

CHAPTER 10 : Comparisons with measured data

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10.1 Introduction

Clearly it is important to establish the accurate of predictions of offshore wind conditions made within POWER. This has been achieved by comparing POWER's model results with measured data from sites off the coasts of The Netherlands (Measuring Network Zeeland (ZEGE) and Measuring Network North Sea (MNZ)), Denmark (Horns Rev and Læsø Syd) and the Mediterranean. Comparison of the POWER model results with those of an earlier EU study, JOUR0072 (Study of offshore wind Energy in the European community), carried out by Germanischer Lloyd AG and partners has also been made .

10.2 The Netherlands

10.2.1 Introduction

This section deals with three main subjects. First an analysis is presented of the wind speed observations of the ZEGE network. It is claimed these have not been processed, and therefore should provide a suitable reference. Then an analysis is made of the MNZ data. Here the situation is different: it is known that the data have been processed, and also that the processing method has not been consistent over the years. Therefore it has to be investigated how the processing has changed over the years, because it is necessary to have a consistent data set. The ZEGE data are invaluable as reference in this respect.

Finally, the reconstructed observed data are being used to compare against calculated results using the method developed in the POWER project. The scarce data that are available should match the results of the calculations. After that some generally conclusions will be drawn.

10.2.2 Data sources

An overview of all offshore locations where observations are being made is given in Figure 10.1 as taken from the SeaNet internet site [Internet SeaNet Workshop]. The locations are a combination of existing oil or gas platforms, a light-isle and coastal meteorological masts. On the internetsite it is also shown on which of the offshore locations wind speeds and/or temperatures and/or wave parameters are being collected. The main differences between ZEGE and MNZ are summarised in Table 10.1.

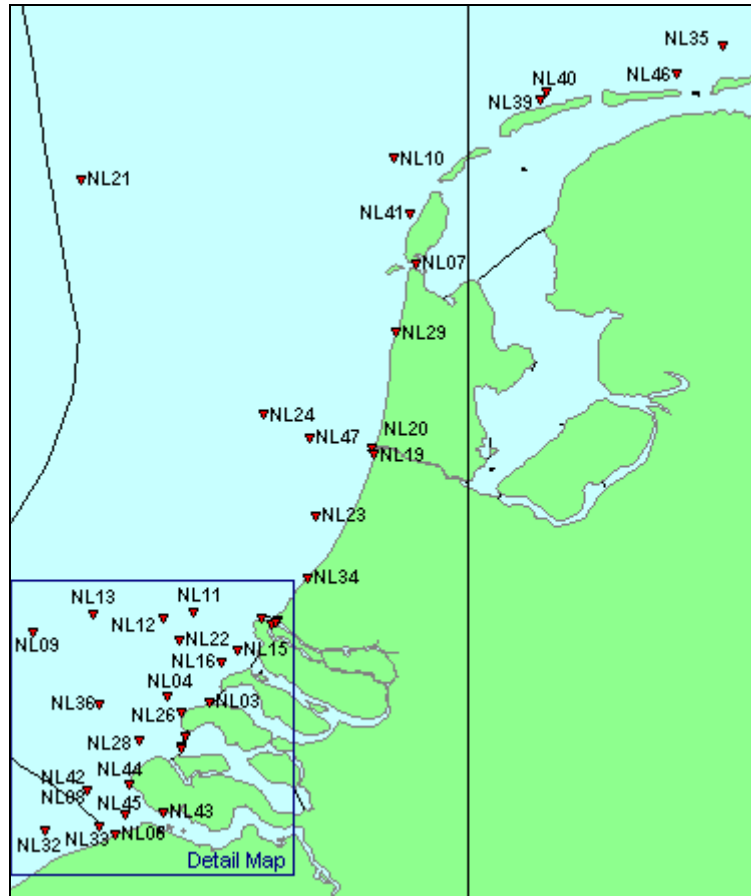


Figure 10.1: Overview of offshore locations with meteorological observations [Internet SeaNet Workshop].

The Measuring Network North Sea makes use of various types of existing offshore structures. Therefore observation heights for wind speeds also vary, which made it necessary to convert the wind speeds to other, standard, heights. In the course of the years however, the data processing has changed considerably leading to inconsistent time series that have to be studied scrutinously to meet the standards required.

The wind speeds observed at these various locations have recently become available for research purposes, and have been subject of thorough investigation to establish their use for climatological study as necessary for our goals. It must be kept in mind that these data were not primarily collected for use in this type of study. The care and attention given to the gathering, processing and storing of the observations may not have been up to the standard required for wind energy purposes. Therefore the quality and consistency of the data must be checked before drawing any conclusions.

Table 10.1: Comparison of Measuring Network North Sea and Measuring Network ZEGE.

Data source	MNZ	ZEGE
Location	North Sea and Dutch coast; mainly Dutch territorial waters	Limited to province of Zeeland, inland waters and a few kilometers of the coast
Observation	Existing offshore structures like light isles, oil and gas platforms	Especially equipped mast with standard anemometer height
Observation height	varying from 15.0 to 103 m above MSL	16.5 m above MSL
Data interval	1 hour	10 minutes

Responsibility	RWS – dir. North Sea & KNMI	RWS – dir. Zeeland
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This has to do with the degree of accuracy and detail that is required for offshore wind energy purposes. For most uses of wind speed observations (weather forecasts, shipping, offshore activities, dike protection) an accuracy of 10% or 20% is quite acceptable. In wind energy projects such margins in average wind speeds may well determine whether or not an investment of many millions is profitable or not.

The character of the data sources as mentioned here led us to using the ZEGE data as a reference for the MNZ data. Whenever the information was either inconsistent, non-existent or unreliable a comparison between the two sources could sometimes be conclusive.

The results here are given for the period of 1985–1997, which is the selected reference period within the POWER-project. Although usually the wind speeds have been converted to a standard height of 10 m and are sometimes recalculated in knots, here all wind speeds have been recalculated for the original observation height (if necessary). There are three main reasons for that: the first is that the height conversion factors have changed throughout the period 1985–1997, making recalculation necessary anyway. The second is that a fixed conversion factor (if deduced properly) may well be valid on average, but the effects of stability and roughness are indeed topics of research. The third is that a particular aspect interesting in describing the wind climate is the calculation of the Weibull parameters. For this an unperturbed frequency distribution is needed (or as much as possible).

10.2.3 Measuring Network ZEGE

10.2.3.1 Description

Within the Measuring Network ZEGE wind data are gathered at 10 locations as shown in Figure 10.2. Some further specifications are given in Table 10.2.



Figure 10.2: Overview of measuring locations for wind data within the Measuring Network ZEGE.

Table 10.2: Description of offshore locations with wind speed observations.

ID ¹	Name	Code	Northing ²	Easting ²	Height (m) ³	Period
NL27	Oosterschelde	OS4	51°39'24"	03°41'43"	16.5 m	1982–1998
NL04	Brouwershavensche Gat	BG2	51°46'06"	03°37'06"	16.5 m	1982–1998
NL42	Vlakte van de Raan	VLR	51°30'16"	03°14'37"	16.5 m	1988–1998
NL14	Prosperpolder	PRO	n.a.	n.a.	16.5 m	1989–1997
NL18	Stavenisse	STA	n.a.	n.a.	16.5 m	1990–1997
NL05	Cadzand	CAD	51°22'48"	03°22'39"	17.0 m	1991–1998
n.a.	Hoofdplaat	HPL	n.a.	n.a.	16.5 m	1991–1998
n.a.	Hansweert	HNW	n.a.	n.a.	16.5 m	1987–1997
n.a.	Terneuzen	TER	n.a.	n.a.	26.5 m	1990–1998
n.a.	Marollegat	MAR	n.a.	n.a.	16.5 m	1982–1997

¹ID as given in the documentation of SeaNet (if available)

²position given if available; otherwise the reader is referred to Figure 10.2

³above Mean Sea Level (MSL)

10.2.3.2 Statistical analysis

Rijkswaterstaat that provided the data stated they had not been processed. To check this, some standard statistical analysis was performed. This includes annual mean wind speeds, monthly and hourly variations, distribution of the wind speed per sector and the determination of histograms and the derivation of the Weibull parameters.

10.2.3.3 Annual mean wind speeds

An important indication for the consistency of the wind speed time series is a comparison of the interannual variability of the wind speed for the different stations. Figure 10.3 shows a similar pattern for all stations. Roughly speaking, the mean wind speed decreases for locations situated more inland, except for MAR. The deviation is probably caused by the large water area around MAR. The most deviating behaviour is observed for HPL: from 1995 to 1997, the annual mean wind speeds appear to be considerably higher than expected compared to the other stations.

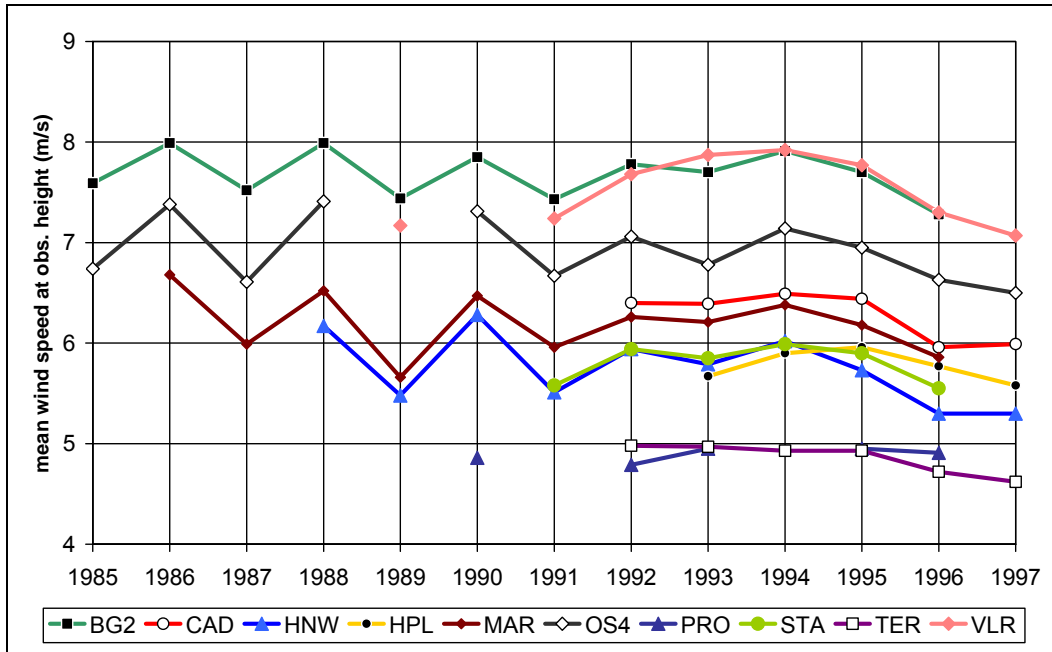


Figure 10.3: Annual mean wind speeds for the stations of ZEGE.

The mean wind speeds in Figure 10.3 at observation height are shown only in case the availability of data exceeds 90%.

To compare the locations more quantitatively we define a measure for the interannual variability ($\Delta_{interannual}$) as follows:

$$\Delta_{interannual} = \frac{U_{annual,max} - U_{annual,min}}{U_{annual,mean}} \times 100\%$$

The results for the calculations are shown in Table 10.3.

Table 10.3: Interannual variability for the stations of ZEGE.

Station	PRO	HPL	TER	CAD	STA	VLR	BG2	OS4	HNW	MAR
$\Delta_{interannual}$	3%	7%	7%	8%	8%	11%	13%	15%	17%	20%

Calculation of $\Delta_{interannual}$ shows values between 3% and 20%. The variability tends to be somewhat larger for the coastal stations than for the 'inland' stations, with the exception of MAR as explained before.

10.2.3.4 Monthly variations

Figure 10.4 shows the annual course of the wind speeds for the ZEGE locations at observation height for the period from 1990–1997. The lines for VLR and BG2 are almost identical. The patterns of OS4 and MAR are similar, but the absolute wind speeds are somewhat lower. The courses of STA, HPL, PRO and TER are roughly similar to each other but differ somewhat more from the course of the 'offshore' stations. The pattern of HNW and CAD deviates significantly from the patterns of the other stations. The most probable explanation is the strong dependence on the wind direction for these stations as they are located on the coast line and are subject to the land/sea transition the most.

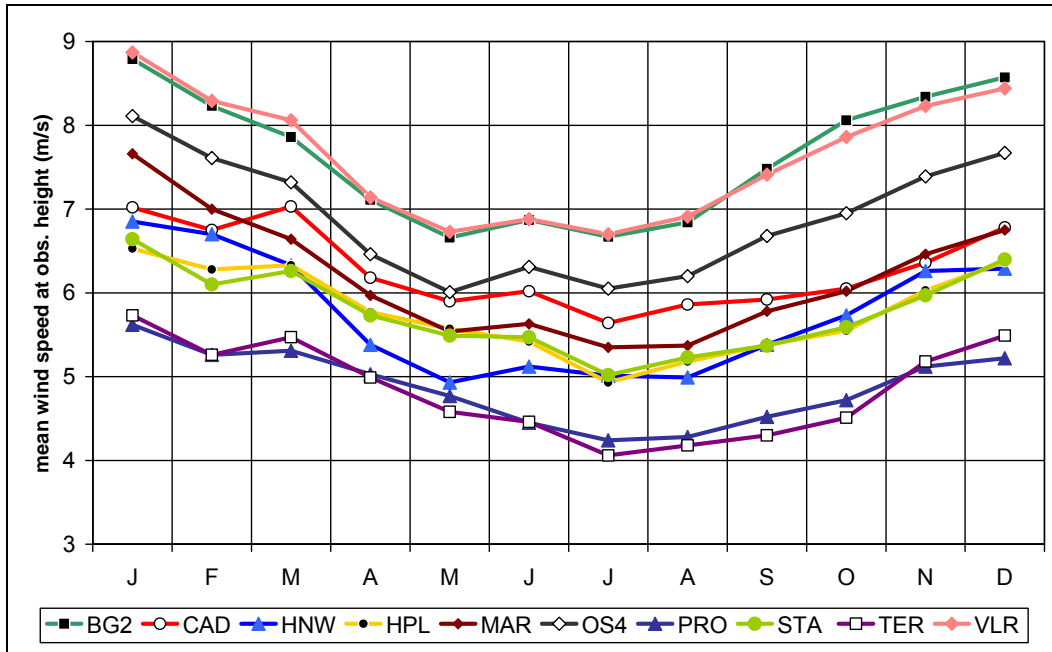


Figure 10.4: Monthly variations of the wind speed for the stations of ZEGE.

As expected the winter months show far higher wind speeds than the summer months. To quantify this a measure called continentality (C_{month}) was calculated, defined as:

$$C_{month} = \frac{U_{month,max} - U_{month,min}}{U_{month,mean}} \times 100\%$$

Table 10.4 gives an overview of the values calculated for all locations.

Table 10.4: Continentality (monthly) for the stations of ZEGE.

Station	CAD	BG2	HPL	PRO	STA	VLR	OS4	HNW	TER	MAR
C_{month}	22%	28%	28%	28%	28%	28%	30%	33%	34%	37%

The calculated values of C_{month} range from 22% (CAD) to 37% (MAR). No clear correlation between location and C_{month} could be derived based on these data.

10.2.3.5 Hourly variations

The hourly variations for the stations is shown in Figure 10.5. Most stations exhibit a day time maximum resulting from the heating of the earth surface. Only VLR and BG2 which are located 'offshore' do not show this, and even tend to have a slight day time minimum. The cause for this is not clear at this moment and requires more detailed analysis.

The ratio of the maximum versus minimum wind speed decreases when getting closer to open sea. An exception to this is MAR that is relatively far inland, but is situated within a large water mass.

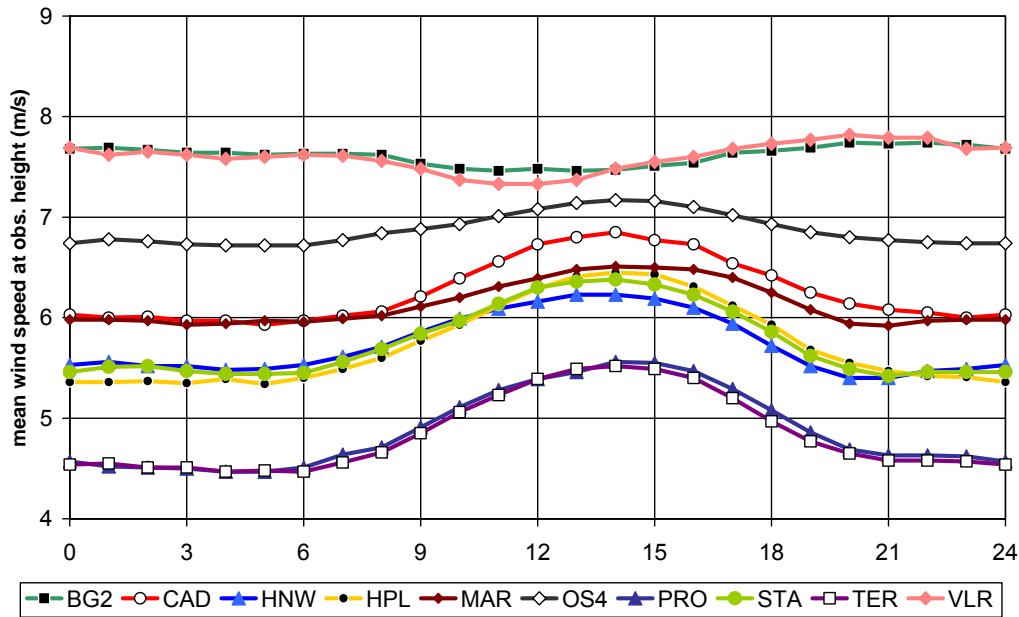


Figure 10.5: Hourly variations of the wind speed for the stations of ZEGE.

As a measure for the influence of the land mass on the behaviour of the hourly variations the measure C_{hour} (analogously to previous calculations) has been defined as follows:

$$C_{hour} = \frac{u_{hour,max} - u_{hour,min}}{u_{hour,mean}} \times 100\%$$

The results have been calculated for all stations and are shown in Table 10.5.

Table 10.5: Continuity (hourly) for the stations of ZEGE.

Station	BG2	VLR	OS4	MAR	HNW	CAD	STA	HPL	TER	PRO
C_{hour}	4%	6%	7%	10%	14%	15%	17%	19%	22%	22%

The calculated values of C_{hour} range from 4% (BG2) to 22% (TER and PRO). This shows that the further the location is located offshore the smaller the day time maximum in the diurnal course, as would be expected, but even resulting (slightly) in the inverse behaviour as shown for VLR and BG2 which cannot be explained and would need further investigation.

10.2.3.6 Variations by wind direction

Finally, the wind speeds by sector have been depicted in Figure 10.6. The wind sectors are defined as customary: they are 30° each, numbered in clockwise order while sector 1 is centred around the north (345°–15°).

The lines for BG2 and VLR nearly coincide. The wind speed at OS4 is somewhat lower: with fetch over land (North-East) the wind speed is considerably lower, with fetch over sea (sector 9) the wind speeds are comparable. The importance of fetch of land or sea is also observed for the other stations.

The wind speed at CAD is larger than at OS4 for sectors 1 to 3 (CAD: fetch over sea while OS4 has a fetch over land), in sector 4 to 7 this is the other way round and so are the wind speeds. In sector 9 to 12 both stations have a fetch over sea and wind speeds are comparable. Similar behaviour is observed when comparing MAR with PRO, STA or HNW.

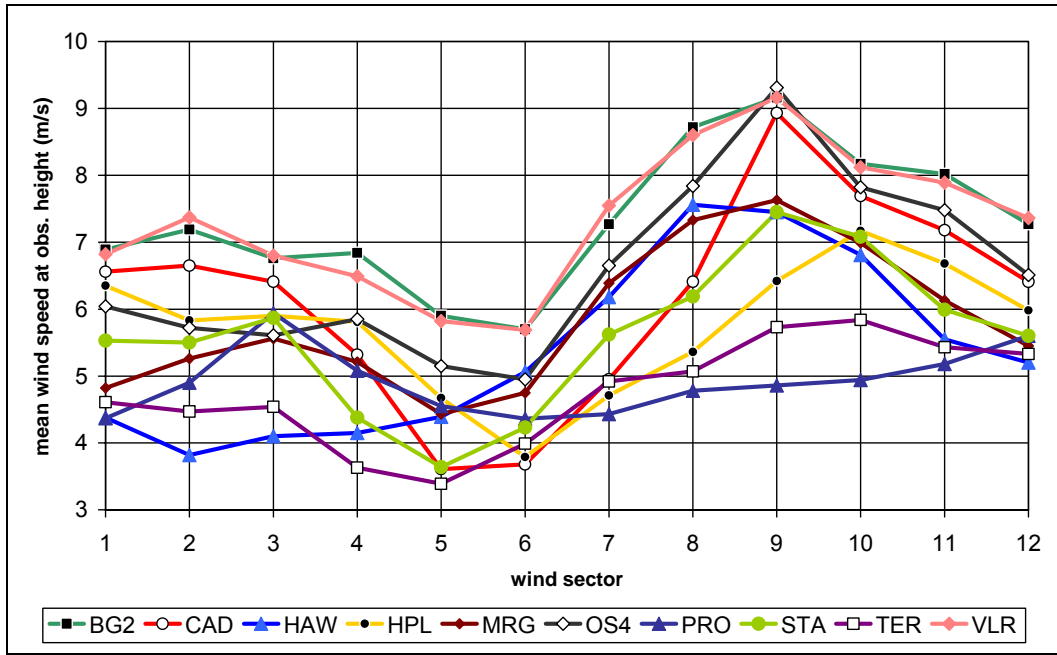


Figure 10.6: Mean wind speeds per sector for the stations of ZEGE.

Figure 10.7 shows the direction distribution for all stations. The course is more or less similar for all stations. Major exception is that for some stations sector 8 shows the highest frequency of occurrence, while sector 9 does for the other stations. This may be due to the way the original values of the wind direction have been grouped statistically into sectors.

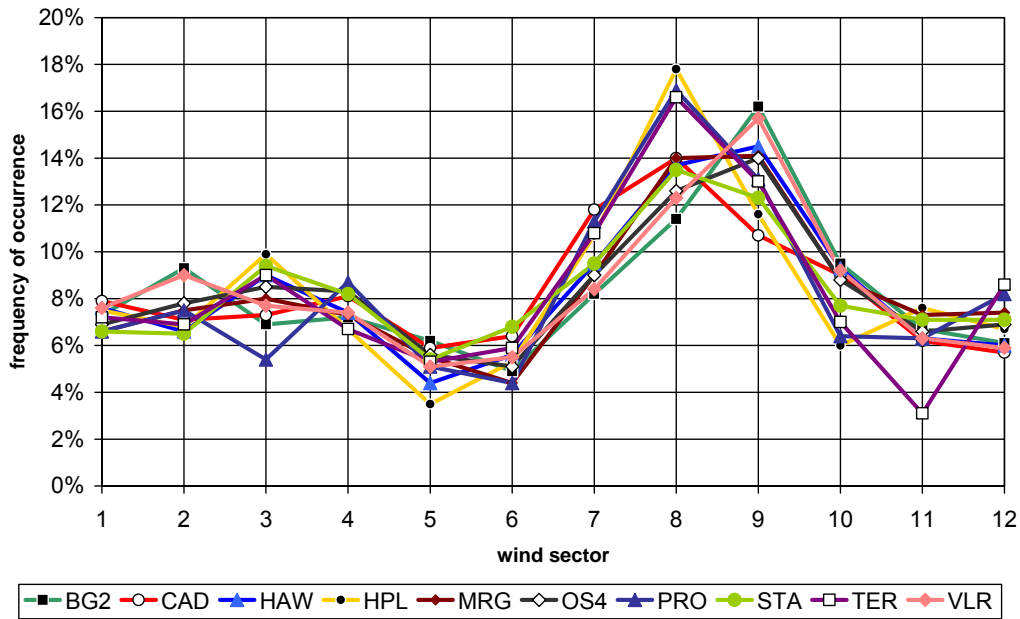


Figure 10.7: Frequency of occurrence per sector for the stations of ZEGE.

10.2.3.7 Histograms and Weibull parameters

The histograms were calculated for every year separately and for the complete period from 1985 to 1997. The resulting Weibull parameters are shown in Table 10.6. As an example the histogram for BG2 is shown in Figure 10.8.

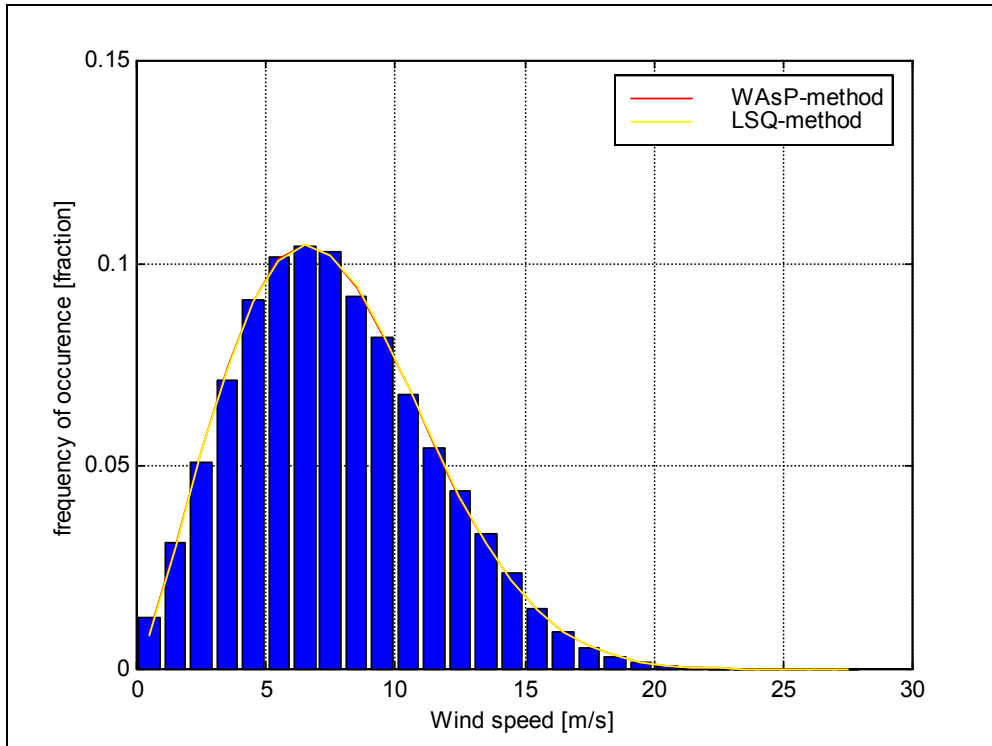


Figure 10.8: Histogram of wind speed for BG2 from 1985 to 1997 and the Weibull fit. Weibull parameters are determined according to the WASP-method and the least squares method.

Table 10.6: Weibull factors, mean wind speed and percentage of available data for the stations of ZEGE.

Station	Period	Mean wind speed (m/s)	k	a (m/s)	Availability (%)
OS4	1985–1997	6.92	1.97	7.78	96
BG2	1985–1997	7.65	2.18	8.70	94
VLR	1988–1997	7.55	2.16	8.59	88
PRO	1989–1997	4.87	1.96	5.46	86
STA	1990–1997	5.77	1.80	6.38	87
CAD	1991–1997	6.27	1.77	6.91	97
HPL	1991–1997	5.75	1.89	6.40	94
HNW	1987–1997	5.76	1.76	6.42	92
TER	1990–1997	4.86	1.80	5.40	86
MAR	1985–1997	6.17	2.01	6.99	94

¹mean wind speed and availability for wind speed and wind direction valid at the same time. The difference with only wind speed valid is negligible (at maximum 0.01 m/s).

The values of the Weibull k-parameter (shape factor) are between 1.77 and 2.18. The largest values are for the stations furthest offshore (BG2 and VLR). The relation between the mean wind speed and the Weibull a-parameter (scale factor) is rather insensitive for values of k between 1.5 and 4.0.

The availability of all stations is good: on average over 90% for all stations. An indication that data may have been processed is the rare occurrence of certain values in the time series. The number of zeros is compatible with the Weibull distributions for all years for nearly all stations. The exceptions are BG2 in 1986 (149 zeros) and PRO in 1990 and 1991 (roughly 80 zeros). Probably missing data are

replaced by zeros. There is at least not a long period of zeros and based on the neighbouring values, wind calm is not impossible at the times in the series.

According to the data sets for BG2, the north sector occurs very often in 1986 and 1987 for wind speeds between 0 and 1 m/s. Most probably, the wind direction of periods with varying wind speeds (occurring especially at low wind speeds) is set to 0, and subsequently interpreted as 0°, therefore grouped in sector 1. This is not observed at other years or for other stations. As these wind speeds are irrelevant for wind energy purposes (below cut-in wind speed of wind turbines), this does not disqualify the use of BG2 for wind energy purposes.

10.2.3.8 Conclusions

The data of ZEGE as obtained from Rijkswaterstaat have been analysed statistically. It was claimed no data processing had been performed other than some basic quality checks. In order to verify this claim, and also to learn about the wind climate several steps were undertaken. In summary, the following points are of interest.

- The annual mean wind speeds of the data sets from ZEGE exhibit a consistent behaviour. For HPL, the wind speeds are relatively high for 1995 to 1997.
- The annual course for the ZEGE stations is as expected. No irregularities were observed.
- The diurnal courses for VLR and BG2 show a small negative peak. We do not know an explanation for this. The other stations do show a slight positive peak. The relative magnitude of this peak decreases for stations further offshore.
- The dependence of the wind speed on the sector was calculated. The variations found can be explained by fetch over land and fetch over sea.
- No irregularities were observed within the histograms. The magnitude of the Weibull factors was as expected.
- No major irregularities were observed in the data set itself.

It indeed appears that the data have not been processed. Therefore, the conclusion is warranted that the data are of sufficient quality and consistency to use as reference to validate the MNZ data.

10.2.4 Measuring Network North Sea (MNZ)

10.2.4.1 Description

The locations of the Measuring Network North Sea (MNZ) are various offshore constructions, like gas and oil platforms, and also a light-isle. As an exception MPN is a platform solely in use for monitoring purposes and research projects. The various locations in use within MNZ have been summarised in Table 10.7. Also given are the observation heights (for wind speed) and the locations. In Figure 10.9 the locations closest to The Netherlands have been depicted, together with the locations of ZEGE located in the North Sea.

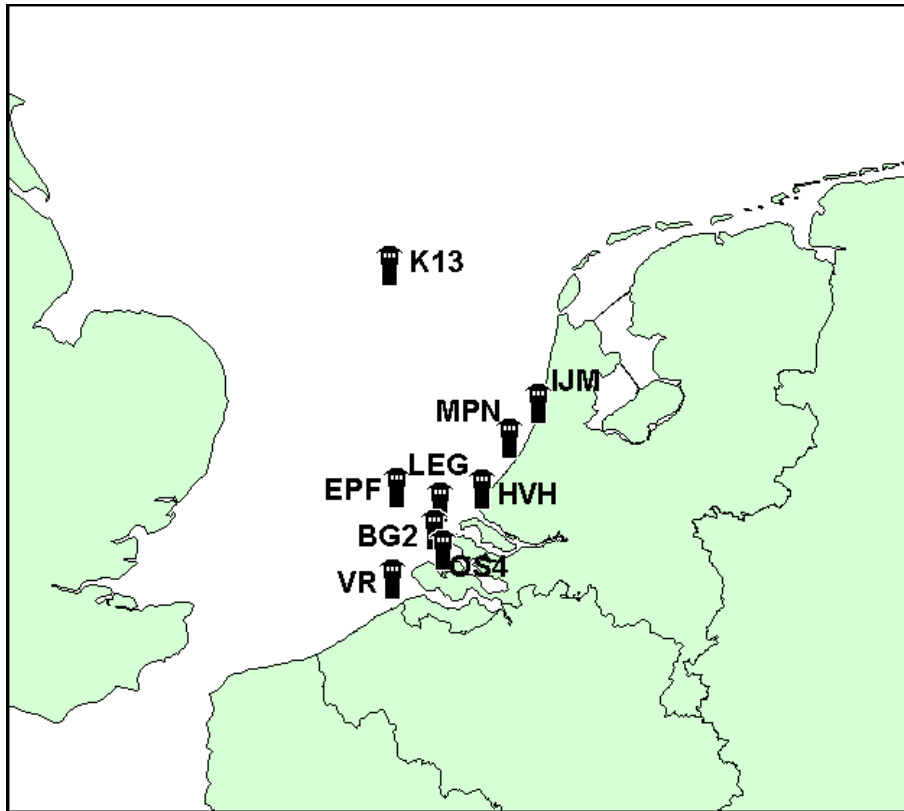


Figure 10.9: Overview of locations in the North Sea (some locations are outside the map).

Three institutes collaborate in running the MNZ. RWS (dir. North Sea) is principally responsible for the maintenance of the hardware and the data collection. KNMI is responsible for the validation of the data, and if necessary the filling of any gaps. Finally RIKZ maintains a central database called DONAR of all types of observations, meteorological, oceanographical, but also chemical and biological. From this database most observations were made available to us.

Table 10.7: Position and water depth of the locations within the Measuring Network North Sea (MNZ).

ID	Name	Code	Northing	Easting	Period	Water depth
NL20	IJmuiden-harbour	IJM	52°27'47"	04°33'22"	1989–1997	n.a.
NL24	IJmuiden depot	IJM	52°33'30"	04°03'30"	1989–1997	21 m
NL23	Measuring post Noordwijk	MPN	52°16'23"	04°17'50"	1987–1997	18 m
NL22	Light Isle Goeree	LEG	51°55'29"	03°40'06"	1991–1997 ²	22 m
NL13	Euro platform	EUR	51°59'55"	03°16'35"	1987–1997	32 m
NL14	F3-3B Platform	F3P	54°51'14"	04°43'39"	1995–1997	n.a.
NL18	Hoek van Holland	HVH	51°59'06"	04°03'00"	1985–1997	n.a.
NL21	K13 platform	K13	53°13'04"	03°13'13"	1985–1997	30 m
NL01	Auk platform	AUK	56°23'59"	02°03'56"	1987–1995	85 m

For the stations of MNZ the observation height differs per location. According to WMO guidelines, wind speeds have to be reported at 10 m above MSL. Therefore, the measured wind speeds are converted from observation height to 10 m by means of a fixed conversion factor. These factors were determined in 1977 by the North Sea Meteorological Panel. Eight different formulas for conversion to 10 m MSL were discussed. The roughness length z_0 of the sea varied within these formulae from

roughly 2×10^{-4} m to 18×10^{-3} m. As a compromise, the average of these options was taken for all stations. The result corresponds relatively well to the power law with a value of 0.13 for the exponent:

$$\frac{u(z)}{u(10)} = \left(\frac{z}{10} \right)^{0.13} \quad (1)$$

with u the wind speed in m/s and z the height above MSL in m. This implies a roughness length of 12.3×10^{-3} m.

Later on, it was concluded that the resulting conversion factors were too large, resulting in a too low wind speeds at 10 m height. [Benschop (1996)] derived new conversion factors based on a more physical basis. The new conversion factors were used from July 12, 1995 onwards [Benschop (2000)]. An overview of both the old and revised conversion factors is given in Table 10.8.

Table 10.8: Characteristics of the offshore locations of MNZ.

Code	Observation height	Conversion factor	Revised conversion factor ¹
AUK	101.3 m	1.355	1.270
EPF	29.1 m	1.148	1.120
F3P	59.2 m	1.260	1.200
K13	73.8 m	1.298	1.230
LEG	22.5 m	1.120	1.150
	38.3 m	1.120 ²	
MPN	27.6 m	1.142	1.120

¹as proposed by [Benschop (1996)] commencing date: July 12, 1995.

²in 1990 the mast at LEG was replaced by a higher mast at another position on the platform; the reason for this was that at the old position the wind flow was obstructed too much from certain directions; therefore the data from this earlier period were discarded; unjustly not adapted to new situation, at April 6, 1990, the observation height was changed from 22.5 m to 38.3 m.

NB:

Note that each year all wind speed data from the measuring Network North Sea are supplied to the KNMI for validation. After validation, the KNMI sends the data back to RIKZ. Unfortunately, not all measuring sets were complete. Therefore, it is possible that periods exist where the old conversion factors are used after July 1995. From the analysis of monthly average wind speeds, we could not deduce this and hence did not take this into account in our reprocessing and further analysis.

Since the early 80s when Measuring Network North Sea has been instituted then reliable and consistent wind speed observations have been made at various locations. Some of these observations were subject of earlier studies (see e.g. [Benschop (1996)], [Cleijne et al. (1991)] and [Coelingh et al. (1997)]). The same goes for the observations of ZEGE (see e.g. [Coelingh et al. (1998)]).

Data have been received from the DONAR database of the RIKZ (Rijksinstituut voor Kust en Zee) for Measuring Network North Sea. Data from the climatological database of the Royal Dutch Meteorological Institute KNMI, KEMA (obtained via RWS) and data of Voluntary Observing Ships have been used for reference to complete or validate data.

Basically, the source of all wind speed measurements is the same. However, the data have been distributed to several parties, and from there they have been processed and stored in different ways. Therefore it is not always exactly clear, particularly for periods in the (far) past, who has been responsible for each step. For the POWER project, the period of interest is from 1985–1997

A short summary of the availability for wind speed data is given in Table 10.9.

Table 10.9: Overview available data at RIKZ.

Station	Period
AUK	1981–7/95
EPF	1983–present
F3P	1995–1998
K13	1981–present
LEG	1981–present
MPN	1983–present

- all wind speeds are 10-minute means;
- all wind speeds are converted to 10 m height by division with the appropriate conversion factor;

10.2.4.2 Annual mean wind speeds

The annual mean wind speeds have been calculated for the six offshore stations of MNZ. The annual mean wind speeds were converted to observation height by multiplying with the relevant conversion factor. Based on a comparison of RIKZ and RWS (dir. Zeeland) it appears that the conversion from m/s to knots was terminated as from 1/1/1991. The course of the annual means per station converted to observation height is plotted in Figure 10.10. In this figure, the conversion from knots to m/s is taken into account until 1/1/1991.

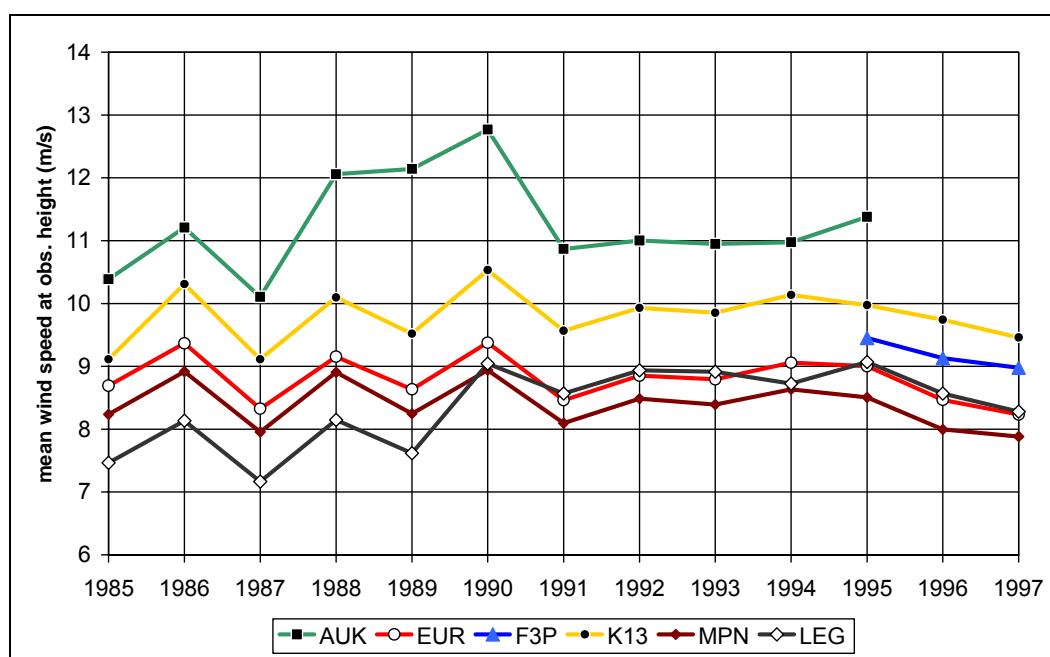


Figure 10.10: Annual mean wind speeds, converted to observation height, for the stations of MNZ.

On the other hand, a 3% deviation in the course of the annual mean is not impossible. Therefore, the performed graphical analysis is not a watertight proof. For the moment, we will however assume that the conversion to knots was terminated at this date.

From the above figure:

- The stations K13, MPN, EUR, F3P show consistent courses.
- The course of the annual mean of AUK is less consistent but is reasonable. Reasons for deviations can be the poor availability for 1989 and 1993 and possibly also the difference in the wind climate due to the large distance to the other stations.

- Originally, an increase in mean wind speed for LEG in 1990 was observed. The cause for this was an increase in anemometer height in April 1990 while the conversion factor had not been adapted. Data before April 11, 1990 has been excluded from the analysis.

For December 1994, no wind speed data are available for LEG. When looking to the monthly averages of LEG compared to MPN, it turns out that the mean wind speed from April to November is somewhat higher at LEG as would be expected from the annual mean. In the period from January to March, the wind speed roughly equals the mean wind speed at MPN. The data supplied by RIKZ for these three months were not reliable (mean wind speed of 2 m/s!) Therefore this period was replaced by the interpolated RWS data. For December 1994, no data are available at all. Effectively, data from before 11 April 1991 are ignored.

The annual mean of the valid wind speed data was already calculated and shown in Figure 10.10. For reference purposes, also some stations from Measuring Network ZEGE are included. The interannual variability is calculated for each station and is shown in Table 10.10.

Table 10.10: Interannual variability for stations of MNZ.

Station	LEG	MPN	EUR	K13	AUK
$\Delta_{\text{interannual}}$	8%	13%	13%	14%	23%

It appears from the table that the further offshore, the larger the interannual variability. This tendency was also recognised for Measuring Network ZEGE (Table 10.3).

10.2.4.3 Monthly variations

The annual courses at observation height have been determined for the period 1985–1997 as far as data were available within this period (Figure 10.11).

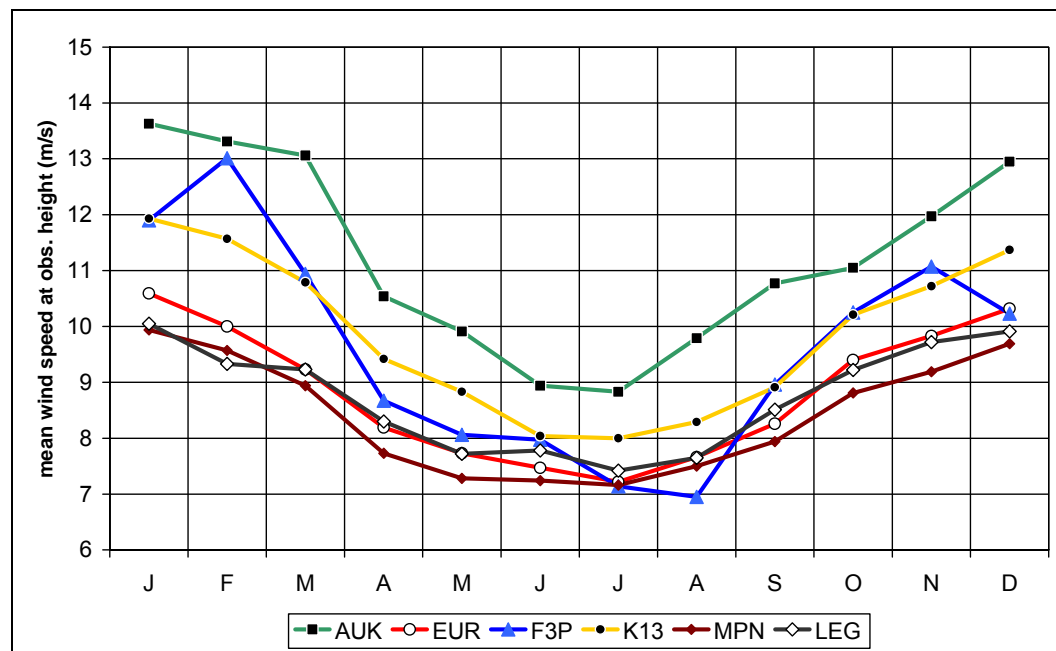


Figure 10.11: Monthly variations of the wind speed for location

The overall pattern seems good apart from the fact that the mean wind speed for February and October at F3P appear to be relatively high. However, for this station, only 3 years of data were available.

In this case the continentality is also calculated. The results are summarised in Table 10.11. The magnitude of the continentality for MNZ is the largest for the stations offshore and in general are higher than for ZEGE stations. Hence, the continentality appears a reasonable measure for the distance of the station to the coast.

Table 10.11: Continentality (monthly) for stations of MNZ.

Station	LEG	MPN	EUR	K13	AUK
Continentality	31%	33%	36%	40%	44%

10.2.4.4 Hourly variations

Figure 10.12 shows the diurnal course for the MNZ stations at observation height. AUK, F3P and K13 do not show a peak as to be expected from their location. LEG, EUR and MPN show a slight negative peak. The cause for this is unknown.

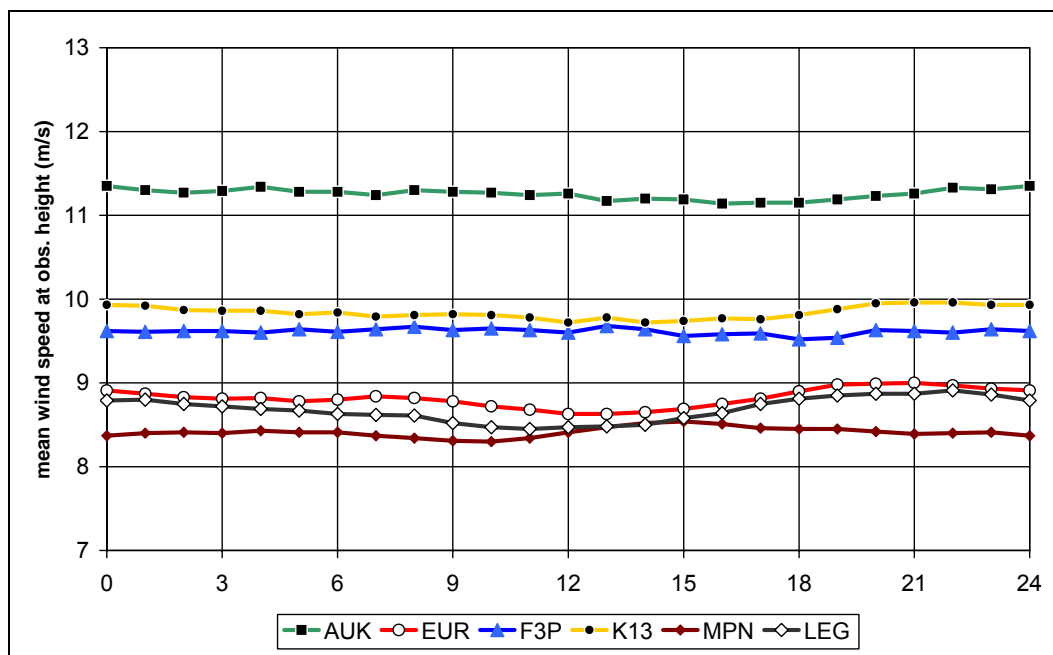


Figure 10.12: Hourly variations of the wind speed for the stations of MNZ.

The peaks of the diurnal course at observation height are again quantified by calculating C_{hour} . The result is shown in Table 10.12.

Table 10.12: Continentality (hourly) for stations of MNZ.

Station	LEG	MPN	EUR	K13	AUK
C_{hour}	5%	3%	5%	2%	2%

As expected, the values are higher for the stations located closer to the shore showing increased influence of land.

10.2.4.5 Variations by wind direction

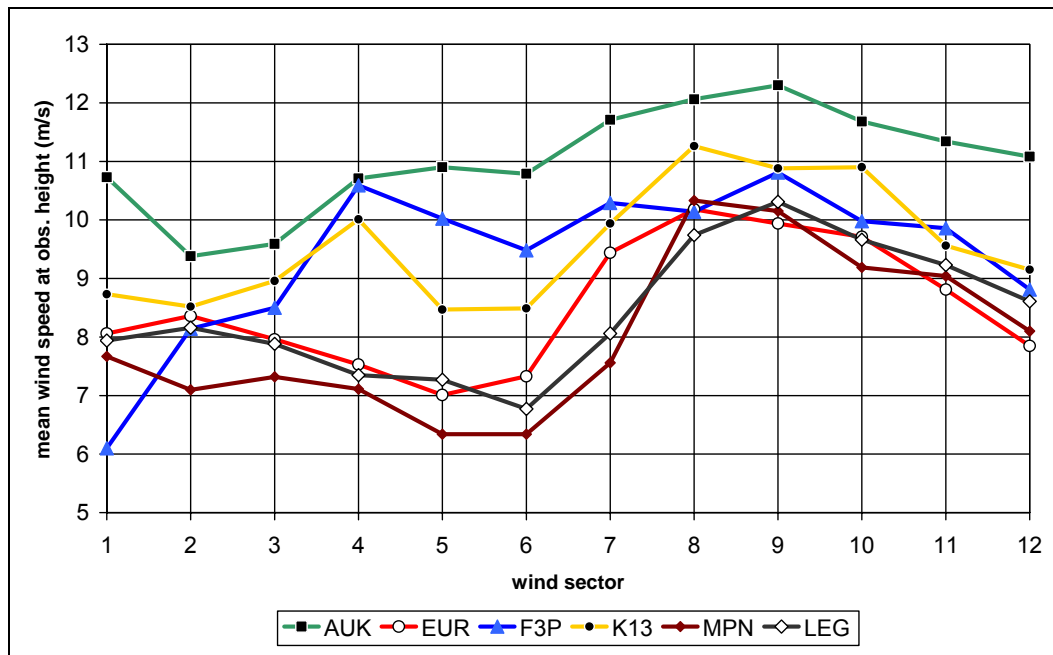


Figure 10.13: Mean wind speed by sector for the stations of MNZ.

The mean wind speed per sector was analysed and is shown in Figure 10.14.

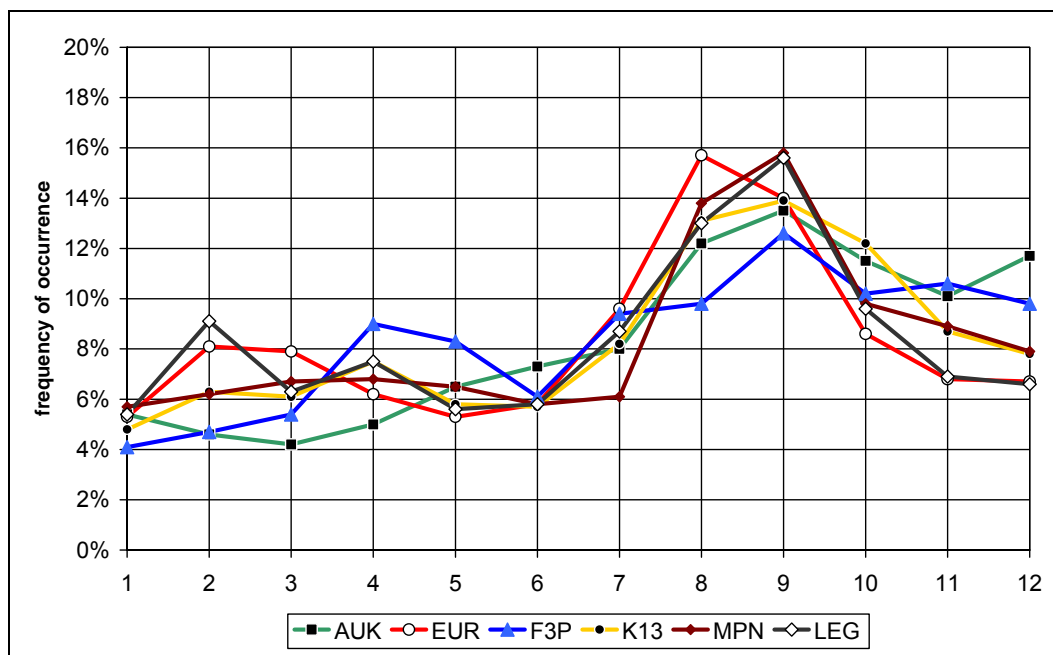


Figure 10.14: Frequency of occurrence by wind sector for the stations of MNZ.

10.2.4.6 Histograms and Weibull parameters

In order to obtain insight into the several processing methods used and to judge the reliability of the data sets, wind speed histograms were made for each year and station. An indication for a change in processing method is a change in shape of the histogram.

After reprocessing the mean wind speeds and Weibull factors have been calculated for all stations for each year and for the available period from 1985–1997. Table 10.13 shows the results.

Table 10.13: Overview availability, mean wind speed and Weibull parameters of offshore wind speed data sets.

Station	Period	Availability [%]	k [-]	a [m/s]	Mean wind speed [m/s]
MPN	1987-1997	99	2.02	9.37	8.42
EUR	1987-1997	98	2.10	9.83	8.81
K13	1985-1997	97	2.05	10.99	9.87
AUK	1987-1995	76	2.18	12.85	11.41
LEG	1991-1997 ¹	94	2.19	9.86	8.71

The several processing methods have altered the shape of the histogram or the originally measured data set. The histograms have been fitted with the ‘WASP’-method and with the ‘least squares’-method. Figure 10.15 shows the result for Measuring Post Noordwijk. The Weibull factors within the table are the ones derived with the WASP-method. The mean wind speeds found correspond within 2% of an earlier study of (part of) the data from MPN, EUR and K13 [Coelingh et al. (1998)].

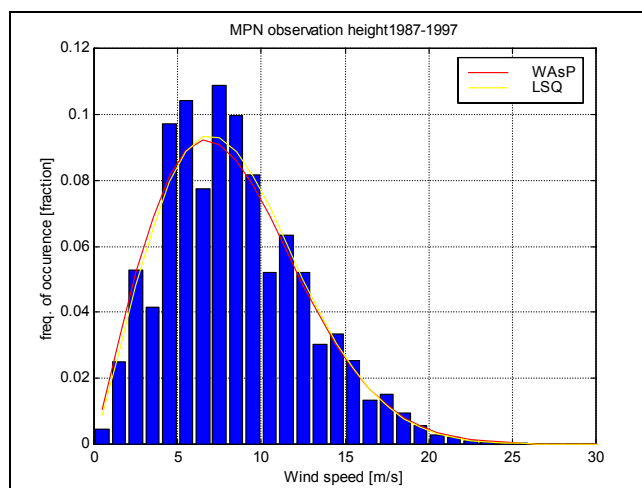


Figure 10.15: Histogram and Weibull fit for MPN.

10.2.5 Conclusions

The wind speed data from the measuring Network North Sea have been processed in several ways. Five different processing methods could be distinguished. Three of them affect the shape of the histogram considerably and possibly also affect the mean wind speed. The time series have been reconverted to observation height by applying the appropriate conversion factors. Also a correction for the conversion from knots to m/s has been applied.

The availability and consistency of the data sets were checked by means of data analysis and comparison with time series from other sources (KEMA, KNMI, voluntary observing ships) and stations from Measuring Network ZEGE. F3P shows good behaviour, but only a limited period (3 years) of data is available. Data of LEG until April 1990 were also not used as before that data the erroneous conversion factor was used in the past and because of the former shielding of the mast.

The time series have been reconverted to observation height by applying the appropriate conversion factors. The mean wind speed and Weibull parameters have been determined from these reconverted time series for the period 1985–1997 (as far as data were available).

¹ LEG: data interpreted as invalid until April 11, 1991 (due to change of mast)

10.2.6 Comparison with POWER results

10.2.6.1 Introduction

In order to validate the results as obtained from the WasP (see Chapter 4) a comparison was made to the observations as acquired and analysed from the Measuring Network North Sea and ZEGE. WasP was run to produce results for the exact location and observation height of the available locations. For a better insight this was done on different temporal scales: annual and monthly. Here we will only show the comparison on an annual basis for 6 locations: three of the Measuring Network North Sea (K13, Euro platform and Measuring Post Noordwijk) and for the three of ZEGE that are in the North Sea (Oosterschelde 4, Brouwershavensche gat 2 and Vlakte van de Raan).

10.2.6.2 Annual variations

Figure 10.16 shows the annual variations over the period 1985–1997 at the observation height for the three locations of Measuring Network North Sea. The solid lines are the results of the WASP calculations, the dashed lines the averages of the (reconstructed) observations.

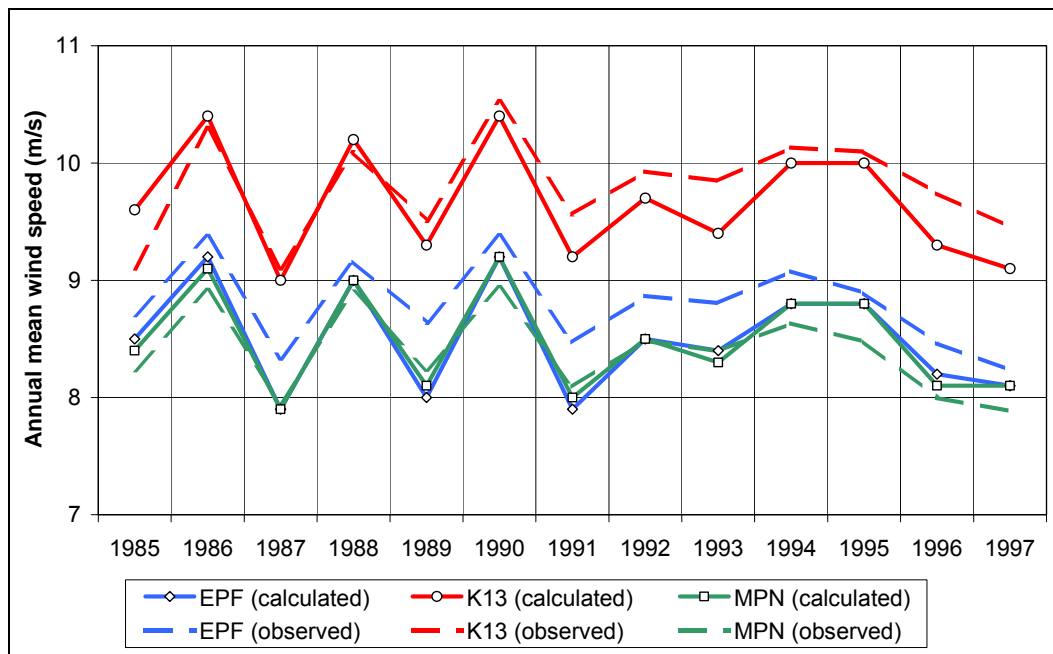


Figure 10.16: Comparison of observed and calculated annual mean wind speeds for three locations of the Measuring Network North Sea.

Looking at the figure the comparison over the years seems fairly good. The figure also shows that the calculated values for EPF and MPN are nearly equal, which is indication for the fact that the model the influence of the land is the same for these two locations.

Figure 10.17 shows the results for the three offshore locations of ZEGE. These are far closer to the shore than those in the previous figure. Furthermore it should be noted that the observations for Vlakte van de Raan are available as of the year 1989.

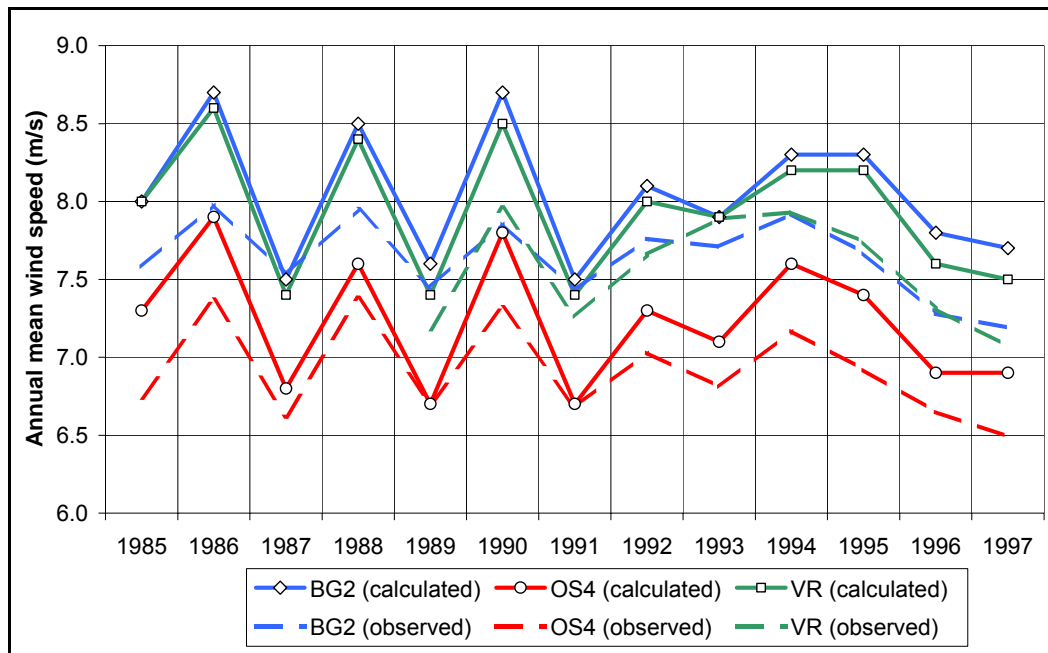


Figure 10.17: Comparison of observed and calculated annual mean wind speeds for three locations of ZEGE.

In this figure the comparison appears to be quite good over the years. In this case the model calculations for VR and BG2 are almost identical, showing the indifference of the model for these locations.

In Table 10.14 the average values over all years have been shown, as well as the ratio of observed vs. calculated mean wind speeds over the whole period. It is shown that the three locations of ZEGE are overestimated by 4-5%, while the three locations further offshore show less deviation. Overall the preliminary conclusion can be that these results are quite satisfactory although the validation will be finalised in the next few months, including a comparison on a monthly scale.

Table 10.14: Overview of observed versus calculated mean wind speeds.

location	EPF	K13	MPN	BG2	OS4	VR
observed mean wind speed (m/s)	8.80	9.80	8.40	7.64	6.91	7.56
calculated mean wind speed (m/s)	8.50	9.66	8.48	8.05	7.23	7.86
observed/calculated	104%	101%	99%	95%	96%	96%

10.2.7 Overall conclusions

In The Netherlands two separate data bases have been acquired containing offshore wind speed observations. The first one, called ZEGE, is a network of simple, relatively low masts specifically located in the province of Zeeland. Three of the masts are located in the North Sea. The advantage of these observations is that they have not been processed in any way, which has been verified. Therefore, the results can be used as reference.

The other data base is called MNZ. This network covers a large part of the North Sea making use of existing structures, like oil- and gas platforms and a light-isle. Therefore the circumstances for good measurements are not ideal, and the anemometer height varies from 20 to 100 m above MSL. Furthermore, the disadvantage of these data is that they have been processed over the years in different ways, making it difficult to reconstruct the original data in order to obtain a consistent time series. However, using the data of ZEGE as reference and with the information from some of the authorities involved a reasonable attempt could be undertaken to understand the different processing steps. In that way a consistent time series could be obtained for the locations of MNZ.

Calculations were made for the respective locations and at the respective anemometers height with the POWER method. Comparison with the observed wind speeds (as well as they could be derived from the originally obtained data) shows fairly good results. For all six points the deviations were less than 5%. Therefore the conclusion is that within the restrictions of this analysis the POWER results are within the range of the observed wind speeds at the 6 locations.

10.3 Denmark

10.3.1 Data source

The POWER WasP modelling results were compared against high quality wind speed profile data collected by ELSAM on purpose-built meteorological masts at two prospective offshore wind farms sites for in Danish waters – Horns Rev and Læsø Syd (see Figure 10.18). These data were gathered over the 12 month period between June 1999 and May 2000.

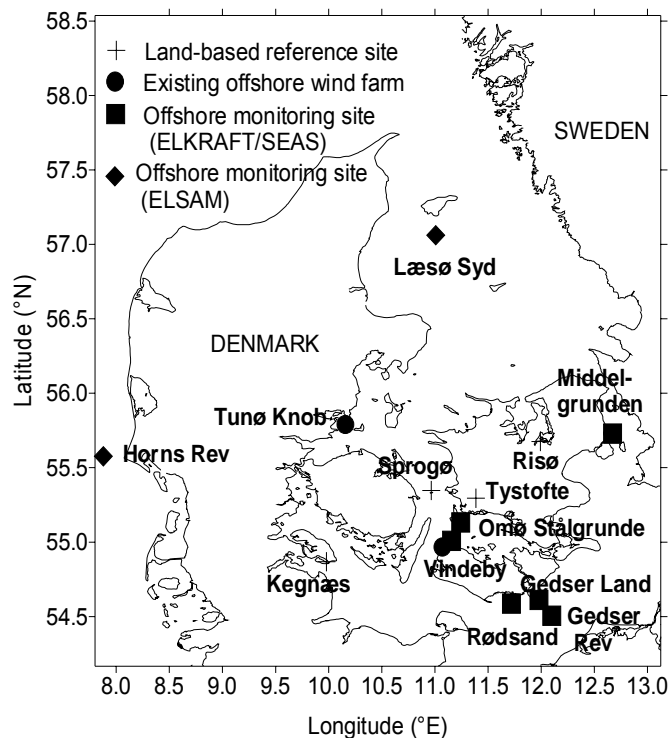


Figure 10.18 – Map showing locations of Horns Rev and Læsø Syd

The ELSAM Horns Rev and Læsø Syd data sets include hourly wind speed measurements at four heights (15m, 30m, 45m and 62m above mean sea level) and wind direction measurements at three heights (28m, 43m and 60m above mean sea level). Note that only one of the POWER prediction heights (30m ASL) coincides exactly with the instrument heights of the observed data.

10.3.2 Wind speeds

Figures 10.19 and 10.20 compare POWER WasP model mean annual wind speed estimates with wind speeds observed at Horns Rev and Læsø Syd respectively.

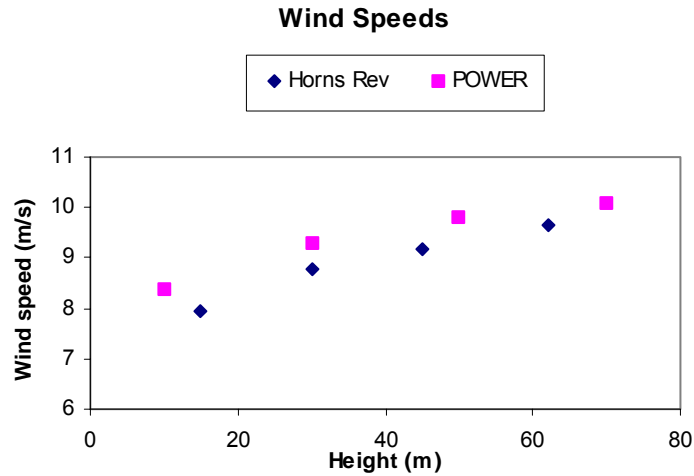


Figure 10.19 – Observed and calculated mean vertical wind speed profile for Horns Rev

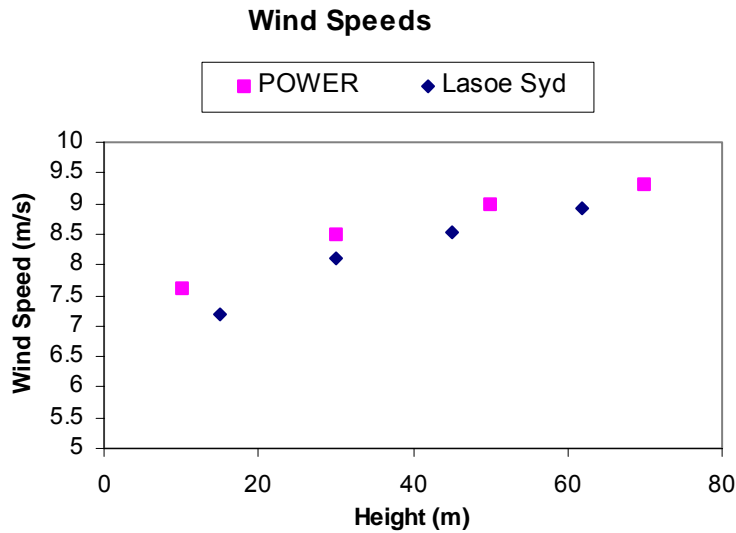


Figure 10.20 – Observed and calculated mean vertical wind speed profile for Læsø Syd

At first sight, these results suggest POWER has overestimated the mean wind speeds at these site by the order of 0.5m/s. However, it must be remembered that the ELSAM Horns Rev/ Læsø Syd observations represent the wind conditions that occurred at these locations during a single 12 month period (June 1999-May 2000), whereas the POWER results represent mean wind speeds over 13 year period (1985-1997). Figures 10.21 and 10.22 show POWER estimates of the inter-annual variation in mean wind speed over this 1985-1997 period at Horns Rev and Læsø Syd respectively. It is clear that from year to year there is significant variation in the mean wind speeds at the sites. Furthermore, the ELSAM Horns Rev/ Læsø Syd observed wind speed values lie within the overall range of mean wind speed values estimated for the sites.

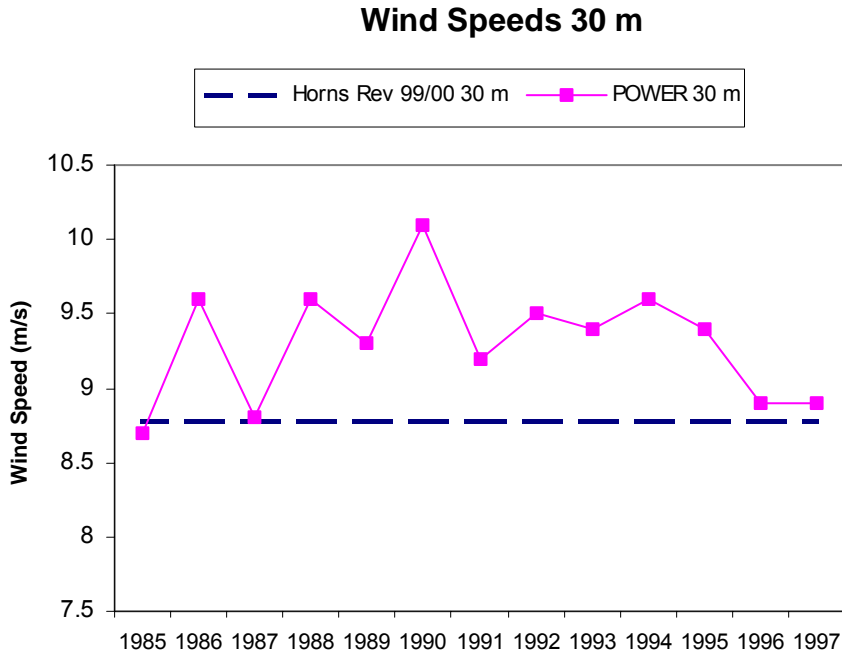


Figure 10.21 – Predicted variation in mean yearly wind speed at 30 m ASL for Horns Rev 1985-97

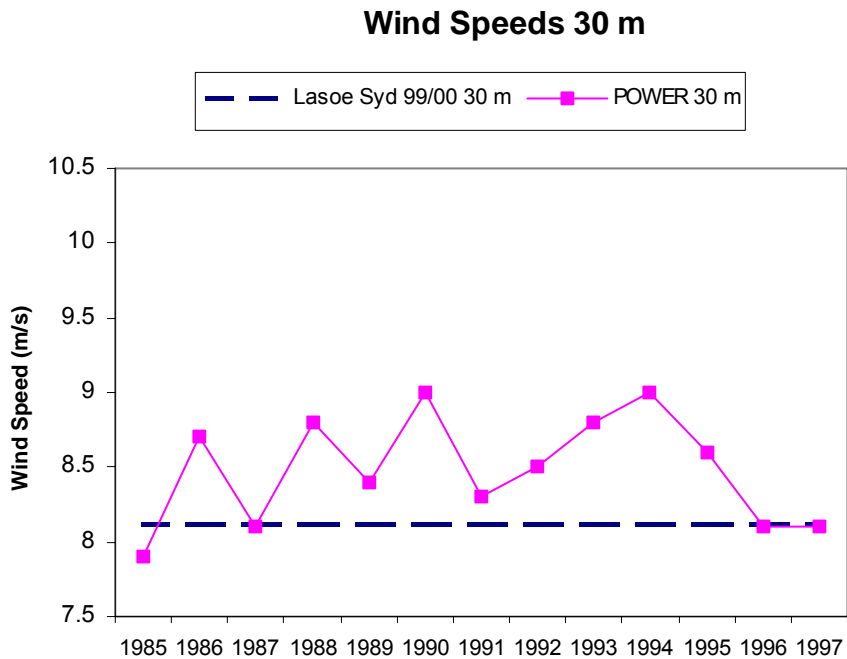


Figure 10.22 – Predicted variation in mean yearly wind speed at 30 m ASL for Læsø Syd 1985-97

10.3.3 Variation in wind speeds through the year

Figures 10.23 and 10.24 compare the observed variation in mean monthly wind speed (for June 1999 to May 2000) with the POWER model estimates for Horns Rev and Læsø Syd. The correlation between the observed and calculated values is good.

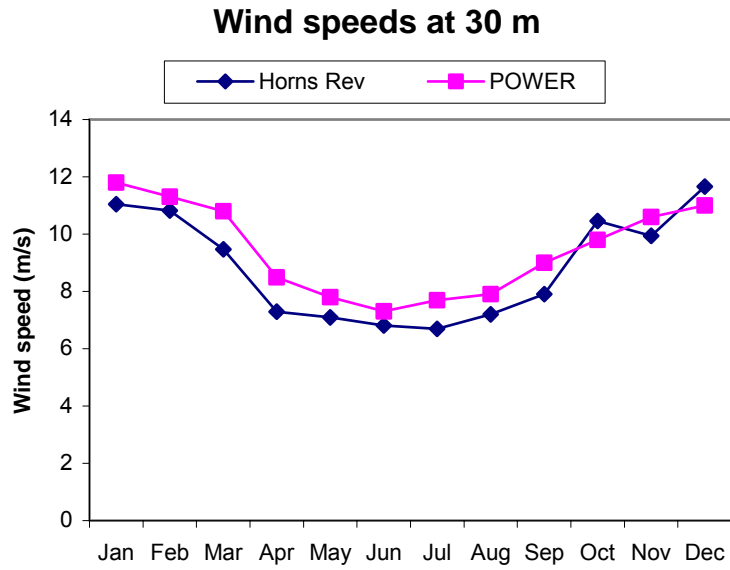


Figure 10.23 – Comparison of observed and calculated monthly variations in wind speed at Horns Rev

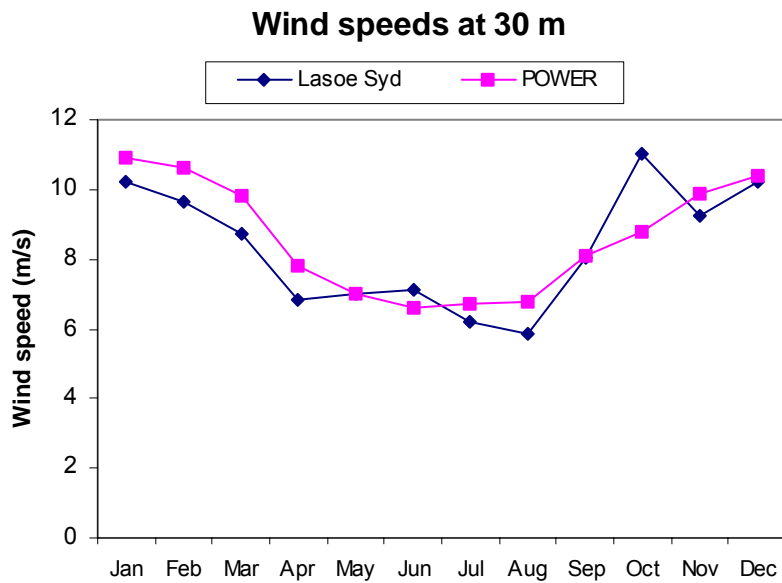


Figure 10.24 – Comparison of observed and calculated monthly variations in wind speed at Læsø Syd

10.3.4 Variation with direction

Figures 10.25 and 10.26 show the observed and calculated wind rose at Horns Rev and Læsø Syd respectively.

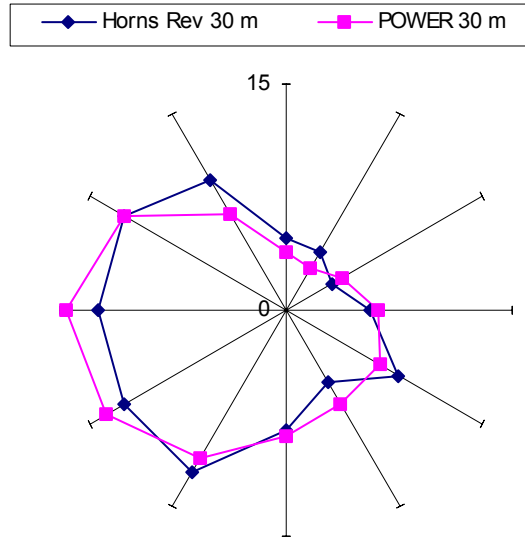


Figure 10.25 – Comparison of observed and calculated wind rose at Horns Rev

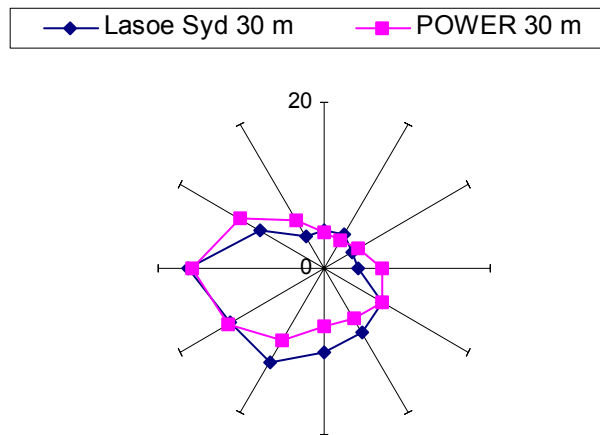


Figure 10.26 – Comparison of observed and calculated wind rose at Læsø Syd

10.3.5 Wind speed distributions

Figures 10.27 and 10.28 show the observed and calculated wind speed distributions at Horns Rev and Læsø Syd respectively.

In both cases, the POWER results seem to have under-estimated the frequency of medium- to low wind speeds, but over-estimated the frequency of high wind speeds

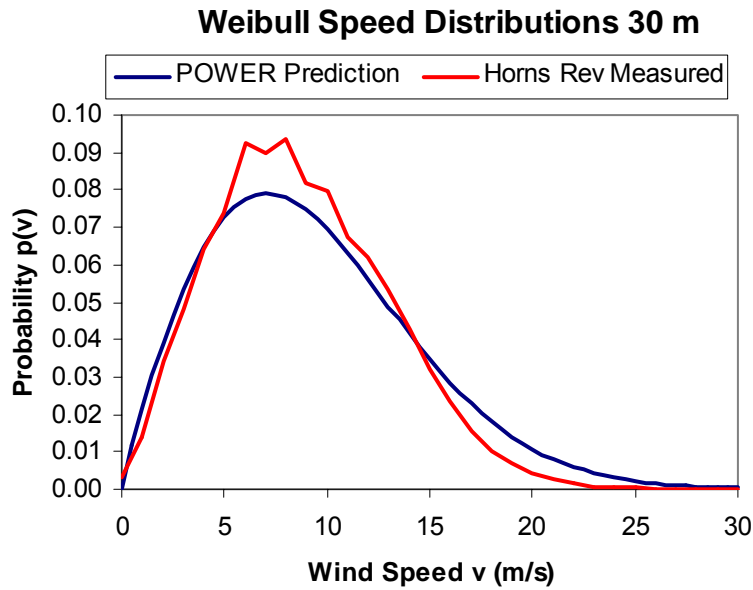


Figure 10.27 – Comparison of observed and calculated wind speed distribution at Horns Rev

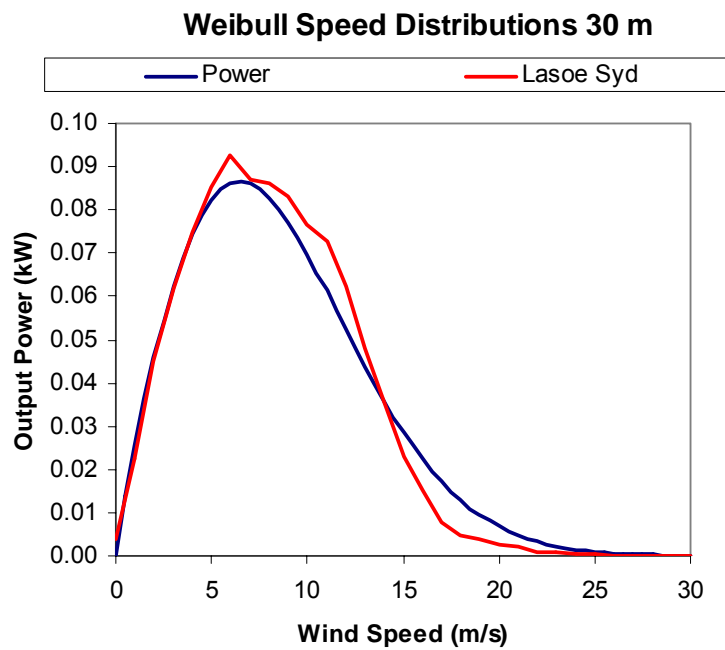


Figure 10.28 – Comparison of observed and calculated wind speed distribution at Læsø Syd

In both cases, the POWER results seem to have under-estimated the frequency of medium to low wind speeds, but over-estimated the frequency of high wind speeds compared to the observations.

10.3.6 Conclusions

Comparison of observed and calculated wind conditions at both of these proposed Danish offshore wind farm sites indicate that the POWER results are a good representation of the typical wind regime for these sites.

10.4 The Mediterranean.

The following paper was presented at the European Wind Energy Conference in Copenhagen in July 2001.

EVALUATION OF METHODS OF ESTIMATING OF WIND ENERGY POTENTIAL OFFSHORE IN MEDITERRANEAN AREAS.

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ABSTRACT: Relatively few studies have been performed on the evaluation of offshore wind resources and mostly in North Europe. In Mediterranean areas the poorness of such studies is mainly linked to three reasons: 1) the difficulty of meteorological monitoring in the deeper waters 2) the complex orography, frequently extending down to the coasts; 3) the sea breezes wind regimes. In the North Adriatic Sea, a shallow basin of the Mediterranean, the first reason is missed, but the other two are challenging enough to make an the effort of evaluating those methods. In the present paper we have estimated estimate the wind climatology at a platform located 16 kilometres offshore of Venice based on 7 years of data and we have compared it with the wind climatology obtained using three different methods based on the long-term data of three coastal meteorological stations: Venezia Tessera, Venezia San Niccolò, Ronchi and Rimini. Furthermore, a Coastal Discontinuity Model (CMD) and a Geostrophic version of the WASP model (Geo WasP) have been tested. We discuss the applicability of those methods and find that WASP is still the best tool for wind climate estimates. The results of the CDM and Geo WasP are promising in view of computer power increase.

Keywords: Off-shore, Coastal sites, Statistical Analysis, Climatic conditions.

1 INTRODUCTION

Relatively few studies have been performed on the evaluation of offshore wind resources and these are mainly concentrated in North Europe. [1], [2], [3]. One reason for this is the additional difficulty of meteorological monitoring in the deeper waters of the Mediterranean. Various methods are available for predicting long-term wind speeds in offshore areas based on long-term data sets from nearby land sites. In this paper, we have chosen three methods that have been used in the evaluation of wind resources at Danish offshore sites and have shown to give promising results there. The used methods rely on long-term measurements at nearby land sites in comparison with short-terms records offshore. The performance of these methods will be evaluated in the North Adriatic area. Here 7 years of hourly data collected on an oceanographic platform 15 Km offshore of Venice and climatological data at four coastal stations (Venezia Tessera, Venezia S. Niccolò, Rimini and Ronchi) are available. Table1 and Figure.1.

Table 1. Location of the stations

Station	Lat. (deg.)	Long. (deg.)	H. asl (m)	H a. (m)	Period
1.Venezia Plat	45.31	12.51	0	15	76-82
2.Venezia Tess.	45.50	12.33	6	10	61-96
3.Venezia S.N.	45.43	12.38	5	10	51-77
4.Rimini	44.03	12.61	13	10	51-96
5.Ronchi	45.61	13.50	17	10	67-96

The main difference between wind climatology of North Europe and Mediterranean coastal areas is that, in the

latter, stability conditions different than neutral and strong see breeze regimes are more frequent. If conditions offshore deviate significantly from near-neutral (either on average or by season), the effect of stability on the wind speed profile can be substantial. These methods are:

1) The standard measure-correlate-predict [3] (MCP) method, which assumes a linear relationship between wind speed at paired sites where one site with a long-term record acts as predictor and the wind speed at short-term measurement sites are the predictand. Once a regression equation has been conditioned based on the measurement overlap period, the regression parameters can then be used to derive an extended data record for the site of interest.

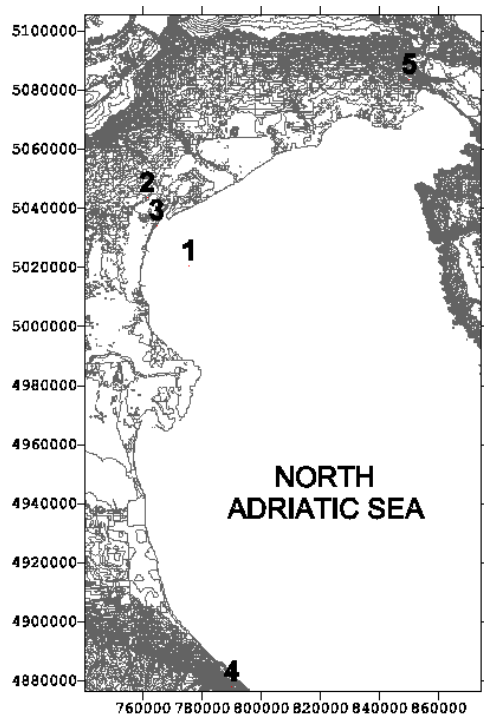


Figure.1. North Adriatic Sea, location of the stations.

This method generally used using one regression for each wind sector. 2) Risø's Wind Atlas Application and Analysis program (WasP7), which calculate the wind climatology in one site from wind climatology of long term representative stations. WASP is a physically-based model and uses the change in heat flux between on- and off-shore to calculate a mean stability correction and the change in roughness to adjust the momentum flux. 3) The Weibull correction method [1] for extrapolating wind data series is based on the concept of modifying the Weibull parameters of the short term data series to characterise a longer data sampling period. It compares sector-based wind speed distributions at the on - and the off-shore site considering the on-shore long-term time series as representative of the area. The Weibull shape (A) and scale (k) factors are determined for 12 sectors at both sites for a common period and the ratio is used to modify the long term wind distribution to represent the off-shore station.

At the Danish sites, MCP tends to under-predict wind speeds in comparison with offshore data. WASP typically gives good results except at sites that are less than five kilometres from the coast where wind speeds are predicted to be a few percent higher than those observed. The Weibull method gives good results provided sufficient data are available to accurately characterise the wind speed distribution in each sector and that the distribution conforms to a Weibull distribution.

Additionally we have used WasP applied to geostrophic wind distributions (Geo WasP) and the Coastal Discontinuity Model (CDM) developed as part of the EC POWER project. WASP runs were conducted for each 0.5 by 0.5 grid of the waters of the European Union and Geostrophic wind speeds and directions are calculated from a sea level pressure data set. WASP predictions were made using geostrophic wind speeds. The CDM works is a slightly different way to WasP. Instead of applying stability and land-sea corrections to the mean wind speed distribution as in WASP, the CDM uses air and sea

temperature, together with the geostrophic wind speed time series to calculate the stability the Monin-Obukhov length parameter for each grid point at each time step (input data are six-hourly). Air and sea temperatures were given for each 1x1° grid. Equilibrium land and sea wind speed profiles are corrected for stability. Finally the program uses the fetch distance to land to determine the internal boundary layer height and interpolates between equilibrium wind speed profiles over land and sea to the fetch distance accounting for the discontinuity caused in the profile by the IBL.

2 DATA AND CLIMATOLOGY

The four selected meteorological stations belong to the Italian Military Meteorological Service. The measurements are taken in integer knots at the synoptic hours (0, 3, 6, 9, 12, 15, 18, 21 GTM). The platform measurements are supplied by the Institute of the Dynamics of Large Masses of the Italian National Council of Research (CNR) in Venice. The platform measurements were hourly with a calm threshold of 2 ms⁻¹. In Table 1, the co-ordinates of the stations, altitude a.s.l (h), the altitude of the anemometers (Ha), and the period of measurements are shown. Data were analysed using WasP7® and WASP Utilities® programmes.

2.1. Climatology of the North-Adriatic coastal areas.

In figure 2a and 2b the mean hourly velocity and the mean monthly velocity are shown respectively for 4 stations. From figure 2a we note that the sea breeze regime produce the effect to enhance the wind speed in the coastal areas and to reduce it at the platform distance in the central part of the day. From figure 2b we notice a maximum of wind speed during the spring and minimum during summer and winter time. The monthly climatology of Rimini is slightly different from the climatology of Venice and Ronchi that are in better agreement.

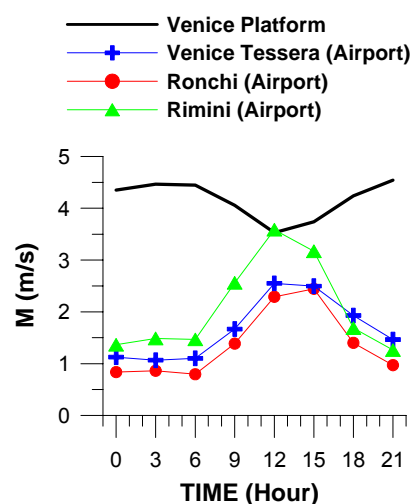


Figure 2a. Mean hourly wind speed.

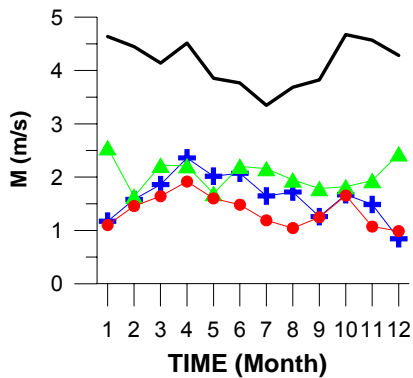


Figure 2b. Mean monthly wind speed. For the legend refer to figure 2a.

3 RESULTS.

We have applied the methodology [1], [2], [3] outlined above, which rely on long-term measurements at the nearby land sites in comparison with short-terms records offshore. The results of the application of the methods and two models are shown below:

1) MCP method. We could not find a satisfying correlation among stations (regression coefficients less than 0.4). This method is not applicable here.

2) WasP 7. Rimini and Ronchi stations are not able to reproduce the platform wind climatology then we focus on the results obtained using Venice Tessera (VT) (figure 3) and Venice San Niccolo' (VSN) (figure 4). There are not overlapping periods between the Platform and VSN. VT has seven years overlapping. Due to the large amounts of calms, (around 40%) in the two stations we have removed them in the estimate of the wind distribution. In WASP the calms are uniformly distributed in the 12 sectors. In a region with large percentage of calms this procedure modify the sector wise frequency distribution especially in the sectors with low percentage. An alternative will be to distribute the calms accordingly to the frequency distribution of the wind speed without calms. Studies in this direction will be performed in stations where calm directions are based to the previous non calm record. In figure 3 and figure 4 the comparison amongst prediction and experimental mean wind speed M and frequency at the platform from VT for 7 years and for 35 years are shown respectively. Using 35 years long term wind distribution improve the prediction but WASP overestimates the mean wind speed. Ratios among prediction and data are between 0.8 and 1.2.

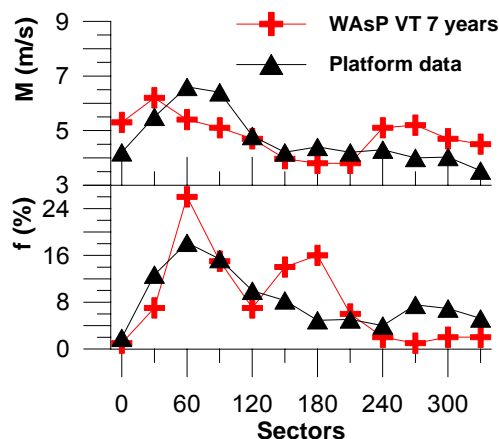


Figure 3. Predicted and experimental wind speed and frequency for each sector using seven years overlapping data from VT.

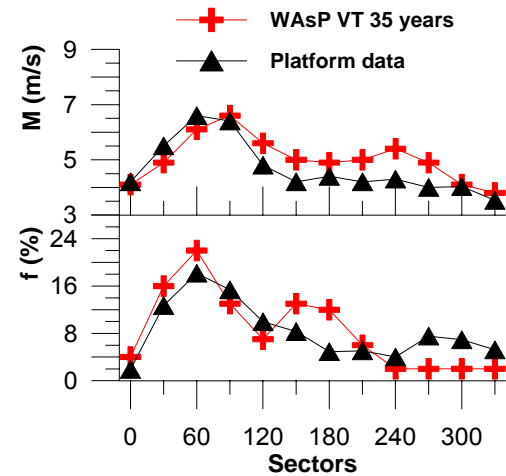


Figure 4. Predicted and experimental wind speed and frequency for each sector, using 35 years data from VT.

In figure 5 the prediction of mean wind speed and frequency at the platform from VSN are shown. Frequency are in better agreement than VT 35 years especially in the sea sectors. However, VSN underpredict the mean wind speed in the sea sector. Generally WASP underestimates the wind at the platform in the sea sectors and overestimate in the land sectors.

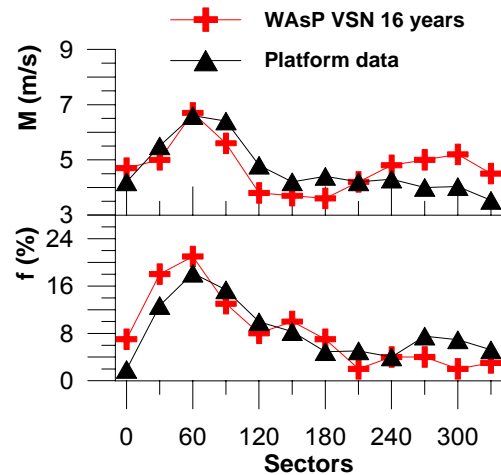


Figure 5. Predicted and experimental wind speed and frequency for each sectors using Venice S. N. 3)

The Weibull correction method. This method has been applied using the 7 years overlapping time series of VT and correcting the 35 years A and K wind distribution of VT. The results are shown in figure 6. The method reproduce well the frequency in all sectors except two. The reasons are under investigation.

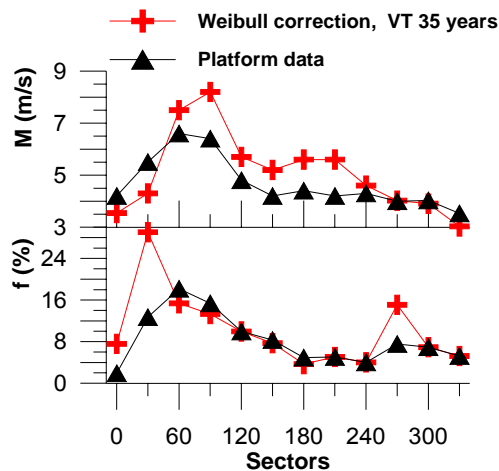


Figure 6. Predicted and experimental wind speed and frequency for each sector, using the Weibull method.

4) The CDM. The sector wise M and frequency obtained from the model, compared to the experimental one are shown in Figure 6. The model overestimate M but the results are promising. The frequency distribution is in agreement with the experimental one. In figure 6 the monthly average wind speed from the model is compared to the experimental averages at the platform. The two curves are in agreement showing a minimum in the summer months but the average wind speed from CDM is overestimated, especially in winter.

5) The Geo WAsP. Concerning the Geo WAsP model the results presented here are at 10 m height while the platform is at 15 m. The sector wise M and frequency obtained from the model, compared to the experimental one are shown in Figure 7. Both M and frequency distribution are in agreement with the experimental one.

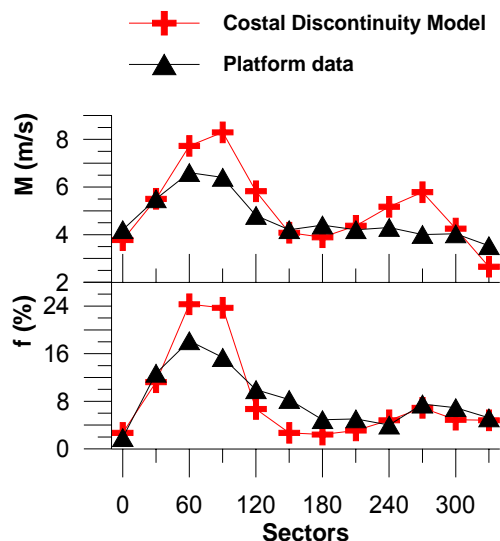


Figure 6. Predicted and experimental wind speed and frequency for each sector, using CDM model.

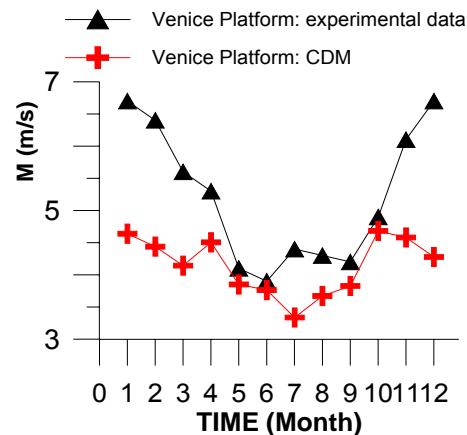


Figure 7. Comparison between Monthly mean wind speed from CDM and experimental values.

4 FINAL REMARKS.

We have applied three empirical methods used in North Europe to estimate climatology offshore by long-term data sets from nearby land sites. The major problems in our Mediterranean study area are: the large amount of calms whose distribution sector wise deserve a proper study and the local wind regimes as sea breeze that influence strongly the wind distribution. Because of the latter problem it is not possible to use long term time series located in a different sea breeze regime as Ronchi and Rimini. Furthermore although for $u > 4 \text{ m}^{-1}$, a small correlation could be found, it is not possible to apply the CMP method as a whole. The methods based on WAsP (WAsP and Geo WAsP) are found to give the best results provided that the predictor station lay in an area with similar local circulations. Also the CDM shows promising results.

In table 2 the ratios between predicted and experimental mean wind speeds are reported for the CMD Model, the Geo WasP Model, the WasP model considering Venice Tesserà 35 years (WAsP VT 35) and 7 years (WAsP VT 7) time series, the WasP model considering Venice SN, and finally the Weibull correction method applied to VT at 35 years.

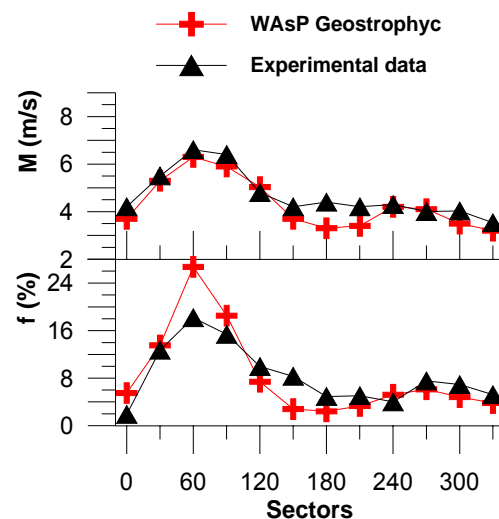


Figure 8. Predicted and experimental wind speed and frequency for each sector, using Geo WAsP.

Table 2. Ratios between mean wind speed M at the platform M_{plat} and predicted values from VT and VSN and applying the different methods M_{pred} .

Method	M(m/s)	A(m/s)	k	Mplat/Mpred
Platform	4.6	5.5	1.28	1.00
CDM	6.3			0.73
Geo WAsP	5.2	5.6	1.33	0.88
WAsP VT 35	5.4	6.1	1.69	0.85
WAsP VT 7	4.11	4.57	1.53	1.12
WAsP VSN	5.1	5.7	1.66	0.90
Weib corr VT35	5.1			0.90

5 ACKNOWLEDGEMENTS

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10.5 Comparison with a previous EU study

An earlier EU study (JOUR0072 : Study of offshore wind energy in the European Community, led by GERMANISCHER LLOYD AG and Garrad Hassan and Partners Ltd) had presented long term wind speed data (mean, Weibull parameters, shear profile) in an IDRISI database. Garrad Hassan and Partners Ltd kindly provided a copy of this database to enable a comparison with the POWER results to be made – hereafter the database will be referred to as the GLGH database. However, before such a comparison could be made two factors had to be taken into account : a) the heights at which wind speed was estimated was different in the two studies, therefore the 50m and 70m POWER wind speeds being interpolated (assuming a logarithmic drag law) to obtain 60m values which could be compared with the GLGH values; b) the GLGH and POWER databases had used different geographical grids – it was therefore decided to restrict the comparison to those points which were nearly co-incident (this was defined as those points whose maximum separation was 2.15 km). There were 1276 such grid points. The comparison was carried out by GLGH sea area with the following results :

Sea Area (GLGH dataset name)	No. of Points	Mean Absolute Error	Root Mean Square error	Correlation Coefficient
		(m/s)	(m/s)	
Belgium & Netherlands (be_nl)	45	0.513	0.968	0.395
Denmark & Germany (de_dk)	94	1.218	1.615	0.722
Spain & Portugal (es_pt)	195	-0.541	0.967	0.637
France, Atlantic (f_atl)	129	-0.034	0.689	0.475
France, Mediterranean (f_med)	72	-0.643	1.022	0.579
Great Britain, North (gb_n)	120	1.421	1.630	0.528
Great Britain, South (gb_s)	103	0.442	0.807	0.446
Greece (gr)	188	-0.055	1.365	0.129
Eire (ie)	75	0.984	1.205	0.391
Italy, North (it_n)	105	0.109	1.019	-0.109
Italy, South (it_s)	150	-0.279	0.813	0.11
Weighted average :		0.181	1.098	0.377
Total :	1276			

10.6 References for Chapter 10

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