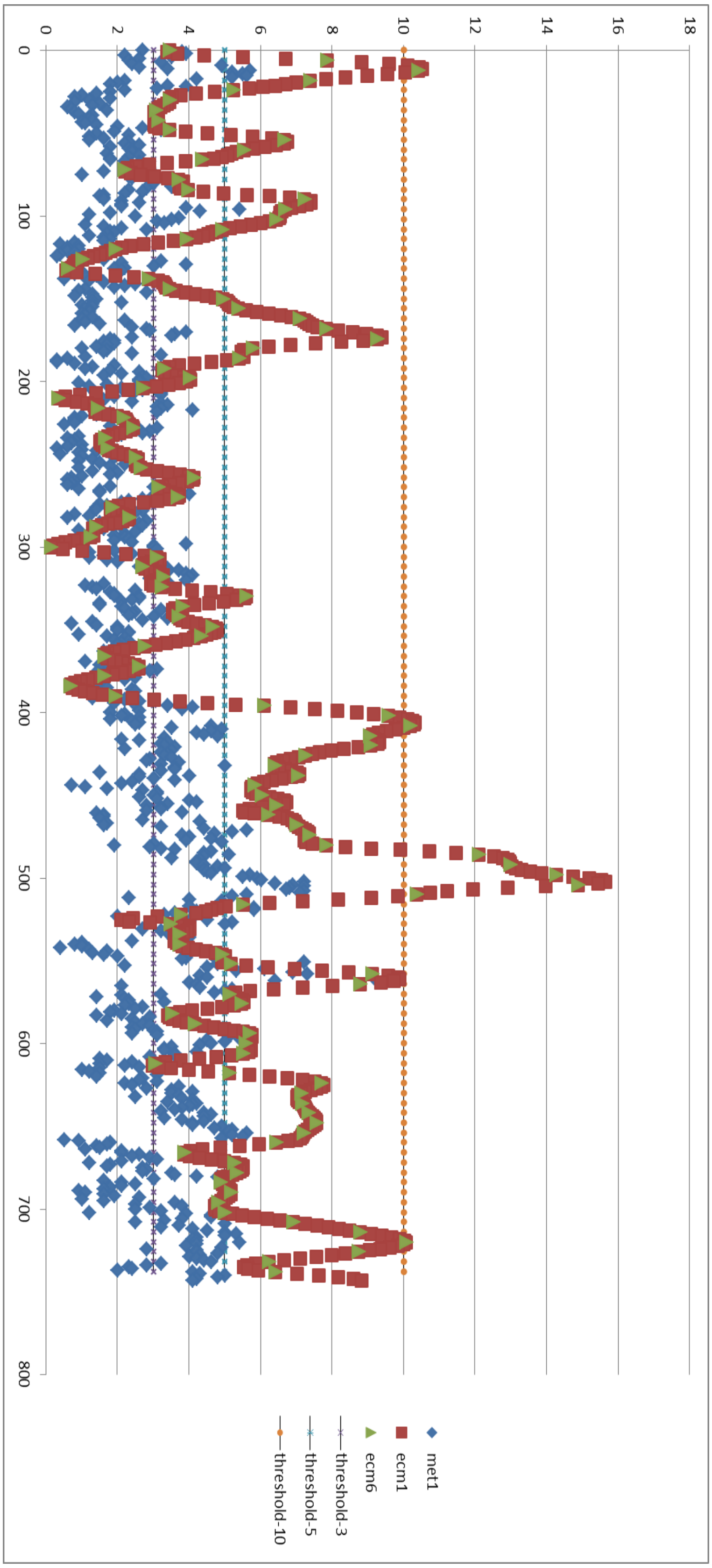


Figure 26 – Time Series for Zonguldak for All Directions

4.3.3 Effect of Threshold Value

Most probable reason for such differences seemed to be the threshold value. As for Zonguldak case, it is shown that almost all of the meteorology data is piled up below 10 m/s threshold. Even when confidence interval of 5% is used, results were not affected. This time, 3 m/s threshold is used for analysis for both data sets. Results are shown at Table 28.

Table 28 – Comparison of Numerical Analysis for Zonguldak Region for 3 m/s Threshold

	MET		BEST DIST	ECM		BEST DIST	Hs_{50} DIFF (%)	Hs_{100}DIFF (%)
	Hs_{50}	Hs_{100}		Hs_{50}	Hs_{100}			
ALL DIRECTIONS	3.63	3.80	Weibull (k4=2.0)	6.82	7.13	Weibull (k4=2.0)	87.65%	87.76%

As it can be seen, although difference has been shrunk, it is still higher than anticipated. This means that threshold value does have an effect on wave heights yet it is not the main reason for such a difference here.

4.3.4 Effect of Spline

Another possible reason for this difference is the spline method that has been used for ECMWF data set. As explained previously, ECMWF stores components of wind velocity for every 6 hour. But all the codes and programs require hourly measurements so that spline method has been used to make this transformation. After this process, all data is used as inputs for wind.exe program which groups data with given threshold and creates storms. When this process is finished, output files are checked and it is seen that durations of storms for different data sets hugely differ as well. As seen from all the graphs that have been presented, ECMWF data move as a continuous line whereas meteorology data are irregular along the path. Spline method is responsible for such differences and it creates a lot higher durations even if there should be no such storm which will also create higher wave heights. An example for this case is presented below at Figure 27 and Figure 28. It should be noted that threshold value is selected as 3 m/s for this case to see the duration differences more clearly.

Meteorology output:

```
    1     1     1 1983    10     1     1 1983     9
25 58 25 58 24 64 25 69 25 64 25 57 25 43 25 39 25 38
   11     1     1 1983    12     1     1 1983     1
25 33
   15     1     1 1983    19     1     1 1983     4
24 55 24 49 24 41 24 31
    5     3     1 1983    10     3     1 1983     5
23 34 23 40 23 32 23 33 23 31
   13     4     1 1983    14     4     1 1983     1
23 39
```

Figure 27 – Storm Durations for Meteorology Data Set

ECMWF output:

```
    0     1     1 1983    16     4     1 1983    88
26 40 26 48 26 53 26 57 26 59 26 59 26 58 26 56 26 53 26 51 25 48 25 47
25 45 25 45 25 45 25 45 25 45 25 45 25 44 25 43 25 42 25 41 24 40 24 39
24 38 24 38 24 38 24 38 24 38 23 38 23 38 23 39 23 39 23 40 23 42 23 43
23 44 23 44 23 45 23 45 23 46 24 46 24 45 24 44 24 43 24 41 24 39 24 37
24 35 24 34 24 33 24 33 24 33 23 34 23 35 23 36 22 38 22 40 22 42 22 43
22 44 22 45 22 45 22 44 22 44 22 43 23 42 23 42 23 42 23 43 23 44 24 45
24 46 24 47 24 48 25 49 25 49 25 49 25 49 25 47 25 46 25 44 26 42 26 40
26 37 26 35 25 33 25 30
```

Figure 28 – Storm Durations for ECMWF Data Set

It can be seen that meteorology data set shows one storm starts at 1.1.1983 at 1st hour and it is 9 hour storm. And there are 4 more storms until 4.1.1983 at 14th hour and their total durations are 20 hours. But for ECMWF data set, it shows one storm only that started at 1.1.1983 at 0 hour continued until 4.1.1983 at 16th hour for straight 88 hours. In reality, they should be the same storm but due to the nature of the spline method, duration of the storm increased more than 4 times instead.

Although this case will not explain the points where ECMWF data set provided lower results than meteorology data set, it can explain larger wave heights in Zonguldak region. Thus, a different approach has been used. Instead of performing spline method only on ECMWF data, this time meteorology data set is transformed into 6 hour data first and spline method has also been used on new meteorology data set. It is expected that if meteorology stations and ECMWF satellites managed to measure similar wind velocities at the same time, results should be a lot similar as well. Same process has been performed for both data sets after using spline method on both of them. After using wind.exe to organize and group storms above threshold, meteorology data set created not enough output for comparison which means that high values of meteorology measurements does not coincide with 6 hour periods. So, last probable reason for presented results is that there is simply not enough data above threshold as presented in section 4.3.2.

4.3.5 Effect of Number of Raw Data Measurements

Last thing that is checked is the raw data sets and number of measurements above threshold. For Zonguldak region, raw data sets are filtered, south directions are omitted and all data below threshold is excluded which is selected as 9.5 m/s to make it consistent with previous analysis. Only number of measurements are checked this time.

When south directions are omitted, meteorology data set shows 100896 data for this point whereas ECMWF data set shows 133833 data which means meteorology station measured more winds from the south directions than ECMWF between 1983 and 2006. When threshold is introduced, for meteorology data set, for 24 years of analysis period, only 71 measurements are found above this value. But for same period for hourly ECMWF data set, 3037 measurements are found. Even raw ECMWF data set which measures wind velocities at 6 hour periods, number of northern winds above threshold value is 537. For this region, it is evident that the main reason for such a high difference for extreme waves for different data set is that meteorology stations simply measured lower wind velocities than ECMWF. By using same procedure rest of the regions are checked and results are shown at Table 29. Also, for each region, w61 outputs are provided to see the effects of these measurement differences on wave heights.

Table 29 – Number of Data Above Threshold for All Regions

Study Region	# of Measurements for Meteorology Data Set	# of Measurements for ECMWF Data Set	Hs_{100} Diff. (%)
İstanbul - Kilyos	8748	9098	-8.19%
İstanbul - Şile	1526	9195	5.34%
Düzce - Akçakoca	142	1393	68.95%
Zonguldak	71	3037	88.09%
Bartın - Amasra	16849	244	-54.57%
Kastamonu - İnebolu	739	4376	23.16%
Sinop	4891	5214	3.14%

İstanbul – Kilyos:

For 27 years of analysis period, number of measurements above 9.5 m/s threshold is shown at Table 30. Numbers are close and extreme analysis shows that ECMWF data set presented 8% less H_{so} value for 100 year return period.

Table 30 – W61 Output for İstanbul - Kilyos

MET		ECMWF	
YEAR	Hs Max	YEAR	Hs Max
1991	7.81	1988	8.08
2004	7.66	2008	7.48
1999	7.1	1987	6.93
2003	6.62	2003	6.45
2001	6.56	2001	6.4
1995	6.54	2002	6.4
1996	6.19	1986	6.39
2000	6.06	1991	6.15
1998	5.91	1992	5.83
1992	5.87	1995	5.79
1997	5.79	1985	5.74
2002	5.76	2004	5.66
2005	5.76	1993	5.51
1993	5.62	2006	5.49
1994	5.59	1989	5.45
2006	5.42	1990	5.37
1987	5.21	1994	5.33
1985	5.16	1999	5.11
1990	5.03	1998	5.04
1988	4.97	1983	4.53
1989	4.79	2005	4.48
1983	4.47	1984	4.44
1986	4.27	2007	4.3
1984	3.82	1997	4.2
2007	2.06	1996	4.11
2009	1.84	2009	3.88
2008	1.76	2000	3.71

İstanbul – Şile:

For 27 years of analysis period, number of measurements above 9.5 m/s threshold is shown at Table 31. Although extreme analysis shows that ECMWF data set gives 5% more H_{s0} value for 100 year return period, number of measurements greatly differ. This clearly affects wave values as can be seen from above w61 output. Meteorology data set cannot create waves for 4 years but their peak values are close to each other which should to be the main reason for only 5% difference.

Table 31 – W61 Output for İstanbul - Şile

MET		ECMWF	
YEAR	Hs Max	YEAR	Hs Max
1988	7.02	2006	7.91
1983	6.6	2002	7.27
1984	5.53	2001	7.22
1991	5.51	2008	7.14
1989	5.32	2004	6.88
2001	4.78	1991	6.32
1987	4.77	2005	6.32
1986	4.66	1987	6.26
1985	4.5	1992	6.07
1992	4.09	1988	5.97
2002	4.01	1986	5.92
1999	3.78	2003	5.86
1990	3.7	1993	5.61
1994	3.7	1998	5.46
1996	3.58	1999	5.45
1998	3.49	1985	5.31
2008	3.33	1995	5.29
1993	3.21	1994	5.23
1995	3.16	1989	5.04
1997	3	2007	4.93
2006	2.93	1996	4.9
2003	1.08	2009	4.8
2005	0.98	2000	4.6
		1984	4.58
		1990	4.56
		1997	4.44
		1983	4.43

Düzce – Akçakoca:

For 27 years of analysis period, number of measurements above 9.5 m/s threshold is shown at Table 32. From extreme analysis, ECMWF data set gives almost 70% higher H_{s0} value for 100 year return period. Difference of number of measurements seems to be the main reason for such a percentage. It can also be seen that peak values of waves greatly differ as well.

Table 32 – W61 Output for Düzce - Akçakoca

MET		ECMWF	
YEAR	Hs Max	YEAR	Hs Max
2001	3.58	2008	6.25
1985	2.92	2006	5.04
1983	2.9	1992	4.47
1986	2.39	2004	3.98
1988	2.14	1988	3.82
1990	2.11	1987	3.81
2008	2.07	1983	3.72
2007	2.02	1985	3.64
1984	2.01	2002	3.3
2002	1.78	1984	3.27
1987	1.77	2005	3.15
1999	1.68	2001	2.87
1992	1.58	2007	2.73
2003	1.55	2003	2.6
1989	1.53	1995	2.46
1993	1.06	1986	2.33
2006	1	1991	2.26
1991	0.99	1994	1.96
1994	0.98	1999	1.83
2009	0.97	1989	1.7
		2009	1.7
		1993	1.36
		1997	1.36
		1990	1.28
		2000	1.26
		1996	0.86

Zonguldak:

For 24 years of analysis period, number of measurements above 9.5 m/s threshold is shown at Table 33. From extreme analysis, ECMWF data set gives almost 90% higher H_{s0} value for 100 year return period. Difference of number of measurements seems to be the main reason for such a percentage. It can also be seen that peak values of waves greatly differ as well. Also, meteorology data set cannot create waves for 10 years whereas ECMWF data set can create for all years.

Table 33 – W61 Output for Zonguldak

MET		ECMWF	
YEAR	Hs Max	YEAR	Hs Max
2003	3.02	2006	5.82
2006	2.48	2001	5.73
1998	2.43	1999	5.19
1988	2.31	1998	5.07
1986	2.2	2004	4.72
1999	2.19	1984	4.67
1992	1.74	1988	4.62
2004	1.21	2005	4.38
1997	1.02	2002	4.32
1994	1	1985	4.22
1993	0.99	1994	3.82
1983	0.98	1990	3.53
2001	0.97	1989	3.48
2002	0.96	2003	3.44
		1983	3.42
		1986	3.41
		1992	3.25
		1987	3.17
		1995	3.03
		1996	2.78
		1991	2.48
		1997	2.13
		1993	1.96
		2000	1.79

Bartın – Amasra:

For 27 years of analysis period, number of measurements above 9.5 m/s threshold is shown at Table 34. From extreme analysis, ECMWF data set gives almost 55% lower H_{s0} value for 100 year return period. Difference of number of measurements seems to be the main reason for such a percentage. It can also be seen that peak values of waves greatly differ as well. Also, ECMWF data set cannot create waves for 11 years whereas meteorology data set can create for all years.

Table 34 – W61 Output for Bartın - Amasra

MET		ECMWF	
YEAR	Hs Max	YEAR	Hs Max
1986	11.11	2006	4.65
1998	10.78	1988	2.3
1994	10.64	1984	2.15
2006	10.64	1992	2.1
1999	10.35	2002	1.99
1997	10.28	2003	1.78
2001	9.99	1987	1.63
1991	9.87	2008	1.5
2005	9.55	2004	1.49
1988	9.52	1985	1.39
2000	9.18	1989	1.36
1990	8.65	1999	1.17
1996	8.64	2005	1.16
1983	8.63	1997	0.85
1987	8.45	2007	0.82
2004	8.2	2000	0.57
1985	8.05		
1993	7.78		
1989	7.58		
2003	7.38		
1992	7.35		
1995	7.17		
2008	6.96		
1984	6.84		
2002	6.04		
2009	5.91		
2007	4.98		

Kastamonu – İnebolu:

For 24 years of analysis period, number of measurements above 9.5 m/s threshold is shown at Table 35. From extreme analysis, ECMWF data set gives almost 23% higher H_{so} value for 100 year return period. Difference is high again but peak values are a lot closer considering the previous three cases. It also affects extreme analysis for which difference is much smaller.

Table 35 – W61 Output for Kastamonu - İnebolu

MET		ECMWF	
YEAR	Hs Max	YEAR	Hs Max
2003	4.07	1987	5.88
1986	3.9	1989	5.85
1988	3.75	2006	5.37
1985	3.73	1988	4.89
1993	3.38	1985	4.76
1983	3.09	2002	4.73
1995	2.59	1990	4.63
1996	2.54	1992	4.41
1990	2.47	2001	4.29
2000	2.38	1991	4.09
1984	2.06	1997	3.8
2004	2.03	1994	3.62
2002	1.84	2004	3.6
1999	1.75	1999	3.56
1998	1.68	1986	3.47
1987	1.63	2005	3.23
1997	1.63	2003	3.16
2005	1.52	1984	2.53
2001	1.29	1995	2.38
2006	1.02	1983	2.03
1992	0.99	1998	1.81
1989	0.96	2000	1.48
		1993	1.16
		1996	0.87

Sinop:

For 24 years of analysis period, number of measurements above 9.5 m/s threshold is shown at Table 36. Numbers are close and extreme analysis shows that ECMWF data set gives 3% more H_{s0} value for 100 year return period.

Table 36 – W61 Output for Sinop

MET		ECMWF	
YEAR	Hs Max	YEAR	Hs Max
1988	6.53	1989	6.95
2006	6.48	1987	5.84
1997	6.06	2003	5.64
1989	5.89	2001	5.61
2001	5.88	2004	5.17
2000	5.81	2006	5.17
1987	5.8	1991	5.04
1984	5.75	1993	4.9
1983	5.67	2005	4.9
1985	5.61	2002	4.8
2004	5.53	1992	4.69
2003	5.46	1999	4.56
1998	5.41	1988	4.54
2002	5.23	2000	4.33
1999	5.07	1996	4.22
1992	4.8	1994	3.89
1993	4.62	1985	3.63
1990	4.57	1990	3.52
2005	4.35	1998	3.44
1986	4.27	1995	3.39
1991	4.18	1997	3.16
1995	4.11	1984	3.06
1994	4.04	1986	2.92
1996	3.77	1983	2.68

4.4. HISTORICAL STORM EVENTS

From analysis and comparison of selected regions show that none of the available data sets are fully reliable. Considering that there is no wave measurement on Turkish coast for a reliable comparison, past events are selected for validation.

For this purpose, an online search is conducted through websites of local and national press agencies. Especially, well prepared archives of Milliyet (gazetearsivi.milliyet.com.tr) and Hürriyet (hurarsiv.hurriyet.com.tr) are lengthy searched by using the combinations of Black Sea, storm and wave as keywords. In addition, search engines are utilized to find out additional national and local news which do not possess an organized online archive.

Hundreds of data have been found from search but many of them must be eliminated simply because they either do not give any specifics about where storms occurred or they do not mention the characteristics about storms like their wind velocities or created wave heights. Also, some data are not included because they do not mention whether storm is on sea or on land. The ones that give such information are compared with available data sets. Also, it should be noted that some sources present wave data, some present wind data and some present both. For all cases, if data exists, both maximum wind velocities that are measured around given dates and calculated maximum wave heights for that year are presented for both data sets. Results are shown at Table 37.

Table 37 – Comparison of Historical Storms with Two Data Sets

		U (m/s)	H (m)	MET		ECMWF	
				U_{max} (m/s)	H_{s0max} (m)	U_{max} (m/s)	H_{s0max} (m)
Düzce-Akçakoca	08.12.2002	-	5	3.5-NNE	1.78	11.9-NE	3.3
Düzce-Akçakoca	09.10.2003	17	-	4.5-NW	1.55	12.2-W	2.6
Düzce-Akçakoca	28.10.2003	-	10	6.9-NNW	1.55	8.35-NNE	2.6
Düzce-Akçakoca	07.12.2003	-	10	5.2-NW	1.55	9.88-NNE	2.6
Düzce-Akçakoca	20.10.2005	14-17	5	4.2-WNW	-	6.22-W	3.15
Düzce-Akçakoca	03.07.2006	14-17	3	5.1-N	1	12.7-NE	5.04
Düzce-Akçakoca	04.11.2006	-	4	5.3-NNW	1	5.58-NE	5.04
Düzce-Akçakoca	14.10.2007	8-11	5	18.5-N	2.02	12.38-N	2.73
Düzce-Akçakoca	29.01.2008	20	4	11.7-N	2.07	10.48-NNE	6.25
Düzce-Akçakoca	27.09.2008	21	-	10.9-NNE	2.07	8.59-NE	6.25
Düzce-Akçakoca	01.09.2009	-	3	-	-	7.5-NNE	4.98
Düzce-Akçakoca	01.11.2009	21	5	-	-	13.7-NE	4.98
Düzce-Akçakoca	29.10.2010	14-17	5	-	-	15.3-NE	5.75
Düzce-Akçakoca	30.01.2011	-	3	-	-	11.7-NE	6.61
Düzce-Akçakoca	26.06.2011	-	3	-	-	8.1-NW	6.61
Düzce-Akçakoca	08.02.2012	-	10	-	-	14.6-NE	4.43
Zonguldak	15.12.1981	28	-	7-W	2.19	-	-
Zonguldak	22.01.2006	-	4	7.3-NNE	2.48	7.8-WNW	5.82
Zonguldak	31.10.2006	17-22	6-7	6.2-NNE	2.48	11.6-NE	5.82
Zonguldak	26.12.2006	-	5-6	7.5-NNE	2.48	12.3-WNW	5.82
Zonguldak	29.01.2008	-	2.5-4	-	-	10.9-NNE	6.63
Zonguldak	16.07.2008	-	5	-	-	7.5-NW	6.63
Zonguldak	28.09.2008	-	5	-	-	9.8-NE	6.63
Zonguldak	09.12.2008	-	5	-	-	7.9-W	6.63
Zonguldak	13.12.2009	-	10	-	-	15.7-N	6.39
Zonguldak	14.10.2011	15	5	-	-	6-NW	5.81
Zonguldak	08.02.2013	10	6	-	-	3.7-W	3.61
Zonguldak	24.03.2013	-	6	-	-	12-W	3.61
Bartın-Amasra	12.11.2007	-	5-6	-	4.98	-	0.82
Bartın-Amasra	08.02.2012	22	20	-	-	15-ENE	4.15
Bartın-Amasra	23.03.2013	-	7	-	-	11.6-W	2.37
Kastamonu-İnebolu	09.09.2007	22	-	-	-	13.8-W	4.33
Kastamonu-İnebolu	24.03.2013	22	8	-	-	17.9-W	2.99
Sinop	05.12.1982	25	-	17.6-NW	5.91	-	-
Sinop	25.01.1983	29	-	16.4-WNW	5.67	10.3-NNW	2.68
İstanbul-Kİlyos	15.08.1983	22	-	14.5-NW	4.47	6.9-NNE	4.53
İstanbul-Kİlyos	03.02.2003	-	3	-	6.62	12.2-N	6.45
İstanbul-Şile	27.02.1986	17-20	-	9.6-NNE	4.66	14.2-NNE	5.92
İstanbul-Şile	14.02.2004	14	6	8.9-N	2.96	17.9-N	6.88

Although almost all of the sources claimed that their numbers were acquired from Turkish State Meteorological Service, in many of the cases, station measurements do not match with sources. In addition, some of these numbers were directly taken from witnesses' opinions so they can be subjective at certain points. Nevertheless, from the general pattern, it can be concluded that whenever a data set provides enough and continuous data for a region, predictions become much closer to witnessed events. For example for Zonguldak region, where ECMWF data set provided higher results in extreme analysis, maximum significant wave height in 2006 for meteorology data is 2.48 m whereas it is 5.82 m for ECMWF data set. Reported wave heights are in better agreement with ECMWF which provides continuous and more reliable data for this region.

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS

This study's aim is to analyze and compare the most frequently used data sets in Turkey, which are meteorology and ECMWF data sets, for western Black Sea coast where research on any of the data set is highly limited, and to gain a better insight into the most important step in design of coastal engineering structures, determining design wave height, as well as to illuminate future studies on similar subjects.

Between İstanbul and Sinop, seven points are selected for study regions. Meteorology and ECMWF data sets are acquired from their respective sources. Two programs are supplied by Coastal Engineering Department, METU to organize and analyze acquired wind data which are wind.exe and W61 programs. Both data sets are re-arranged to make a proper comparison by matching their start and end dates as a first step. These data sets are further altered to make them compatible with programs. After making a graphical comparison, these data sets are used as input to wind.exe and its outputs for each year are used for W61 FORTRAN code. Outputs of W61 program, mainly individual Hs and Ts values, are organized and annual maximum values are used as inputs for pre-created extreme analysis Excel sheet by using the methodology presented in Goda, 2000 as basis for analysis. Directional and non-directional extreme analyses are performed for each data set and results are compared. Conclusions from graphical and numerical analyses are summarized below.

Initial graphical comparison shows the first signs of significant differences between data sets but the behavior of these data sets is different for each site. For Bartın – Amasra region, meteorology data set presented much higher wind velocities whereas for Düzce – Akçakoca region, ECMWF data set presented several peaks which meteorology data set could not measure.

Since visual inspection of graphical comparison is performed only for one month due to practical reasons, wind roses are also drawn for each season and for all years for both data sets to provide a better comparison. In many cases, observed differences from scatter plots are also observed from wind roses. Moreover, wind roses of ECMWF data set are in good agreement with the wind roses provided in Berkün, U. (2007) and Çaban, S. (2007) studies.

Since graphical comparison is not accurate enough for some cases, a numerical comparison is made by using extreme analysis and obtained significant wave height values for different return periods are compared. Since plotted wind roses were in good agreement with previous Berkün, U. (2007) and Çaban, S. (2007) studies, results of extreme analysis of ECMWF are also in good agreement. On the other hand, when ECMWF data set is compared with meteorology data set, some of the results are highly unexpected. For example, for Zonguldak, ECMWF data set provides 90.49% higher Hs_{50} value than meteorology data. This value drops to 88.09% for Hs_{100}. Although ECMWF generally provides higher results, one exception is the case for Bartın – Amasra, where ECMWF data produces 63.08% less Hs_{50} value and it drops to 54.57% for Hs_{100}. On the other hand, for Sinop both data sets are very close in terms of extreme characteristics. For this region, ECMWF creates 0.63% higher Hs_{50} value but difference for Hs_{100} increased this time to 3.14%.

Also, direction-wise analyses are conducted to further analyze the results of non-directional study presented above. For analysis, only the directions where enough data for different years, which is selected as 60% of the analysis period for both data sets, are selected. Thus, selected directions differ for each analysis point and for Zonguldak region no direction can be found suitable for a reliable comparison. From comparisons, it can be concluded that although differences from directional analyses increase or decrease depending on the region and dominant wind directions for data sets, in general results follow the patterns of non-directional analyses.

To understand the significant differences between two data sets, possible reasons for such variations are investigated for Zonguldak region where ECMWF data set overestimated Hs_{100} value by 88.09%. Considered reasons are calculations errors, misuse of programs, effect of omitting southern directions on the peak values and number of data above threshold, performed alterations on data sets like using spline method on ECMWF to make it compatible with programs, threshold value and finally raw data itself. All of these reasons are checked one by one. No error or misuse is detected during analysis process. South directions are included in the graphical comparison and no significant change is observed for peak values. Also number of data is checked for both data sets when all directions are included. It is found that including south directions has negligible effect for meteorology data set. Spline method is used for both data sets but results are not affected. Lowering threshold value decreased the difference but not significantly as expected. Finally, only raw data is analyzed by simply counting the number of data above threshold for both data sets. This analysis is performed on all study points. General pattern suggests that numbers of measurements are the main reason for such differences in extreme wave characteristics.

Also, an additional research is provided by comparing historical storm events acquired from online sources of local and national press agencies to the data sets. This is performed to provide initial validation of the data sets since limited amount of measured wave data exists for the regions considered. Although this type of validation is not accurate, it provides a limited insight to the comparisons. Generally, whenever a data set provides more continuous data, its results match better with given information of the past events on these sources.

This study shows that a better understanding of wind data is required first for Black Sea coasts of Turkey for feasible and reliable designs. A study on larger scale is needed by using more regions and more data, if exist.

Also, a quality check is necessary for meteorology stations since they fail to make continuous measurements and many of their end results greatly differ from observed historical storms and results of previous studies.

On-site buoy measurements and comparing results of this measurement with available data sets will help greatly in determining the correct data set. For this purpose a study on this subject for west coast of Black Sea in Turkey will be a significant improvement.

Due to economic burden of buoys, wind data seem to be only option for Turkey for the foreseeable future. It is believed that further research on this area will illuminate the way to more reliable and accurate designs by means of determining wave characteristics from wind data more precisely. Most importantly, it is highly recommended to use both data sets and previous studies on project area during design processes as it is showed that none of these data sets can provide reliable results for all studied regions. A methodology to utilize both data sets for engineering applications would be a valuable contribution as future work.

REFERENCES

1. Hürriyet Arşiv, (n.d.) Retrieved from www.hurarsiv.hurriyet.com.tr [Last accessed on 12.05.2014]
2. Milliyet Gazete Arşivi, Günün Yayınları (n.d.), retrieved from www.gazetearsivi.milliyet.com.tr [Last accessed on 12.05.2014]
3. www.sabah.com.tr [Last accessed on 10.05.2014]
4. www.habervitrini.com [Last accessed on 05.05.2014]
5. www.izmirhaberajansi.com [Last accessed on 01.05.2014]
6. TMİGM, Türkiye Meteoroloji İşeri Genel Müdürlüğü, 2006, “Republic Of Turkey, Ministry Of Environment and Forests, General Directorate of Turkish State Meteorological Service”, www.mgm.gov.tr
7. ECMWF, 2006, "The European Center for Medium-Range Weather Forecasts", http://www.ecmwf.int
8. Goda, Y., 1985, “Random Seas and Design of Maritime Structures”, University of Tokyo Press, Tokyo
9. Özhan, E. and Abdalla, S., 1999, “Turkish Coast Wind and Deep Water Wave Atlas”, Applied Project Report, Middle East Technical University, Civil Engineering Dept., Ocean Eng. Research Center, Ankara.

10. Berkün, U., 2007, “Wind and Swell Wave Climate for the Southern Part of Black Sea”, M. Sc. Thesis, Middle East Technical University, Civil Engineering Dept., Ocean Eng. Research Center, Ankara.

11. Çaban, S., 2007, “Wind and Wind Wave Climate Research Along the Southern Part of Black Sea”, M. Sc. Thesis, Middle East Technical University, Civil Engineering Dept., Ocean Eng. Research Center, Ankara.

12. Hsu, S.A., 1980, “On the Correction of Land-Based Wind Measurements for Oceanographic Applications”, Proc. 17th Conf. On Coastal Engrg., Sdyney, Vol.1, pp. 709 – 721.

13. Yüksel Proje Uluslararası A.Ş., 2011, “Ordu – Giresun Havalimanı Rüzgar ve Dalga İklimi Çalışmaları Sonuç Raporu”

14. K. E. Saraçoğlu, 2011, “The wave modeling and analysis of the Black Sea and the Sea of Marmara”, M. Sc. Thesis, Yıldız Technical University, Civil Engineering Dept., İstanbul.

15. Bilyay, E., Ünal A., Özbahçeci, B.O. and Yalçıner, A.C., 2010, “Extreme Waves at Filyos, Southern Black Sea”, 7. National Coastal Engineering Symposium, pp. 87-96

16. Şahin,C, 2007, “Parametric Wind Wave Modeling and Western Black Sea Case Study”, M. Sc. Thesis, Yıldız Technical University, Civil Engineering Dept., İstanbul.

17. Akbaşoğlu, S., 2004, ”Short Term Statistics of Wind Waves around the Turkish Coast”, M. Sc. Thesis, Middle East Technical University, Civil Engineering Dept., Ocean Eng. Research Center, Ankara.

18. Yılmaz,N., 2007, ”Spectral Characteristics of Wind Waves in the Eastern Black Sea” , Ph. D. Thesis, Middle East Technical University, Civil Engineering Dept., Ocean Eng. Research Center, Ankara.
19. Özyurt G., Özbahçeci, B.Ö., 2008, “Tasarım Dalgasının Bulunmasında Dağılım Modelinin Etkisi”, Türkiye’nin Kıyı ve Deniz Alanları 7. Ulusal Kongresi
20. Akpınar, A., 2012, “Wave Modeling and Wave Power Potential Determination in the Black Sea”, Ph. D. Thesis, Karadeniz Technical University, Civil Engineering Dept., Trabzon.
21. Ergin, A. and Özhan, E., 1986, “15 Deniz Yöresi İçin Dalga Tahminleri ve Tasarım Dalgası Özelliklerinin Belirlenmesi”, Middle East Technical University, Civil Engineering Dept., Ocean Eng. Research Center, Ankara.

APPENDIX – A

NON-DIRECTIONAL ANALYSIS

Non – directional analyses are performed and best fitting distributions are presented for all regions.

İstanbul – Kilyos:

Meteorology data set:

Table 38 – Results of Non - Directional Analysis of Meteorology Data Set for İstanbul - Kilyos

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	6.38	7.22	8.03	9.08	9.87	11.69	12.47	-	Best Distr.	-	-
FT 2 (k1=2.5)	5.67	6.35	7.22	8.78	10.40	16.44	20.49	-	-	-	-
FT 2 (k2=3.33)	5.86	6.63	7.56	9.11	10.58	15.45	18.39	-	-	-	-
FT 2 (k3=5.0)	6.04	6.89	7.82	9.25	10.51	14.19	16.18	-	-	-	-
FT 2 (k4=10.0)	6.22	7.08	7.98	9.23	10.25	12.89	14.16	-	-	-	-
Weibull (k1=0.75)	5.86	6.75	7.74	9.16	10.32	13.22	14.56	-	-	-	-
Weibull (k2=1.0)	6.13	7.04	7.96	9.16	10.08	12.20	13.11	-	-	-	-
Weibull (k3=1.4)	6.37	7.23	8.03	9.00	9.69	11.19	11.81	-	-	-	-
Weibull (k4=2.0)	6.52	7.30	7.98	8.75	9.28	10.37	10.80	Best Distr	-	-	-
LogNormal	6.74	7.87	8.94	10.32	11.35	13.78	14.85	-	-	Best Distr	-

ECMWF data set:

Table 39 – Results of Non - Directional Analysis of ECMWF Data Set for İstanbul - Kilyos

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	6.31	6.97	7.60	8.41	9.02	10.43	11.04	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	5.79	6.37	7.12	8.46	9.86	15.04	18.52	-	-	Best Distr	-
FT 2 (k2=3.33)	5.94	6.59	7.37	8.66	9.89	13.96	16.42	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	6.08	6.77	7.53	8.69	9.72	12.72	14.34	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	6.21	6.89	7.60	8.60	9.41	11.51	12.52	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	5.96	6.72	7.57	8.79	9.78	12.28	13.42	-	-	Best Distr	-
Weibull (k2=1.0)	6.16	6.91	7.67	8.67	9.43	11.18	11.94	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	6.32	7.01	7.64	8.41	8.96	10.16	10.64	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	6.41	7.01	7.52	8.12	8.52	9.35	9.68	Best Distr	-	Best Distr	Best Distr.
LogNormal	6.39	6.99	7.53	8.18	8.65	9.68	10.11	-	-	Best Distr	Best Distr.

İstanbul – Şile:

Meteorology data set:

Table 40 – Results of Non - Directional Analysis of Meteorology Data Set for İstanbul - Şile

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	5.10	5.96	6.78	7.84	8.63	10.47	11.26	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	4.43	5.18	6.14	7.89	9.70	16.42	20.94	-	-	-	-
FT 2 (k2=3.33)	4.61	5.46	6.46	8.14	9.74	15.01	18.19	-	-	Best Distr	-
FT 2 (k3=5.0)	4.80	5.69	6.67	8.18	9.51	13.40	15.50	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	4.96	5.85	6.77	8.07	9.12	11.85	13.16	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	4.63	5.61	6.70	8.27	9.54	12.75	14.22	-	-	-	-
Weibull (k2=1.0)	4.89	5.86	6.83	8.12	9.09	11.35	12.32	-	-	Best Distr	-
Weibull (k3=1.4)	5.10	5.99	6.80	7.80	8.51	10.05	10.68	-	-	Best Distr	-
Weibull (k4=2.0)	5.23	6.01	6.67	7.44	7.97	9.05	9.48	Best Distr	-	Best Distr	Best Distr.
LogNormal	5.36	6.49	7.61	9.11	10.26	13.07	14.34	-	-	Best Distr	-

ECMWF data set:

Table 41 – Results of Non - Directional Analysis of ECMWF Data Set for İstanbul - Şile

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	6.43	7.01	7.57	8.30	8.84	10.10	10.64	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	5.97	6.48	7.15	8.35	9.59	14.21	17.32	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	6.10	6.68	7.37	8.53	9.63	13.27	15.46	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	6.22	6.84	7.52	8.56	9.48	12.16	13.61	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	6.34	6.95	7.58	8.47	9.19	11.07	11.98	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	6.12	6.81	7.58	8.68	9.58	11.84	12.88	-	-	-	-
Weibull (k2=1.0)	6.30	6.98	7.67	8.57	9.25	10.84	11.53	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	6.44	7.06	7.63	8.32	8.81	9.89	10.32	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	6.52	7.05	7.51	8.03	8.39	9.14	9.43	Best Disrt	-	Best Distr	Best Distr.
LogNormal	6.48	6.98	7.42	7.95	8.32	9.13	9.47	-	-	Best Distr	Best Distr.

Düzce – Akçakoca:

Meteorology data set:

Table 42 – Results of Non - Directional Analysis of Meteorology Data Set for Düzce - Akçakoca

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	2.40	2.83	3.24	3.78	4.18	5.11	5.51	Best Distr	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	2.07	2.48	3.00	3.96	4.94	8.61	11.08	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	2.16	2.61	3.15	4.04	4.90	7.71	9.41	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	2.25	2.72	3.24	4.03	4.72	6.76	7.86	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	2.33	2.79	3.26	3.93	4.47	5.87	6.55	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	2.17	2.70	3.29	4.14	4.82	6.55	7.34	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	2.30	2.82	3.33	4.00	4.51	5.70	6.21	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	2.40	2.86	3.28	3.79	4.15	4.94	5.27	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	2.45	2.84	3.18	3.57	3.83	4.38	4.59	-	-	Best Distr	Best Distr.
LogNormal	2.40	2.86	3.29	3.87	4.31	5.35	5.82	-	-	Best Distr	Best Distr.

ECMWF data set:

Table 43 – Results of Non - Directional Analysis of ECMWF Data Set for Düzce - Akçakoca

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	3.80	4.59	5.35	6.33	7.07	8.77	9.50	Best Distr	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	3.19	3.91	4.84	6.52	8.27	14.74	19.10	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	3.36	4.17	5.13	6.73	8.25	13.29	16.32	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	3.53	4.37	5.31	6.73	7.99	11.66	13.65	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	3.68	4.51	5.37	6.58	7.57	10.12	11.35	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	3.38	4.33	5.38	6.90	8.13	11.23	12.65	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	3.63	4.55	5.48	6.71	7.63	9.78	10.71	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	3.81	4.65	5.41	6.35	7.01	8.46	9.05	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	3.91	4.63	5.24	5.95	6.44	7.44	7.83	-	-	Best Distr	Best Distr.
LogNormal	3.84	4.79	5.74	7.05	8.08	10.66	11.85	-	-	Best Distr	Best Distr.

Zonguldak:

Meteorology data set:

Table 44 – Results of Non - Directional Analysis of Meteorology Data Set for Zonguldak

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	2.22	2.65	3.07	3.60	4.00	4.92	5.32	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	1.89	2.30	2.83	3.78	4.77	8.44	10.91	-	-	Best Distr	-
FT 2 (k2=3.33)	1.99	2.44	2.97	3.86	4.71	7.51	9.20	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	2.08	2.54	3.06	3.84	4.53	6.55	7.65	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	2.16	2.61	3.08	3.75	4.28	5.68	6.35	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	2.00	2.53	3.11	3.95	4.64	6.36	7.15	-	-	Best Distr	-
Weibull (k2=1.0)	2.13	2.64	3.15	3.83	4.34	5.53	6.04	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	2.23	2.69	3.11	3.62	3.98	4.78	5.10	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	2.28	2.67	3.01	3.40	3.66	4.21	4.42	Best Disrt	-	Best Distr	Best Distr.
LogNormal	2.20	2.65	3.10	3.70	4.15	5.26	5.76	-	-	Best Distr	-

ECMWF data set:

Table 45 – Results of Non - Directional Analysis of ECMWF Data Set for Zonguldak

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	4.61	5.28	5.92	6.75	7.37	8.82	9.43	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	4.07	4.63	5.36	6.68	8.05	13.13	16.55	-	-	-	-
FT 2 (k2=3.33)	4.21	4.86	5.63	6.91	8.13	12.17	14.60	-	-	-	-
FT 2 (k3=5.0)	4.36	5.05	5.81	6.98	8.01	11.01	12.63	-	-	-	Best Distr.
FT 2 (k4=10.0)	4.49	5.19	5.91	6.91	7.73	9.86	10.88	-	-	-	Best Distr.
Weibull (k1=0.75)	4.23	4.99	5.82	7.03	8.02	10.48	11.62	-	-	-	-
Weibull (k2=1.0)	4.44	5.20	5.96	6.96	7.72	9.49	10.25	-	-	-	-
Weibull (k3=1.4)	4.61	5.31	5.96	6.74	7.30	8.52	9.01	-	-	-	Best Distr.
Weibull (k4=2.0)	4.71	5.33	5.86	6.47	6.88	7.74	8.08	Best Disrt	-	Best Distr	Best Distr.
LogNormal	4.74	5.47	6.16	7.04	7.70	9.23	9.89	-	-	Best Distr	Best Distr.

Bartın – Amasra:

Meteorology data set:

Table 46 – Results of Non - Directional Analysis of Meteorology Data Set for Bartın - Amasra

Return Period	5	10	20	50	100	500	1000	r	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	9.73	10.67	11.59	12.76	13.65	15.69	16.57	-	-	-	-
FT 2 (k1=2.5)	8.93	9.69	10.66	12.40	14.22	20.96	25.49	-	-	-	-
FT 2 (k2=3.33)	9.14	10.01	11.06	12.79	14.45	19.91	23.21	-	-	-	-
FT 2 (k3=5.0)	9.35	10.30	11.35	12.96	14.38	18.52	20.75	-	-	-	-
FT 2 (k4=10.0)	9.55	10.52	11.53	12.94	14.08	17.06	18.49	-	-	-	-
Weibull (k1=0.75)	9.16	10.18	11.31	12.94	14.26	17.59	19.12	-	-	-	-
Weibull (k2=1.0)	9.46	10.51	11.56	12.95	14.00	16.43	17.48	-	-	-	-
Weibull (k3=1.4)	9.73	10.72	11.62	12.73	13.52	15.23	15.93	-	-	-	-
Weibull (k4=2.0)	9.89	10.77	11.53	12.41	13.00	14.23	14.71	-	-	-	Best Distr.
LogNormal	9.96	10.91	11.76	12.80	13.54	15.18	15.85	Best Disrt	Best Distr.	Best Distr	Best Distr.

ECMWF data set:

Table 47 – Results of Non - Directional Analysis of ECMWF Data Set for Bartın - Amasra

Return Period	5	10	20	50	100	500	1000	r	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	2.37	2.91	3.43	4.11	4.61	5.78	6.28	-	-	-	Best Distr.
FT 2 (k1=2.5)	1.99	2.59	3.35	4.73	6.15	11.46	15.02	Best Disrt	Best Distr.	Best Distr	Best Distr.
FT 2 (k2=3.33)	2.11	2.73	3.48	4.71	5.89	9.78	12.13	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	2.22	2.84	3.53	4.58	5.50	8.21	9.67	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	2.30	2.89	3.50	4.36	5.06	6.87	7.74	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	2.12	2.85	3.65	4.81	5.75	8.12	9.20	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	2.27	2.94	3.61	4.49	5.16	6.70	7.37	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	2.37	2.94	3.47	4.11	4.57	5.56	5.97	-	-	-	Best Distr.
Weibull (k4=2.0)	2.42	2.89	3.30	3.78	4.10	4.76	5.02	-	-	-	-
LogNormal	2.28	2.84	3.40	4.17	4.77	6.29	6.99	-	-	-	Best Distr.

Kastamonu – İnebolu:

Meteorology data set:

Table 48 – Results of Non - Directional Analysis of Meteorology Data Set for Kastamonu - İnebolu

Return Period	5	10	20	50	100	500	1000	r	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	3.02	3.61	4.18	4.91	5.46	6.72	7.27	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	2.56	3.07	3.73	4.93	6.16	10.76	13.86	-	-	-	-
FT 2 (k2=3.33)	2.69	3.27	3.96	5.11	6.21	9.84	12.02	-	-	-	-
FT 2 (k3=5.0)	2.82	3.43	4.11	5.15	6.07	8.75	10.20	-	-	-	Best Distr.
FT 2 (k4=10.0)	2.93	3.54	4.18	5.07	5.80	7.68	8.59	-	-	-	Best Distr.
Weibull (k1=0.75)	2.71	3.40	4.16	5.26	6.15	8.40	9.44	-	-	-	-
Weibull (k2=1.0)	2.89	3.57	4.26	5.16	5.85	7.43	8.12	-	-	-	Best Distr.
Weibull (k3=1.4)	3.04	3.66	4.23	4.93	5.42	6.50	6.94	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	3.11	3.65	4.12	4.65	5.01	5.77	6.06	-	-	Best Distr	Best Distr.
LogNormal	3.06	3.75	4.42	5.33	6.04	7.78	8.57	Best Disrt	-	Best Distr	Best Distr.

ECMWF data set:

Table 49 – Results of Non - Directional Analysis of ECMWF Data Set for Kastamonu - İnebolu

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	4.60	5.43	6.23	7.25	8.02	9.80	10.57	-	Best Distr.	-	Best Distr.
FT 2 (k1=2.5)	3.92	4.60	5.47	7.05	8.68	14.75	18.83	-	-	-	-
FT 2 (k2=3.33)	4.10	4.88	5.81	7.35	8.83	13.69	16.62	-	-	-	-
FT 2 (k3=5.0)	4.29	5.12	6.05	7.47	8.72	12.37	14.35	-	-	-	-
FT 2 (k4=10.0)	4.46	5.31	6.19	7.42	8.43	11.03	12.29	-	-	-	-
Weibull (k1=0.75)	4.12	5.02	6.02	7.46	8.64	11.58	12.94	-	-	-	-
Weibull (k2=1.0)	4.38	5.30	6.22	7.43	8.35	10.49	11.41	-	-	-	-
Weibull (k3=1.4)	4.61	5.47	6.25	7.22	7.91	9.40	10.01	-	-	-	-
Weibull (k4=2.0)	4.74	5.51	6.17	6.93	7.44	8.51	8.93	Best Disrt	-	-	Best Distr.
LogNormal	4.89	6.08	7.28	8.92	10.21	13.43	14.93	-	-	Best Distr	-

Sinop:

Meteorology data set:

Table 50 – Results of Non - Directional Analysis of Meteorology Data Set for Sinop

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	5.78	6.25	6.69	7.26	7.69	8.69	9.12	-	-	-	-
FT 2 (k1=2.5)	5.40	5.78	6.27	7.15	8.07	11.47	13.75	-	-	-	-
FT 2 (k2=3.33)	5.50	5.94	6.46	7.32	8.15	10.87	12.51	-	-	-	-
FT 2 (k3=5.0)	5.61	6.07	6.59	7.39	8.08	10.13	11.23	-	-	-	-
FT 2 (k4=10.0)	5.70	6.18	6.67	7.36	7.92	9.38	10.08	-	-	-	-
Weibull (k1=0.75)	5.51	6.02	6.58	7.38	8.04	9.69	10.44	-	-	-	-
Weibull (k2=1.0)	5.66	6.17	6.69	7.37	7.88	9.08	9.59	-	-	-	-
Weibull (k3=1.4)	5.79	6.27	6.71	7.25	7.64	8.47	8.81	-	-	-	-
Weibull (k4=2.0)	5.86	6.29	6.66	7.08	7.37	7.97	8.20	-	-	-	Best Distr.
LogNormal	5.88	6.31	6.69	7.15	7.46	8.15	8.44	Best Disrt	Best Distr.	Best Distr	Best Distr.

ECMWF data set:

Table 51 – Results of Non - Directional Analysis of ECMWF Data Set for Sinop

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	5.22	5.86	6.47	7.26	7.85	9.22	9.81	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	4.72	5.28	6.02	7.34	8.70	13.79	17.20	-	-	Best Distr	-
FT 2 (k2=3.33)	4.86	5.49	6.25	7.51	8.71	12.68	15.08	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	4.99	5.66	6.40	7.53	8.53	11.45	13.02	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	5.12	5.78	6.47	7.44	8.22	10.27	11.25	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	4.87	5.61	6.43	7.61	8.57	10.99	12.10	-	-	Best Distr	-
Weibull (k2=1.0)	5.07	5.80	6.53	7.50	8.23	9.93	10.66	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	5.22	5.89	6.50	7.25	7.79	8.94	9.42	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	5.31	5.90	6.39	6.97	7.37	8.18	8.49	-	-	Best Distr	Best Distr.
LogNormal	5.30	5.92	6.49	7.19	7.70	8.84	9.33	Best Disrt	-	Best Distr	Best Distr.

APPENDIX – B

DIRECTIONAL ANALYSIS

Direction-wise analyses are performed and best fitting distributions are presented for selected directions for all regions.

İstanbul – Kilyos:

For this point, three directions are selected. These are NNE, NNW and N directions.

Meteorology data set:

NNE:

Table 52 – Results of Directional Analysis of Meteorology Data Set for İstanbul – Kilyos for NNE Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	4.31	5.17	6.00	7.07	7.87	9.73	10.53	-	Best Distr.	-	Best Distr.
FT 2 (k1=2.5)	3.61	4.34	5.28	6.97	8.73	15.27	19.66	-	-	-	-
FT 2 (k2=3.33)	3.80	4.63	5.62	7.27	8.84	14.04	17.17	-	-	-	-
FT 2 (k3=5.0)	3.99	4.87	5.86	7.36	8.68	12.55	14.64	-	-	-	-
FT 2 (k4=10.0)	4.16	5.06	5.98	7.28	8.33	11.07	12.39	-	-	-	Best Distr.
Weibull (k1=0.75)	3.82	4.79	5.87	7.43	8.70	11.88	13.34	-	-	-	-
Weibull (k2=1.0)	4.09	5.07	6.06	7.35	8.34	10.62	11.60	-	-	-	-
Weibull (k3=1.4)	4.32	5.23	6.06	7.08	7.80	9.37	10.02	-	-	-	Best Distr.
Weibull (k4=2.0)	4.45	5.25	5.93	6.72	7.26	8.37	8.80	Best Distr.	-	Best Distr	Best Distr.
LogNormal	4.46	5.61	6.79	8.42	9.71	12.98	14.50	-	-	Best Distr	Best Distr.

NNW:

Table 53 – Results of Directional Analysis of Meteorology Data Set for İstanbul – Kilyos for NNW Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type				**Hs**							
Gumbel	6.45	7.09	7.69	8.48	9.07	10.44	11.03	-	-	Best Distr	Best Distr.
FT 2 (k1=2.5)	5.95	6.50	7.22	8.51	9.84	14.82	18.16	-	-	-	-
FT 2 (k2=3.33)	6.09	6.71	7.46	8.70	9.89	13.80	16.16	-	-	-	Best Distr.
FT 2 (k3=5.0)	6.22	6.88	7.62	8.74	9.73	12.62	14.18	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	6.35	7.01	7.69	8.66	9.44	11.47	12.45	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	6.10	6.84	7.65	8.83	9.78	12.18	13.28	-	-	-	-
Weibull (k2=1.0)	6.30	7.03	7.76	8.72	9.45	11.14	11.87	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	6.46	7.12	7.73	8.48	9.01	10.16	10.63	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	6.55	7.13	7.62	8.20	8.59	9.40	9.71	-	-	Best Distr	Best Distr.
LogNormal	6.54	7.13	7.64	8.27	8.72	9.71	10.11	Best Distr.	Best Distr.	Best Distr	Best Distr.

N:

Table 54 – Results of Directional Analysis of Meteorology Data Set for İstanbul – Kilyos for N Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type				**Hs**							
Gumbel	4.59	5.57	6.50	7.71	8.62	10.71	11.61	-	Best Distr.	-	Best Distr.
FT 2 (k1=2.5)	3.80	4.63	5.70	7.63	9.63	17.07	22.07	-	-	-	-
FT 2 (k2=3.33)	4.02	4.96	6.08	7.95	9.73	15.62	19.17	-	-	-	-
FT 2 (k3=5.0)	4.23	5.23	6.34	8.04	9.54	13.92	16.28	-	-	-	-
FT 2 (k4=10.0)	4.43	5.44	6.48	7.95	9.14	12.23	13.72	-	-	-	Best Distr.
Weibull (k1=0.75)	4.04	5.14	6.36	8.12	9.55	13.15	14.80	-	-	-	-
Weibull (k2=1.0)	4.35	5.46	6.56	8.03	9.14	11.71	12.82	-	-	-	-
Weibull (k3=1.4)	4.60	5.63	6.56	7.71	8.53	10.31	11.03	-	-	-	Best Distr.
Weibull (k4=2.0)	4.75	5.65	6.42	7.31	7.92	9.17	9.66	Best Distr.	-	Best Distr	Best Distr.
LogNormal	4.77	6.17	7.64	9.72	11.40	15.77	17.86	-	-	Best Distr	Best Distr.

ECMWF data set:

NNE:

Table 55 – Results of Directional Analysis of ECMWF Data Set for İstanbul – Kilyos for NNE Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type				**Hs**							
Gumbel	5.78	6.87	7.92	9.28	10.30	12.66	13.67	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	4.89	5.82	7.01	9.16	11.38	19.66	25.23	-	-	-	-
FT 2 (k2=3.33)	5.13	6.18	7.44	9.53	11.52	18.10	22.07	-	-	-	-
FT 2 (k3=5.0)	5.37	6.49	7.74	9.64	11.32	16.22	18.87	-	-	-	-
FT 2 (k4=10.0)	5.59	6.72	7.89	9.54	10.88	14.35	16.02	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	5.15	6.38	7.74	9.70	11.29	15.29	17.13	-	-	-	-
Weibull (k2=1.0)	5.50	6.73	7.97	9.60	10.83	13.70	14.93	-	-	-	-
Weibull (k3=1.4)	5.79	6.93	7.98	9.26	10.17	12.15	12.96	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	5.96	6.96	7.83	8.83	9.51	10.91	11.46	Best Distr.	-	Best Distr	Best Distr.
LogNormal	6.06	7.58	9.12	11.23	12.90	17.08	19.03	-	-	Best Distr	-

NNW:

Table 56 – Results of Directional Analysis of ECMWF Data Set for İstanbul – Kilyos for NNW Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	2.97	3.76	4.51	5.48	6.21	7.89	8.62	-	-	Best Distr	Best Distr.
FT 2 (k1=2.5)	2.39	3.15	4.14	5.92	7.76	14.62	19.23	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	2.56	3.40	4.39	6.05	7.63	12.85	16.00	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	2.73	3.58	4.53	5.99	7.27	11.01	13.03	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	2.87	3.70	4.57	5.78	6.77	9.33	10.56	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	2.59	3.59	4.69	6.28	7.57	10.82	12.31	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	2.82	3.77	4.72	5.97	6.92	9.12	10.07	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	2.99	3.82	4.59	5.52	6.19	7.63	8.22	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	3.07	3.77	4.37	5.07	5.55	6.53	6.91	-	-	Best Distr	Best Distr.
LogNormal	2.85	3.81	4.84	6.34	7.59	10.92	12.56	Best Distr.	Best Distr.	Best Distr	Best Distr.

N:

Table 57 – Results of Directional Analysis of ECMWF Data Set for İstanbul – Kilyos for N Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	4.53	5.26	5.96	6.86	7.53	9.10	9.77	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	3.96	4.59	5.40	6.87	8.39	14.04	17.85	-	-	Best Distr	-
FT 2 (k2=3.33)	4.11	4.82	5.67	7.08	8.43	12.87	15.55	-	-	Best Distr	-
FT 2 (k3=5.0)	4.27	5.02	5.86	7.13	8.25	11.54	13.31	-	-	Best Distr	-
FT 2 (k4=10.0)	4.41	5.17	5.95	7.04	7.93	10.24	11.36	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	4.12	4.94	5.85	7.16	8.23	10.90	12.13	-	-	Best Distr	-
Weibull (k2=1.0)	4.35	5.16	5.98	7.06	7.88	9.78	10.60	-	-	Best Distr	-
Weibull (k3=1.4)	4.53	5.29	5.98	6.83	7.43	8.74	9.27	-	-	Best Distr	-
Weibull (k4=2.0)	4.65	5.31	5.88	6.54	6.99	7.92	8.28	Best Distr.	-	Best Distr	Best Distr.
LogNormal	4.70	5.59	6.44	7.55	8.40	10.43	11.33	-	-	Best Distr	-

İstanbul – Şile:

For this point, two directions are selected. These are NNE and N directions.

Meteorology data set:

NNE:

Table 58 – Results of Directional Analysis of Meteorology Data Set for İstanbul – Şile for NNE Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	5.05	5.95	6.80	7.91	8.74	10.67	11.49	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	4.34	5.13	6.15	7.99	9.90	16.98	21.75	-	-	Best Distr	-
FT 2 (k2=3.33)	4.54	5.42	6.47	8.22	9.89	15.41	18.73	-	-	Best Distr	-
FT 2 (k3=5.0)	4.73	5.65	6.69	8.26	9.65	13.70	15.89	-	-	Best Distr	-
FT 2 (k4=10.0)	4.90	5.83	6.79	8.14	9.24	12.08	13.46	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	4.54	5.55	6.67	8.28	9.59	12.89	14.40	-	-	Best Distr	-
Weibull (k2=1.0)	4.81	5.82	6.82	8.15	9.15	11.49	12.49	-	-	Best Distr	-
Weibull (k3=1.4)	5.04	5.97	6.82	7.86	8.60	10.21	10.86	-	-	Best Distr	-
Weibull (k4=2.0)	5.19	6.00	6.70	7.52	8.07	9.21	9.66	Best Distr.	-	Best Distr	Best Distr.
LogNormal	5.33	6.58	7.83	9.52	10.84	14.11	15.61	-	-	Best Distr	-

N:

Table 59 – Results of Directional Analysis of Meteorology Data Set for İstanbul – Şile for N Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	4.02	4.95	5.83	6.98	7.84	9.83	10.69	Best Distr.	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	3.32	4.21	5.34	7.40	9.53	17.45	22.77	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	3.52	4.49	5.65	7.57	9.40	15.45	19.10	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	3.72	4.72	5.82	7.52	9.01	13.37	15.73	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	3.89	4.87	5.88	7.30	8.46	11.47	12.92	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	3.54	4.68	5.93	7.74	9.21	12.90	14.59	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	3.82	4.91	6.01	7.45	8.54	11.08	12.17	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	4.03	5.01	5.90	7.00	7.77	9.47	10.16	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	4.14	4.98	5.70	6.53	7.09	8.26	8.71	-	-	Best Distr	Best Distr.
LogNormal	4.04	5.23	6.49	8.26	9.70	13.44	15.23	-	-	Best Distr	Best Distr.

ECMWF data set:

NNE:

Table 60 – Results of Directional Analysis of ECMWF Data Set for İstanbul – Şile for NNE Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	5.50	6.44	7.34	8.51	9.38	11.40	12.27	-	Best Distr.	-	-
FT 2 (k1=2.5)	4.69	5.38	6.28	7.89	9.56	15.78	19.96	-	-	-	-
FT 2 (k2=3.33)	4.89	5.71	6.70	8.33	9.89	15.03	18.13	-	-	-	-
FT 2 (k3=5.0)	5.11	6.01	7.02	8.56	9.92	13.89	16.04	-	-	-	-
FT 2 (k4=10.0)	5.31	6.26	7.24	8.61	9.73	12.63	14.03	-	-	-	-
Weibull (k1=0.75)	4.90	5.84	6.88	8.39	9.61	12.69	14.10	-	-	-	-
Weibull (k2=1.0)	5.21	6.21	7.21	8.53	9.53	11.85	12.85	-	-	-	-
Weibull (k3=1.4)	5.49	6.46	7.35	8.44	9.21	10.90	11.58	-	-	-	-
Weibull (k4=2.0)	5.69	6.57	7.33	8.21	8.81	10.04	10.52	Best Distr.	-	-	-
LogNormal	6.02	7.65	9.32	11.64	13.51	18.24	20.48	-	-	-	-

N:

Table 61 – Results of Directional Analysis of ECMWF Data Set for İstanbul – Şile for N Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	4.58	5.37	6.12	7.10	7.83	9.53	10.26	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	3.97	4.69	5.61	7.27	9.00	15.41	19.72	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	4.14	4.94	5.89	7.48	8.99	13.97	16.98	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	4.31	5.15	6.07	7.49	8.73	12.38	14.35	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	4.46	5.29	6.14	7.35	8.32	10.86	12.08	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	4.16	5.10	6.14	7.64	8.86	11.91	13.32	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	4.40	5.32	6.24	7.45	8.37	10.50	11.42	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	4.59	5.42	6.18	7.11	7.77	9.20	9.78	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	4.69	5.41	6.02	6.73	7.21	8.21	8.59	Best Distr.	-	Best Distr	Best Distr.
LogNormal	4.65	5.51	6.33	7.41	8.22	10.16	11.02	-	-	Best Distr	Best Distr.

Düzce – Akçakoca:

For this point, two directions are selected. These are NNE and N directions.

Meteorology data set:

NNE:

Table 62 – Results of Directional Analysis of Meteorology Data Set for Düzce – Akçakoca for NNE Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	1.77	2.05	2.32	2.67	2.93	3.53	3.79	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	1.56	1.83	2.17	2.79	3.44	5.84	7.45	-	-	-	-
FT 2 (k2=3.33)	1.62	1.91	2.26	2.84	3.40	5.23	6.33	-	-	-	-
FT 2 (k3=5.0)	1.68	1.98	2.32	2.83	3.28	4.60	5.31	-	-	-	Best Distr.
FT 2 (k4=10.0)	1.73	2.03	2.33	2.76	3.11	4.02	4.46	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	1.63	1.98	2.36	2.91	3.36	4.49	5.01	-	-	-	-
Weibull (k2=1.0)	1.71	2.05	2.38	2.82	3.16	3.93	4.27	-	-	-	Best Distr.
Weibull (k3=1.4)	1.78	2.07	2.35	2.68	2.92	3.43	3.64	Best Distr.	-	Best Distr	Best Distr.
Weibull (k4=2.0)	1.81	2.06	2.28	2.53	2.70	3.06	3.20	-	-	Best Distr	Best Distr.
LogNormal	1.76	2.03	2.28	2.60	2.83	3.38	3.61	-	-	Best Distr	-

N:

Table 63 – Results of Directional Analysis of Meteorology Data Set for Düzce – Akçakoca for N Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	2.06	2.44	2.81	3.29	3.65	4.48	4.83	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	1.78	2.18	2.70	3.63	4.60	8.19	10.61	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	1.86	2.29	2.80	3.64	4.45	7.12	8.73	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	1.94	2.37	2.85	3.58	4.22	6.10	7.11	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	2.01	2.42	2.85	3.45	3.94	5.21	5.82	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	1.87	2.37	2.93	3.73	4.38	6.01	6.76	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	1.98	2.45	2.92	3.54	4.01	5.10	5.57	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	2.06	2.47	2.84	3.30	3.63	4.34	4.63	Best Distr.	-	Best Distr	Best Distr.
Weibull (k4=2.0)	2.10	2.44	2.74	3.08	3.31	3.80	3.98	-	-	Best Distr	Best Distr.
LogNormal	2.02	2.40	2.76	3.23	3.59	4.45	4.83	-	-	Best Distr	Best Distr.

ECMWF data set:

NNE:

Table 64 – Results of Directional Analysis of ECMWF Data Set for Düzce – Akçakoca for NNE Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	3.07	3.64	4.18	4.88	5.40	6.62	7.14	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	2.63	3.13	3.78	4.95	6.17	10.69	13.73	-	-	-	-
FT 2 (k2=3.33)	2.75	3.31	3.99	5.11	6.18	9.71	11.84	-	-	-	-
FT 2 (k3=5.0)	2.87	3.47	4.12	5.13	6.02	8.61	10.01	-	-	-	Best Distr.
FT 2 (k4=10.0)	2.98	3.57	4.18	5.04	5.74	7.55	8.43	-	-	-	Best Distr.
Weibull (k1=0.75)	2.77	3.44	4.18	5.24	6.11	8.29	9.29	-	-	-	-
Weibull (k2=1.0)	2.94	3.60	4.26	5.14	5.80	7.33	7.99	-	-	-	Best Distr.
Weibull (k3=1.4)	3.08	3.68	4.23	4.90	5.38	6.42	6.84	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	3.16	3.67	4.12	4.63	4.98	5.70	5.98	Best Distr.	-	Best Distr	Best Distr.
LogNormal	3.08	3.70	4.30	5.09	5.69	7.15	7.80	-	-	Best Distr	Best Distr.

N:

Table 65 – Results of Directional Analysis of ECMWF Data Set for Düzce – Akçakoca for N Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	2.74	3.26	3.77	4.42	4.92	6.05	6.54	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	2.34	2.86	3.53	4.73	5.98	10.63	13.76	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	2.45	3.01	3.68	4.79	5.85	9.34	11.45	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	2.56	3.13	3.77	4.74	5.59	8.09	9.43	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	2.66	3.22	3.79	4.61	5.27	6.98	7.80	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	2.46	3.10	3.81	4.84	5.67	7.76	8.72	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	2.61	3.22	3.84	4.65	5.26	6.69	7.30	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	2.73	3.28	3.78	4.40	4.84	5.79	6.18	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	2.80	3.27	3.68	4.15	4.47	5.14	5.39	Best Distr.	-	Best Distr	Best Distr.
LogNormal	2.86	3.56	4.27	5.25	6.02	7.94	8.83	-	-	Best Distr	Best Distr.

Zonguldak:

For this point, no direction is found to be suitable for comparison mainly because ECMWF data set creates enough amount of data for 24 year analysis period but meteorology data set cannot.

Bartın – Amasra:

For this point, one direction is selected. This is NE direction.

Meteorology data set:

NE:

Table 66 – Results of Directional Analysis of Meteorology Data Set for Bartın – Amasra for NE Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	6.44	7.57	8.66	10.07	11.13	13.57	14.61	-	-	Best Distr	Best Distr.
FT 2 (k1=2.5)	5.62	6.79	8.29	11.01	13.83	24.31	31.36	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	5.86	7.11	8.60	11.08	13.45	21.25	25.96	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	6.09	7.35	8.76	10.90	12.78	18.30	21.27	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k4=10.0)	6.29	7.51	8.76	10.53	11.97	15.71	17.51	Best Distr.	-	Best Distr	Best Distr.
Weibull (k1=0.75)	5.89	7.35	8.96	11.29	13.18	17.93	20.12	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	6.21	7.58	8.94	10.75	12.12	15.29	16.66	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	6.44	7.64	8.73	10.07	11.02	13.10	13.94	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	6.55	7.57	8.43	9.44	10.12	11.53	12.08	-	-	Best Distr	Best Distr.
LogNormal	6.42	7.54	8.61	10.00	11.05	13.53	14.62	-	-	-	Best Distr.

ECMWF data set:

NE:

Table 67 – Results of Directional Analysis of ECMWF Data Set for Bartın – Amasra for NE Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	3.03	3.81	4.55	5.52	6.24	7.91	8.63	-	-	Best Distr	Best Distr.
FT 2 (k1=2.5)	2.53	3.50	4.74	6.99	9.31	17.97	23.79	Best Distr.	Best Distr.	Best Distr	Best Distr.
FT 2 (k2=3.33)	2.70	3.67	4.83	6.76	8.60	14.68	18.34	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	2.84	3.78	4.81	6.40	7.80	11.88	14.08	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	2.95	3.82	4.71	5.97	6.99	9.64	10.92	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	2.73	3.89	5.17	7.01	8.51	12.28	14.01	-	-	-	Best Distr.
Weibull (k2=1.0)	2.91	3.92	4.93	6.26	7.27	9.62	10.63	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	3.02	3.85	4.62	5.55	6.22	7.66	8.25	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	3.06	3.73	4.32	4.99	5.45	6.39	6.76	-	-	Best Distr	-
LogNormal	2.72	3.40	4.09	5.04	5.79	7.67	8.55	-	-	Best Distr	Best Distr.

Kastamonu – İnebolu:

For this point, one direction is selected. This is WNW direction.

Meteorology data set:

WNW:

Table 68 – Results of Directional Analysis of Meteorology Data Set for Kastamonu – İnebolu for WNW Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	2.85	3.45	4.02	4.75	5.31	6.58	7.13	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	2.40	2.98	3.73	5.07	6.46	11.64	15.12	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	2.54	3.16	3.92	5.17	6.36	10.29	12.67	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	2.66	3.31	4.02	5.12	6.09	8.91	10.44	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	2.77	3.40	4.05	4.97	5.72	7.65	8.59	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	2.56	3.30	4.12	5.31	6.28	8.71	9.82	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	2.73	3.44	4.15	5.10	5.81	7.46	8.17	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	2.86	3.49	4.07	4.77	5.27	6.37	6.81	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	2.92	3.46	3.92	4.45	4.81	5.56	5.85	-	-	Best Distr	Best Distr.
LogNormal	2.82	3.46	4.10	4.96	5.63	7.28	8.03	Best Distr.	-	Best Distr	Best Distr.

ECMWF data set:

WNW:

Table 69 – Results of Directional Analysis of ECMWF Data Set for Kastamonu – İnebolu for WNW Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	3.80	4.63	5.43	6.46	7.23	9.01	9.78	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	3.15	3.88	4.83	6.54	8.31	14.90	19.33	-	-	-	-
FT 2 (k2=3.33)	3.33	4.16	5.15	6.79	8.35	13.52	16.64	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	3.51	4.38	5.35	6.83	8.13	11.93	13.99	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	3.67	4.54	5.44	6.70	7.72	10.39	11.67	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	3.36	4.34	5.42	6.99	8.26	11.46	12.93	-	-	-	-
Weibull (k2=1.0)	3.62	4.58	5.55	6.83	7.80	10.04	11.01	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	3.82	4.69	5.50	6.48	7.18	8.70	9.32	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	3.93	4.68	5.33	6.08	6.59	7.65	8.06	Best Distr.	-	Best Distr	Best Distr.
LogNormal	3.84	4.88	5.96	7.45	8.64	11.69	13.12	-	-	Best Distr	Best Distr.

Sinop:

For this point, four directions are selected. These are WNW, NW, NNW and N directions.

Meteorology data set:

WNW:

Table 70 – Results of Directional Analysis of Meteorology Data Set for Sinop for WNW Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	5.73	6.30	6.85	7.56	8.09	9.32	9.85	-	Best Distr.	-	-
FT 2 (k1=2.5)	5.26	5.71	6.30	7.37	8.47	12.58	15.34	-	-	-	-
FT 2 (k2=3.33)	5.38	5.91	6.54	7.59	8.59	11.89	13.88	-	-	-	-
FT 2 (k3=5.0)	5.51	6.08	6.71	7.68	8.53	11.02	12.37	-	-	-	-
FT 2 (k4=10.0)	5.63	6.21	6.81	7.66	8.35	10.14	11.00	-	-	-	-
Weibull (k1=0.75)	5.38	5.99	6.66	7.63	8.41	10.38	11.29	-	-	-	-
Weibull (k2=1.0)	5.56	6.18	6.81	7.63	8.25	9.69	10.31	-	-	-	-
Weibull (k3=1.4)	5.72	6.31	6.85	7.51	7.98	9.00	9.42	-	-	-	-
Weibull (k4=2.0)	5.83	6.36	6.81	7.34	7.69	8.43	8.72	Best Distr.	-	-	-
LogNormal	5.92	6.53	7.08	7.76	8.25	9.34	9.79	-	-	Best Distr	-

NW:

Table 71 – Results of Directional Analysis of Meteorology Data Set for Sinop for NW Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	4.89	5.44	5.97	6.66	7.17	8.36	8.87	-	-	-	Best Distr.
FT 2 (k1=2.5)	4.45	4.92	5.52	6.61	7.74	11.95	14.78	-	-	-	-
FT 2 (k2=3.33)	4.57	5.10	5.74	6.80	7.81	11.15	13.16	-	-	-	-
FT 2 (k3=5.0)	4.69	5.26	5.89	6.85	7.70	10.19	11.52	-	-	-	Best Distr.
FT 2 (k4=10.0)	4.80	5.37	5.96	6.80	7.47	9.23	10.07	-	-	-	Best Distr.
Weibull (k1=0.75)	4.58	5.21	5.91	6.91	7.73	9.78	10.72	-	-	-	-
Weibull (k2=1.0)	4.76	5.38	6.01	6.84	7.47	8.93	9.56	-	-	-	-
Weibull (k3=1.4)	4.90	5.48	6.00	6.65	7.11	8.12	8.52	-	-	-	Best Distr.
Weibull (k4=2.0)	4.98	5.48	5.92	6.42	6.76	7.47	7.74	-	-	Best Distr	Best Distr.
LogNormal	4.98	5.52	6.01	6.60	7.03	8.00	8.40	Best Distr.	Best Distr.	Best Distr	Best Distr.

NNW:

Table 72 – Results of Directional Analysis of Meteorology Data Set for Sinop for NNW Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	4.35	4.96	5.54	6.30	6.87	8.19	8.75	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	3.86	4.41	5.11	6.37	7.69	12.56	15.84	-	-	-	-
FT 2 (k2=3.33)	4.00	4.61	5.34	6.55	7.70	11.51	13.81	-	-	-	Best Distr.
FT 2 (k3=5.0)	4.13	4.77	5.48	6.57	7.53	10.33	11.84	-	-	-	Best Distr.
FT 2 (k4=10.0)	4.25	4.89	5.55	6.48	7.23	9.19	10.14	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	4.01	4.73	5.52	6.67	7.60	9.94	11.01	-	-	-	-
Weibull (k2=1.0)	4.20	4.91	5.61	6.54	7.25	8.89	9.59	-	-	-	Best Distr.
Weibull (k3=1.4)	4.35	4.99	5.58	6.29	6.81	7.92	8.37	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	4.43	4.99	5.47	6.02	6.39	7.17	7.47	Best Distr.	-	Best Distr	Best Distr.
LogNormal	4.44	5.07	5.66	6.42	6.97	8.25	8.80	-	-	Best Distr	Best Distr.

N:

Table 73 – Results of Directional Analysis of Meteorology Data Set for Sinop for N Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type	Hs										
Gumbel	3.54	4.26	4.94	5.83	6.50	8.03	8.69	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	3.00	3.69	4.58	6.19	7.85	14.05	18.21	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	3.16	3.91	4.80	6.29	7.71	12.39	15.22	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	3.31	4.07	4.93	6.24	7.39	10.75	12.56	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	3.44	4.19	4.97	6.07	6.96	9.28	10.39	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	3.17	4.03	4.99	6.38	7.51	10.33	11.63	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	3.38	4.21	5.05	6.15	6.98	8.92	9.76	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	3.54	4.29	4.97	5.81	6.41	7.71	8.24	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	3.63	4.28	4.83	5.48	5.91	6.82	7.17	Best Distr.	-	Best Distr	Best Distr.
LogNormal	3.65	4.56	5.49	6.75	7.76	10.26	11.43	-	-	Best Distr	Best Distr.

ECMWF data set:

WNW:

Table 74 – Results of Directional Analysis of ECMWF Data Set for Sinop for WNW Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type				Hs							
Gumbel	4.90	5.87	6.80	8.01	8.91	11.01	11.91	-	Best Distr.	Best Distr	-
FT 2 (k1=2.5)	4.11	4.93	5.98	7.88	9.85	17.18	22.11	-	-	-	-
FT 2 (k2=3.33)	4.32	5.24	6.35	8.20	9.96	15.76	19.26	-	-	-	-
FT 2 (k3=5.0)	4.53	5.52	6.62	8.30	9.78	14.11	16.44	-	-	-	-
FT 2 (k4=10.0)	4.73	5.73	6.76	8.22	9.40	12.48	13.96	-	-	Best Distr	-
Weibull (k1=0.75)	4.32	5.39	6.57	8.28	9.66	13.14	14.74	-	-	-	-
Weibull (k2=1.0)	4.63	5.71	6.79	8.22	9.30	11.82	12.90	-	-	-	-
Weibull (k3=1.4)	4.90	5.91	6.83	7.97	8.78	10.53	11.24	-	-	Best Distr	-
Weibull (k4=2.0)	5.06	5.96	6.73	7.62	8.23	9.48	9.97	Best Distr.	-	Best Distr	-
LogNormal	5.23	6.81	8.46	10.80	12.71	17.67	20.06	-	-	Best Distr	-

NW:

Table 75 – Results of Directional Analysis of ECMWF Data Set for Sinop for NW Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type				Hs							
Gumbel	3.64	4.26	4.85	5.62	6.19	7.52	8.09	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	3.18	3.77	4.52	5.88	7.30	12.55	16.08	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	3.31	3.96	4.73	6.01	7.23	11.26	13.69	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	3.44	4.11	4.85	5.98	6.98	9.89	11.46	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	3.56	4.21	4.89	5.84	6.61	8.61	9.58	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	3.33	4.09	4.93	6.14	7.13	9.60	10.74	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	3.52	4.25	4.98	5.94	6.67	8.37	9.10	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	3.65	4.30	4.90	5.63	6.14	7.27	7.73	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	3.72	4.28	4.75	5.30	5.68	6.45	6.75	-	-	Best Distr	Best Distr.
LogNormal	3.66	4.28	4.87	5.63	6.20	7.55	8.14	Best Distr.	-	-	Best Distr.

NNW:

Table 76 – Results of Directional Analysis of ECMWF Data Set for Sinop for NNW Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type				Hs							
Gumbel	3.43	4.06	4.67	5.46	6.05	7.41	8.00	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	2.92	3.48	4.20	5.49	6.83	11.83	15.18	-	-	-	-
FT 2 (k2=3.33)	3.06	3.68	4.43	5.67	6.86	10.76	13.12	-	-	-	-
FT 2 (k3=5.0)	3.20	3.86	4.59	5.71	6.69	9.57	11.13	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	3.32	3.98	4.66	5.62	6.40	8.43	9.40	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	3.07	3.80	4.60	5.77	6.71	9.08	10.17	-	-	-	-
Weibull (k2=1.0)	3.27	3.99	4.71	5.67	6.39	8.07	8.79	-	-	-	-
Weibull (k3=1.4)	3.43	4.09	4.70	5.44	5.97	7.12	7.59	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	3.52	4.10	4.60	5.18	5.57	6.38	6.69	Best Distr.	-	Best Distr	Best Distr.
LogNormal	3.58	4.42	5.27	6.41	7.31	9.53	10.55	-	-	Best Distr	Best Distr.

N:

Table 77 – Results of Directional Analysis of ECMWF Data Set for Sinop for N Direction

Return Period	5	10	20	50	100	500	1000	*r*	MIR	DOL	REC
Distribution Type				Hs							
Gumbel	2.92	3.56	4.18	4.97	5.57	6.95	7.54	-	Best Distr.	Best Distr	Best Distr.
FT 2 (k1=2.5)	2.43	3.06	3.88	5.35	6.87	12.52	16.33	-	-	Best Distr	Best Distr.
FT 2 (k2=3.33)	2.57	3.25	4.07	5.42	6.71	10.96	13.53	-	-	Best Distr	Best Distr.
FT 2 (k3=5.0)	2.71	3.40	4.17	5.36	6.40	9.44	11.08	-	-	Best Distr	Best Distr.
FT 2 (k4=10.0)	2.82	3.50	4.21	5.20	6.00	8.08	9.09	-	-	Best Distr	Best Distr.
Weibull (k1=0.75)	2.58	3.37	4.25	5.52	6.54	9.12	10.31	-	-	Best Distr	Best Distr.
Weibull (k2=1.0)	2.77	3.52	4.28	5.28	6.03	7.79	8.54	-	-	Best Distr	Best Distr.
Weibull (k3=1.4)	2.91	3.58	4.20	4.96	5.49	6.66	7.14	-	-	Best Distr	Best Distr.
Weibull (k4=2.0)	2.99	3.57	4.07	4.64	5.03	5.84	6.16	Best Distr.	-	Best Distr	Best Distr.
LogNormal	3.03	3.94	4.88	6.22	7.32	10.15	11.51	-	-	Best Distr	Best Distr.

APPENDIX – C

ALL DIRECTIONS STUDY

By using all directions, graphical comparison of all regions are presented through Figure 29 to Figure 34.

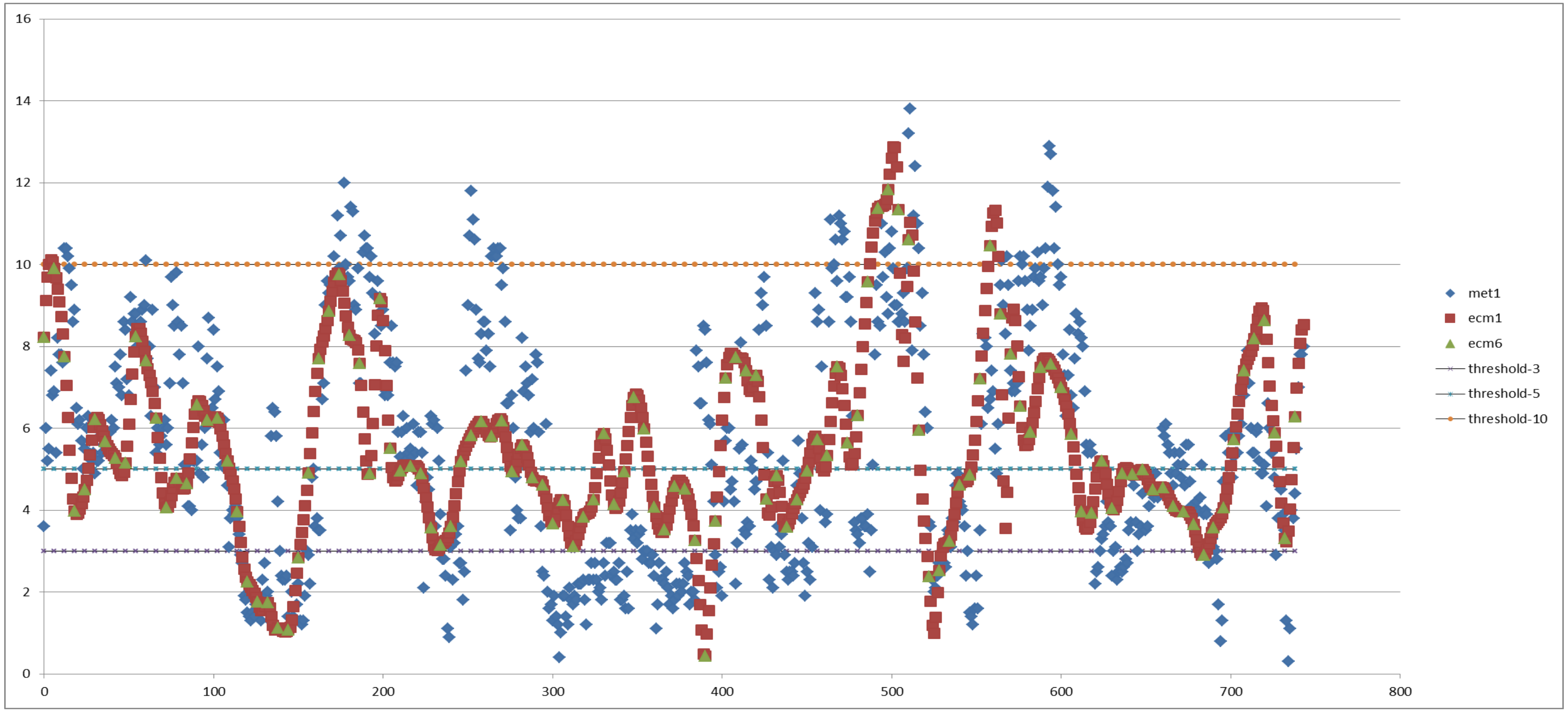


Figure 29 – Istanbul - Kilyos

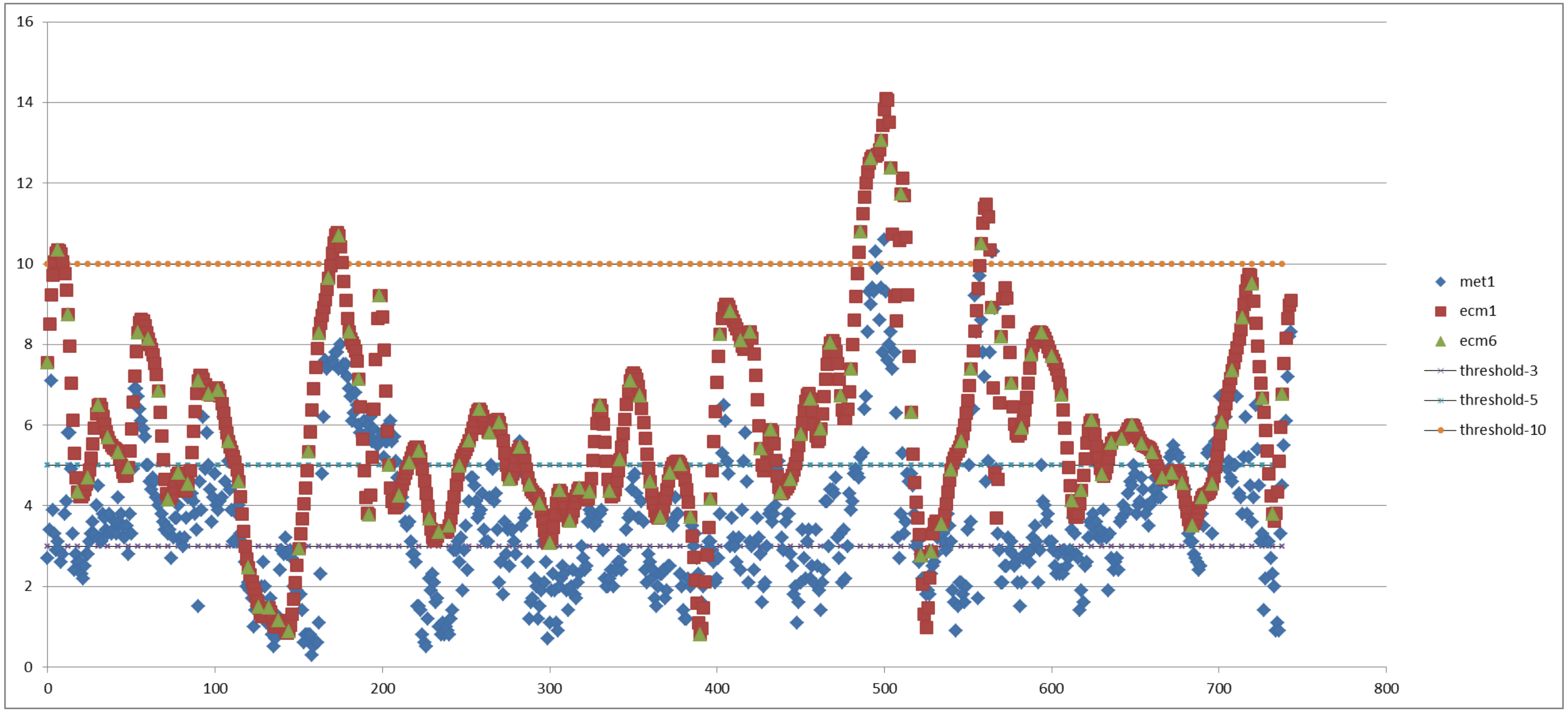


Figure 30 – İstanbul – Şile

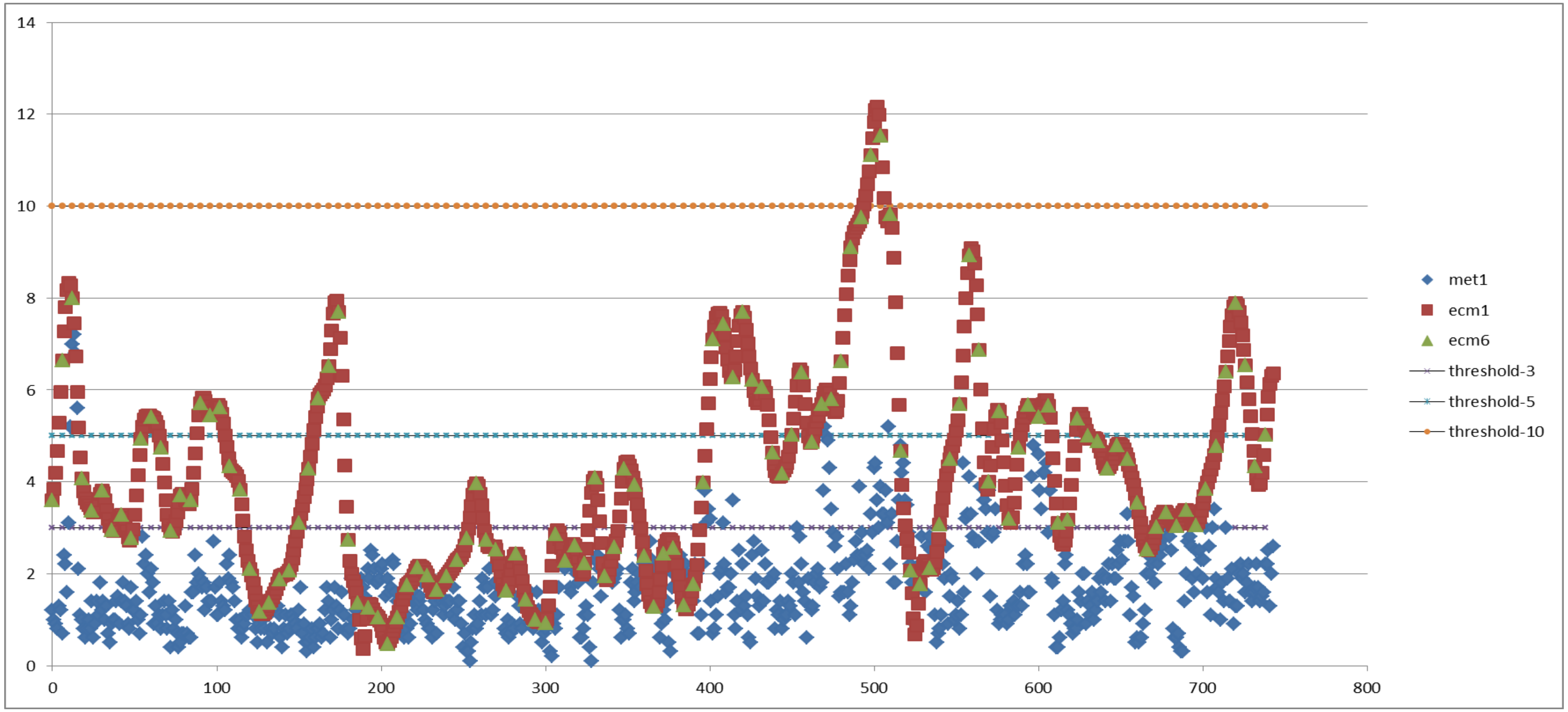


Figure 31 – Düzce – Akçakoca

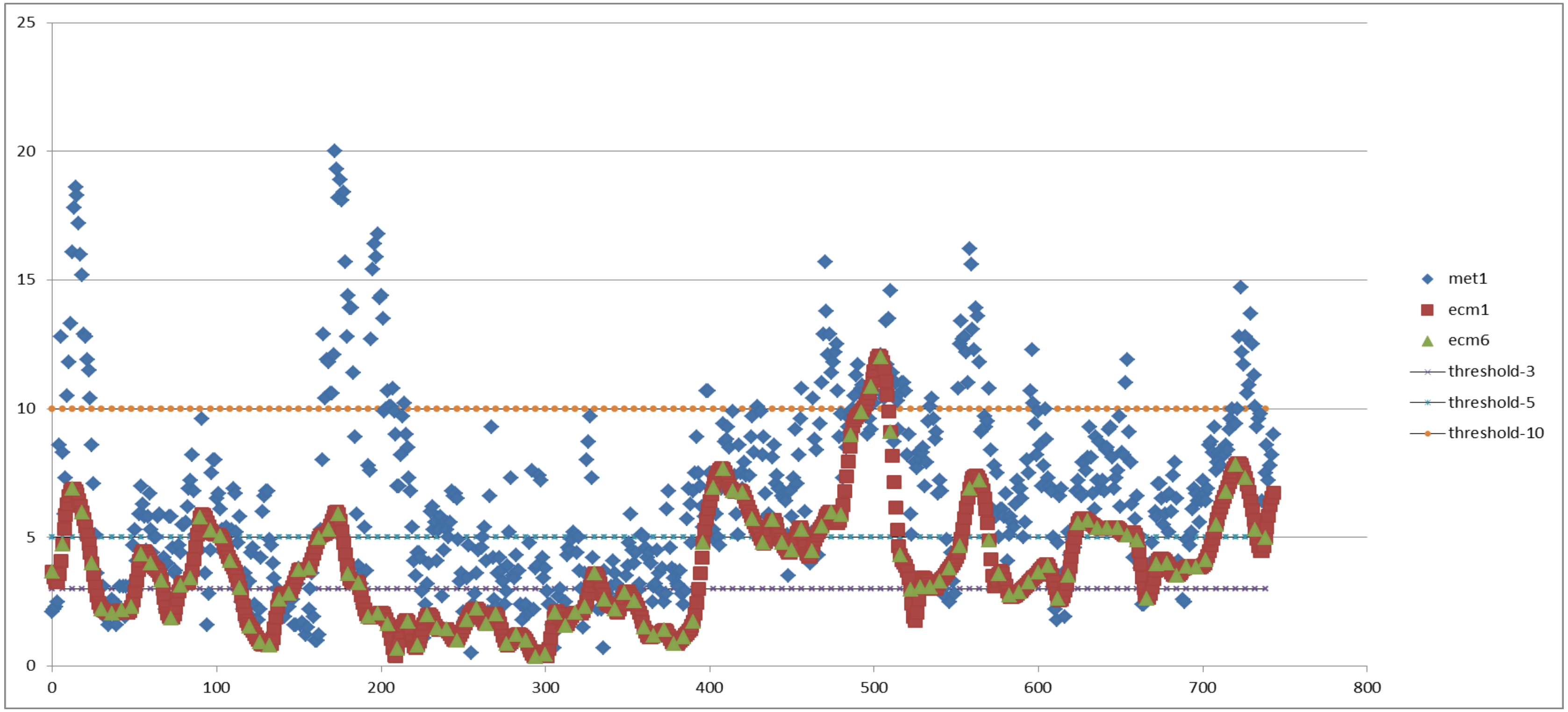


Figure 32 – Bartin – Amasra

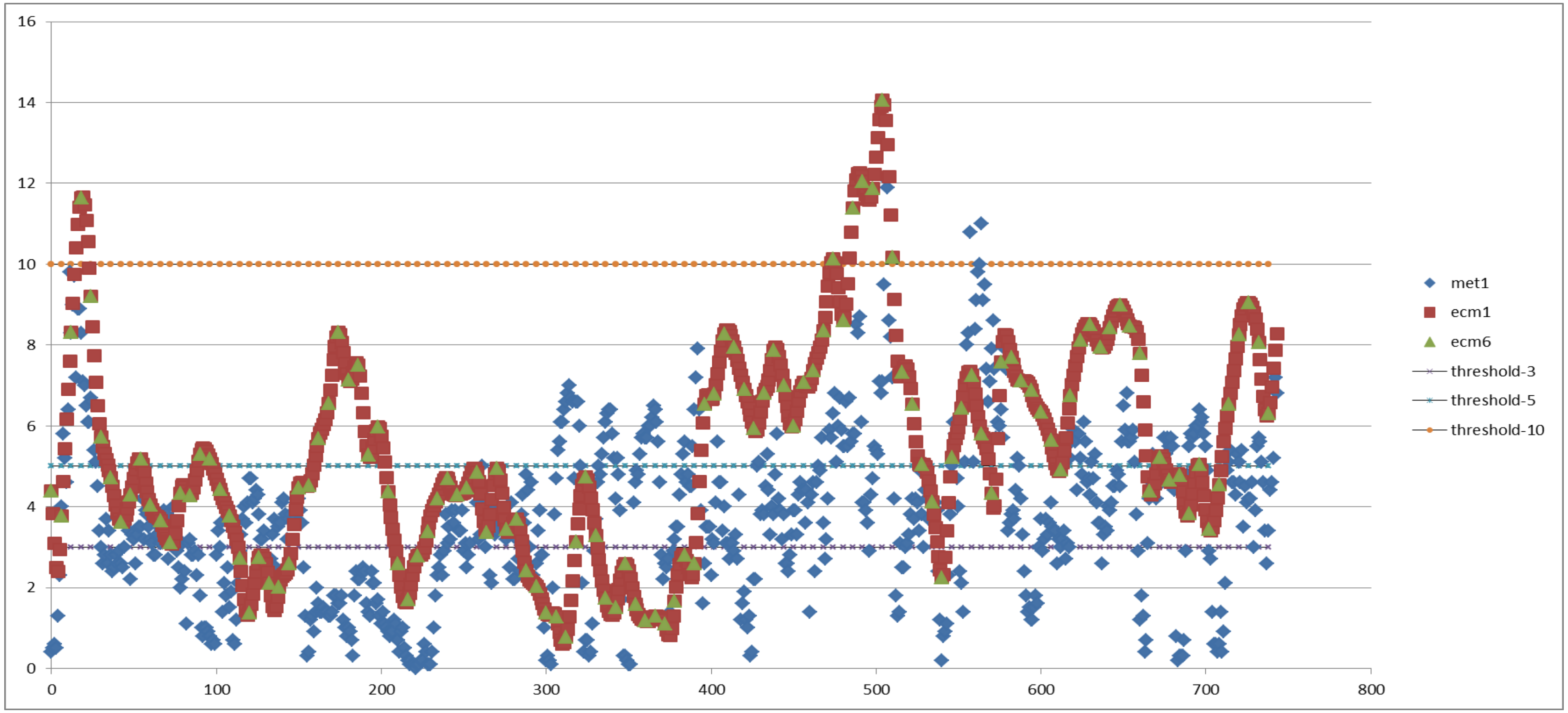


Figure 33 – Kastamonu – İnebolu

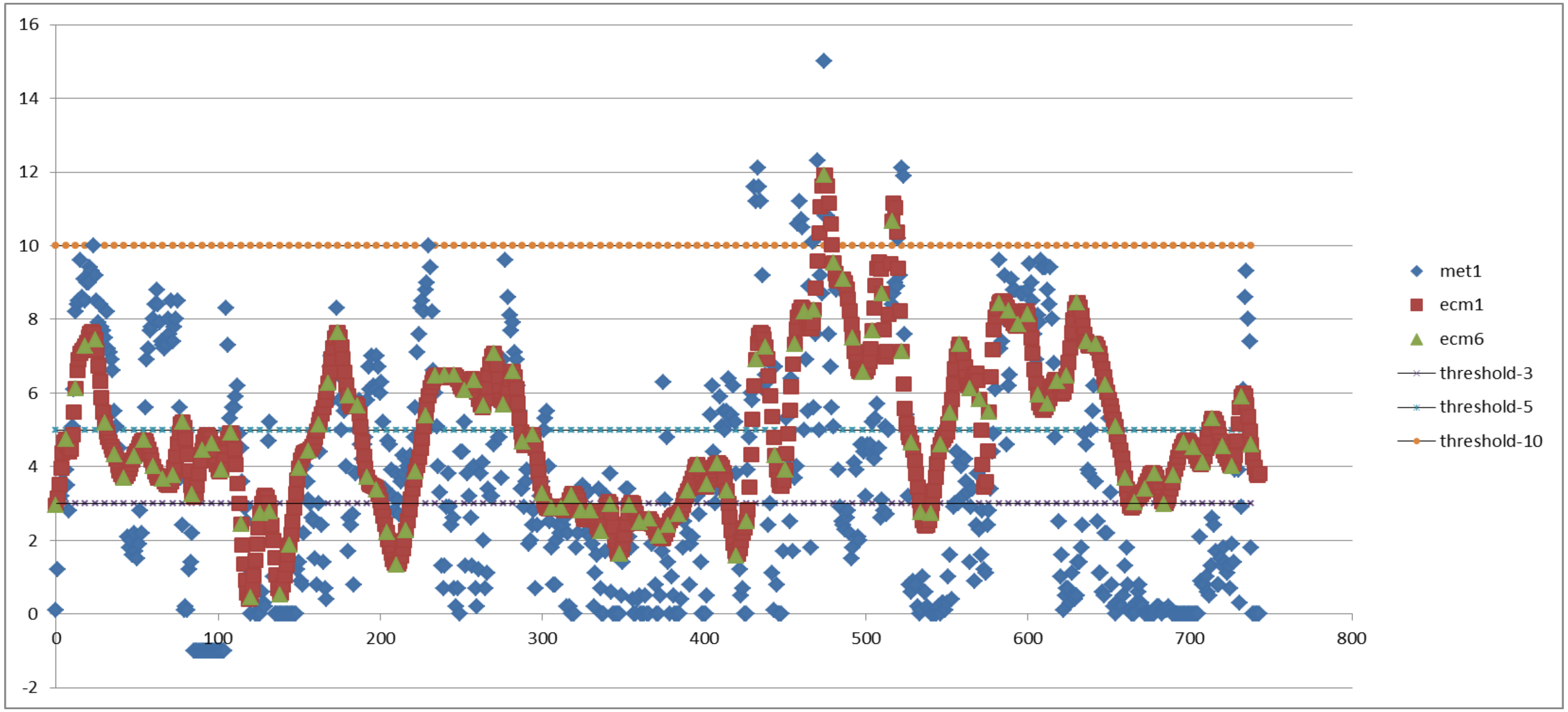


Figure 34 – Sinop