CHAPTER 8 : WIND AND WAVE LOADING

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8.1 Introduction

In their lifetime of about 20 years, OWECs have to withstand several environmental forces. Traditionally, for wind turbines the only factor to account for has been the wind. In the offshore industry, structures much more solid than wind turbines show a limited dynamic response to hydrodynamic loading because of their high structural stiffness. Now with the realisation of offshore wind farms with slender wind turbines, both aerodynamic and hydrodynamic forces inducing dynamic responses have to be accounted for, requiring a merging of the offshore and the wind turbine design technology. Wind and water each have their own distinctive contribution to the overall environmental loading of an OWEC. The loading comprises extreme loading by large loads with a certain probability of occurrence and fatigue loading due to loads with a cyclic nature.

Standards for determining the extreme and fatigue loading by aerodynamic and hydrodynamic forces separately have been developed, but it is the combination of the two latter that needs to be focussed on. Recent studies have shown that taking into account the combined wind and wave loading in the design codes may lead to less conservative designs [Kuhn(2001)]. In order to take advantage of this design method, it is necessary that relevant data for wind and wave loading become available.

Experimental data on the combination of wind and wave loading is scarce. For the determination of combined loads, therefore, use is often made of a hind-cast data set. Starting from known meteorological conditions on e.g. a 3 hourly time scale, the sea wave state is calculated by means of a wave model. An example of such a data set is the North European Storm Study (NESS) data base. This is proprietary information and the owners are not willing to disclose the underlying data to third parties. Fortunately, the project team has been able to get access to a comparable data set, which has been compiled by the UK Meteorological Office, which is very well suited for making the aforementioned cross-correlation analysis.

In this section the following topics are touched upon:
- Loading of wind turbines under offshore conditions
- Background
- Description of the UKMO data set

In the past, a number of projects have reported results for wind and wave loading of offshore wind turbines [Hendriks et al. (2000) and Kuhn (1998)]. This is the first study in which a complete set of hind cast data is reported.

8.1.1 Environmental conditions for offshore wind turbines

An Offshore Wind Energy Converter (OWEC) must be designed to withstand:
- fatigue loads caused by the turbulence in the wind and the cyclic loading of the incoming waves, sometimes combined with sea currents.
- extreme loads caused by heavy storms and extreme wave conditions. This may include breaking waves slamming on the construction.

A number of design codes have been developed for the certification of OWECS (e.g. [Germanischer Lloyd (2000)]). These design codes give a list of load cases, which must fall within the design envelope of the OWECS. These load cases are defined by the sea state.

The sea state is a statistical description of the wind and wave conditions at the sea surface during a 3-hour time interval. It is assumed that the wind and wave conditions remain constant during this 3-hour interval and that the same holds for all statistical parameters. Examples of statistical parameters are windspeed, turbulence intensity, significant wave height, wave period, wave direction, wave spectrum, etc.

The sea state is a description of the properties of the wind sea and swell in a 3 hour period. It is considered as a stationary stochastic process, defined by the average zero-crossing wave period and the significant wave height. Within a given sea state the wave height varies at random; the wave height distribution can be described by the wave energy spectrum and the wave direction spectrum.

Thus when describing waves we can distinguish between:
1. The wave climate. The wave climate describes the long term likelihood of sea states at a given location.
2. The wave energy spectrum: distribution of period and height within a sea state.

These items will be discussed next.

It is common to classify surface waves according to their periods as in the table below.

Period	Wave length	Name
0 – 0,2 s	centimetres	ripples
0,2 – 9 s	to about 130 m	wind sea
9 – 15 s	hundreds of meters	swell
15 – 30 s	many hundreds of meters	long swell
30 s – hours	to thousands of kilometres	long period waves
12.5 h, 25 h, etc.	thousands of kilometres	tides

In this overview, it is the wind sea and swell that are most important to the loading of OWECs. Wind sea includes all waves generated by local winds. They are generated by the wind blowing for some hours duration over a certain length of sea called fetch. Waves receive their energy from the movement (turbulent stress) of wind on the ocean surface. During generation the disturbed sea surface is not regular and contains many different oscillatory motions at different frequencies. The directional distribution and the height of wind sea corresponds with the wind speed.
As wind sea grows the sea surface becomes more regular, and wind sea turns into swell that is able to leave the area of generation (figure 8.1).

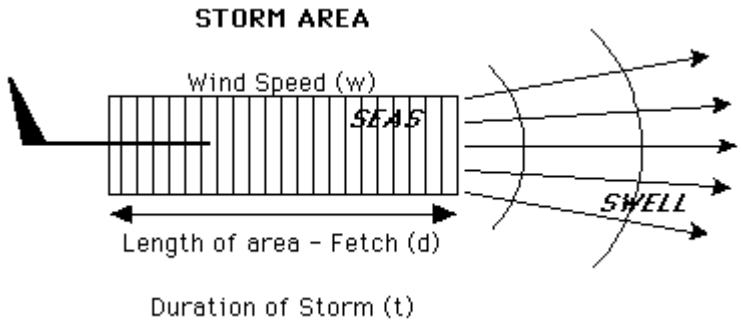

Figure 8.1 Development of wind sea and swell

Thus swell refers to waves generated by distant wind fields. Swell travels in one direction and is much more regular than wind sea. Swell is mostly low frequent, wind sea is generally of a higher frequency.

The transition regime between wind sea and swell in the area close to but outside the immediate wind generation region, where the wind forcing has already decreased but the non-linear interactions are still important, plays a critical role in determining the ratio of wind sea to swell energy. Laboratory experiments have shown that wind sea achieves lower energy density, and hence amplitudes, in the presence of swell compared with their energy without swell.

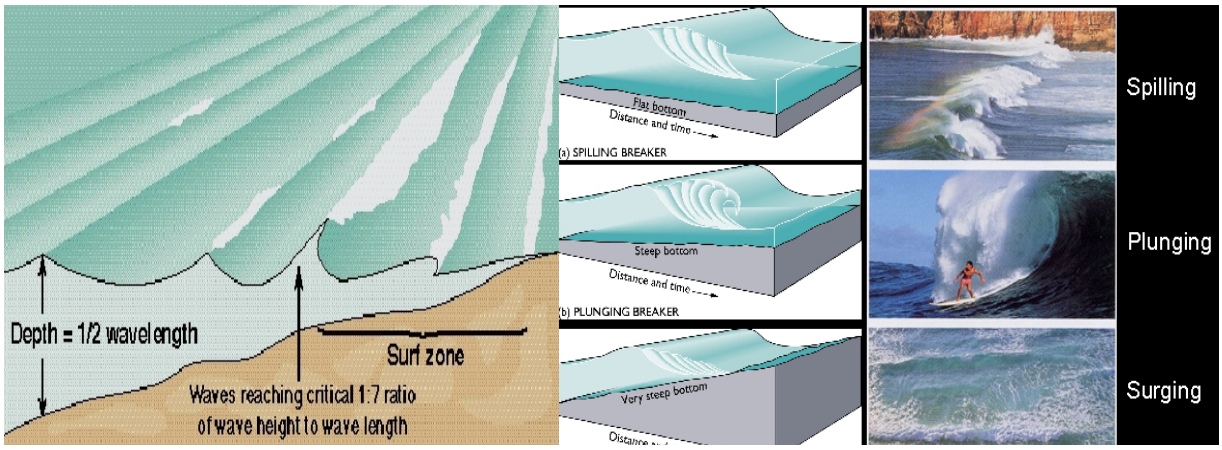

Figure 8.2 Criteria for and types of Breaking waves

In shallow water the waves start to “feel” the bottom and this leads to shoaling. The bottom becomes noticeable if the water depth is less than 0.5 the wave length. In the shoaling area two effects take place. The waves refract and they steepen. Since the waves travel slower in undeep water, they bend towards the coast and the wave crests and the coast line become more parallel. However the wind direction is not affected by this process, which can lead to a significant difference between wave and wind direction. The steepening of the waves can eventually lead to breaking or plunging waves. This can lead to severe loads on the wind turbine structure. Waves break when the wave height becomes more than 7 times the wave length. It depends on the bottom slope, which kind of breaking occurs (see figure 8.2).

1. Long term distribution; wave scatter

The probability distribution of sea states is presented in a wave scatter diagram, describing the long term distribution. A wave scatter diagram is a two dimensional histogram of the significant wave height and wave period for all sea states. A sea state is assumed to be stationary during three hours. Wave heights and periods can be ‘binned’ in scatter diagrams with for example 0.5 meter and 1 second width. Not being able to consider all sea states, a limited number of typical load cases are extracted, referred to as lumped sea states.
Like for wind, information about the distributions of wave heights and the frequency of the varying wave directions can be presented in a wave rose based on meteorological observations of wave heights and wave directions.

2. Short term distribution; wave spectrum

Statistical description assumes that waves of all frequencies and corresponding wavelengths are present. It does not attempt to describe the form of the sea surface but concentrates on wave energy.

The Pierson-Moskowitz spectrum is generally agreed to be representative for fully developed seas. When the waves are in the process of growing under strong winds, this spectrum is, however, too broad and the peak of maximum density is too low. It is based on the significant wave height and the zero crossing period. The PM spectrum is a special case of the Gamma spectrum.

$$S_{zz}(\omega) = \frac{4\pi^3 H_s^{\,2}}{T_z^{\,4}\omega^5}\exp\left[-\frac{1}{\pi}\left(\frac{\omega T_z}{2\pi}\right)^{-4}\right]$$

The JONSWAP spectrum, a peak enhanced version of the PM spectrum is usually considered to be appropriate when the fetch is limited, as is the case for wind sea. The model is based on significant wave height and the mean wave period.

$$S_{zz}(\omega) = \frac{5{,}23\pi^3 H_s^{\,2}}{T_1^{\,4}\omega^5}\exp\left[-32{,}29\frac{\pi^3}{T_1^{\,4}\omega^4}\right]\gamma^p$$

$$p = \exp\left(-\left(\frac{0.191\omega T_1 - 1}{\sqrt{2\sigma}}\right)^2\right)$$

$$\gamma = 3.3$$

$\sigma = 0.07$ for $\omega \le 5.24/T_1$

$\sigma = 0.09$ for $\omega > 5.24/T_1$

γ is a peak-enhancement factor, the effect of which is to increase the peak of the Pierson-Moskowitz spectrum. σ is a relative measure of the width of the peak The effect of the additional factors for the JONSWAP spectrum allowes narrower, more peaked spectra which are typical forms of growing wind seas in deep water.
Both spectra are characterised by the significant wave height H_s and the wave period T_1. The significant wave height is defined by the 33% exceedance level.

8.1.2 Design criteria

The difficulty in the specification of extreme load cases is further complicated by the presence of wave and current. In general it is assumed that the wind and wave loads are not correlated during a sea state (3 hours). Furthermore, extreme loads are not always result of extreme environmental conditions. Operating conditions, control system and dynamics of the structure etc. have also influence on the extreme loads.

Extreme conditions are characterised by the return period. An extreme wind speed with a return period of 50 years refers to a wind speed that, on average, occurs once in 50 years. This concept also applies to the wave height. The problem arises in the combination of extreme values. One can calculate the extreme wind load and extreme wave load separately and adds them together. This approach would be too conservative, as mentioned before, the correlation between the wind speed and wave in small time scale is non existent.

8.1.3 The UKMO-data set

The UKMO data covers 10 years: 1987 to 1996. The data has been retrieved from the European Wave Model archive data covering the area 30.5ºN to 66.75ºN and 14.0ºW to 35.5ºE at grid point intervals of 0.4º in longitude and 0.25 º latitude. This comprises the Baltic Sea, the North Sea, the Atlantic, the Mediterranean and the Black Sea.
The number of grid points in the European waters considered is 8467. The data is 3-hourly (6-hourly prior to mid 1988) and provides the following:

1. Wind speed and wind direction (at 19.5 m ASL)
2. Wind sea height and wind sea period
3. Swell height, swell period and swell direction
4. Resultant wave height, resultant wave period and resultant wave direction.

The wind data is taken from the UKMO Unified model, at 19.5m above sea level for neutral atmospheric stability conditions. The wind speed and wind direction are the input for the wave model. The UKMO European Wave Model is a fine resolution model nested within a coarser global wave model, taking its boundary conditions directly from the global model. In shallow regions, bathymetry is taken into account by means of the following phenomena:

– bottom friction
– refraction
– shoaling
– depth dependent group velocity

Processes that are not included are:

– gustiness of surface wind
– wave induced motion of muddy bottom
– percolation of water through porous sea floor
– resonant triad interaction near coastline
– wave breaking

Water is assumed to be deep beyond 200 meters depth. The global model assimilates significant wave heights from the ERS-2 satellite, but the European model does not assimilate any observed data.
The mean wave period and the significant wave height are calculated from the wind speed, determining the JONSWAP spectrum of that particular sea state. The wave energy of growing wind sea is then forced to match the JONSWAP spectrum. The wave model represents non-linear transfer of wave energy from high frequencies to lower frequencies, as wind seas grow to become swell. The fully developed sea fits a Pierson Moskowitz spectrum. The fully developed sea is described by the significant wave parameters.

The consistency of the data set has been checked by careful inspection of the data. Three periods showed missing data:
– 22 February 1988 to 2 May 1988, due to loss of archive tape by UKMO
– Several records in 1989
– January 1994 is lacking a large number of data

It showed that complete records are missing for each of the grid points in the spatial domain. Since the number of missing data records is limited, the analysis will be continued using the complete data set without further corrections. The impact on the accuracy of the analysis will estimated.

- model
- dataset (gridsize, parameters and timeperiod)
- quality
- credits

8.1.4 Wind and wave climate analysis

The UKMO data set has been analysed and has been presented in maps and graphs.

Figures 8.3-8.16 shows the spatial data, displayed in maps. Maps are presented for 4 categories of data. Resultant wave data, wind sea, swell data and wind speed data. For each of these categories is displayed: average value, i.e. average wave height and wind speed, wave period, direction and the estimated 50 year extreme.

More detailed footprint data is presented for 14 locations (table 8.1) selected to represent different areas in the European waters. These include data for mean conditions, direction, 50 year extremes, Weibull parameters, frequency distributions, annual variations, monthly variations. (Annex 1). Wind wave interaction has been analysed and is presented in Annex 2. This includes wind-wave diagrams, wave scatter diagrams and wave-period diagrams.

Table 8.1 Locations for the footprint data

Location	**Lattitude**	**Longitude**
Adriatic Sea	43.00	15.53
Aegean Sea	38.00	25.53
Atlantic (North)	60.00	-10.07
Atlantic (Central)	44.00	-12.87
Atlantic (South)	35.00	-10.07
Baltic Sea	58.00	20.33
Bay of Biscay	45.00	-2.87
Black Sea	42.00	29.93
Ionian Sea	36.00	19.13
Mediterranean (East)	33.50	27.93
Mediterranean (West)	39.00	5.93
North Sea	57.00	3.13
Norwegian Sea	65.00	2.33
Tyrrhenian Sea	40.00	12.33

Mean conditions
The mean values of the following parameters were calculated:

- Wind: wind speed, and wind direction
- Significant: wave height, wave direction and wave period
- Swell: wave height, wave direction and wave period
- Wind sea: wave height, wave direction (by definition equal to the wind direction) and wave period

Annual variation
The average wave height and wind speed are presented for each year and compared to the overall mean. This shows the interannual variation of the presented parameters.

Monthly variations
The average wave height and wind speed for each month, averaged over all the years in the data set are presented to show the monthly variation. This graph is relevant for planning maintenance periods.

Annual variation the maximum value
The maximum value of wave height and wind speed for each year is presented and compared with the extrapolated 50 year extreme level.

Extreme conditions
The once per 50-year exceedance level was calculated for the wind speed and wave height using Gumbel-theory. The yearly maximum value was stored and sorted. The sorted maximum values were then used to estimate the parameters *a* and and *y* in the Gumbel distribution.

$$P(x \le x_i) = \exp(-\exp(-a(x_i - y))$$

Using the distribution parameters, the 50 year extreme value was estimated by extrapolation.

Frequency distributions
Bin analyses were made of the wind and wave parameters. In the analysis, the following values were used:

Parameter	Bin size	Maximum value
Wave height	0.5 m	15 m
Wind speed	0.5 m/s	25 m/s
Direction	30	360
Wave period	0.5 s	25 s

Weibull parameters
The frequency distributions for wind speed and wave height were used to estimate the two parameter Weibull-distribution. The shape factor ‘k’ and the scale factor ‘a’ were estimated by a least square fit between exceedance levels of 10% and 90%.

Scatter diagram
The scatter diagram shows the distribution of wind sea wave height vs. the wave direction.

Wind wave diagram
The wind wave diagram shows the distriburion of wind speed vs. wind sea wave height. This diagram is a requirement for calculating integral wind wave loading on wind turbines

Wave period diagram
The wave period diagram presents the relation between the wind sea wave height and the wave period

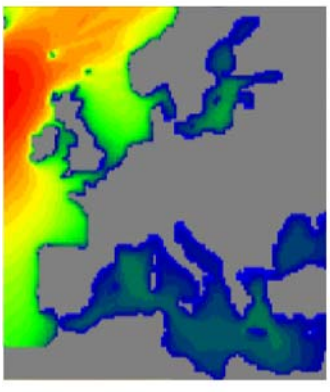

Fig 8.3 Resultant wave height

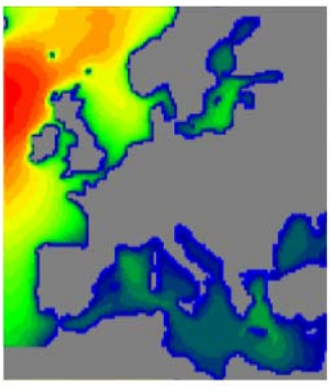

Fig 8.4 Windsea wave height

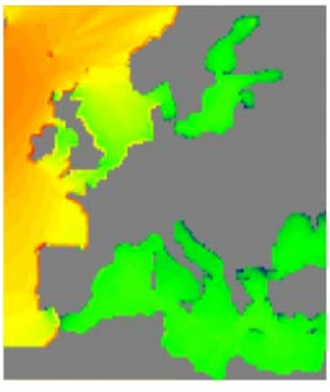

Fig 8.5 Resultant wave period

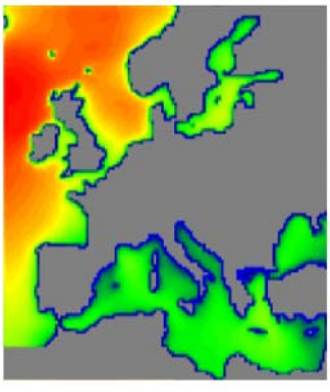

Fig 8.6 Windsea wave period

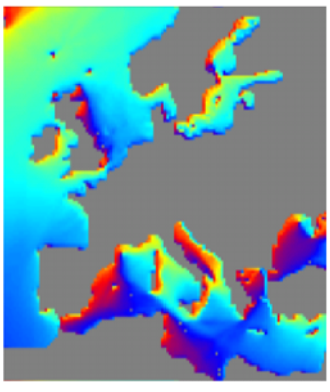

Fig 8.7 Resultant wave direction

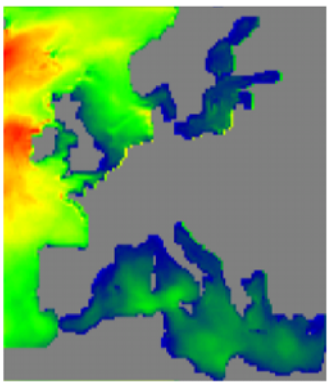

Fig 8.8 Resultant 50 year extreme wave height

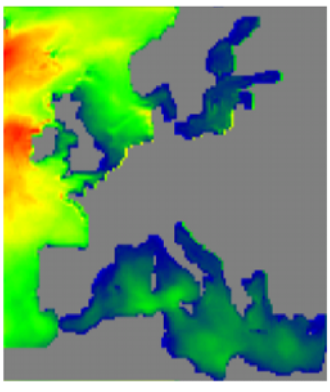

Fig 8.9 Wind sea 50 year extreme wave height

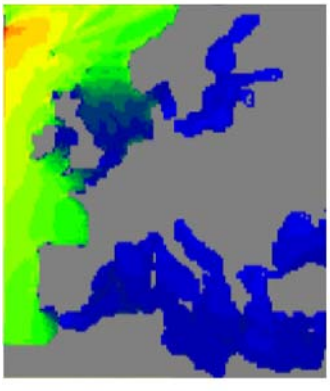

Fig 8.10 Swell Wave height

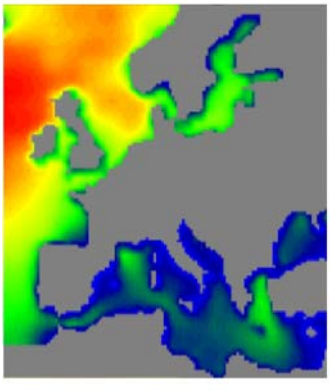

Fig 8.11 Average wind speed

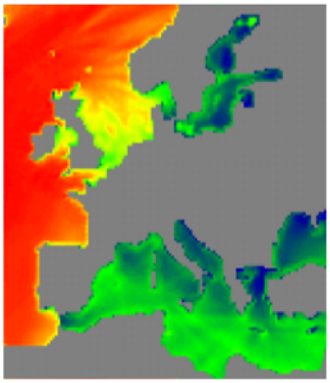

Fig 8.12 Swell wave period

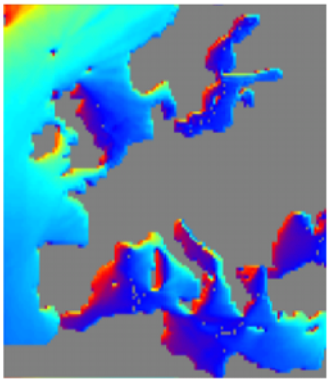

Fig 8.13 Swell wave direction

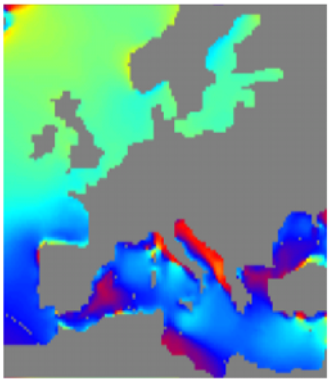

Fig 8.14 Wind direction

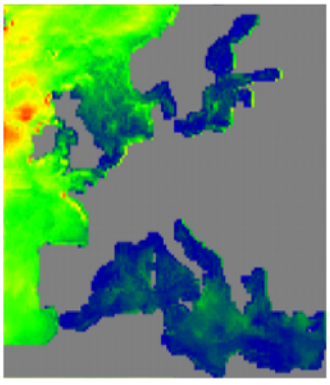

Fig 8.15 Swell 50 year extreme wave height

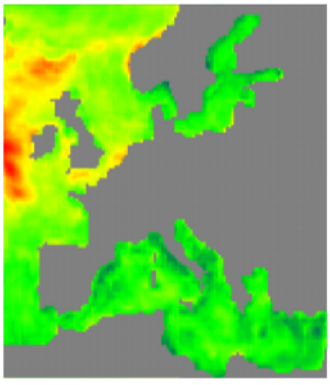

Fig 8.16 50 year extreme wind speed

8.1.5 Relevant conclusions

The UKMO wave data archive has shown to be very valuable for the calculation of the wave climate in the European waters.

The wave height can be well described by a Weibull-type distribution. The 50-year extremes were derived by fitting the annual extremes to a Gumbel distribution.

The wave climate in the Atlantic and the North Sea is more severe than in the Baltic, the Mediterranean and the Black Sea. The most severe wind conditions are in the West Coast of Ireland.

	Average (m/s)	**50-year extreme (m/s)**
Atlantic (N)	3.2	20.1
North Sea	2.1	12.9
Mediterranean Sea	1.1	9.9
Black Sea	0.9	6.2
Baltic Sea	1.2	6.7

The wave height varies considerably over the seasons. The winter seasons shown an average wave height, which is a factor of 2 - 2.5 higher than that in the summer season. This is an important factor for scheduling offshore installations and maintenance.

8.1.6 References

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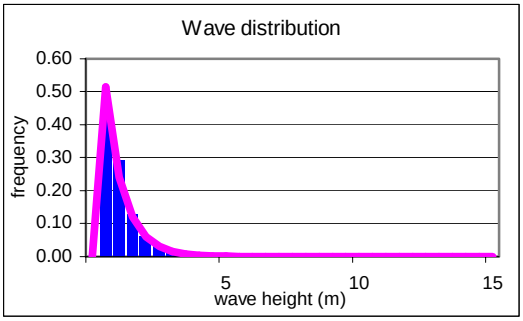
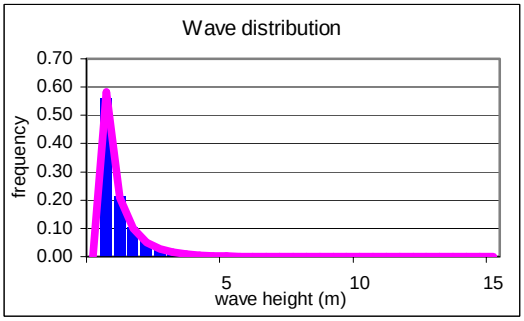
8.1.7 Annex 1 : Footprint data for 14 locations

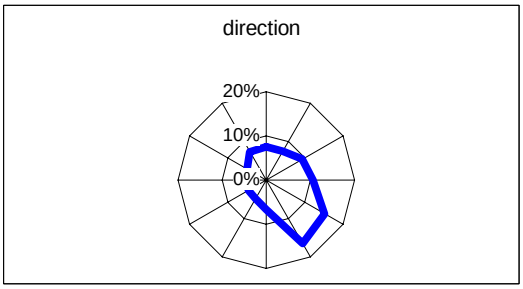
Location	Adriatic Sea	Lattitude	43.00	Longitude	15.53

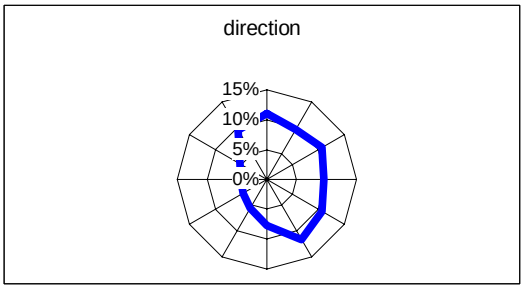
	Significant wave height
Average height	0.7 m
Average direction	9.1
Average Period	3.8 S
Maximum	5.1 m
50 yr return value	5.6 m
Weibull scale factor	0.7 m
Weibull shape factor	0.96

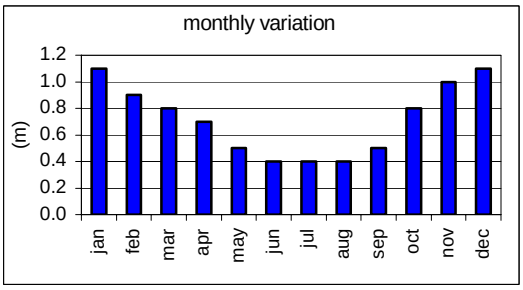
	Wind Sea wave height
Average height	0.6 m
Average direction	-
Average Period	2.2 S
Maximum	5.1 m
50 yr return value	5.6 m
Weibull scale factor	0.59 m
Weibull shape factor	0.84

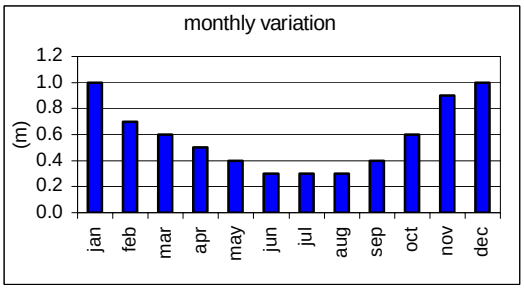


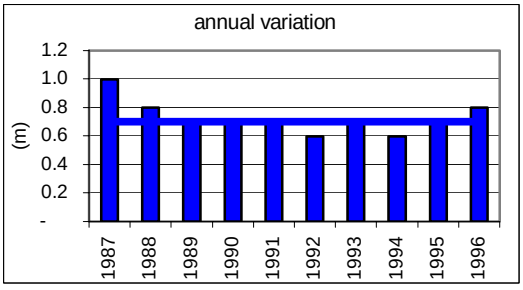


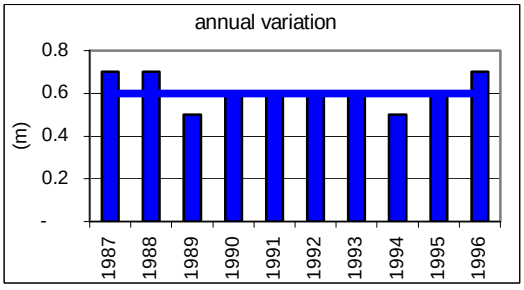


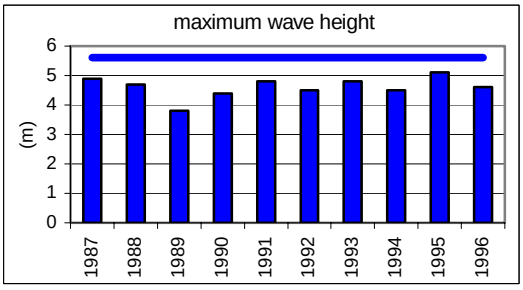


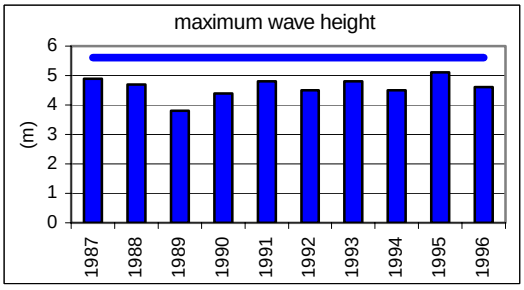








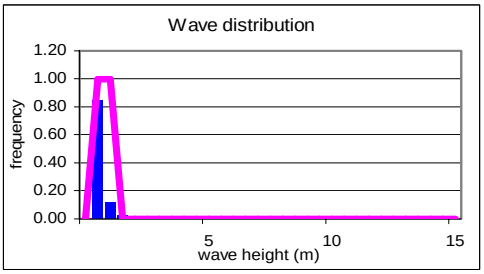


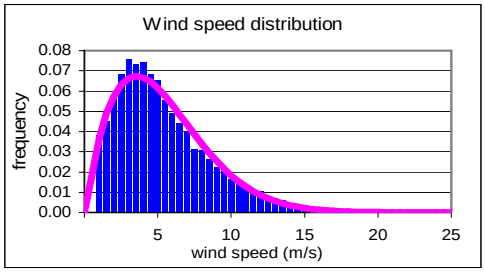


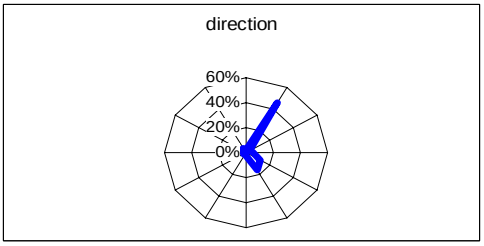
Location	Adriatic Sea	Lattitude	43.00	Longitude	15.53

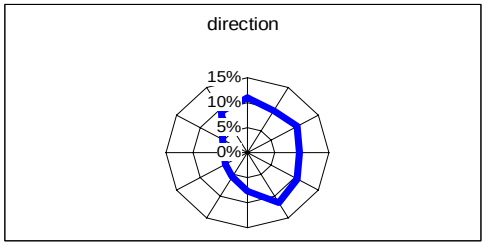
	Swell wave height
Average height	0.2 m
Average direction	3.2
Average Period	2.9 S
Maximum	2.9 m
50 yr return value	3.3 m
Weibull scale factor	0.94 m
Weibull shape factor	90.4

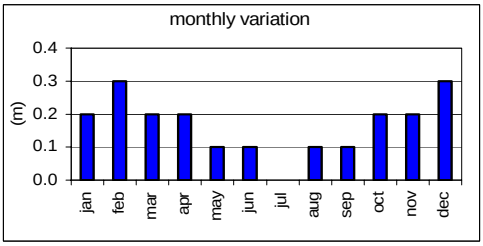
	Wind Speed
Average height	5.1 m/s
Average direction	5.8
Average Period	- S
Maximum	22.5 m/s
50 yr return value	23.6 m/s
Weibull scale factor	5.73 m/s
Weibull shape factor	1.66

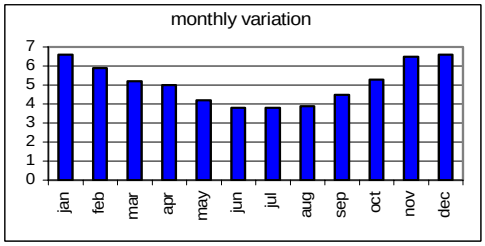


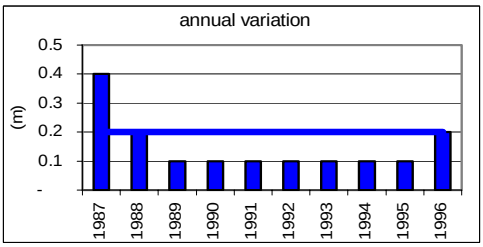


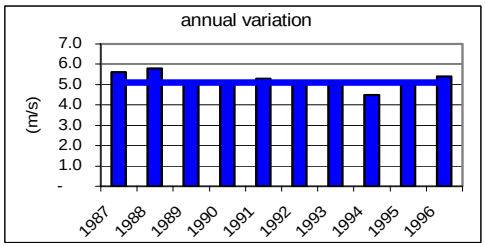


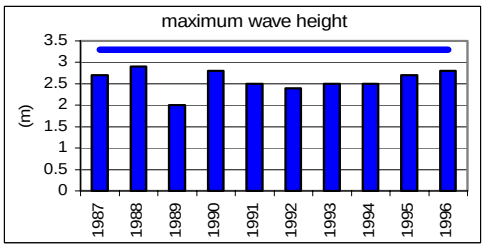


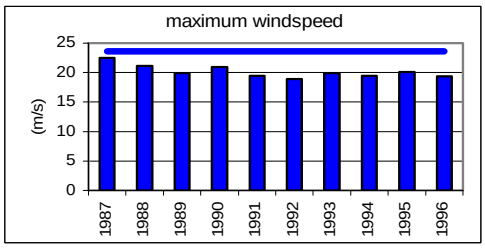








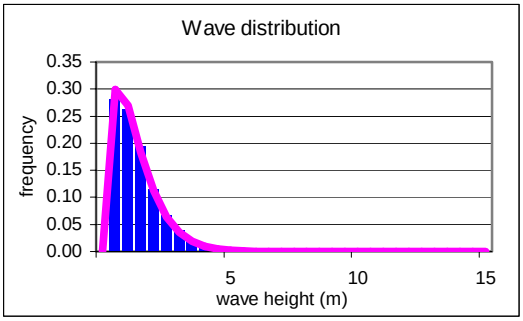


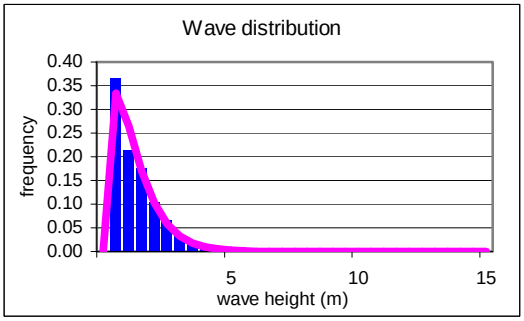


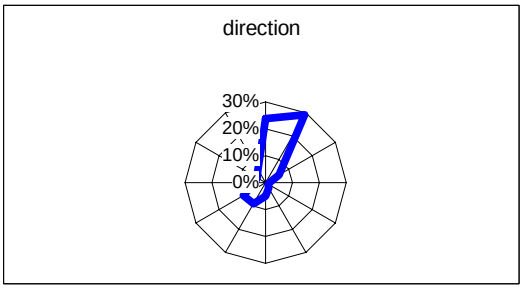
Location	Aegean Sea	Lattitude	38.00	Longitude	25.53

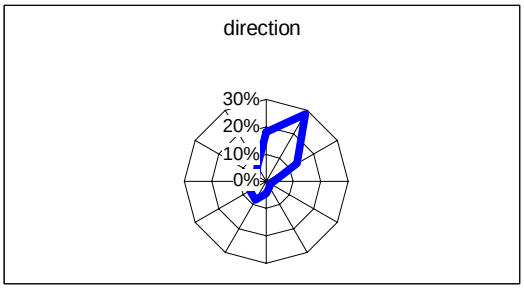
	Significant wave height
Average height	1 m
Average direction	34.6
Average Period	4.2 S
Maximum	6.1 m
50 yr return value	7.1 m
Weibull scale factor	1.15 m
Weibull shape factor	1.24

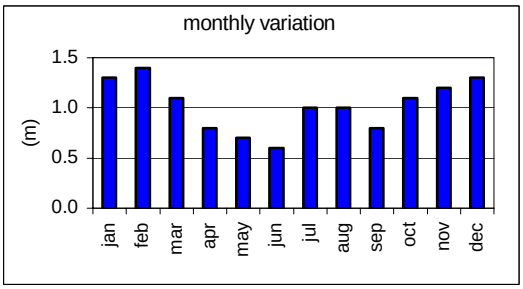
	Wind Sea wave height
Average height	0.9 m
Average direction	-
Average Period	3.2 S
Maximum	6 m
50 yr return value	6.9 m
Weibull scale factor	1.08 m
Weibull shape factor	1.17

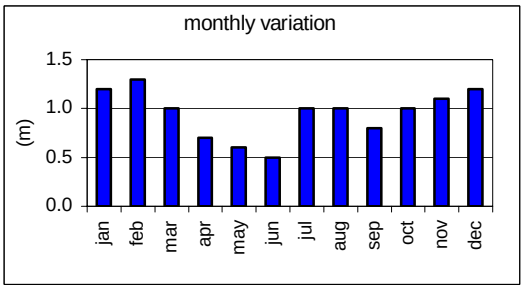


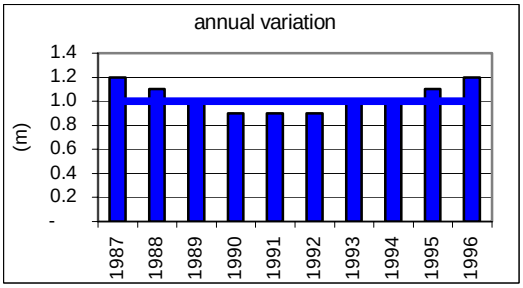


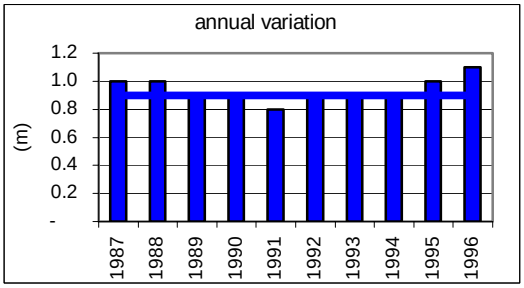


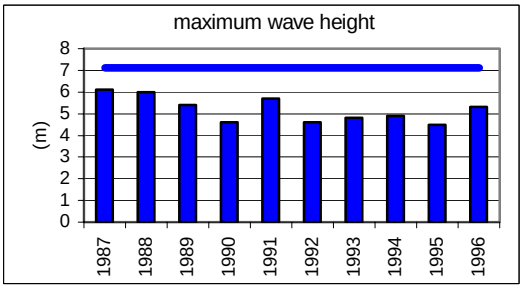


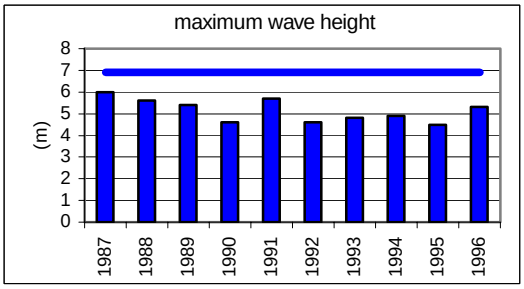








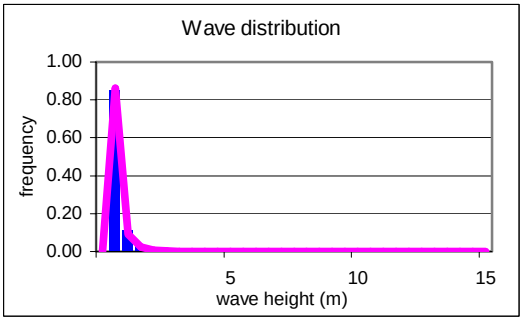


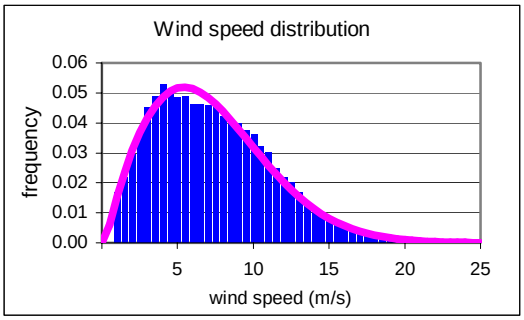


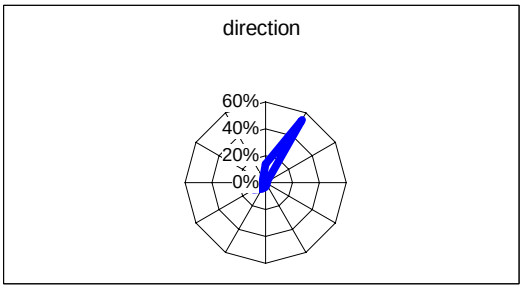
Location	Aegean Sea	Lattitude	38.00	Longitude	25.53

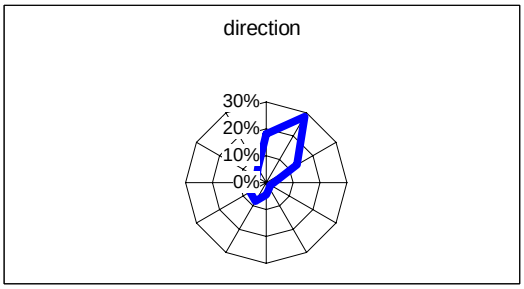
	Swell wave height	
Average height	0.2	m
Average direction	34.5	
Average Period	3	S
Maximum	4	m
50 yr return value	5	m
Weibull scale factor	0.18	m
Weibull shape factor	0.71	

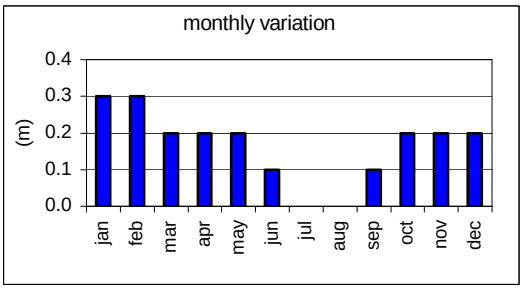
	Wind Speed	
Average height	6.9	m/s
Average direction	35.9	
Average Period	-	S
Maximum	27.2	m/s
50 yr return value	31.4	m/s
Weibull scale factor	7.87	m/s
Weibull shape factor	1.85	

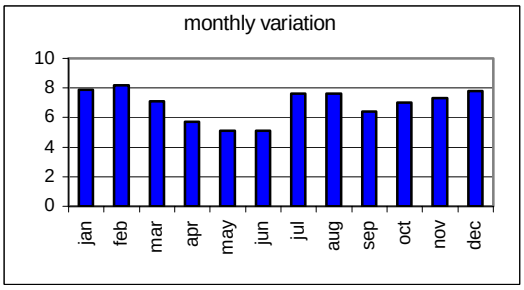


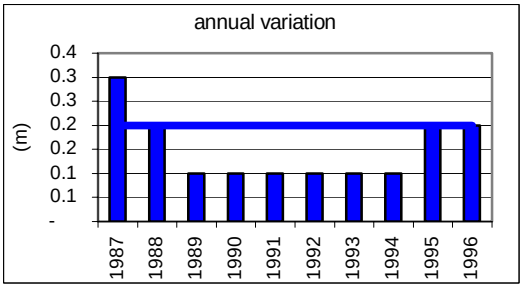


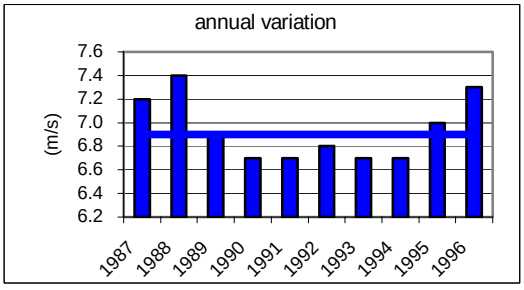


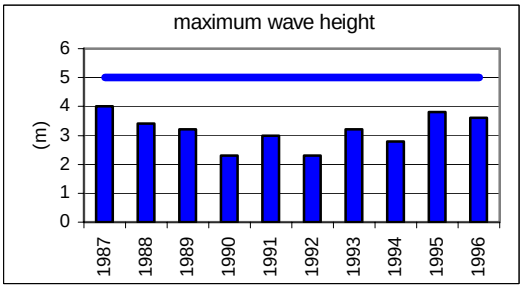


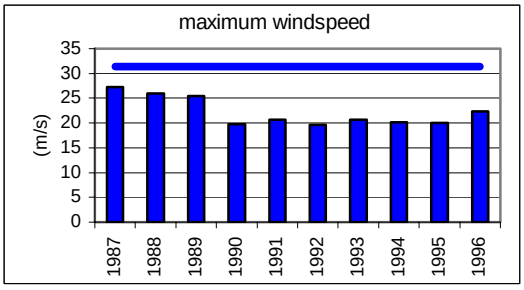








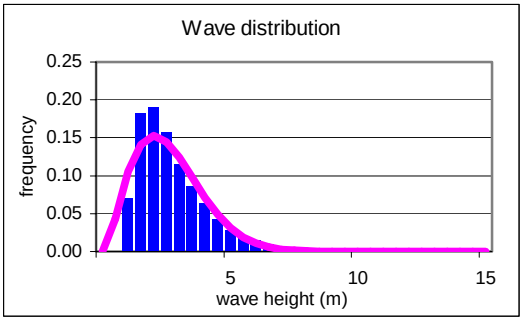


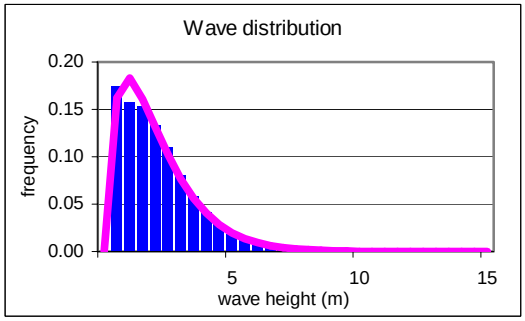


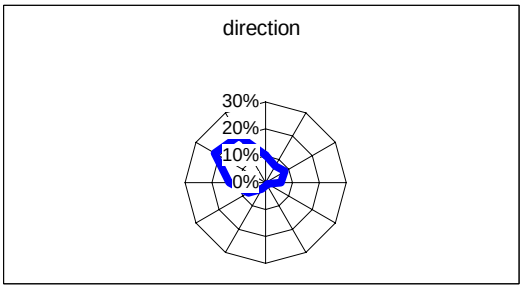
Location	Atlantic (Central)	Lattitude	44.00	Longitude	12.87-

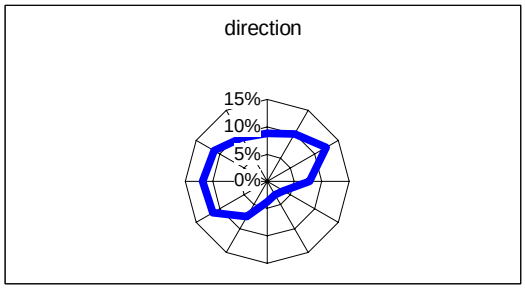
	Significant wave height
Average height	2.4 m
Average direction	30.6
Average Period	6.3 S
Maximum	13.6 m
50 yr return value	16.9 m
Weibull scale factor	2.67 m
Weibull shape factor	1.86

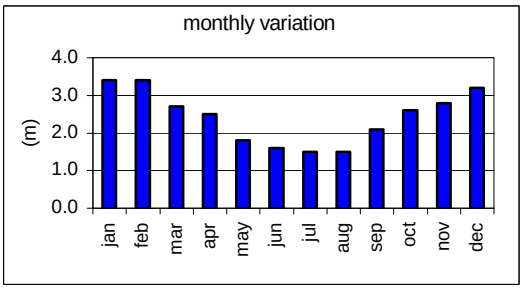
	Wind Sea wave height
Average height	1.8 m
Average direction	-
Average Period	4.6 S
Maximum	13.6 m
50 yr return value	16.9 m
Weibull scale factor	1.98 m
Weibull shape factor	1.26

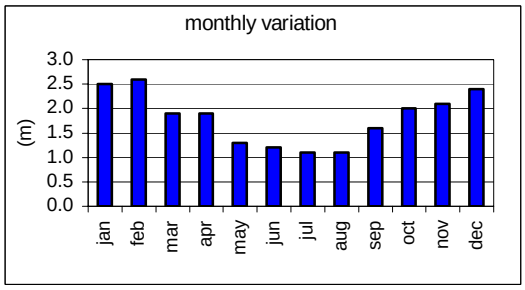


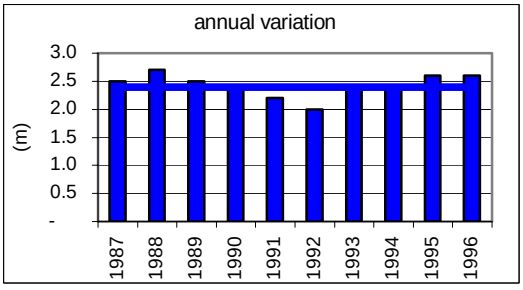


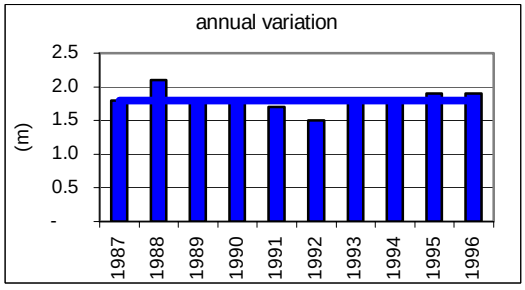


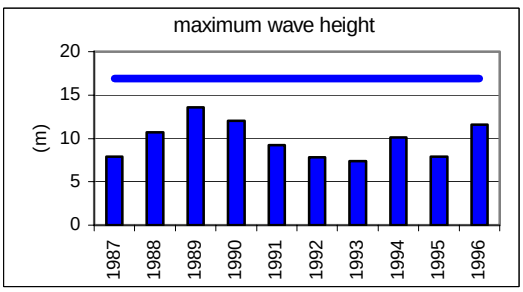


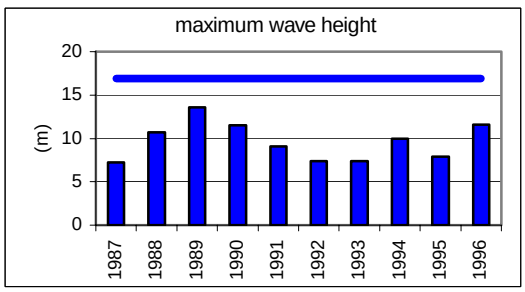








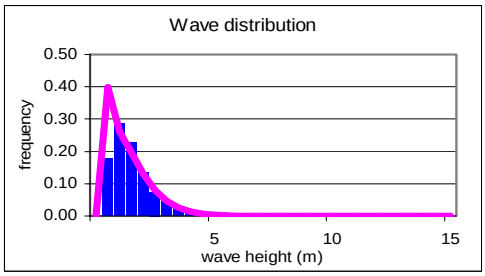


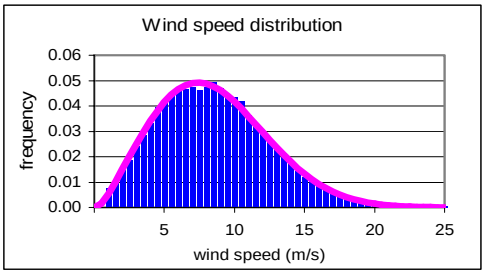


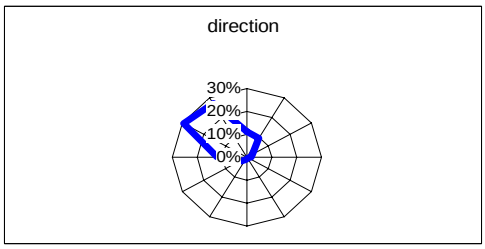
Location	Atlantic (Central)	Lattitude	44.00	Longitude	12.87-

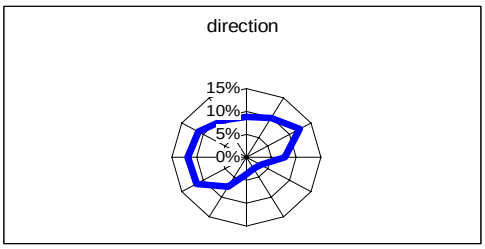
	Swell wave height
Average height	1.2 m
Average direction	30.4
Average Period	9.7 S
Maximum	7.9 m
50 yr return value	9.5 m
Weibull scale factor	1.32 m
Weibull shape factor	1.34

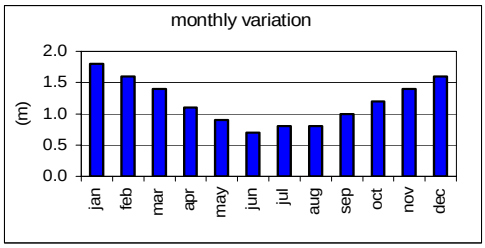
	Wind Speed
Average height	8.3 m/s
Average direction	31
Average Period	- S
Maximum	29.8 m/s
50 yr return value	31.1 m/s
Weibull scale factor	9.35 m/s
Weibull shape factor	2.22

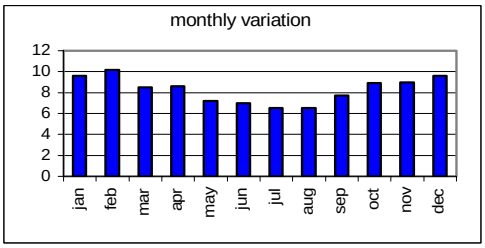


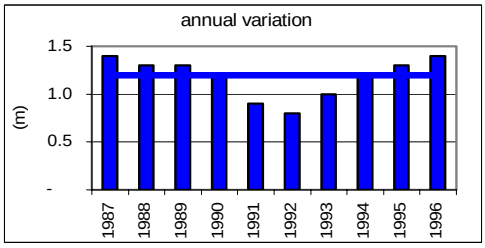


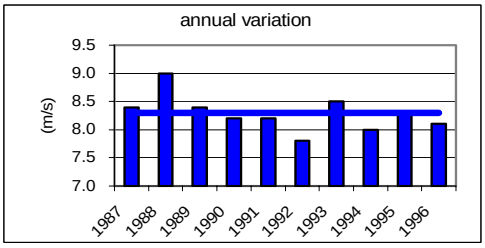


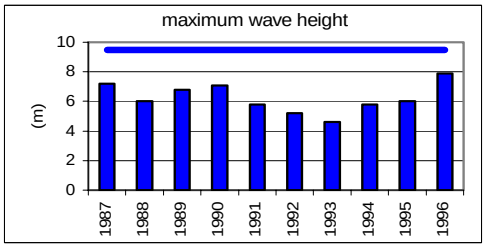


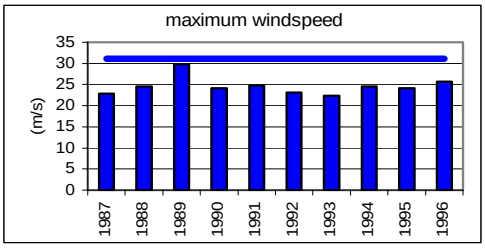








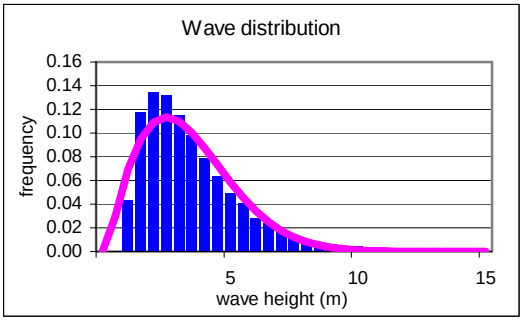


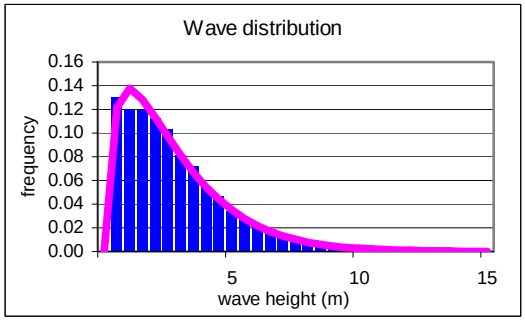


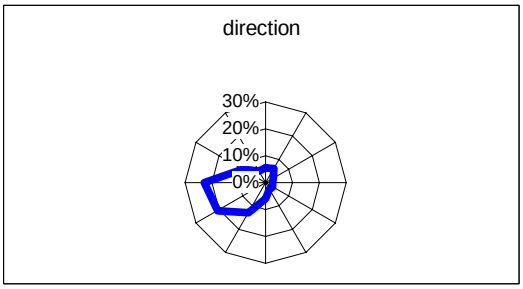
Location	Atlantic (North)	Lattitude	60.00	Longitude	10.07-

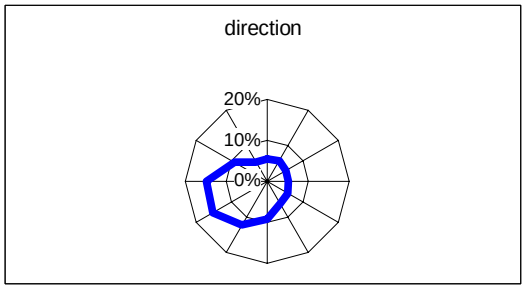
	Significant wave height
Average height	3.2 m
Average direction	24.2
Average Period	6.8 S
Maximum	16 m
50 yr return value	20.1 m
Weibull scale factor	3.53 m
Weibull shape factor	1.79

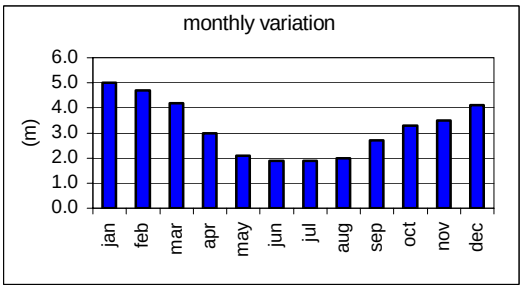
	Wind Sea wave height
Average height	2.5 m
Average direction	-
Average Period	5.4 S
Maximum	16 m
50 yr return value	20.1 m
Weibull scale factor	2.7 m
Weibull shape factor	1.21

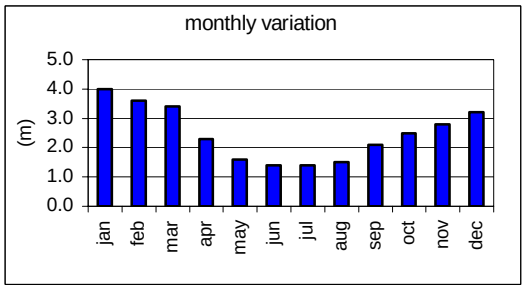


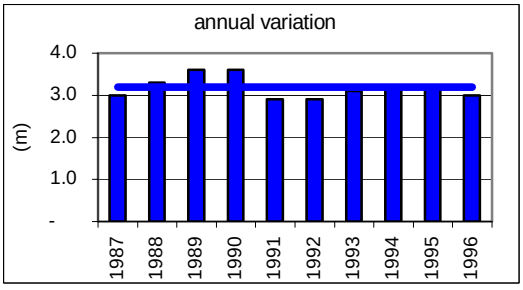


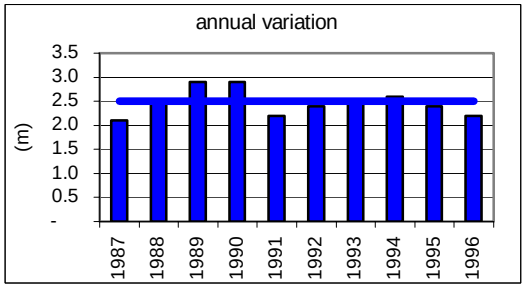


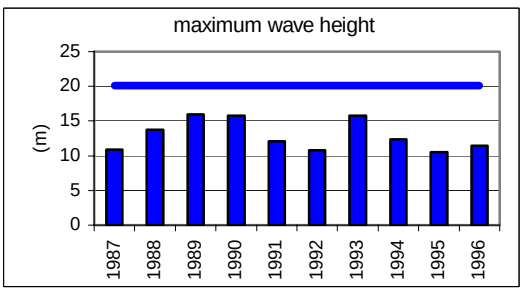


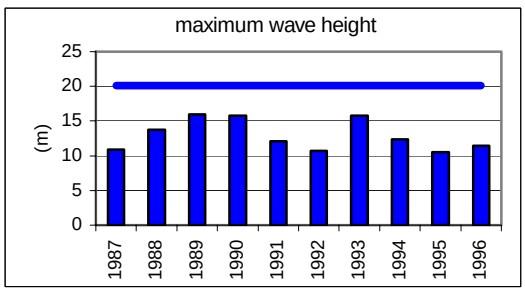








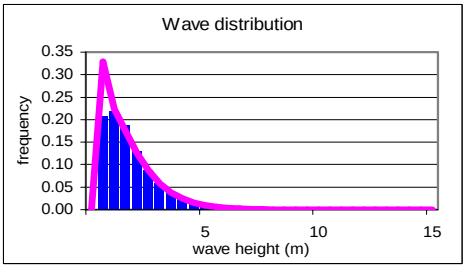


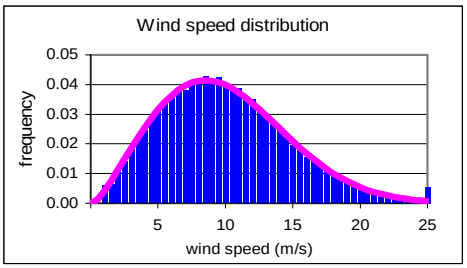


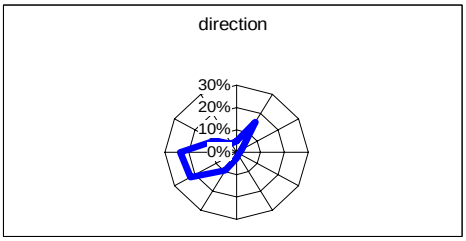
Location	Atlantic (North)	Lattitude	60.00	Longitude	10.07-

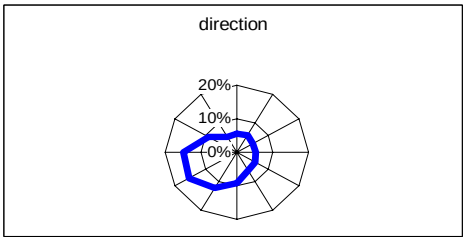
	Swell wave height
Average height	1.4 m
Average direction	26.3
Average Period	9.8 S
Maximum	10.9 m
50 yr return value	13.2 m
Weibull scale factor	1.52 m
Weibull shape factor	1.21

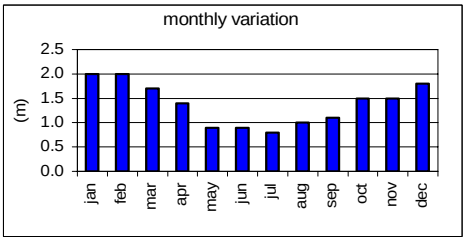
	Wind Speed
Average height	9.7 m/s
Average direction	22.6
Average Period	- S
Maximum	36.2 m/s
50 yr return value	43.8 m/s
Weibull scale factor	10.97 m/s
Weibull shape factor	2.18

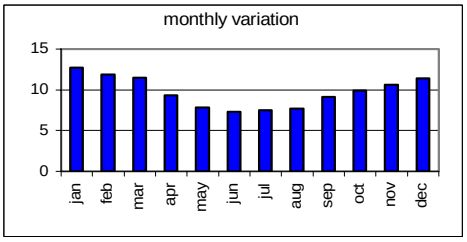


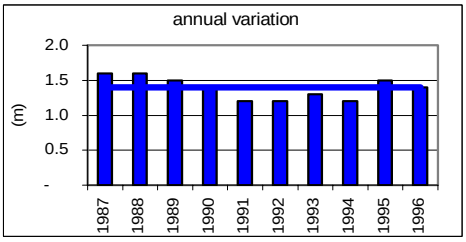


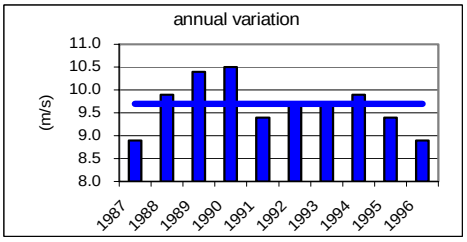


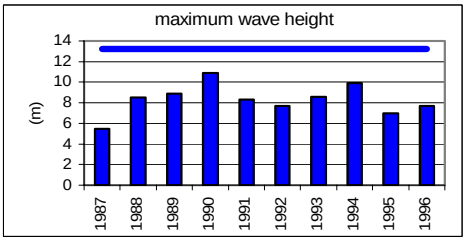


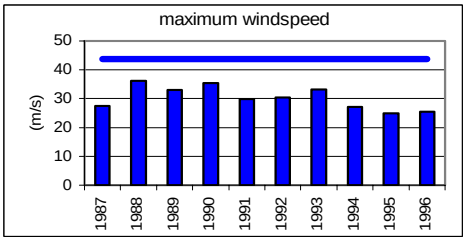








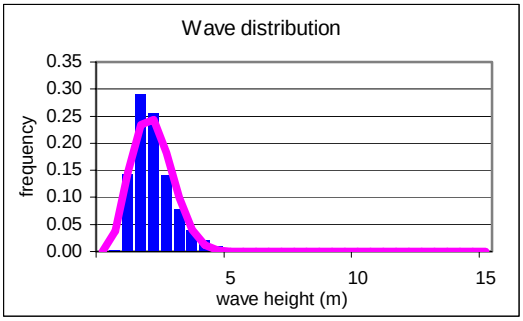


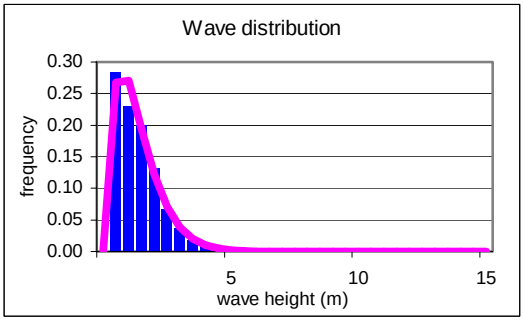


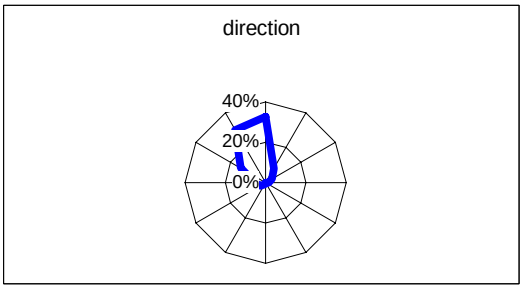
Location	Atlantic (South)	Lattitude	35.00	Longitude	10.07-

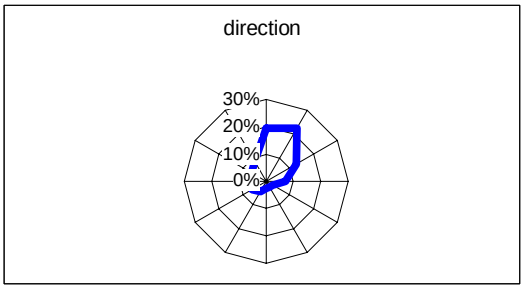
	Significant wave height
Average height	1.7 m
Average direction	32.4
Average Period	5.9 S
Maximum	8.9 m
50 yr return value	11.3 m
Weibull scale factor	1.93 m
Weibull shape factor	2.41

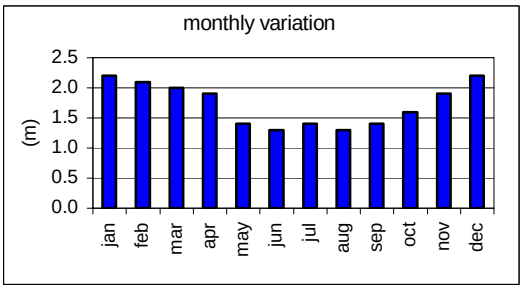
	Wind Sea wave height
Average height	1.1 m
Average direction	-
Average Period	3.4 S
Maximum	8.7 m
50 yr return value	11.3 m
Weibull scale factor	1.22 m
Weibull shape factor	1.31

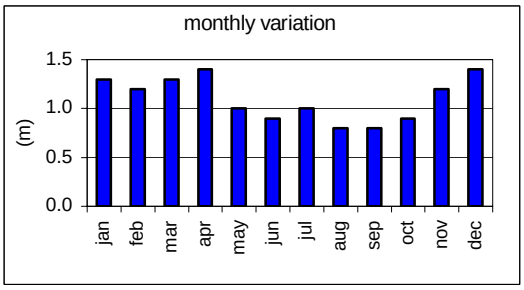


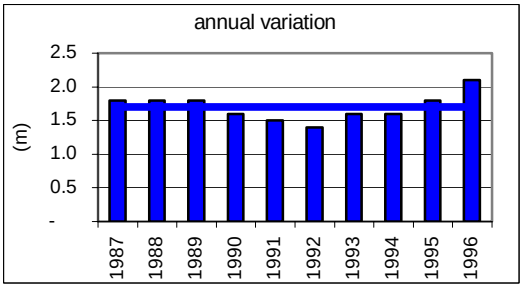


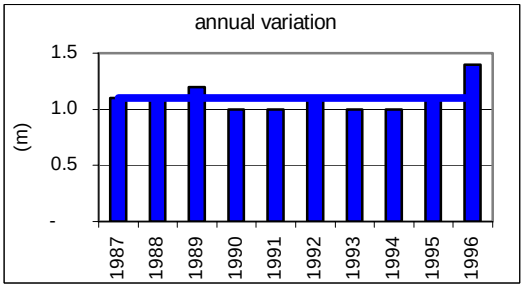


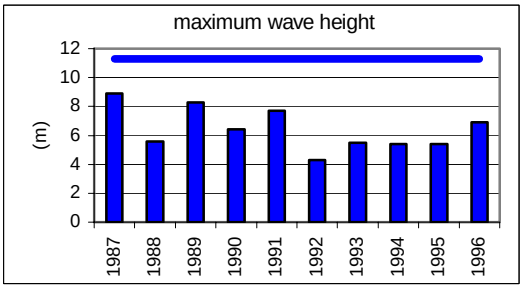


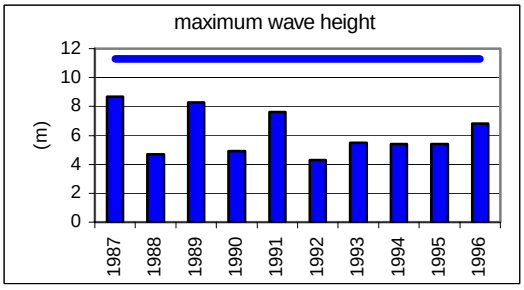








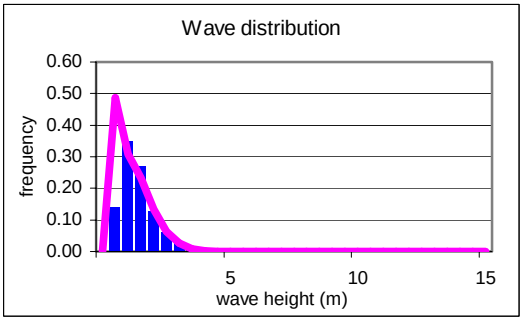


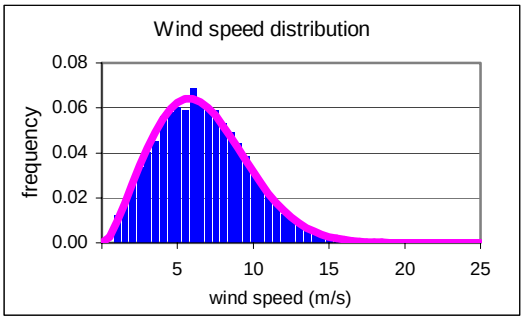


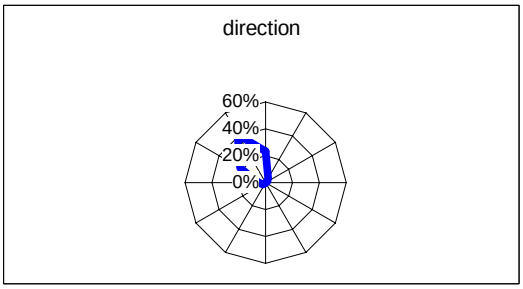
Location	Atlantic (South)	Lattitude	35.00	Longitude	10.07-

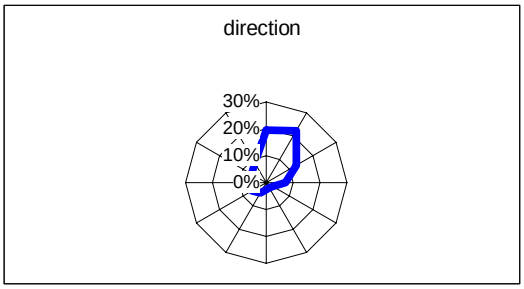
	Swell wave height	
Average height	1.1	m
Average direction	31.3	
Average Period	9.2	S
Maximum	6.5	m
50 yr return value	8.6	m
Weibull scale factor	1.19	m
Weibull shape factor	1.59	

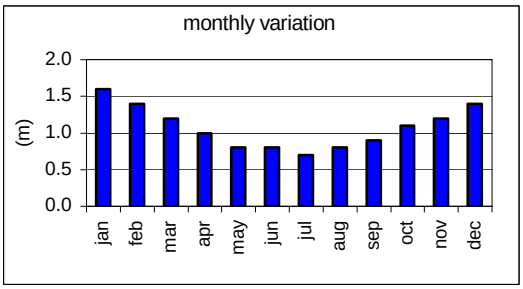
	Wind Speed	
Average height	6.4	m/s
Average direction	35.8	
Average Period	-	S
Maximum	22.7	m/s
50 yr return value	27.5	m/s
Weibull scale factor	7.2	m/s
Weibull shape factor	2.23	

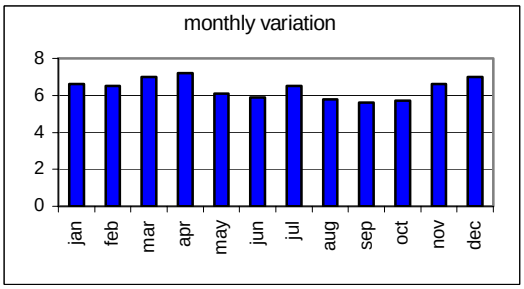


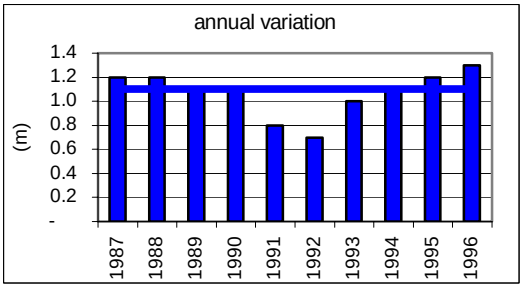


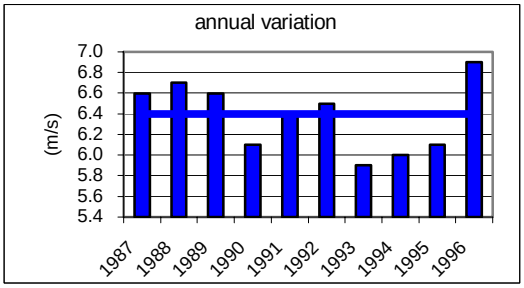


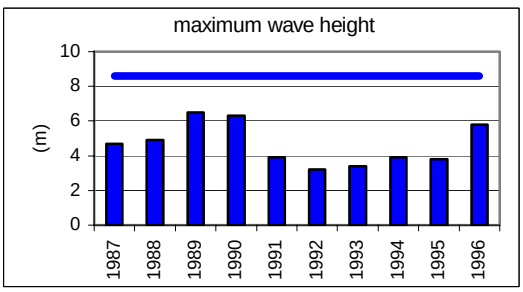


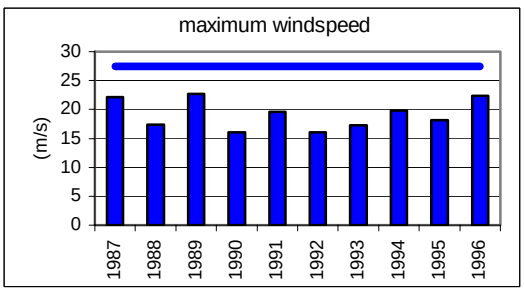








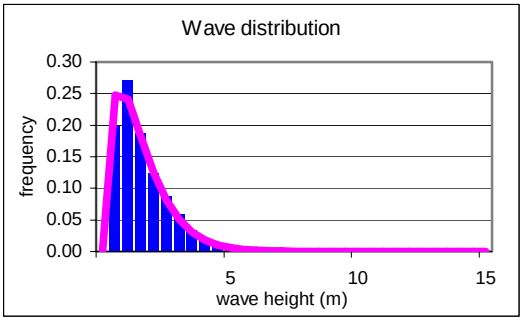


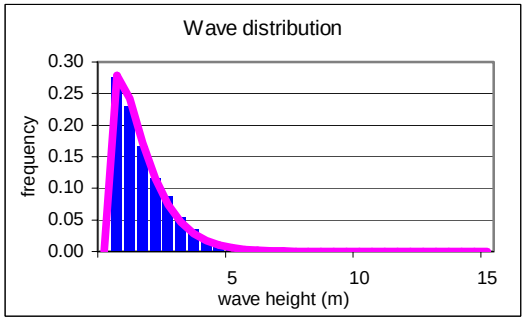


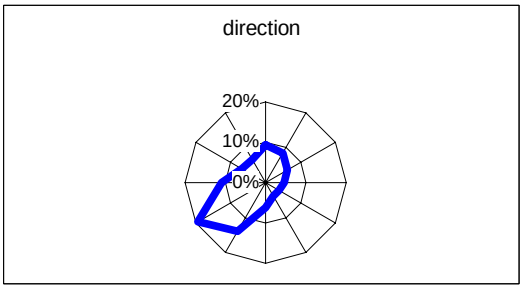
Location	Baltic Sea	Lattitude	58.00	Longitude	20.33

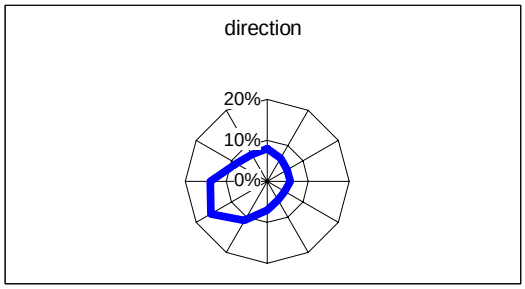
	Significant wave height
Average height	1.2 m
Average direction	24.5
Average Period	4.4 S
Maximum	6.3 m
50 yr return value	6.7 m
Weibull scale factor	1.38 m
Weibull shape factor	1.24

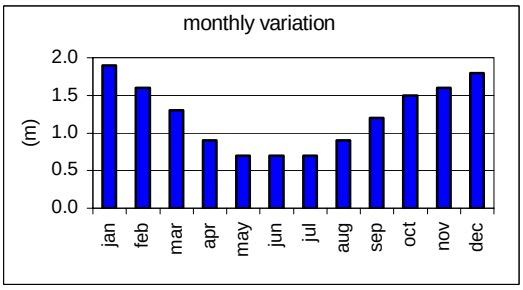
	Wind Sea wave height
Average height	1.2 m
Average direction	-
Average Period	3.7 S
Maximum	6.3 m
50 yr return value	6.8 m
Weibull scale factor	1.3 m
Weibull shape factor	1.17

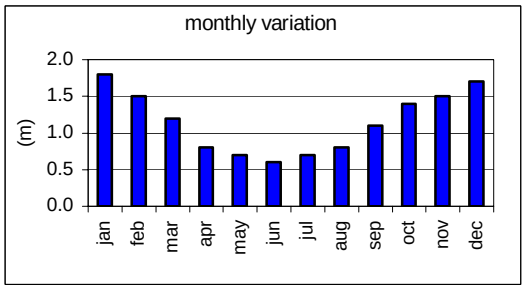


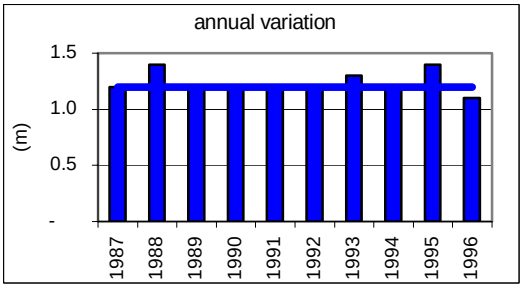


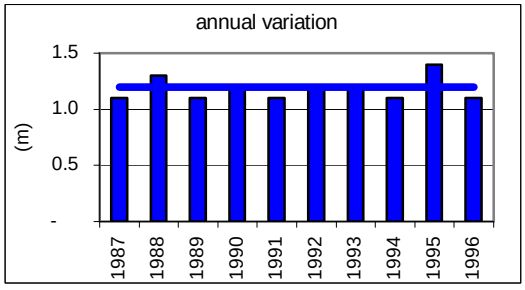


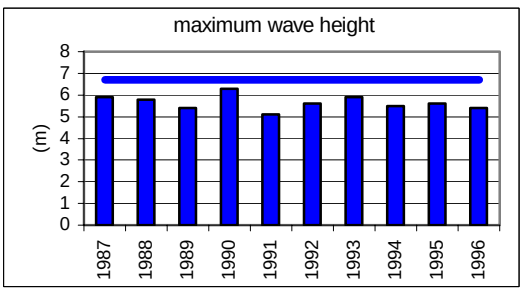


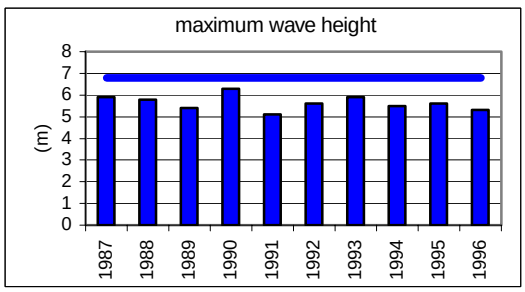








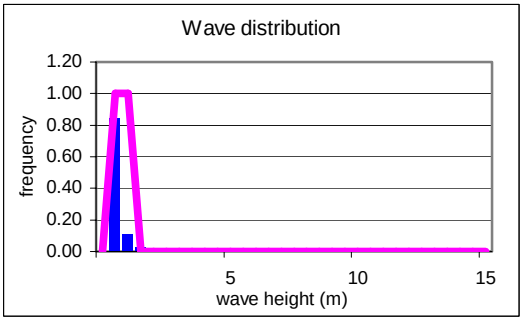


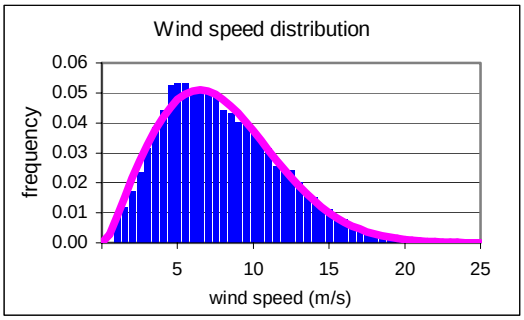


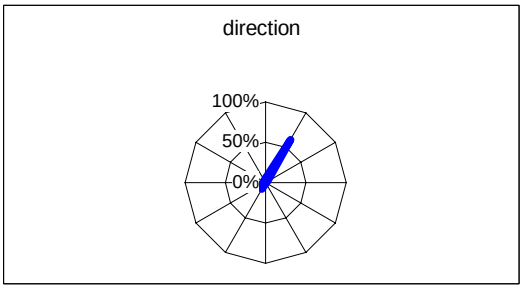
Location	Baltic Sea	Lattitude	58.00	Longitude	20.33

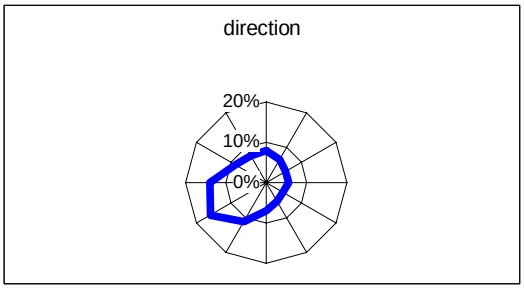
	Swell wave height	
Average height	0.2	m
Average direction	34.9	
Average Period	3	S
Maximum	4.2	m
50 yr return value	5.1	m
Weibull scale factor	0.93	m
Weibull shape factor	47.21	

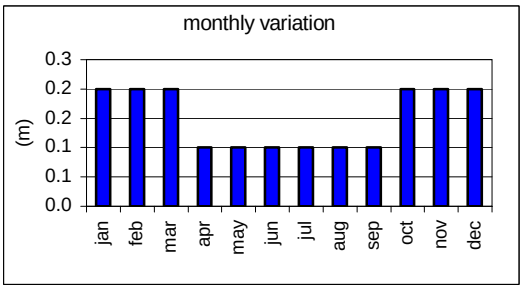
	Wind Speed	
Average height	7.6	m/s
Average direction	24.5	
Average Period	-	S
Maximum	24.9	m/s
50 yr return value	27.1	m/s
Weibull scale factor	8.57	m/s
Weibull shape factor	2.06	

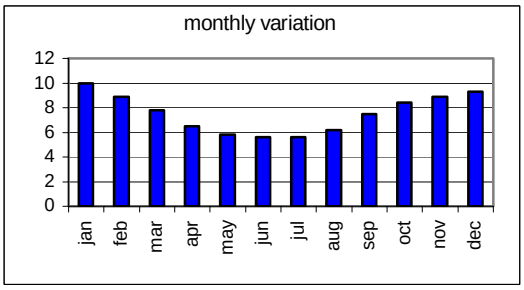


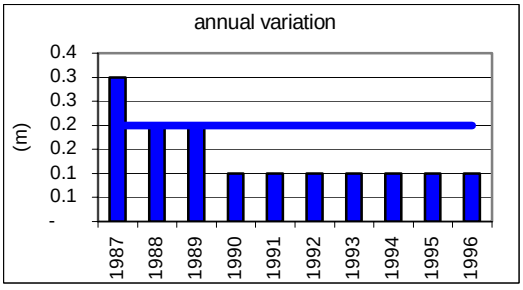


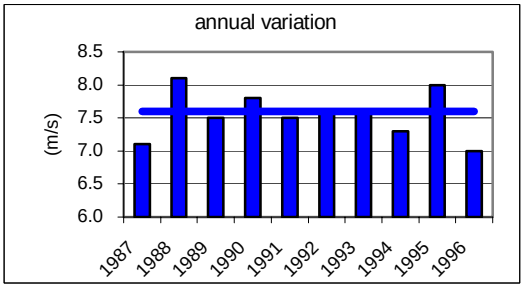


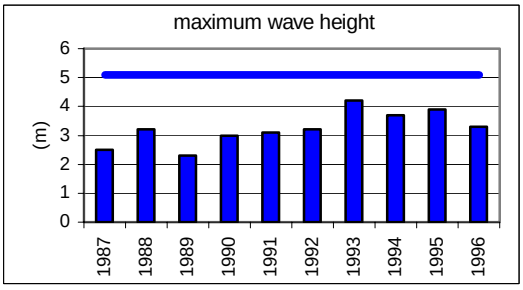


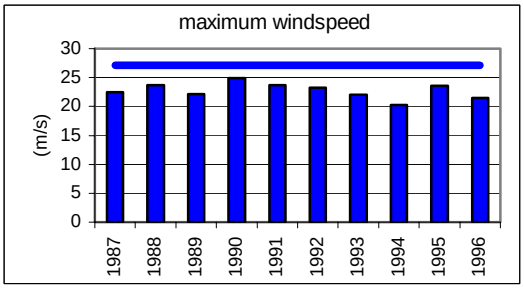








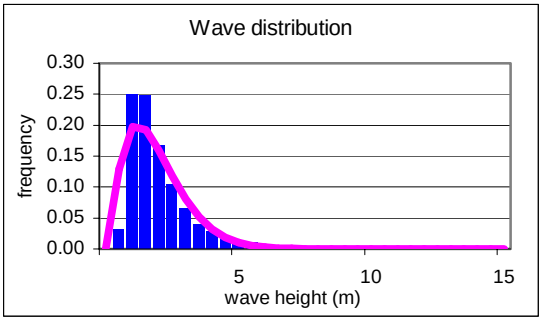


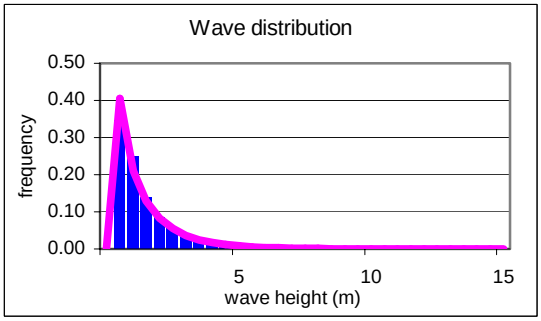


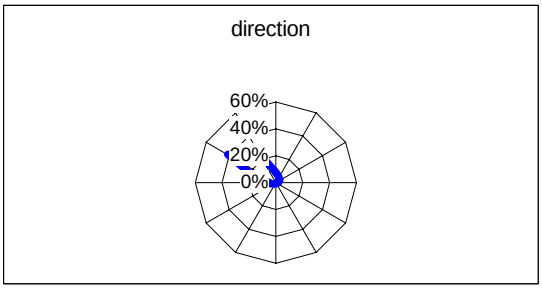
Location	Bay of Biscay	Lattitude	45.00	Longitude	2.87-

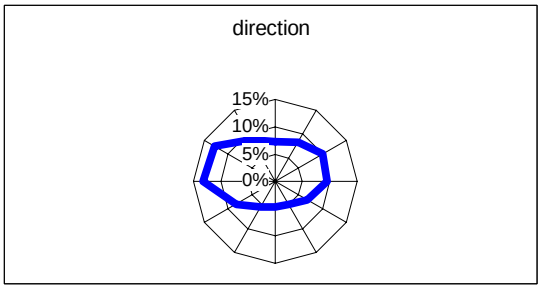
	Significant wave height
Average height	1.7 m
Average direction	29.9
Average Period	5.9 S
Maximum	12.1 m
50 yr return value	15 m
Weibull scale factor	1.84 m
Weibull shape factor	1.52

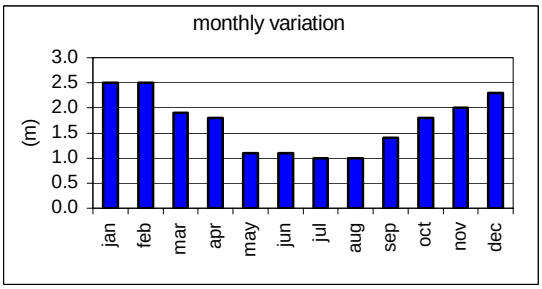
	Wind Sea wave height
Average height	1.1 m
Average direction	-
Average Period	3.3 S
Maximum	12.1 m
50 yr return value	15 m
Weibull scale factor	1.05 m
Weibull shape factor	0.88

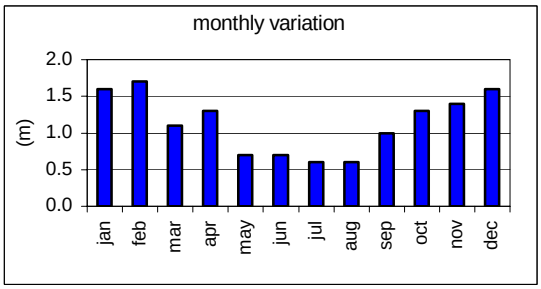


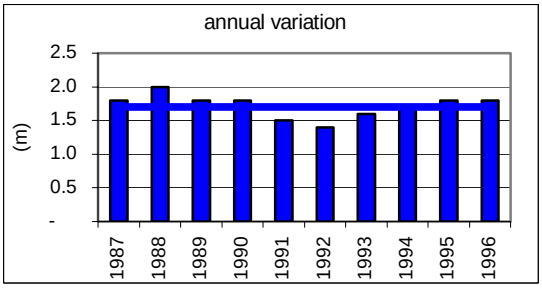


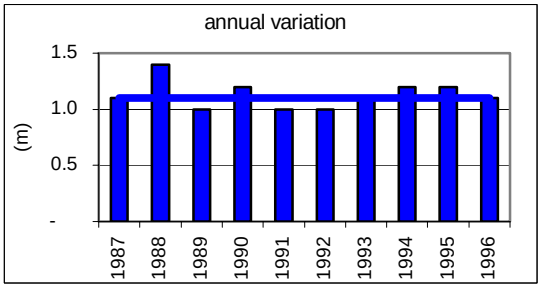


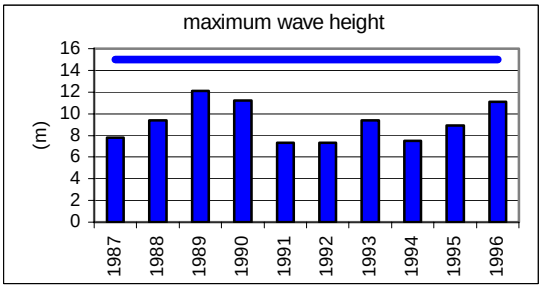


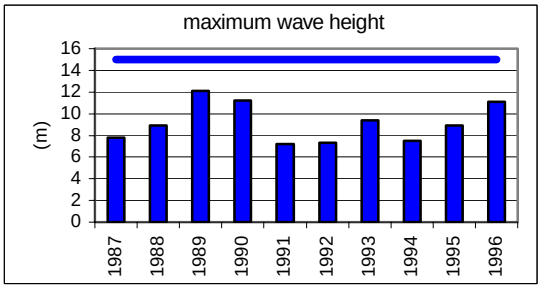








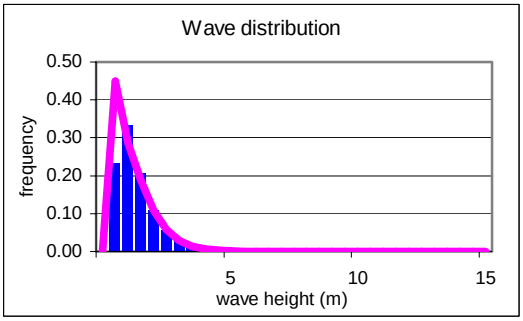


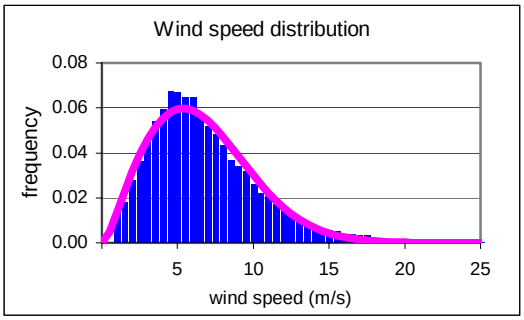


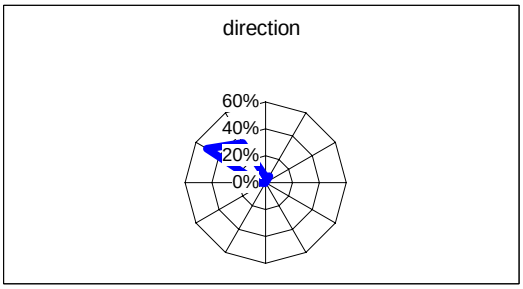
Location	Bay of Biscay	Lattitude	45.00	Longitude	2.87-

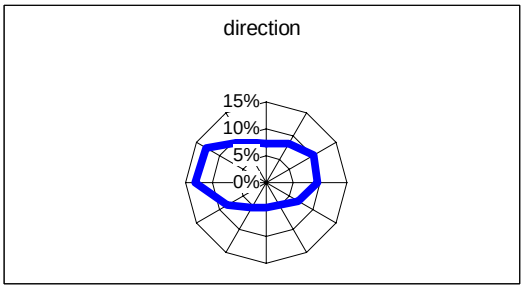
	Swell wave height	
Average height	1	m
Average direction	29.8	
Average Period	8.9	S
Maximum	6.8	m
50 yr return value	8.3	m
Weibull scale factor	1.08	m
Weibull shape factor	1.29	

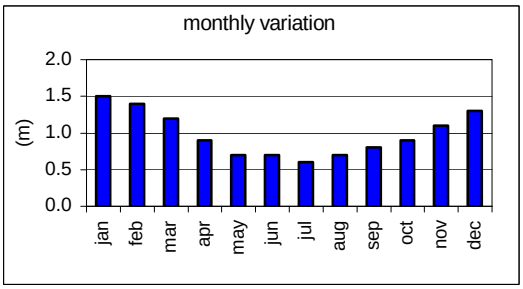
	Wind Speed	
Average height	6.4	m/s
Average direction	31.2	
Average Period	-	S
Maximum	26	m/s
50 yr return value	29.8	m/s
Weibull scale factor	7.19	m/s
Weibull shape factor	2.01	

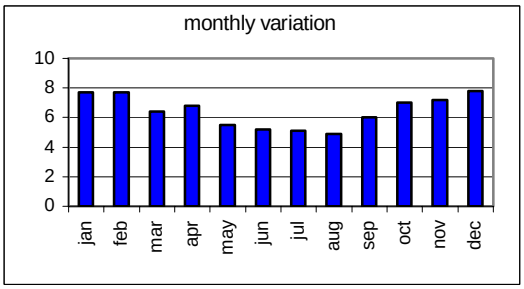


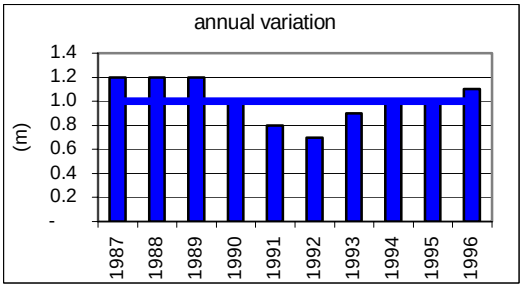


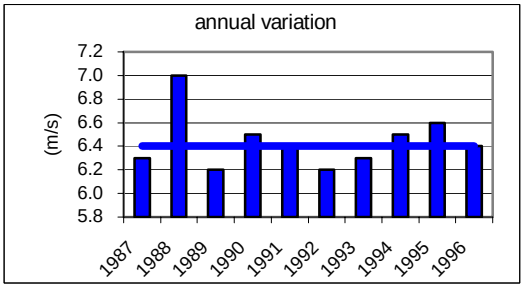


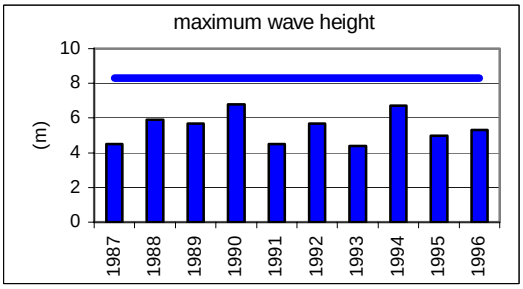


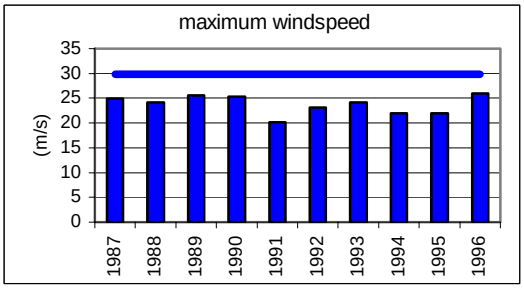








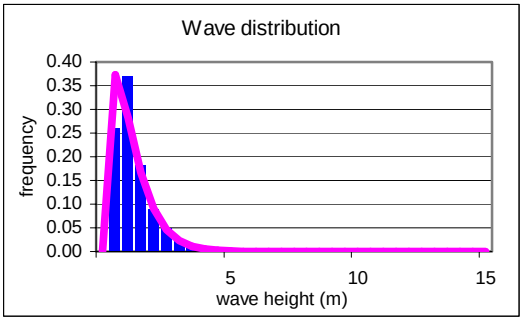


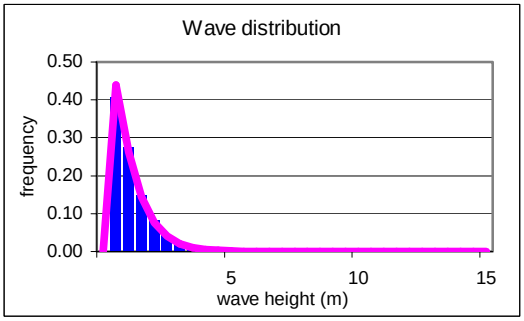


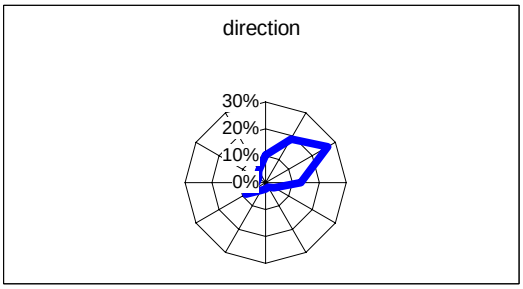
Location	Black Sea	Lattitude	42.00	Longitude	29.93

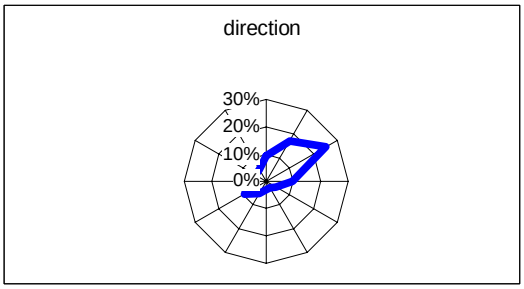
	Significant wave height	
Average height	0.9	m
Average direction	2.9	
Average Period	4	S
Maximum	6.2	m
50 yr return value		m
Weibull scale factor	0.95	m
Weibull shape factor	1.19	

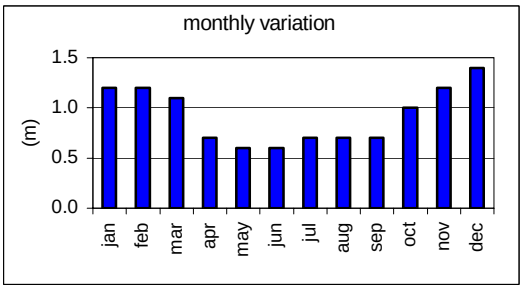
	Wind Sea wave height	
Average height	0.8	m
Average direction	-	
Average Period	2.8	S
Maximum	6.2	m
50 yr return value		m
Weibull scale factor	0.84	m
Weibull shape factor	1.06	

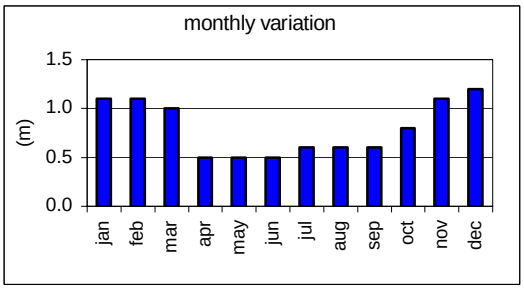


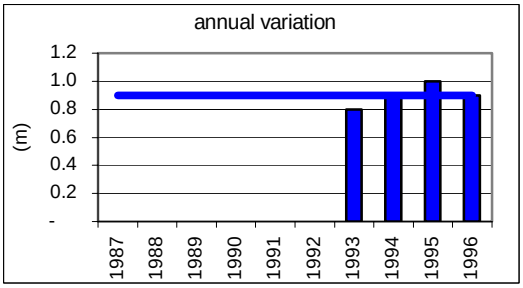


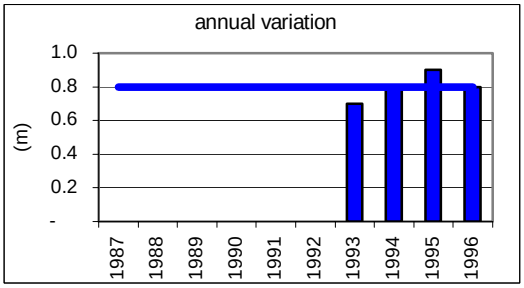


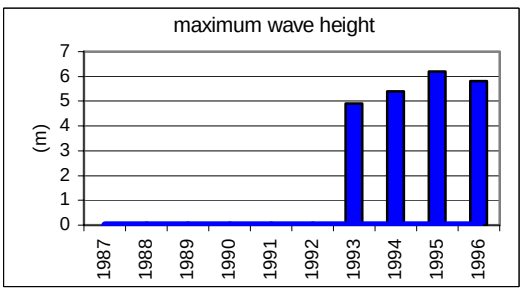


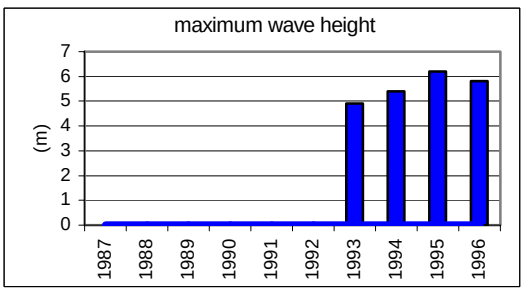








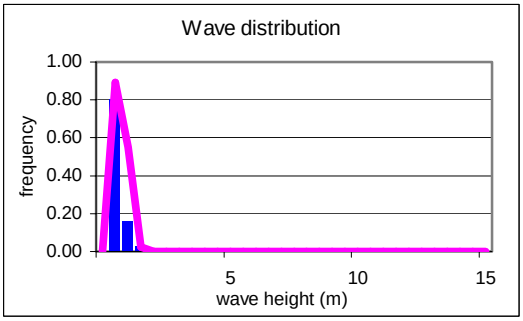


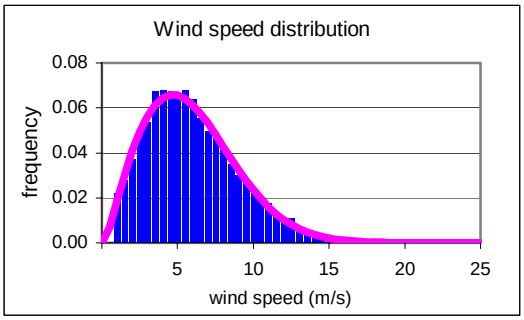


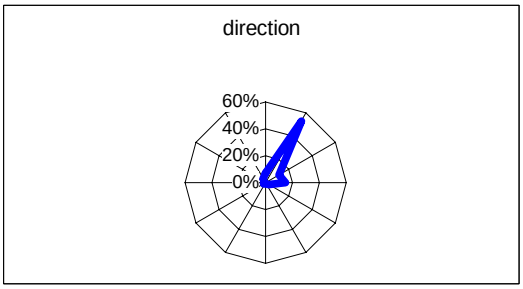
Location	Black Sea	Lattitude	42.00	Longitude	29.93

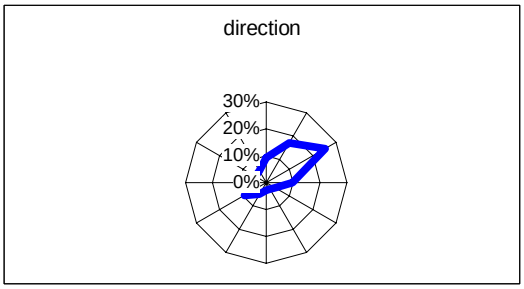
	Swell wave height	
Average height	0.2	m
Average direction	1.7	
Average Period	3	S
Maximum	3.2	m
50 yr return value		m
Weibull scale factor	0.62	m
Weibull shape factor	2.74	

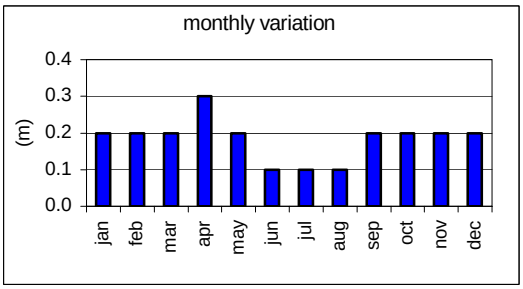
	Wind Speed	
Average height	5.7	m/s
Average direction	2.5	
Average Period	-	S
Maximum	18.4	m/s
50 yr return value		m/s
Weibull scale factor	6.41	m/s
Weibull shape factor	1.96	

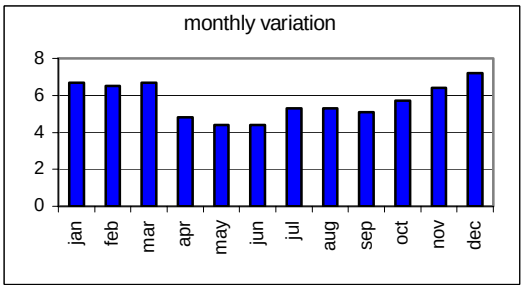


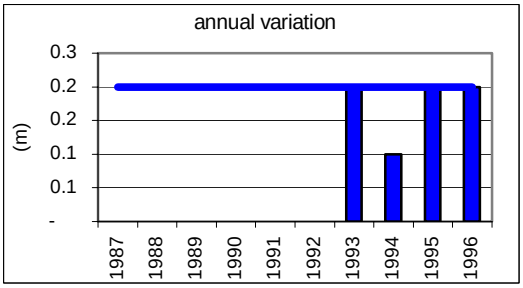


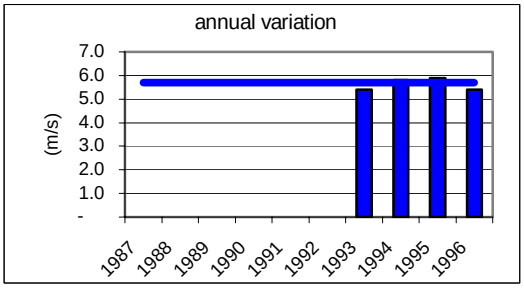


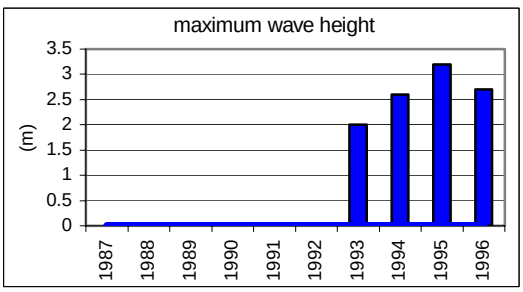


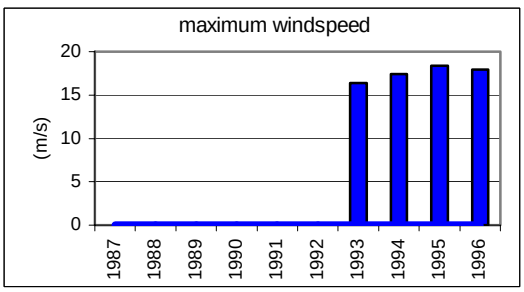








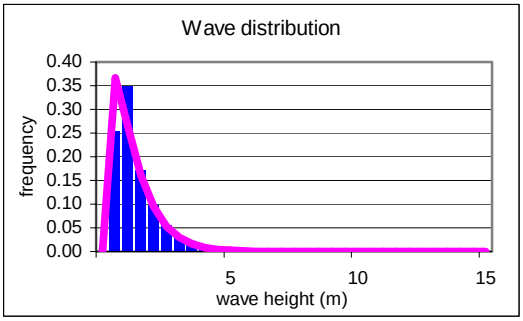


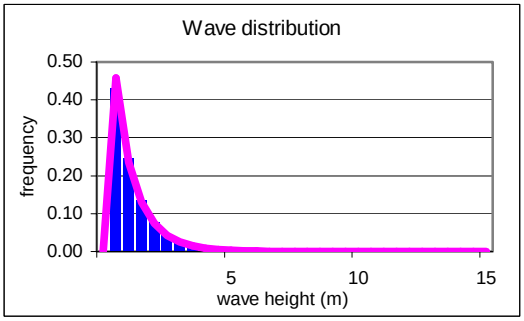


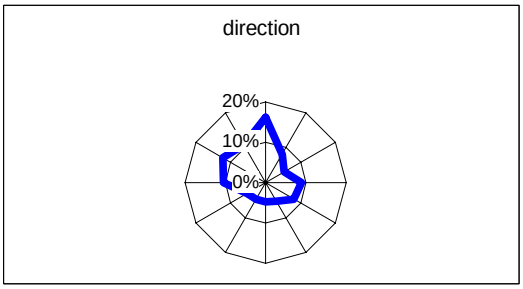
Location	Ionian Sea	Lattitude	36.00	Longitude	19.13

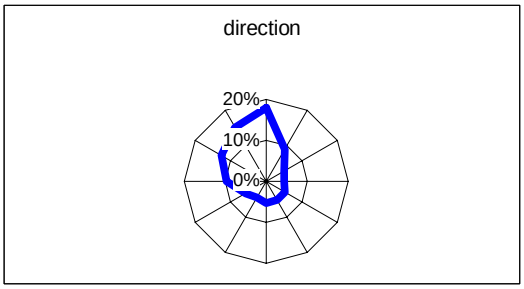
	Significant wave height
Average height	1 m
Average direction	32.8
Average Period	4.2 S
Maximum	7.4 m
50 yr return value	8.7 m
Weibull scale factor	1.01 m
Weibull shape factor	1.12

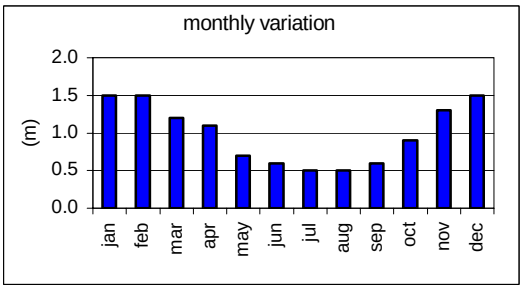
	Wind Sea wave height
Average height	0.8 m
Average direction	-
Average Period	2.8 S
Maximum	7.4 m
50 yr return value	8.6 m
Weibull scale factor	0.84 m
Weibull shape factor	0.95

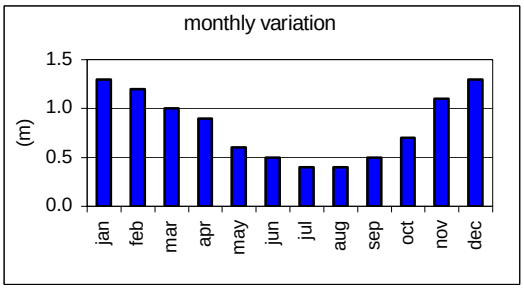


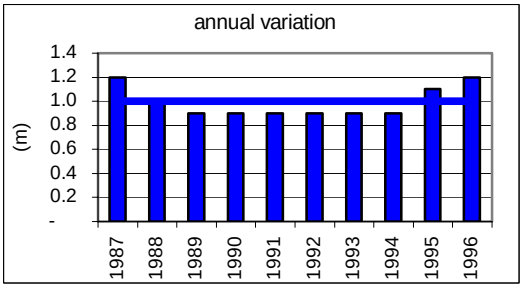


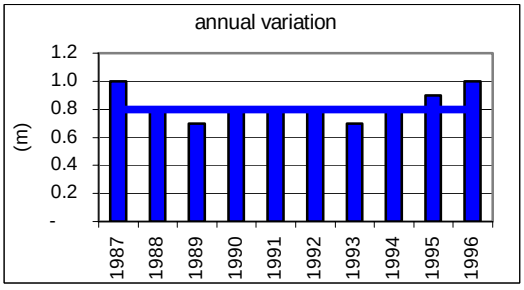


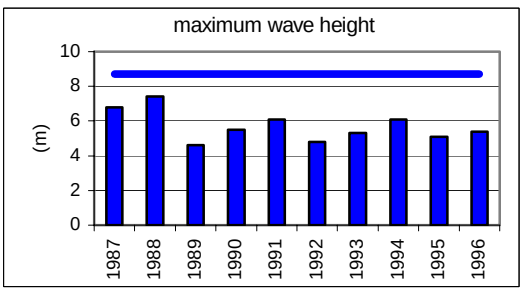


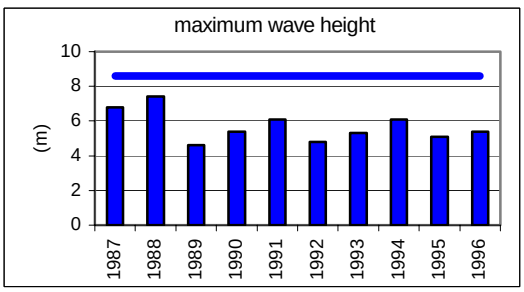








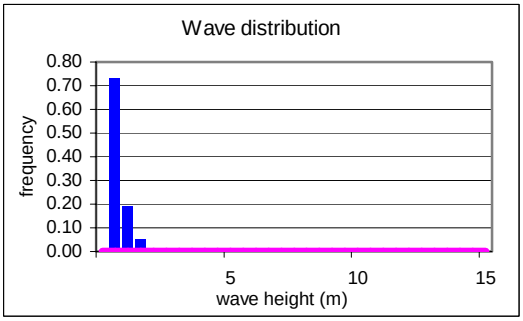


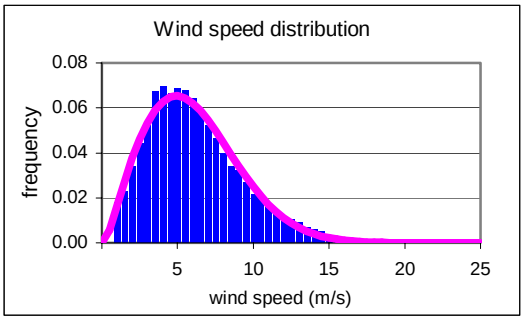


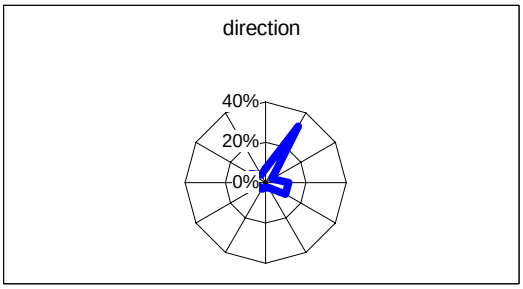
Location	Ionian Sea	Lattitude	36.00	Longitude	19.13

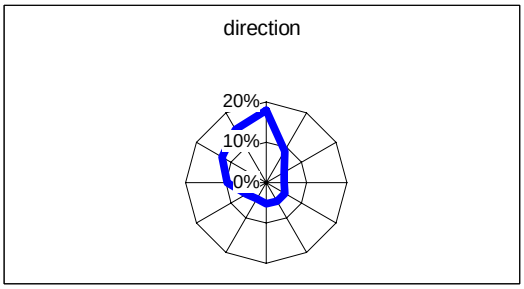
	Swell wave height	
Average height	0.3	m
Average direction	0.6	
Average Period	4.4	S
Maximum	4.1	m
50 yr return value	5.2	m
Weibull scale factor		m
Weibull shape factor	1	

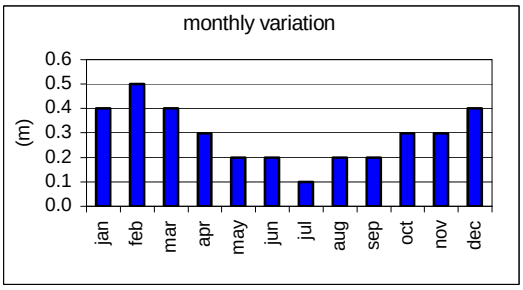
	Wind Speed	
Average height	5.8	m/s
Average direction	31.7	
Average Period	-	S
Maximum	25.1	m/s
50 yr return value	29	m/s
Weibull scale factor	6.57	m/s
Weibull shape factor	2.01	

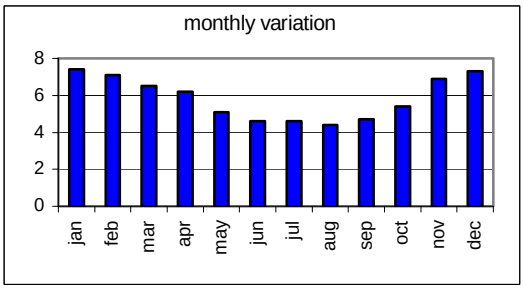


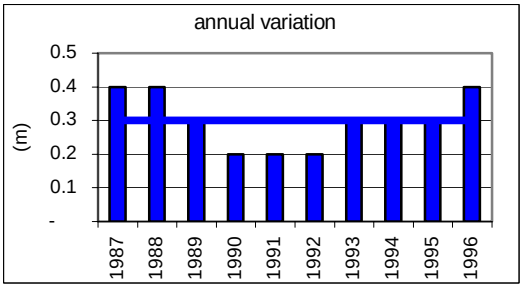


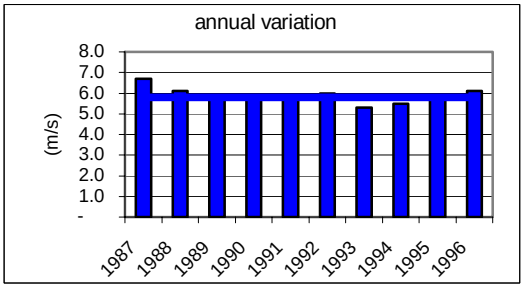


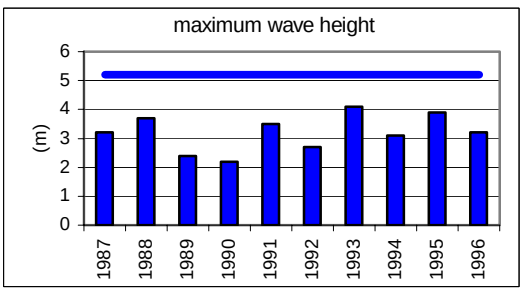


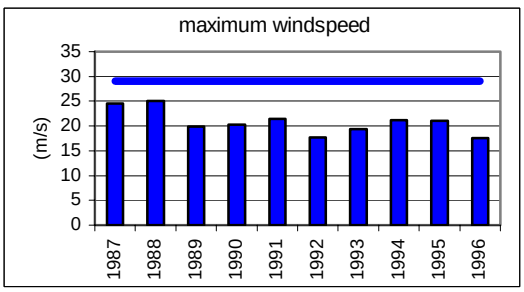








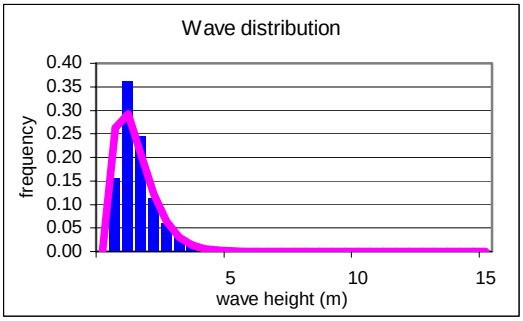


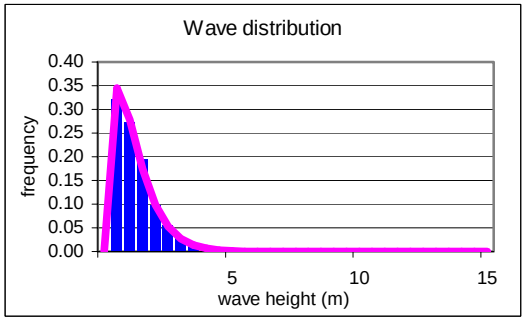


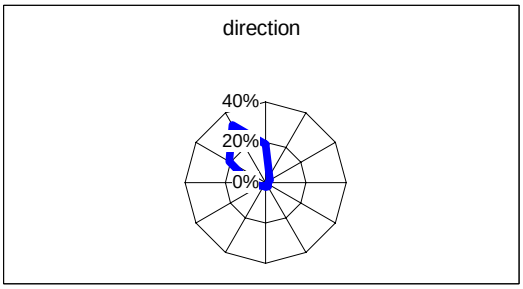
Location	Mediterranean (East)	Lattitude	33.50	Longitude	27.93

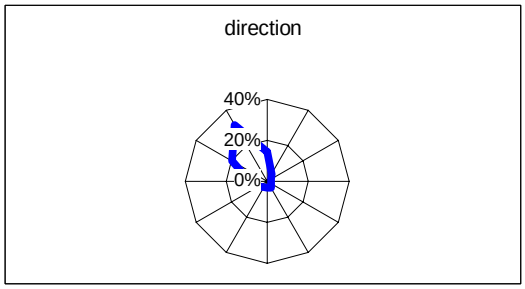
	Significant wave height
Average height	1.1 m
Average direction	30.9
Average Period	4.3 S
Maximum	6.8 m
50 yr return value	8.6 m
Weibull scale factor	1.16 m
Weibull shape factor	1.41

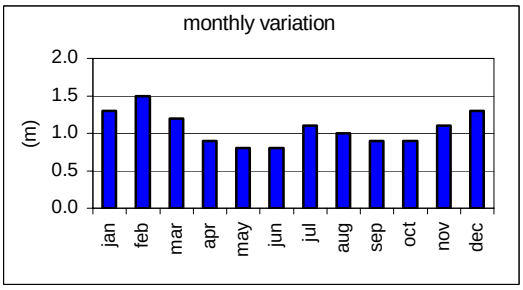
	Wind Sea wave height
Average height	0.9 m
Average direction	-
Average Period	3.2 S
Maximum	6.8 m
50 yr return value	8.6 m
Weibull scale factor	1.02 m
Weibull shape factor	1.21

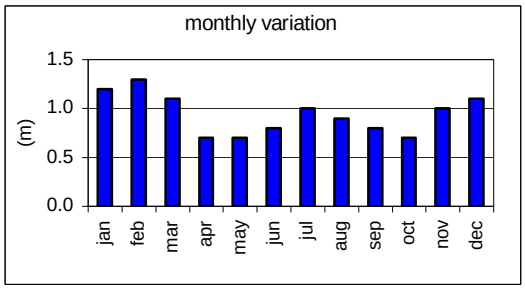


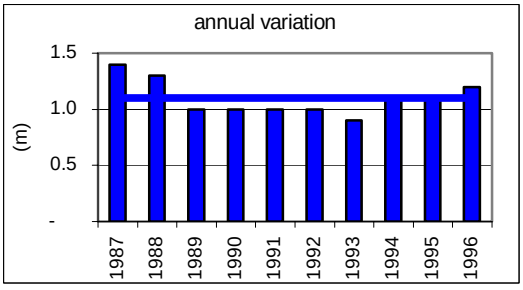


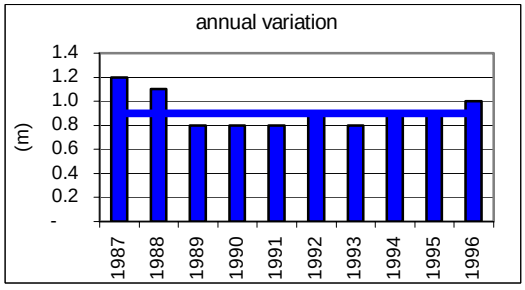


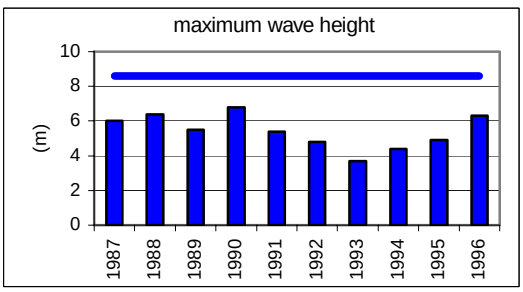


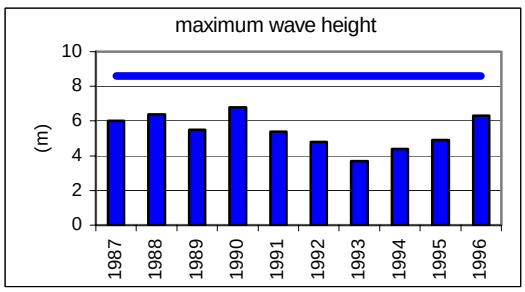








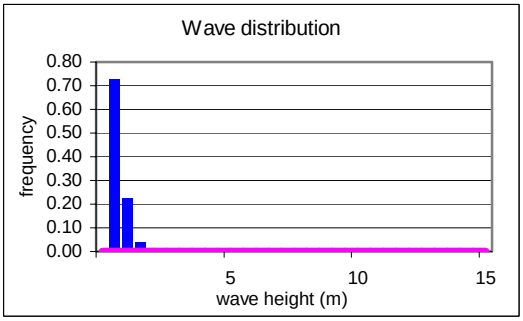


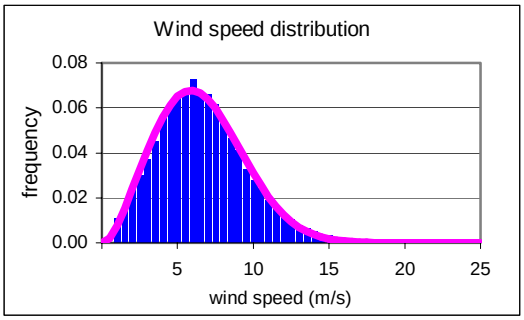


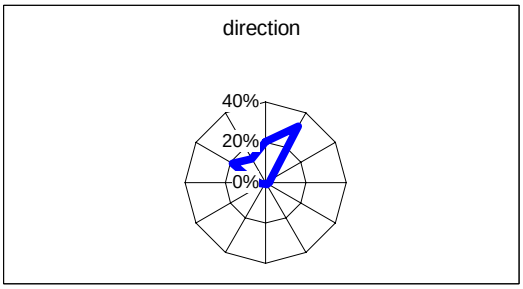
Location	Mediterranean (East)	Lattitude	33.50	Longitude	27.93

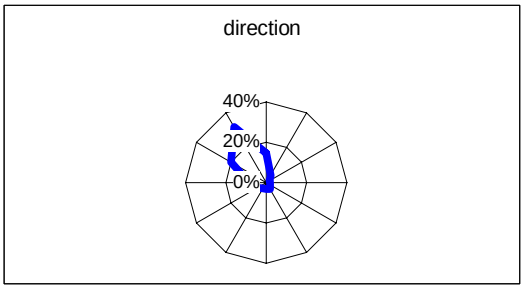
	Swell wave height	
Average height	0.3	m
Average direction	33.2	
Average Period	4.5	S
Maximum	2.8	m
50 yr return value	3.5	m
Weibull scale factor		m
Weibull shape factor		

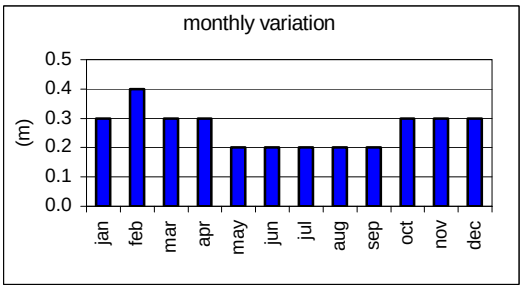
	Wind Speed	
Average height	6.3	m/s
Average direction	30.4	
Average Period	-	S
Maximum	24.8	m/s
50 yr return value	28.9	m/s
Weibull scale factor	7.11	m/s
Weibull shape factor	2.36	

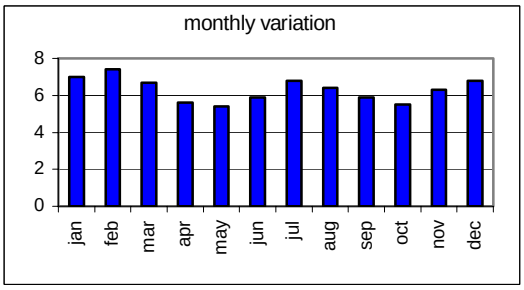


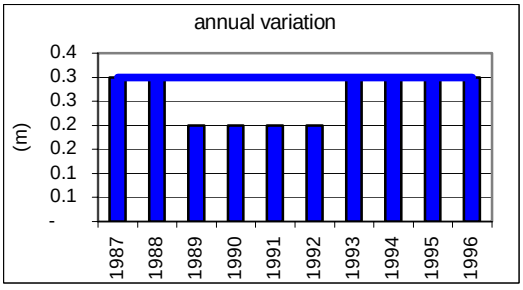


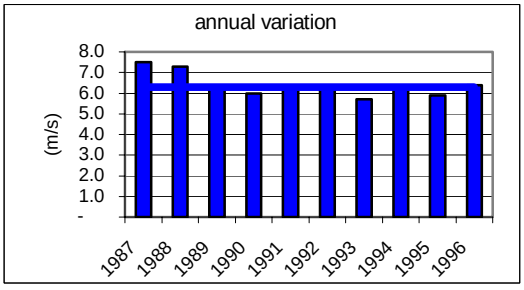


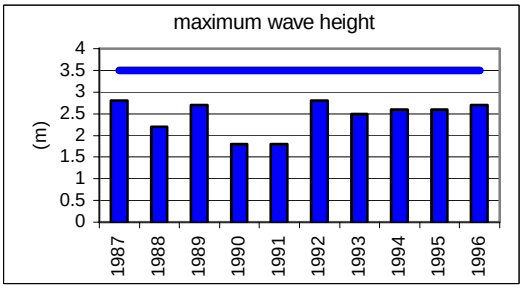


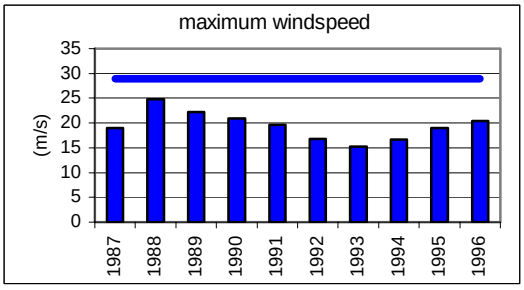








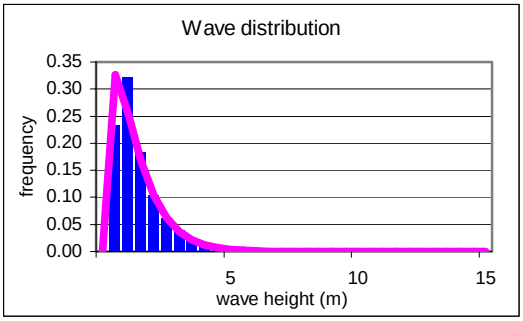


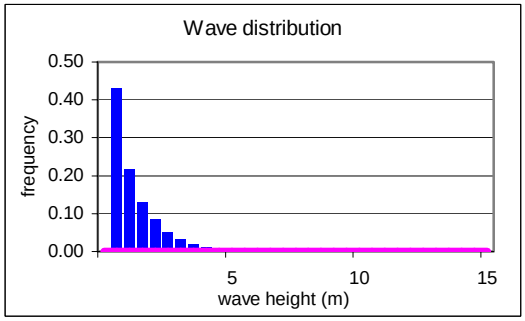


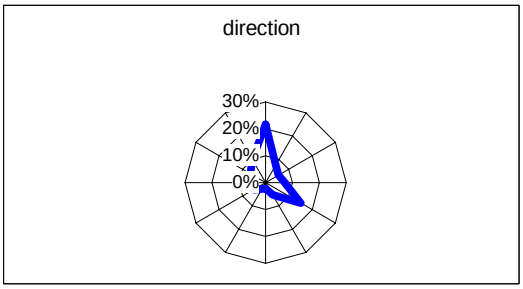
Location	Mediterranean (West)	Lattitude	39.00	Longitude	5.93

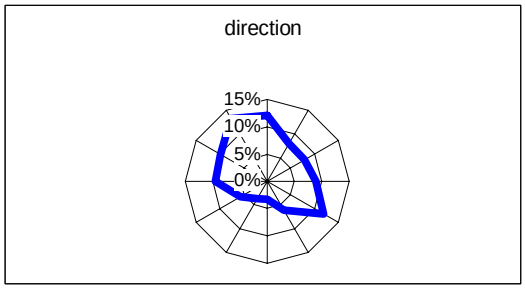
	Significant wave height
Average height	1.1 m
Average direction	35.3
Average Period	4.4 S
Maximum	8.7 m
50 yr return value	9.9 m
Weibull scale factor	1.13 m
Weibull shape factor	1.14

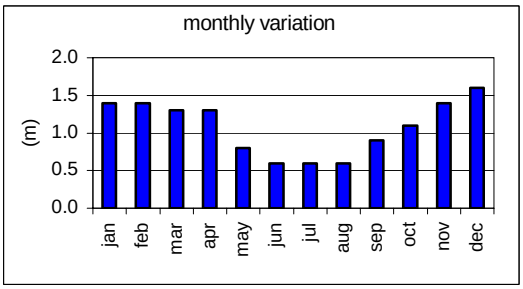
	Wind Sea wave height
Average height	0.9 m
Average direction	-
Average Period	2.9 S
Maximum	8.7 m
50 yr return value	9.9 m
Weibull scale factor	m
Weibull shape factor	

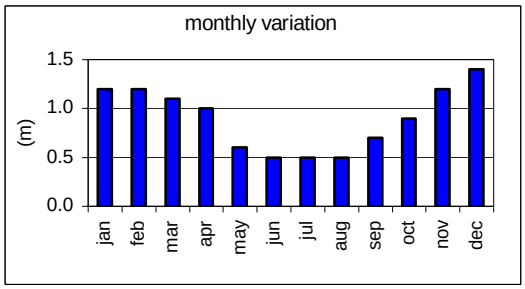


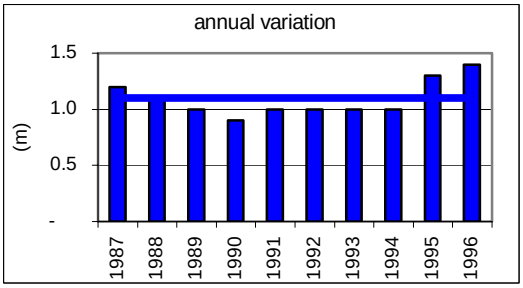


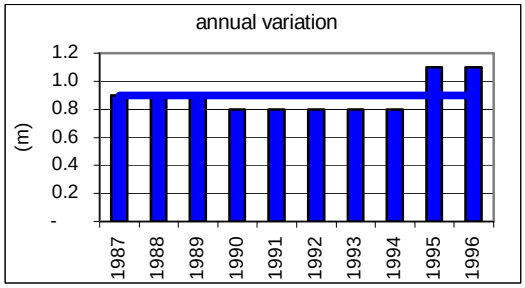


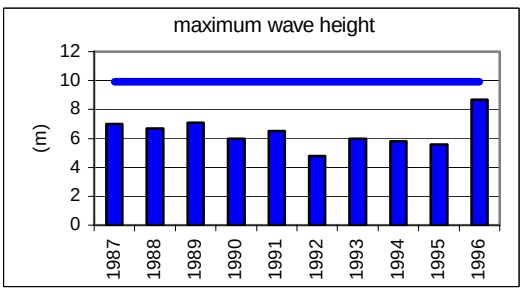


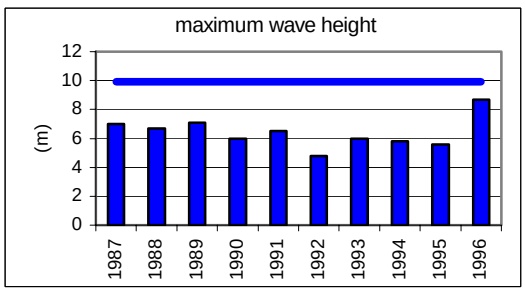








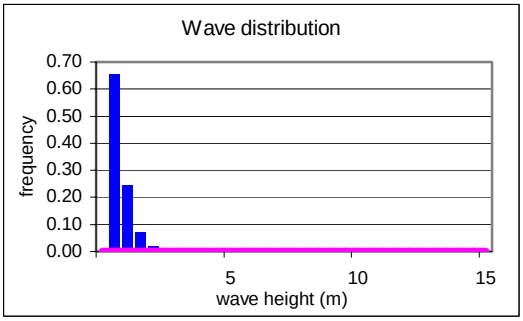


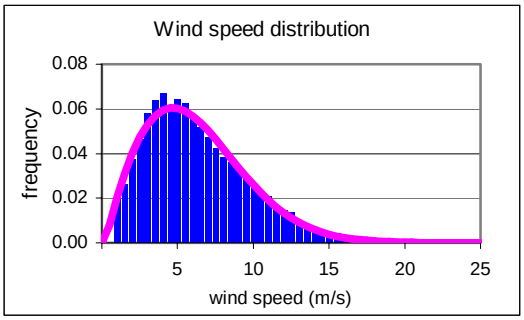


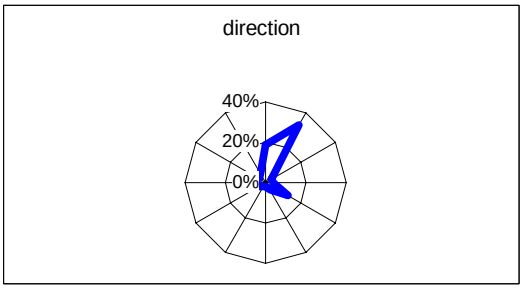
Location	Mediterranean (West)	Lattitude	39.00	Longitude	5.93

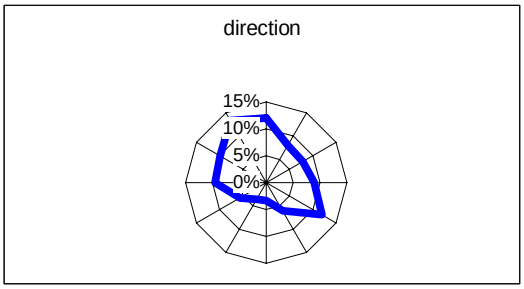
	Swell wave height	
Average height	0.3	m
Average direction		
Average Period	4.4	S
Maximum	4.7	m
50 yr return value	5.7	m
Weibull scale factor		m
Weibull shape factor		

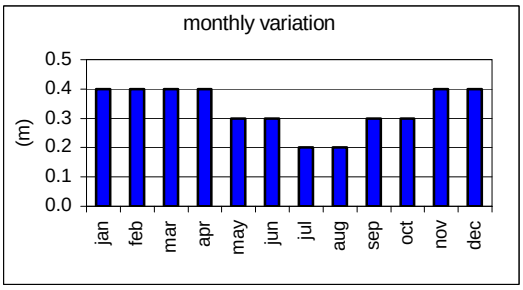
	Wind Speed	
Average height	6	m/s
Average direction	35	
Average Period	-	S
Maximum	24.8	m/s
50 yr return value	28.6	m/s
Weibull scale factor	6.75	m/s
Weibull shape factor	1.85	

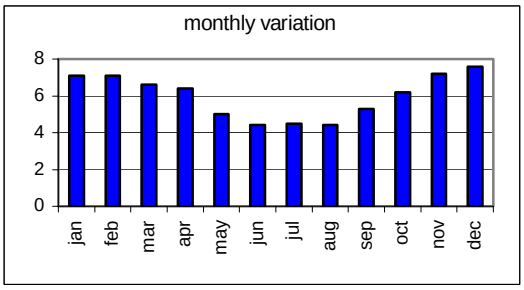


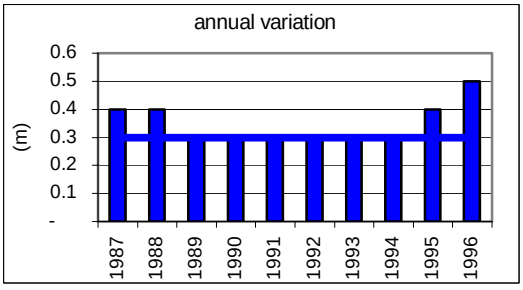


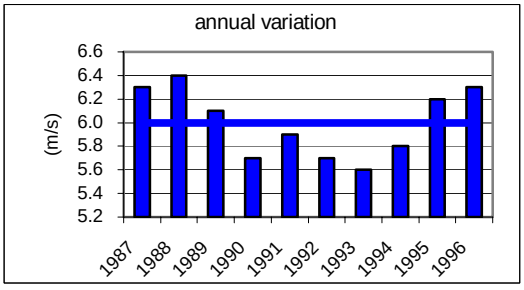


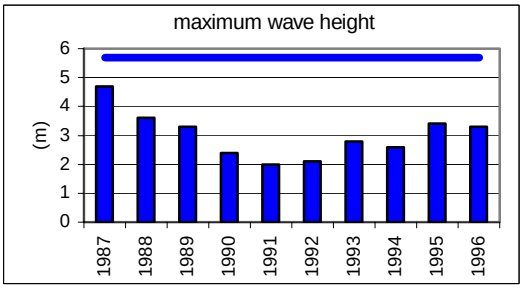


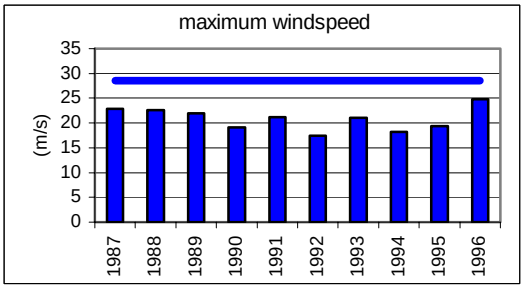








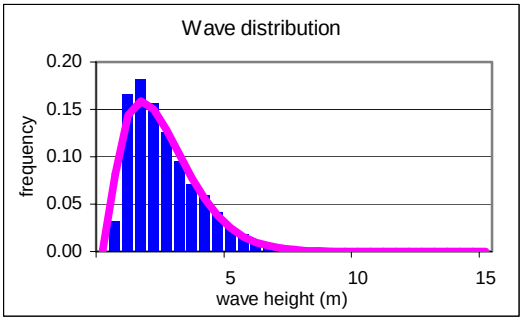


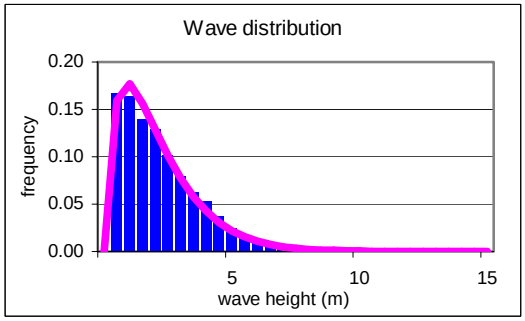


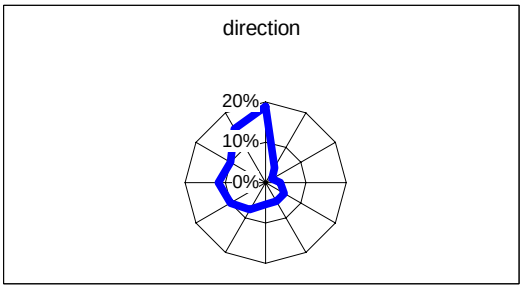
Location	North Sea	Lattitude	57.00	Longitude	3.13

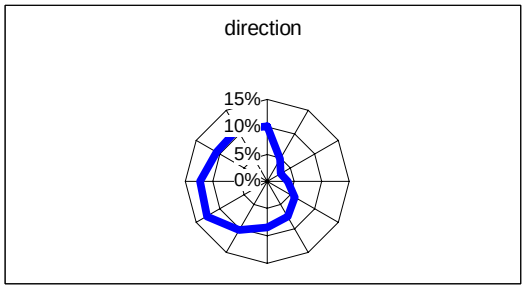
	Significant wave height
Average height	2.1 m
Average direction	28.8
Average Period	5.6 S
Maximum	11.7 m
50 yr return value	12.9 m
Weibull scale factor	2.37 m
Weibull shape factor	1.58

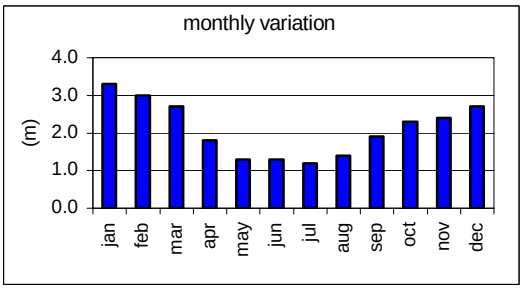
	Wind Sea wave height
Average height	1.8 m
Average direction	-
Average Period	4.7 S
Maximum	11.7 m
50 yr return value	12.9 m
Weibull scale factor	2.05 m
Weibull shape factor	1.24

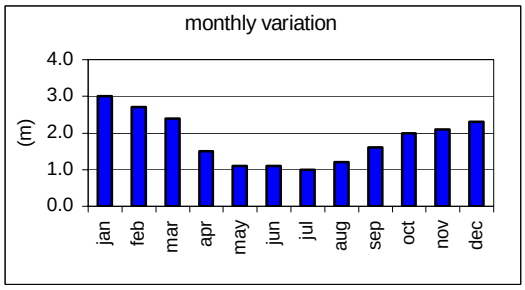


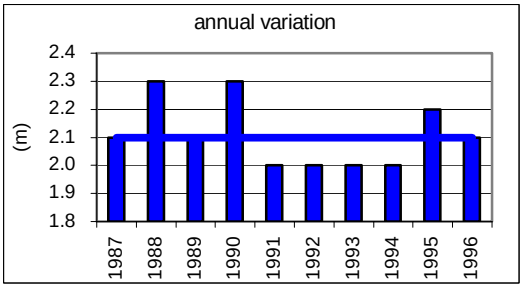


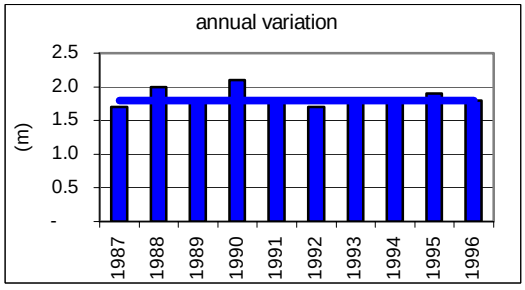


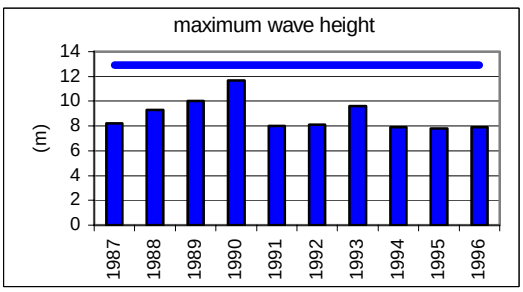


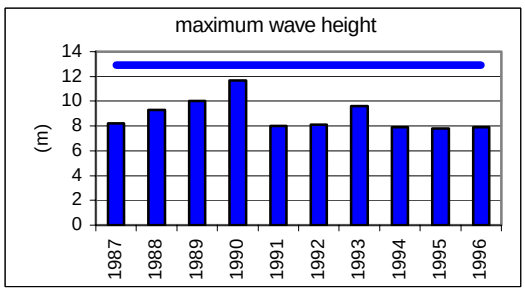








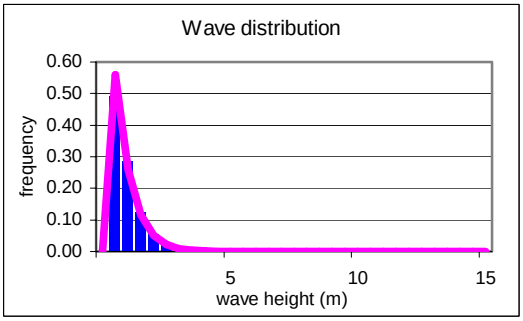


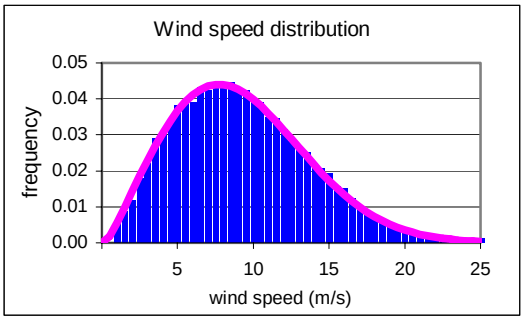


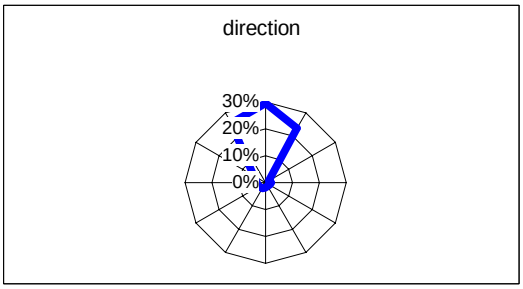
Location	North Sea	Lattitude	57.00	Longitude	3.13

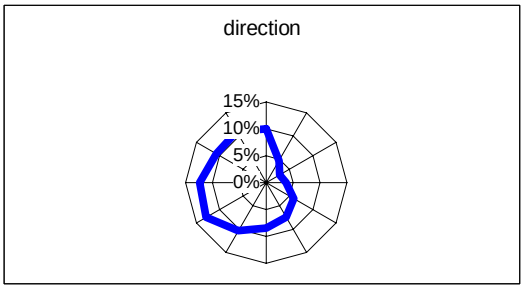
	Swell wave height	
Average height	0.6	m
Average direction	33.6	
Average Period	7.9	S
Maximum	5	m
50 yr return value	5.5	m
Weibull scale factor	0.64	m
Weibull shape factor	1.05	

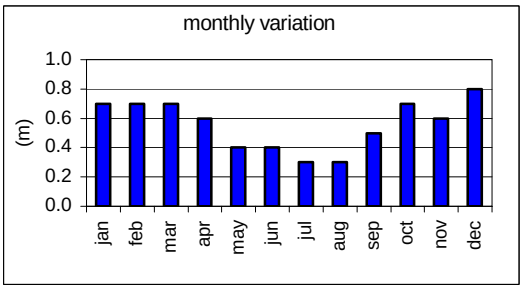
	Wind Speed	
Average height	8.9	m/s
Average direction	24.8	
Average Period	-	S
Maximum	29.9	m/s
50 yr return value	34.3	m/s
Weibull scale factor	10.12	m/s
Weibull shape factor	2.12	

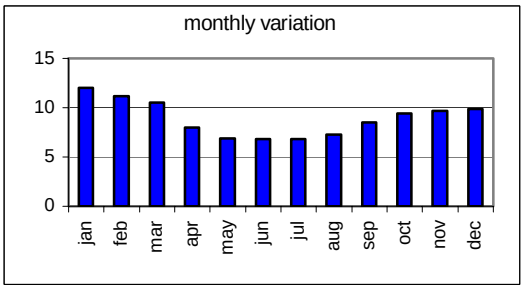


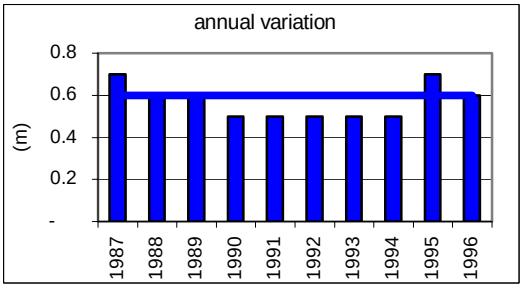


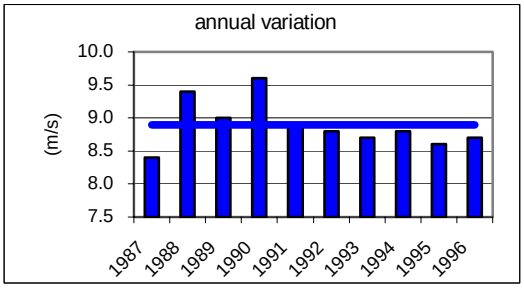


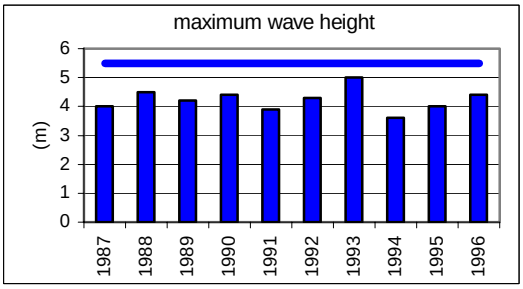


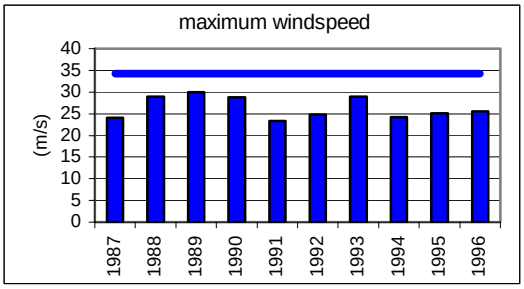








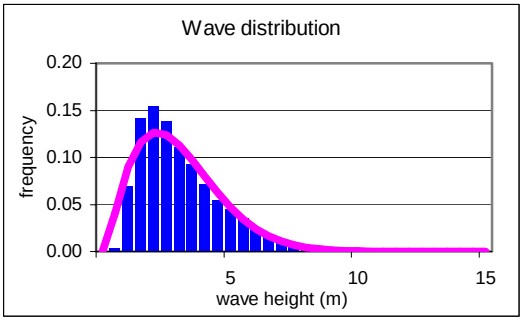


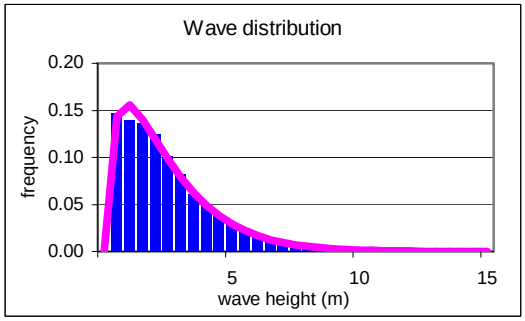


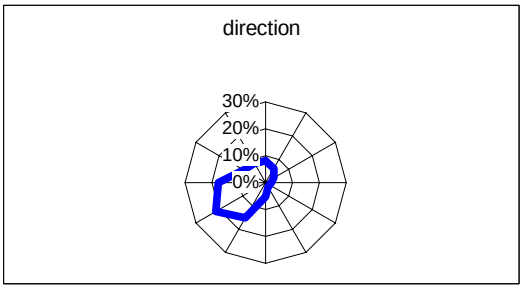
Location	Norwegian Sea	Lattitude	65.00	Longitude	2.33

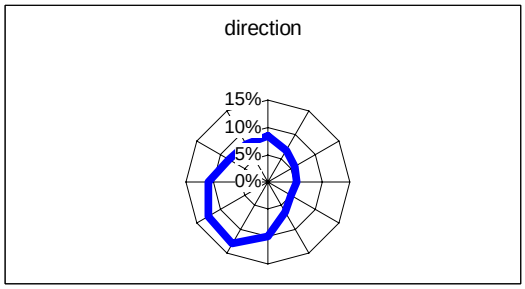
	Significant wave height
Average height	2.8 m
Average direction	24.8
Average Period	6.5 S
Maximum	13.1 m
50 yr return value	15.2 m
Weibull scale factor	3.1 m
Weibull shape factor	1.73

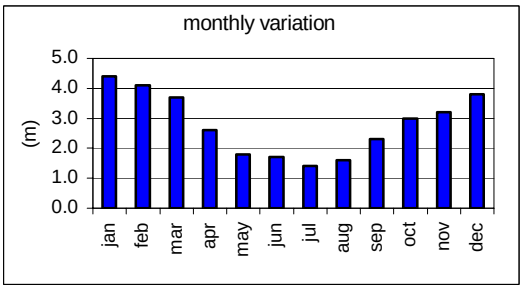
	Wind Sea wave height
Average height	2.2 m
Average direction	-
Average Period	5 S
Maximum	13.1 m
50 yr return value	15 m
Weibull scale factor	2.37 m
Weibull shape factor	1.2

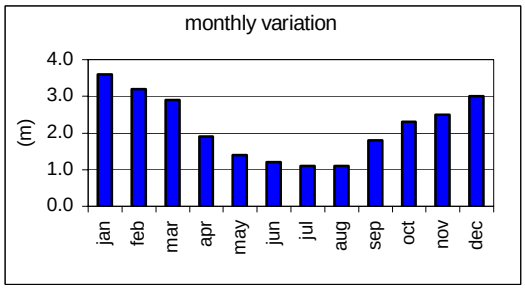


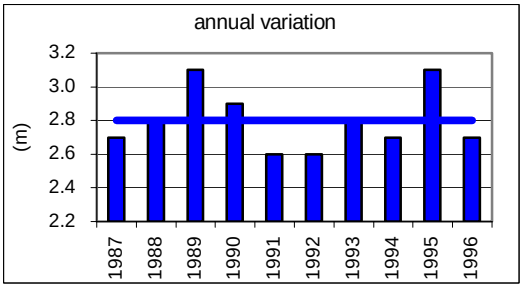


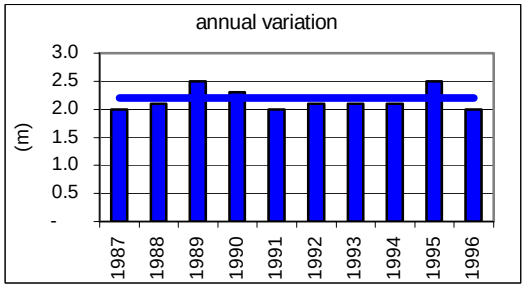


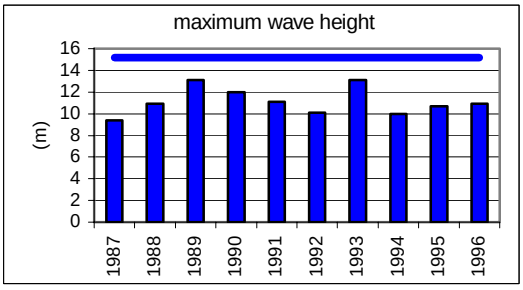


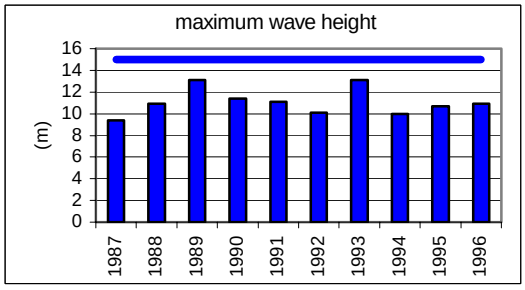








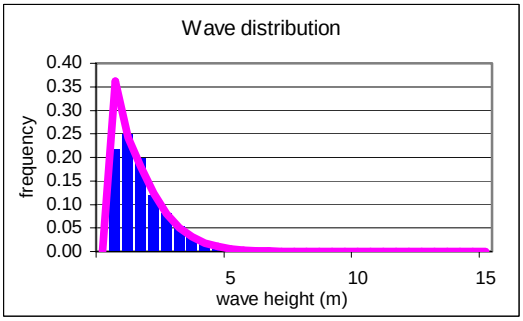


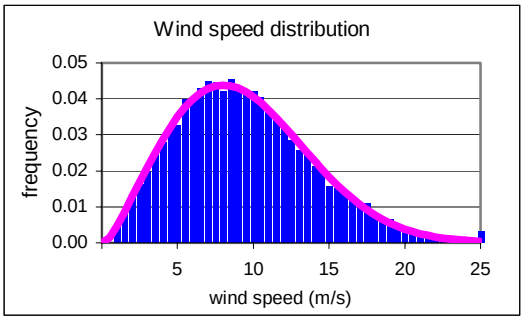


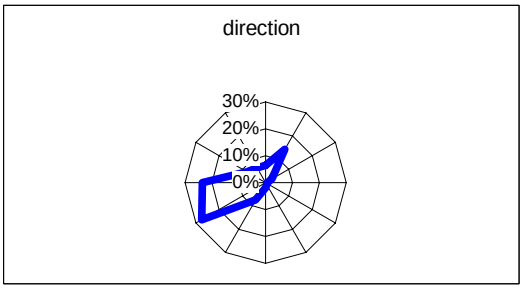
Location	Norwegian Sea	Lattitude	65.00	Longitude	2.33

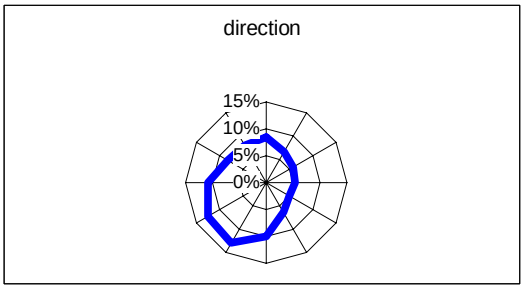
	Swell wave height	
Average height	1.2	m
Average direction	26.3	
Average Period	9.6	S
Maximum	9.2	m
50 yr return value	10.7	m
Weibull scale factor	1.37	m
Weibull shape factor	1.23	

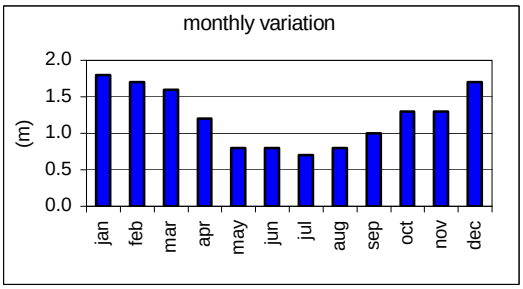
	Wind Speed	
Average height	9.1	m/s
Average direction	23.2	
Average Period	-	S
Maximum	29.2	m/s
50 yr return value	32.2	m/s
Weibull scale factor	10.34	m/s
Weibull shape factor	2.17	

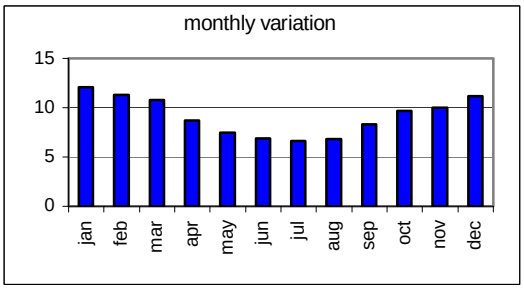


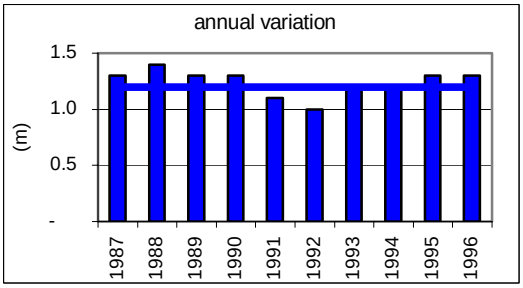


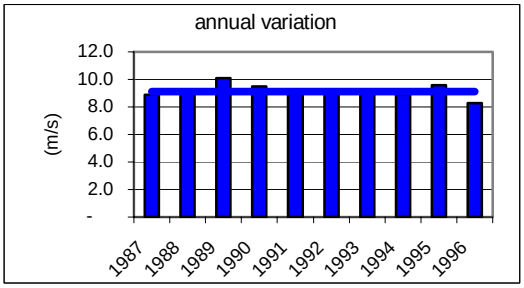


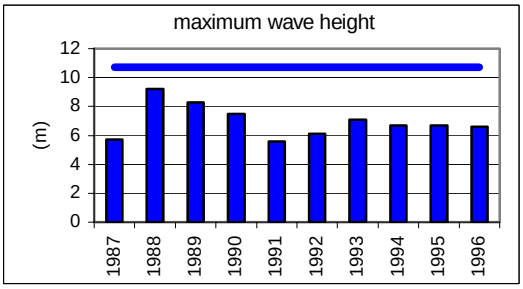


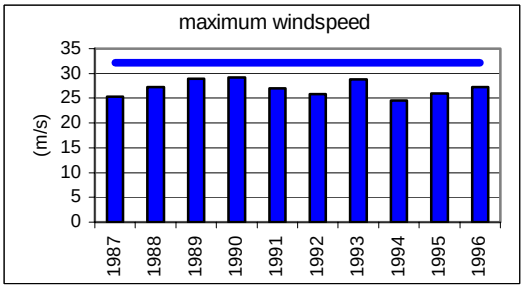








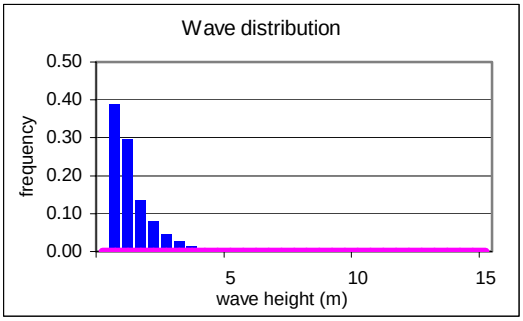


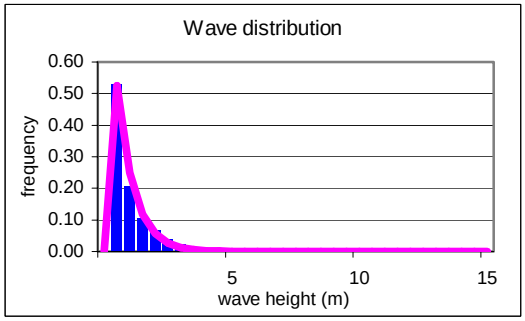


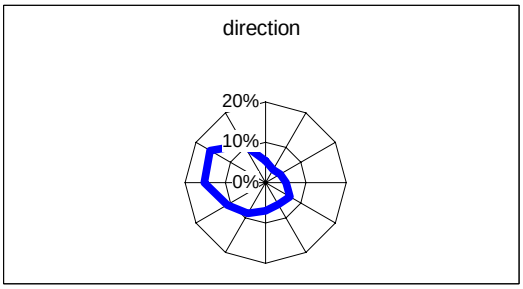
Location	Tyrrhenian Sea	Lattitude	40.00	Longitude	12.33

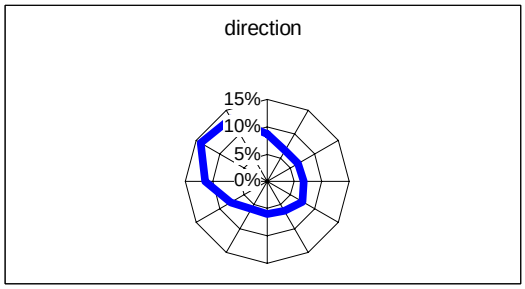
	Significant wave height
Average height	0.8 m
Average direction	25.3
Average Period	4 S
Maximum	7.1 m
50 yr return value	7.7 m
Weibull scale factor	0.82 m
Weibull shape factor	

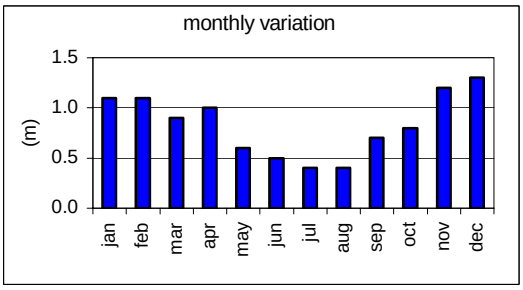
	Wind Sea wave height
Average height	0.7 m
Average direction	-
Average Period	2.4 S
Maximum	6.9 m
50 yr return value	7.5 m
Weibull scale factor	0.67 m
Weibull shape factor	1

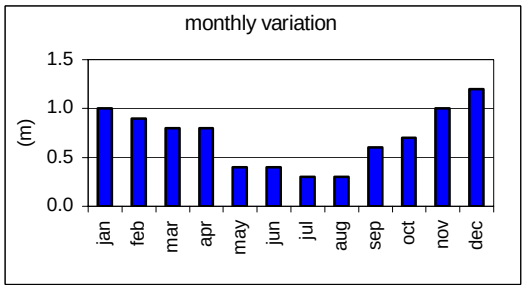


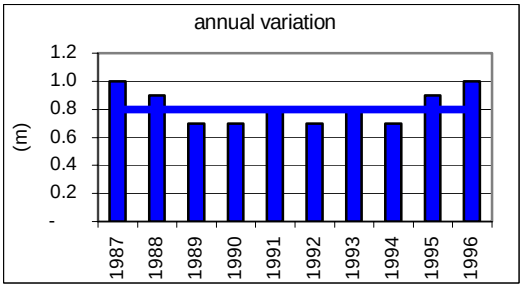


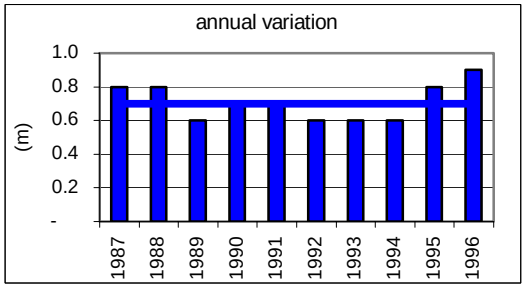


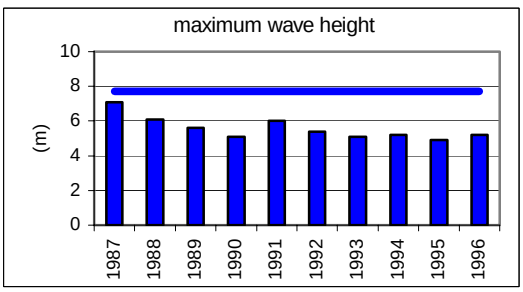


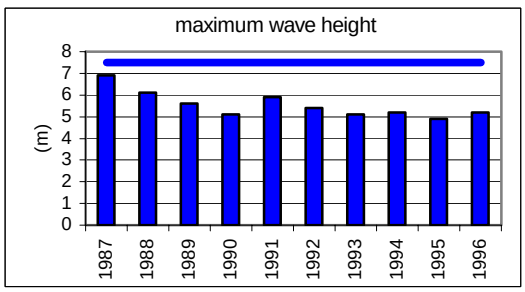








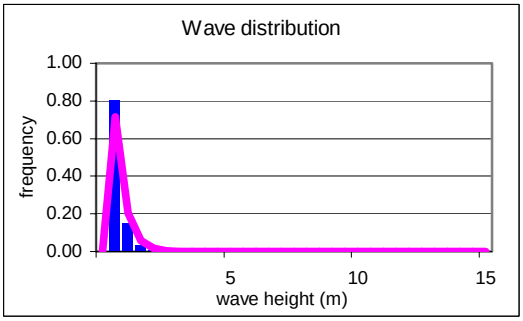


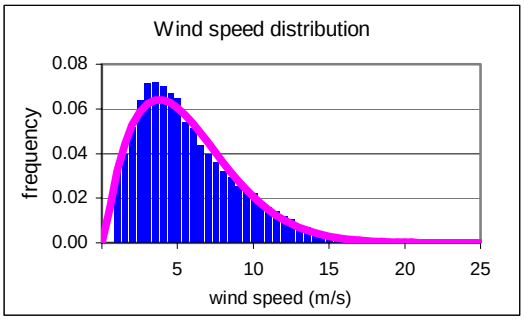


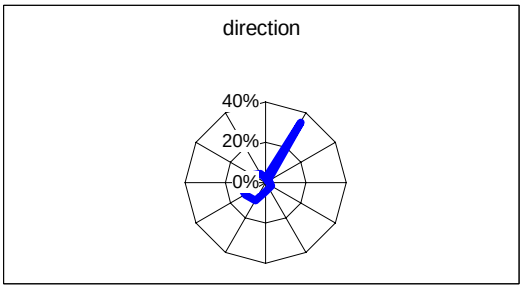
Location	Tyrrhenian Sea	Lattitude	40.00	Longitude	12.33

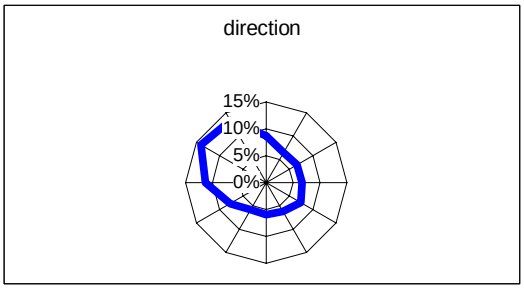
	Swell wave height
Average height	0.2 m
Average direction	29.8
Average Period	3.7 S
Maximum	3.9 m
50 yr return value	4.7 m
Weibull scale factor	0.4 m
Weibull shape factor	1

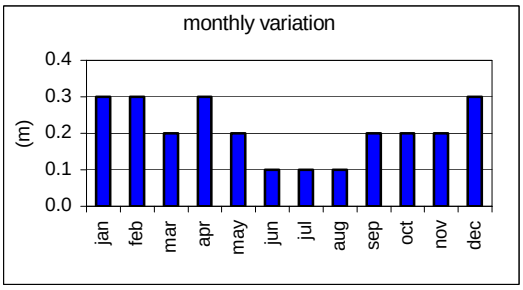
	Wind Speed
Average height	5.4 m/s
Average direction	29.4
Average Period	- S
Maximum	25 m/s
50 yr return value	28.5 m/s
Weibull scale factor	6.05 m/s
Weibull shape factor	1.68

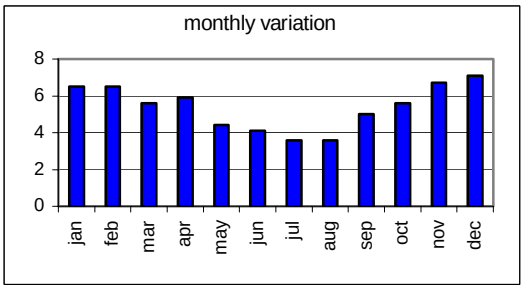


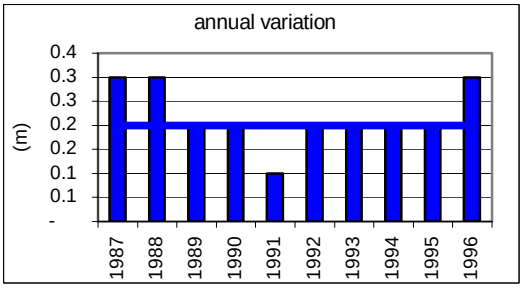


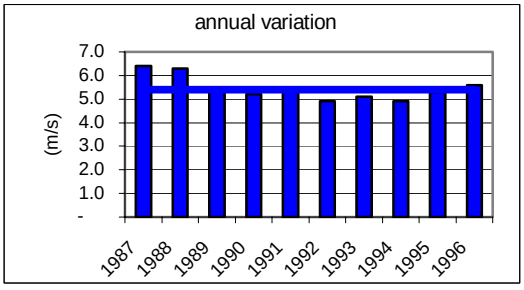


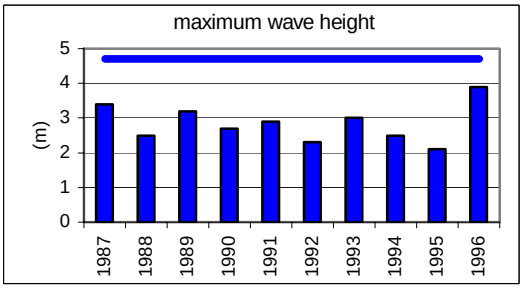


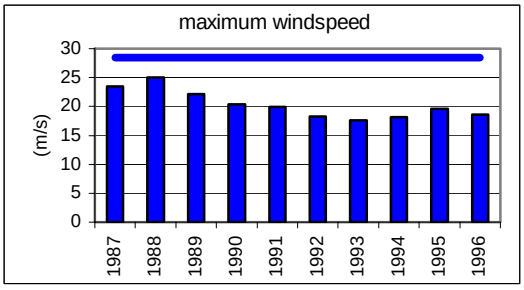








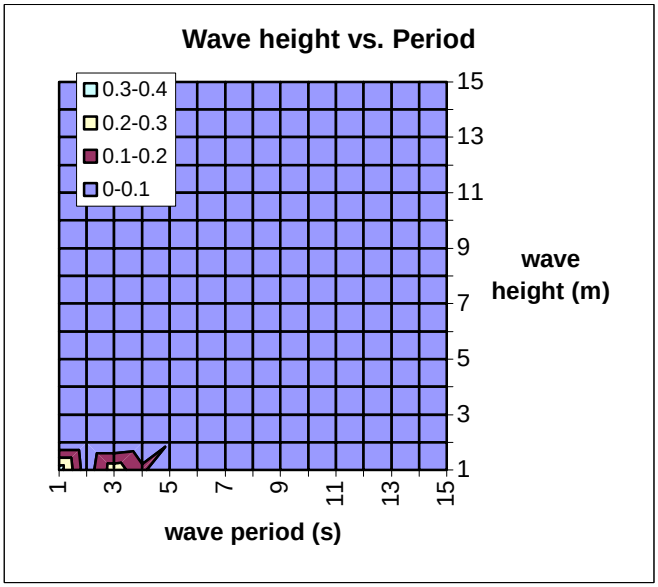


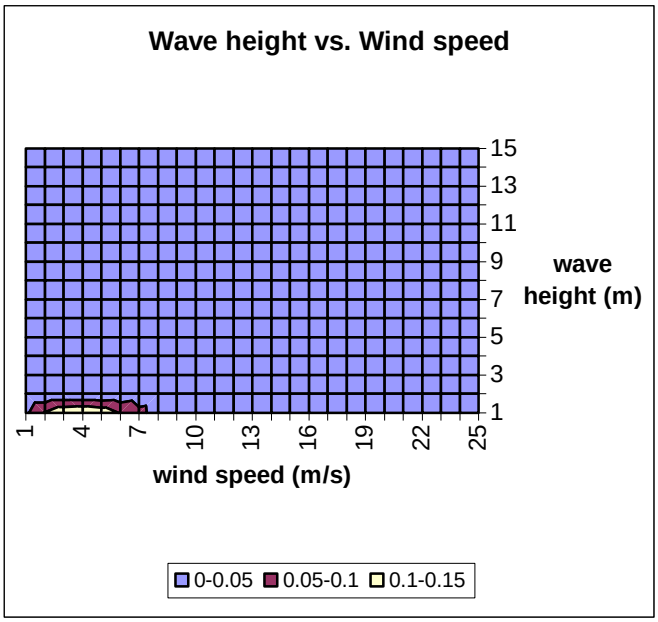


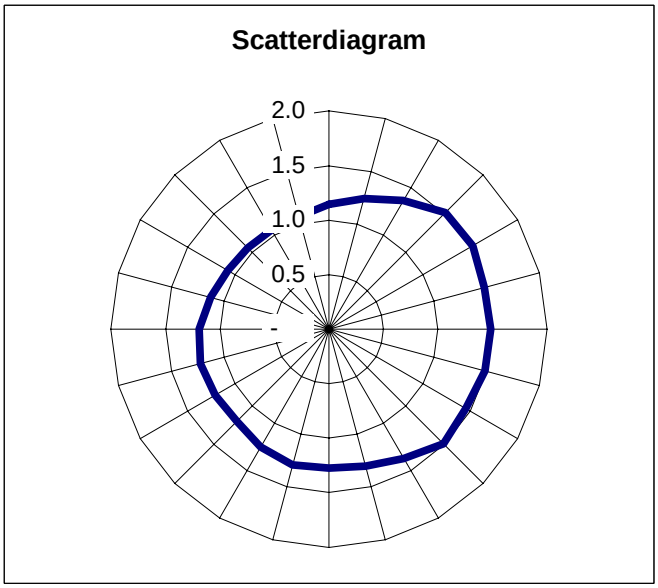
Annex 2 Wind wave diagrams

Location	Adriatic Sea	Lattitude	43.00	Longitude	15.53

Wind sea waves

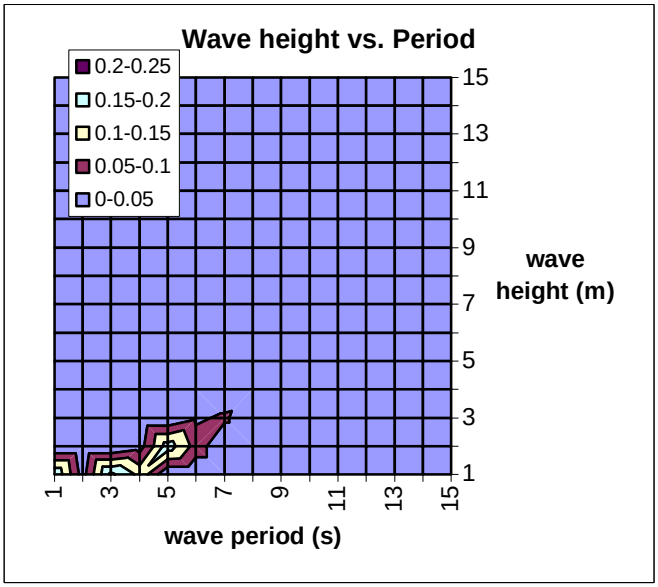


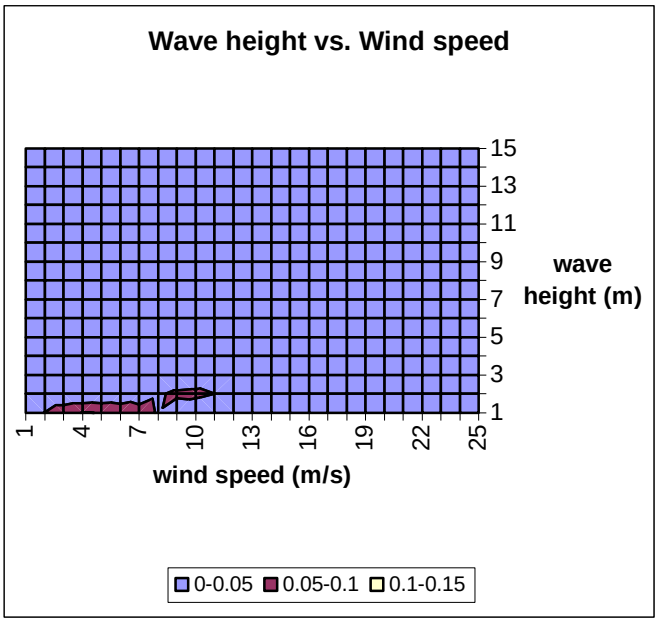


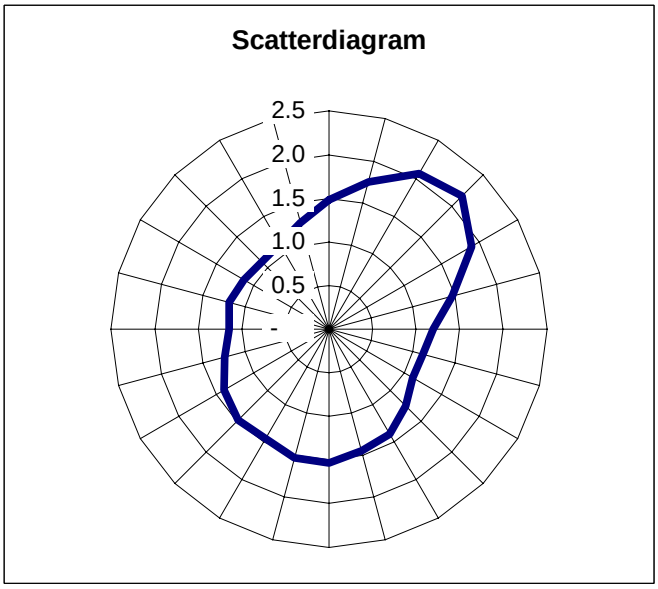


Location	Aegean Sea	Lattitude	38.00	Longitude	25.53

Wind sea waves

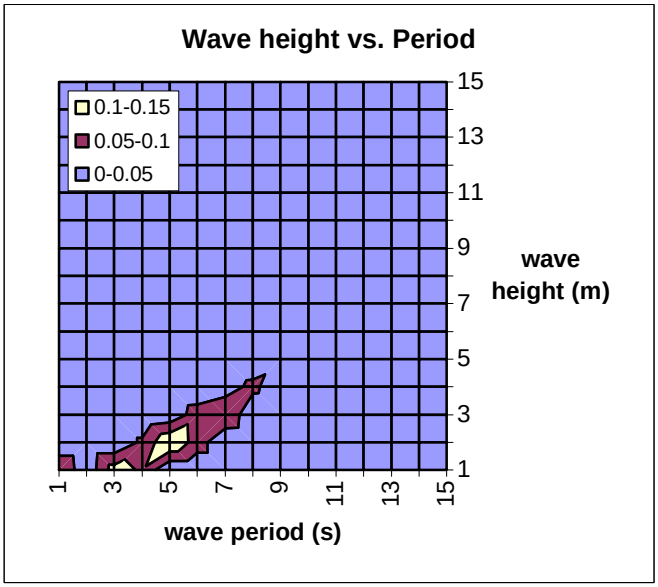


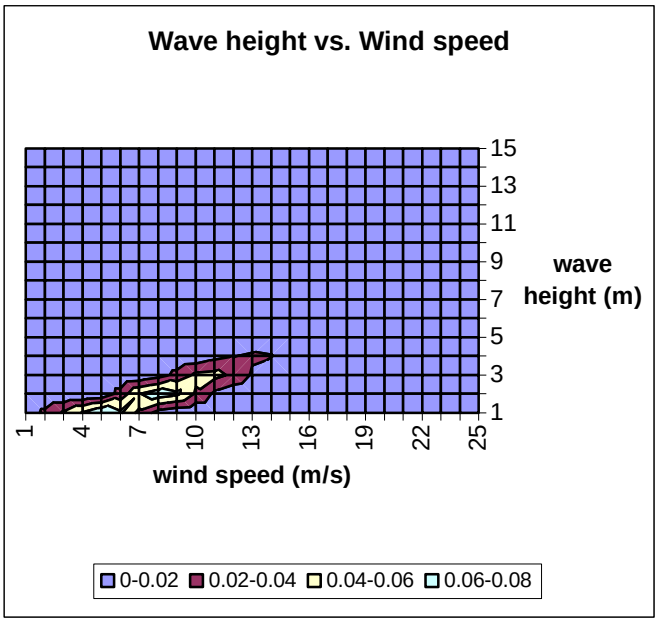


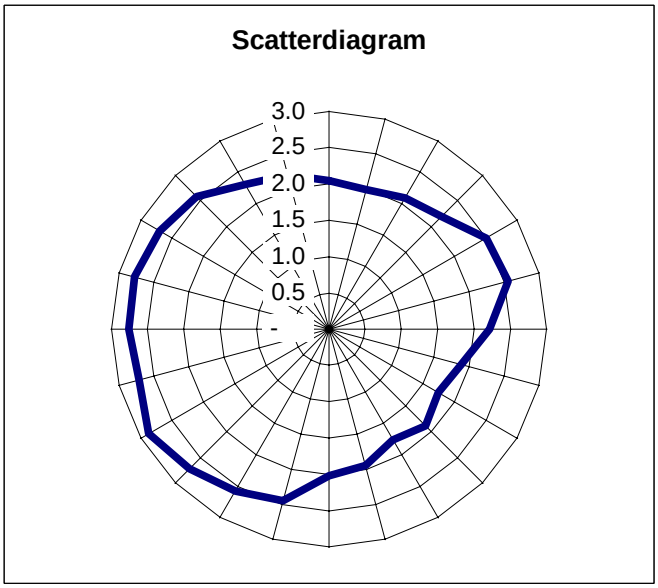


Location	Atlantic (Central)	Lattitude	44.00	Longitude	12.87-

Wind sea waves

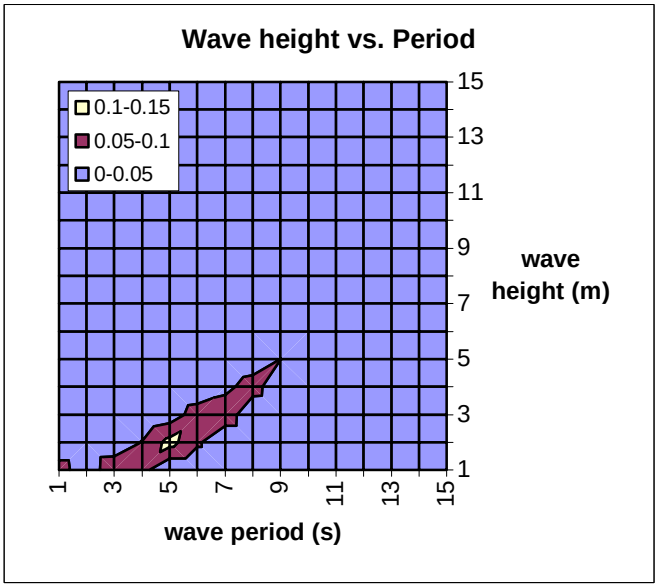


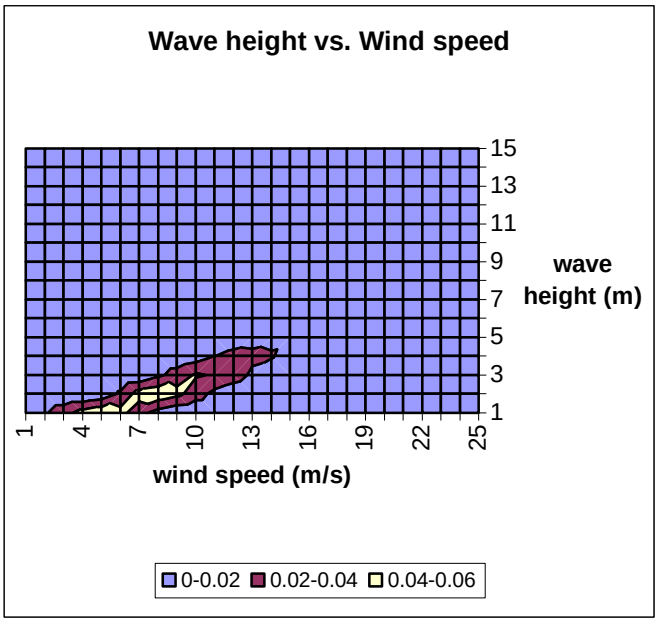


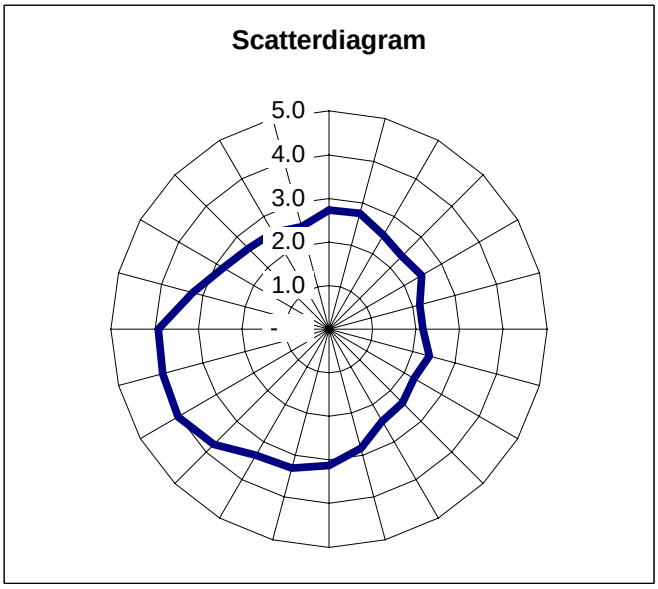


Location	Atlantic (North)	Lattitude	60.00	Longitude	10.07-

Wind sea waves

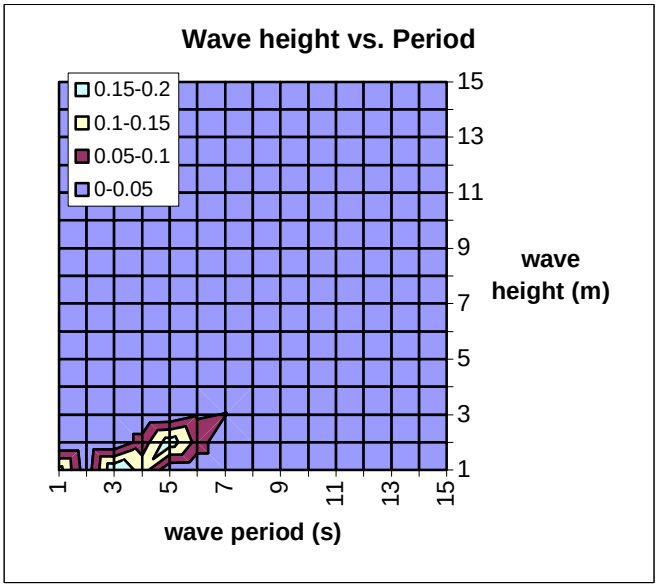


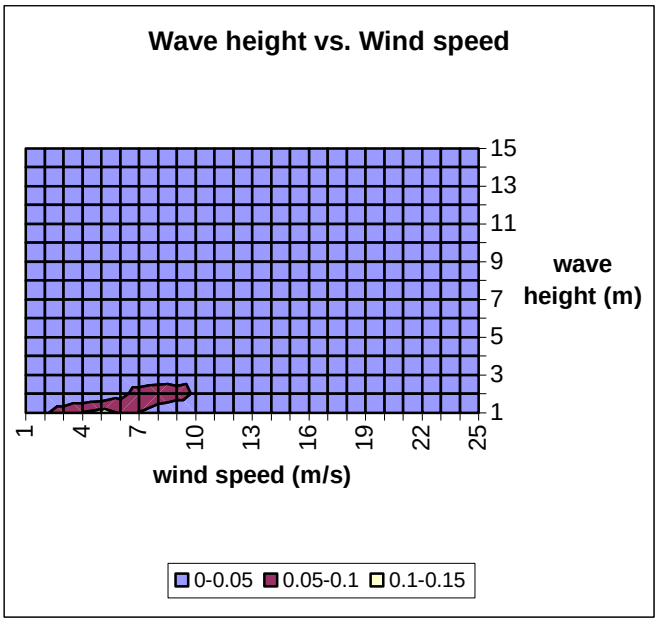


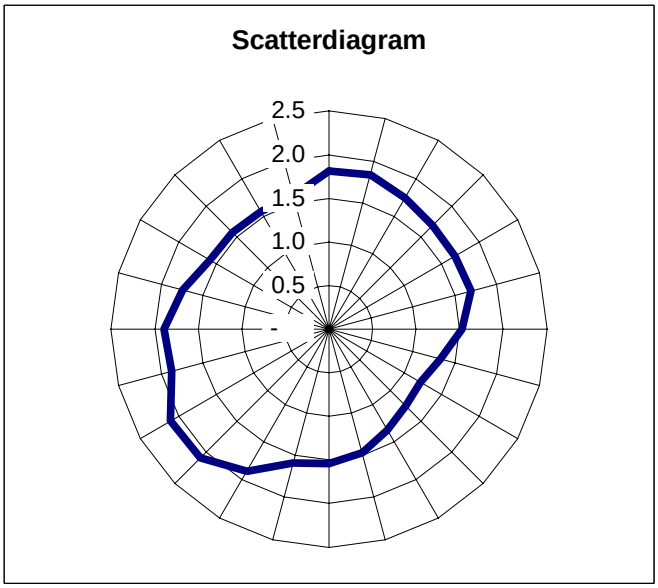


Location	Atlantic (South)	Lattitude	35.00	Longitude	10.07-

Wind sea waves

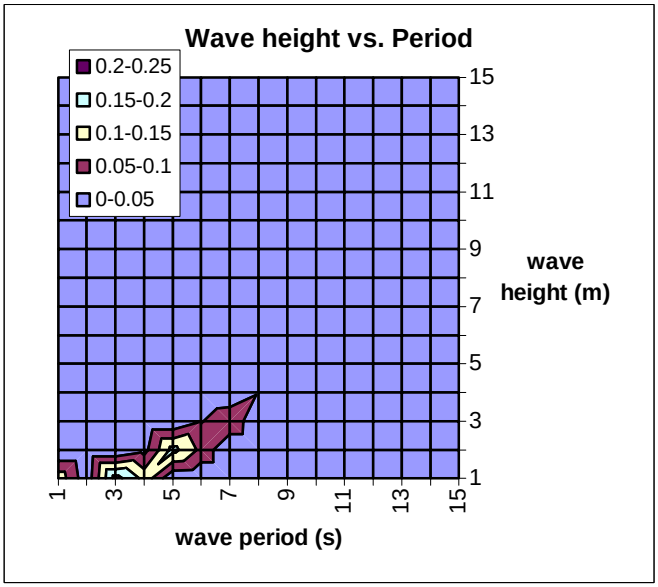


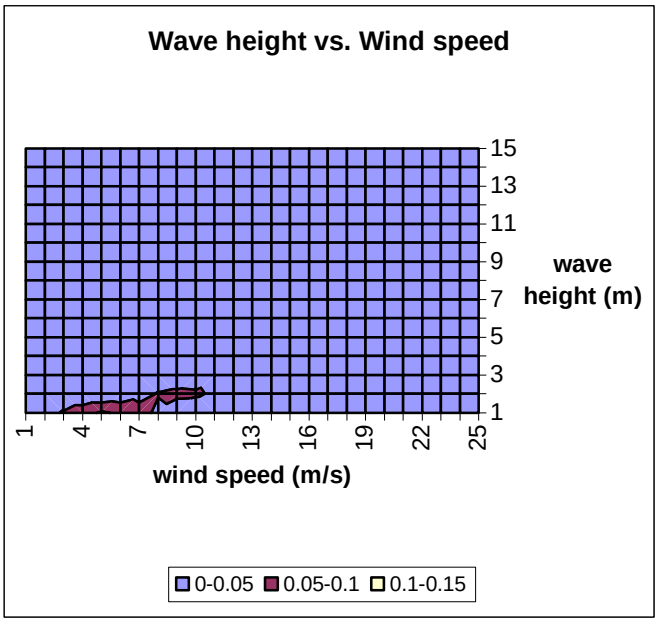


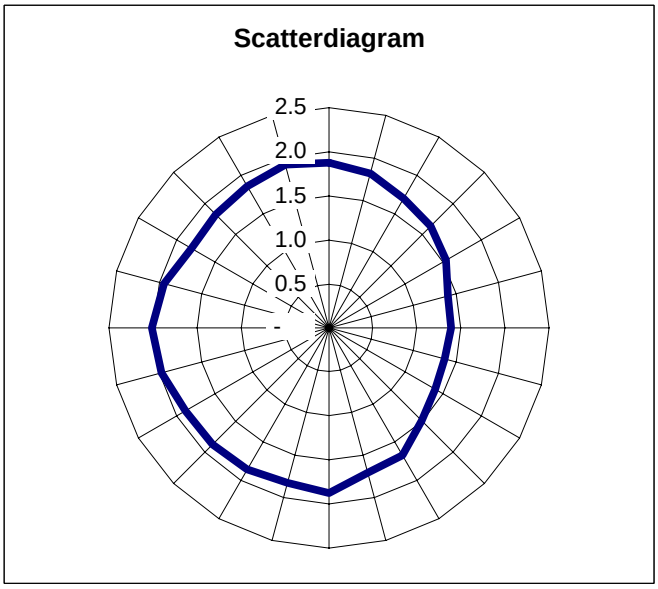


Location	Baltic Sea	Lattitude	58.00	Longitude	20.33

Wind sea waves

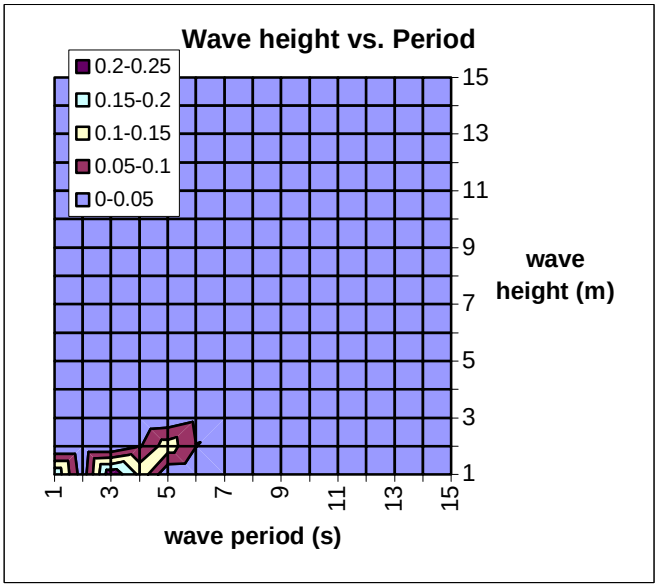


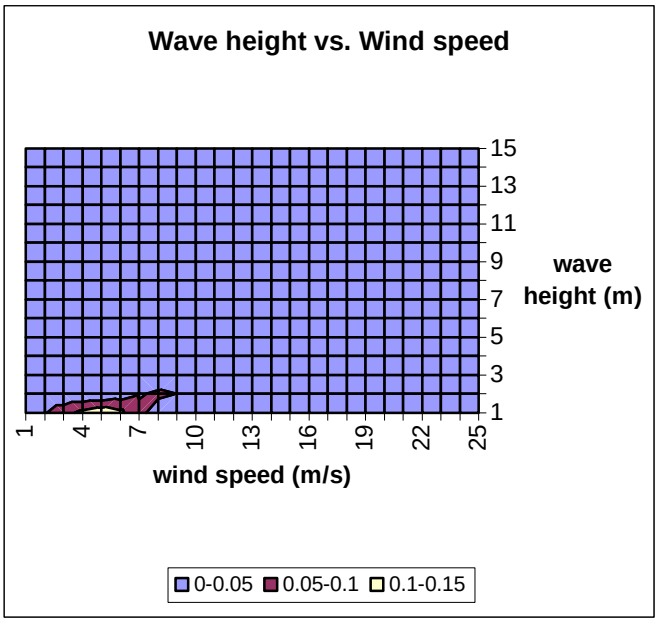


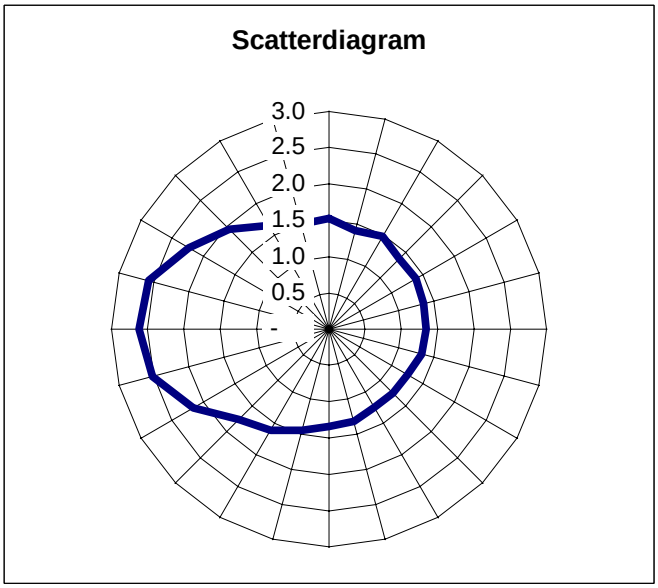


Location	Bay of Biscay	Lattitude	45.00	Longitude	2.87-

Wind sea waves

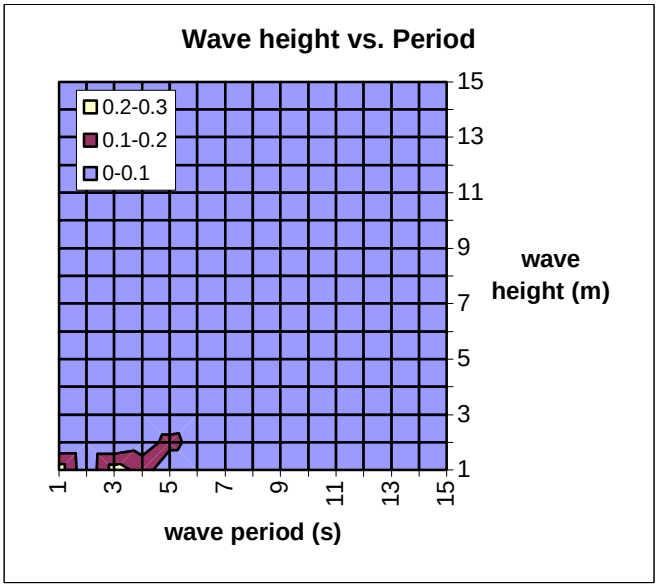


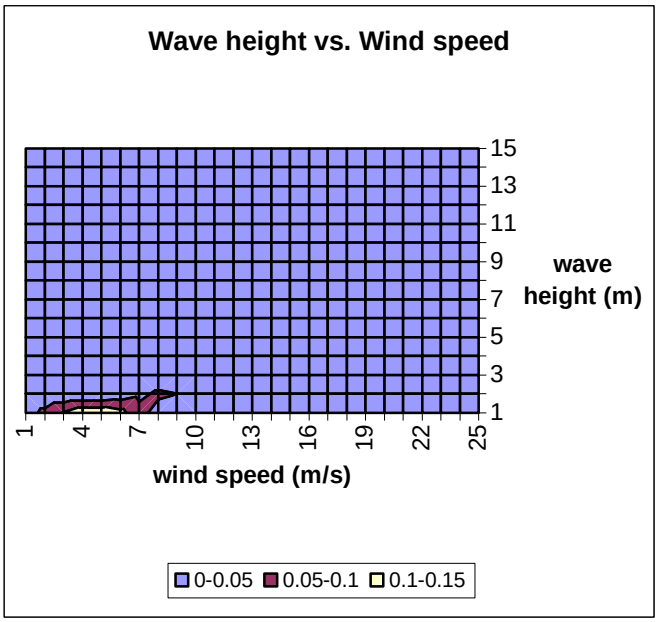


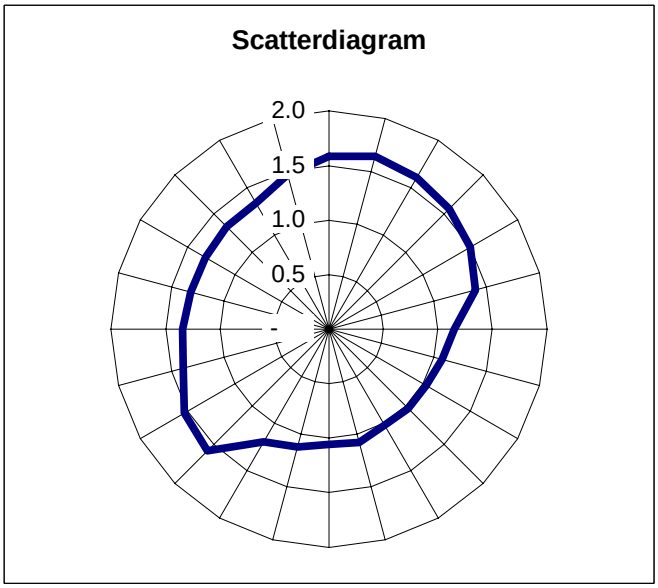


Location	Black Sea	Lattitude	42.00	Longitude	29.93

Wind sea waves

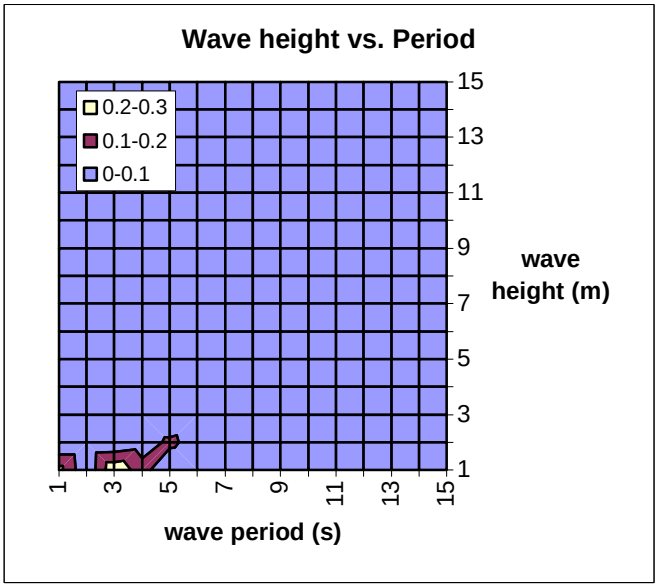


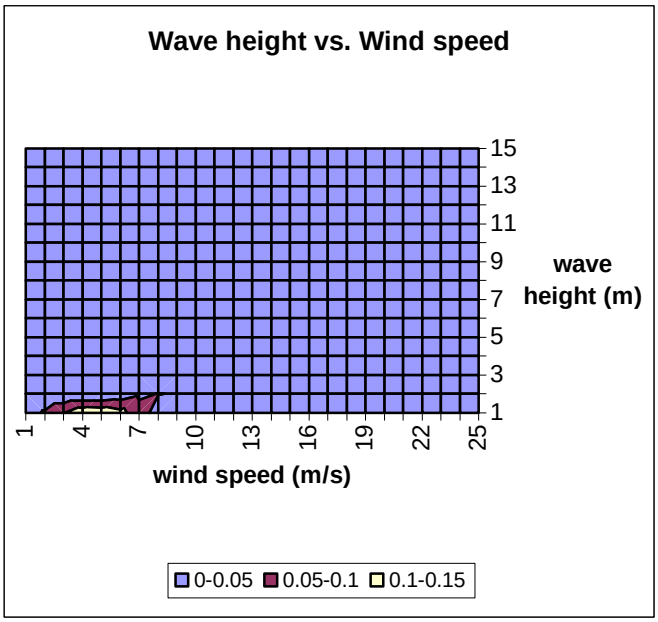


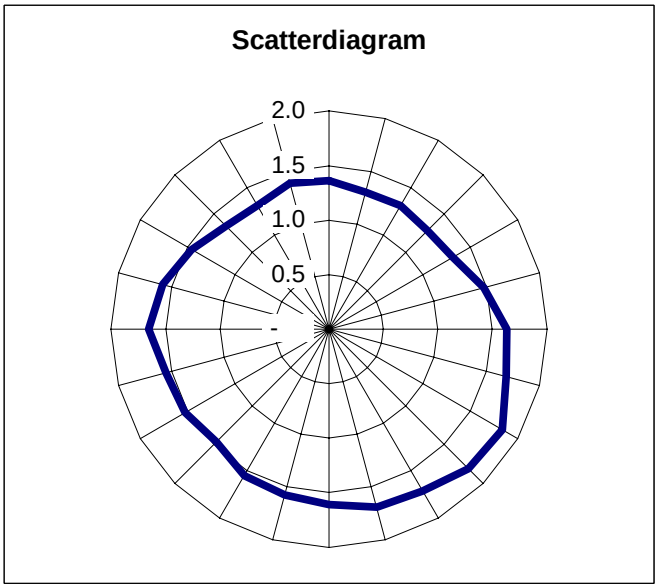


Location	Ionian Sea	Lattitude	36.00	Longitude	19.13

Wind sea waves

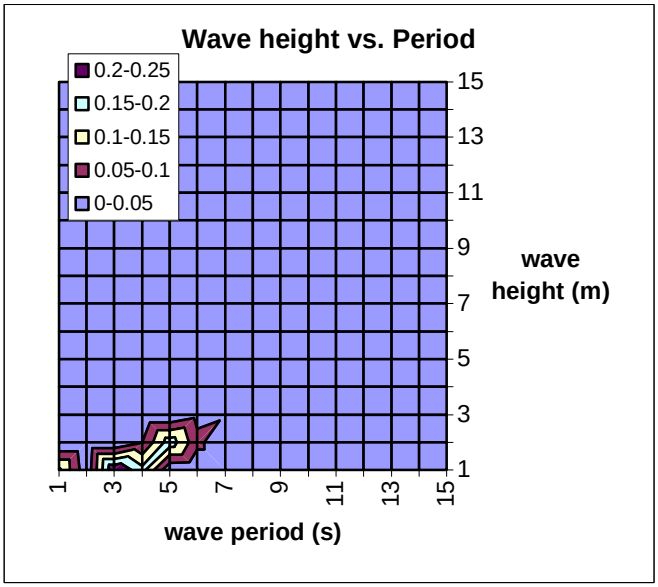


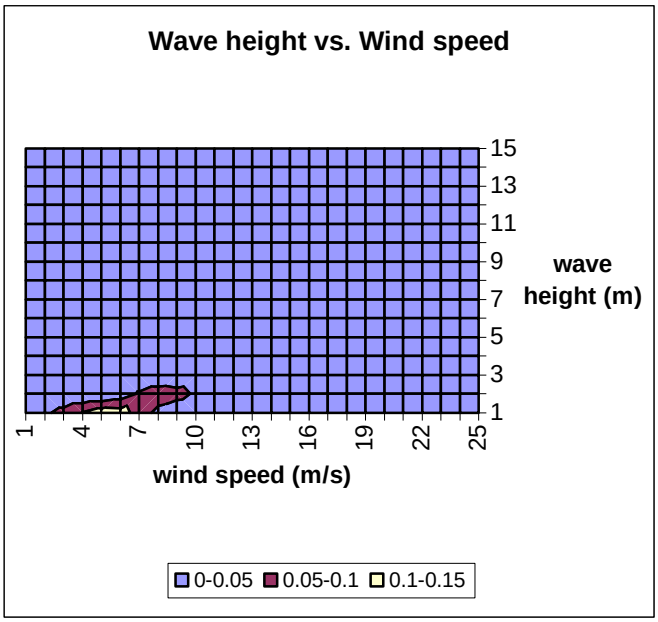


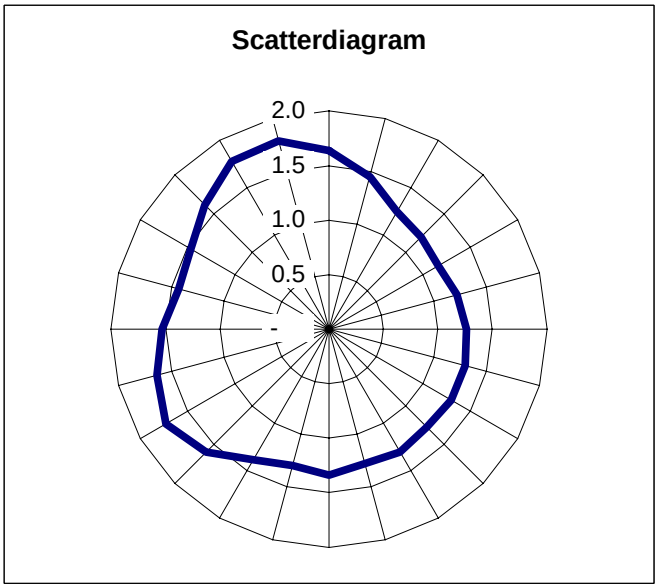


Location	Mediterranean (East)	Lattitude	33.50	Longitude	27.93

Wind sea waves

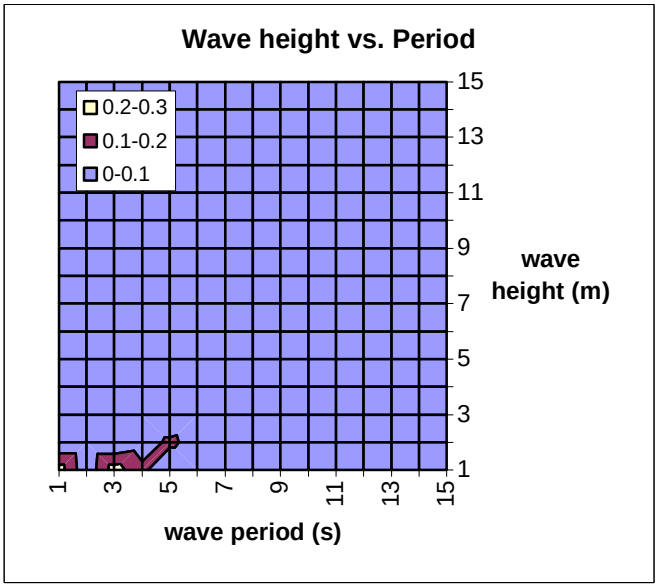


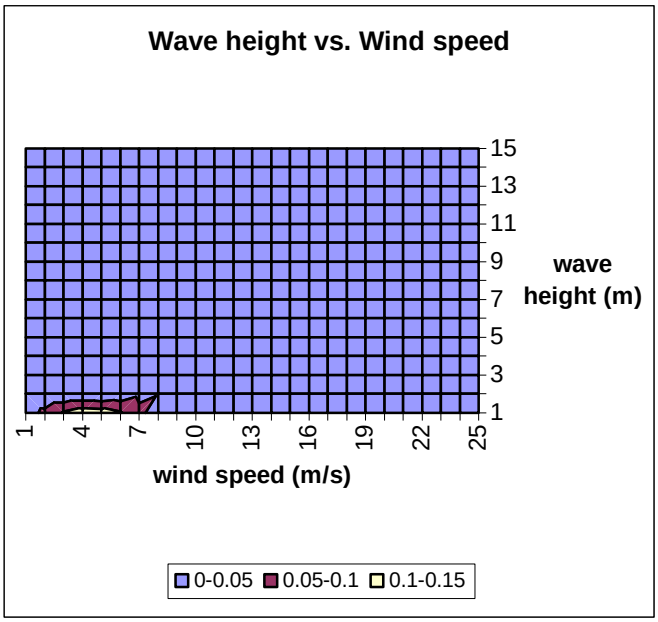


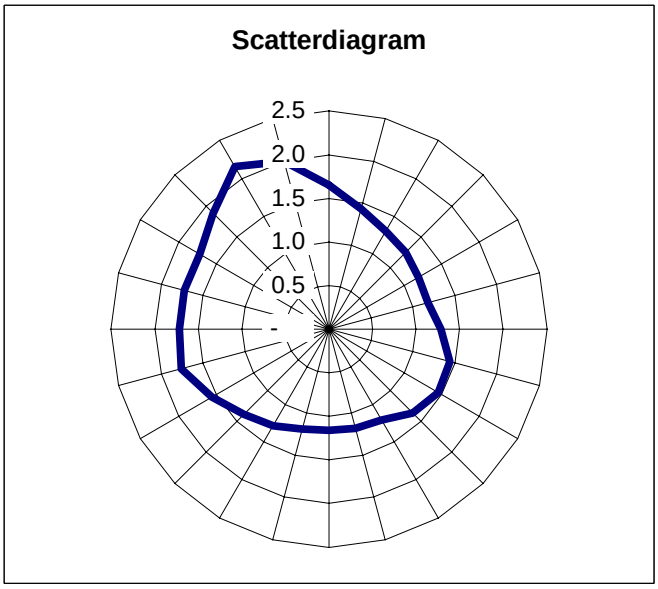


Location	Mediterranean (West)	Lattitude	39.00	Longitude	5.93

Wind sea waves

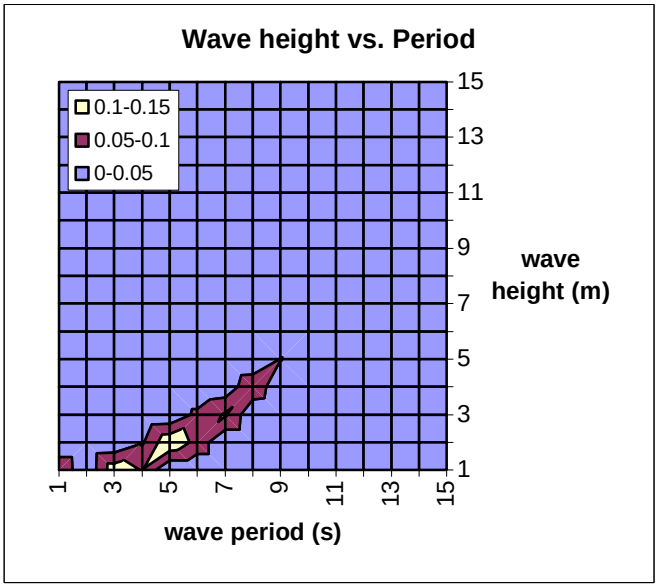


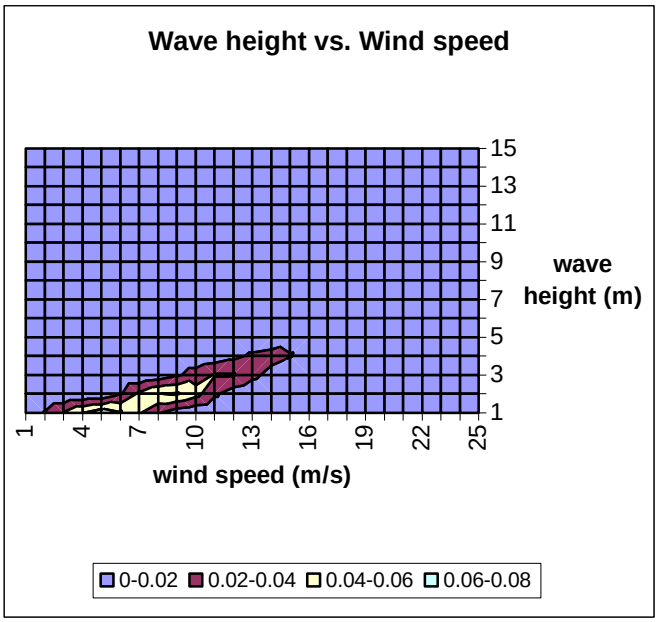


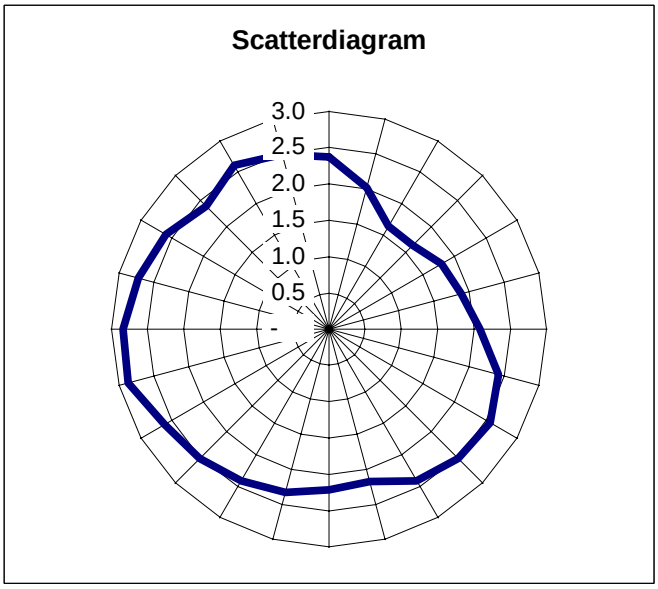


Location	North Sea	Lattitude	57.00	Longitude	3.13

Wind sea waves

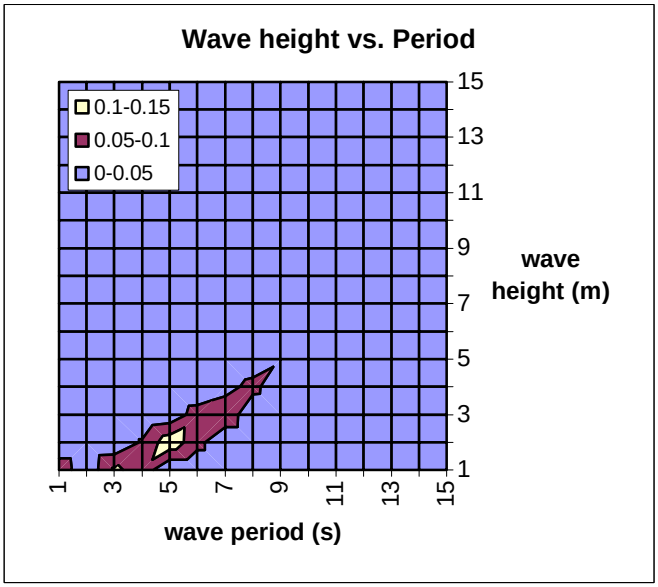


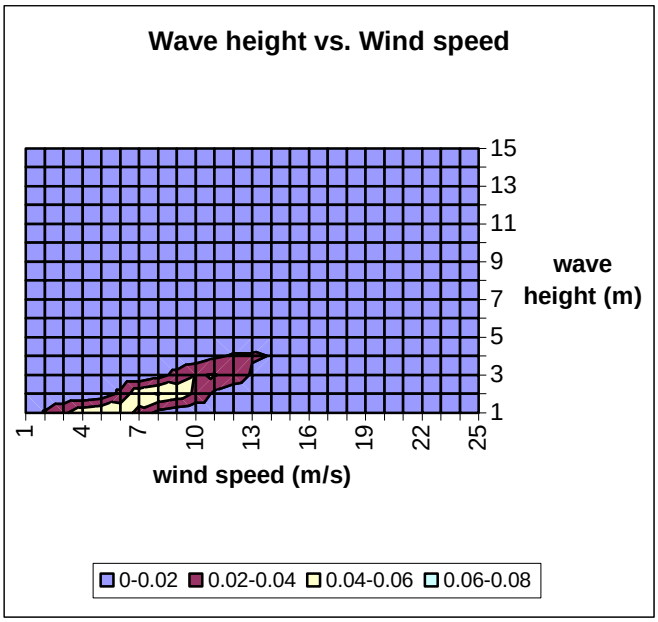


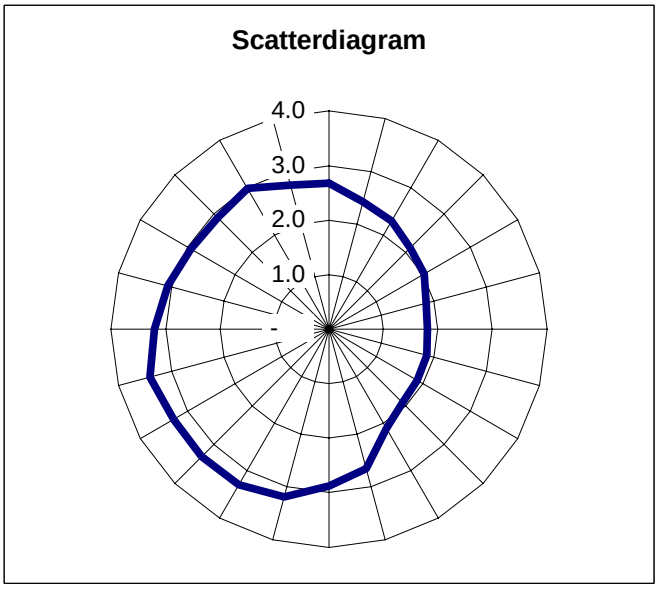


Location	Norwegian Sea	Lattitude	65.00	Longitude	2.33

Wind sea waves







Location	Tyrrhenian Sea	Lattitude	40.00	Longitude	12.33

Wind sea waves