WIND AND WAVE CLIMATE IN EASTERN MEDITERRANEAN BASIN

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ABSTRACT

WIND AND WAVE CLIMATE IN EASTERN MEDITERRANEAN BASIN

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The wind and wave (wind wave/swell wave) climate has an important role in the design and operation of coastal and marine structures, harbors and ports. The objective of this study is to identify the statistical characteristics of the winds, wind waves and swell waves in Eastern Mediterranean, and coastline of Türkiye. For this purpose, the data of wind speed and direction, swell and wind wave height, period and direction for a certain duration with the six hours time intervals are obtained from ECMWF for the wind and wave climate computations. The data covers the area of eastern Mediterranean region. In order to compute the wind and wave climate at any selected coastal location, a software is developed by Serhan Aldoğan in his MSc thesis. For every location, the wind wave roses, significant height of wind wave and swell wave versus mean period of primary wind directions, extreme probability analysis and distribution, and log-linear cumulative probability analysis and distributions is presented, compared and discussed. By the help of the specifically developed software, it is possible and convenient to analyze the wind and wave climate using ECMWF data at any coordinate.

Keywords: Wind Climate, Swell Climate, Wave Statistics, Eastern Mediterranean, Coastline of Türkiye

ÖZ

DOĞU AKDENİZ HAVZASINDA RÜZGAR VE DALGA İKLİMİ

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Rüzgar kaynaklı dalgalar, kıyı ve deniz yapıları, limanlar, barınaklar, deniz araçları üzerinde önemli etkilere sahiptir. Bu sebeple, rüzgar dalga iklimi kıyı ve deniz yapıları, barınaklar ve limanların tasarımında önemli bir parametre olarak kullanılmaktadır. Bu çalışmanın amacı Türkiye'nin Akdeniz kıyılarındaki rüzgar dalga ikliminin kullanılabilir durumda açığa çıkarılmasıdır. Bu amaçla ECMWF (Avrupa Orta Vadeli Tahminler Merkezi) tarafından 1995 ve sonrasi rüzgar, rüzgar dalgaları belli bir ay süreli data sağlanmıştır. Elde edilen veriler, Serhan Aldoğan tarafından geliştirilmiş olan özel bir yazılım aracılığıyla Türkiye'nin Akdeniz kıyıları boyunca seçilen çeşitli bölgelerdeki rüzgar ve dalga iklimi istatistiksel olarak hesaplanmıştır. Her bölge için rüzgar ve rüzgar dalgaları ve solugan dalgaların gülleri, belirgin dalga yüksekliğine karşılık ortalama rüzgar dalgası yönü ve periyodu ilişkisi, en yüksek değerler analiz ve istatistiği, log-lineer istatistikler dağılımları sunulmuştur. Geliştirilen yazılım ile kullanıcı tarafından seçilen kıyı bölgelerinin koordinatları kullanılarak ECMWF verileri yardımıyla ayrıntılı analizler yapılması olanaklı duruma getirilmiştir.

Anahtar Kelimeler: Rüzgar İklimi, Soluğan Dalga İklimi, Doğu Akdeniz, Türkiye Kıyı Şeridi

To My Family

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ABBREVIATIONS AND ACRONYMS

WIND	10 meter wind speed (m/s)
MDPS	Mean direction of primary swell (degrees)
MDWW	Mean direction of wind wave (degrees)
MPPS	Mean period of primary swell (s)
MPWW	Mean period of wind wave (s)
SHPS	Significant height of primary swell (m)
SHWW	Significant height of wind wave (m)
T	Wave period (s)

CHAPTER 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

The aim of this study is to investigate and analyze the wind and swell wave climate along the eastern Mediterranean and Turkish coastline by using satellite and wave model data. Until now wind wave and swell wave climate are collectively studied. This study focuses on swell wave and wind wave climate along the Turkish coasts in more detailed way, namely both the observation period and grid spacings are decreased to half of the previous studies, thus completing the previous works of Uğur BERKÜN, Wind and Swell Wave Climate for Southern Part of Black Sea, 2007, Saygın Kemal DEREBAY, Wind and Swell Wave Climate for the Southern Part of Aegean and the Mediterranean Sea, 2007 and Serhan ALDOĞAN, Wind and Wind Wave Climate Turkish Coast of Aegean and Mediterranean Sea, 2008 . Besides, by the help of the software developed by Serhan ALDOĞAN, for any coordinate, all parameters for swell and wind data can be easily extracted from ECMWF database. Moreover analyses for the extracted data can be easily done by this user friendly software.

The term swell waves refer to wind generated waves that have moved out of their generation zone. Swell waves can travel long distances and show distinct characteristics such as regular heights, periods and directions with rounded crests and troughs. Swell waves are important for small craft harbors and fisheries since they cause harbor tranquility dangerous for small craft. Also swell waves have an important role on cross-shore sediment transport.

The term wind wave refers to sea waves caused by winds over sea surface. Nevertheless, in this study the term "Wind Wave" is used for wind-generated waves, encountered in their generation zone. Wind waves are the main parameter in the design of coastal structures. All coastal structures are designed, or at least checked, against wind waves.

The scope of this study is limited to investigation of wind and swell wave climate at locations shown on figure 1.1.1 along the coastline of Türkiye. The area in scope is analyzed in 9 different locations. Statistical analyses are carried out for these locations and results are presented by wind and swell wave roses, significant wave height versus Mean period of primary swell relations, extreme probability distribution, and log-linear cumulative probability distribution. The results are provided separately for locations and entirely for the region in scope.

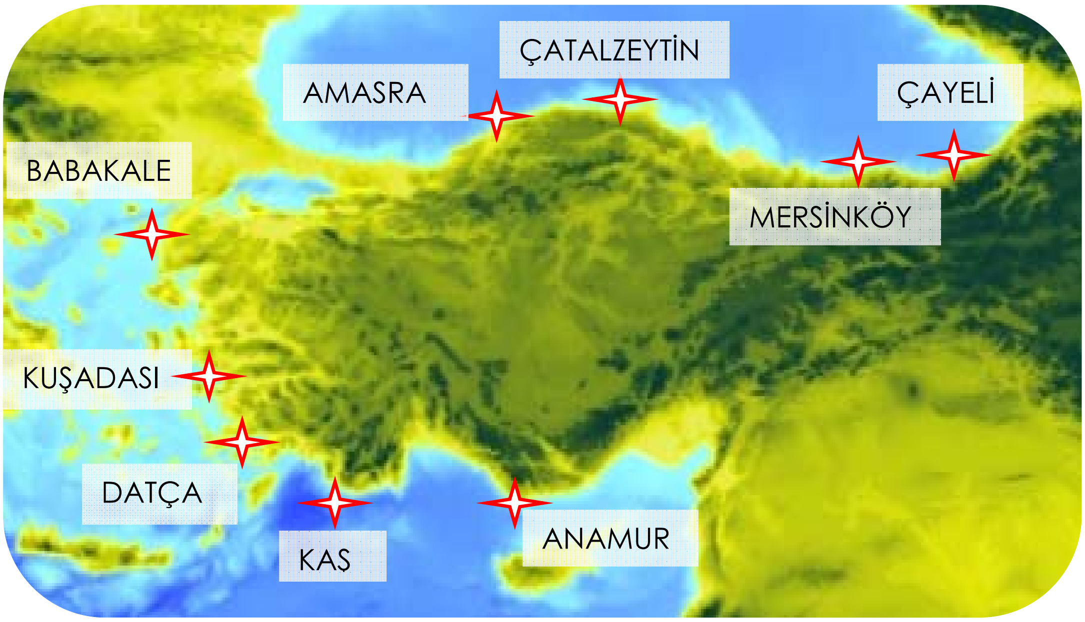


Figure 1.1.1 The Layout of The 9 Locations

The region of study is coastline of Türkiye, namely Mediterranean, Aegean and Black Sea coasts. For the purpose of the study, data is obtained from

ECMWF [ECMWF, 2008] for the whole eastern Mediterranean Basin for the dates between 1.1.1995 to 19.10.2008, in other words for 166 months period. 9 locations are identified along the coastline. And the data is analyzed in detail for the selected locations. The thirteen locations are identified as Anamur, Titreyengöl, Kaş, Datça, Kuşadası, Babakale, Güneyli, Marmara Ereğlisi, Tuzla, Amasra, Çatalzeytin, Mersinköy and Çayeli.

Previous works on wave climate of Turkish Black Sea shores is limited mainly because of limitations on obtaining data. The "Turkish Coast Wind and Deep Water Wave Atlas, 1999" Özhan and Abdalla, [1999] and "Determination of Design Wave Properties and Wave Forecasts for 15 Coastal Regions,1986" Ergin and Özhan [1986] are the two main works on wave climate research both of which include coastline of Türkiye, in which wind speeds and significant wave heights; yearly and seasonal wind and wave roses, monthly means and extreme values, extreme value statistics and also significant wave height vs. mean wave period relations in 30 km intervals along north coast of Türkiye (Özhan and Abdalla, 1999) are given. However neither of the studies mentioned in this section considered swell waves separately.

1.2 METHOD OF STUDY

The method of this study is carried in the following steps; the data gathering, re-arrangement and refining of data, analysis of data in scope and presentation of findings. Data used in this study is obtained from the ECMWF Data Server. [ECMWF, 2008] The data is obtained for the area bounded by throughout 10 E to 43 E and 30 N and 46 N geographical coordinates which includes the coastline of Türkiye. The data period is between 01.07.1998 to 30.09.2008, totally 123 months in length. Data for the 9 locations are extracted from the whole data group and re-arranged for analysis. The 9 locations are analyzed separately and for every location results are presented graphically. The wind and swell wave roses, significant wave height versus mean period of primary swell relations, extreme probability distribution and log-linear cumulative probability distribution are provided for the locations in the scope of the study.

The arrangement of the subsequent sections of this study is as follows. Chapter 2 presents a summary of theoretical considerations on swell and wind waves and previous works related to this study. Detailed methodology of analysis and details of the data gathered are presented in Chapter 3, followed by results of analysis for the thirteen locations in Chapter 4. Summaries and discussions of the results and some detailed analysis are given in Chapter 5. Finally conclusion of the study is given in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

In this chapter general information on swell wave and wind wave characteristics and previous works on swell wave and wind wave climate researches are given. In section 2.1 information about swell waves and wind waves, swell wave propagation and importance is given in general. In section 2.2 previous works on swell wave and wind wave climate researches are given.

2.1 GENERAL INFORMATION ON SWELL WAVES AND WIND WAVES

The term swell wave refers to wind generated waves that have moved out of their generation zone [CEM, 2006]. Wind seas and swells together account for more than half of the energy carried by all waves on the ocean surface, surpassing the contribution of tides, tsunamis, coastal surges, etc. [Alves, 2004][Kinsman, 1965]. But it is necessary to differentiate swell waves from other surface waves since swell waves have some unique characteristics. In calm areas far from winds, some characteristics of swell waves can be observed with bare eye. Such as their uniform shapes, smooth and well-defined crests and relatively long periods.

Swell waves attain these characteristics while they propagate over long distances. Swell is known to propagate across entire ocean basins along great circle paths with very little attenuation [Kantha, 2004] [Barber and Ursell, 1948; Munk and Snodgrass, 1957; Munk et al., 1963]. The wave-dissipation process, or wave decay, is brought about by (1) internal friction within the waves, (2) resistance met as waves overtake the wind, (3) restraint caused by crosswinds, (4) action of ocean currents in the path of waves, and (5) effects of seaweed, ice, shoals, islands, or continents in the path of waves. [Aerographer's Mate 1&C, 2006] However it is the dispersion process that makes swell waves organized according to wave periods.

Swell waves propagate in the form of wave trains, where the wave train means the group of waves that have the same wave period and direction. The rate of propagation of waves or the wave celerity is;

$$C_o = L/T \tag{2.1}$$

where "L" and "T" are wave length and wave period. The energy of wave train travels with group velocity which is defined as half of the wave celerity for waves traveling in deep water. In deep water wave length is defined as;

$$L_0 = \frac{g.T^2}{2.\pi} \tag{2.2}$$

where "g" is the gravitational acceleration. Substituting equation (2) in (1) follows that the speed of waves on deep water is only affected by wave period.

$$C_o = \frac{g}{2.\pi}.T \tag{2.3}$$

The consequence of the above equation is that swell waves with different periods propagates with different velocities. Swell waves with higher periods moves ahead of the lower period swell waves. In a sufficiently long basin the swell wave trains are dispersed according to their periods and this process provides swell waves their regular period characteristic. [CEM, 2006]

The regularity of swell waves causes them to be critical for the harbor resonance phenomenon. The performance of ports and harbors which experience downtime due to excessive vessel motion induced by long period swells is a critical consideration. Small crafts are dangerously affected by swell waves when the rolling period of craft coincides and resonates with the swell wave period.

The swell waves also have an important role on cross-shore sediment transport. The relatively low wave steepness of swells causes them to transport sediment from offshore to onshore [CSMW, 2007]. Swells tend to mobilize offshore sediment bar and redeposit onshore and the littoral drift and littoral current decrease as the offshore bar is removed [CSMW, 2007].

The term wind wave is the general abbreviation to wind generated waves. In this study the wind wave term is used to emphasize the wind generated waves encountered in their generation zone. This definition is used to differentiate the wind waves from non-wind generated waves like tides, tsunamis, surges etc. and from other wind generated waves, mainly, from swells.

The most distinguishing property of wind waves is their irregularity. This irregularity brings forth a non-uniform sea surface, with interfered crest and troughs and short periods resulting in smaller steepness. As a result of this irregularity, some descriptive statistical methods for identification of wave characteristics are proposed. The concept of significant wind wave height is used to define the characteristics of wave trains, where the wave train means the group of waves that have the same wave period and direction.

The concept of significant wave height is first introduced by Sverdrup and Munk (1947). The definition of significant wave height is the mean height of the highest one third of all waves. Significant height is mainly denoted by "H_s" or "$H_{1/3}$". Significant wave height has been found to be very similar to the estimated visual height by an experienced observer (Kinsman 1965).

The average of the chosen waves defines the significant wave height as

$$H_s = \frac{1}{\frac{N}{3}} \cdot \sum_{i=1}^{\frac{N}{3}} H_i \qquad (2.4)$$

where "N" is the number of individual wave heights H_i in a record ranked highest to lowest. Although the significant wave height concept seems to be a rather old fashioned method, it is a useful tool to reduce the complexity of a sea surface into one number. It should be kept in mind that this is a statistical distribution given only for wave heights, and do not give us any clue about period and direction of the wave. [CEM, 2006]

A similar simplification with a different statistical approach is also proposed for wave periods and directions. For periods and directions mean wind wave period and mean wind wave direction concepts are introduced, where mean wind wave period is the arithmetic mean of all observed periods in a group of waves and mean wind wave direction is the arithmetic mean of directional counts in an observation.

The wind waves are the primary factor affecting the design and construction of coastal structures. All on-shore and off-shore coastal structures are designed, or at least checked, primarily against wind waves whatever purpose they have. The armor weight and thickness of rubble mound structures, the height and stability of wall type structures are all controlled by wind waves in general.

Wind have also important role in naval transportation. All freight and passenger ships around the world are designed against wind waves including offshore platforms.

2.2 LITERATURE SURVEY

In this section previous works related to wind and wave climate analysis is summarized. In this scope works on swell wave propagation and climate analysis in the world seas and wind and wind wave climate works in Eastern Mediterranean Basin are listed. The current information on wind and wave climate along Turkish coast is very limited. Also swell waves have not been studied on these works.

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

One of the informative sections is given in The Technical Standards and Commentaries for Port and Harbour Facilities in Japan, page 46. (Japanese Standard, 1999) The following figure 2.2.1 has been extracted from The Technical Standards and Commentaries for Port and Harbour Facilities in Japan (Japanese Standard, 1999) and is used for swell hindcasting by Bretschneider method. According to the figure, the swell waves with 10, 8 and 6 seconds periods can decay in 344 km's, 430 km's and 573 km's respectively.

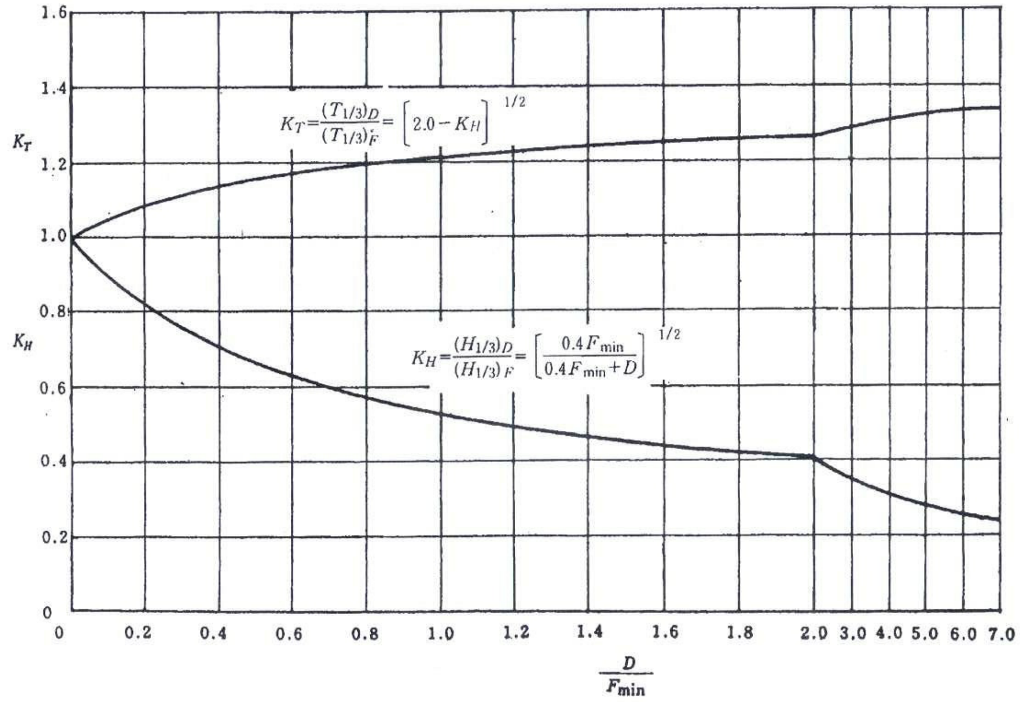


Figure 2.2 1 Swell Hindcasting Diagram

In METU Civil Engineering Department Coastal and Ocean Engineering Division 4 thesis have been completed by Berkun (2006), Çaban (2007), Derebay (2007), and Aldoğan (2008) on the analysis of ECMWF data for some selected coastal regions of Türkiye.

CHAPTER 3

DATA SOURCE AND ANALYSES OF DATA

In this chapter information about the data that is used in the analyses are given and analyses steps are explained. In section 3.1 the details of data source and download procedure are explained. In section 3.2, information about the data gathered from ECMWF database and the rearrangement of the data are discussed. Finally in section 3.3 the analysis procedures and presentation steps are given.

3.1 DATA SOURCE AND OBTAINING DATA

3.1.1 The Data Source

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

ECMWF Data Server by special permission from General Directorate of Turkish State Meteorological Service and ECMWF.

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

3.1.2 Obtaining Data

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

3.2 INFORMATION ON DATA AND DATA RE-ARRANGEMENT

3.2.1 Information on Obtained Data

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

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

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

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

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

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

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

For the purpose of this study, the study area is selected as 10 E to 43 E and 30 N to 46 N which is enough to cover whole Mediterranean region. The spatial resolution is selected as 0.50°x0.50° for all parameters which are stated above. This way a 65x33 matrix is formed over where every cell indicates a location. And the naming of locations was made due to this matrix, e.g. 04-03 refers to 4th column, 3rd row of this matrix counted from left to right and bottom to top. The wind and wave data is obtained for a 166 months period starting from 01.01.1995 to 19.10.2008 with 6 hour data record interval covering whole Mediterranean basin. Totally 194150 data records for all locations inside the matrix are acquired, providing data elements which are the wind components 10 meter above sea level, the mean direction of primary swell, the mean direction of wind wave, the mean period of primary swell, the mean period of wind wave, the significant height of primary swell and the significant height of wind wave.

Table 3.2.1.1 Location Indices

LOCATION INDEX	NAME	LAT	LON
46x13	ANAMUR	36,10	32,04
39x13	KAŞ	36,19	29,64
35x14	DATÇA	36,64	27,68
34x17	KUŞADASI	37,87	27,75
32x20	BABAKALE	39,28	26,03
45x25	AMASRA	41,76	32,40
48x25	ÇATALZEYTİN	41,96	34,22
59x23	MERSİNKÖY	41,09	39,48
61x23	ÇAYELİ	41,09	40,72

3.2.2 The GRIB File Format

The source data are obtained in GRIB format as explained in Section 3.1.2. The GRIB is an abbreviation for "Gridded Binary". The GRIB file format is a bit-oriented data exchange and storage format. In GRIB form the data is efficiently packed and compacted and this way storage and transmission of data is made efficiently. However GRIB files cannot be opened and/or viewed in conventional software before extraction. Special software is needed to unpack the GRIB files. Few programs exist for this purpose and unfortunately it is hard to find satisfactory documentation for any of them. In this study a free software named WGRIB is used. But also the ECMWF serves another free software product, named GRIBEX for handling GRIB files which is available for UNIX systems [ECMWF, 2008]. WGRIB runs in DOS environment and is well established and usage is quite simple and straightforward once commands are understood. The program is available from National Oceanic & Atmospheric Administration (NOAA) of U.S. Department of Commerce [NOAA, 2006]. The decoding process is carried out by using WGRIB program and the decoded GRIB files are saved as text files. Every GRIB file contained data for a month period, and so text files for every month was produced for wind and wave data totaling in 166 separate text files. The usage of WGRIB and links to detailed help files are given in the appendix. Although the extracted text files can be viewed in conventional software at this level, they are still not meaningful. The data in text files had to be re-arranged for processing the data as described in the following section.

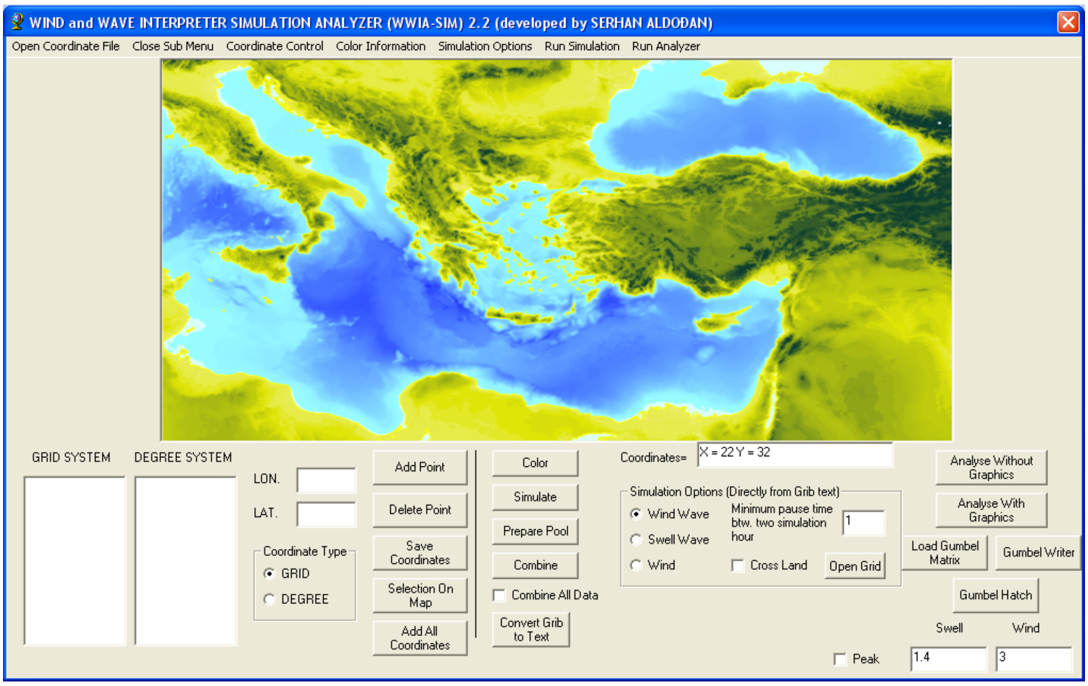
3.2.3 Re-arrangement of Data

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

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

3.3 DATA ANALYSIS AND PRESENTATION

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



Coordinates= X = 22 Y = 32

Coordinate Type: ● GRID

● Wind Wave

Minimum pause time btw. two simulation hour: 1

Swell: 1.4

Wind: 3

Figure 3.3.1 General View of the WWIA-SIM2.2

3.3.1 Wind and Wave Roses

Wind and Wave Roses are angular histograms plotted on polar coordinate system. Roses give the frequency distribution of geographical bearing of incoming winds and waves. To show the information about the distributions of wind speeds and wave heights, and the frequency of the varying directions, one may draw a so-called wind rose.

The frequency is given in percent of all directions plus the calm duration and the percent scale is given on the polar coordinate system. The roses at the same time have a magnitude scale and show the percentage of each magnitude interval. The magnitude intervals legend is given on a color scale. For every bearing, the percentages of magnitude intervals are added on former interval and thus the percent of any bearing is the total of percentages of each interval. Therefore, the calculation of percent of an interval e.g. 7.5 to 10 m/s for wind speed should be made for any direction by subtracting the percent reading of interval minimum from interval maximum.

Roses are plotted by using WWIA-SIM 2.2. Software simply prepares all roses with a 5% incremental view by using the user interval and color information. In this study, the wind classes, that are the colored magnitude scale or intervals, are prepared as; 0-2, 2-5, 5-7.5, 7.5-12.5, 12.5-15, 15-17.5, 17.5-20, 20-22.5 and 22,5-25 in meters/second. This way, wind speed spectrum is divided into 10 intervals. The wind speeds lower than 2 m/s is treated as calm and the calm percentage is indicated at the lower right corner of the roses separately. If the calm duration or 0-2 m/s interval were to be indicated in the rose, the total of all petals would have made 100%. However, in the given roses the total percentage of all petals made up to 100% minus the percentage of calm duration or interval.

The wind wave roses are handled in a similar way to wind roses. The wave classes or intervals are selected as; 0-0.3, 0.3-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8 and 8-9 in meters. The wave spectrum is divided into 10 intervals. Wind wave heights lower than 0.3 meters is treated as calm and the calm percentage is indicated at the lower right corner of roses separately. The total percentage of petals of the rose makes 100% minus the calm percentage similar to the wind roses. If the user interval input cannot define the highest occurrence of the wave height, then the software automatically set the highest interval to that value.

The generation procedure for wind and wave roses are similar. The prepared data files are directly used as input to WWIA-SIM 2.2 at this step. These files were divided according to location covering all data period. By pressing “Analyze with Graphics” button, software creates all the roses.

On the roses only the cardinal directions are given. The calm data frequency is indicated at the lower right corner of each rose as “calms” in percent. The corresponding season of the roses are indicated. The color scale and wind and wave classes are kept constant through all locations. For the sake of presentation, the seasonal and full year roses are assembled in a single page for every location as given in Chapter 5.

3.3.2 H_s vs. T_m Relation Graphs

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

The H_s vs. T_m relations are given in two pages and the directions are indicated above the graphs. The axis maximum and minimum values are kept constant through the locations to make the comparisons easier. The H_s maximum is 8 meters, Tm maximum is 10 seconds, and the minima are zero.

As in the roses, all the graphs are prepared by the WWIA-SIM 2.2.

3.3.3 Extreme Probability Distribution Graph

The Extreme Probability distribution is a tool for estimating probable wind wave heights for a given return period. In this section, the procedure used in this study for generation of extreme probability distribution graphs are explained.

The data that is used for generation of extreme probability distributions consist of the yearly maximums of wind wave heights. WWIA-SIM 2.2 simply gives all maxima values for each year in a text file prepared for each location folder called as “Sta.txt” and uses an insertion sort algorithm to put values in ascending order. Afterwards, the extreme value probability distributions; Fisher Tippet Type 1 (GODA), Fisher Tippet Type 2 –k=2.5, Fisher Tippet Type 2 –k=3.33, Fisher Tippet Type 2 –k=5.0, Fisher Tippet Type 2 – k=10.0, Weibull – k=0.75, Weibull – k=1.0, Weibull – k=1.4, Weibull – k=2.0, and Old Gumble are computed and plotted by using WWIA-SIM 2.2, automatically. The extreme value probability distribution with highest coefficient of correlation is selected as representative for the location and plotted.

The maximum values for axis are selected the same for every location. The vertical axis in the graphs represents the significant wind wave height in meters and the range is selected as 0 to 10. The horizontal axis shows the non-exceedance probability.

After the data points are set on the graph, WWIA-SIM 2.2 uses its “REGRESS” algorithm based on the least squares method to find the best graphical solution line.

3.3.4 Log-Linear Cumulative Probability Distribution

The log-linear cumulative probability distribution gives a relation between the occurrence probability and a given significant wind wave height. The graph is generally used for estimating the duration of exceedance of a certain wave height. In this section, the method that has been followed in this study for generation of Log-Linear cumulative probability distributions is explained.

The frequency distribution of incoming wind waves is used as input for generation of log-linear cumulative probability distributions. The frequency distribution shows the counts of wind wave occurrences divided according to wind wave heights as used in wind wave roses and from each direction. These frequency distributions are obtained from WWIA-SIM 2.2. WWIA-SIM 2.2 uses its procedures and subroutines to analyze frequency distributions. Then frequency distributions are modified to obtain the cumulative frequency distributions. In the cumulative frequency distribution, every smaller wind wave height interval includes the occurrences observed at higher intervals. In this way, the smallest interval shows the total number of observations excluding calms. Afterwards the significant directions are extracted from the whole frequency distribution table. In addition, an “all directions" case is composed by adding counts for all directions. Then the all directions case and other significant directions are tabulated as cumulative frequency distribution table. Finally, the frequencies are converted to percentages by dividing table cells by total number of occurrences excluding calms. The final cumulative percent frequency distributions are plotted on a logarithmic-linear graph and a logarithmic trend is added to these data.

The horizontal axis in the graphs show probability and the maximum and minimum values are fixed to 1 and 0.0001 for every location. The vertical axis is the significant height of wind waves in meters. The range of vertical axis is arranged so that all locations can easily be compared.

Again, WWIA-SIM 2.2 uses its subroutines to draw the plots. If any direction has data less than 3 to draw, then it is simply rejected. Afterwards, a regression line is drawn by WWIA-SIM 2.2 using least squares method.

CHAPTER 4

RESULTS

In this chapter results of the analysis for each location are given. As described in detail in the 3rd Chapter, there are 9 locations along the Black Sea, Aegean and the Mediterranean Sea encompassing Turkish coasts. For each location firstly a brief description of location is given and following this description analysis results are discussed based on graphics provided.

The results of each location are given in a sub-chapter and follow an order starting from east-most location on Mediterranean following the coastline of Türkiye. Geographical coordinates of the locations are also indicated. In addition, the location is approximately shown by a star on the Black Sea, Aegean and the Mediterranean Sea map given with the graphs. Inside the sub-chapters, the graphics provided from analysis results are given in the following order; Wind Roses, Wind Wave Roses, Significant Wave Height (Hs) vs. Mean Wave Period (Tm) Relations, Extreme value probability statistics and Log-linear cumulative probability distribution for Wind Waves and Swell Waves Roses, Significant Wave Height (Hs) vs. Mean Wave Period (Tm) Relations, Extreme value probability statistics and Log-linear cumulative probability distribution for Swell Waves. Detailed descriptions of generation of these graphs are explained in section 3.3 Data Analysis and Presentation.

The wind and wind and swell waves roses carry important information such as dominant directions, calm durations, and range of observed magnitudes with occurrence probability and seasonal changes of these parameters. The relations of significant height and mean period of wind and swell waves show all available data for all considerable directions along with the maximum values. The distributions of extreme probability and log-linear cumulative probability are useful for analysis purposes.

The wind and wind and swell wave roses plotted by WWIA-SIM 2.2 show the yearly and seasonal distribution of occurrence probability and magnitude of incoming winds or wind and swell waves respectively. Roses are divided into 16 geographical directions. The directions are indicated on roses as N (North), NNW (North-Northwest), NW (North-West) etc. Every direction counts for a total of 22.5° (degrees) segment. The percentile distribution is scaled on the roses. The magnitude of the parameter can be seen from the color scale on the figure. The scale starts from a non-zero value. Magnitudes below that minimum value are regarded as "calm" values. The percentage of calm duration is indicated at right-bottom of each rose. The roses are given for full year and for all seasons separately.

Wind roses are related to wind speed, which is given as wind speed 10 meters above the sea, i.e. U10 in meters/second. For wind roses, magnitude scale is from 3 m/s to 17.5 m/s. Minimum wind speed is 3 m/s, below that level the wind state is regarded as calm. In the discussions of each results section comparisons with Özhan and Abdalla, 1999 are given. Since this study and the study Özhan and Abdalla, 1999 are based on different data sources the differences may be expected. In the case of using these results in any future engineering applications, the user must perform his/her own analysis procedure with the new available wind data and perform further comparisons between the results given in these studies and also his/her and other available result. Besides, the software prepared for this thesis study provides a very time saving tool. Any update in the database can simply be updated by just a few clicks.

Wind and swell waves are related to significant height of wind and swell wave in meters. For wind and swell waves magnitude scale is from 0.5 m to 12 m. Minimum wind and swell wave height is 0.5 m, below that level wind wave state is regarded as calm.

Roses are followed by Significant Wave Height (H_s) vs. Mean Wave Period (T_m) Relation Graphs. In this graph, the horizontal axis represents significant height of wind and swell waves (H_s) in meters and the vertical axis represents mean period of wind and swell waves (T_m) in seconds. Every graph is created by WWIA-SIM 2.2. WWIA-SIM 2.2 defines the graphs upper and lower limits automatically. In these graphs, every dot relates to a wind and swell wave data, plotted according to its H_s (m) and T_m (s) respective to wind and swell wave-incoming direction. All directions are given for the detailed comparisons. These graphs can be used to relate wind and swell wave height to wind and swell wave period. In addition, these graphs show the general distribution of wind and swell waves according to their directions.

Extreme value probability statistics graph plotted by WWIA-SIM 2.2 follows the H_s vs. T_m graph. Yearly maximum values for significant wave height of swell and wind waves are plotted on extreme value graph, as the distribution of yearly maximums is assumed to be fitting Gumbel distribution. In this graph, horizontal axis represents percent non-exceedance probability, and vertical axis represents significant wave height of swell or wind waves in meters. Best line is fit to these data values and the best line is elongated. Using this graph expected significant wave height can be obtained for reasonable return periods.

Log-linear cumulative probability distribution follows the extreme value probability graph. WWIA-SIM 2.2 plots all directions' points, if the direction has at least three (3) points to be analyzed. In this graph, horizontal axis represents occurrence probability and the vertical axis represents significant wind and swell wave height in meters. As the name of the graph implies the horizontal axis is in logarithmic scale. The log-linear cumulative distribution graph is useful for estimating the duration of exceedance of a certain wave height. The orientation of the data points in the graph should be close to a line ideally. However, because of limited data the exact linear distribution cannot be observed.

Results relate to data covering all year of analysis duration, i.e. 166 months, as described in the 3rd Chapter. However, some locations have less data. Also extreme value probability graph is not given for these locations because of lack of data. Details on extreme value probability graphs are also given in the 3rd Chapter.

4.1 LOCATION – ANAMUR (36.10 N 32.04 E)

A point at the offshore location near Anamur is selected at coordinates 36.10 N 32.04 E (at 46x13 grid nodes). The point is approximately 15 km east of Anamur Burnu and 3 km west of Bozyazi about 22 km away from the shoreline.

Following figures given in this section are the results of the analysis of wind, wind wave and swell wave analysis for Anamur region.

Wind roses given in Figure 4.1.1 show that Anamur is subject to mainly E, W and WNW winds during a year. Moreover during winter period E and ESE winds dominates. In winter wind speed rise up to 13 m/s from east.

Wind wave roses given in Figure 4.1.2 show directional distribution and height of incoming wind waves. It is seen from the graphs that 3% of the time wind waves are coming from E, 2.9% of the time wind waves are coming from W, 2.3% of the time wind waves are coming from WSW directions in a year. Additionally, E directed wind waves' percentile reaches up to 8.9% in winter period. The maximum wind wave height is 3.8 meters from the direction of WSW.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.1.3. From this figure the steepness of wind waves in the region representing all years from all directions is computed as 0,039 for the wave height greater than 1 m in deep water. Wind wave domination from directions E and WSW can be seen from these figures. Throughout the observation period wind waves are observed to be less than 4 m at offshore

Anamur. Maximum significant wave height is observed form WSW and height is observed to be 3.7 meters. The corresponding wave period is 8.3 s.

The graph of extreme value probability statistics is given in Figure 4.1.4. Data values show high correlation. Significant wind wave height for 30 years is estimated as 4.5 m in this region according to the duration of analyzed data.

Figure 4.1.5 shows log-linear cumulative probability distribution of wind waves for Anamur region. The figure is drawn to present dominant directions individually and all directions' data as whole. It is seen from this graph that significant height of wind waves in deep water exceeds 2.6 meters in about 10 hours duration every year.

Figure 4.1.6 shows swell wave rose. The roses show a clear indication of direction of incoming swell waves. As expected from the geographic location of Anamur, swell waves from WSW and W direction are dominant with respect to other directions. Swell waves from direction WSW are observed almost 45.2% of a year and nearly 13 % of the time swell waves are coming from W direction. In summer percentile of swell wave from WSW direction increases up to 61.1%. The maximum swell wave height is 3.6 meters. The period of some waves becomes higher than 11 seconds reaching up to 12 seconds for some waves.

The relations between Significant Wave Height (H_s) vs. Mean Wave Period (T_m) are given in Figure 4.1.7. Swell wave domination from directions WSW and W can be observed from these graphs. A rather more scattered distribution is observed in SW direction. Several data points, exceeding 10 second periods and few data points exceeding 3.0 m of swell wave heights are observed from WSW direction with a maximum wave height of 3.4 m. Swell waves having 11 seconds periods can be observed from W, WSW directions.

The graph of extreme value probability statistics is given in Figure 4.1.8. Data values show a good correlation. Significant wave height is estimated as 3.9 m for 30 year return period.

Log-linear cumulative probability distribution for swell waves is given in Figure 4.1.9. Two dominating directions, namely WSW and W are plotted along with all directions. It is seen from the graph that significant height of swell waves exceeds 2.6 meters in about 10 hours duration every year.

Following graphs given in this section are the results of the data analysis for Anamur.

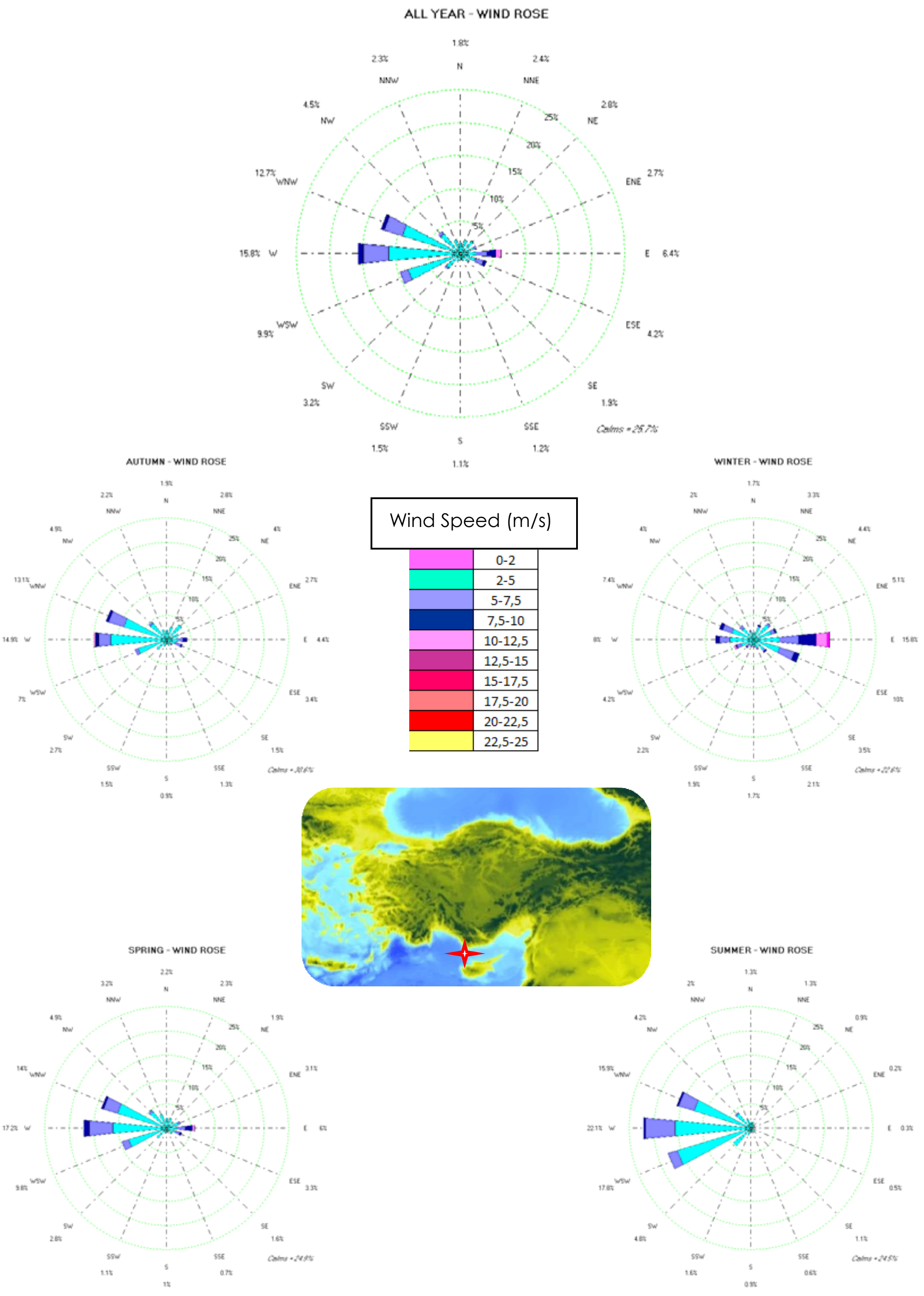


Figure 4.1.1 Wind Climate at Anamur

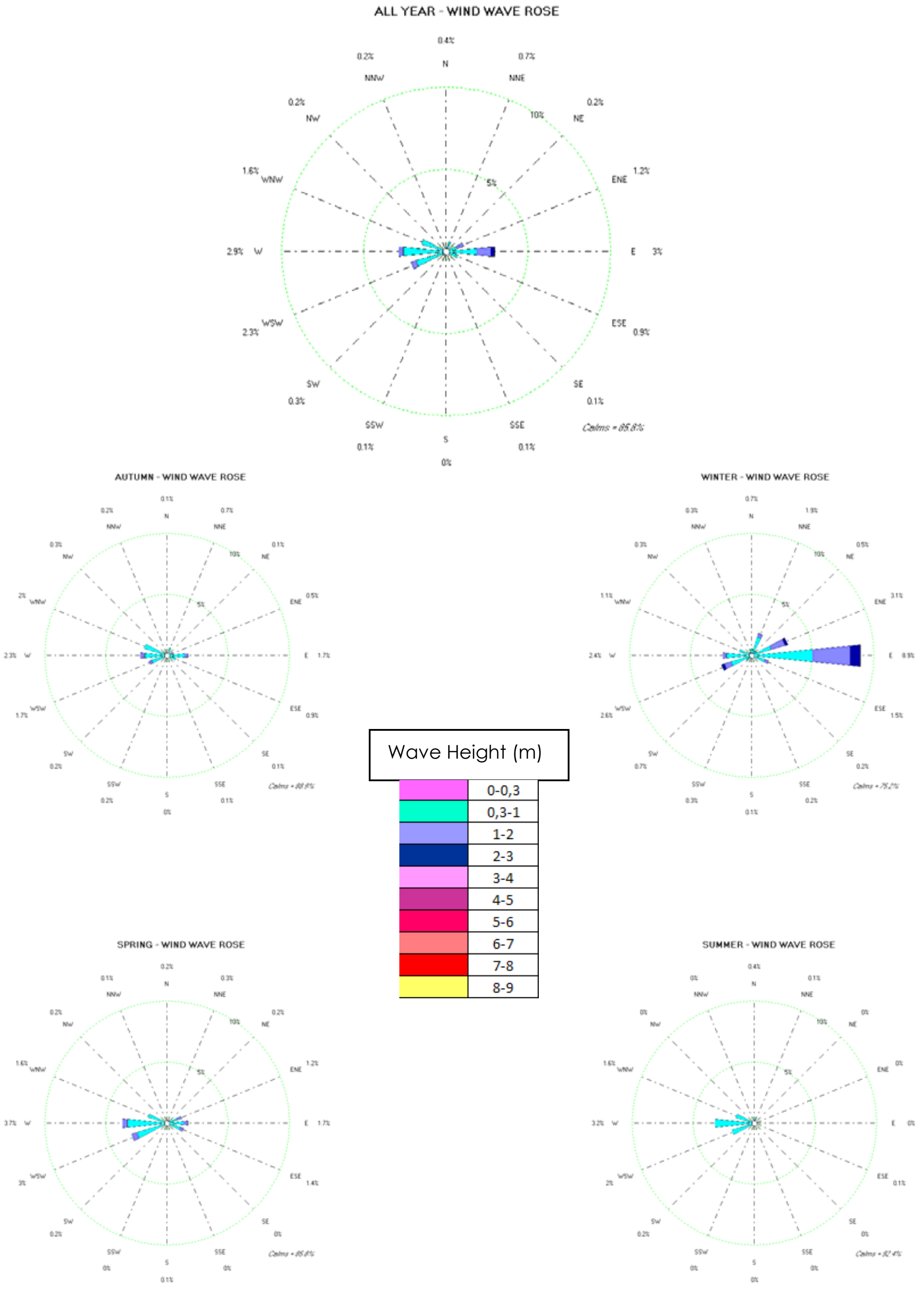


Figure 4.1.2 Wind Wave Climate at Anamur

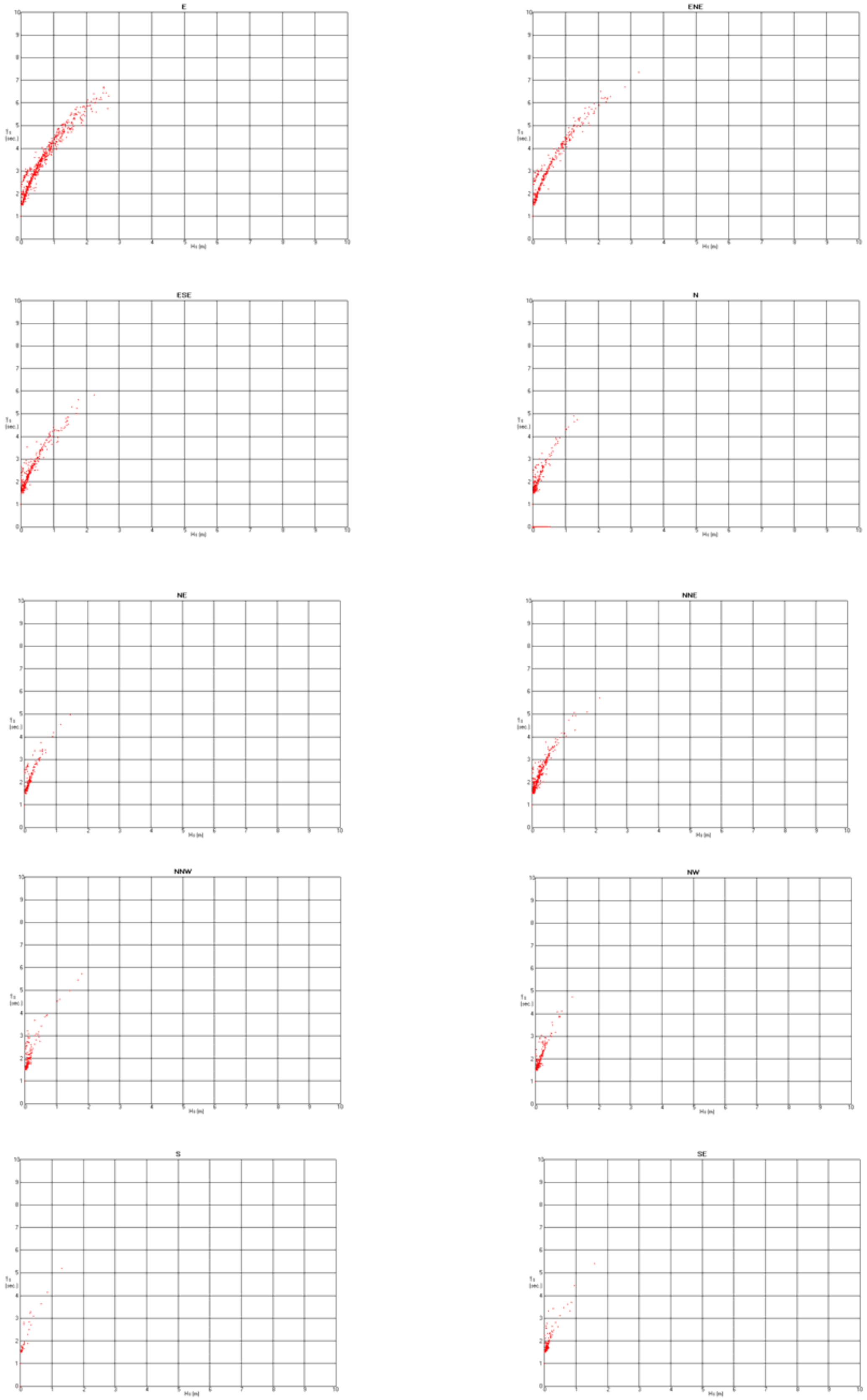


Figure 4.1.3 Relationship between MPWW & SHWW at Anamur

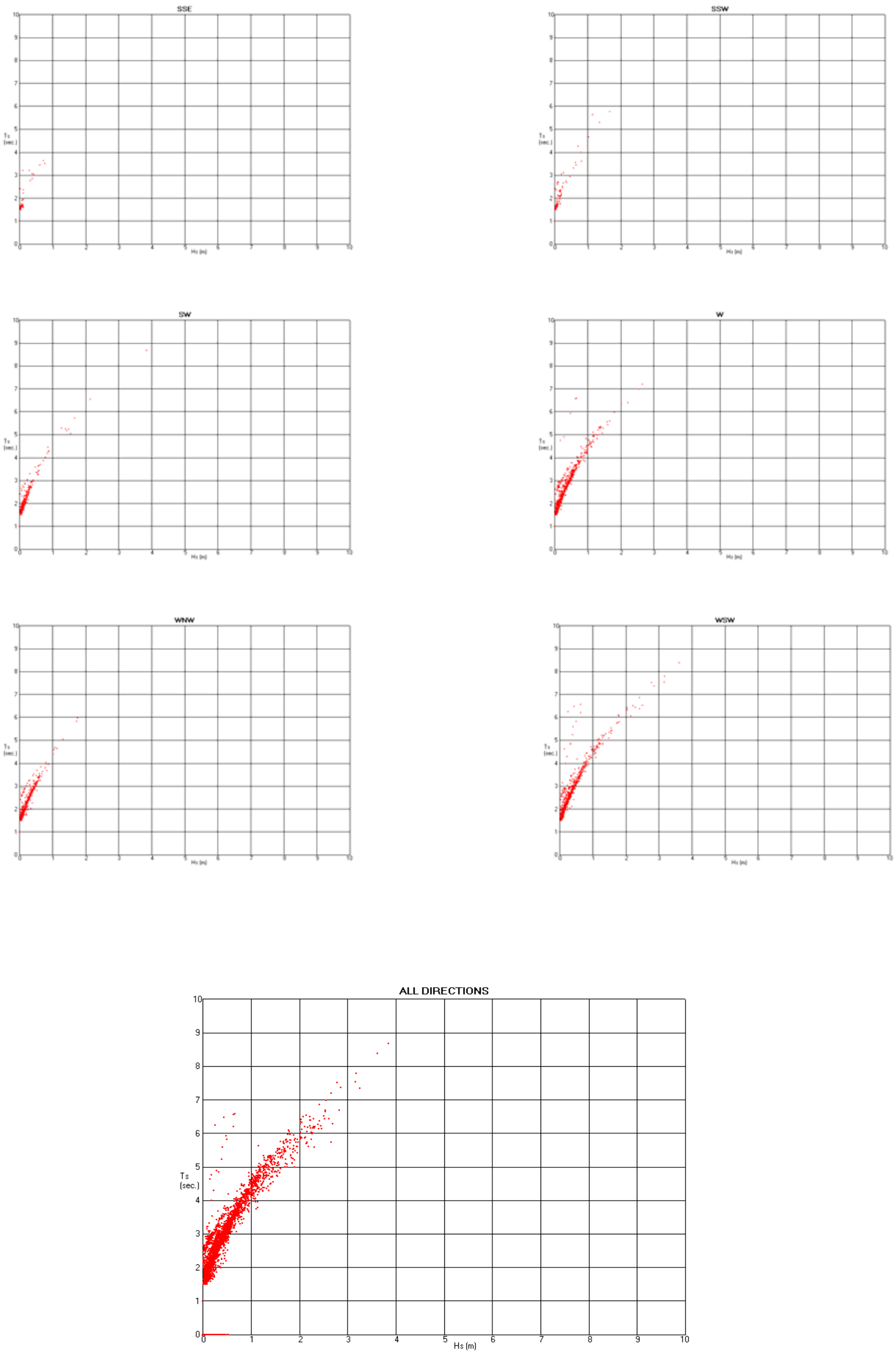


Figure 4.1.3 Relationship between MPWW & SHWW at Anamur
(continued)

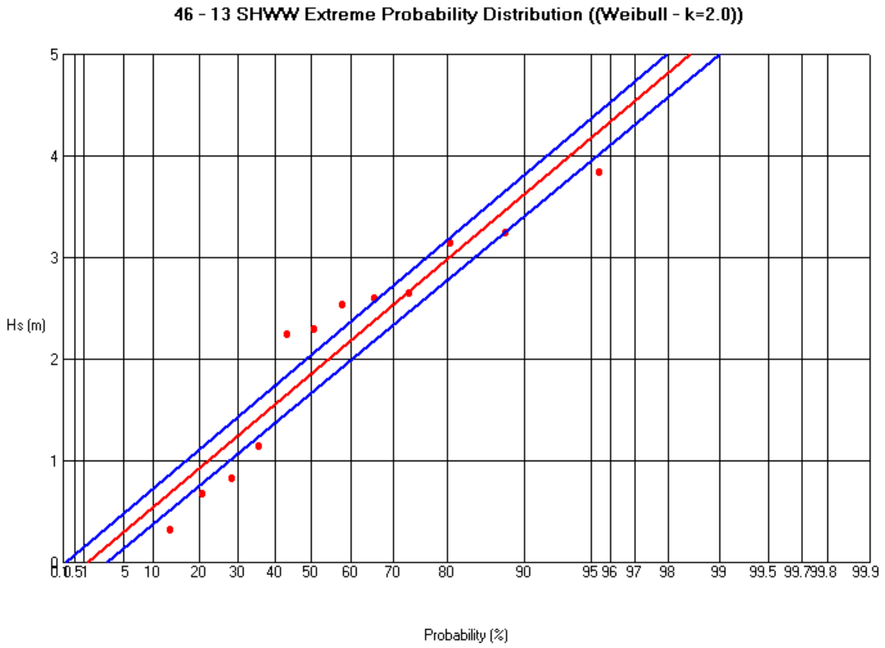


Figure 4.1.4 Extreme Probability Distribution of SHWW at Anamur

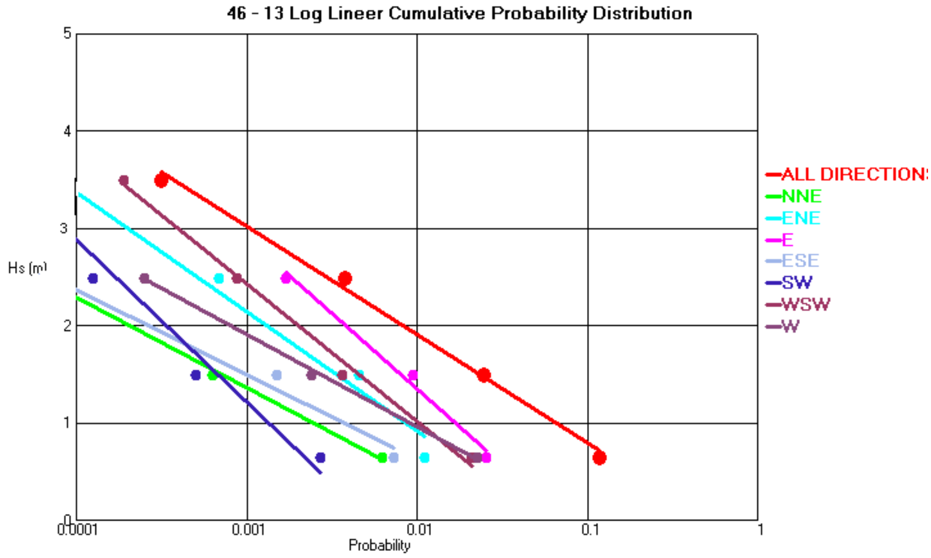


Figure 4.1.5 Log-lineer Cumulative Probability Distribution SHWW at Anamur

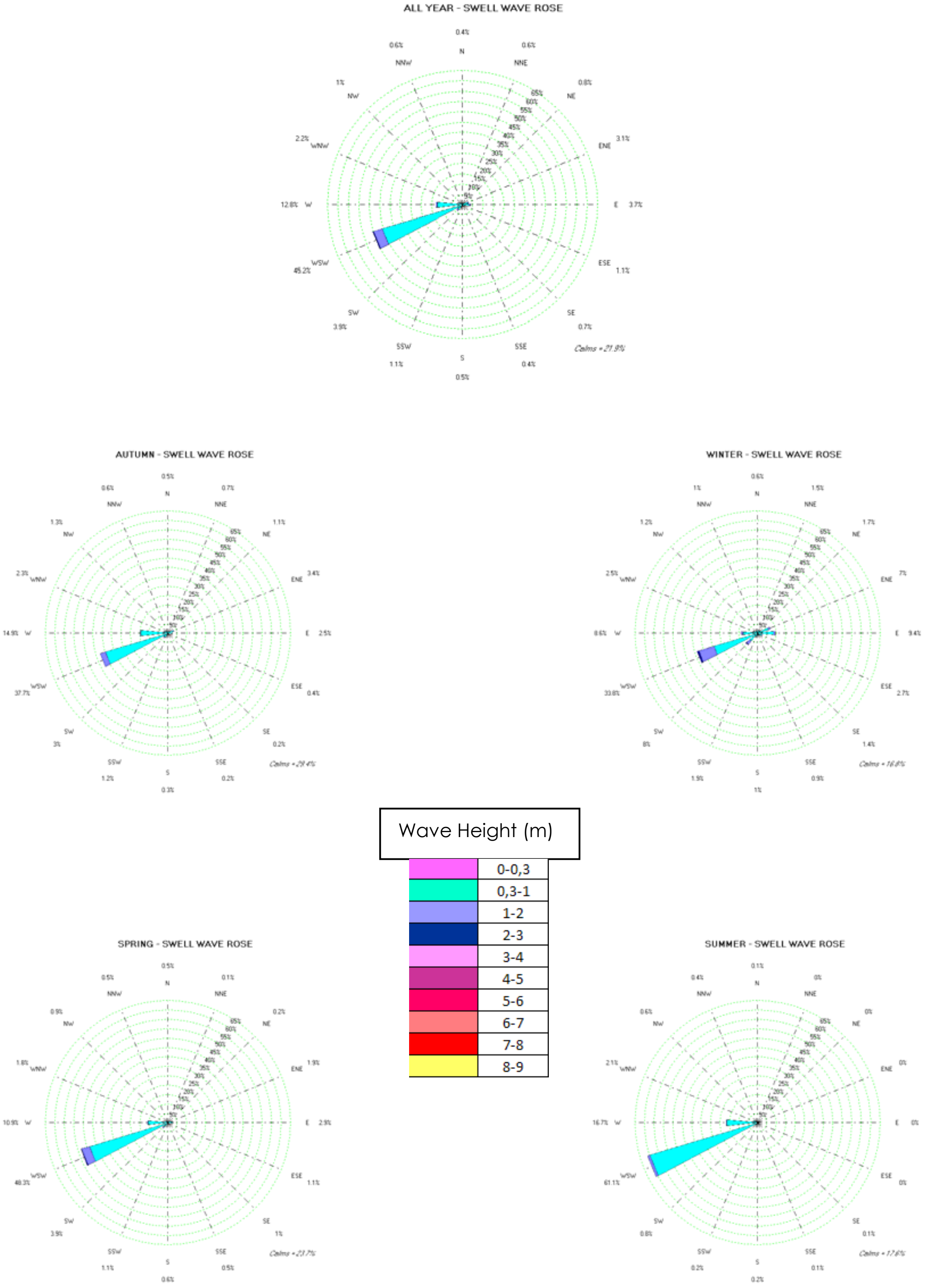


Figure 4.1.6 Swell Wave Climate at Anamur

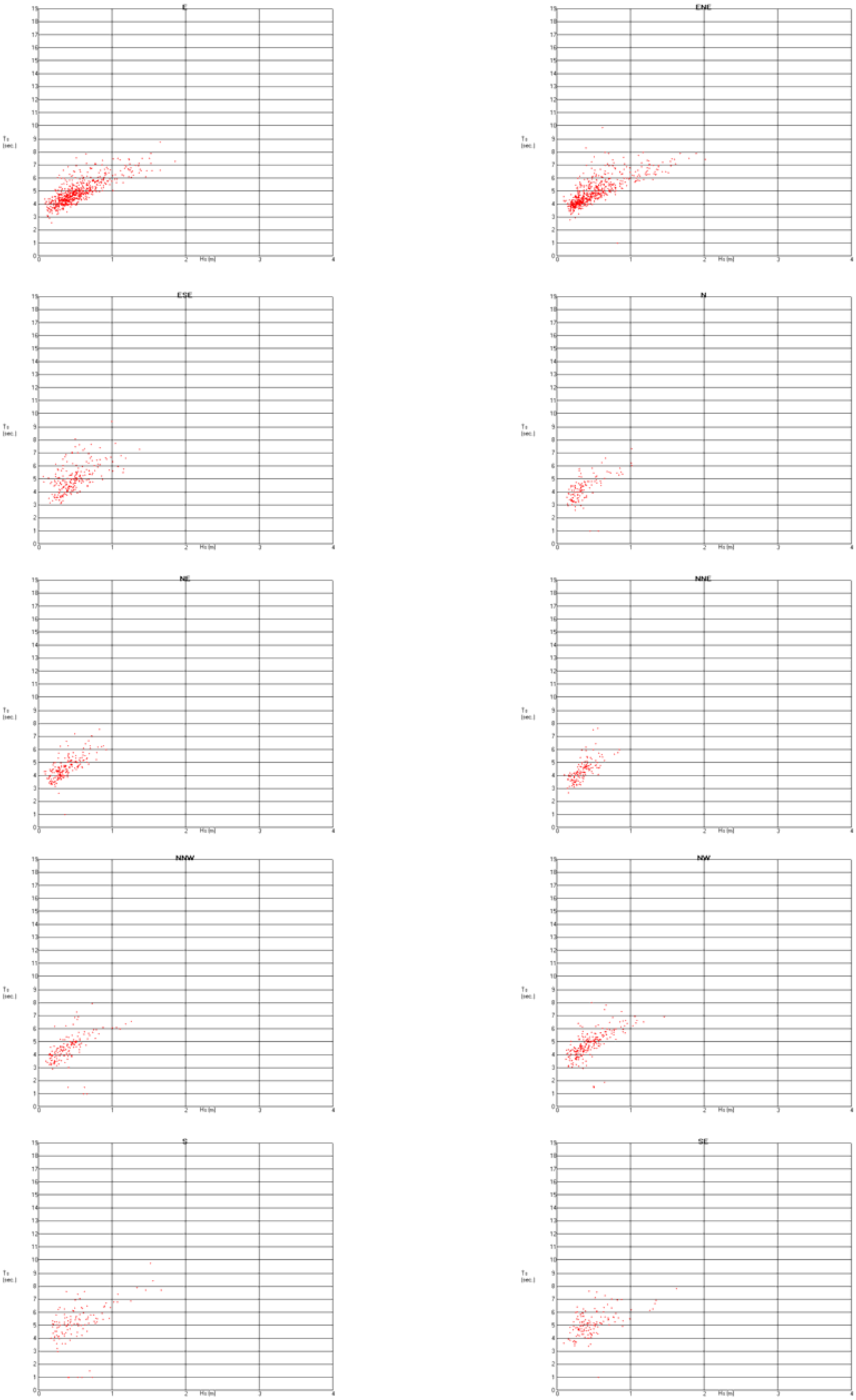


Figure 4.1.7 Relationship Between MPPS and SHPS at Anamur

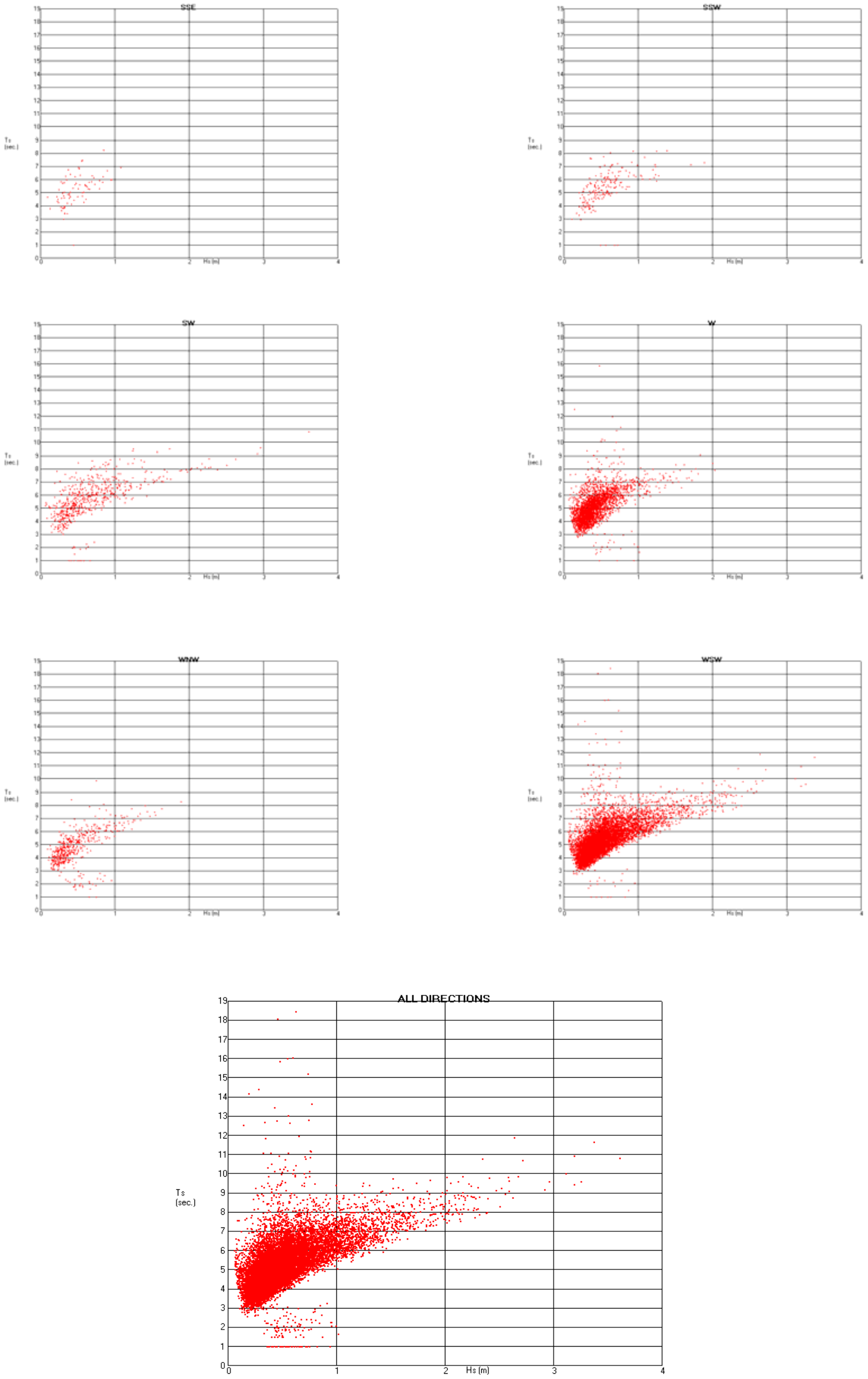


Figure 4.1.7 Relationship Between MPPS and SHPS at Anamur (continued)

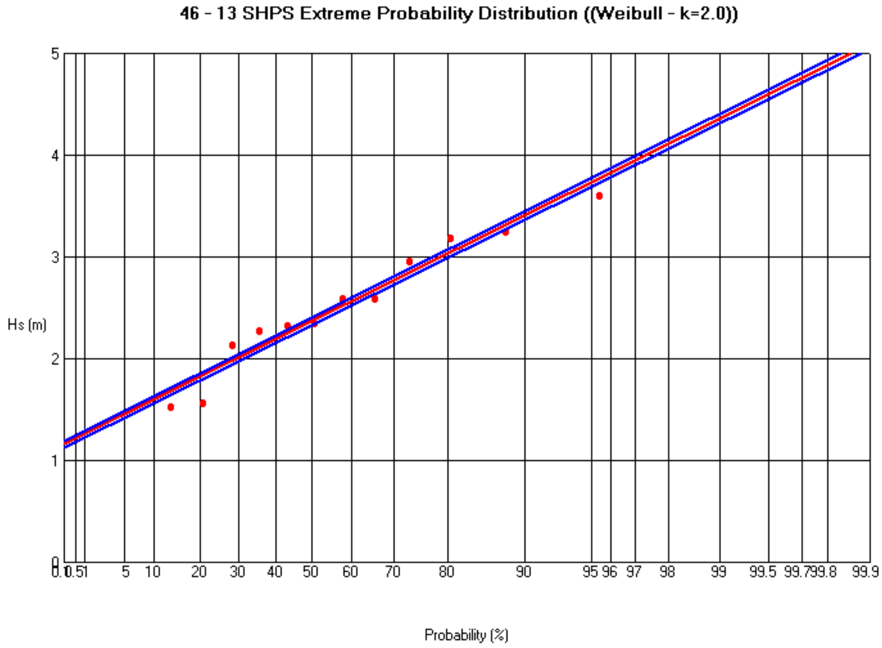


Figure 4.1.8 Extreme Probability Distribution of SHPS atAnamur

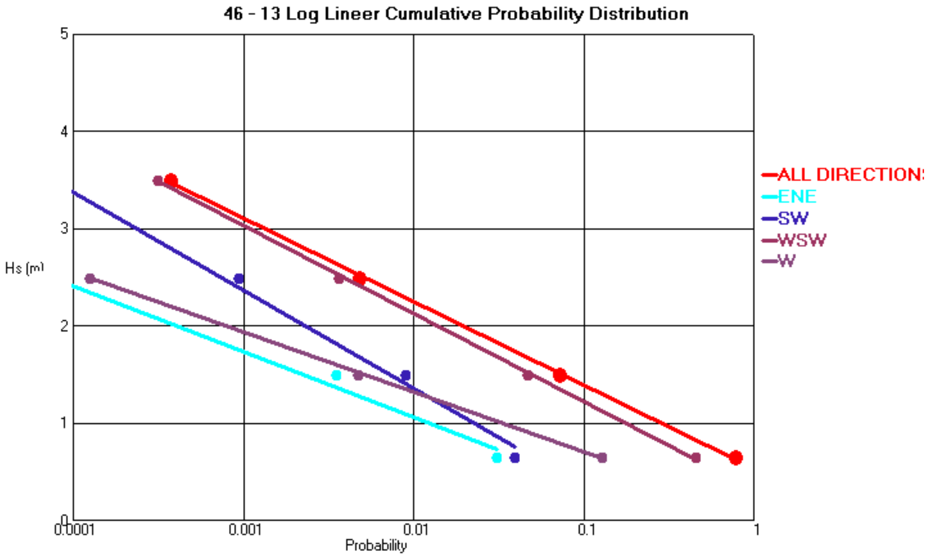


Figure 4.1.9 Log-lineer Cumulative Probability Distribution of SHPS at Anamur

4.2 LOCATION –KAŞ (36.19 N 29.64 E)

A point at the offshore location near Kaş is selected at coordinates 36.19 N 29.64 E (at 39x13 grid nodes). The point is located at approximately 120 km west of Antalya, about 1 km away from shoreline.

Following figures given in this section are the results of the analysis of wind, wind wave and swell wave analysis for Kaş region.

Wind roses given in Figure 4.2.1 show that the location analyzed near Kaş is subject to mainly NW, WNW, NNW, ESE and SE winds during a year. During summer period WNW winds dominates in number of occurrence with a percentile of 33.9 % of time. In spring, however, highest wind speed of about 13.5 m/s is observed from ESE.

Wind wave roses given in Figure 4.2.2 show the directional distribution and height of incoming wind waves. It is seen from the graphs that 12.6% of the time wind waves are coming from WNW, 9.1% of the time wind waves are coming from NW to the point of investigation in a year. During winter period ESE directed wind waves' percentile reaches up to 8.7%. The maximum wind wave height is 3.5 m form ESE.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.2.3. From this figure the steepness of wind waves in the region representing all years from all directions is computed as 0,048 for the wave height greater than 1 meter in deep water. Wind wave domination from directions ESE, NW and WNW can be seen from these figures. The maximum wind wave height is observed from WNW direction with a height of 4.2 meters from the data analyzed. The corresponding wave period is 8.0 seconds. Throughout the observation period wind waves are observed to be generally less than 3 m at the studied location near Kaş.

The graph of extreme value probability statistics is given in Figure 4.2.4. Data values show high correlation. Significant wind wave height is estimated as

4.40 m for 30 year return period in this region according to the analyzed data.

Figure 4.2.5 log-linear cumulative probability distribution of wind waves for Kaş region. The figure is drawn to present dominant directions individually and all directions' data as whole. It is seen from this graph that significant height of wind waves exceeds 3.2 meters in about 10 hours duration every year.

Figure 4.2.6 shows swell wave roses. The roses show a clear indication of direction of incoming swell waves. As expected from the geographic location of the investigated point near Kaş, swell waves from WSW, WNW and SW directions are dominant with respect to other directions. Swell waves from direction W are also significant. Swell waves from WNW direction are observed 16.1%, from W direction 11.5 % and from WSW direction 10 % of a year. In summer, percentile of swell wave from WNW direction become 30 %. The maximum swell wave height is 3.5 meters. The period corresponding to the maximum swell is 9.5 seconds.

The relations between Significant Wave Height (H_s) vs. Mean Wave Period (T_m) are given in Figure 4.2.7. Swell wave domination from directions WSW, SW, WNW and NW can be observed from these graphs. A rather more scattered distribution is observed in SW and WSW direction. Several data points, exceeding 8 second periods and few data points exceeding 2.0 m of swell wave heights are observed from SW direction with a maximum wave height of 3.2 m. Swell waves having 11 seconds periods can be observed from W and WSW directions.

The graph of extreme value probability statistics is given in Figure 4.2.8. Significant wave height is estimated as 3.9 meters for 30 year return period.

Log-linear cumulative probability distribution for swell waves is given in Figure 4.2.9. Dominating direction, namely SW is plotted along with other directions. It is seen from this graph that significant height of swell waves exceeds 2.57 meters in about 10 hours duration every year.

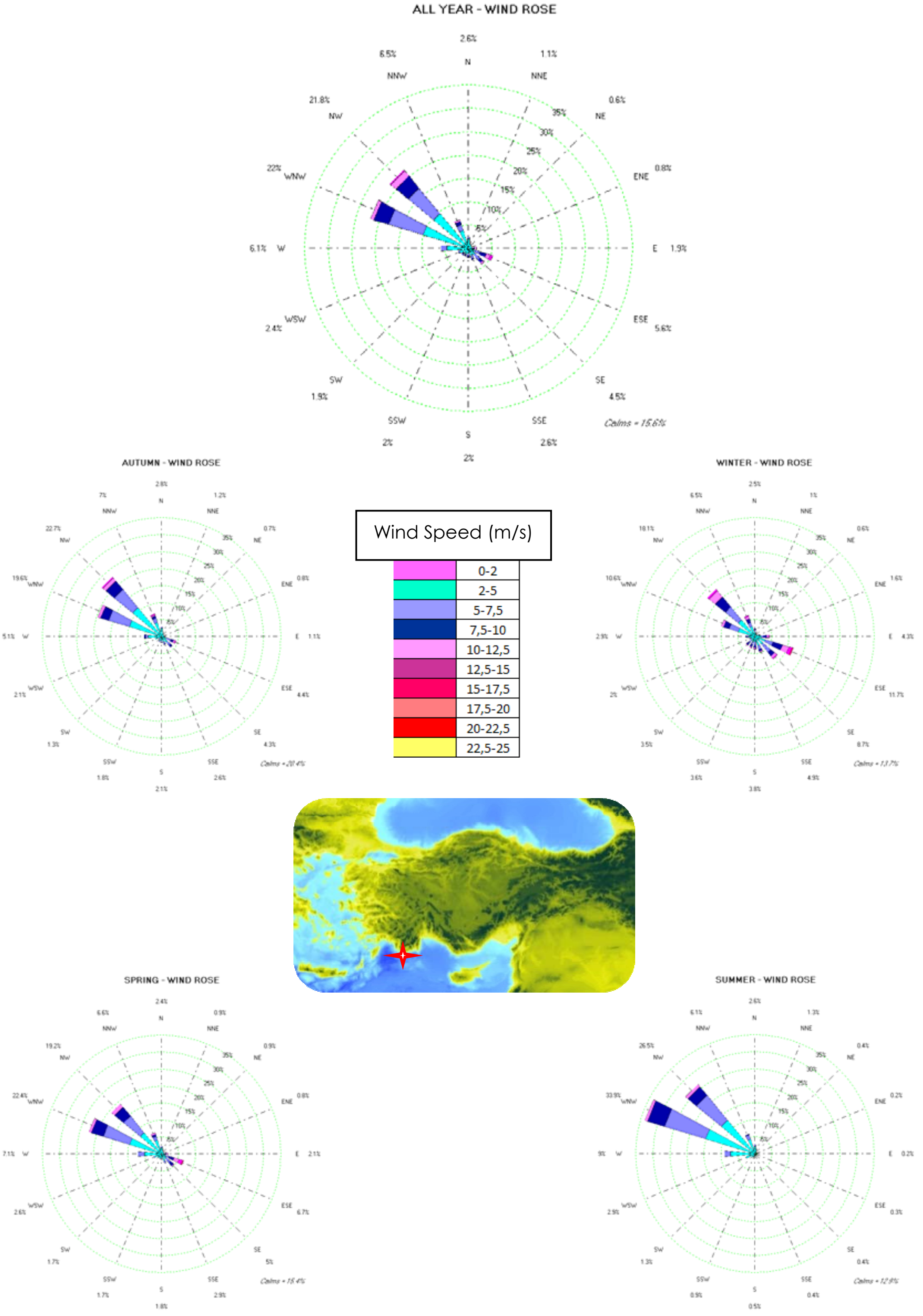


Figure 4.2.1 Wind Climate at Kaş

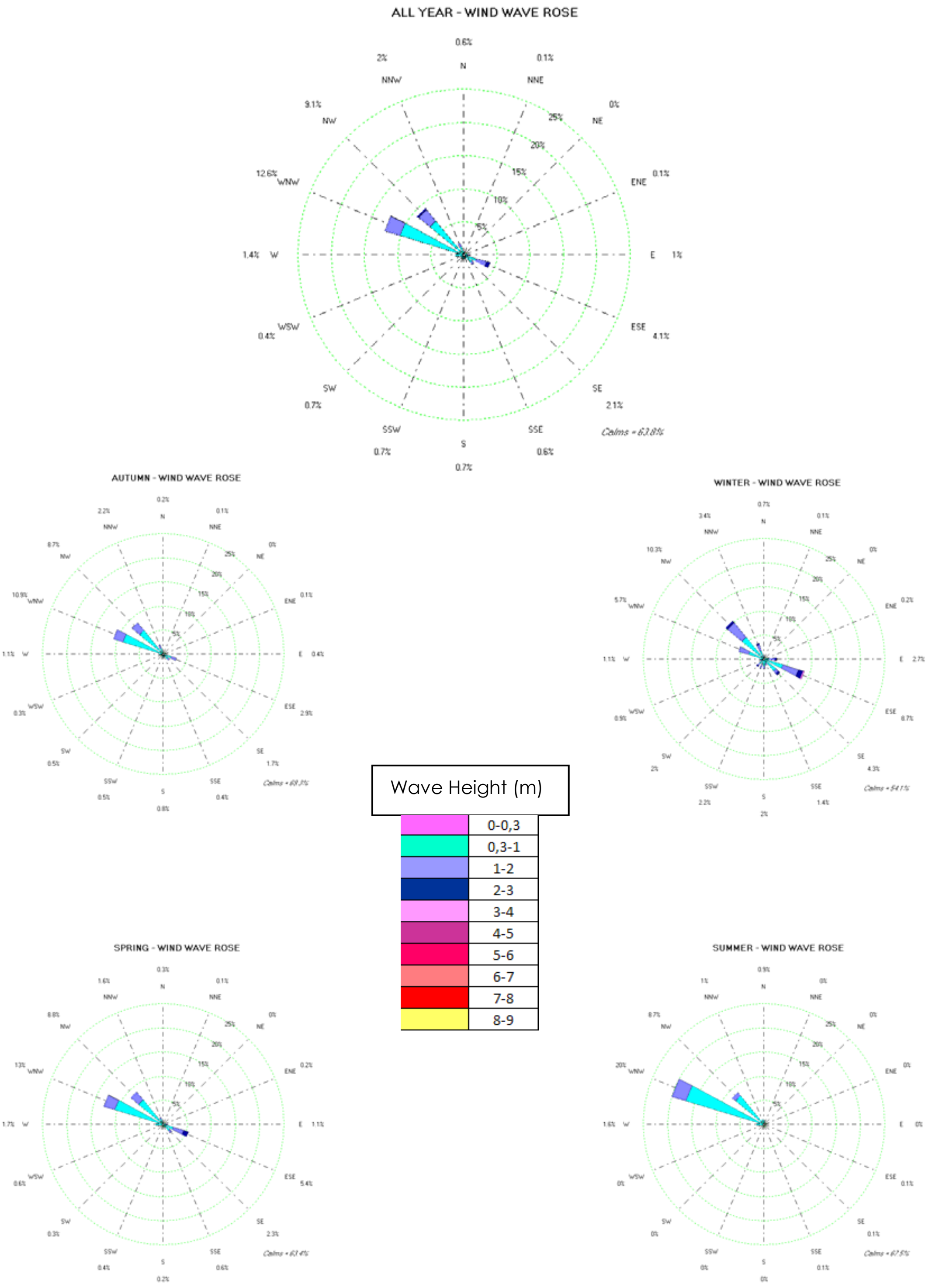


Figure 4.2.2 Wind Wave Climate at Kaş

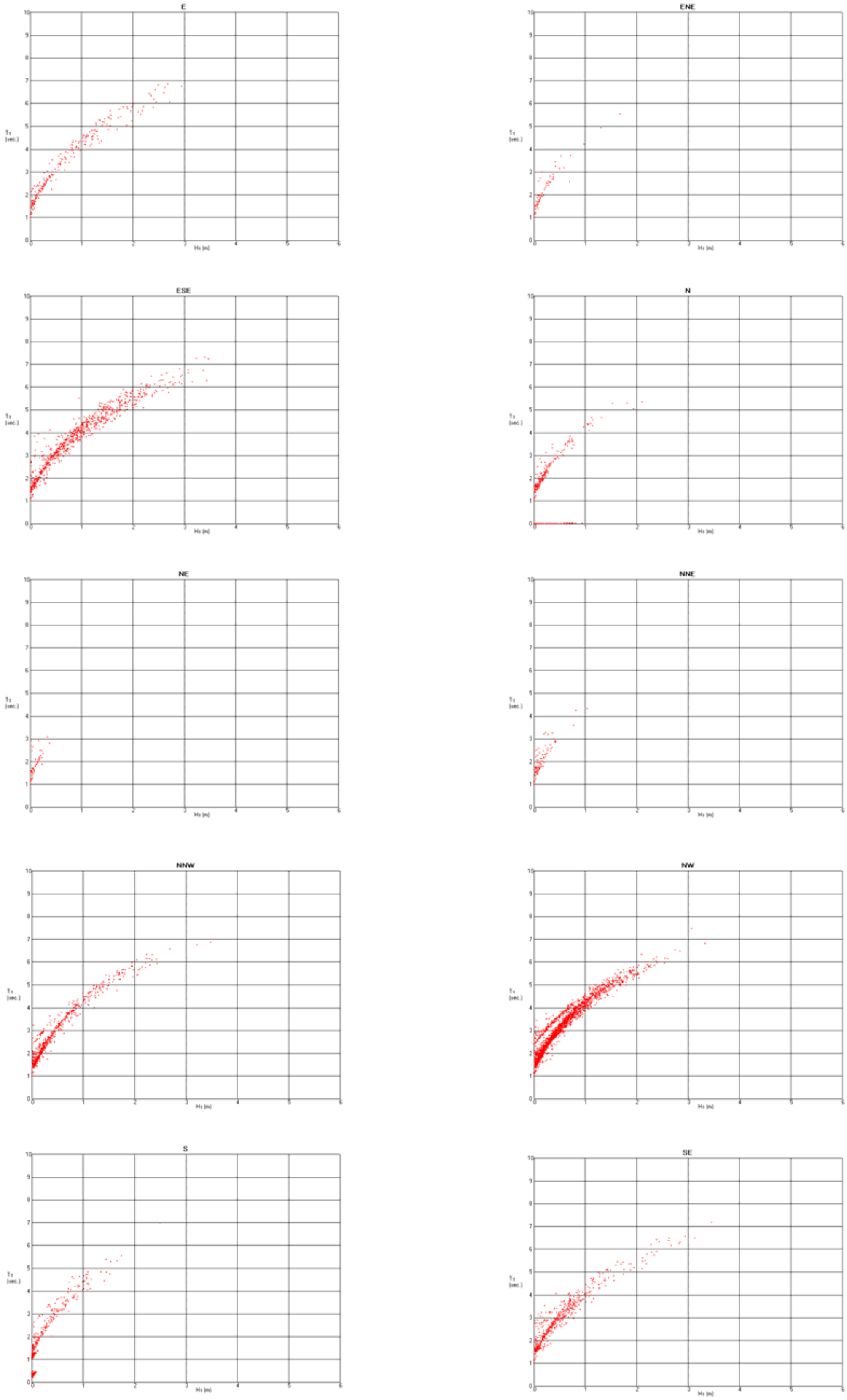


Figure 4.2.3 Relationship between MPWW & SHWW at Kaş

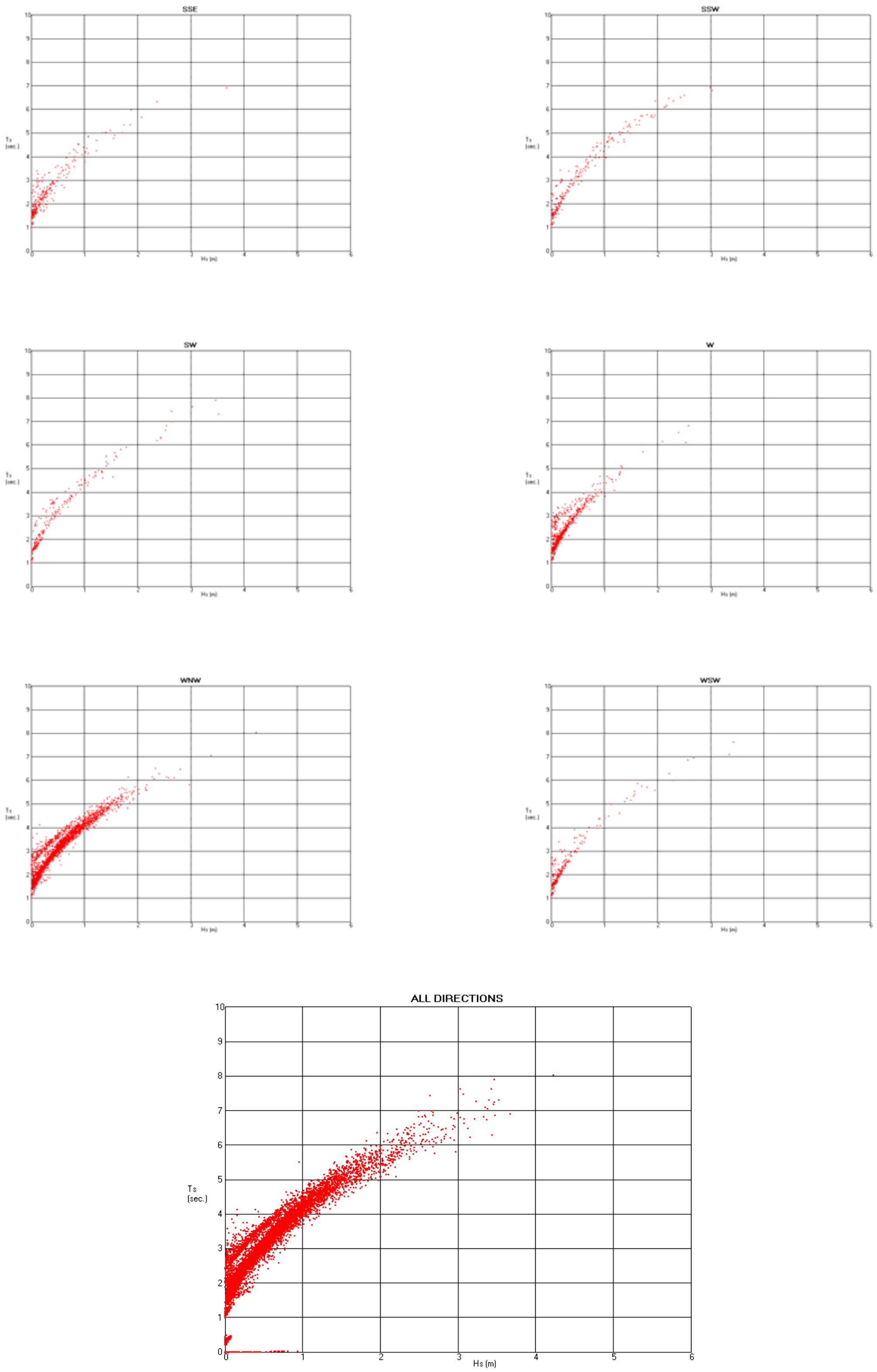


Figure 4.2.3 Relationship between MPWW & SHWW at Kaş (continued)

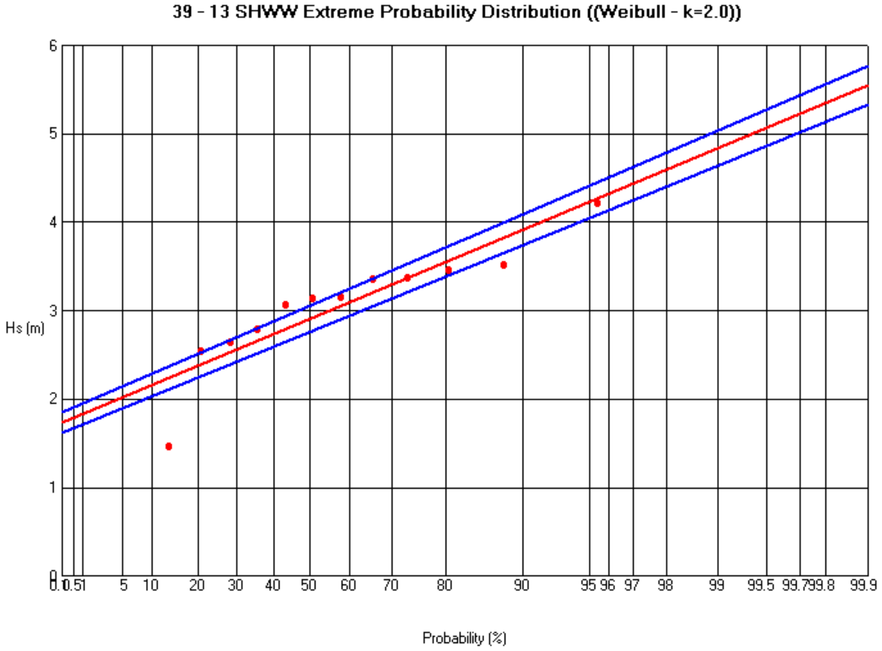


Figure 4.2.4 Extreme Probability Distribution of SHWW at Kaş

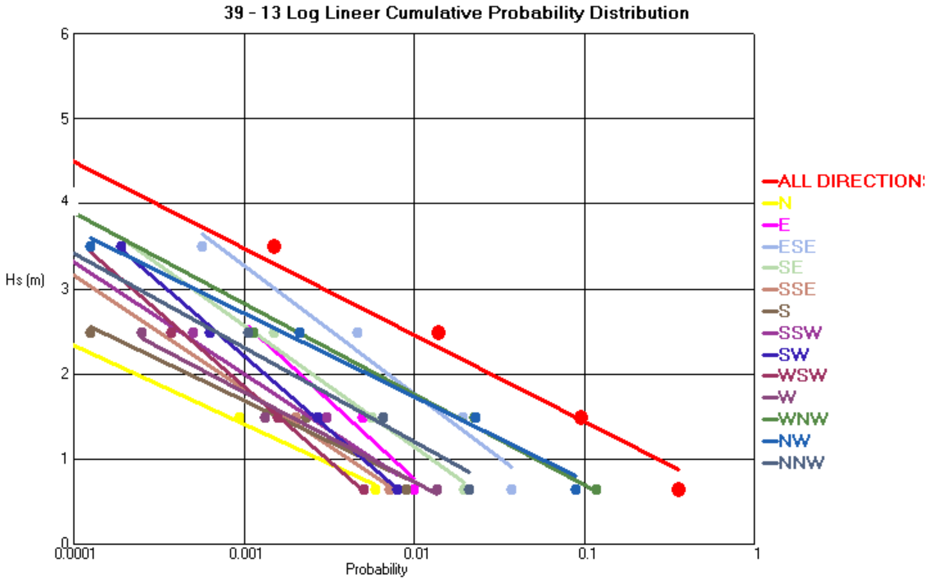


Figure 4.2.5 Log-lineer Cumulative Probability Distribution of SHWW at Kas

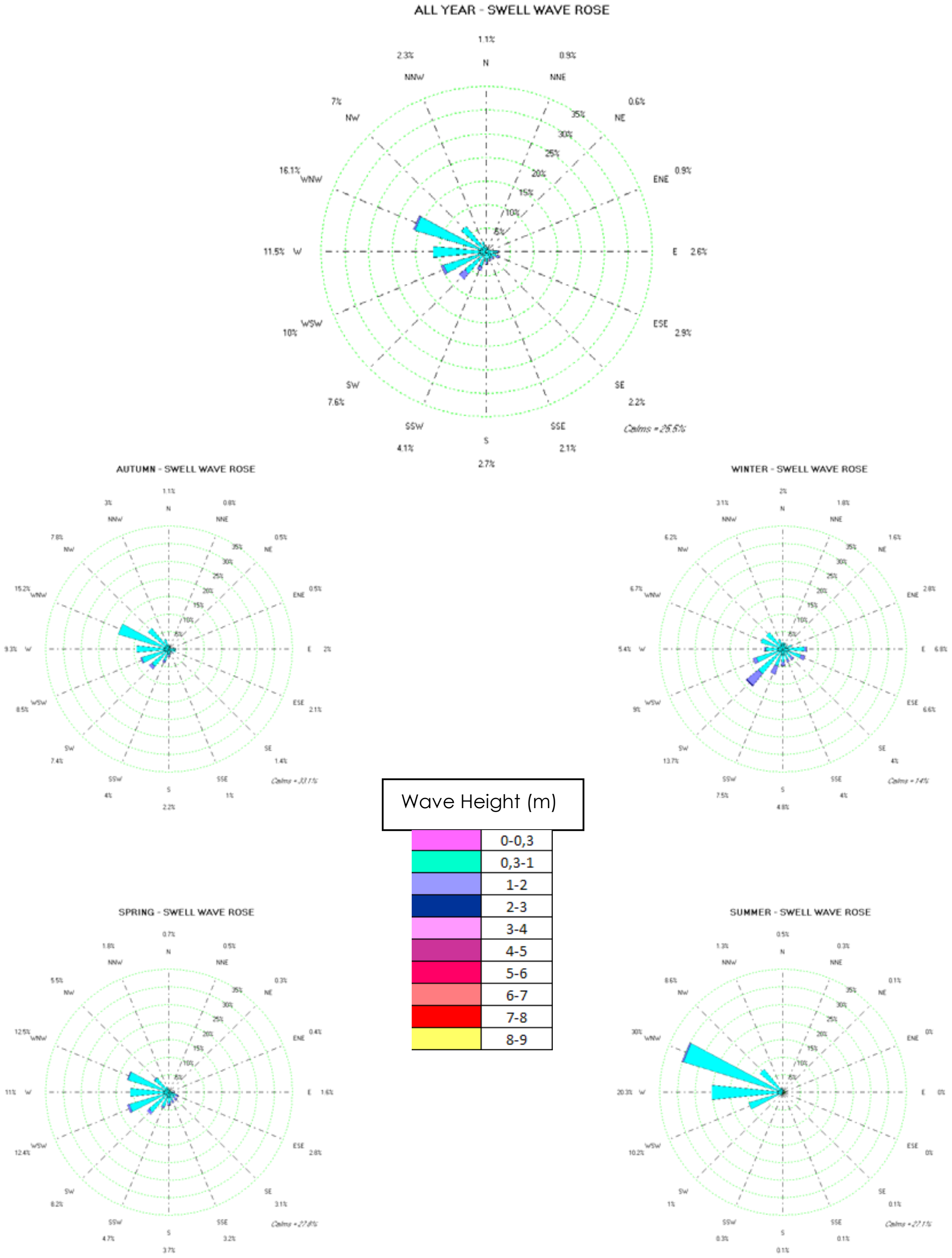


Figure 4.2.6 Swell Wave Climate at Kaş

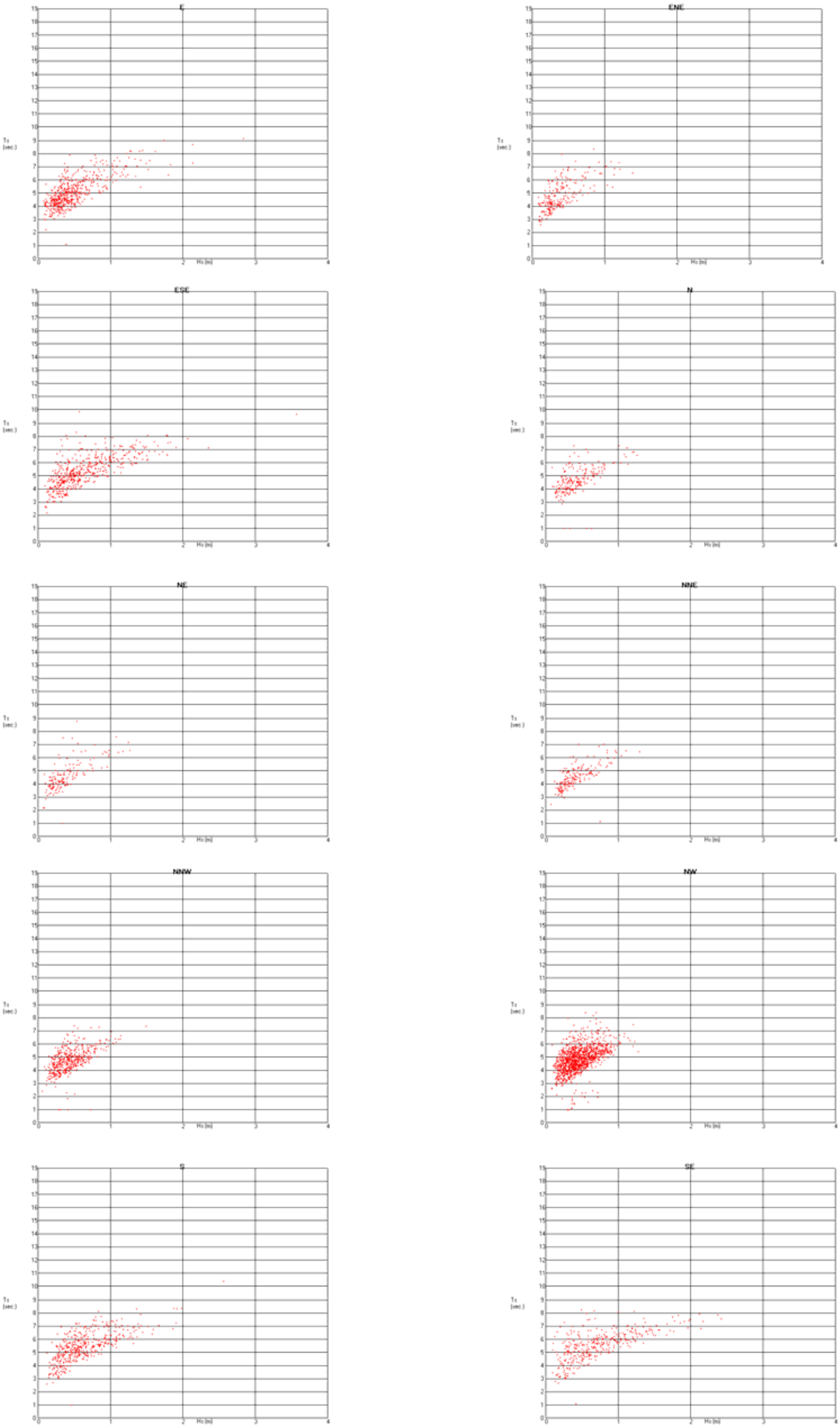


Figure 4.2.7 Relationship Between MPPS and SHPS at Kaş

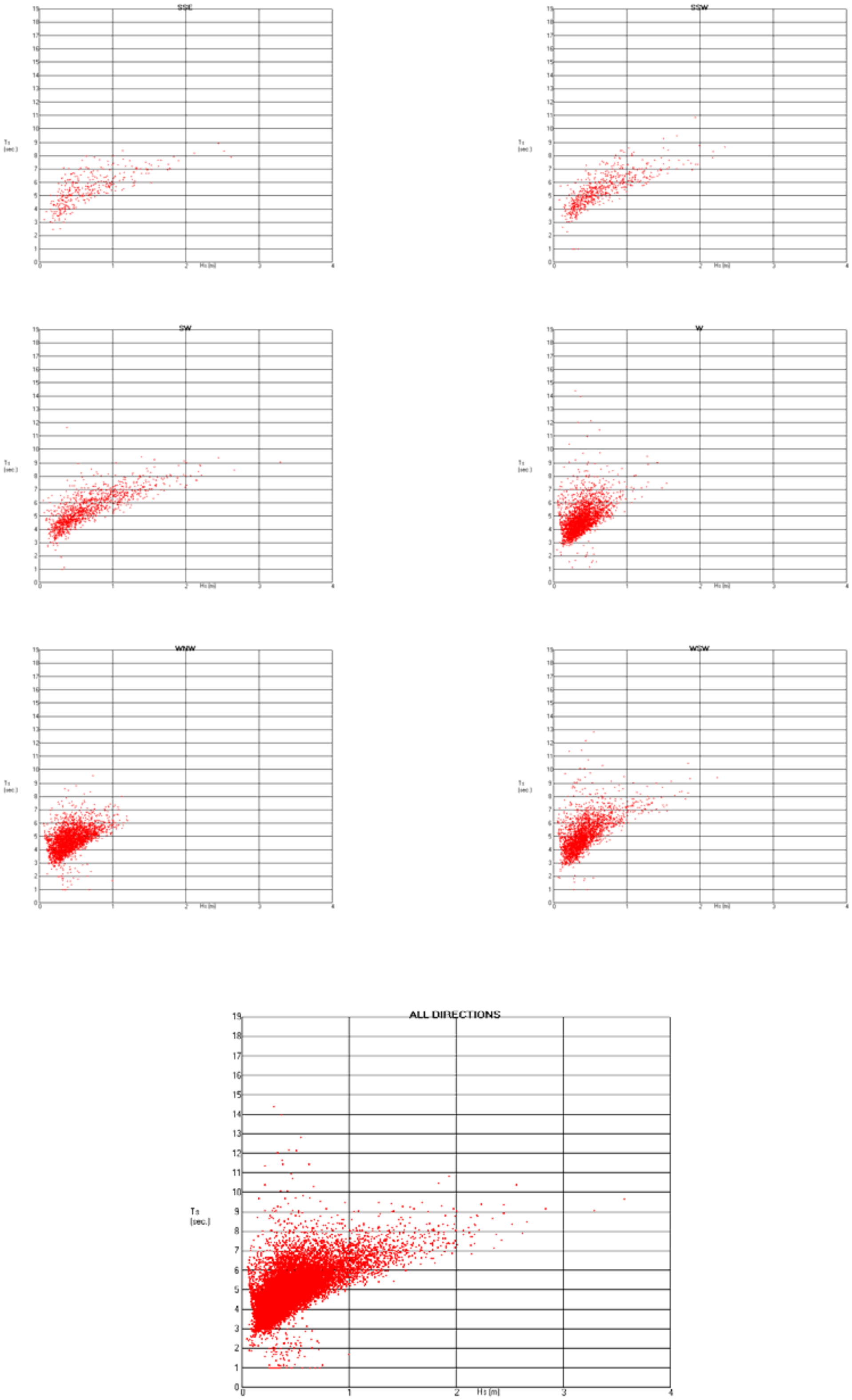


Figure 4.2.7 Relationship Between MPPS and SHPS at Kaş (continued)

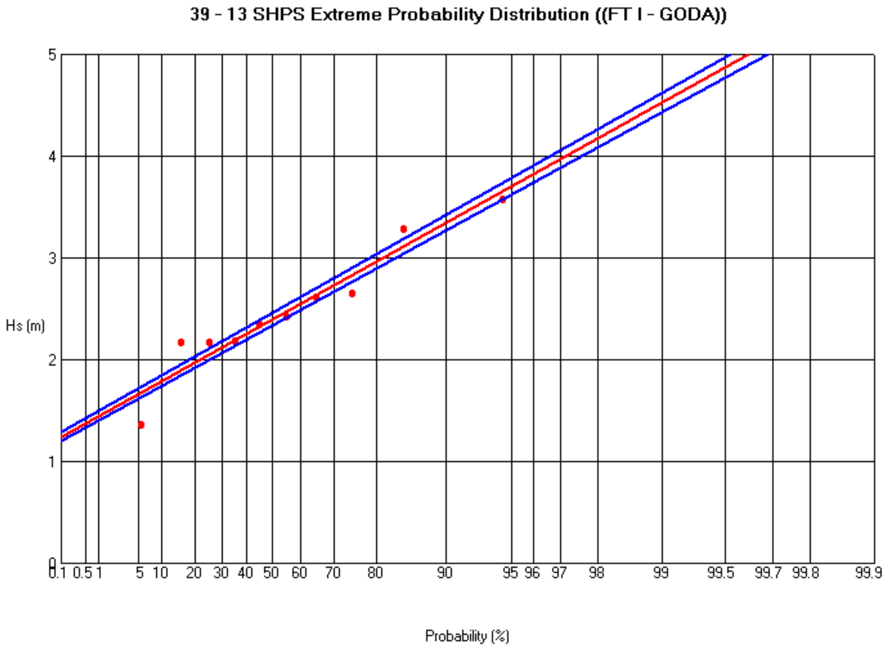


Figure 4.2.8 Extreme Probability Distribution of SHPS at Kaş

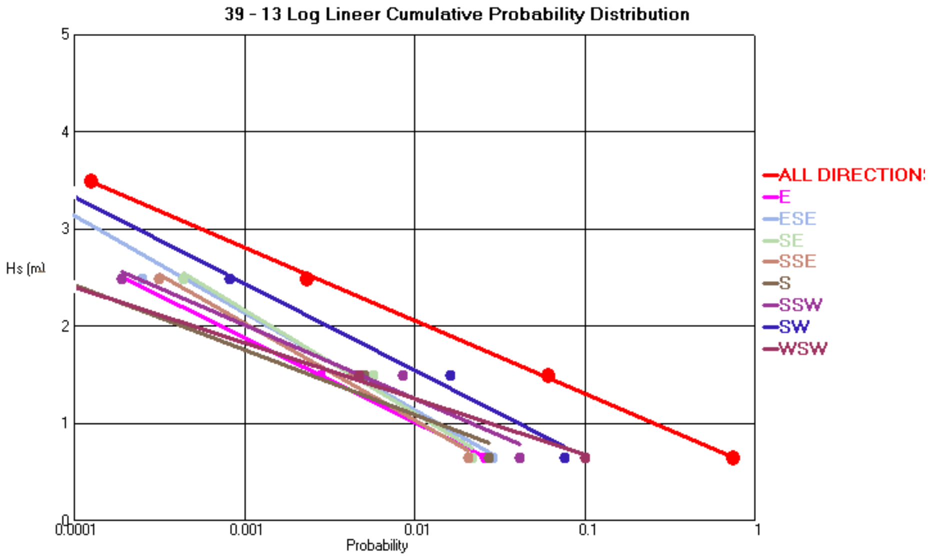


Figure 4.2.9 Log-lineer Cumulative Probability Distribution of SHPS at Kaş

4.3 LOCATION – DATÇA (36.64 N 27.68 E)

A point at the offshore location near Datça is selected at coordinates 36.64 N 27.68 E (at 35x14 grid nodes). The point is located approximately 35 km west of Bozburun 50 km west of Marmaris 3 km away from shoreline.

Following figures given in this section are the results of the analysis of wind, wind wave and swell wave analysis for Datça region.

Wind roses given in Figure 4.3.1 show that the location analyzed near Datça is subject to mainly NNW, NW and N winds during a year. During summer period NNW winds dominates in number of occurrence with a percentile of 34.2 % of time. In winter highest wind speed of about 16 m/s is observed from west.

Wind wave roses given in Figure 4.3.2 show the directional distribution and height of incoming wind waves. It is seen from the graphs that 23.9% of the time wind waves are coming from NNW, 12.5% of the time wind waves are coming from NW to the point of investigation. During winter period wind wave height rise above 3 m.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.3.3. From this figure the steepness of wind waves in the region representing all years from all directions is computed as 0,046 for the wave height greater than 1 m in deep water. Wind wave domination from directions N, NW, NNW and SSW can be seen from these figures. The maximum wind wave height is observed from NW direction with a height of 5.2 meters from the data analyzed. The corresponding wave period is 9.0 seconds. Throughout the observation period wind waves are observed to be generally less than 3 m at the studied location near Datça.

The graph of extreme value probability statistics is given in Figure 4.3.4. Data values show high correlation. Significant wind wave height is estimated as

5.6 meters for 30 year return period in this region according to the analyzed data.

Figure 4.3.5 log-linear cumulative probability distribution of wind waves for Datça region. The figure is drawn to present dominant directions individually and all directions' data as whole. It is seen from this graph that significant height of wind waves exceeds 4.0 meters in about 10 hours duration every year.

Figure 4.3.6 shows swell wave roses. The roses show a clear indication of direction of incoming swell waves. As expected from the geographic location of the investigated point near Datça, swell waves from WSW, W, WNW, NW and NNW directions are dominant with respect to other directions. Swell waves from NW direction are observed 17.7%, from NNW direction 13.8 % and from WSW direction 12 % of a year. In summer, percentile of swell wave from NW direction become 29 %. The maximum swell wave height from NW is 1.8 meters. The period corresponding to the maximum swell is 10.5 seconds.

The relations between Significant Wave Height (H_s) vs. Mean Wave Period (T_m) are given in Figure 4.3.7. Swell wave domination from directions WSW, W, NW and NNW can be observed from these graphs. A rather more scattered distribution is observed in W and WSW direction. Several data points, exceeding 9 second periods and few data points exceeding 2.0 m of swell wave heights are observed from WSW direction with a maximum wave height of 3.0 m. Swell waves having 11 seconds periods can be observed from W and WSW directions.

The graph of extreme value probability statistics is given in Figure 4.3.8. Significant wave height is estimated as 3.5 meter for 30 year return period.

Log-linear cumulative probability distribution for swell waves is given in Figure 4.3.9. Dominating directions, namely WSW and SSW are plotted along with other directions. It is seen from this graph that significant height of swell waves exceeds 3.0 meters in about 10 hours duration every year.

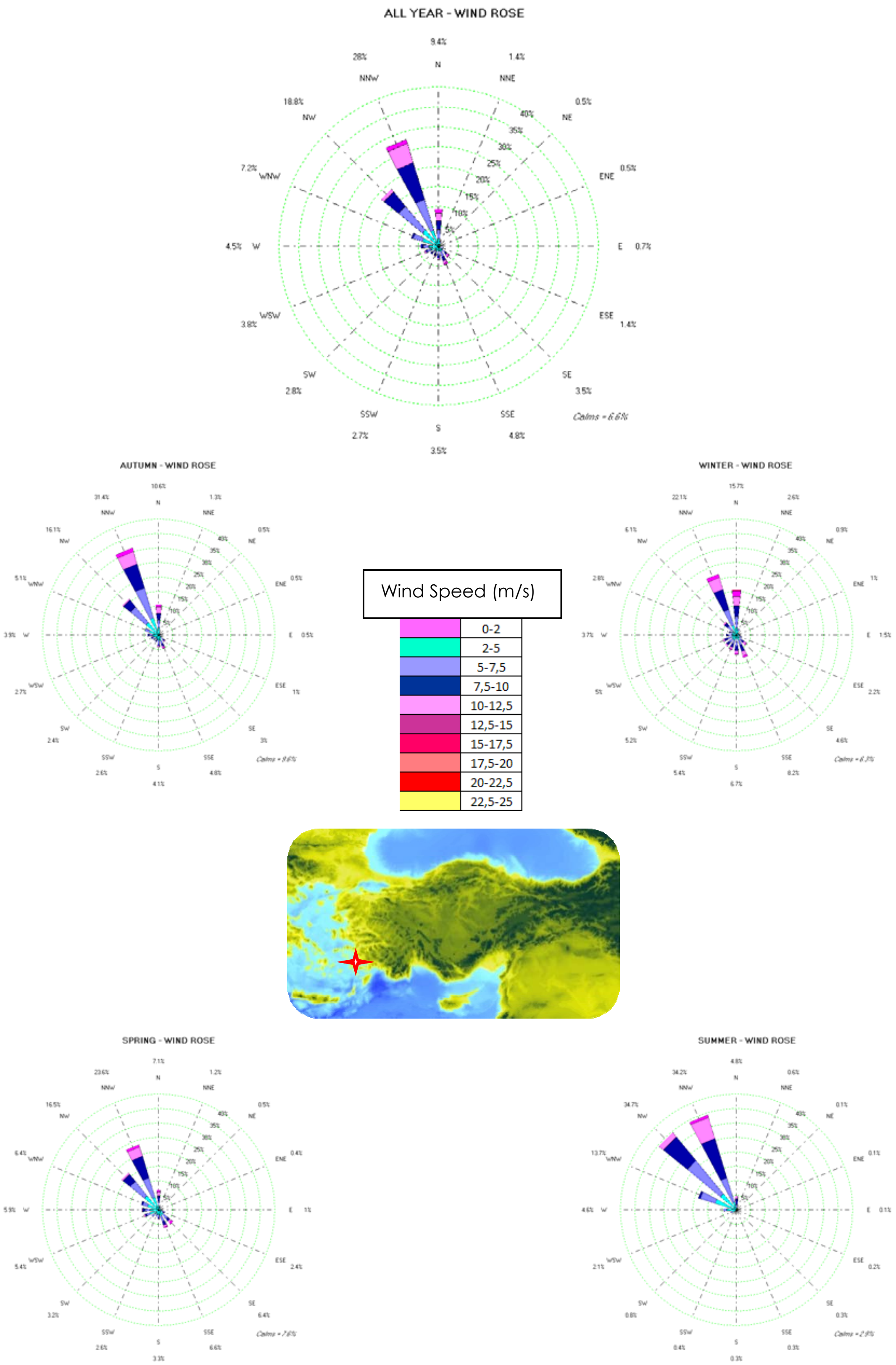


Figure 4.3.1 Wind Climate at Datça

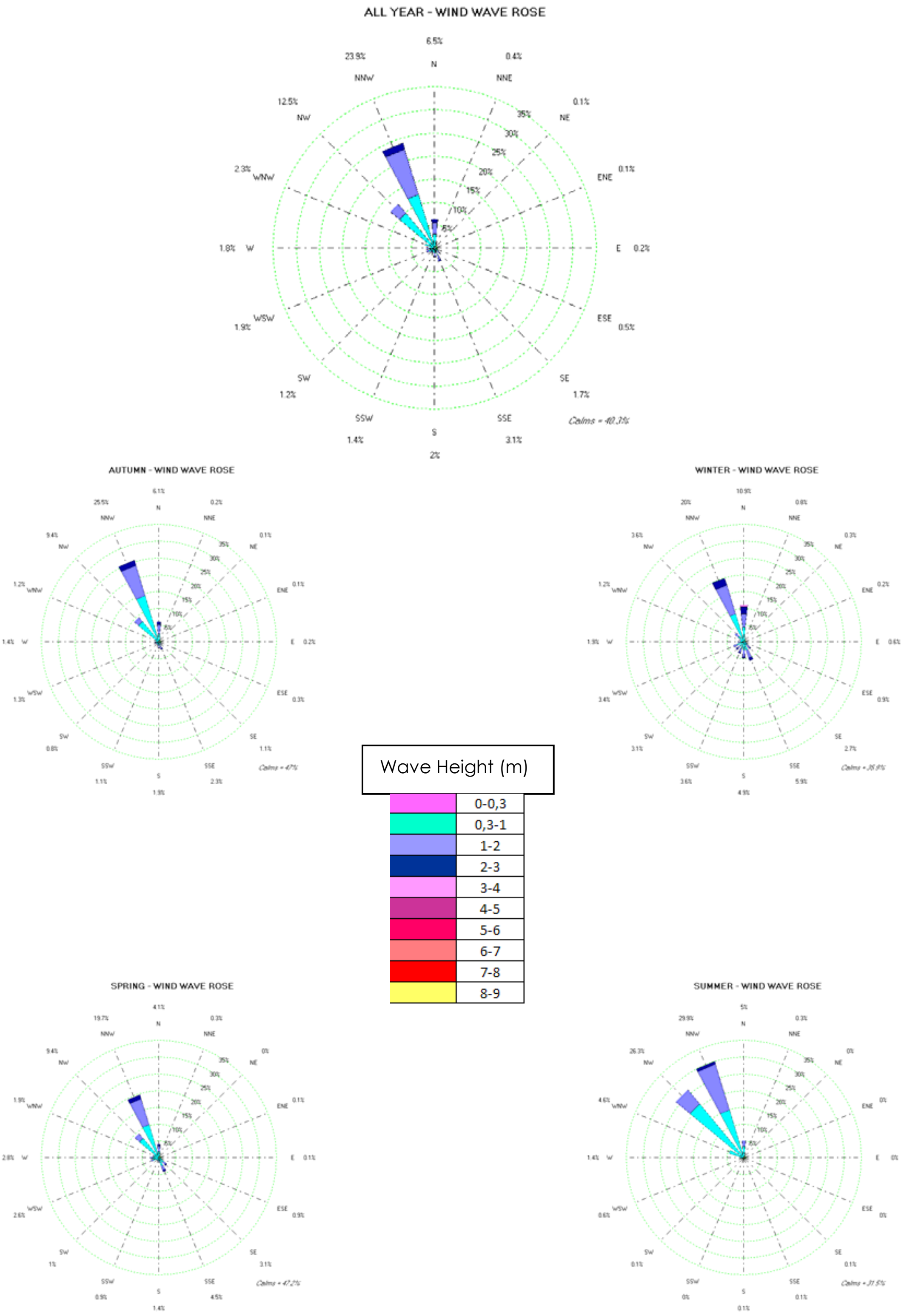


Figure 4.3.2 Wind Wave Climate at Datça

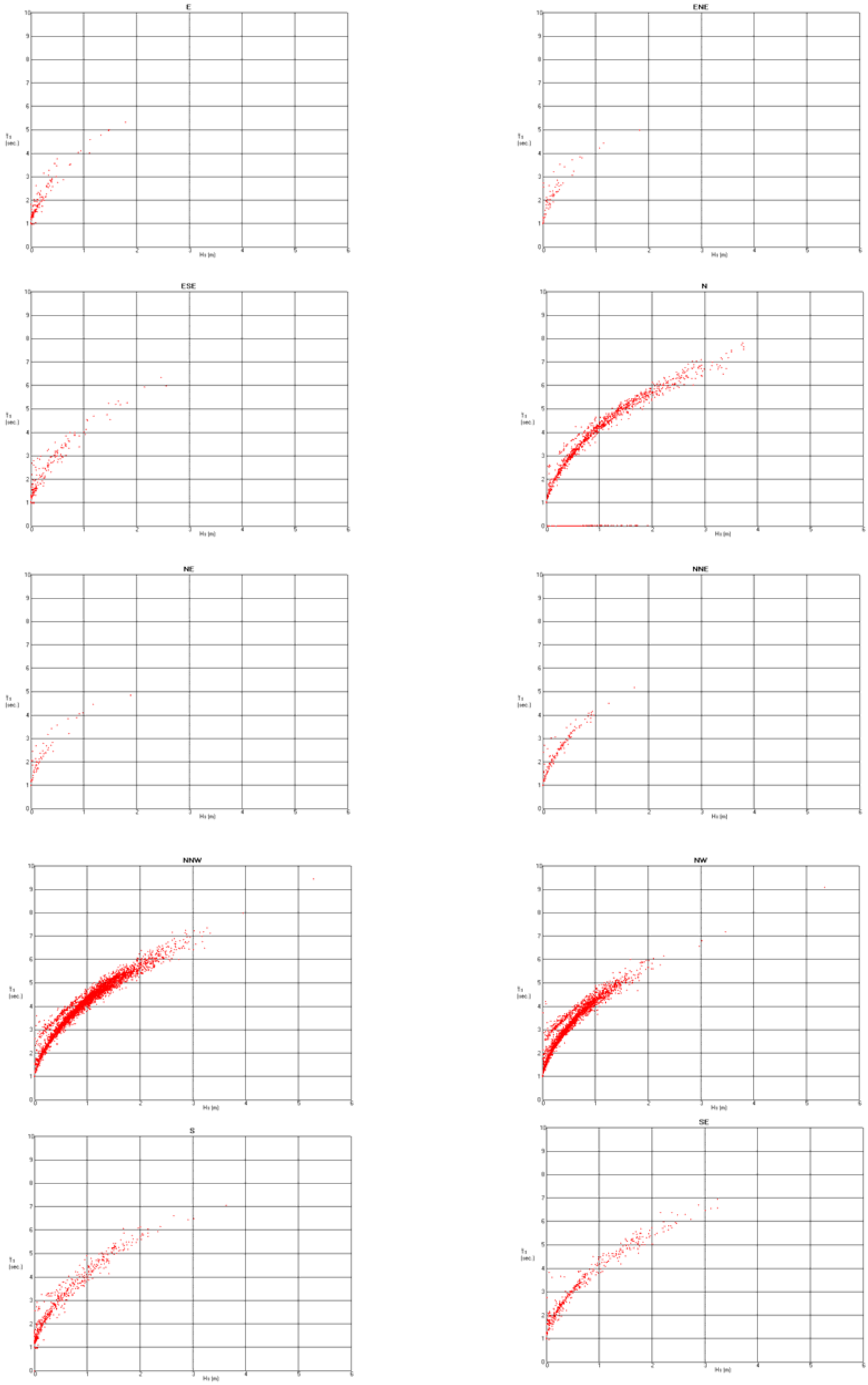


Figure 4.3.3 Relationship between MPWW & SHWW at Datça

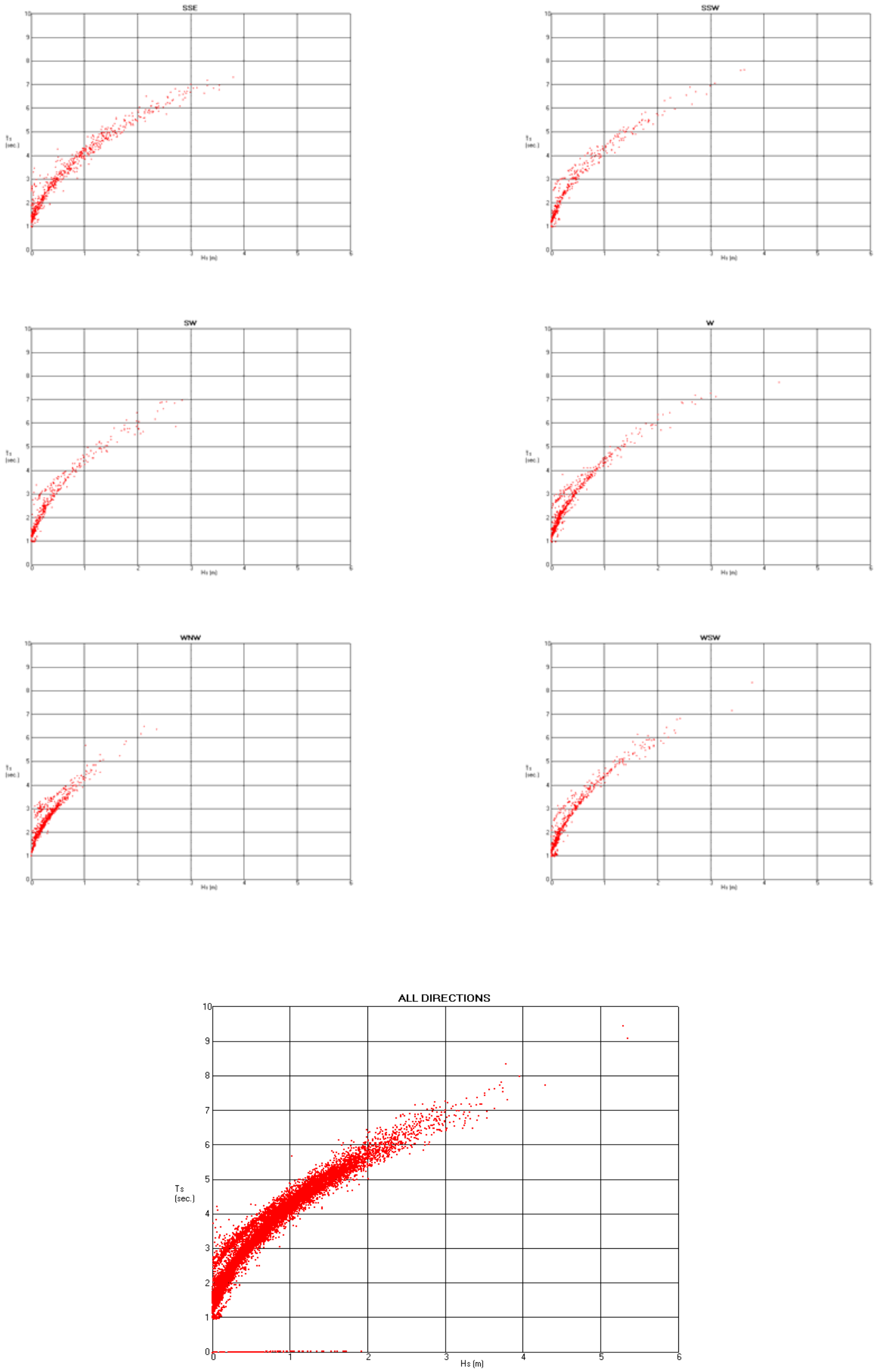


Figure 4.3.3 Relationship between MPWW & SHWW at Datça (continued)

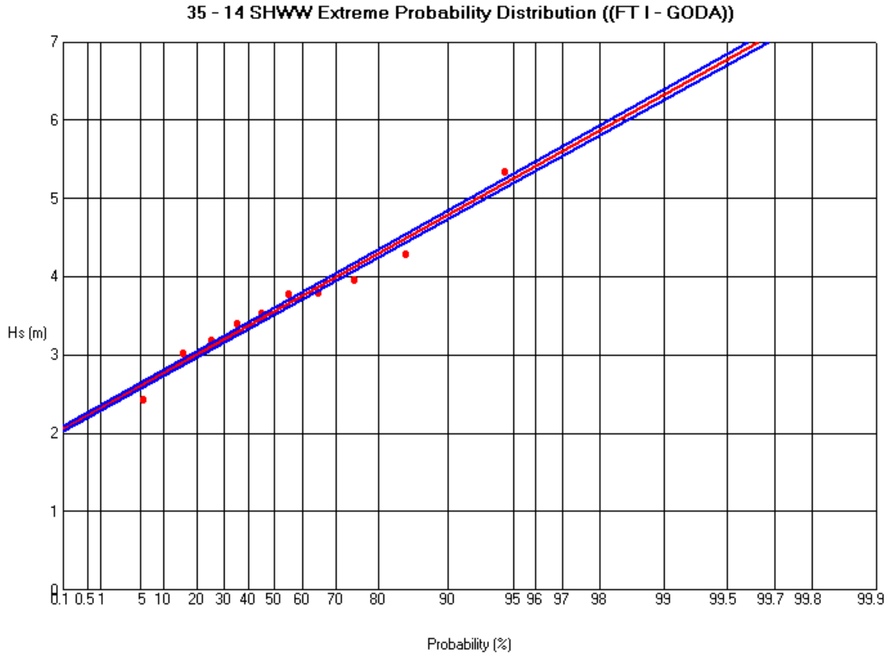


Figure 4.3.4 Extreme Probability Distribution of SHWW at Datça

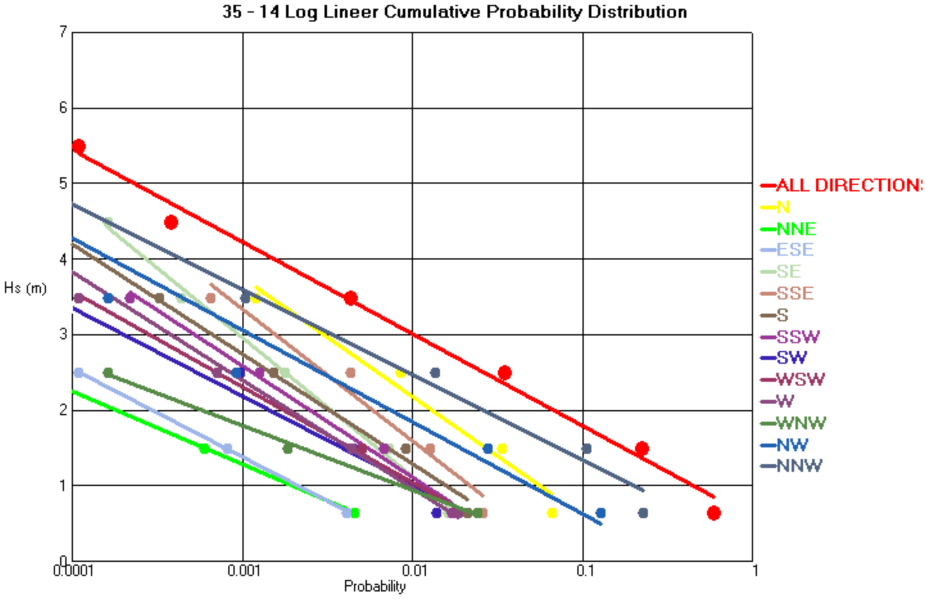


Figure 4.3.5 Log-lineer Cumulative Probability Distribution of SHWW at at Datça

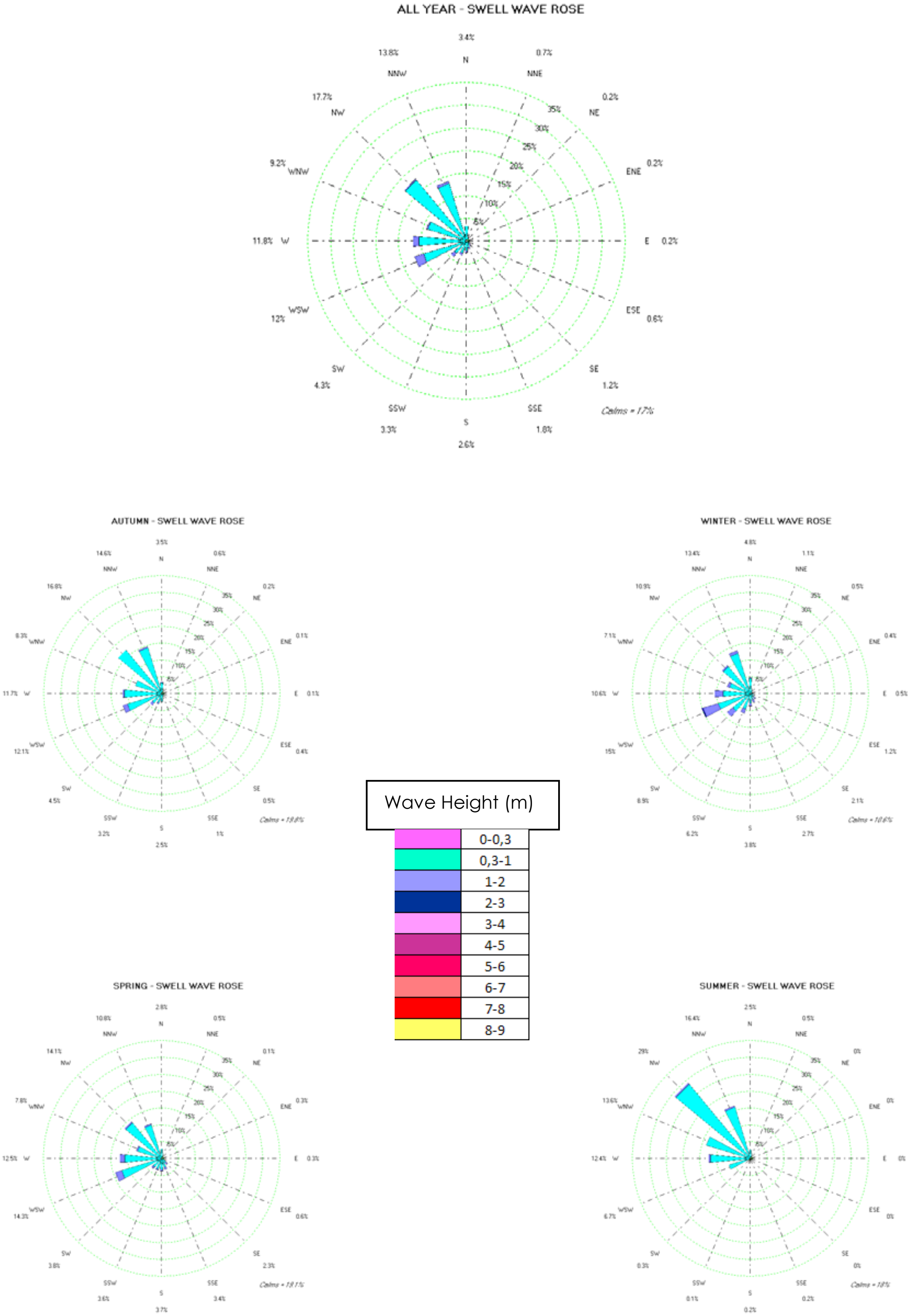


Figure 4.3.6 Swell Wave Climate at Datça

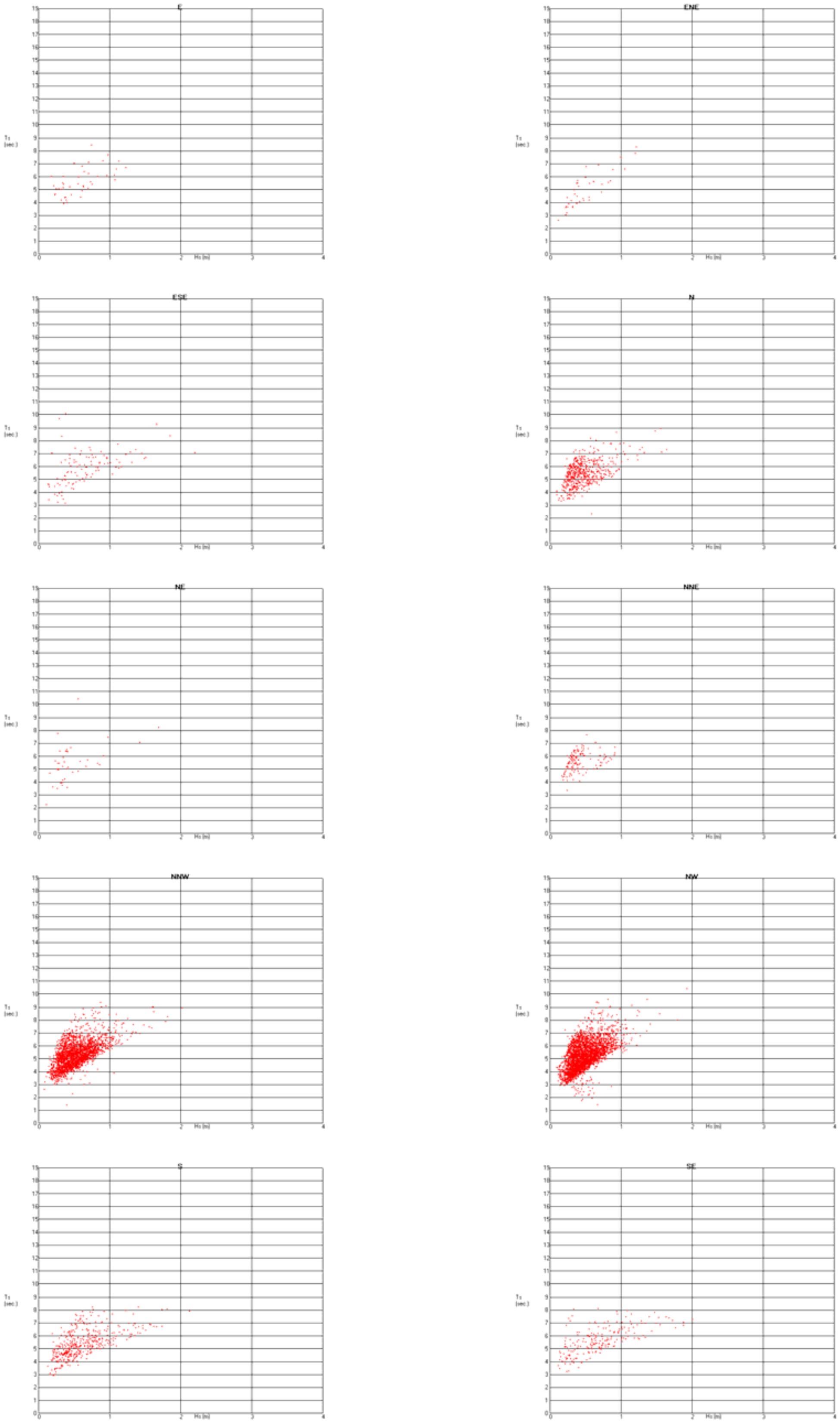


Figure 4.3.7 Relationship Between MPPS and SHPS at Datça

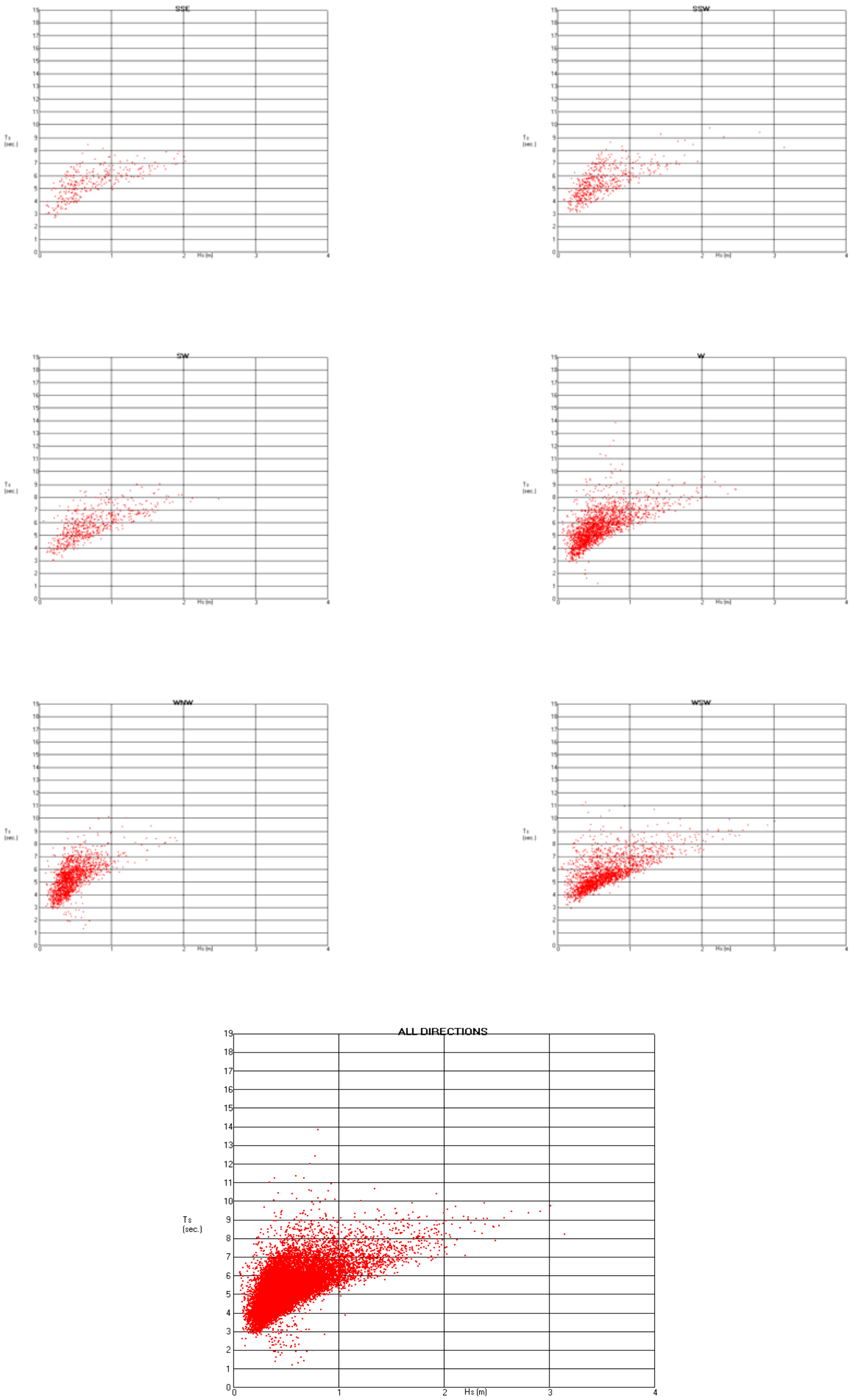


Figure 4.3.7 Relationship Between MPPS and SHPS at Datça

(continued)

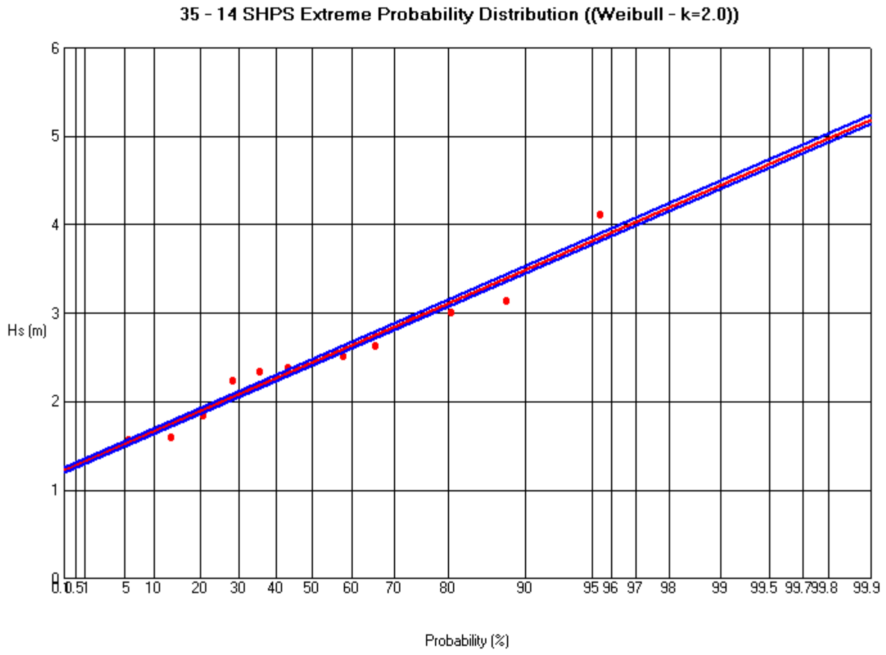


Figure 4.3.8 Extreme Probability Distribution of SHPS at Datça

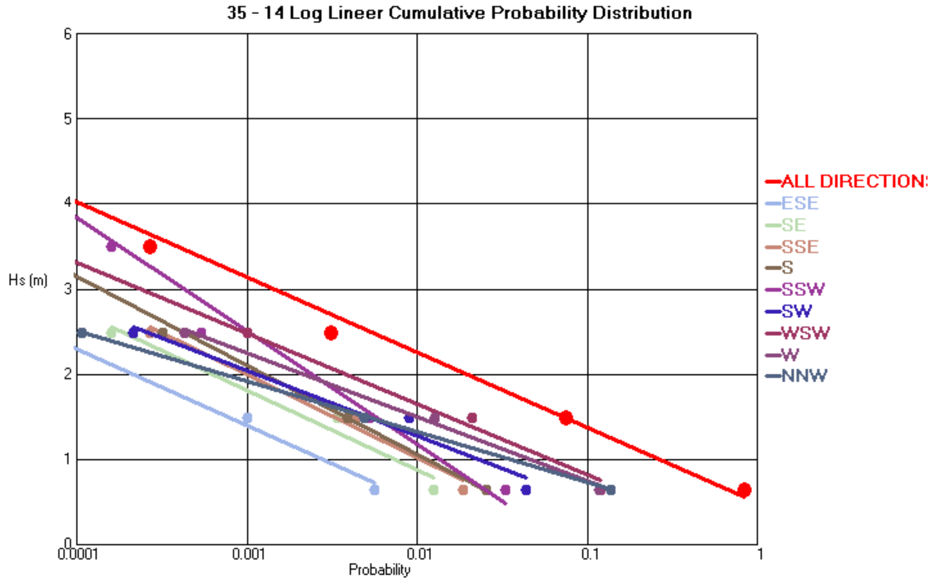


Figure 4.3.9 Log-lineer Cumulative Probability Distribution of SHPS at Datça

4.4 LOCATION – KUŞADASI (37.87 N 27.75 E)

A point at the offshore location near Kuşadası town of Aydın is selected at coordinates 37.87 N 27.25 E(at 34x17 grid nodes). The point is located 1 km away from shoreline.

Following figures given in this section are the results of the analysis of wind, wind wave and swell wave analysis for Kuşadası region.

Wind roses given in Figure 4.4.1 show that the location analyzed near Kuşadası is subject to mainly N, NNE and SSE winds during a year. During winter period NNE winds dominates in number of occurrence with a percentile of 26.5 % of time. In winter highest wind speed of about 15.7 m/s is observed from west.

Wind wave roses given in Figure 4.4.2 show the directional distribution and height of incoming wind waves. It is seen from the graphs that 16.2% of the time wind waves are coming from N, 7.9% of the time wind waves are coming from NNW to the point of investigation. During winter period wind wave height rise above 3 m.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.4.3. From this figure the steepness of wind waves in the region representing all years from all directions is computed as 0,047 for the wave height greater than 1 m in deep water. Wind wave domination from directions N, NNW and SSW can be seen from these figures. The maximum wind wave height is observed from SSW direction with a height of 4.0 meters from the data analyzed. The corresponding wave period is 7.95 seconds. Throughout the observation period wind waves are observed to be generally less than 3 m at the studied location near Kuşadası.

The graph of extreme value probability statistics is given in Figure 4.4.4. Data values show high correlation. Significant wind wave height is estimated as

4.8 m for 30 year return period in this region according to the analyzed data.

Figure 4.4.5 log-linear cumulative probability distribution of wind waves for Kuşadası region. The figure is drawn to present dominant directions individually and all directions' data as whole. It is seen from this graph that significant height of wind waves exceeds 3.3 meters in about 10 hours duration every year.

Figure 4.4.6 shows swell wave roses. The roses show a clear indication of direction of incoming swell waves. As expected from the geographic location of the investigated point near Kuşadası, swell waves from SSW, WSW, SW, WNW, NW and NNW directions are dominant with respect to other directions. Swell waves from SW direction are observed 11.6%, from NW direction 11.3 % and from NW direction 10.8 % of a year. In summer, percentile of swell wave from NW direction becomes 20.3 %. The maximum swell wave height is observed from SW is 2.8 meters. The period corresponding to the maximum swell is 9 seconds.

The relations between Significant Wave Height (H_s) vs. Mean Wave Period (T_m) are given in Figure 4.4.7. Swell wave domination from directions WSW, SW and SSW can be observed from these graphs. A rather more scattered distribution is observed in SSW direction. Several data points, exceeding 8 second periods and few data points exceeding 2.0 m of swell wave heights are observed from WSW direction with a maximum wave height of 2.6 m. Swell waves having 10 seconds periods can be observed from SW and WSW directions.

The graph of extreme value probability statistics is given in Figure 4.4.8. Significant wave height is estimated as 3.0 m for 30 year return period.

Log-linear cumulative probability distribution for swell waves is given in Figure 4.4.9. Dominating directions, namely SW and SSW are plotted along with other directions. It is seen from this graph that significant height of swell waves exceeds 2.0 meters in about 10 hours duration every year.

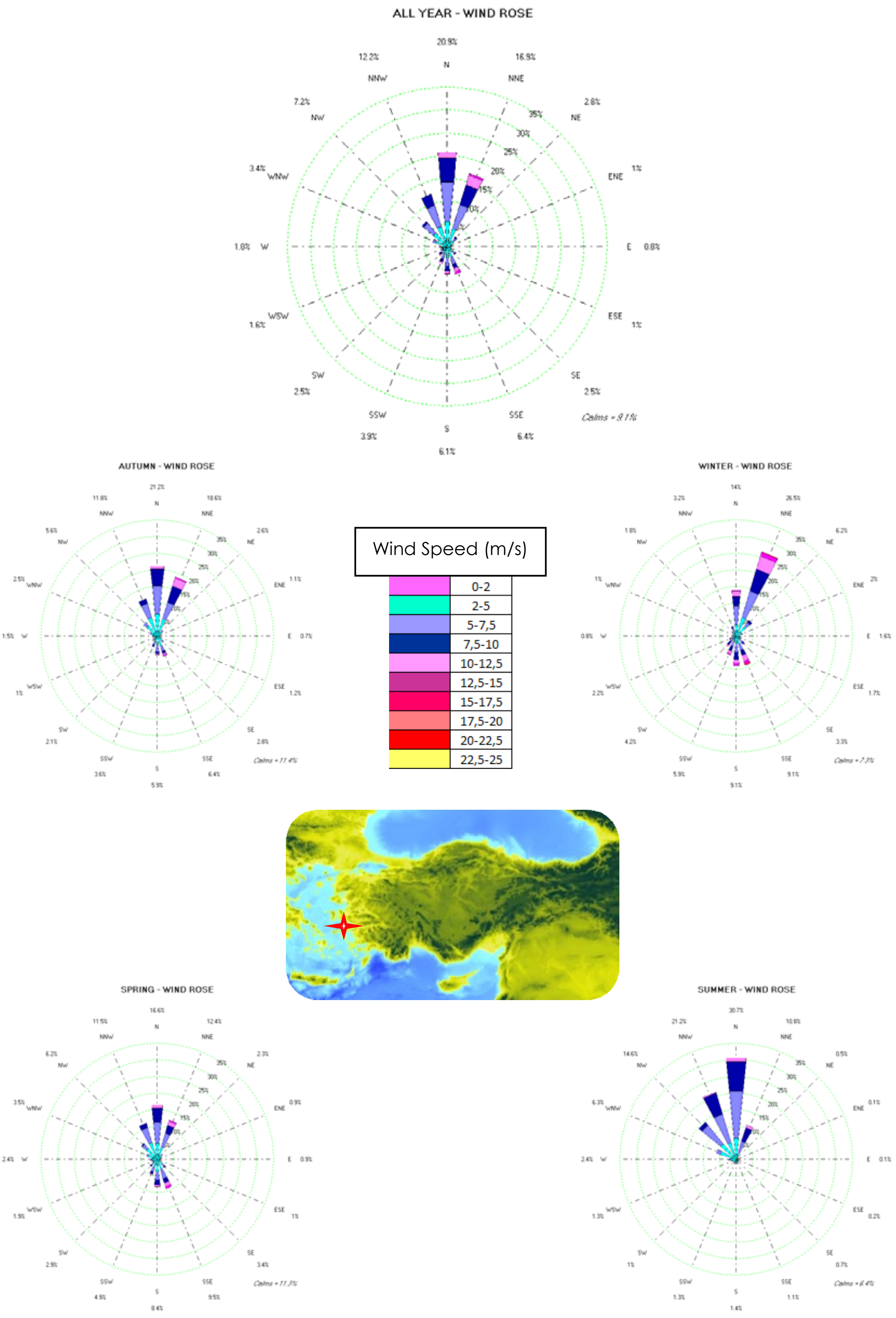
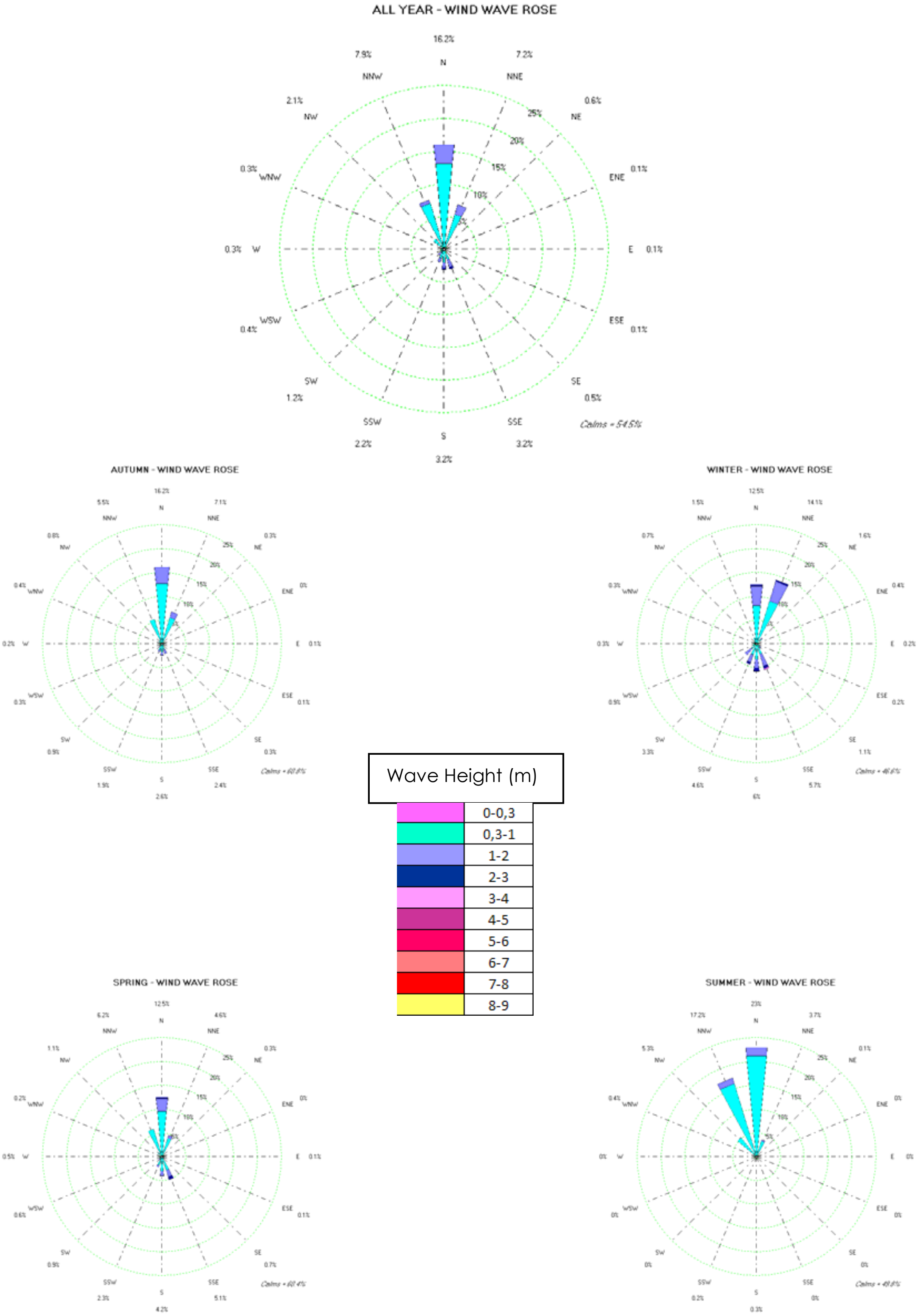


Figure 4.4.1 Wind Climate at Kuşadası



Wave Height (m)	
🟪	0-0,3
🟩	0,3-1
🟪	1-2
🟦	2-3
🟪	3-4
🟪	4-5
🟥	5-6
🟥	6-7
🟥	7-8
🟨	8-9

Figure 4.4.2 Wind Wave Climate at Kuşadası

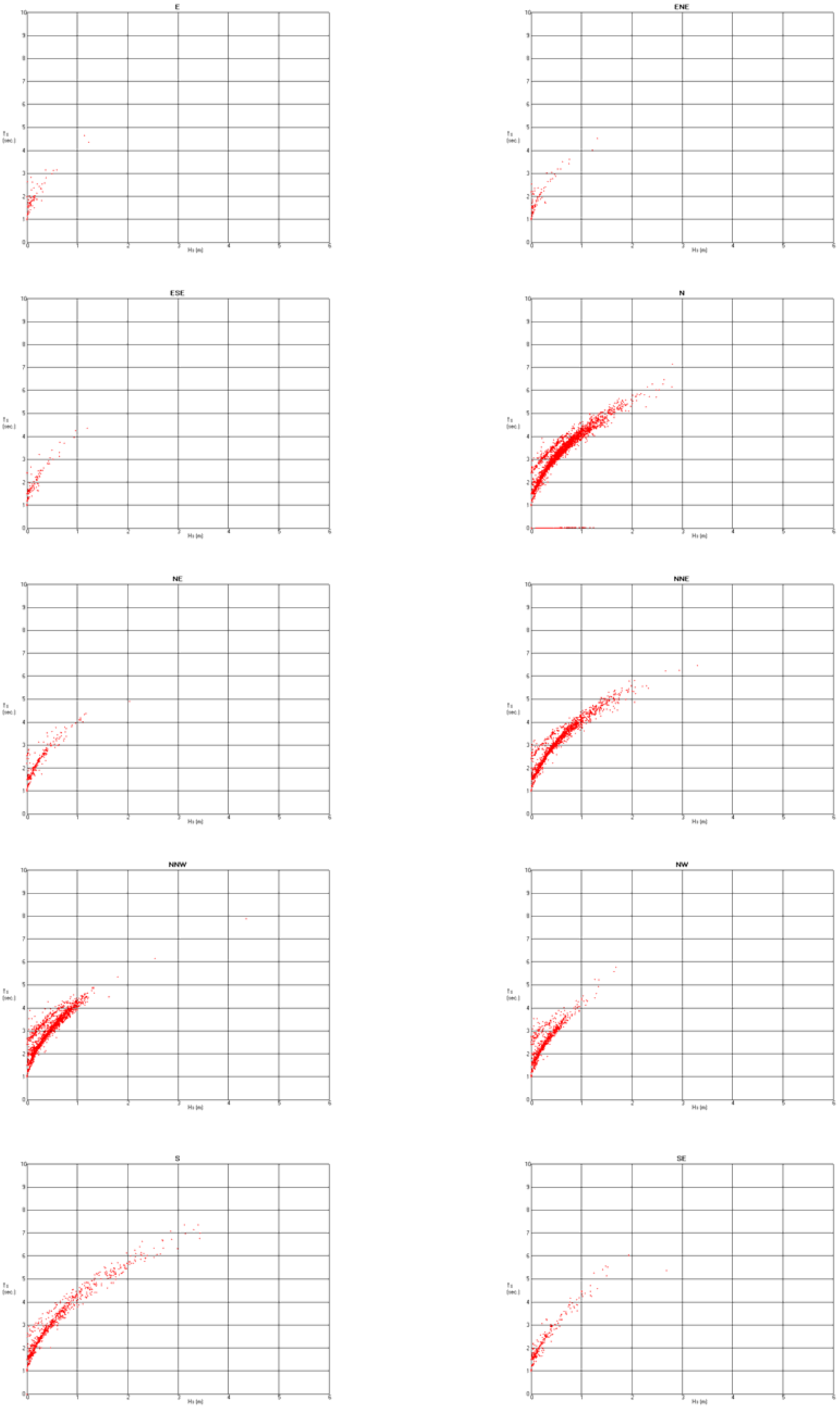


Figure 4.4.3 Relationship between MPWW & SHWW at Kuşadası

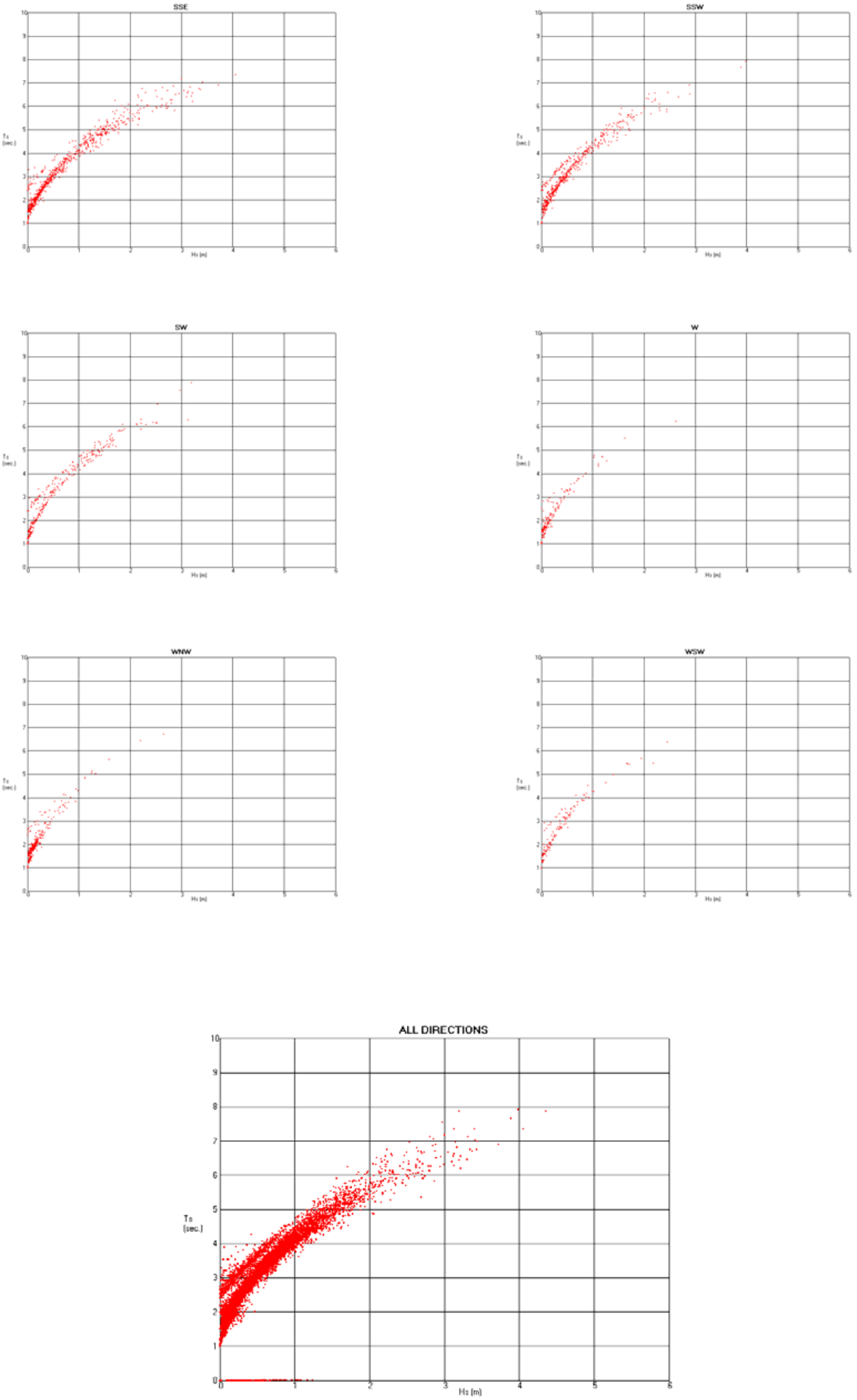


Figure 4.4.3 Relationship between MPWW & SHWW at Kuşadası (continued)

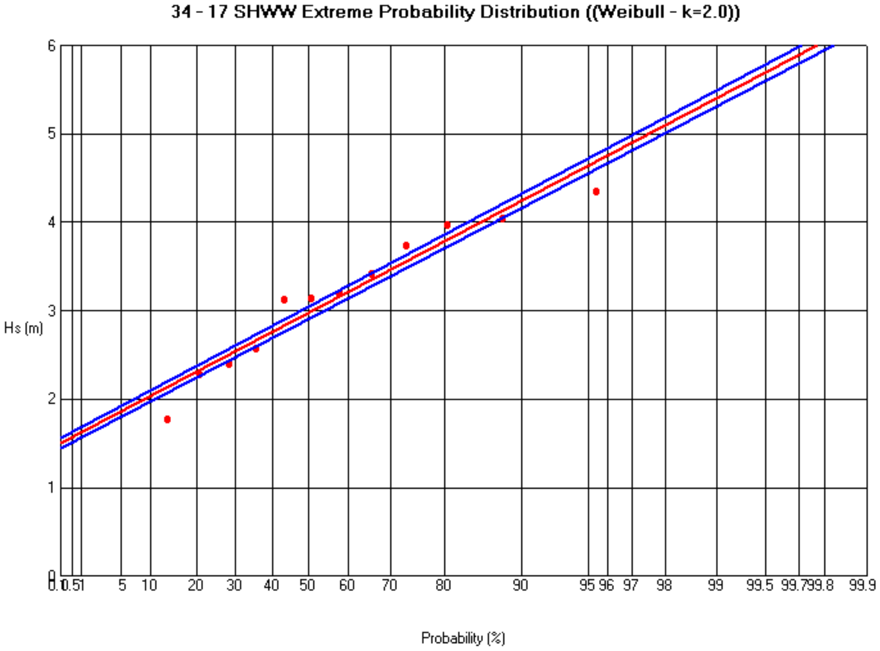


Figure 4.4.4 Extreme Probability Distribution of SHWW at Kuşadası

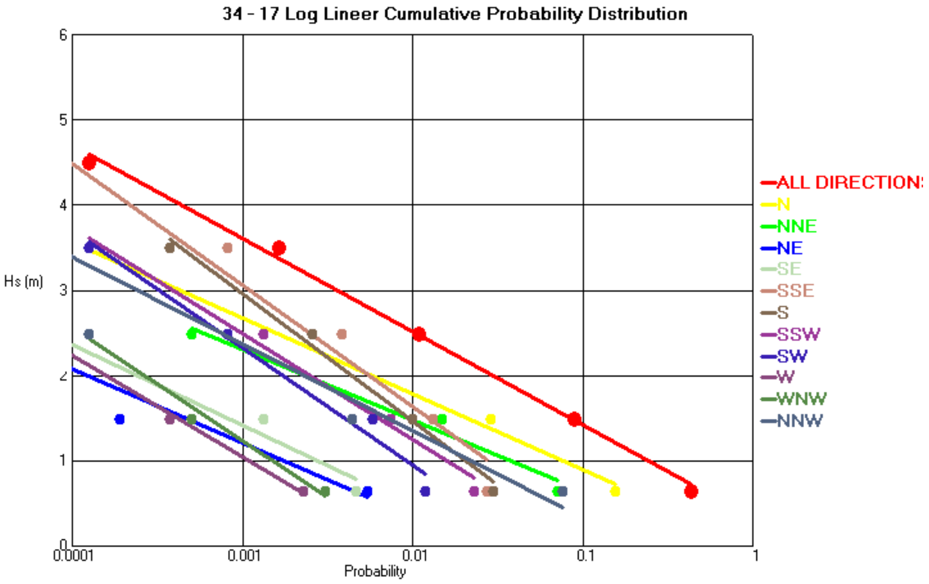


Figure 4.4.5 Log-lineer Cumulative Probability Distribution of SHWW at at Kuşadası

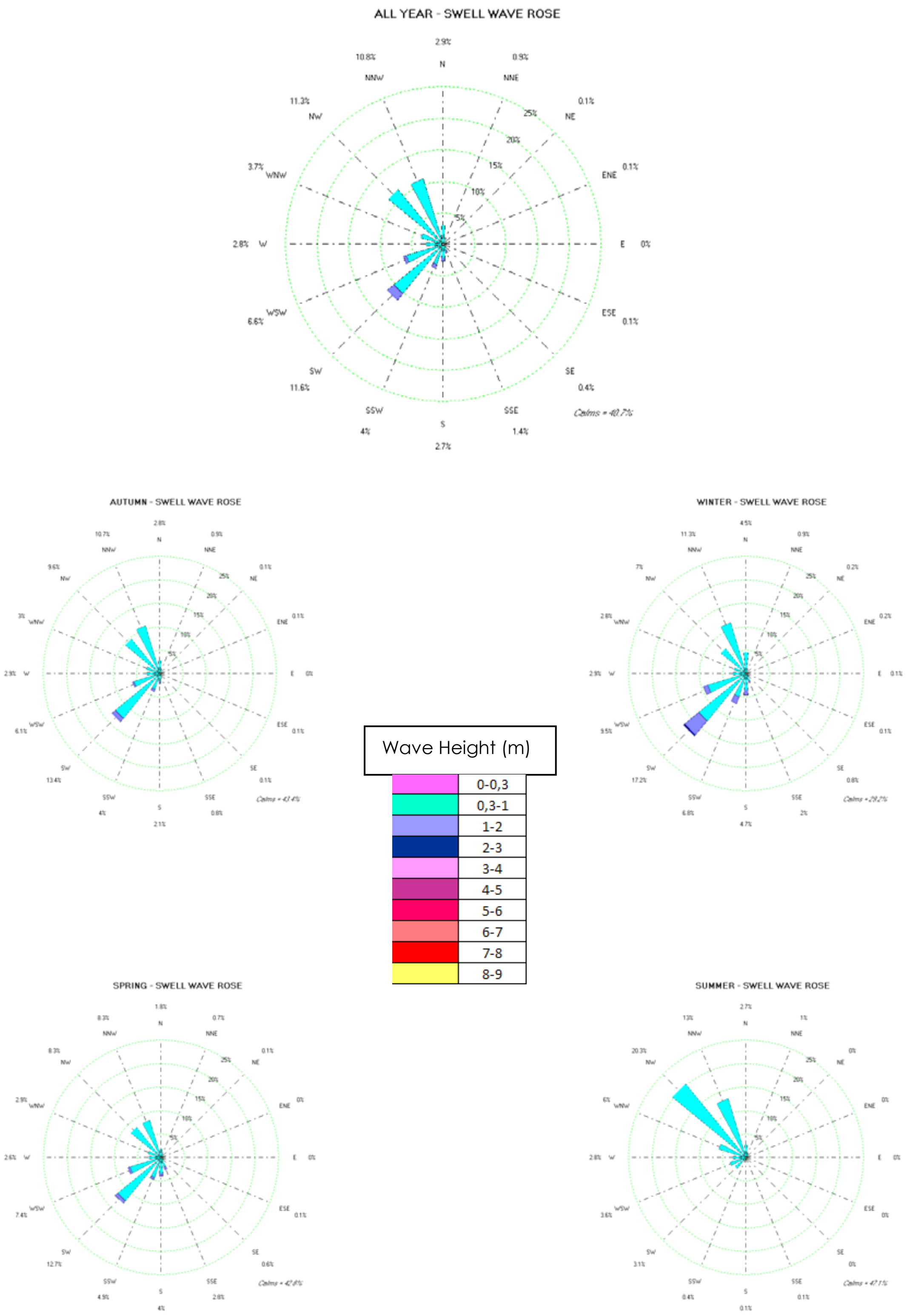


Figure 4.4.6 Swell Wave Climate at Kuşadası

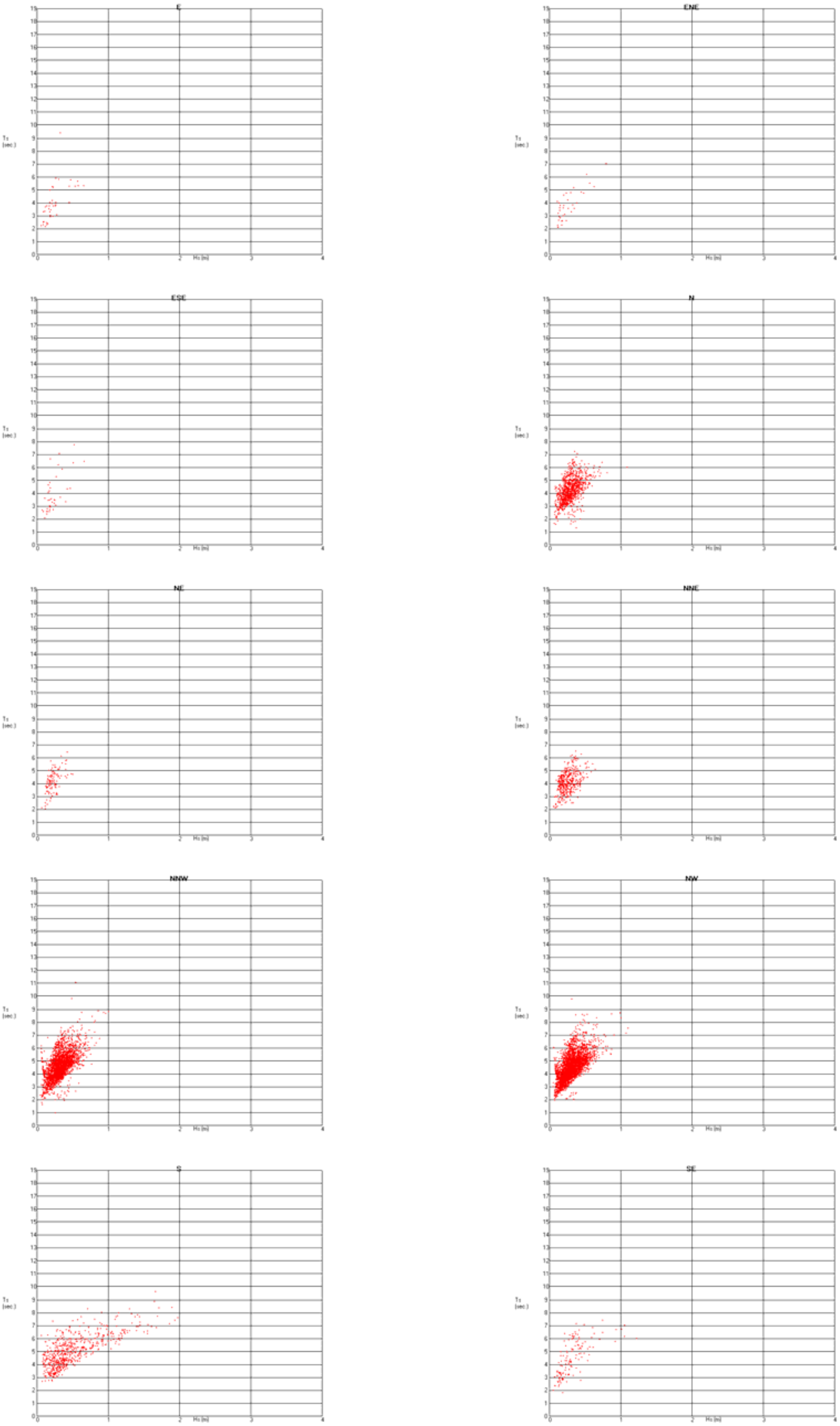


Figure 4.4.7 Relationship Between MPPS and SHPS at Kuşadası

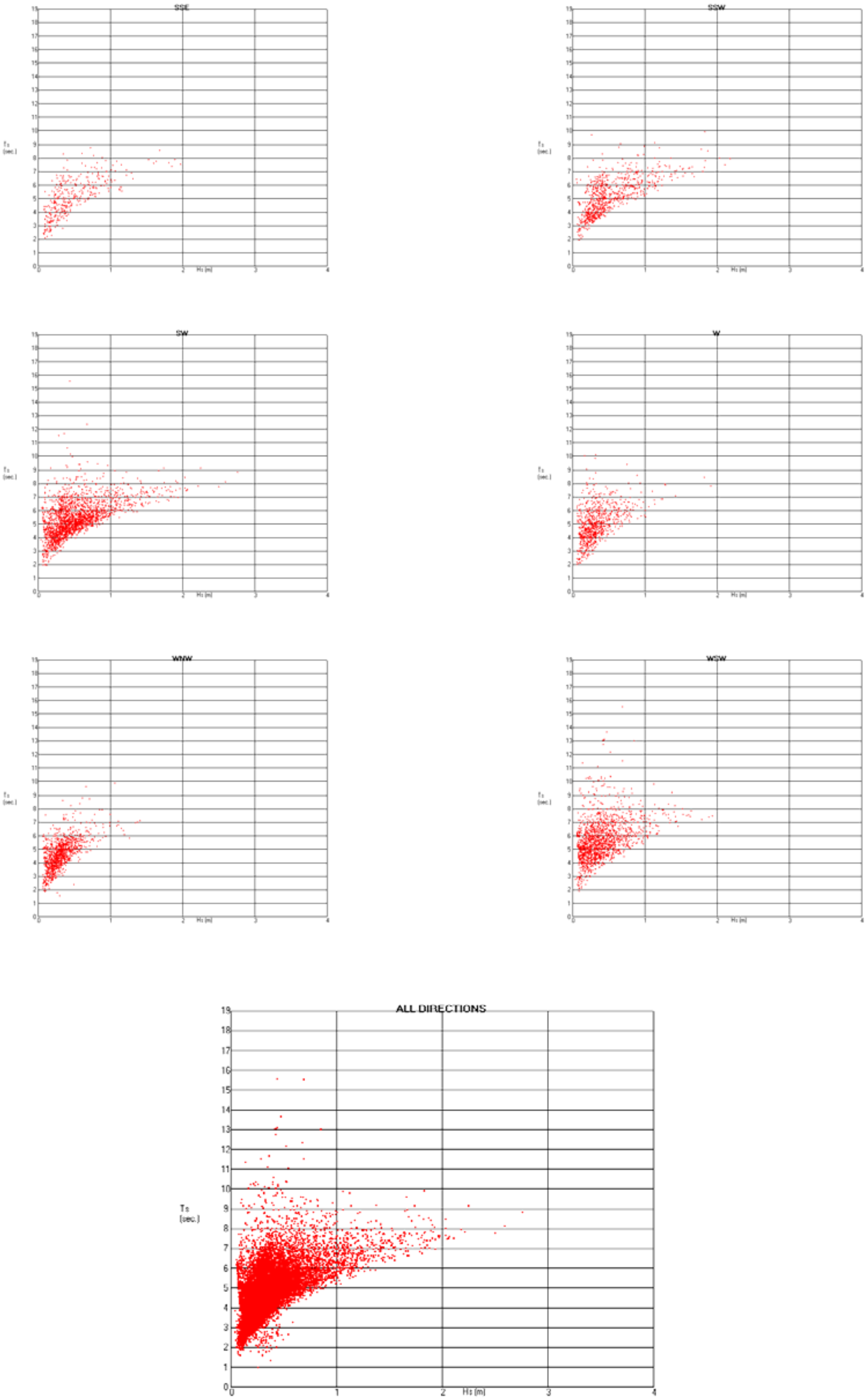


Figure 4.4.7 Relationship Between MPPS and SHPS at Kuşadası (continued)

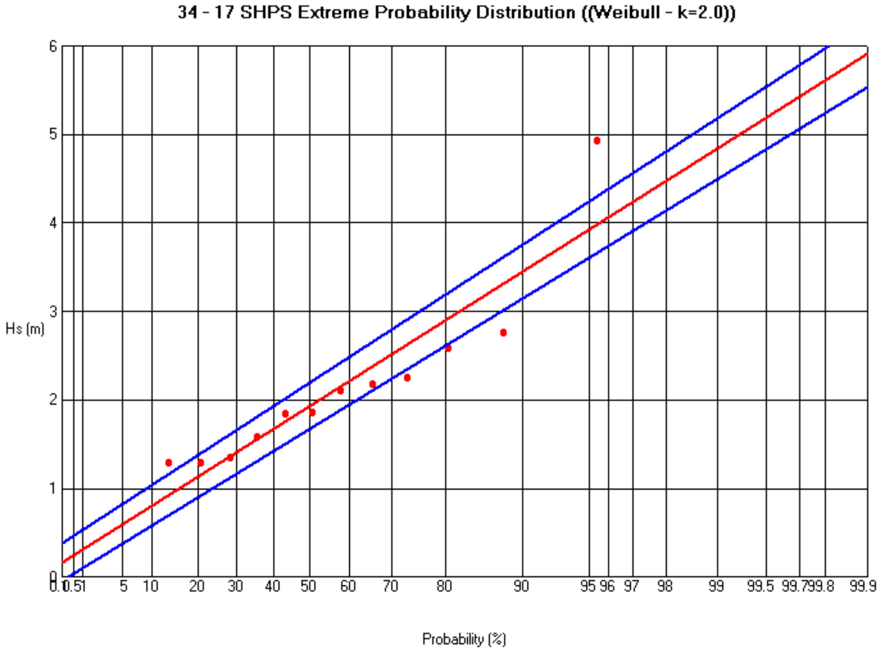


Figure 4.4.8 Extreme Probability Distribution of SHPS at Kuşadası

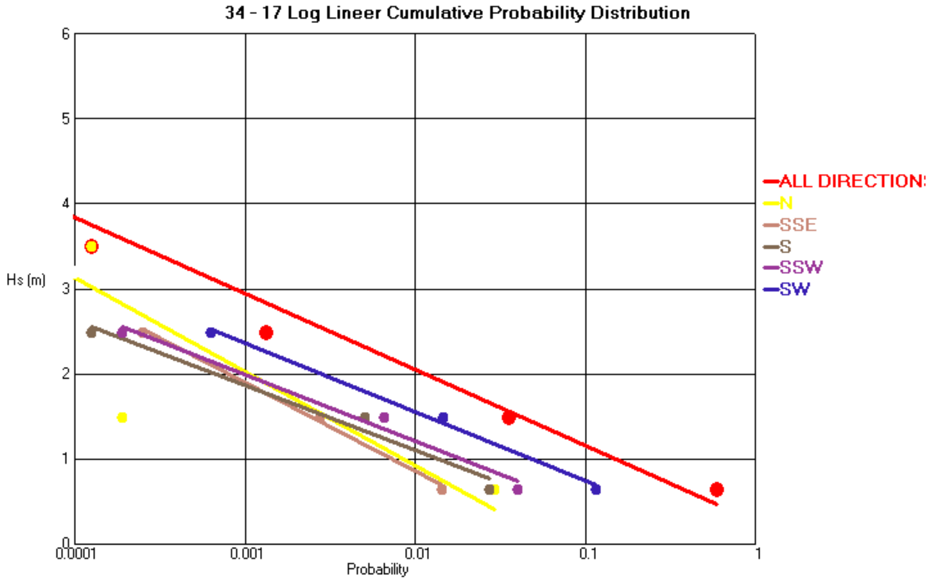


Figure 4.4.9 Log-lineer Cumulative Probability Distribution of SHPS at Kuşadası

4.5 LOCATION – BABAKALE (39.28 N 26.03 E)

A point at the offshore location near Asos approximately 30 km west of Ayvacık town of Çanakkale, is selected at coordinates 39.28 N 26.03 E (at 32x20 grid nodes). The point is located 2.5 km away from shoreline.

Following figures given in this section are the results of the analysis of wind, wind wave and swell wave analysis for Babakale region.

Wind roses given in Figure 4.5.1 show that the location analyzed near Babakale is subject to mainly NE, NNE and S winds during a year. During winter period NE winds dominates in number of occurrence with a percentile of 27.7 % of time. In winter highest wind speed of about 18 m/s is observed from north-northeast.

Wind wave roses given in Figure 4.5.2 show the directional distribution and height of incoming wind waves. It is seen from the graphs that 18.7% of the time wind waves are coming from NNE, 17.1% of the time wind waves are coming from NE to the point of investigation. During winter period wind wave height rise above 4 m.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.5.3. From this figure the steepness of wind waves in the region representing all years from all directions is computed as 0,050 for the wave height greater than 1 m in deep water. Wind wave domination from directions N, NNE, S and SSW can be seen from these figures. The maximum wind wave height is observed from NNE direction with a height of 5.3 meters from the data analyzed. The corresponding wave period is 8.3 seconds.

The graph of extreme value probability statistics is given in Figure 4.5.4. Data values show high correlation. Significant wind wave height is estimated as 5.9 m for 30 year return period in this region according to the analyzed data.

Figure 4.5.5 log-linear cumulative probability distribution of wind waves for Babakale region. The figure is drawn to present dominant directions individually and all directions' data as whole. It is seen from this graph that significant height of wind waves exceeds 4.3 meters in about 10 hours duration every year.

Figure 4.5.6 shows swell wave roses. The roses show a clear indication of direction of incoming swell waves. As expected from the geographic location of the investigated point near Babakale, swell waves from SSW, SW, SW, N and NNE directions are dominant with respect to other directions. Swell waves from NNE direction are observed 9.3%, from N direction 8.7 % and from S direction 5.9 % of a year. In winter, percentile of swell wave from S direction becomes 9.7 %. The maximum swell wave height observed from S is 2.2 meters. The period corresponding to the maximum swell is 8 seconds.

The relations between Significant Wave Height (H_s) vs. Mean Wave Period (T_m) are given in Figure 4.5.7. Swell wave domination from directions SSW, SW, N and NNE can be observed from these graphs. A rather more scattered distribution is observed in S direction. Several data points, exceeding 8 second periods and few data points exceeding 2.0 m of swell wave heights are observed from S direction with a maximum wave height of 2.4 m. Swell waves having 8 seconds periods can be observed from S direction.

The graph of extreme value probability statistics is given in Figure 4.5.8. Significant wave height is estimated as 2.4 m for 30 year return period.

Log-linear cumulative probability distribution for swell waves is given in Figure 4.5.9. Dominating directions, namely N and S are plotted along with other directions. It is seen from this graph that significant height of swell waves exceeds 3.2 meters in about 10 hours duration every year.

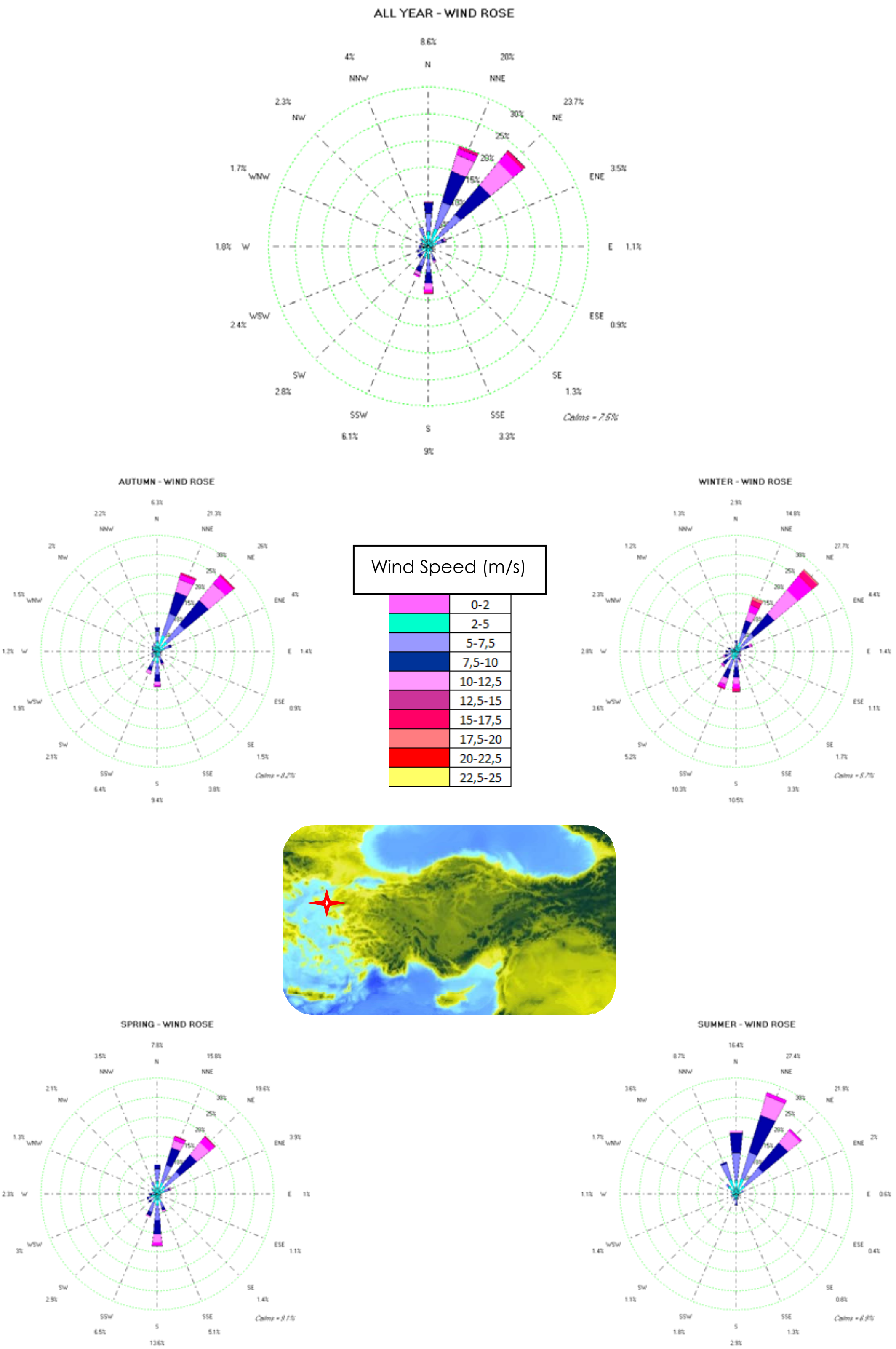


Figure 4.5.1 Wind Climate at Babakale

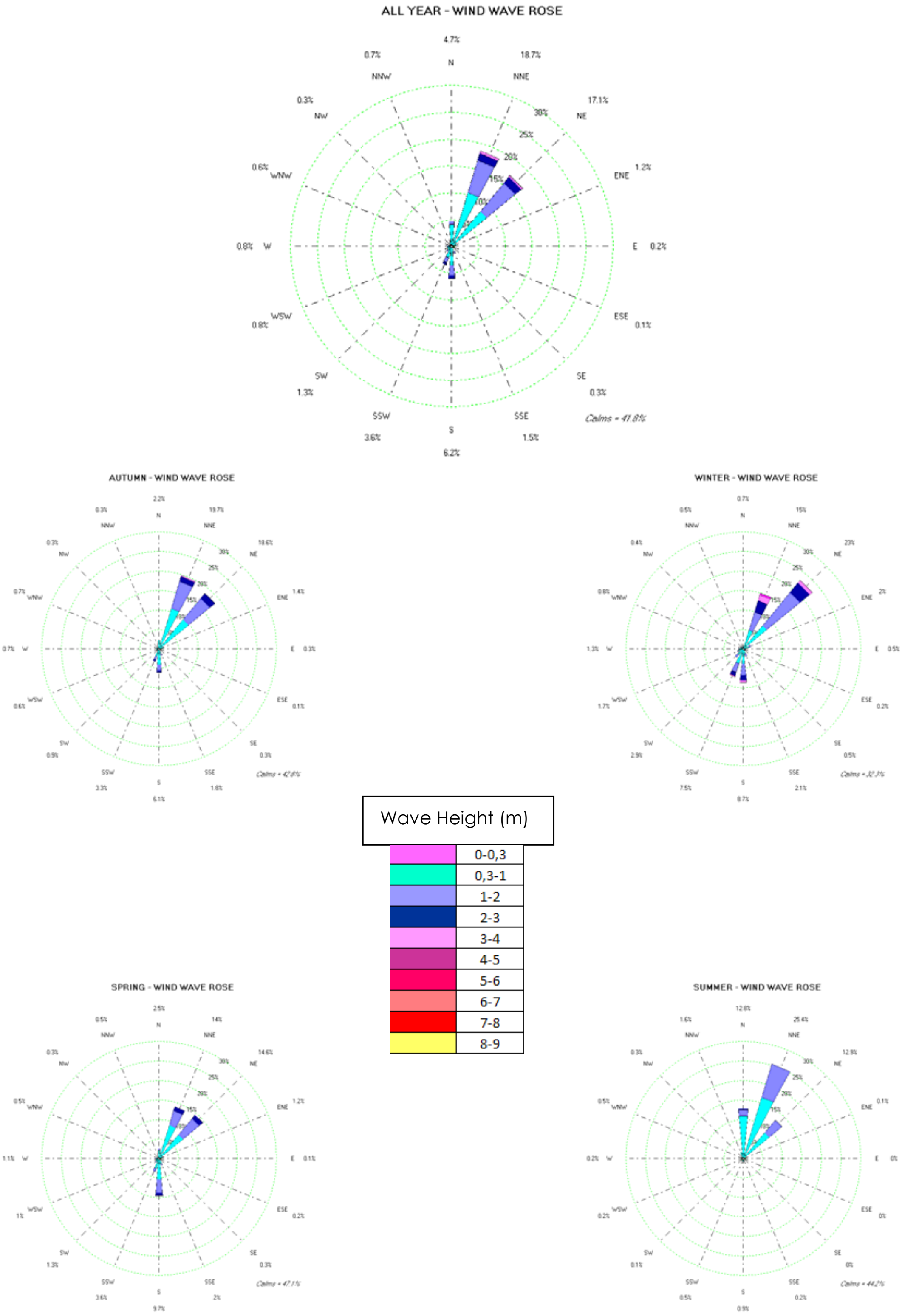


Figure 4.5.2 Wind Wave Climate at Babakale

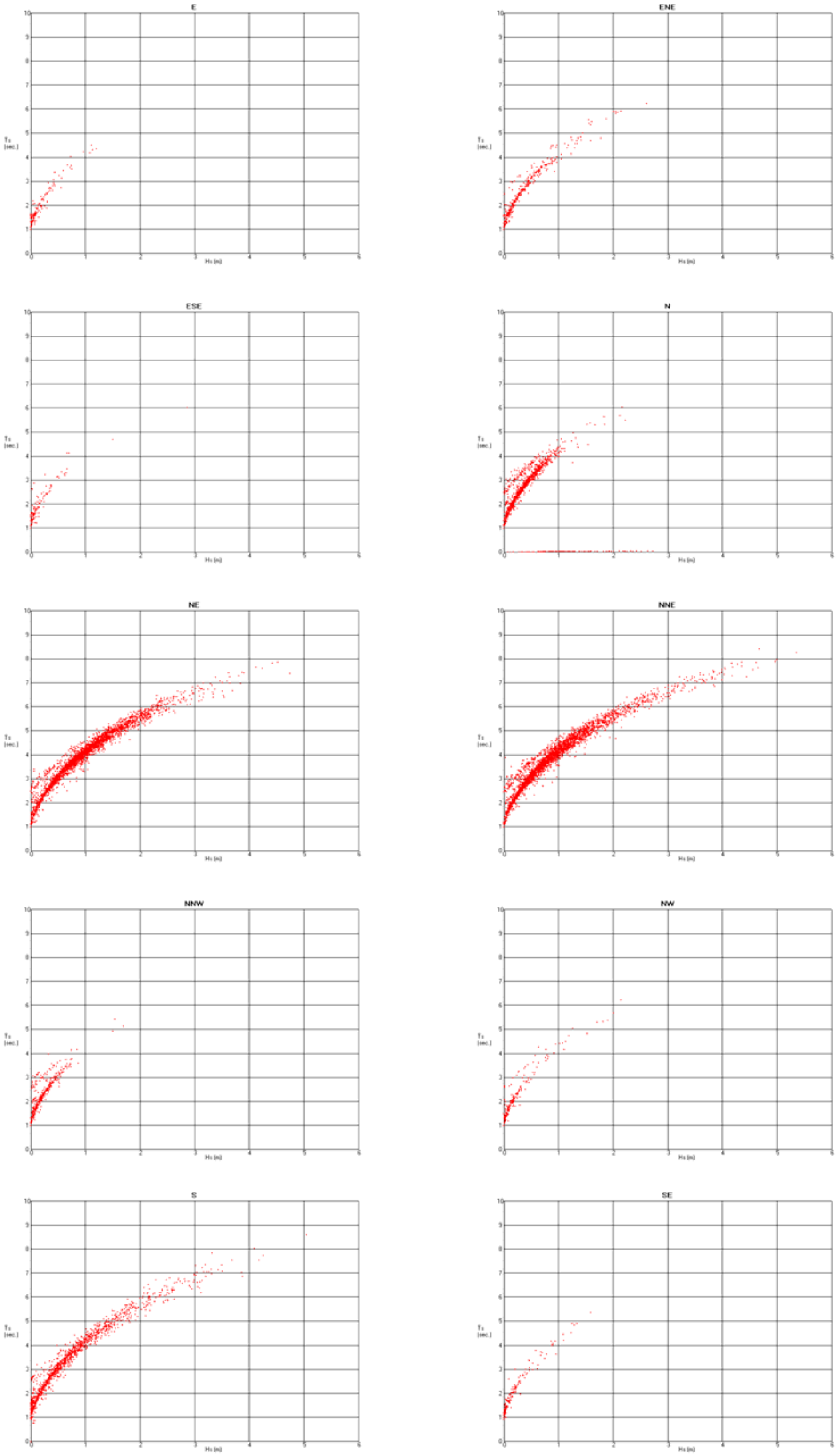


Figure 4.5.3 Relationship between MPWW & SHWW at Babakale

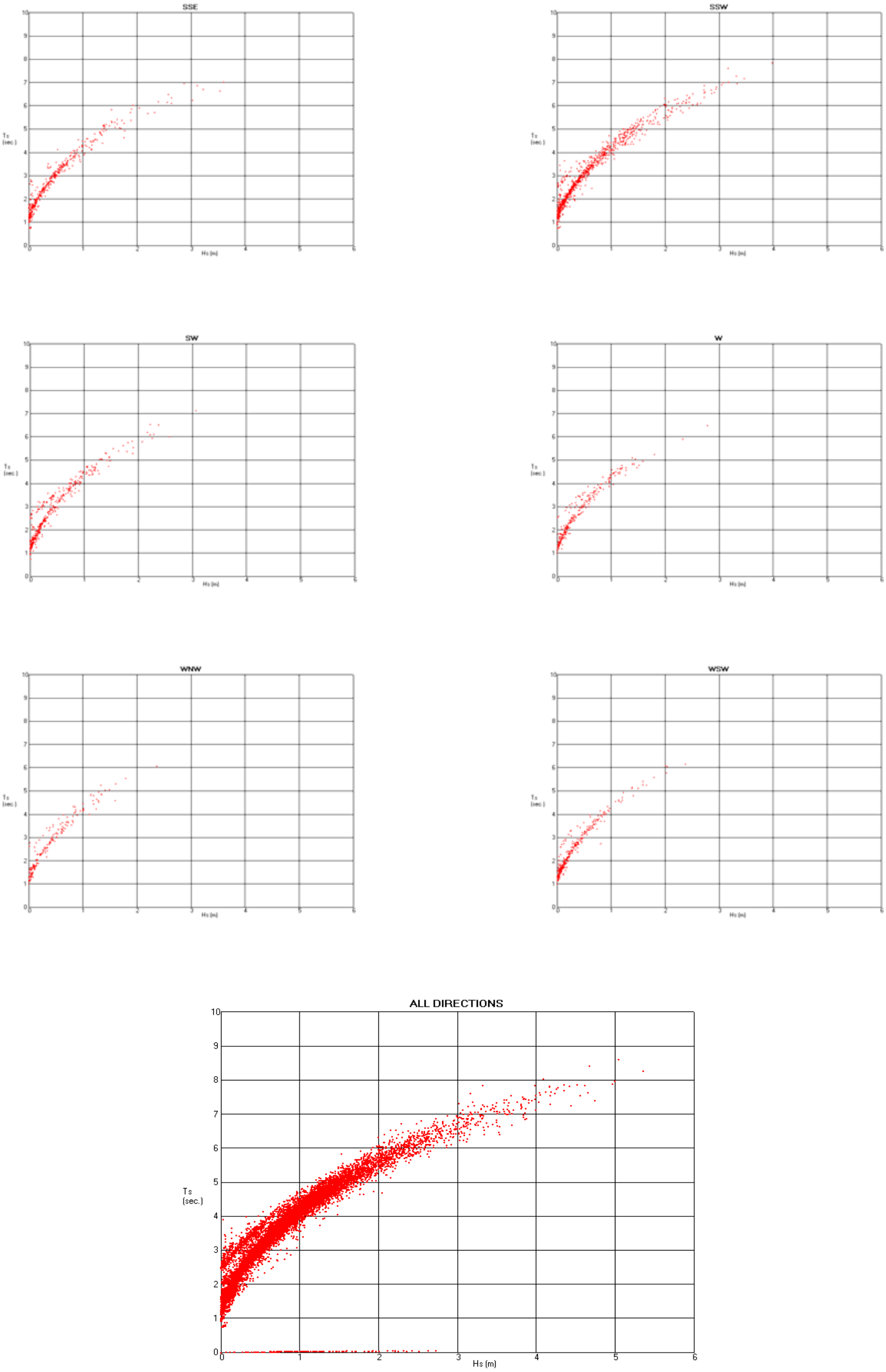


Figure 4.5.3 Relationship between MPWW & SHWW at Babakale (continued)

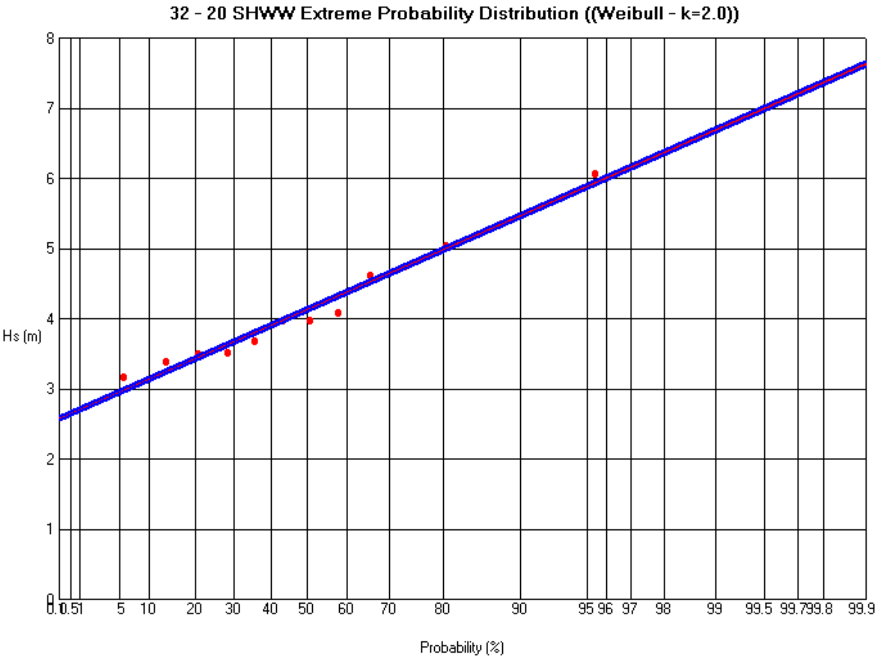


Figure 4.5.4 Extreme Probability Distribution of SHWW at Babakale

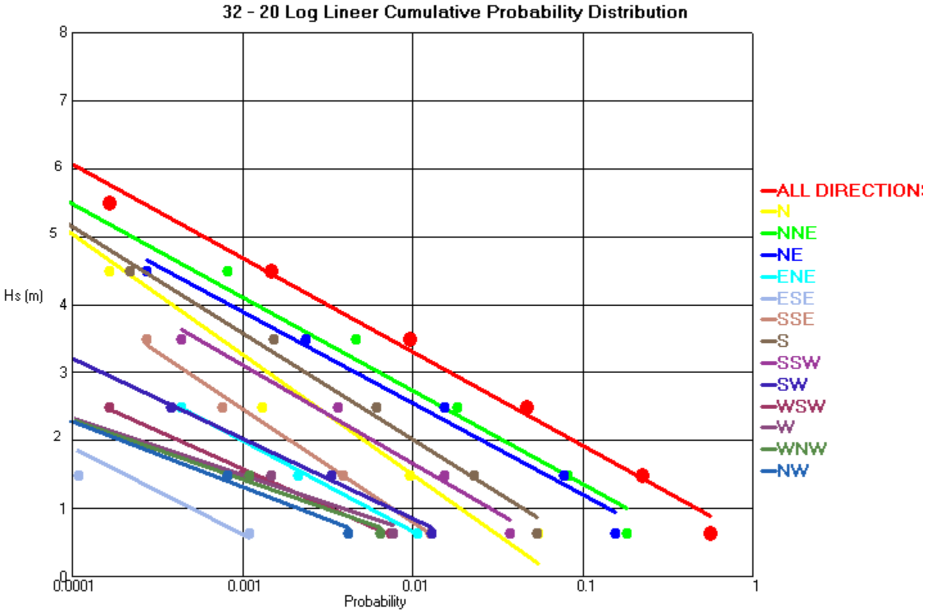


Figure 4.5.5 Log-lineer Cumulative Probability Distribution at Babakale

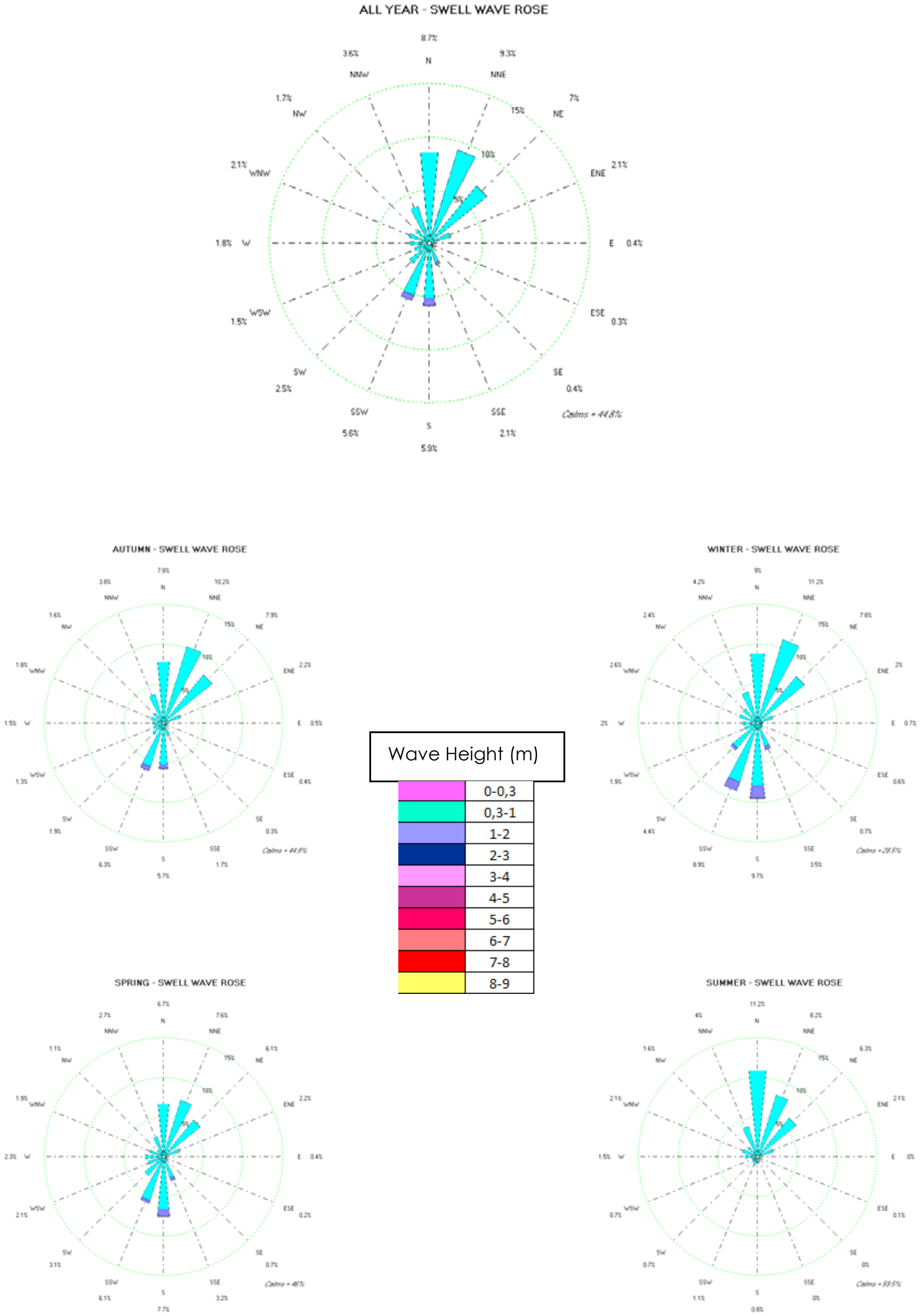


Figure 4.5.6 Swell Wave Climate at Babakale

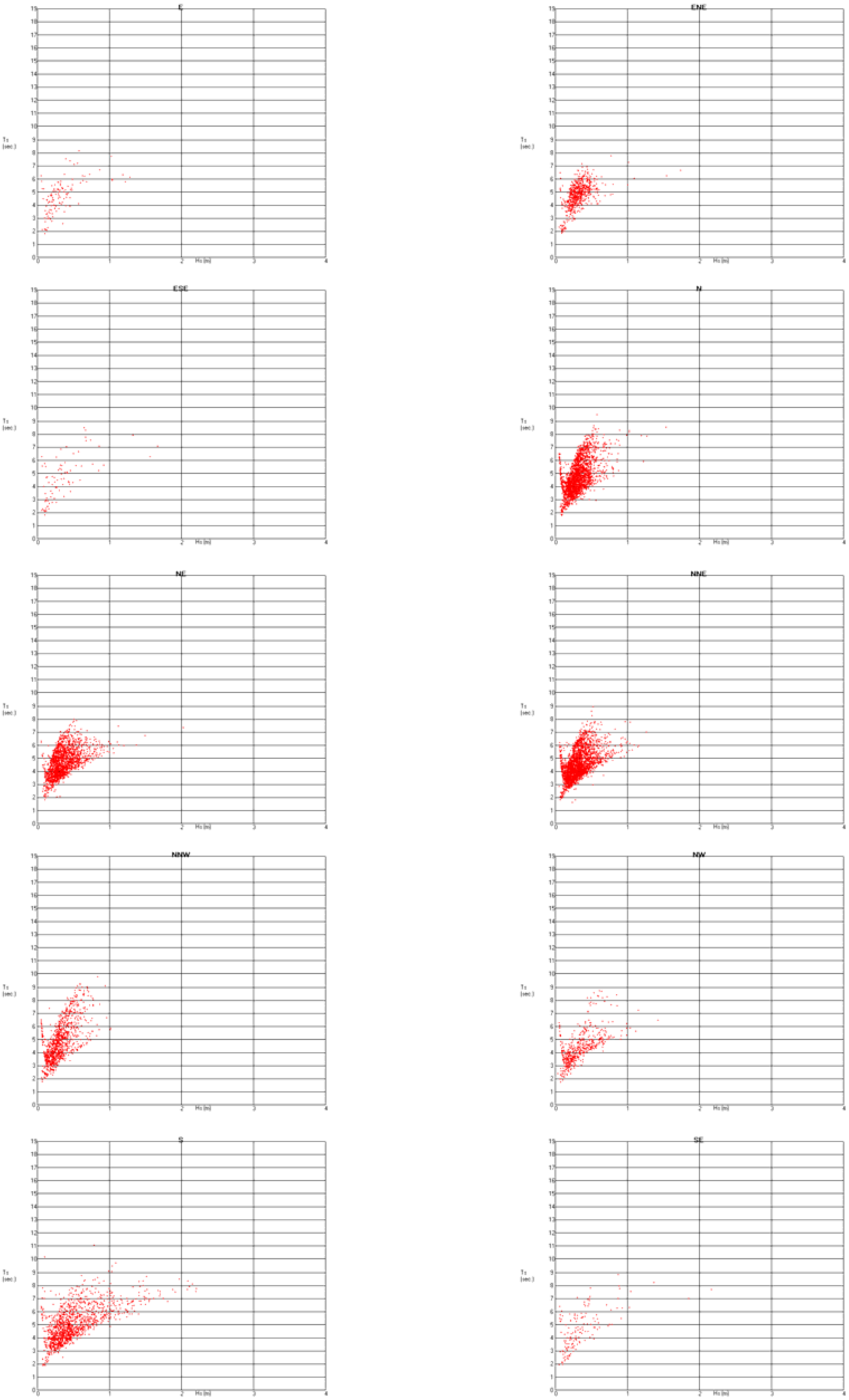


Figure 4.5.7 Relationship Between MPPS and SHPS at Babakale

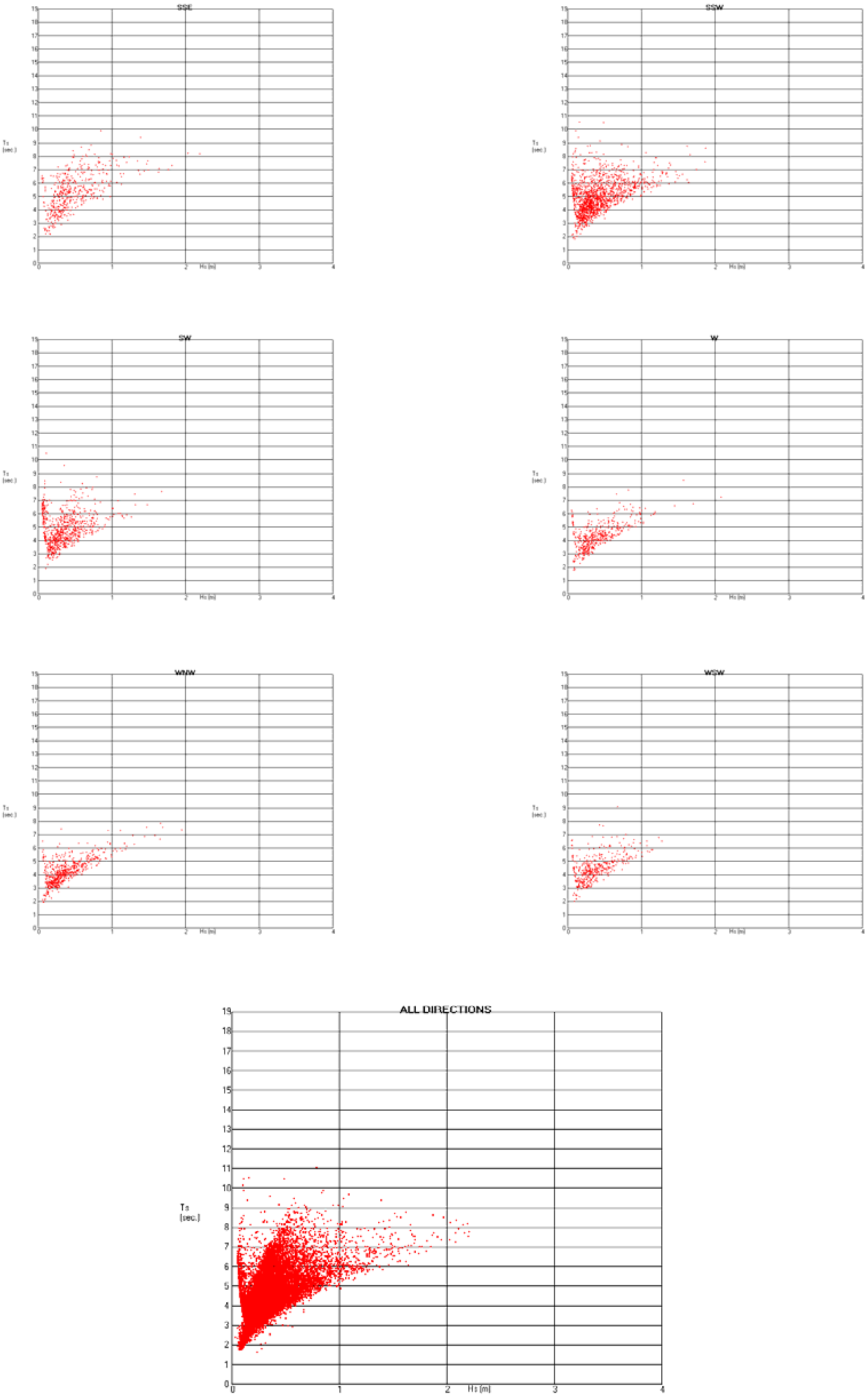


Figure 4.5.7 Relationship Between MPPS and SHPS at Babakale (continued)

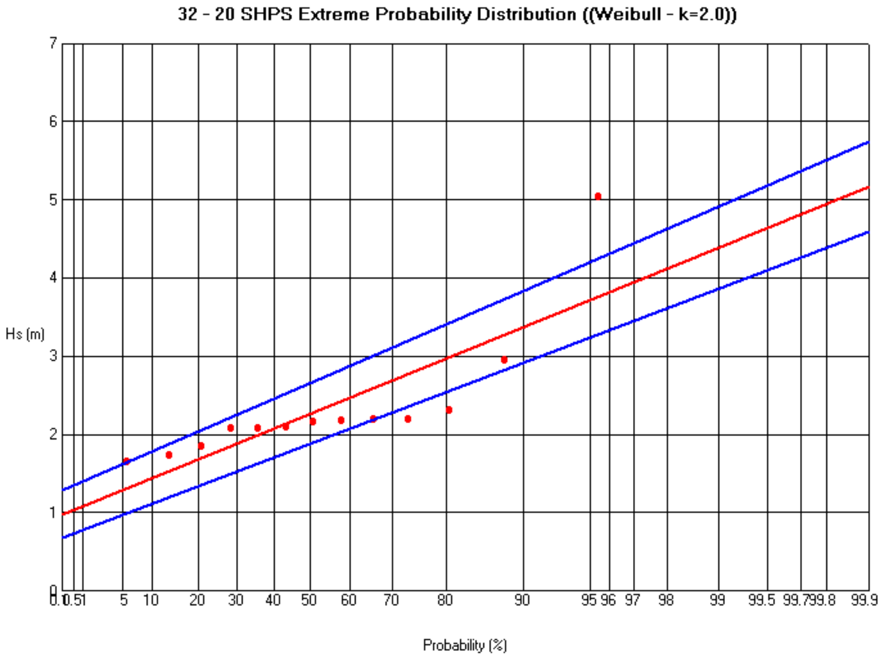


Figure 4.5.8 Extreme Probability Distribution Babakale

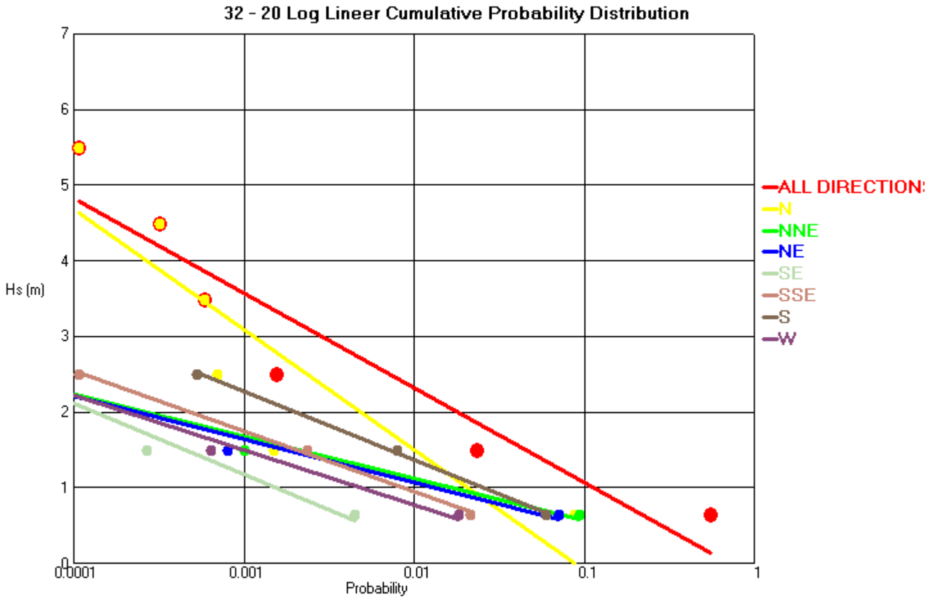


Figure 4.5.9 Log-lineer Cumulative Probability Distribution at Babakale

4.6 LOCATION –AMASRA (41.76 N 32.40 E)

A point at the offshore location near Amasra is selected at coordinates 41.76 N 32.40 E (at 45x25 grid nodes). The point is approximately 1 km north of Amasra about 1 km away from the shoreline.

Following figures given in this section are the results of the analysis of wind, wind wave and swell wave analysis for Amasra region.

Wind roses given in Figure 4.6.1 shows that the location near Amasra is subject to mainly WSW, NE and ENE winds during a year. However during winter and summer periods NE and ENE winds dominate. In winter, wind speed rise above 15 m/s from ENE direction.

Wind wave roses given in Figure 4.6.2 show directional distribution and height of incoming wind waves. It is seen from the graphs that 9.9% of the time wind waves are coming from NE, 8.8% of the time wind waves are coming from ENE, 4.6% of the time wind waves are coming from WSW directions in a year. Additionally, NE directed wind waves' percentile becomes 13.6% in summer period. The maximum wind wave height is 3.8 meters from the direction of NE.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.6.3. From this figure the steepness of wind waves in the region representing all years from all directions is computed as 0,047 for the wave height greater than 1 m in deep water. Wind wave domination from directions NE, ENE and WSW can be seen from these figures. Throughout the observation period wind waves are observed to be generally less than 4 m at offshore Amasra. Maximum significant wave height is observed form NE and height is observed to be 4.5 meters. The corresponding wave period is 8.2 s.

The graph of extreme value probability statistics is given in Figure 4.6.4. Data values show high correlation. Significant wind wave height is estimated as

5.0 m for 30 year return period in this region according to the duration of analyzed data.

Figure 4.6.5 shows log-linear cumulative probability distribution of wind waves for Amasra region. The figure is drawn to present dominant directions individually and all directions' data as whole. It is seen from this graph that significant height of wind waves in deep water exceeds 4.5 meters in about 10 hours duration every year.

Figure 4.6.6 shows swell wave rose. The roses show a clear indication of direction of incoming swell waves. As expected from the geographic location of Anamur, swell waves from N, NNW, NNE and NE direction are dominant with respect to other directions. Swell waves from direction NE are observed almost 16% of a year and nearly 13.7 % of the time swell waves are coming from NNW direction. In winter percentile of swell wave from N becomes 14.6%. The maximum swell wave height is 3.0 meters. The period of some waves becomes higher than 8 seconds reaching up to 10 seconds for some waves.

The relations between Significant Wave Height (H_s) vs. Mean Wave Period (T_m) are given in Figure 4.6.7. Swell wave domination from directions N, NNW can be observed from these graphs. A rather more scattered distribution is observed in NE direction. Several data points, exceeding 8.5 second periods and few data points exceeding 2.5 m of swell wave heights are observed from N direction with a maximum wave height of 3.4 m.

The graph of extreme value probability statistics is given in Figure 4.6.8. Data values show a good correlation. Significant wave height is estimated as 4.1 m for 30 year return period.

Log-linear cumulative probability distribution for swell waves is given in Figure 4.6.9. Dominating directions are plotted along with all directions' data as whole. It is seen from the graph that significant height of swell waves exceeds 2.8 meters in about 10 hours duration every year.

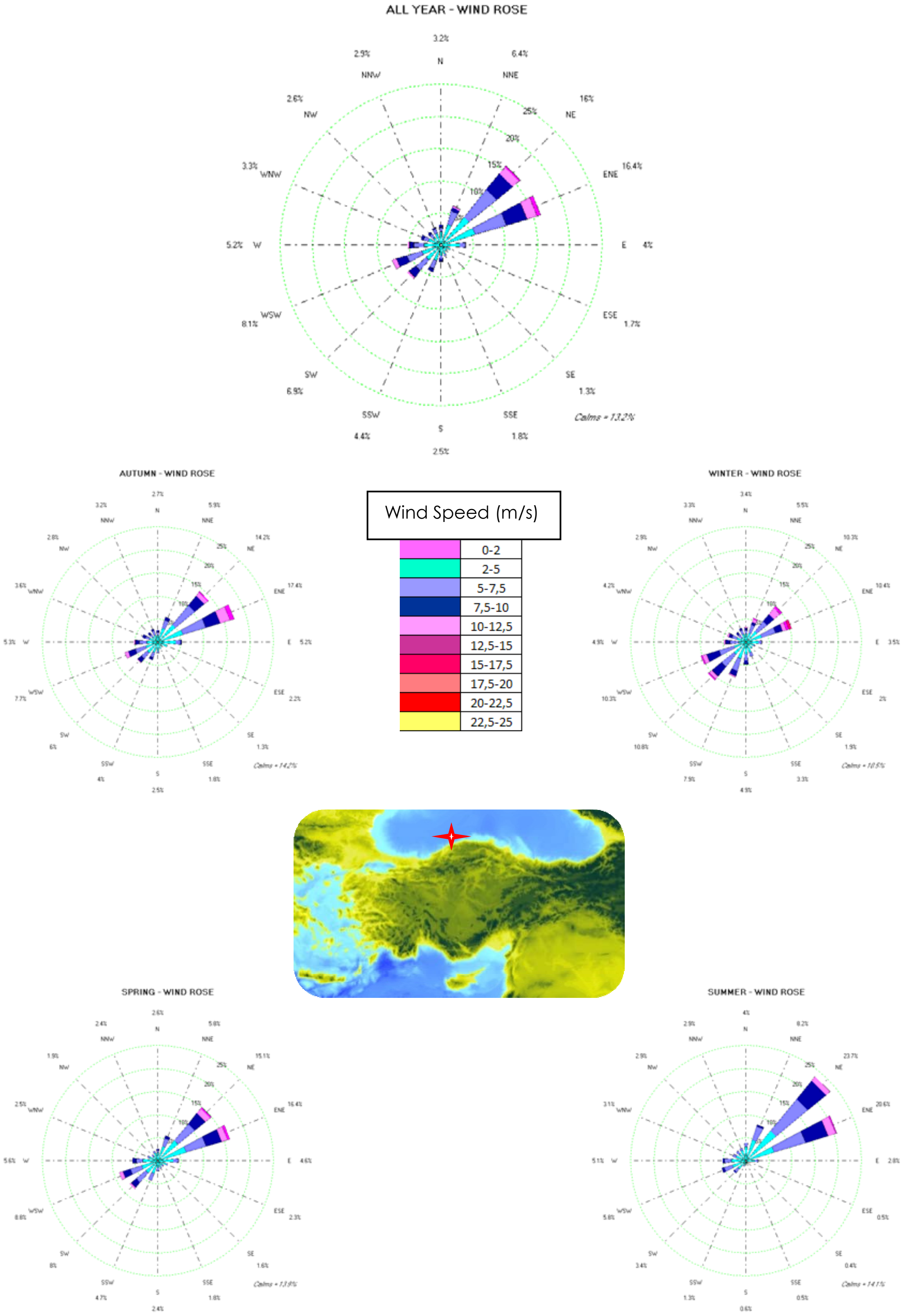


Figure 4.6.1 Wind Climate at Amasra

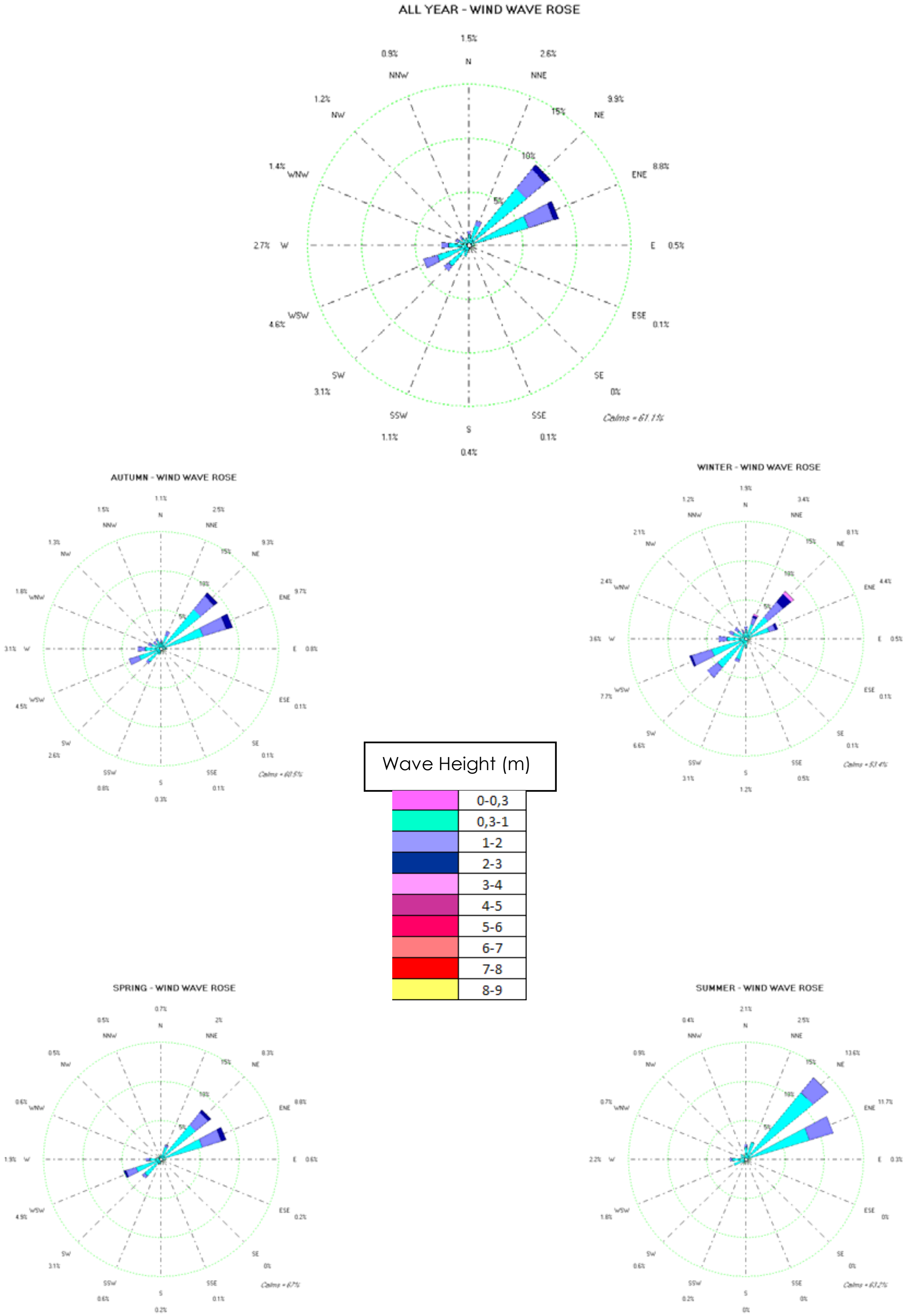


Figure 4.6.2 Wind Wave Climate at Amasra

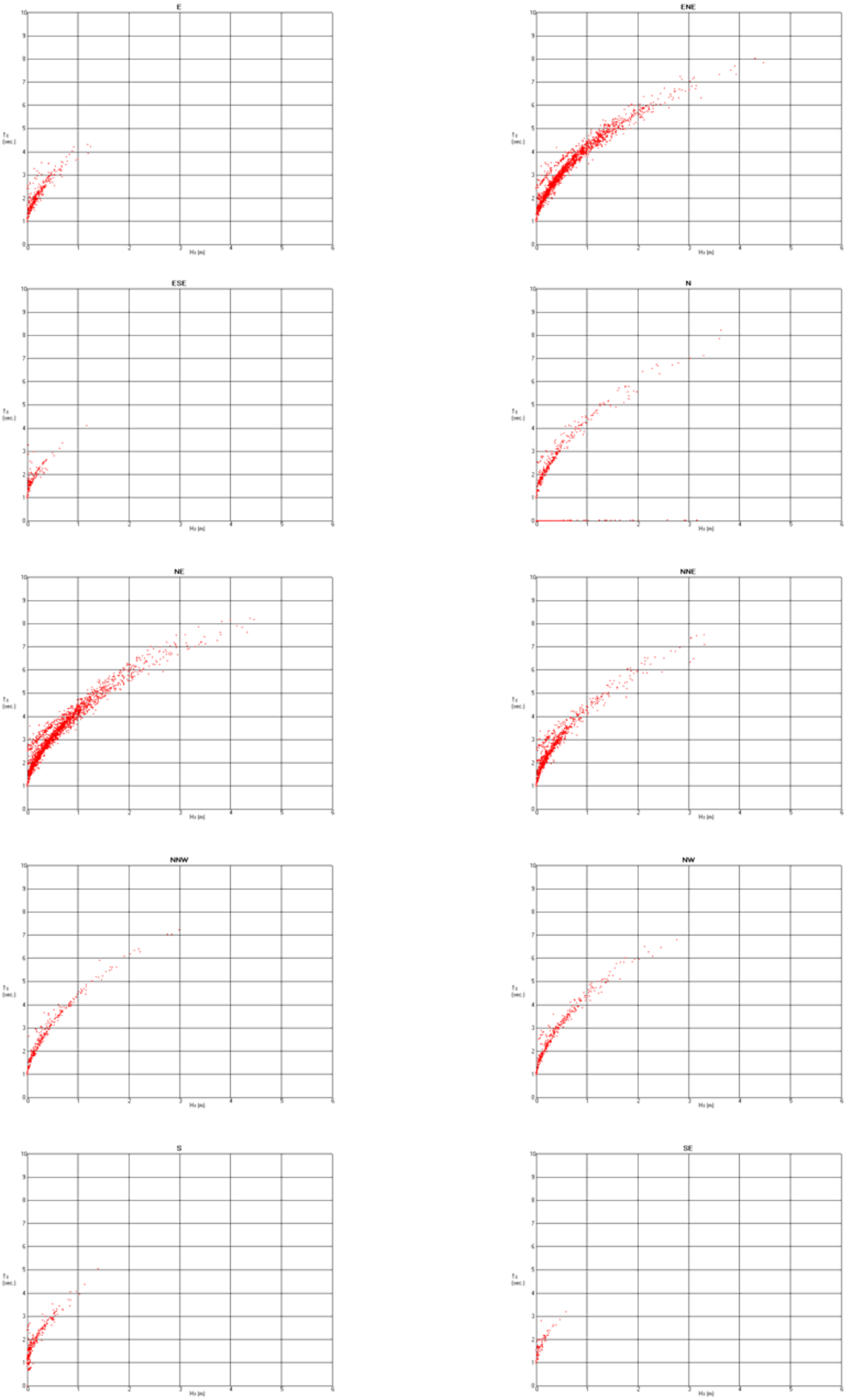


Figure 4.6.3 Relationship between MPWW & SHWW at Amasra

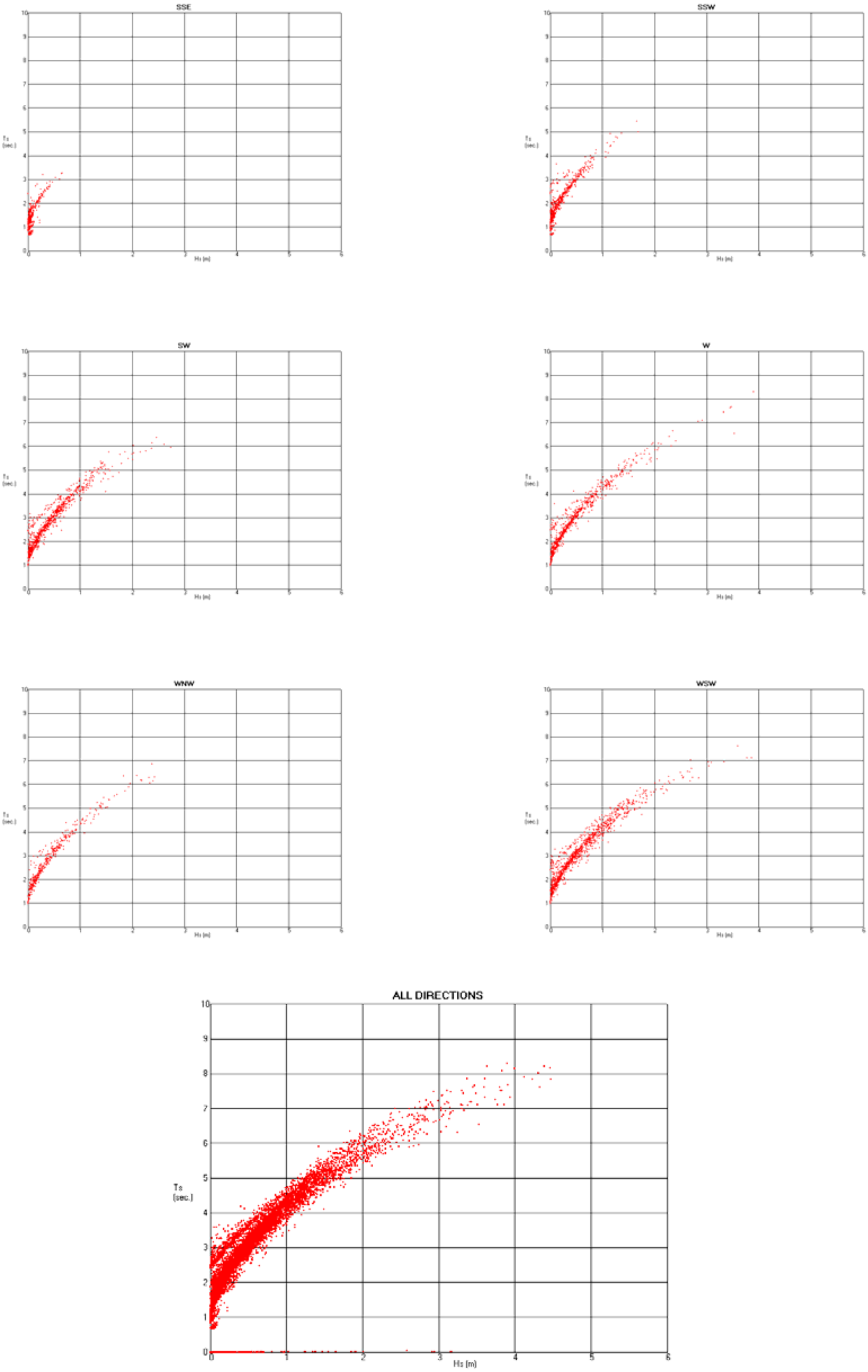


Figure 4.6.3 Relationship between MPWW & SHWW at Amasra (continued)

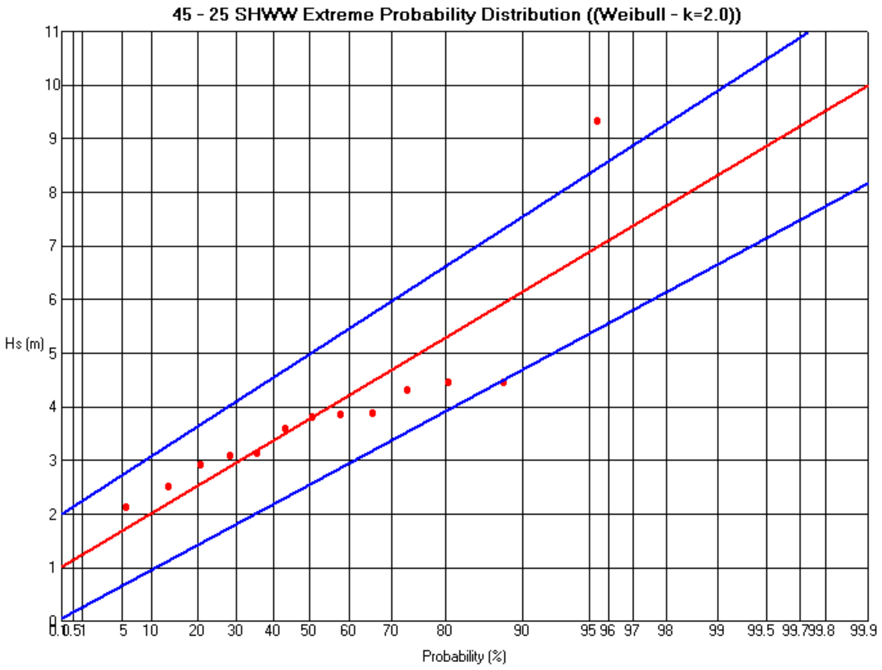


Figure 4.6.4 Extreme Probability Distribution of SHWW at Amasra

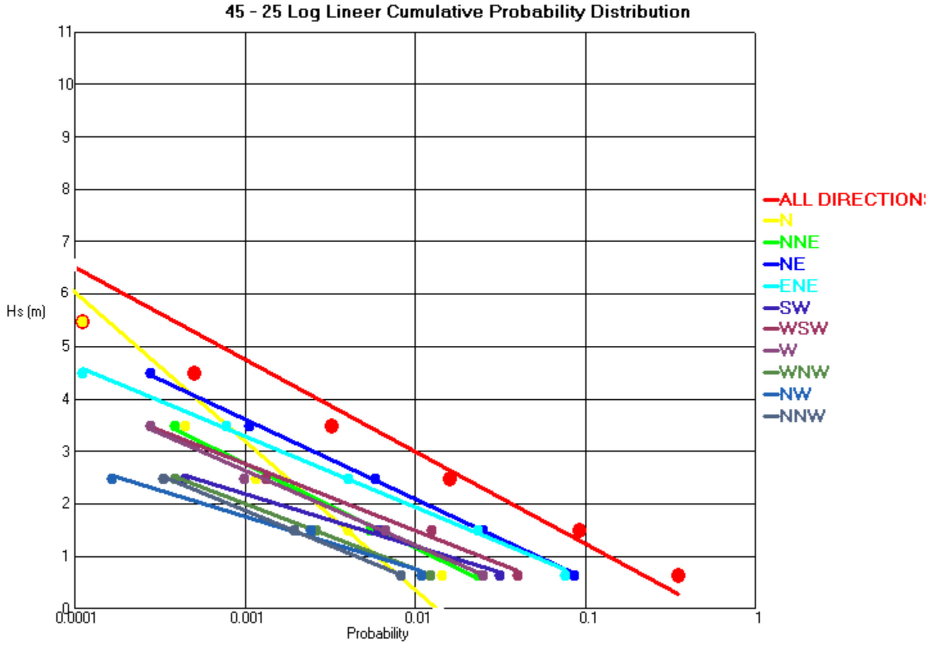


Figure 4.6.5 Log-lineer Cumulative Probability Distribution of SHWW at Amasra

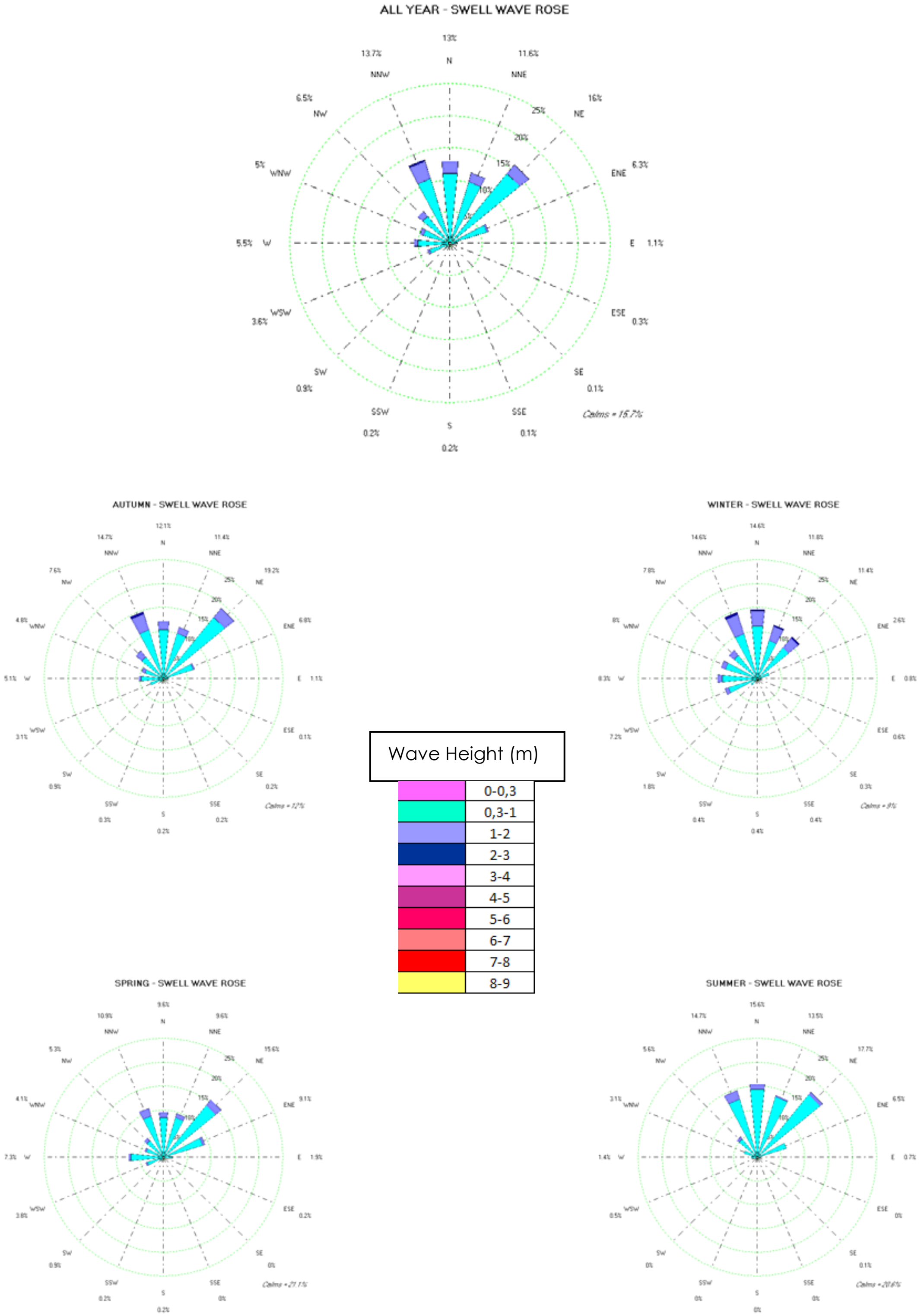


Figure 4.6.6 Swell Wave Climate at Amasra

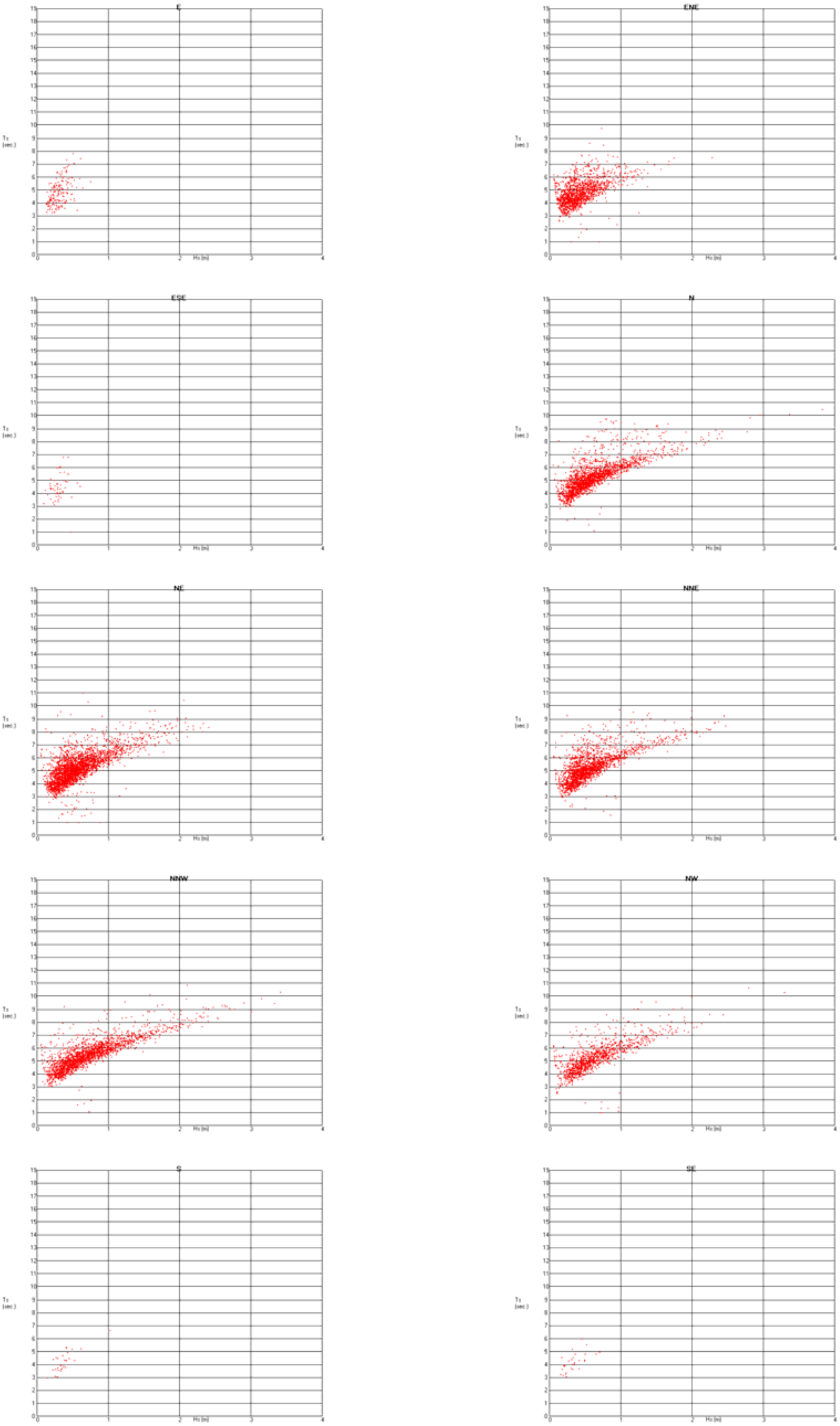


Figure 4.6.7 Relationship between MPPS and SHPS at Amasra

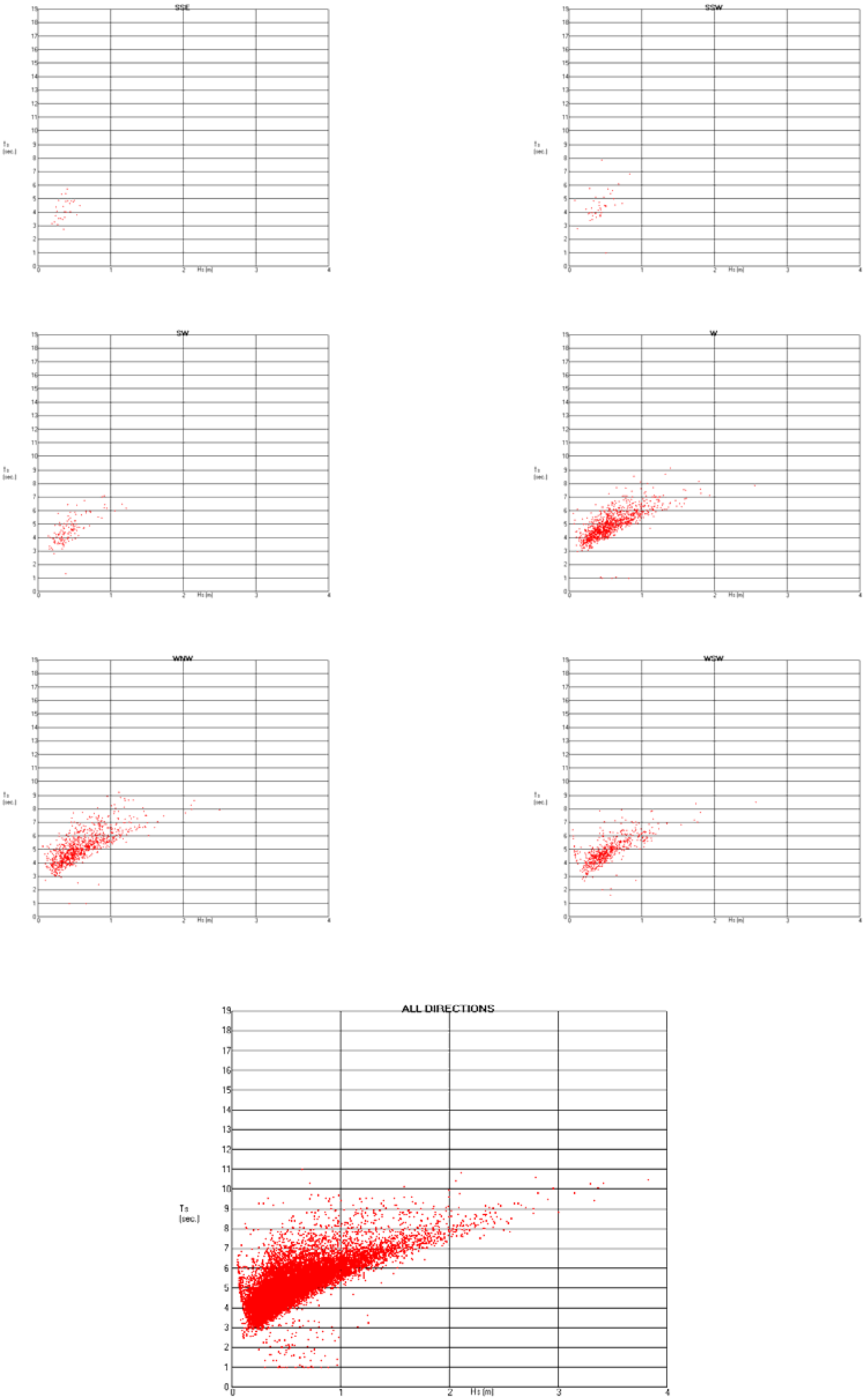


Figure 4.6.7 Relationship between MPPS and SHPS at Amasra (continued)

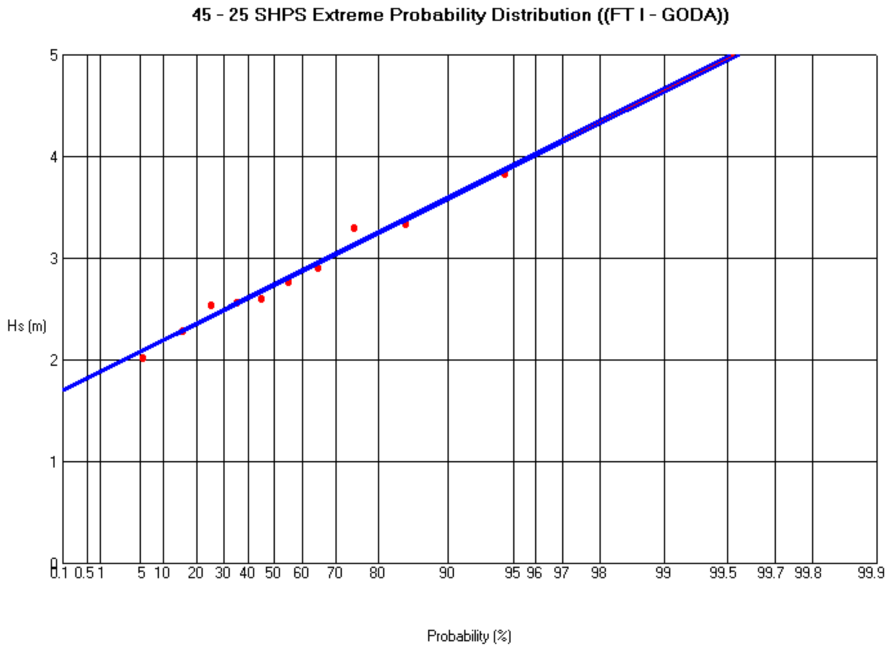


Figure 4.6.8 Extreme Probability Distribution of SHPS at Amasra

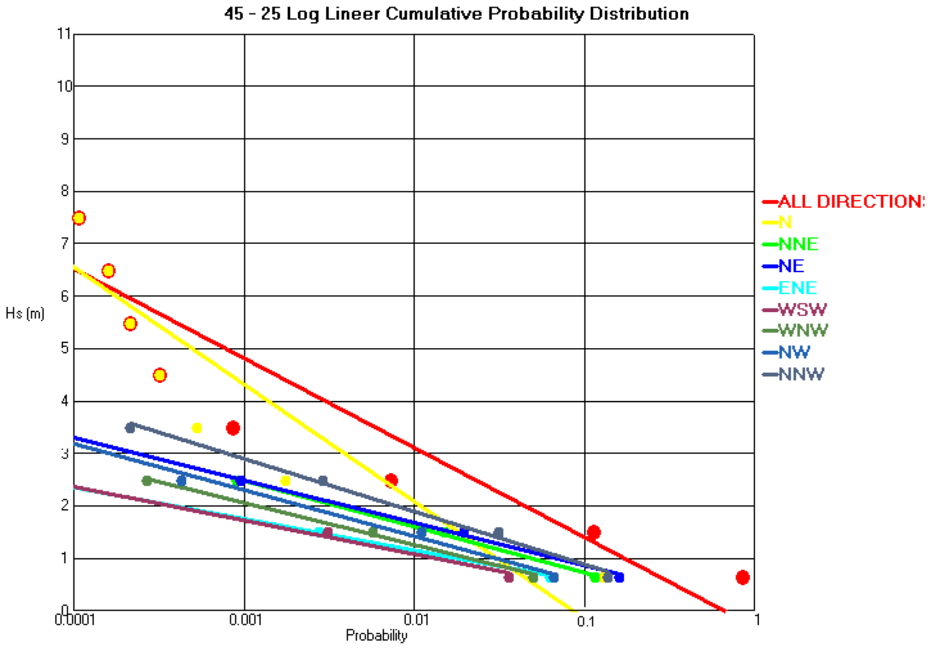


Figure 4.6.9 Log-lineer Cumulative Probability Distribution of SHPS at Amasra

4.7 LOCATION – ÇATALZEYTİN (41.96 N 34.22 E)

A point at the offshore location near Çatalzeytin town of Kastamonu at the Black Sea is selected at coordinates 41.96 N 34.22 E (at 48x25 grid nodes). The point is approximately 1 km north of Çatalzeytin about 1 km away from the shoreline.

Following figures given in this section are the results of the analysis of wind, wind wave and swell wave analysis for Çatalzeytin region.

Wind roses given in Figure 4.7.1 shows that the location near Çatalzeytin is subject to mainly WSW, W and ENE winds during a year. However during winter period WSW, W and S winds dominates. In winter wind speed rise up to 12 m/s from NNE.

Wind wave roses given in Figure 4.7.2 show directional distribution and height of incoming wind waves. It is seen from the graphs that 6.7% of the time wind waves are coming from ENE, 6.6% of the time wind waves are coming from W directions in a year. In winter period, WSW directed wind waves' percentile becomes 7.2%. The maximum wind wave height is 3.5 meters from the direction of W.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.7.3. From this figure the steepness of wind waves in the region representing all years from all directions is computed as 0,045 for the wave height greater than 1 m in deep water. Wind wave domination from directions ENE, W and WSW can be seen from these figures. Throughout the observation period wind waves are observed to be generally less than 3 m at offshore Çatalzeytin. Maximum significant wave height is observed form W and height is observed to be 3.5 meters. The corresponding wave period is 8 second.

The graph of extreme value probability statistics is given in Figure 4.7.4. Data values show high correlation. Significant wind wave height is estimated as

7.20 m for 30 year return period in this region according to the duration of analyzed data.

Figure 4.7.5 shows log-linear cumulative probability distribution of wind waves for Amasra region. The figure is drawn to present dominant directions individually and all directions' data as whole. It is seen from this graph that significant height of wind waves in deep water exceeds 2.5 meters in about 10 hours duration every year.

Figure 4.7.6 shows swell wave rose. The roses show a clear indication of direction of incoming swell waves. As expected from the geographic location of Çatalzeytin, swell waves from N, NNW, NNE and NE direction are dominant with respect to other directions. Swell waves from direction NNW are observed almost 13.1% of a year and nearly 12.4 % of the time swell waves are coming from NNE direction. In winter percentile of swell wave from N becomes 14.2%. The maximum swell wave height is 2.5 meters. The corresponding swell wave period is 8.5 seconds.

The relations between Significant Wave Height (H_s) vs. Mean Wave Period (T_m) are given in Figure 4.7.7. Swell wave domination from directions N, NNW and NNE can be observed from these graphs. A rather more scattered distribution is observed in NW direction. Several data points, exceeding 8.5 second periods and few data points exceeding 2.5 m of swell wave heights are observed from NNW direction.

The graph of extreme value probability statistics is given in Figure 4.7.8. Data values show a good correlation. Significant wave height is estimated as 4.4 m for 30 year return period.

Log-linear cumulative probability distribution for swell waves is given in Figure 4.7.9. Dominating directions are plotted along with all directions' data as whole. It is seen from the graph that significant height of swell waves exceeds 2.6 meters in about 10 hours duration every year.

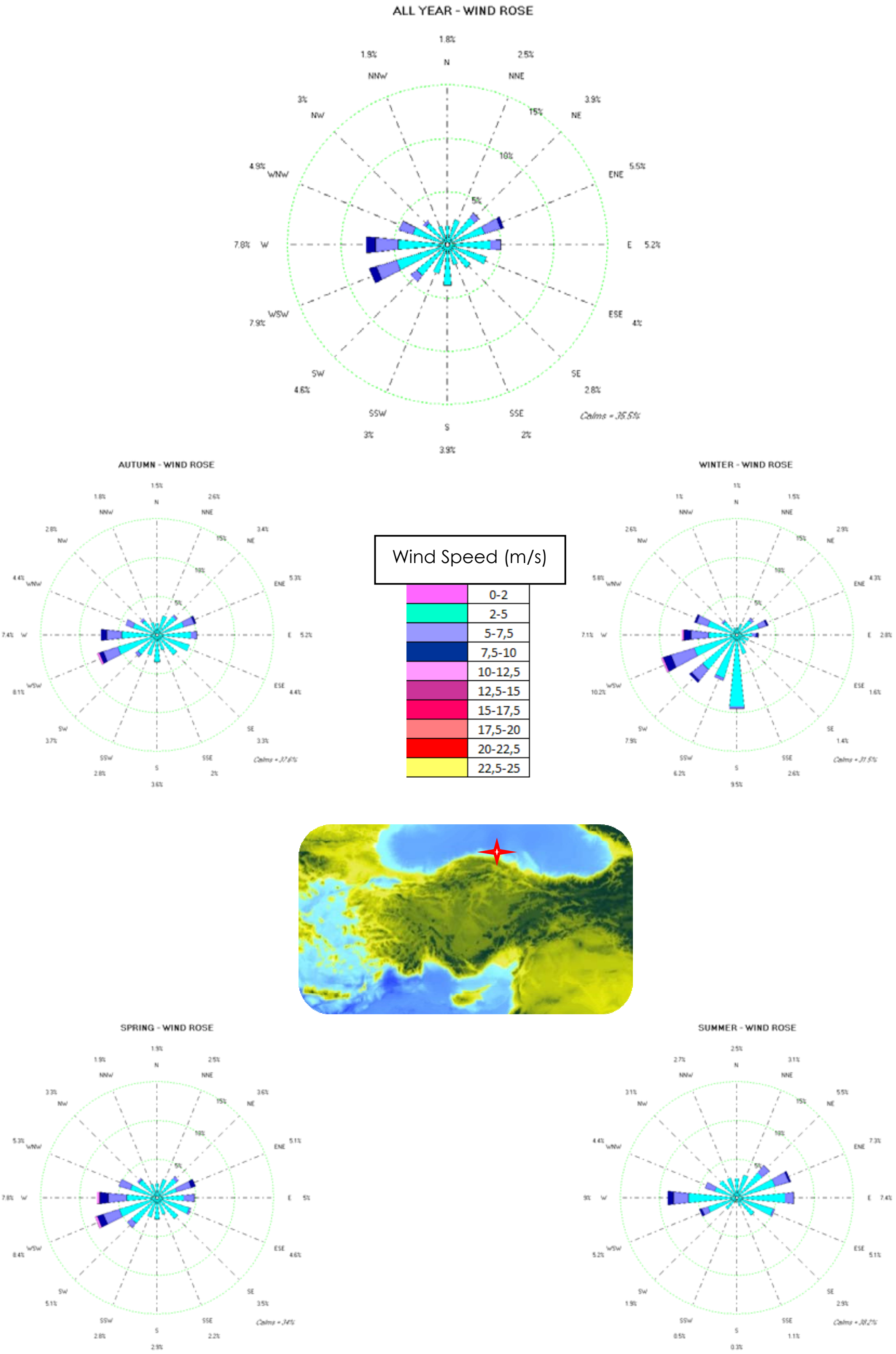


Figure 4.7.1 Wind Climate at Çatalzeytin

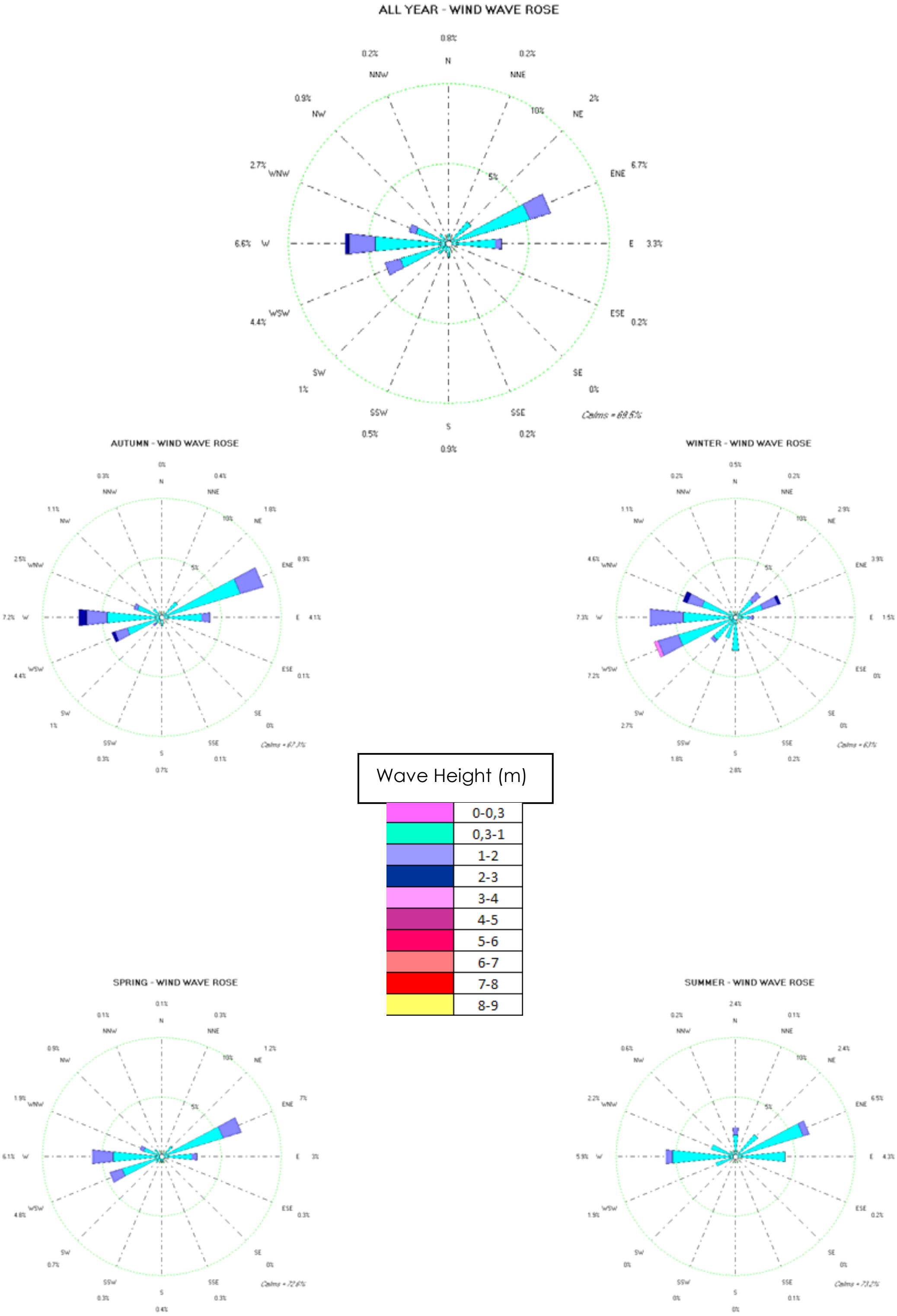


Figure 4.7.2 Wind Wave Climate at Çatalzeytin

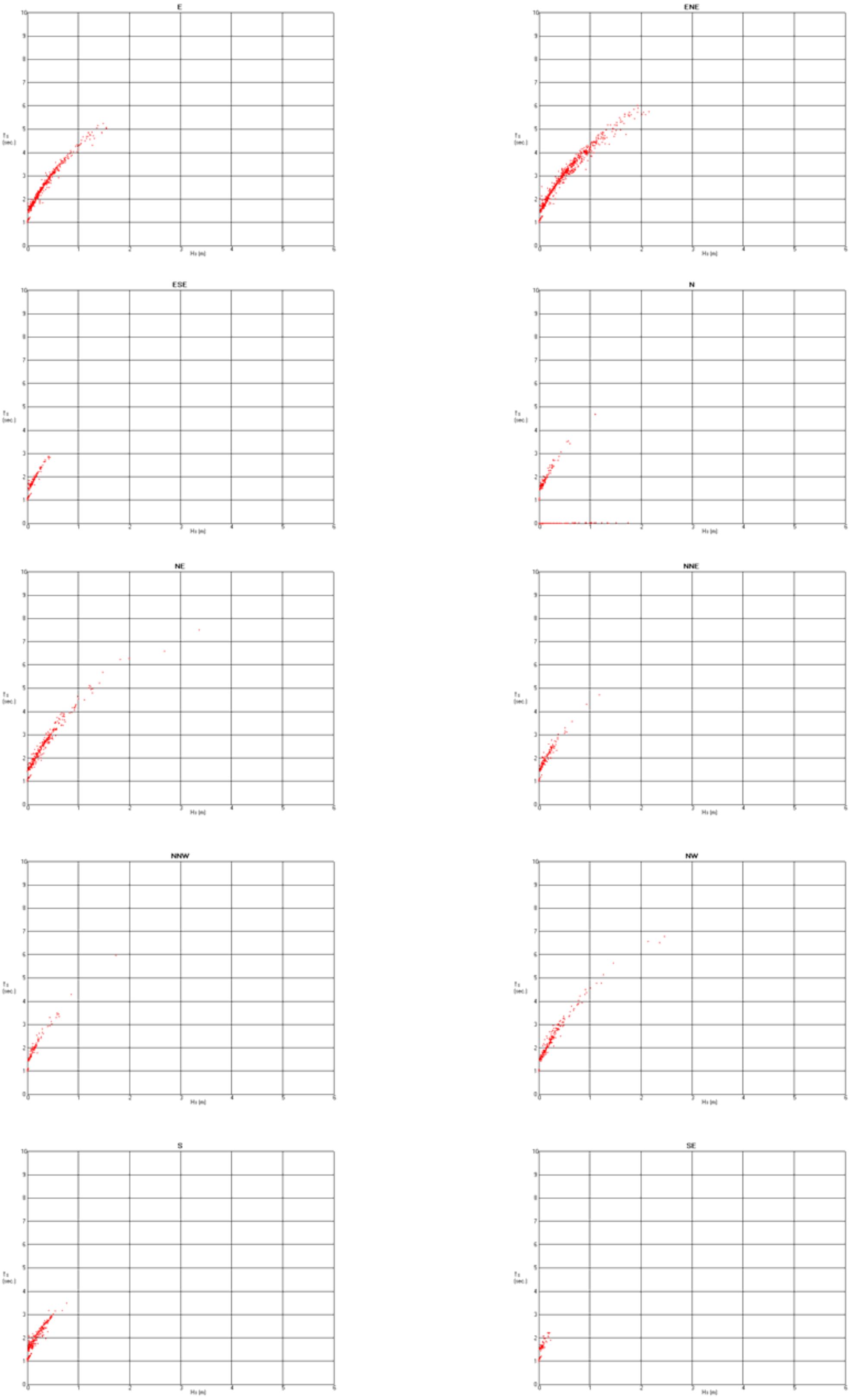


Figure 4.7.3 Relationship between MPWW & SHWW at Çatalzeytin

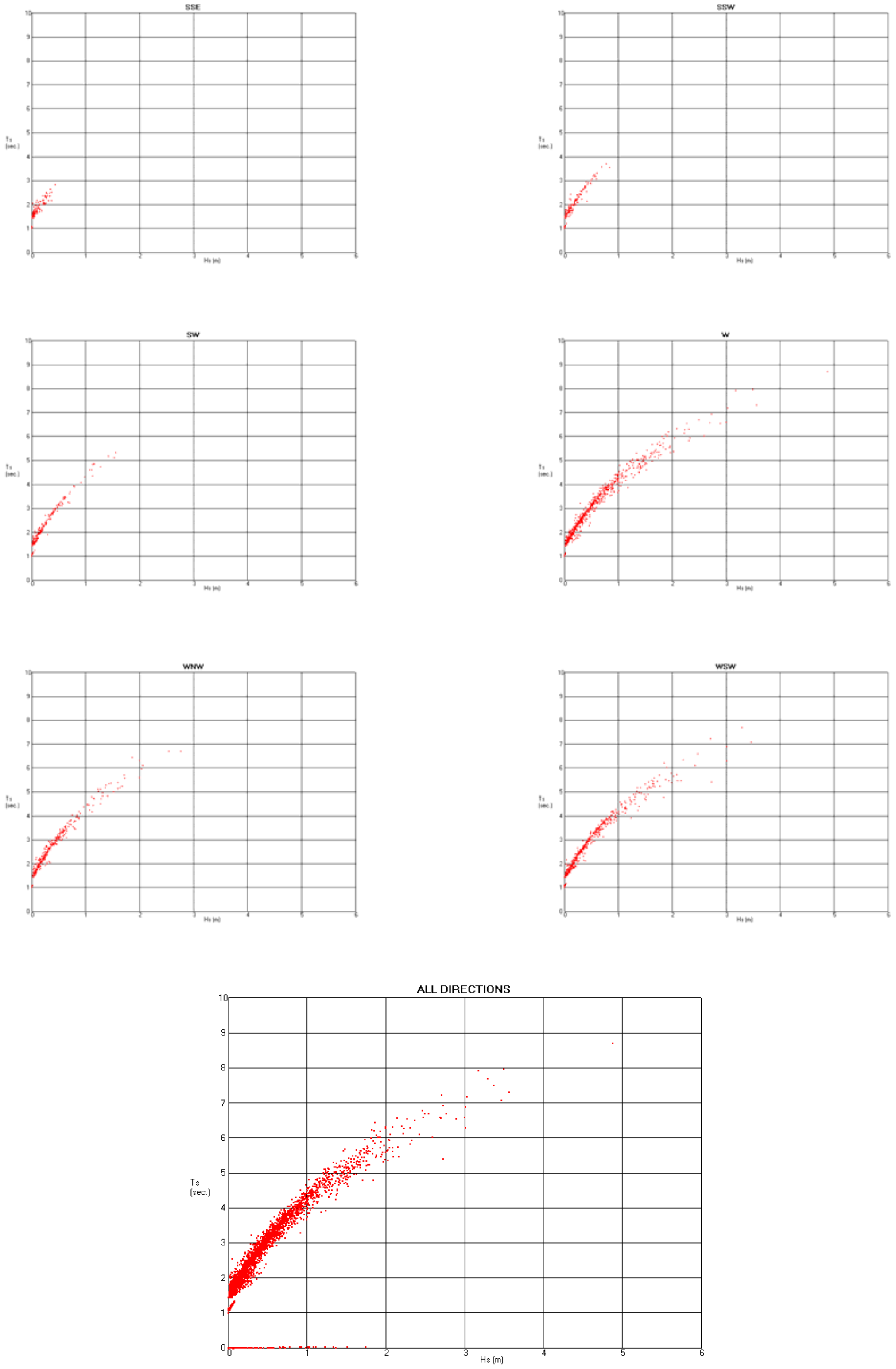


Figure 4.7.3 Relationship between MPWW & SHWW at Çatalzeytin (continued)

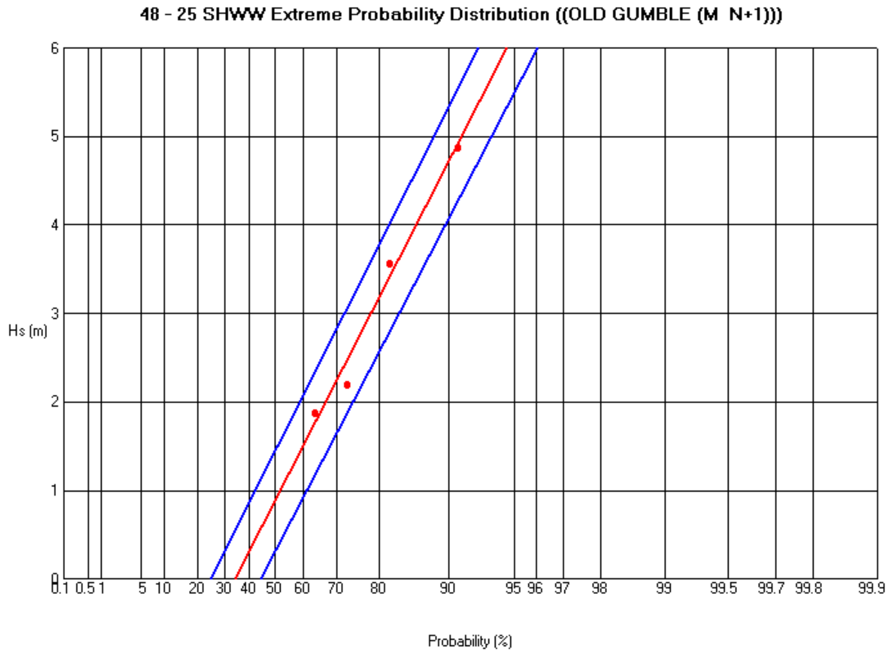


Figure 4.7.4 Extreme Probability Distribution of SHWW at Catalzeytin

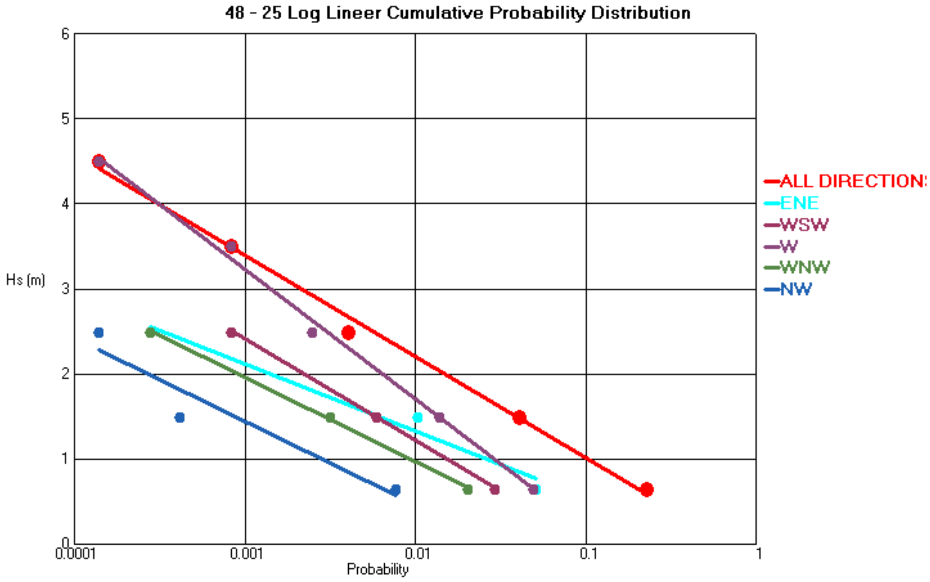


Figure 4.7.5 Log-lineer Cumulative Probability Distribution of SHWW at Çatalzeytin

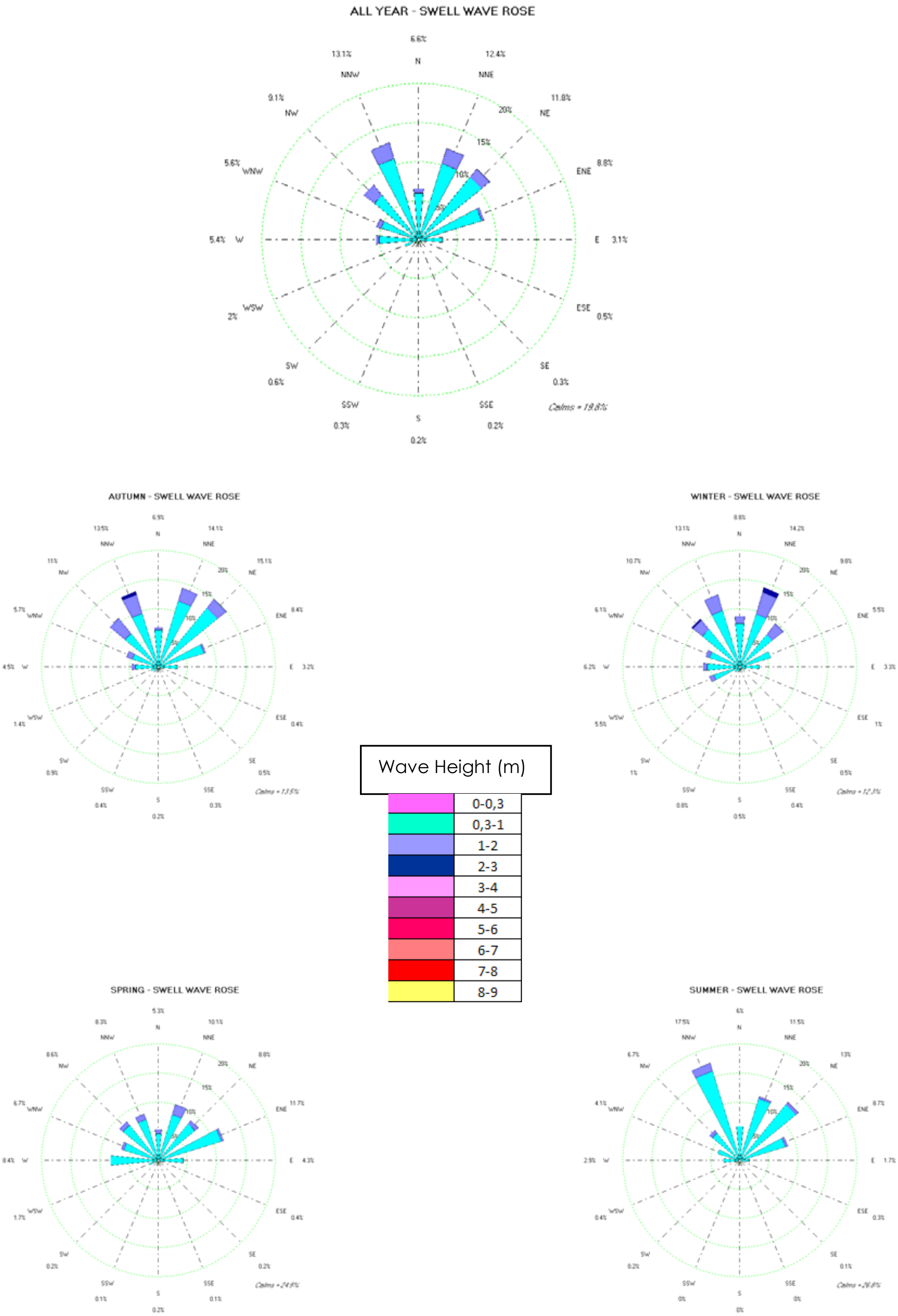


Figure 4.7.6 Swell Wave Climate at Çatalzeytin

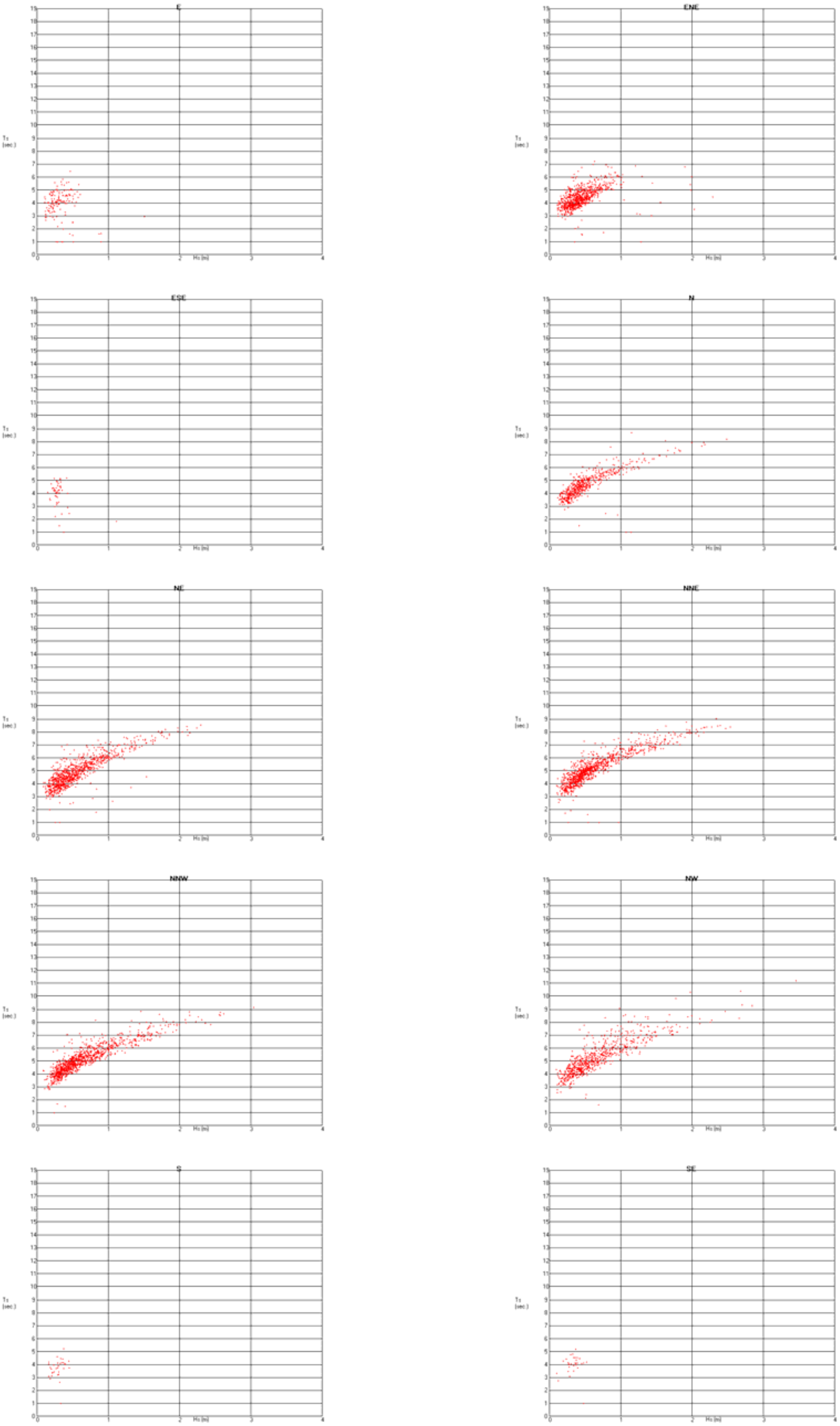


Figure 4.7.7 Relationship between MPPS and SHPS at Çatalzeytin

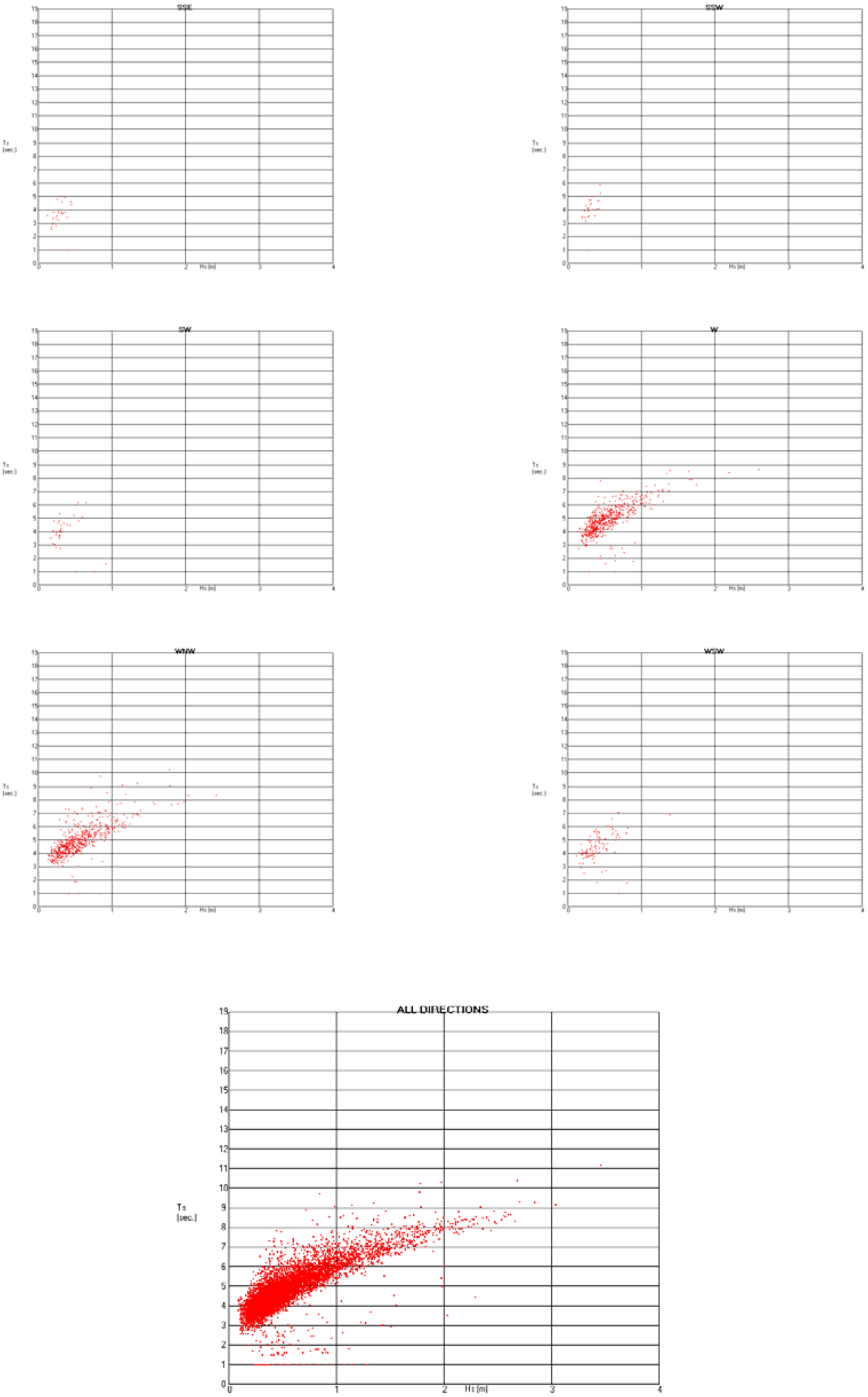


Figure 4.7.7 Relationship between MPPS and SHPS at Çatalzeytin (continued)

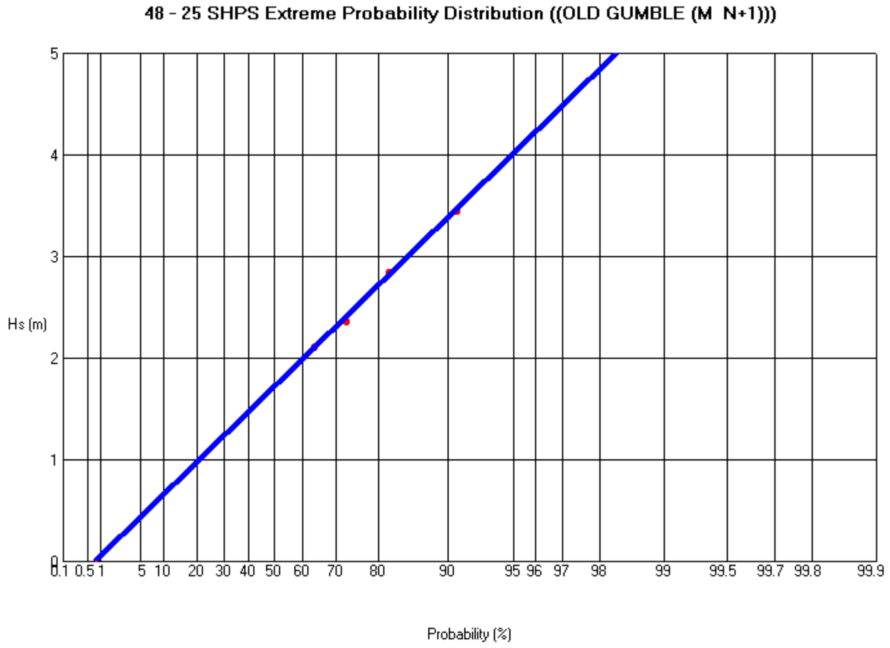


Figure 4.7.8 Extreme Probability Distribution of SHPS at Çatalzeytin

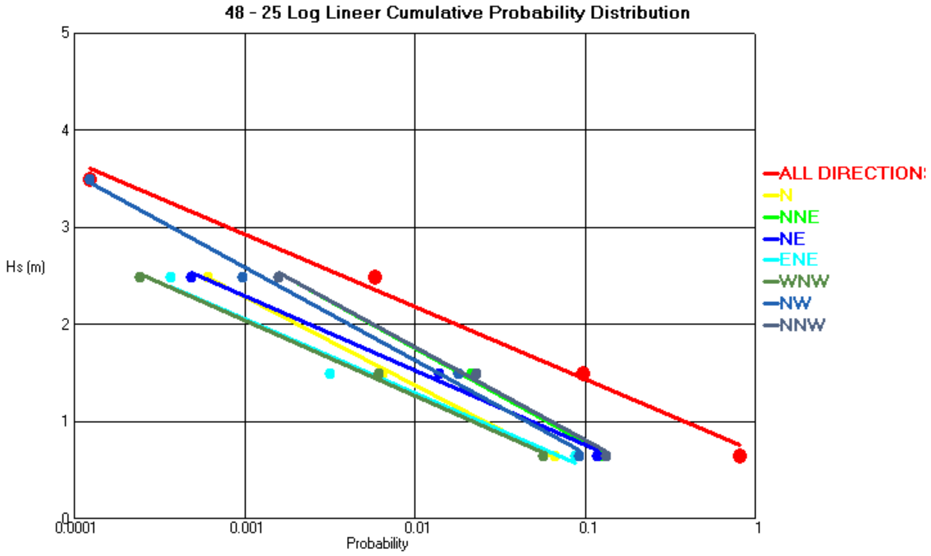


Figure 4.7.9 Log-lineer Cumulative Probability Distribution of SHWW at Çatalzeytin

4.8 LOCATION –MERSİNKÖY (41.09 N 39.48 E)

A point at the offshore location near Akçaabat town of Trabzon at the Black Sea is selected at coordinates 41.09 N 39.48 E (at 59x23 grid nodes). The point is approximately 12 km northwest of Akçaabat about 2 km away from the shoreline.

Following figures given in this section are the results of the analysis of wind, wind wave and swell wave analysis for Mersinköy region.

Wind roses given in Figure 4.8.1 shows that the location near Mersinköy is subject to mainly W, WSW and NNE winds during a year. However during winter period SSE winds also become significant in number of occurrence. In winter wind speed rise up to 8.5 m/s from W and WNW direction.

Wind wave roses given in Figure 4.8.2 show directional distribution and height of incoming wind waves. It is seen from the graphs that this location does not receive much wind wave. It is seen from graphs that 1.9% of the time wind waves are coming from W, 1.5% of the time wind waves are coming from WSW and 1.6% of the time wind waves come from SSE directions in a year. In winter period, W directed wind waves' percentile becomes 4.8%. The maximum wind wave height is 2.2 meters from the direction of W.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.8.3. From this figure the steepness of wind waves in the region representing all years from all directions is computed as 0,049 for the wave height greater than 1 m in deep water. Wind wave domination from directions W and WSW can be seen from these figures. Throughout the observation period wind waves are observed to be generally less than 1.5 m at offshore Mersinköy. Maximum significant wave height is observed form W and height is observed to be 2.2 meters. The corresponding wave period is 6.0 second.

Since there is not enough data extreme value statistics is not studied.

Figure 4.8.5 shows log-linear cumulative probability distribution of wind waves for Mersinköy region. The figure is drawn to present dominant directions WNW and all directions' data as whole. It is seen from this graph that significant height of wind waves in deep water exceeds 1.5 meters in about 10 hours duration every year.

Figure 4.8.6 shows swell wave rose. The roses show a clear indication of direction of incoming swell waves. As expected from the geographic location of Mersinköy, swell waves from NW and NNW direction are dominant with respect to other directions. Swell waves from direction NW are observed almost 28.5% of a year and nearly 14.4% of the time swell waves are coming from NNW direction. In winter percentile of swell wave from NW becomes 30.6%. The maximum swell wave height is 2.25 meters. The corresponding swell wave period is 8.5 seconds.

The relations between Significant Wave Height (H_s) vs. Mean Wave Period (T_m) are given in Figure 4.8.7. Swell wave domination from directions NW can be observed from these graphs. Several data points, exceeding 6.5 second periods and few data points exceeding 1.5 m of swell wave heights are observed from NW direction.

Since there is not enough data extreme value statistics is not studied.

Log-linear cumulative probability distribution for swell waves is given in Figure 4.8.8. Dominating directions are plotted along with all directions' data as whole. It is seen from the graph that significant height of swell waves exceeds 1.8 meters in about 10 hours duration every year.

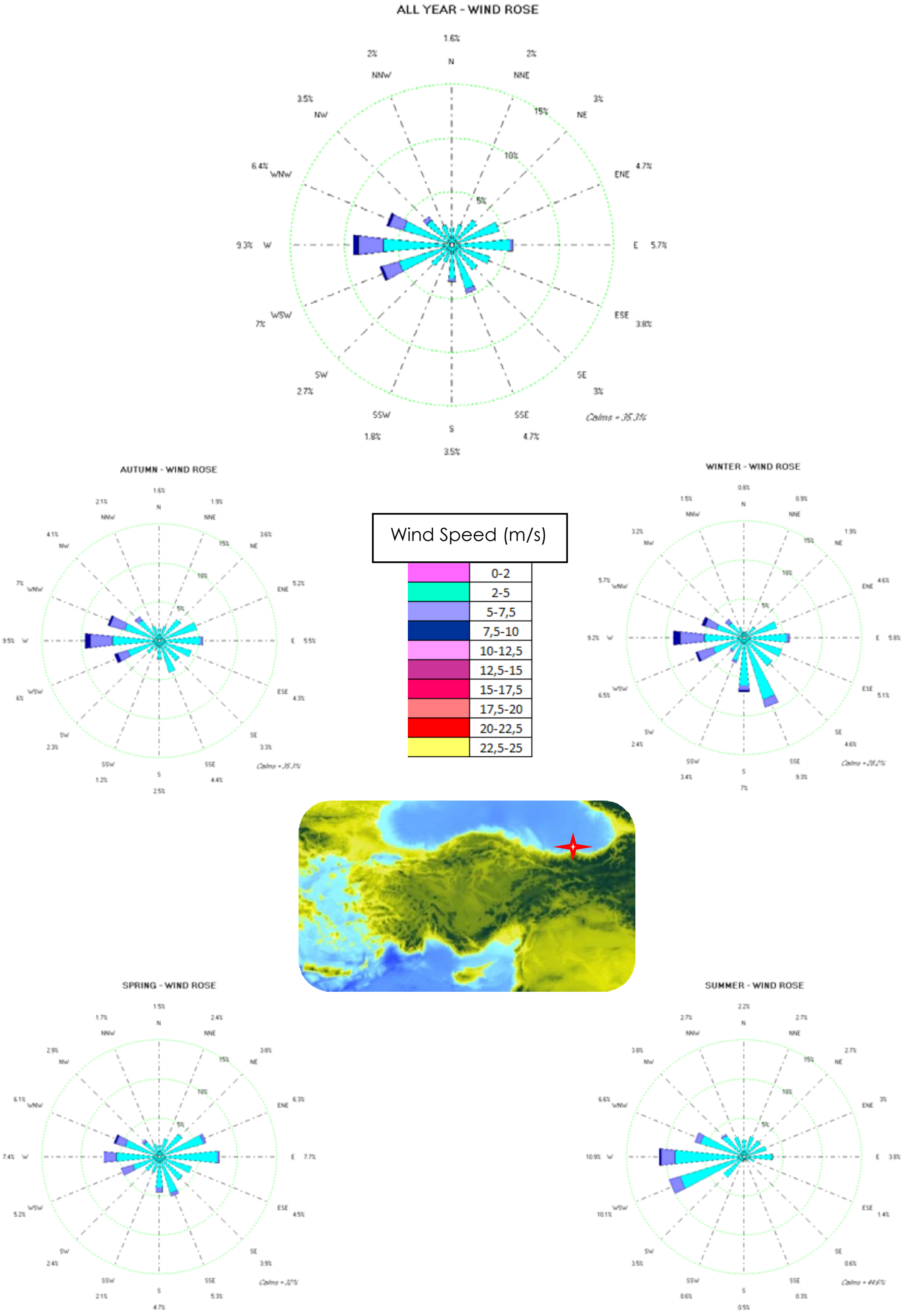


Figure 4.8.1 Wind Climate at Mersinköy

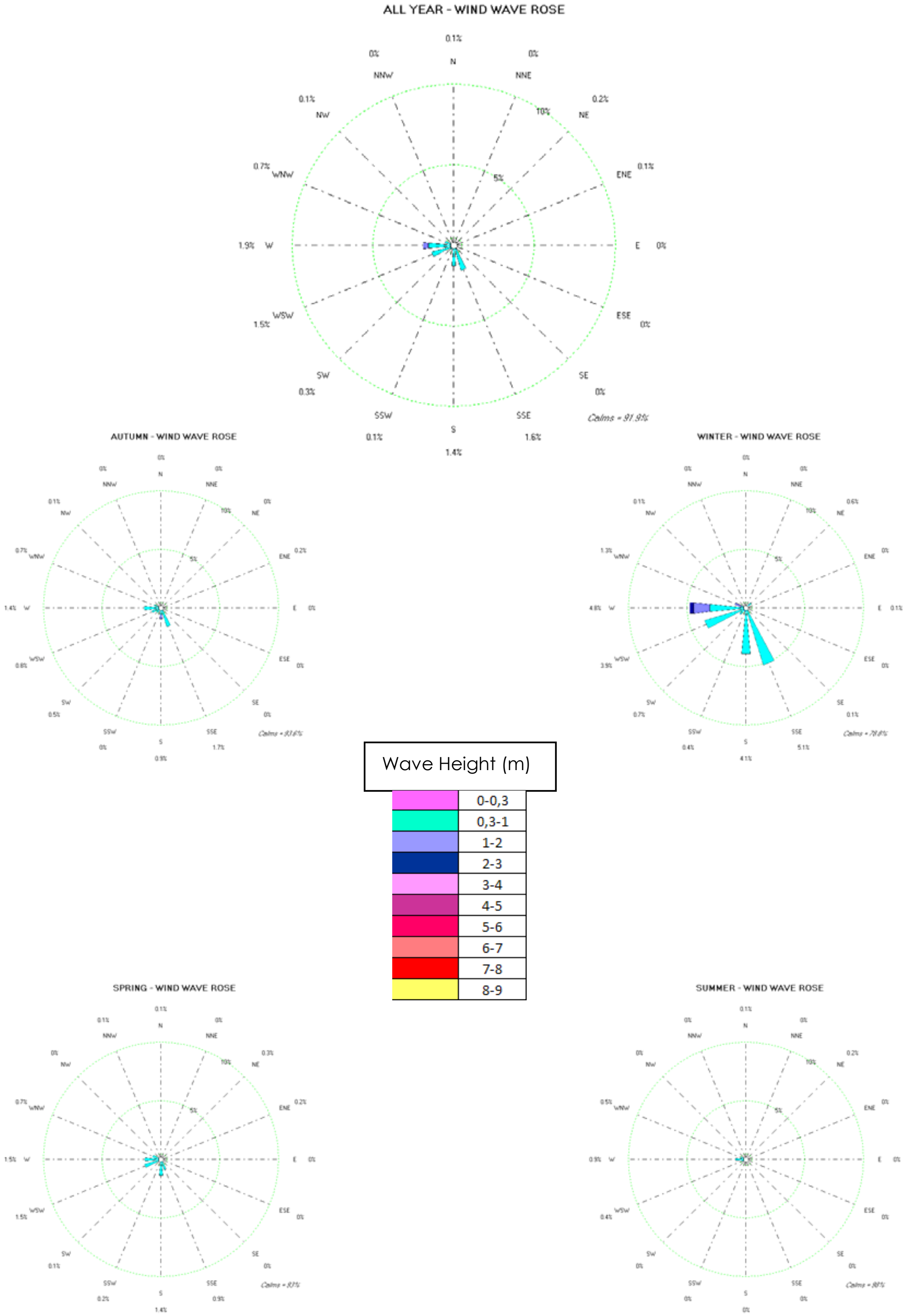


Figure 4.8.2 Wind Wave Climate at Mersinköy

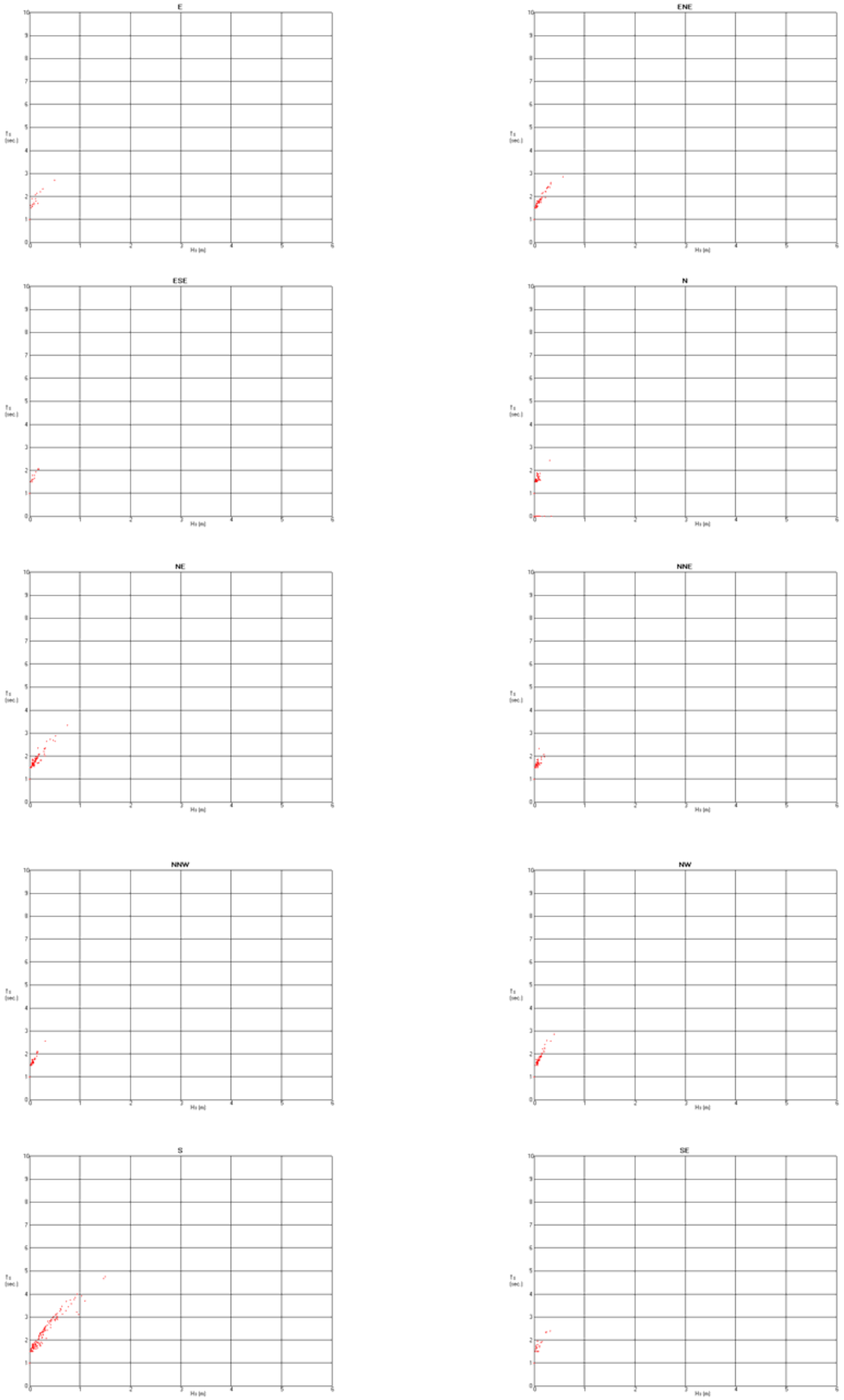


Figure 4.8.3 Relationship between MPWW & SHWW at Mersinköy

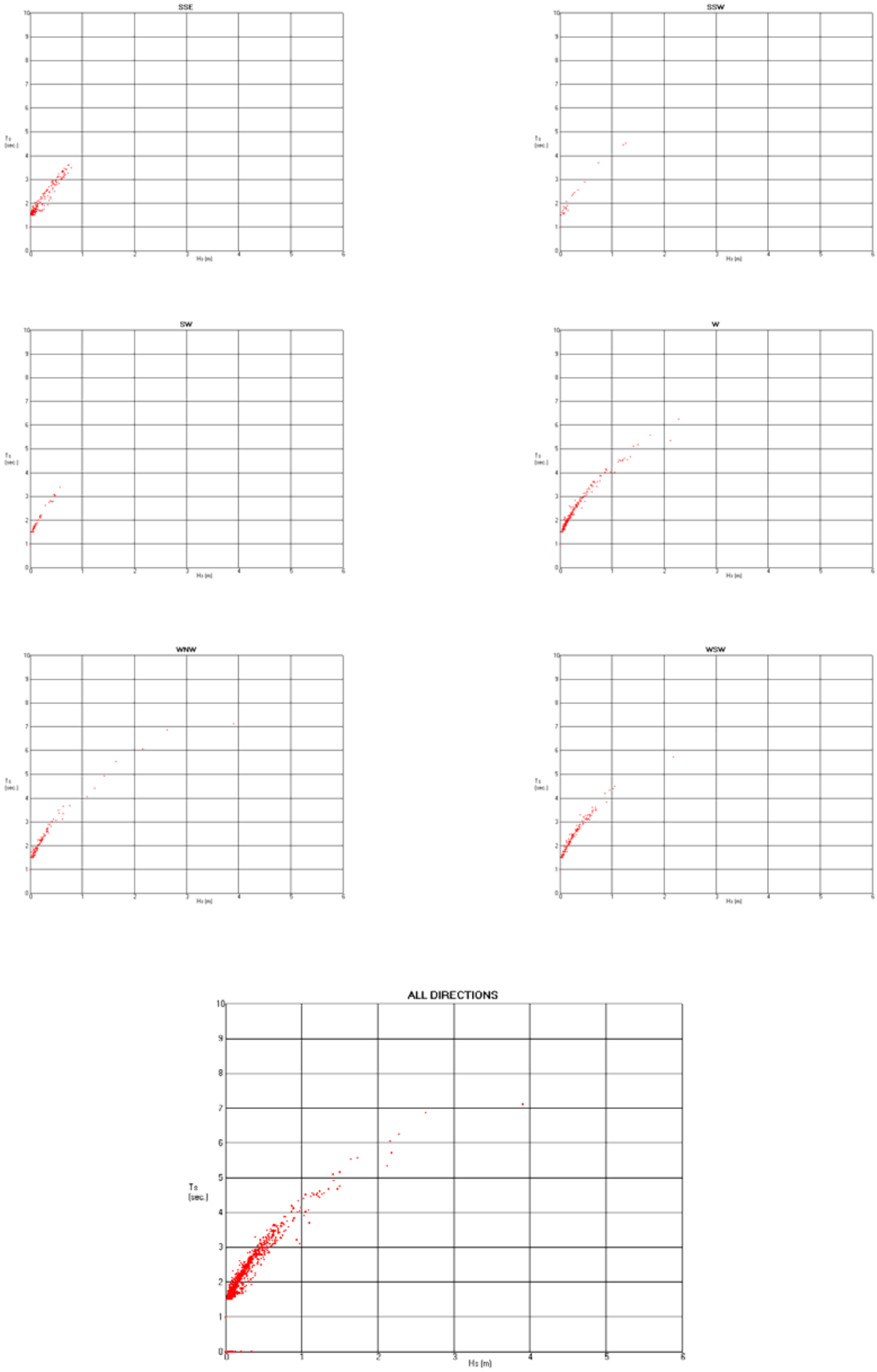


Figure 4.8.3 Relationship between MPWW & SHWW at Mersinköy (continued)

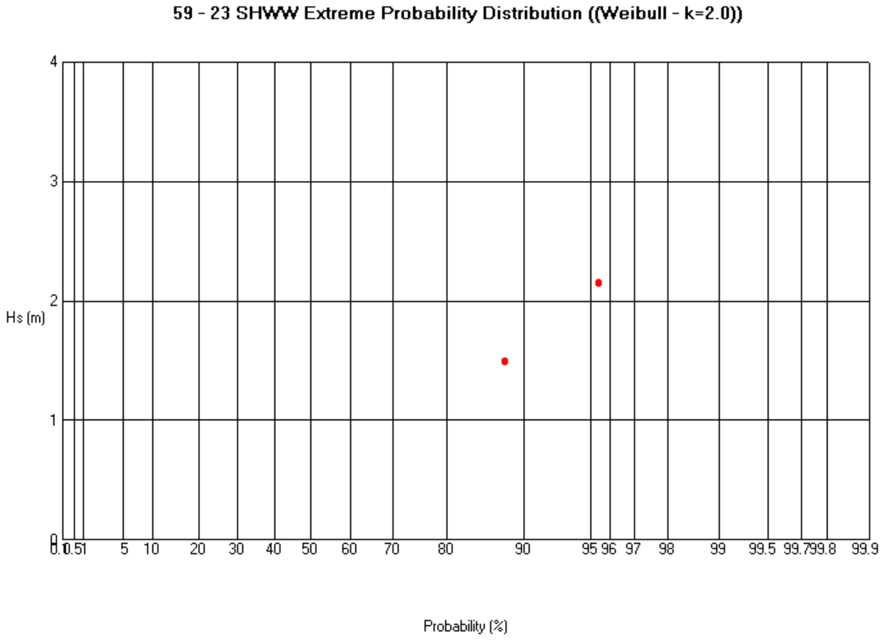


Figure 4.8.4 Extreme Probability Distribution of SHWW at Mersinköy

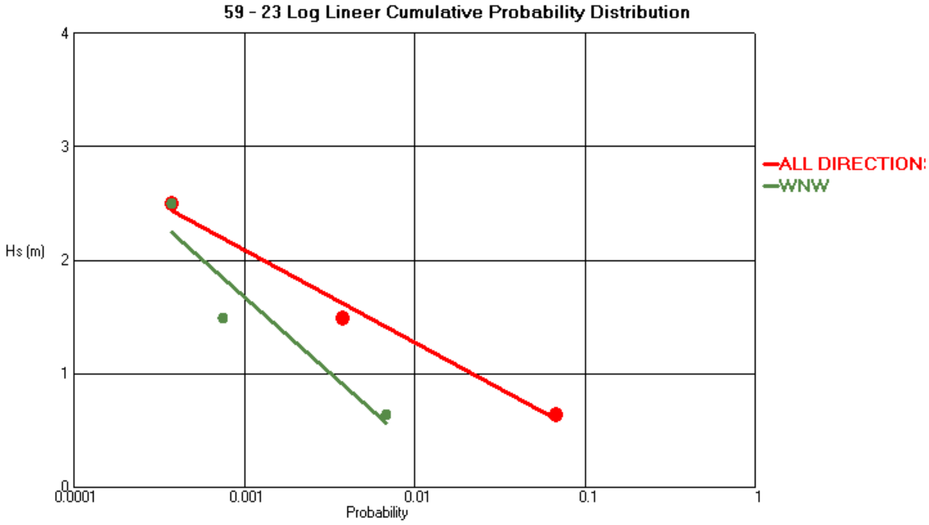


Figure 4.8.5 Log-lineer Cumulative Probability Distribution of SHWW at Mersinköy

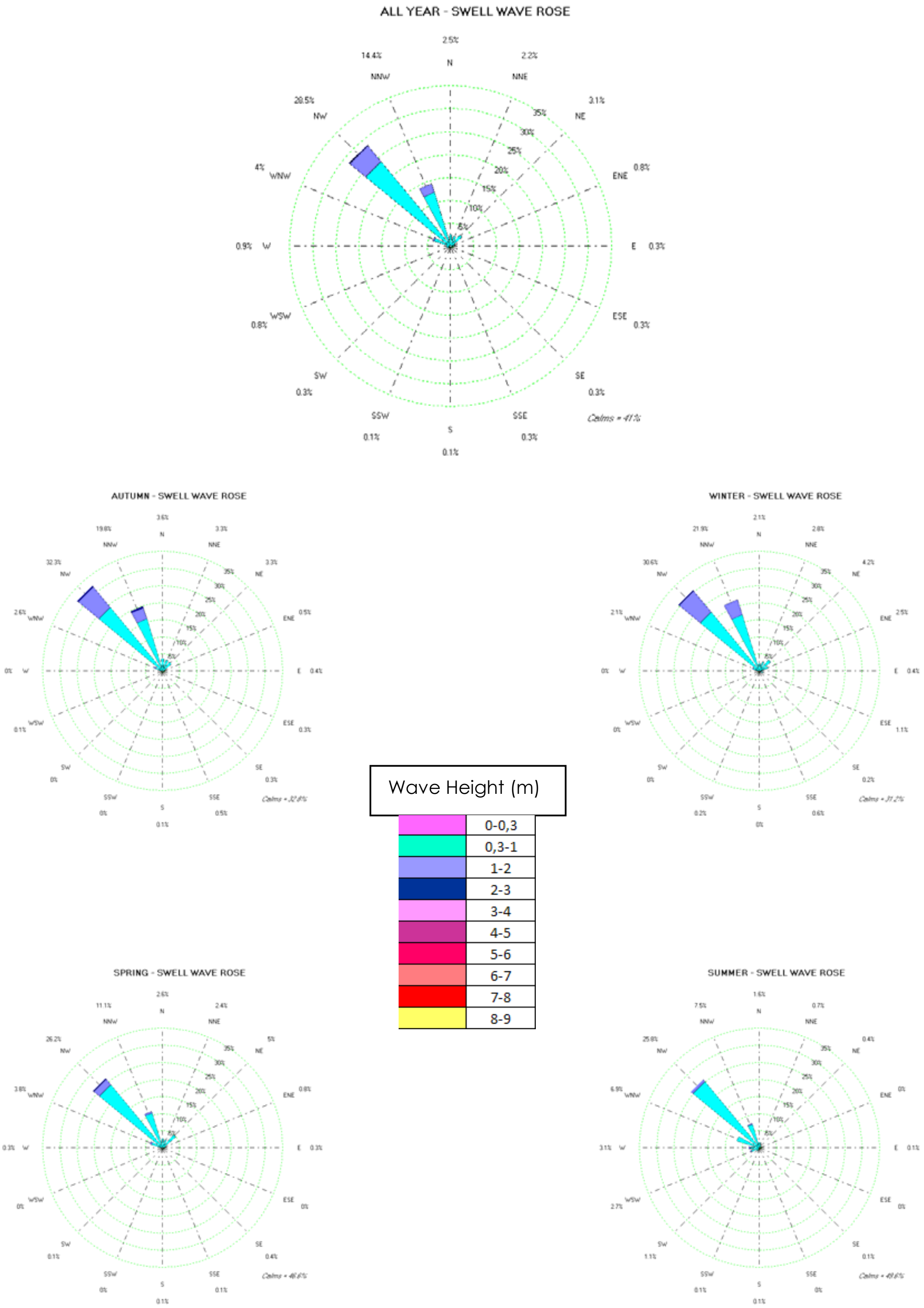


Figure 4.8.6 Swell Wave Climate at Mersinköy

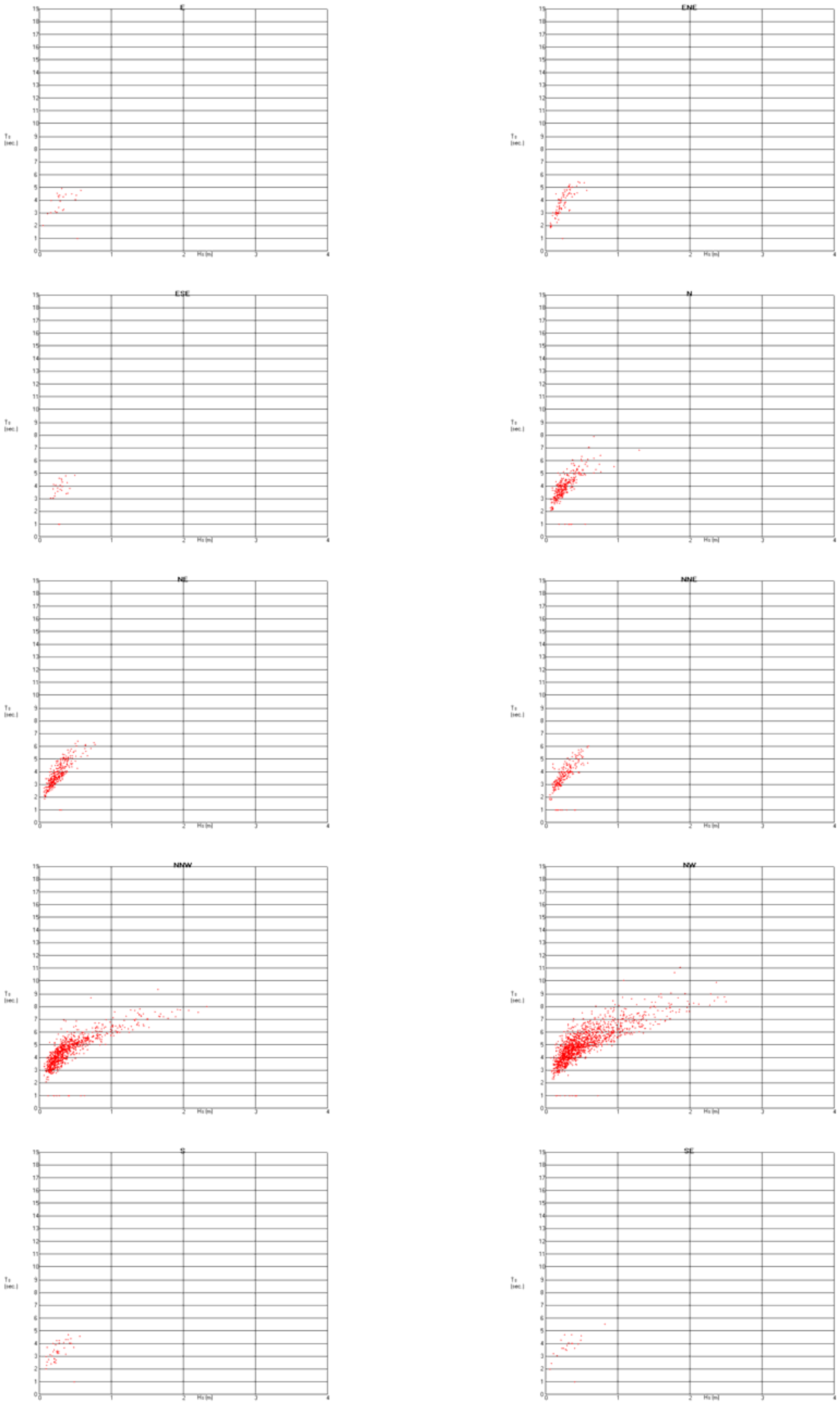


Figure 4.8.7 Relationship Between MPPS and SHPS at Mersinköy

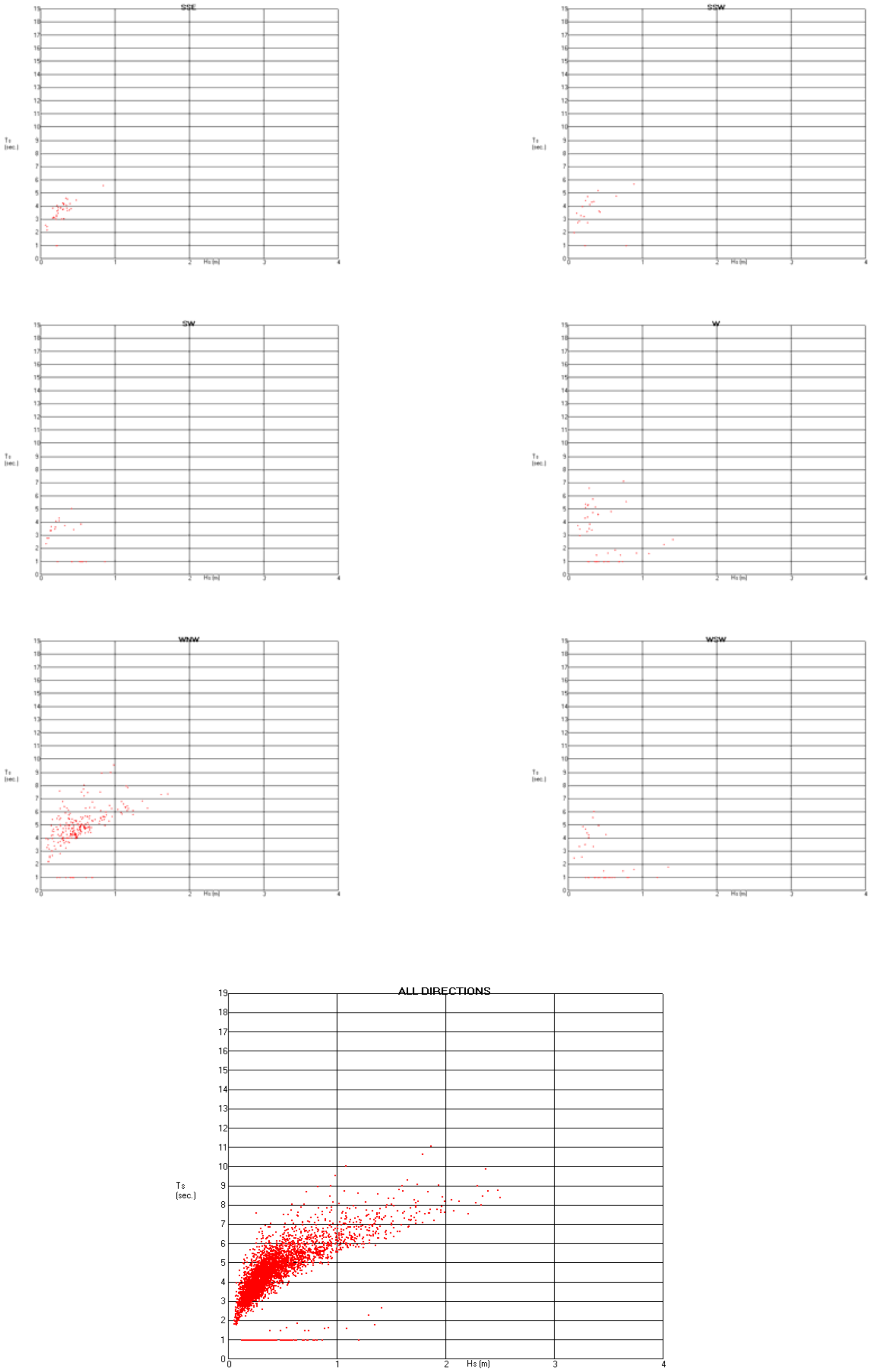


Figure 4.8.7 Relationship Between MPPS and SHPS at Mersinköy (continued)

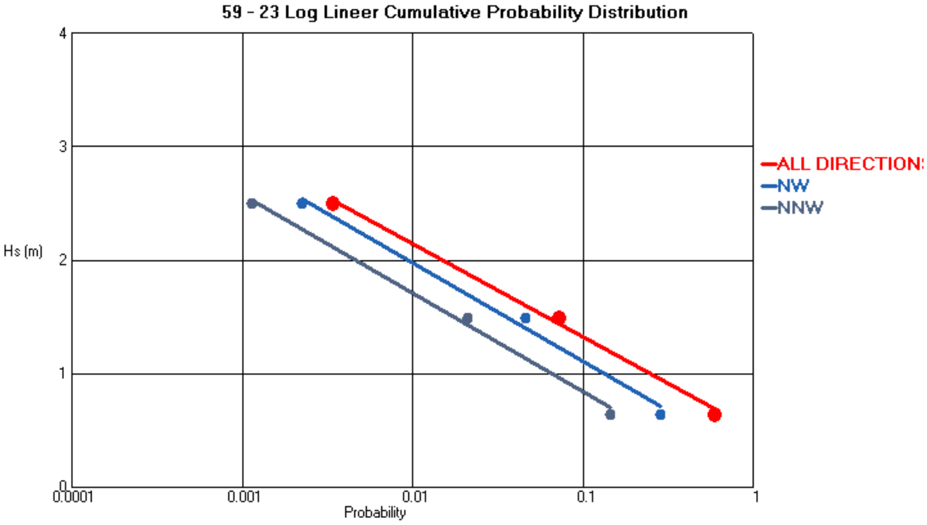


Figure 4.8.8 Log-lineer Cumulative Probability Distribution of SHPS at Mersinköy

4.9 LOCATION – ÇAYELİ (41.09 N 40.72 E)

A point at the offshore location near Çayeli is selected at coordinates 41.09 N 40.72 E (at 61x23 grid nodes). The point is located approximately 20 km northeast of Rize, 1 km away from shoreline.

Following figures given in this section are the results of the analysis of wind, wind wave and swell wave analysis for Çayeli region.

Wind roses given in Figure 4.9.1 show that the location analyzed near Çayeli is subject to mainly WNW, NW and W winds during a year. During winter period W winds becomes more significant in number of occurrence with a percentile of 7.7 % of time. In winter highest wind speed of about 12 m/s is observed from east.

Wind wave roses given in Figure 4.9.2 show the directional distribution and height of incoming wind waves. It is seen from the graphs that the location is not exposed to wind waves too much. During autumn period wind waves coming from WNW reach 2.8 m height.

In order to understand the steepness of wind waves in deep water, the relations between Significant Wave Height (Hs) vs. Mean Wave Period (Tm) are given in Figure 4.9.3. From this figure the steepness of wind waves in the region representing all years from all directions is computed as 0,041 for the wave height greater than 1 m in deep water. Wind wave domination from directions WNW, NW and can be seen from these figures. The maximum wind wave height is observed from WNW direction with a height of 2.8 meters from the data analyzed. The corresponding wave period is 7.5 seconds. Throughout the observation period wind waves are observed to be generally less than 1 m at the studied location near Çayeli for the data used in analysis.

The graph of extreme value probability statistics is given in Figure 4.9.4. Data values show high correlation. Significant wind wave height is estimated as 5.9 m for 30 year return in this region according to the analyzed data.

Log-linear cumulative probability distribution for swell waves is given in Figure 4.9.5 for Çayeli region. It is seen from this graph that significant height of wind waves exceeds 1.6 meters in about 10 hours duration every year.

Figure 4.9.6 shows swell wave roses. The roses show a clear indication of direction of incoming swell waves. As expected from the geographic location of the investigated point near Çayeli, swell waves from NW and NNW directions are dominant with respect to other directions. Swell waves from NW direction are observed 29.8%, from NNW direction 8.7% of a year. In winter, percentile of swell wave from NW direction becomes 38.4%. The maximum swell wave height from this direction is 2 meters. The period corresponding to the maximum swell is 8 seconds.

The relations between Significant Wave Height (H_s) vs. Mean Wave Period (T_m) are given in Figure 4.9.7. Swell wave domination from directions NW and NNW can be observed from these graphs. A rather more scattered distribution is observed in WNW direction. Several data points, exceeding 9 second periods and few data points exceeding 1.5 m of swell wave heights are observed from WSW direction with a maximum wave height of 2.25 m. Swell waves having 8 seconds periods can be observed from NW directions.

The graph of extreme value probability statistics is given in Figure 4.9.8. Significant wave height is estimated as 3.4 meters for 30 year return period.

Log-linear cumulative probability distribution for swell waves is given in Figure 4.9.9. Dominating directions, namely NW and NNW are plotted along with other directions. It is seen from this graph that significant height of swell waves exceeds 2.3 meters in about 10 hours duration every year.

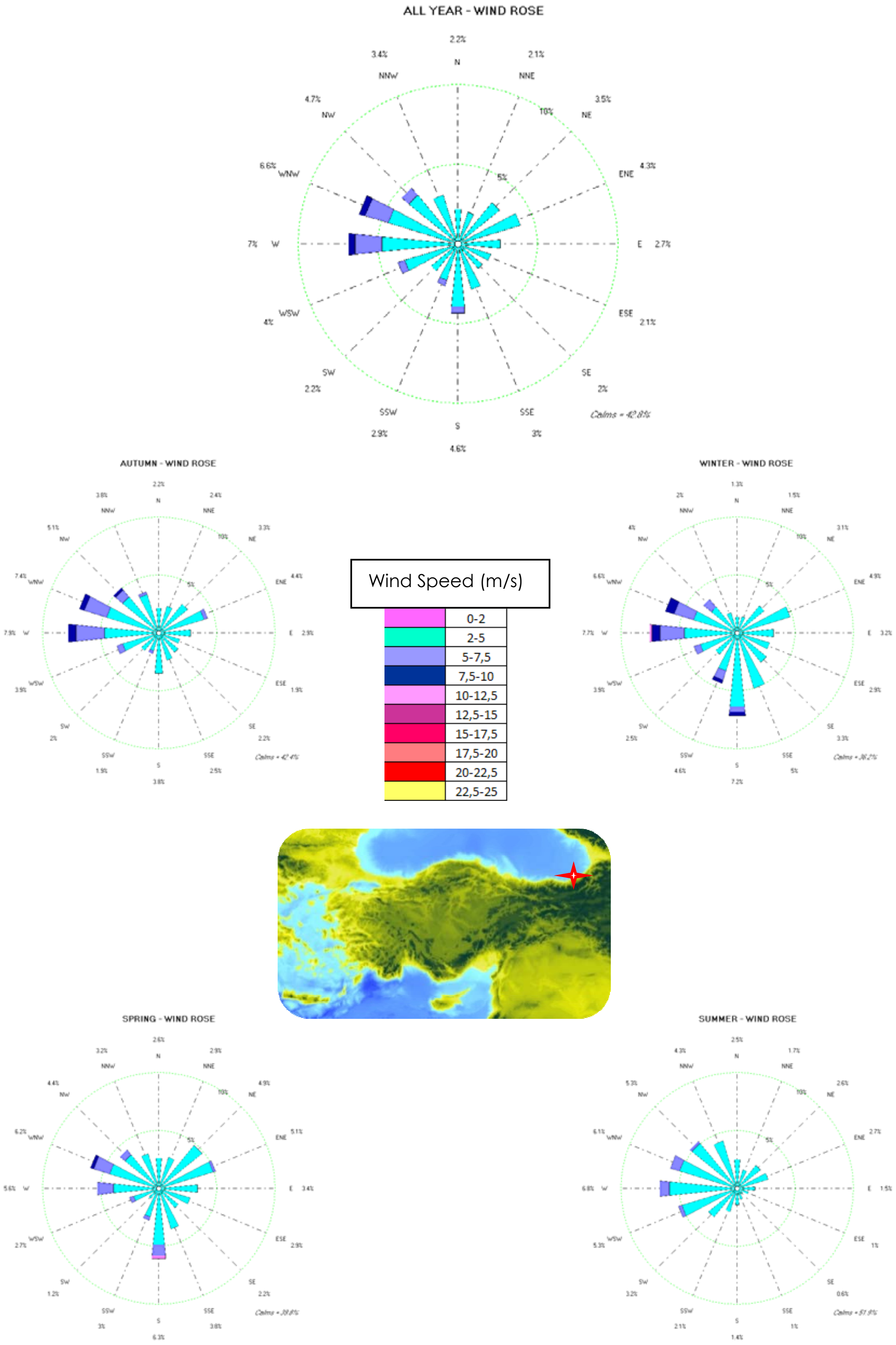


Figure 4.9.1 Wind Climate at Çayeli

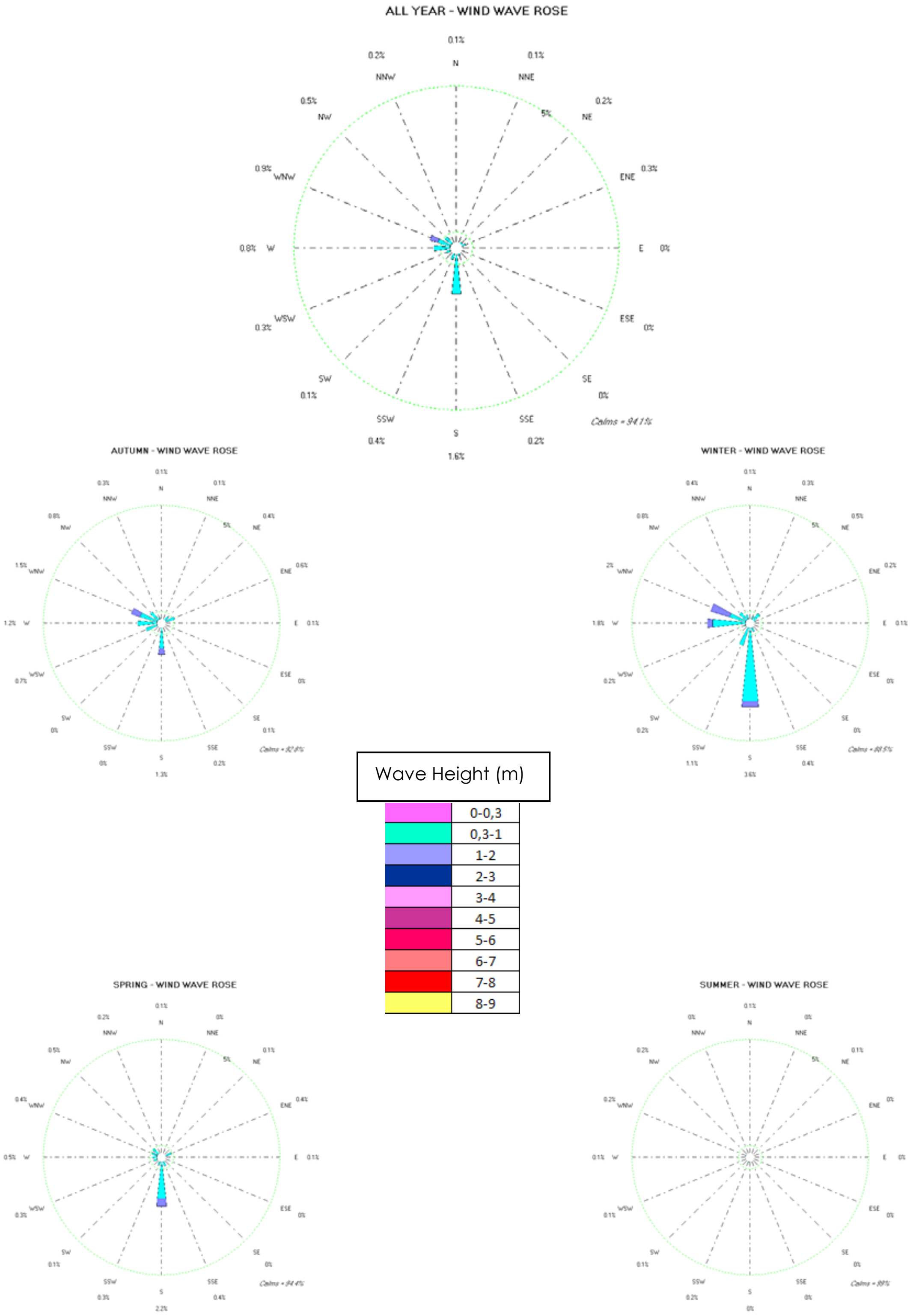


Figure 4.9.2 Wind Wave Climate at Çayeli

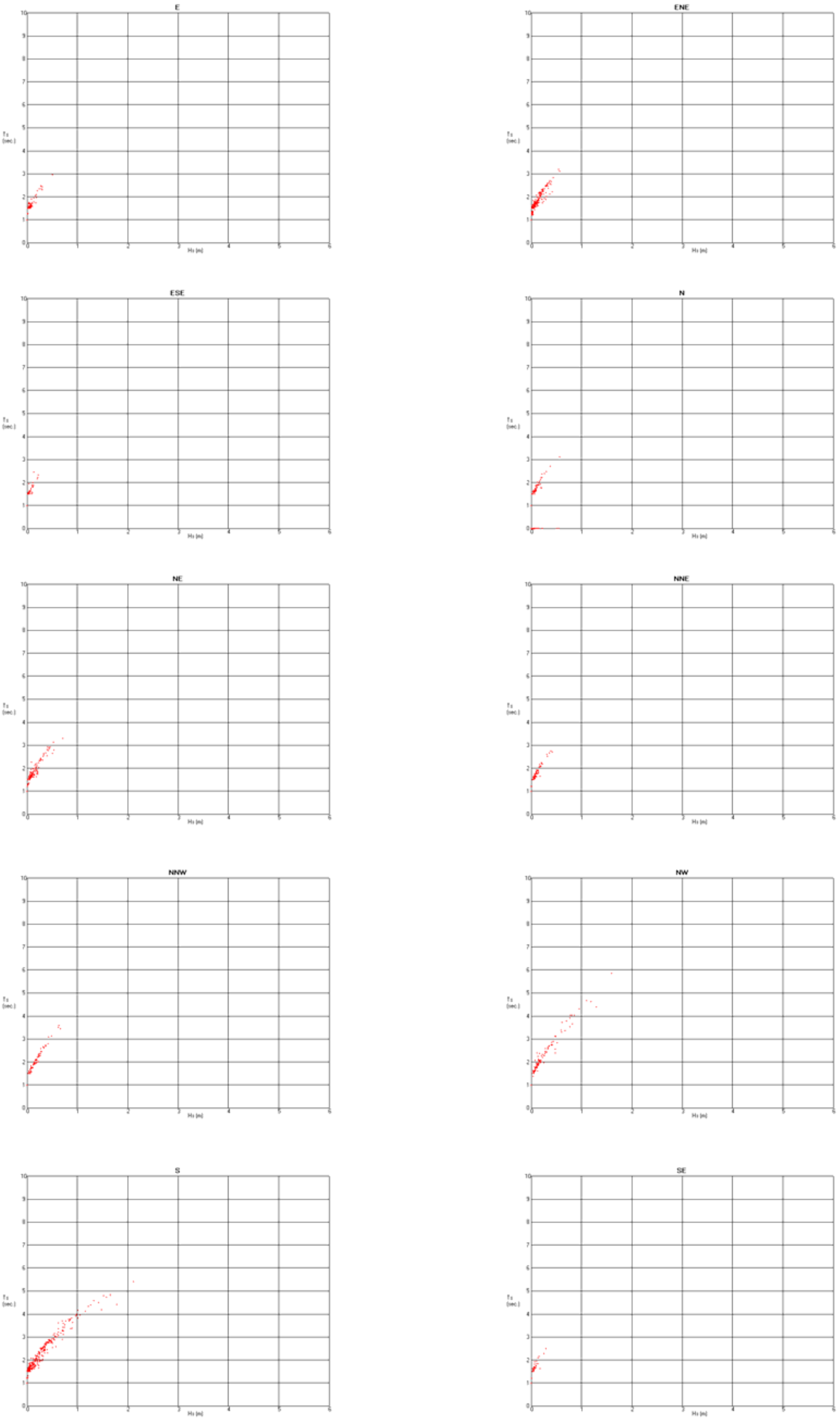


Figure 4.9.3 Relationship between MPWW & SHWW at Çayeli

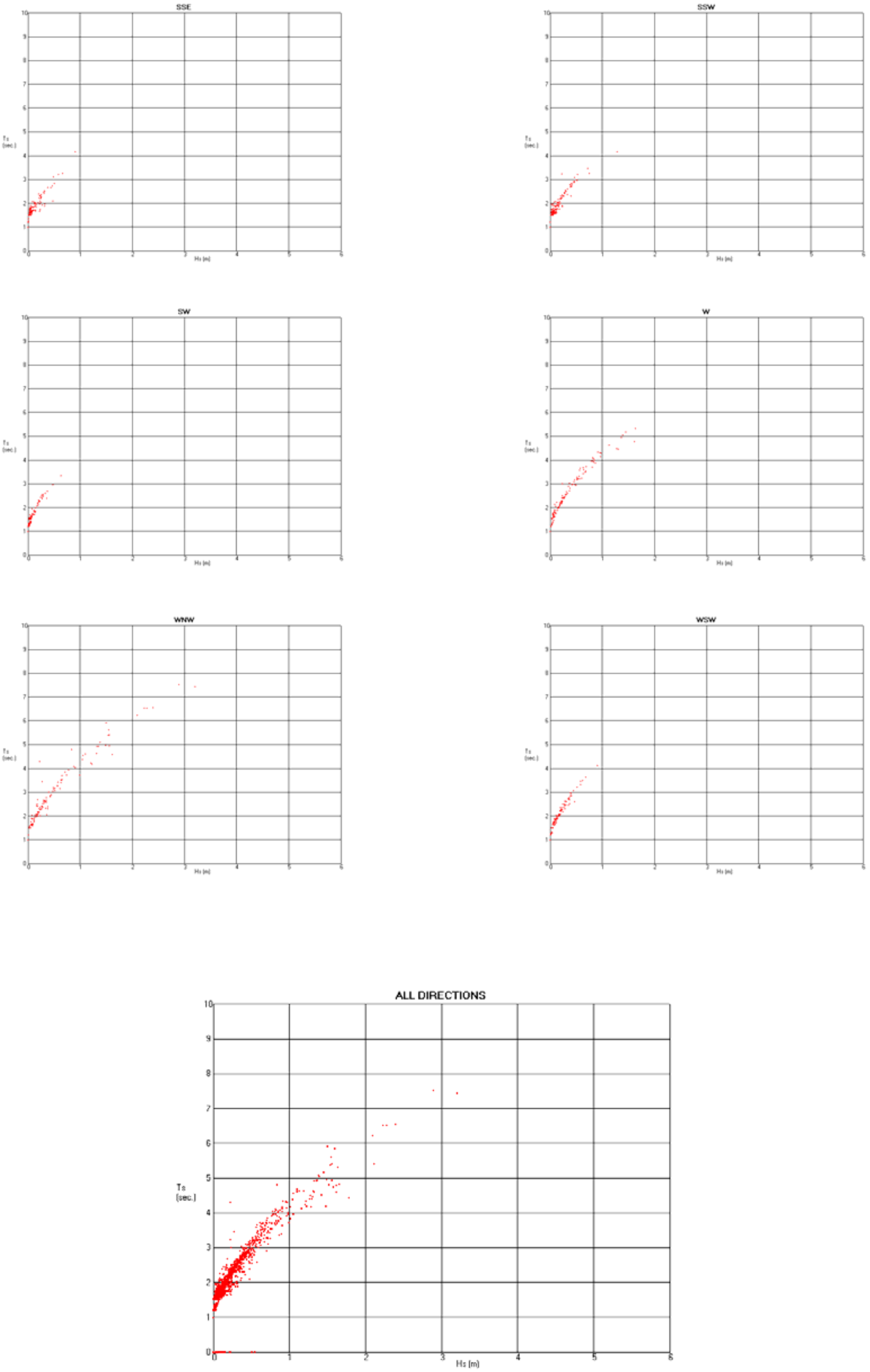


Figure 4.9.3 Relationship between MPWW & SHWW at Çayeli (continued)

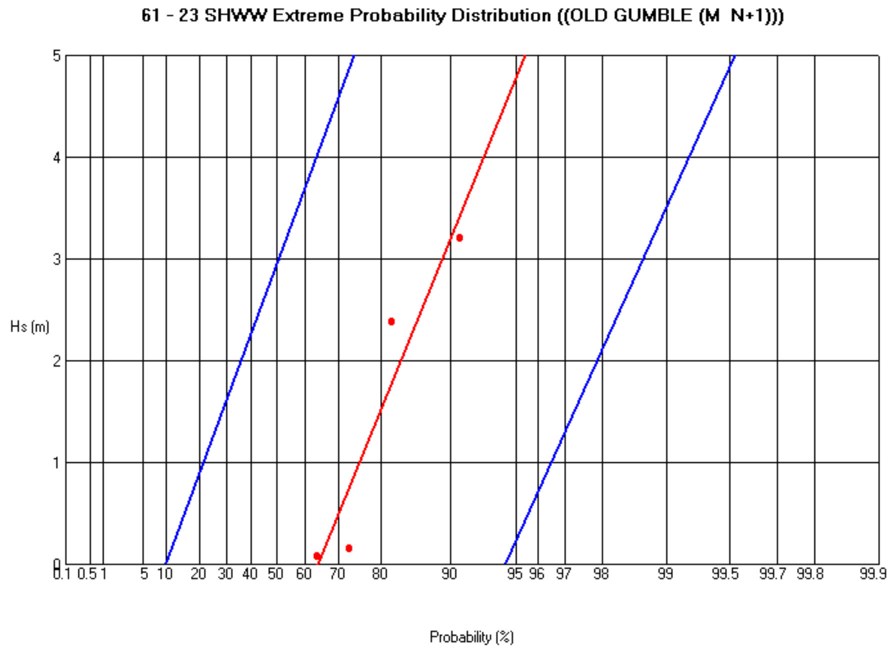


Figure 4.9.4 Extreme Probability Distribution of SHWW at Çayeli

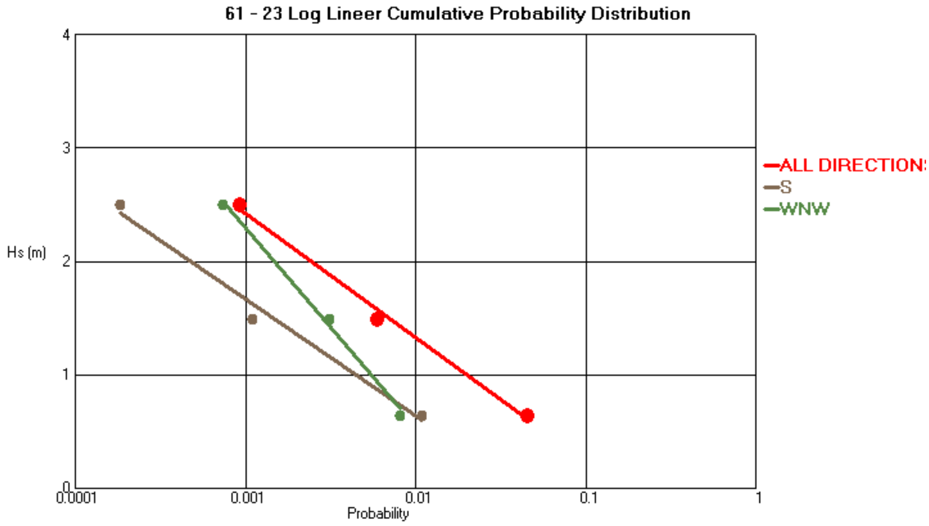


Figure 4.9.5 Log-lineer Cumulative Probability Distribution of SHWW at Çayeli

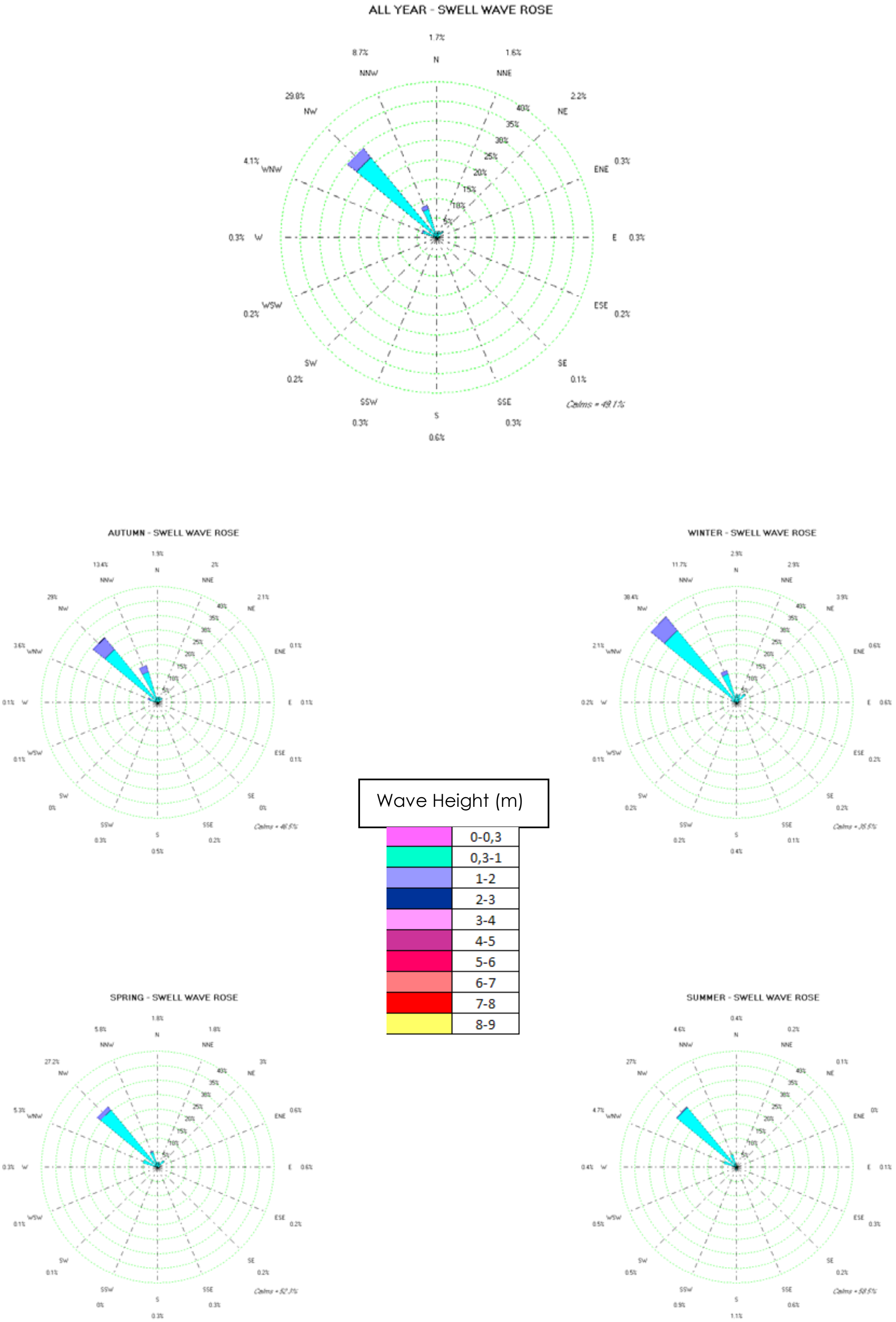


Figure 4.9.6 Swell Wave Climate at Çayeli

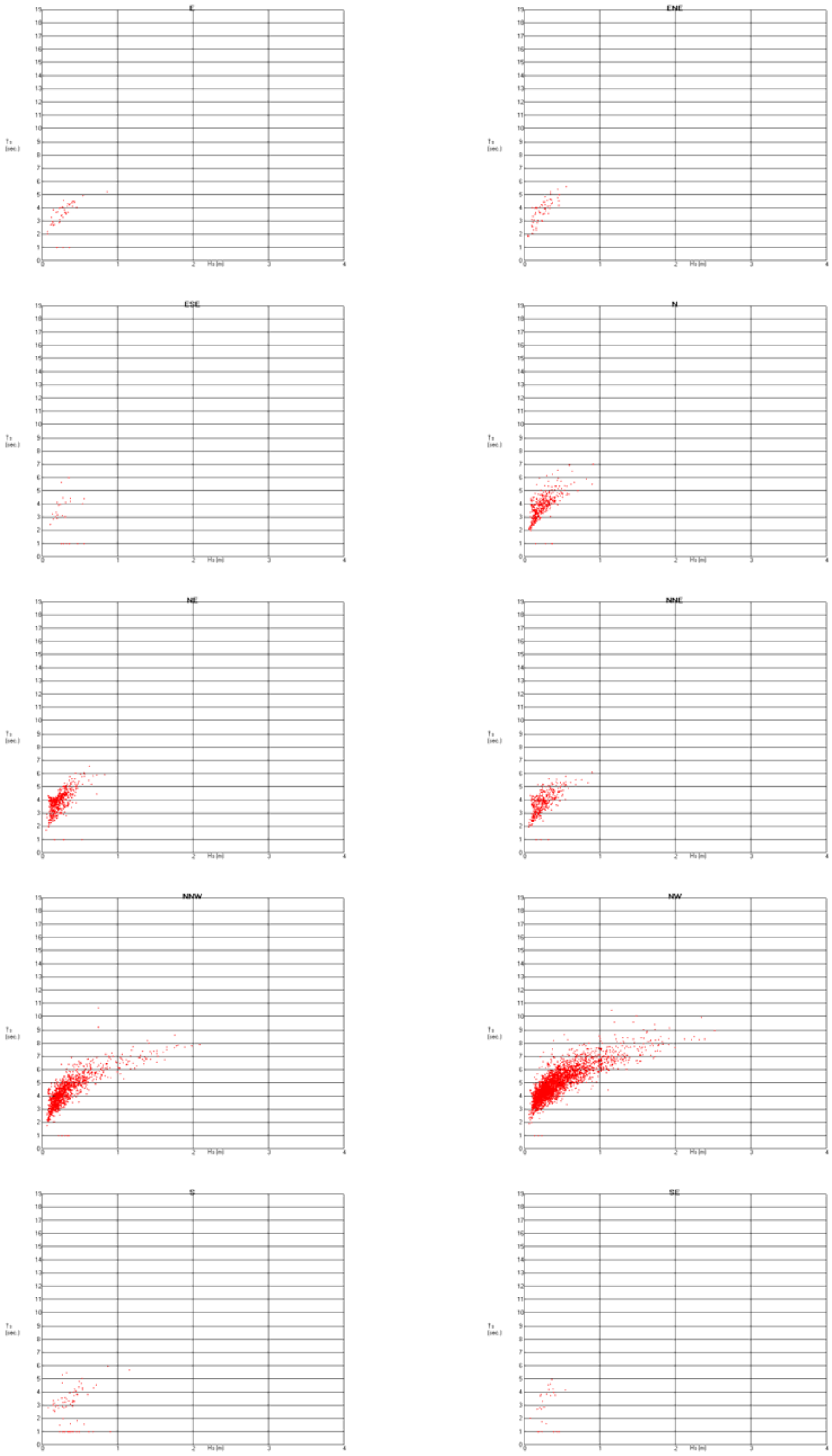


Figure 4.9.7 Relationship between MPPS and SHPS at Çayeli

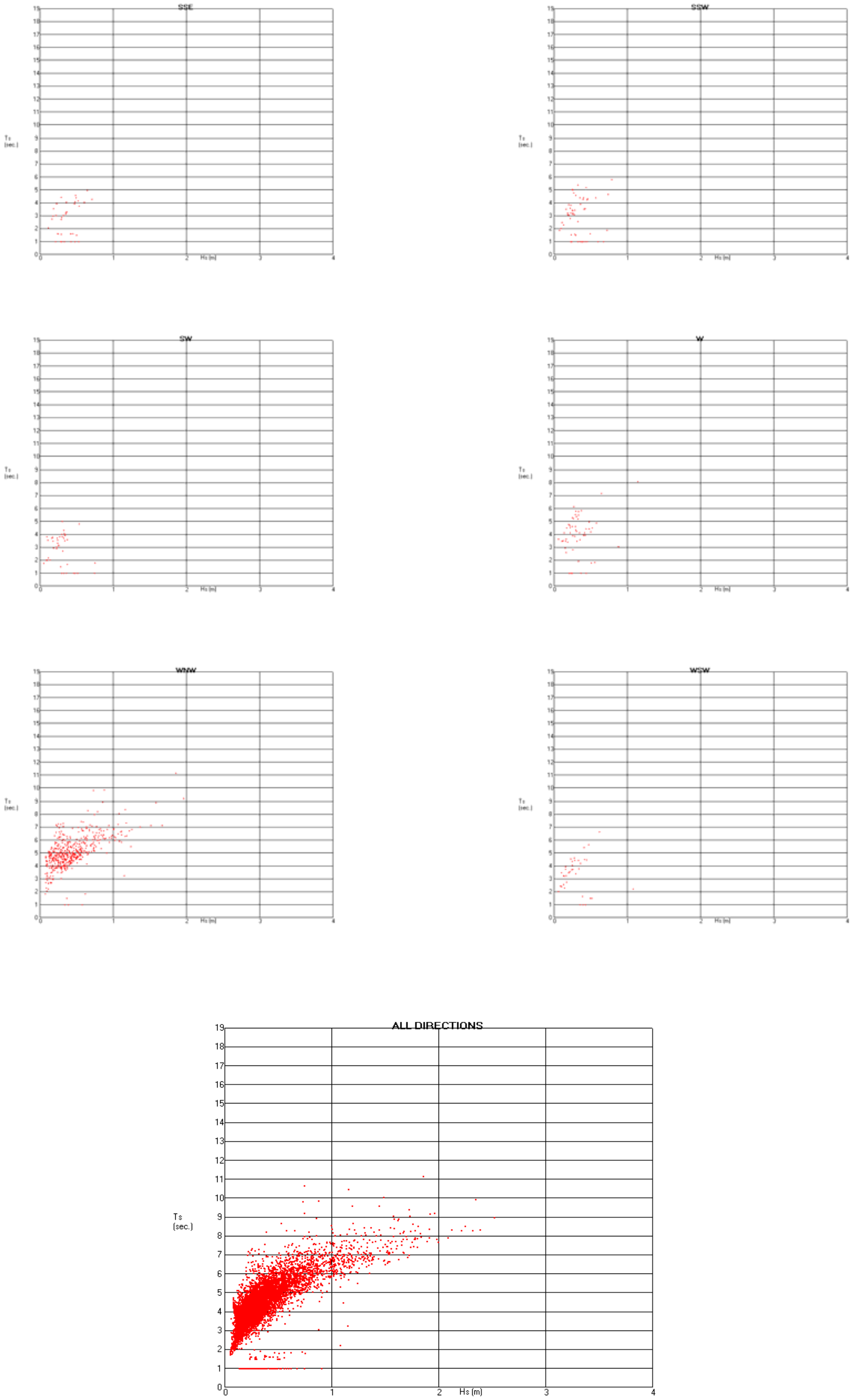


Figure 4.9.7 Relationship between MPPS and SHPS at Çayeli (continued)

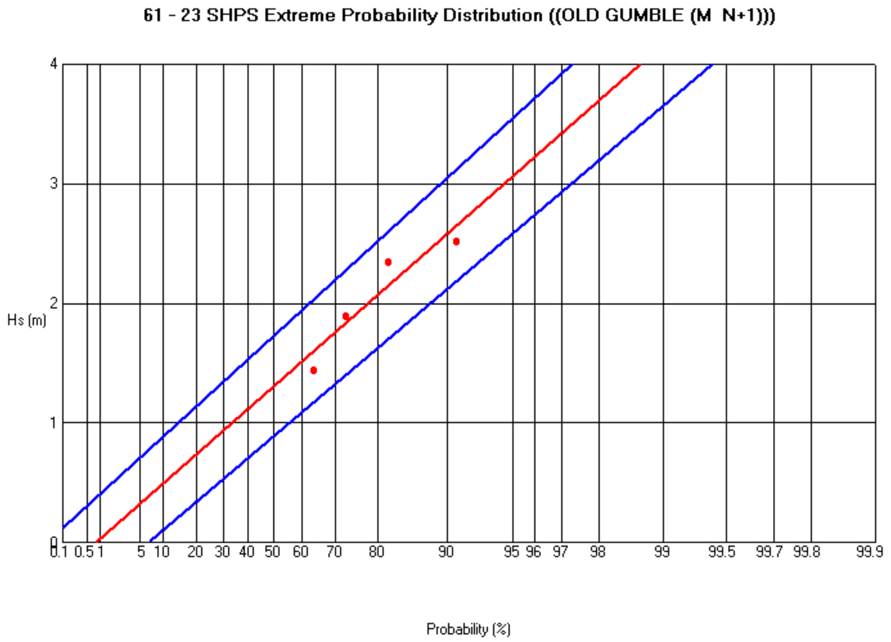


Figure 4.9.8 Extreme Probability Distribution of SHPS at Çayeli

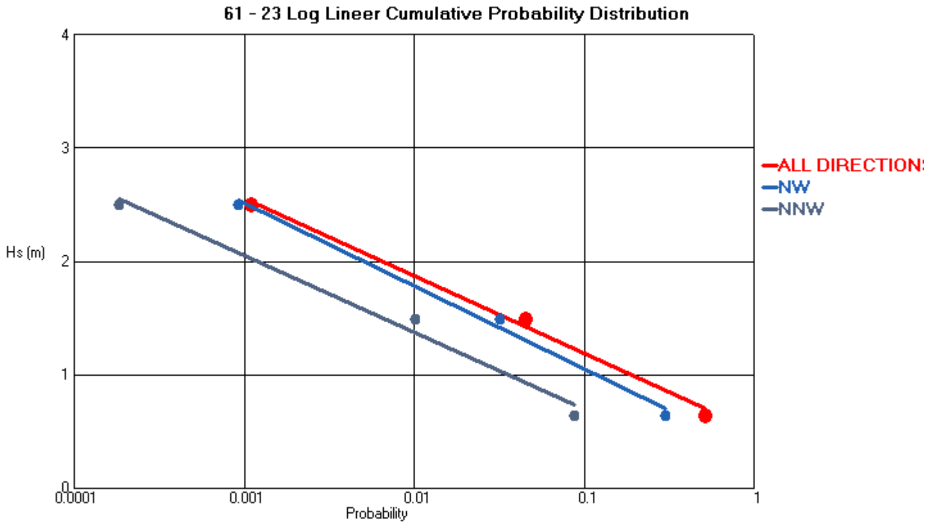


Figure 4.9.9 Log-lineer Cumulative Probability Distribution of SHPS at Çayeli

CHAPTER 5

DISCUSSION OF RESULTS AND USAGE OF SOFTWARE

The results of analysis were given in Chapter 4 for every location. In Chapter 4, some of the results, which can be obtained very easily, prepared by WWIA-SIM 2.2, are given. In this chapter a general discussion of the results and the usage of the software will be given.

In Chapter 4, analyses were made for the 9 locations. The details of locations were given in Chapter 3. Although in Aldoğan 2007, 5 locations are investigated, in this thesis, 9 locations are investigated to show the effect of the detailed the data.

Discussions on the results are given in the following section. General notes are stated here before the discussion. The data are obtained for 166 months duration in 6-hour intervals and the results are based on only this duration of data. As stated in Derebay 2007, 12-hour interval is rough for wind wave observations in Aegean and Mediterranean Sea. Therefore this study is carried on 6 hour intervals data.

5.1 GENERAL DISCUSSION OF RESULTS

In this thesis a new software, developed by Serhan Aldoğan, is used to extract data from ECMWF, combine wave and atmosphere model data, analyze data and using the analyzed data prepare the graphics. Therefore, all the stages are simply based on the data taken from the ECMWF. Any missing value or unmatched wave and wind model combination leads the software in wrong direction and thus lots of useless results.

Software is powered to enhance the unexpected situations. One of these is unmatched time durations of the wave and atmosphere model results. In combination command, all the data values are matched such that wind and wave model values for the same time duration is combined together. If one of the model type result is missing somehow, the software is simply uses the user response at the beginning. If the user has chosen to combine all data, then WWIA-SIM 2.2 just uses “1000” instead of missing values. Otherwise, the software passes this time duration and looks for the next duration.

Another unexpected situation is location land or sea condition change. Some of the locations’ in both Black-Sea and Mediterranean Database, condition may change month to month. This may cause the software to gain very few data for that location and leads to result in useless values especially in statistical analyses. In order to solve this situation if less than 3 years data exist, then software does not apply extreme probability analyses.

In order to observe the relation between this study an aforementioned studies; Ergin and Özhan, 1986 and Özhan and Abdalla, 1999, the following tables are presented. From tables the reader can observe that most of the results are in accordance with each other.

Table 5.1.1 Comparison Table for SHWW for 30 years Return Period

NO	LOCATION NAME	Wind Wave Hs(m) for Rp=30 yrs		
		Expected Hs	Expected Hs (from Özhan and Abdalla, 1999)	Expected Hs (from Ergin and Özhan, 1986)
1	ANAMUR	4,5	10,0	6,7
2	KAŞ	4,4	8,10	5,9
3	DATÇA	5,6	8,0	6,25
4	KUŞADASI	4,8	5,5	4,1
5	BABAKALE	5,9	6,0	5,65
6	AMASRA	5,0	7,5	4,9
7	ÇATALZEYTİN	7,20	7,75	7,2
8	MERSİNKÖY	-	6,5	4,1
9	ÇAYELİ	5,9	6,1	4,7

Table 5.1.2 Comparison Table for SHWW for 50 years Return Period

NO	LOCATION NAME	Wind Wave Hs(m) for Rp=50 yrs		
		Expected Hs	Expected Hs (from Özhan and Abdalla, 1999)	Expected Hs (from Ergin and Özhan, 1986)
1	ANAMUR	4,8	10,5	7,2
2	KAŞ	4,6	8,5	6,4
3	DATÇA	5,4	9,5	6,7
4	KUŞADASI	5,1	5,5	4,4
5	BABAKALE	6,4	6,5	6
6	AMASRA	7,75	8	5,25
7	ÇATALZEYTİN	6	8,25	7,5
8	MERSİNKÖY	-	6,8	4,4
9	ÇAYELİ	4,3	6,6	5

The Extreme values of Wind Waves for 30 and 50 years show the results for the locations Kusadasi, Babakale, Amasra, Catalzeytin, Mersinkoy, Cayeli are in agreement with Ozhan Abdalla, (1999) and Ergin and Ozhan (1984). The reason of the difference seen for the data in Anamur, Kusadası, and Datça is the difference in the coordinates of the selected locations to be studied and the difference in data period.

Additionally the steepness of the wind waves (Hs/L0) in deep water are in the range between 0,039 and 0,050 for the wind waves of height greater than 1 m. In the following table wind wave steepness values for selected locations are given.

Table 5.1.3 Wind Wave Steepness Table of the 9 Locations

NO	LOCATION NAME	WAVE STEEPNESS (H_s/L_0)
1	ANAMUR	0,039
2	KAŞ	0,048
3	DATÇA	0,046
4	KUŞADASI	0,047
5	BABAKALE	0,050
6	AMASRA	0,047
7	ÇATALZEYTİN	0,045
8	MERSİNKÖY	0,049
9	ÇAYELİ	0,041

5.2 USAGE OF SOFTWARE (WWIA-SIM 2.2)

5.2.1 DATABASE ENTRY

First, the user must use the correct database. If the user will work on Black-Sea, then in the "ATMOSPHERE" folder, there must be atmosphere model results for the Black-Sea and in the "WAVE" folder there must be atmosphere model results for the Black-Sea. These folders must be in the same directory with the software.

After WWIA-SIM 2.2 is executed, user must choose which location will be studied from the GUI (Graphical User Interface).

5.2.2 LOCATION ENTRY

User may enter the location information in different ways. First one is using the textboxes. User simply writes locations' longitude and latitude values with choosing "DEGREE" from the "COORDINATE TYPE" frame.

Second way is the writing grid numbers, which is one of the constraints in database. As same before, user may simply writes grid numbers in textboxes with choosing "GRID" from the "COORDINATE TYPE".

Third way is picking points from the map. After activating "SELECTION ON MAP", user may select any location by just clicking on it. As the user left-clicks, software puts a circle on the location. When the user right-clicks, software cancels selection on map mode.

If all the locations in the database wanted to be added, then user just clicks "ADD ALL COORDINATES" button. Last method is the opening a coordinate file, saved before. However, if a coordinate file is loaded then all previous location information will be lost.

All the coordinates added will be shown in the list boxes in the lower left of the GUI.

5.2.3 SAVING COORDINATES

After all the necessary location information is given, user must save the coordinates. In order to save locations, "SAVE COORDINATES" button must be clicked. If already a coordinate file is activated, then the software asks whether to overwrite the document of save as different document. Otherwise, directly save-as procedure is activated.

5.2.4 DATA GATHERING AND COMBINING

After databases are put in directories, data places (Mediterranean or Black Sea) is chosen and location information are entered user may press

“PREPARE POOL” button to create a file named “POOL” in the same directory. In this directory, all location values will be stores. If one of the locations is 1-1 (GRID Method), then “1-1-Wave.txt” and “1-1-Wind.txt” files will be created. Wave model results will be written in wave text and atmosphere model results will be written in wind text. This will be repeated for every location. While data gathering procedure is active, software also stores the maxima values for wind speed, wave heights, and periods.

After data gathering, user must click “COMBINE” to combine two model results together. However, user must pay attention that, database time durations may vary. If the user wants to use all the data at the hand, then “COMBINE ALL DATA” must be activated. Otherwise only the time durations both of the model have, will be combined. Combined data will be stored in “CPOOL” folder.

5.2.5 ANALYZE

Software can easily analyze extracted data. If the user wants a complete analyze, then “ANALYSE WITH GRAPHICS” must be pressed. “ANALYSE WITHOUT GRAPHICS” is useful if the user has chosen a very large amount of locations and just wants extreme value results. If latter one is activated, then software handles all data and only prepare a file named “GUMBLESTA.sta” in the “RESULT” file where all the analyze results will be stored in the folder for each of the locations.

CHAPTER 6

CONCLUSIONS

In this study swell wave and wind wave climate in eastern Mediterranean Sea and coastline of Türkiye is attempted to be enlightened by analysis of certain swell wave, wind and wave data. The data used in this study is obtained from the ECMWF Data Server. [ECMWF, 2008] The data is obtained for the whole Aegean and Mediterranean Sea basin. The data period is between 01.07.1998 to 30.09.2008, totally 123 months in length. Analyses were made for 9 locations along the Black Sea, Aegean and Mediterranean Sea coastline of Türkiye.

In this study the 9 locations are analyzed separately and for every location results are presented graphically via software used in this thesis study called WWIA-SIM 2.2. The wind and wind wave roses, significant wave height versus Mean period of primary wind relations, extreme probability distribution and log-linear cumulative probability distributions are provided for the locations and are presented in the 4th chapter. The 4th chapter thus presents the wind wave climate for the south coast of the Black Sea, Aegean and the Mediterranean Sea. In the 5th chapter, more detailed information about the software is given.

The Extreme values of Wind Waves for 30 and 50 years are computed in this study for the selected 9 stations. The results for the locations Kuşadasi, Babakale, Amasra, Çatalzeytin, Mersinkoy, Çayeli are in agreement with Özhan Abdalla, (1999) and Ergin and Özhan (1984). The reason of the difference for Anamur, Kuşadasi, and Datça may come from the coordinates of the locations (in ECMWF data) which do not fully coincide with location in other studies.

The steepness of the wind waves (H_s/L_0) in deep water are found for the selected 9 locations as in the range between 0,039 and 0,050 for the wind waves of the significant height greater than 1 m.

The results of wind wave climatology analyses expose the directions and magnitudes of wind waves that the selected locations are subject to. The results are provided in seasonal basis for comparison of seasonal differences. The calm durations, which indicate very limited wind or wind activity, are also given for the locations.

In this study a sound and straightforward method for inspection of swell and wind wave climate is introduced and the method is used to discover swell and wind wave climate along the Black Sea, Aegean and Mediterranean Sea. Moreover WWIA-SIM 2.2 is also capable of the Black-Sea database. Thus a complete analysis for the Türkiye coasts is very easy. Besides, by using all coordinates all of the Black Sea, Marmara, Aegean and Mediterranean Sea can be analyzed in couple of days without any man power loss.

The results of this study are based on the ECMWF data for academic purposes. It is highly recommended and emphasized that these results cannot be applied to any application or project without the consent AND APPROVAL of the author and supervisors of this thesis.

REFERENCES

1. Aerographer's Mate 1&C, 2006, “Aerographer's Mate 1&C, 2006”, (Last visited on Jan. 3, 2007), http://tpub.com/content/aerographer/14010/

2. Aldoğan , S., 2008 “Wind and Wind Wave Climate Turkish Coast of Aegean and Mediterranean Sea”, M.Sc. Thesis, Middle East Technical University, Civil Engineering Dept., Ocean Eng. Research Center, Ankara

3. Alves, J.H.G.M., 2004, “Numerical modeling of ocean swell contributions to the global wind-wave climate”, Ocean Modelling 11, 98-122.

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

5. CEM, 2006, “Coastal Engineering Manual, Coastal and Hydraulics Laboratory”, (Last visited on Dec. 26 2006), http://chl.erdc.usace.army.mil

6. Derebay, Saygın Kemal, 2007, “Wind and Swell Wave Climate for the Southern Part of Aegean and the Mediterranean Sea”, M.Sc. Thesis, Middle East Technical University, Civil Engineering Dept., Ocean Eng. Research Center, Ankara
7. ECMWF, 2008, "The European centre for Medium-Range Weather Forecasts", (Last visited on Dec. 01, 2008) http://www.ecmwf.int

8. Ergin, A. "15 Region Report", Middle East Technical University, Ankara

9. Goda, Y., 1985, "Random Seas and Design of Maritime Structures", University of Tokyo Press, Tokyo
10. Kantha, L., 2004, "A note on the decay rate of swell", Ocean Modelling 11, 167-173.

11. Kinsman, B., 1965, "Wind Waves", Prentice-Hall, Englewood Cliffs, NJ, p. 676

12. Munk, W.H., Miller, G.R., Snodgrass, F.E., Barber, N.F., 1963. Philos. Trans. Roy. Soc. London A255, 505–584.

13. Özhan, E. and Abdalla, S., 1999, "Türkiye Kıyıları Rüzgar ve Derin Dalga Atlası", "Turkish Coast Wind and Deep Water Wave Atlas", Middle East Technical University, Civil Engineering Department Ocean Engineering Research Center, Ankara, 94-03-03-02-01 Project Report

14. Özyurt, G. and Özbahçeci, B. 2008, "Tasarım Dalgasının Bulunmasında Dağılım Modelinin Etkisi", "The Effect of Statistical Distribution Model on the Determination of Design Wave", Türkiye Kıyıları 08 Konferansı Bildiriler Kitabı, Ankara

15. The Technical Standards and Commentaries for Port and Harbour Facilities in Japan, The Overseas Coastal Area Development Institute of Japan, 1999

APPENDIX

USAGE OF WGRIB

The steps followed for handling for *.grib files by WGRIB program is given in the following.

WGRIB is a tool for handling *.grib files and works in DOS environment. In Microsoft Windows hit win+R and type "cmd" to open command prompt. Using DOS commands locate the directory of WGRIB executable. The following commands are given assuming that the input file, "wgrib.exe" and "cygwin1.dll" are in the same directory. (The wgrib program is standalone and can be carried and run in any directory, in the following commands wgrib is located in c:/wgrib/ and the input file name is 2003_04.grib)

```
c:/wgrib>wgrib
```

Starts wgrib and/or shows the help screen

```
C:/wgrib>wgrib 2003_04.grib -s
```

Displays short inventory of the input file (replace -s with -v for verbose)

```
C:/wgrib>wgrib 2003_04.grib -V -d N
```

Displays the details of a single (N'th) data record (if –d is not stated all data records are displayed in this way)

```
C:/wgrib>wgrib 2003_04.grib -d N –text
```

The N'th data record is extracted to a "dump" file in ascii format.

```
C:/wgrib>wgrib 2003_04.grib -d all -text -o -2003_04.txt
```

The input file is transformed into 2003_04.txt file in ascii format. This command is sufficient for generally all cases. A single data record can be opened by replacing “all” with data record number “N”.