ECN-RX--04-132

WIND RESOURCE IN THE DUTCH PART OF THE NORTH SEA

A.J. Brand

T. Hegberg

This paper has been presented at the European Wind Energy Conference,

London, 22-25 November, 2004

NOVEMBER 2004

Wind resource in the Dutch part of the North Sea

A.J. Brand and T. Hegberg
ECN Wind Energy, PO Box 1, NL 1755 ZG Petten

Abstract

A wind resource map of the Dutch part of the North Sea was made. Impressions of the mean wind speed, the wind speed distribution, the wind direction distribution, the turbulence intensity and the stability class at 60 meter above sea level are presented. The 99% confidence interval for the measured wind speed ranges from (U_{map} - 0.5) m/s to (U_{map} + 0.2) m/s, where U_{map} is the wind speed according to the map.

Key words: Wind atlas, Offshore, North Sea

1. Introduction

The Dutch government aims at 6 gigawatt offshore wind power by the year 2020. Dutch offshore wind energy will be developed in the Dutch part of the North Sea, also known as the Netherlands Exclusive Economic Zone (NEEZ). To date two sites are being developed: NSW Egmond and Q7-WP.

The wind speed at turbine hub height is the primary parameter that determines the energy production. State-of-the-art offshore hub height is 60 meter, but it may increase to 150 meter within five to ten years. Maps with the average wind speed between 60 and 150 meter above mean sea level therefore contain information for a rough estimate of the average energy production. For a realistic production estimate and for design purposes more detailed information is needed: the distribution of the wind speed and the wind direction (site selection or farm design), and the distributions of the turbulence intensity and of stability class (turbine design).

Current wind resource maps of the North Sea are based on observations from a small number of meteo stations [1][2][3][4][5]. Consequently these maps lack detail and their quality can not be assessed. Nevertheless sites in the Dutch part of the North Sea are mainly developed on basis of these rough maps.

A new wind resource map of the Dutch part of the North Sea is made by combining data from:

- The numerical weather prediction model Hirlam, and
- The meteorological stations at the North Sea [6].

This innovative approach, a variation to the Numerical Wind Atlas method [7], gives a realistic map because:

- The resource map is geographically detailed, and
- The observed data is used to validate rather than create the map.

The map contains:

- A detailed grid (2.5 to 10 kilometer),
- Four heights (60, 90, 120 and 150 meter above mean sea level),
- The wind speed and direction distribution, and
- The turbulence intensity and the stability class.

Like all wind resource maps the new map gives a description of the past (period 1997 to 2002 in this case) but gives only an indication of the future.

This paper presents the methods that were used in order to create the wind resource map of the Dutch part of the North Sea (section 2), an impression of the map (section 3), and the validation of the wind speed in the map (section 4).

2. Method

2.1 Overview

The method is built up of five steps:

1) A medium term period and a representative year are selected.
2) The wind speed, the wind direction, the shear stress and the stability length in the representative year are calculated.
3) The accuracy of the calculated wind speed in the representative year is determined.
4) The mean wind speed in the medium term period is calculated by applying a two layer model.
5) The turbulence intensity and the stability class in the representative year are determined.

2.2 Selection of medium term period and representative year

In the Dutch part of the North Sea measured wind data is available from six offshore meteo stations in the form of the potential wind speed [6]. (The potential wind speed is a fictitious measured wind speed at a height of 10 m, with a surface roughness length of 0.2 mm, and assuming a neutral wind speed profile [5].) Figure 1 shows the location of these meteo stations.

Figure 1

The periods with valid data are presented in Table 1 [8]. The common period is from 1997 to 2002. This period of 6 years therefore is selected as the medium term period.

Table 1

Meteo station	Period
K13 Alpha	1990 - 2002
Meetpost Noordwijk	1990 - 2002
Europlatform	1990 - 2002
Lichteiland Goeree	1993 - 2002
Oosterschelde	1982 - 2002
Vlakte v.d. Raan	1997 - 2002

In general the wind speed distribution over a year is not equal to the wind speed distribution over a longer period. As an example Table 2 shows the annual variation for the station K13 Alpha [8]. (In this table the distribution of the potential wind speed is expressed in the scale parameter A and the shape parameter k of the Weibull distribution.) Nevertheless the year 2002 could be selected as the year with a wind speed distribution that represents the distribution over the longer period 1997-2002 [8].

Table 2

Year	A [m/s]	k [-]
1997	8.55	2.14
1998	9.43	2.41
1999	9.19	2.14
2000	9.02	2.03
2001	8.67	2.22
2002	9.01	2.21
1997 - 2002	8.98	2.19

2.3 Calculation of wind speed, wind direction, shear stress and stability length in the representative year 2002

The wind speed, the wind direction, the shear stress and the stability length in the representative year 2002 are calculated from Hirlam output, at:

1) The anemometer heights of the offshore meteo stations, and
2) Four fixed heights (60 m, 90 m, 120 m and 150 m) in a grid covering the North Sea.

Hirlam (High Resolution Limited Area Model) is a numerical weather prediction model operated by KNMI. It gives hourly values of the ten-minute averages of the two wind speed components, the temperature and the pressure at (in this case) two heights and in a course grid. From these data in a grid point first the shear stress and the stability length and next the wind speed at the given height are calculated. To this end the Bussinger-Dyer profiles and the Charnock roughness length are applied. Subsequently the shear stress, the stability length and the wind speed components in the location are calculated by interpolating between the four adjacent grid points.

2.4 Accuracy of the calculated wind speed in the representative year 2002

Since measured wind speed is available in the form of the potential wind speed, the only way to establish the accuracy of the calculated wind speed is to reduce it into the potential wind speed. Table 3 contains the mean and the standard deviation of the potential wind speed as measured and as calculated for the 6 offshore meteo stations.

Table 3

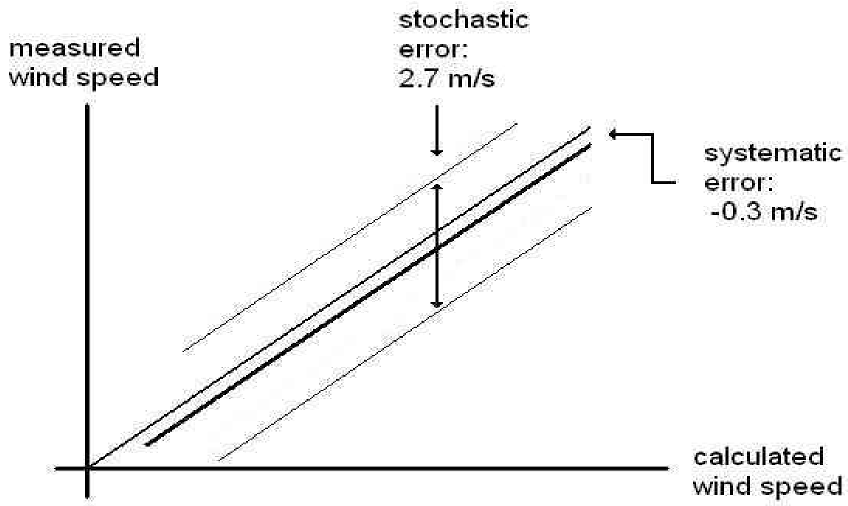
	Potential wind speed [m/s] (2002)			
Meteo station	Measured Average	Calculated Average	Measured St.Deviation	Calculated St.Deviation
K13 Alpha	8.0	8.1	3.8	4.5
Meetpost Noordwijk	7.4	7.9	3.6	4.7
Europlatform	7.8	8.0	3.7	4.7
Lichteiland Goeree	7.6	7.5	3.6	4.3
Oosterschelde	7.4	8.2	3.5	4.8
Vlakte v.d. Raan	7.5	7.6	3.6	4.2

Now we define the error in a calculated value as the difference between the measured and the calculated value. From table 3 it follows that:

- The systematic error in the potential wind speed ranges between the meteo stations from -0.8 m/s to +0.1 m/s, with a mean of -0.3 m/s, and
- The stochastic error in the potential wind speed ranges between the stations from 2.2 m/s to 3.3 m/s, with a mean of 2.7 m/s.

This means that averaged over all wind speeds in the year 2002 the calculated potential wind speed is 0.3 m/s larger than the measured potential wind speed. A given calculated potential wind speed however differs from the measured one, with a standard deviation of 2.7 m/s. This is shown in figure 2.

Figure 2

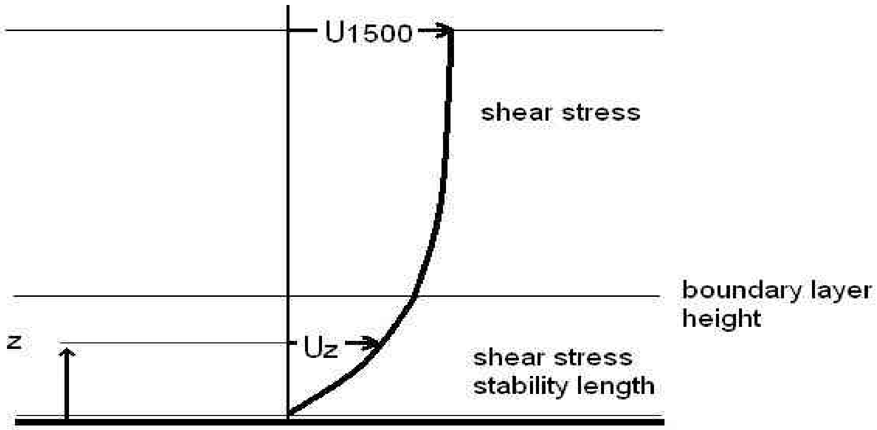


From the small systematic error in the calculated potential wind speed we conclude that the mean of the calculated wind speed is a realistic estimate for the mean of the measured wind speed. On the other hand, because of the large stochastic error in the calculated potential wind speed, the standard deviation of the calculated wind speed must be compensated for this stochastic error in order to get a realistic estimate for the standard deviation of the measured wind speed.

2.5 Two-layer model: mean values of boundary layer parameters and mean wind speeds in the medium term period 1997-2002

Mean values of the wind speed at 1500 m, the shear stress and the stability length are determined from the mean calculated wind speed at 60 m, 90 m, 120 m and 150 m in the grid covering the North Sea. To this end a two-layer model for the mean wind speed is used, with a mean velocity profile that is slightly stable in the lower layer. The two-layer model, which was developed for this porpose, is shown in figure 3.

Figure 3



The mean wind speed U_z at height z is given by:

$U_z = U_{1500} + (u_* / \bullet) (\ln(z / z_{1500}) - 5 (z - h) / L)$ for $z_0 \bullet z \bullet h$,

and

$U_z = U_{1500} + (u_* / \bullet) \ln(z / z_{1500})$ for $h \bullet z \bullet z_{1500}$,

where U_{1500} is the wind speed at a height of 1500 m, u_* is the shear stress and L is the stability length. The parameter h is the boundary layer height, which depends on the shear stress u_* and the latitude $\bullet$:

$h = u_* / f'$,

with $f' = 2 \bullet \sin(\bullet) \exp(A)$, where $\bullet = 7.27\ 10^{-5}$ 1/s (angular velocity of earth rotation) and A = 1.9 (a constant).

Subsequently, the mean wind speed is calculated at:

- Four fixed heights (60 m, 90 m, 120 m and 150 m) in a fine grid in order to create the wind maps.
- The anemometer heights of the six offshore meteo stations, in order to establish the accuracy of the wind maps.

To this end the two-layer model is applied to the mean values of the wind speed at 1500 m, the shear stress and the stability length.

An impression of the map with the mean wind speed at 60 m in the period 1997-2002 is presented in section 3.1. The accuracy of the wind maps is addressed in section 4.

2.6 Turbulence intensity and stability class in the representative year

The turbulence intensity I is derived from the shear stress u_* by using [5]: $I = 2.5\ u_*$.

Seven stability classes are defined on basis of the inverse stability length 1/L; see Table 4.

Table 4:

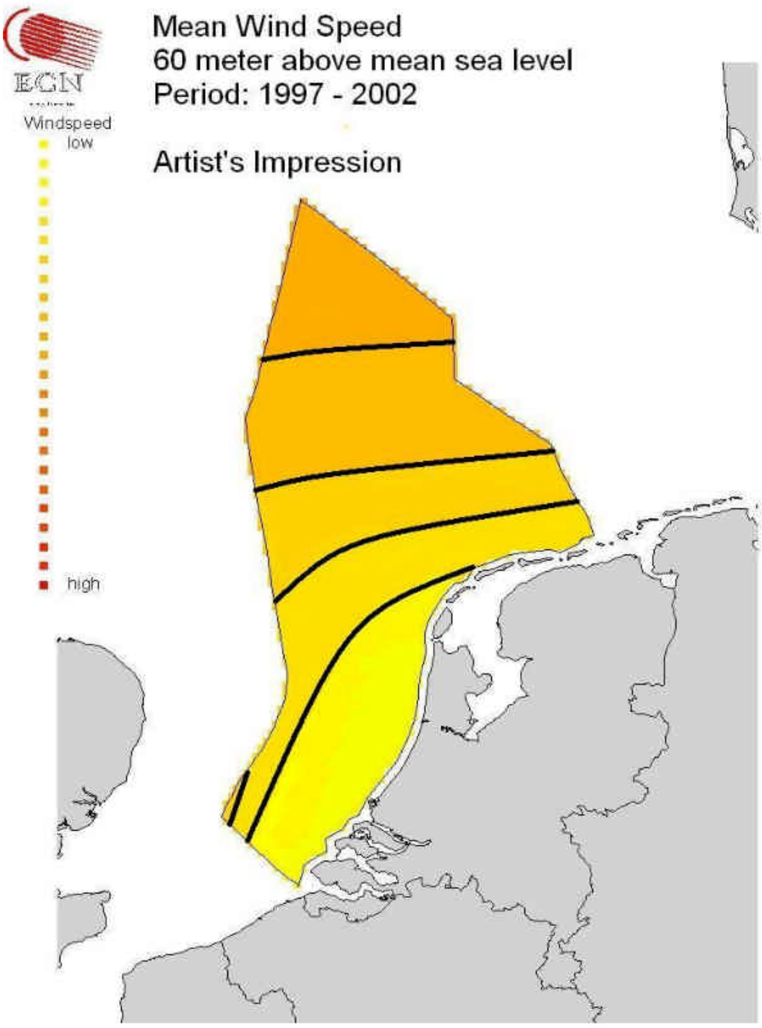
Inverse stability length [1/m]	Stability class
1/L • -0.01	very unstable
-0.01 < 1/L • -0.001	unstable
-0.001 < 1/L • -0.0001	slightly unstable
-0.0001 < 1/L • 0.0001	neutral
0.0001 < 1/L • 0.001	slightly stable
0.001 < 1/L • 0.01	stable
1/L > 0.01	very stable

3. Wind resource map

3.1 Mean wind speed

Figure 4 presents an impression of the map with the mean wind speed a 60 m in the period 1997-2002.

Figure 4



3.2 Wind speed distribution and wind direction distribution

Table 5 presents an impression of the distributions of the wind speed and the wind direction at a height of 60 m. The frequency gives the relative occurrence. The variation coefficient is the ratio of the average and the standard deviation of the wind speed.

Table 5

	Wind direction sector [deg]											
	-15-+15	15-45	45-75	75-135	105-135	135-175	175-205	205-235	235-265	265-295	295-315	315-345
Frequency [%]	6	5	5	7	7	8	12	15	12	10	7	6
Variation coefficient [-]	0.41	0.27	0.23	0.36	0.32	0.33	0.37	0.36	0.39	0.40	0.42	0.30

3.3 Turbulence intensity and stability class

Table 6 presents an impression of the turbulence intensity at a height of 60 m.

Table 6

	Turbulence intensity [m/s]									
	0.00-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1.00-1.25	1.25-1.50	1.50-1.75	1.75-2.00	2.25-2.50	>2.50
Frequency [%]	7	17	27	21	13	7	5	2	1	0

Table 7 presents an impression of the stability class distribution.

Table 7

	Stability class						
	very unstable	unstable	slightly unstable	neutral	slightly stable	stable	very stable
Frequency [%]	35	23	7	2	5	25	3

4 Validation: Accuracy of mean calculated wind speed medium term period

The accuracy of the mean wind speed according to the map in the medium term period 1997-2002 is determined by comparing it to the mean wind speed as measured in the offshore meteo stations. Again, both the calculated and the measured wind speed are reduced to the potential wind speed. The result is presented in Table 4.

Table 4

	Average potential wind speed [m/s] (1997-2002)	
Meteo station	Measured	Map
K13 Alpha	8.1	8.2
Meetpost Noordwijk	7.5	7.5
Europlatform	7.8	7.8
Lichteiland Goeree	7.6	7.7
Oosterschelde	7.3	7.8
Vlakte v.d. Raan	7.3	7.6

This table shows that the difference between the measured potential wind speed and the potential wind speed according to the map is between -0.5 m/s and 0.0 m/s. This corresponds to a 99% confidence interval for the measured potential wind speed that ranges from (U_{map} - 0.5) m/s to (U_{map} + 0.2) m/s, where U_{map} is the potential wind speed according to the map.

5. Summary

A wind resource map of the Dutch part of the North Sea was made by combining data from two sources: the numerical weather prediction model Hirlam and the meteorological stations at the North Sea. The method consists of five steps:

1) The medium term period 1997-2002 and the representative year 2002 are selected.
2) The wind speed, the wind direction, the shear stress and the stability length in the year 2002 are calculated.
3) The accuracy of the calculated wind speed in the year 2002 is determined.
4) The mean wind speed in the period 1997-2002 is calculated by applying a two-layer model.
5) The turbulence intensity and the stability class in the year 2002 are determined.

Impressions of the mean wind speed, the wind speed distribution, the wind direction distribution, the turbulence intensity and the stability class at 60 meter above sea level are presented. (The real data can be obtained from ECN.) The 99% confidence interval for the measured wind speed ranges from (U_{map} - 0.5) m/s to (U_{map} + 0.2) m/s, where U_{map} is the wind speed according to the map.

Acknowledgements

The project Offshore Wind Atlas of ECN is supported by the Programme "Duurzame Energie in Nederland" as operated by SenterNovem for the Dutch Ministry of Economic Affairs.

The observed potential wind data and the roughness map of the Netherlands originate from the project Hydra of Koninklijk Nederlands Meteorologisch Instituut KNMI.

The Hirlam data is obtained from KNMI under agreement 2001/265 for the daily delivery of meteorological data.

References

1. J.W. Cleijne et al., 1991, Description of the North Sea wind climate for offshore wind energy applications, TNO Environmental and Energy Research
2. Michealsen et al., 1998, Climate of the North Sea, DWD, ISBN 3-88148-370-5
3. C.G. Korevaar, 1990, North Sea climate based on observations from ships and lightvessels, Kluwer Academic Publishers, ISBN 0-7923-0664-3
4. R.R. Nino and P.J. Eecen, 2002, Zones with similar wind regimes at the North Sea, ECN Wind Energy, Report ECN-Wind Memo-02-011
5. J. Wieringa & P.J. Rijkoort, 1983, Windklimaat van Nederland, Staatsuitgeverij 's Gravenhage, ISBN 90 12 04466 9
6. A. Smits et al., 1998-2003, KNMI project Hydra: Wind climate assessment of the Netherlands, www.knmi.nl/samenw/hydra
7. L. Landberg et al., 2003, Wind resource estimation - An overview, Wind Energy 6 (3), p. 261
8. T. Hegberg, 2003, Bruikbaarheid van windgegevens van meteorologische waarnemingsstations, ECN Wind Energy, Report ECN-C- -03-094