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Reference wind speed anomaly over the Dutch part of the North Sea

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Abstract This work presents the reference wind speed at heights between 60 and 150 meter over the Dutch part of the North Sea, as determined by using the Gumbel-Bergström method in combination with wind statistics from the Offshore Wind Atlas of the Dutch part of the North Sea. Reference wind speed is the extreme 10 minute average wind speed at turbine hub height with a recurrence period of 50 years.

Key words Extreme wind speed, Offshore wind energy, North Sea

1. Introduction

To date sites in the Dutch part of the North Sea are evaluated for wind farm development. According to the standard IEC61400-3 site assessment must include the reference wind speed [1], which is the extreme 10 minute average wind speed at turbine hub height with a recurrence period of 50 years. The recurrence period is the average time lapse between exceeding events.

In this paper reference wind speeds over the Dutch part of the North Sea are presented, as obtained by employing the Gumbel-Bergström method in combination with wind speed statistics from the Offshore Wind Atlas of the Dutch part of the North Sea. First, section 2 gives an overview of previous information on reference wind speeds over the Dutch part of the North Sea. Next, the methodology is described in section 3 and the reference wind speeds are discussed in section 4. Finally, the conclusions are presented in section 5.

2. Previous information on the reference wind speed

Korevaar obtained climatological data of the North Sea by processing weather observations made by ships and lightvessels [2, section 3.8.5]. These data include the extreme wind speeds at a height of 20 m above the sea surface with a recurrence period of 50 years at the positions of four lightvesssels (table 1), and the same for one-degree squares of the North Sea (table 2). Korevaar concludes that the highest extreme wind speeds occur in the centre of the northern part of the North Sea, and that the extreme values decrease towards the coast and the south. In addition table 1 presents the reference wind speed at four heights between 60 m and 150 m, as extrapolated from the observation height h_{obs} of 20 m by using a neutral wind speed profile:

$$\frac{V_{ref}(h)}{V_{ref}(h_{obs})} = \frac{\ln \frac{h}{z_0}}{\ln \frac{h_{obs}}{z_0}}$$

and a value of 2 mm for the surface roughness length z_0 of water.

Verkaik et al. published wind speeds over the Netherlands with recurrence periods between six months and ten thousand years, as valid at a standard height (10 m) and for a standard surface roughness (2 mm over water) [3]. To this end they developed a statistical method which evaluates observed wind speeds [4]. Table 3 shows the reference wind speeds for some meteo stations in the North Sea. From these data it is concluded that the extreme wind speeds increase from south to north, and from the coast to open sea. Table 3 also shows the reference wind speeds at heights between 60 m and 150 m as extrapolated by using the neutral logarithmic wind speed profile.

The geographical trends in the reference wind speeds published by Korevaar and Verkaik are in agreement. The published values on the other hand can not be compared directly because of the difference in the observation heights. When extrapolated to the same height, for example 60 m, the values published by Verkaik et al. are found to be 4-5 m/s smaller than those by Korevaar.

Table 1: Reference wind speeds as observed at a height of 20 m over the sea surface (source: [2, p. 24]), and as extrapolated to heights between 60 m and 150 m

Station			**Period**	**Reference wind speed [m/s]**				
	Longitude East	**Latitude North**		**Based on observation at height**	**Extrapolated from observation to height**			
				20 m	**60 m**	**90 m**	**120 m**	**150 m**
LS Terschellingerbank	**05°08'**	**53°29'**	**1949-1975**	33.5	37.5	39.0	40.0	40.8
LS Texel	**04°22'**	**53°01'**	**1949-1977**	33.5	37.5	39.0	40.0	40.8
LS Noord Hinder	**02°34'**	**51°39'**	**1953-1980**	32.5	36.4	37.8	38.8	39.6
LS Goeree	**03°40'**	**51°56'**	**1949-1970**	32.0	35.8	37.2	38.2	39.0

Table 2: Reference wind speeds at a height of 20 m above the sea surface as derived from observations (source: [2, p. 95])

Reference wind speed [m/s] at 20 m	**Longitude East [deg]**				
Latitude North [deg]	**2.5**	**3.5**	**4.5**	**5.5**	**6.5**
55.5	33.5	33.5	33.0		
54.5	33.5	32.0	33.5	32.5	31.5
53.5	34.0	32.0	31.5	32.0	27.5
52.5	31.5	31.0	29.5		
51.5	28.5	30.0			

Table 3: Reference wind speeds at a height of 10 m above the sea surface normalized to a surface roughness length of 2 mm as derived from observations (source: [3]), and as extrapolated to heights between 60 m and 150 m

Station			**Period**	**Reference wind speed [m/s]**				
	Longitude East	**Latitude North**		**Based on observation at height**	**Extrapolated from observation to height**			
				10 m	**60 m**	**90 m**	**120 m**	**150 m**
K13	**03°13'**	**53°13'**	**1980-2003**	30.2	36.6	38.0	39.0	39.8
Meetpost Noordwijk	**04°18'**	**52°16'**	**1990-2003**	26.2	31.7	33.0	33.8	34,5
Europlatform	**03°17'**	**52°00'**	**1983-2003**	27.5	33.3	34.6	35.5	36.2
LE Goeree	**03°40'**	**51°55'**	**1974-2003**	26.5	31.7	33.0	33.8	34.5
Oosterschelde	**03°37'**	**51°46'**	**1982-2003**	25.9	31.3	32.6	33.5	34.1

3. Methodology

3.1 Overview

The reference wind speed is determined by employing the Gumbel-Bergström method [5] in combination with wind speed statistics from the Offshore Wind Atlas of the Dutch part of the North Sea [6]. First brief introductions to the Gumbel-Bergström method and the Offshore Wind Atlas are presented (sub-sections 3.2 and 3.3). Next follows the calculation method (sub-section 3.4).

3.2 Gumbel-Bergström method

In the Gumbel-Bergström method it is recognized that the Weibull distribution $F_W(V)$ of wind speed V

$$F_W(V) = 1 - \exp\left(-\left(\frac{V}{A}\right)^k\right)$$

is the parent distribution of extreme wind speed, where $F_W(V)$ is the probability that a wind speed is smaller than V given the scale parameter A and the shape parameter k. This implies that if the distribution of wind speed at a site is known in terms of the two Weibull parameters A and k, the distribution $F_G(V_e)$ of extreme wind speed V_e

$$F_G(V_e) = \exp(-\exp(-\alpha(V_e - \beta)))$$

at that site is known in terms of the two Gumbel parameters α and β provided that the number of independent wind speeds is known. The reference wind speed follows in a straightforward way. More detailed descriptions are available in the literature [5][7].

3.3 Offshore Wind Atlas of the Dutch part of the North Sea

The Offshore Wind Atlas of the Dutch part of the North Sea is a numerical wind atlas based on data from the atmospheric model HiRLAM of KNMI. It was validated on basis of wind data measured in offshore and coastal meteorological stations. It contains the average wind speed at four heights between 60 and 150 meter on a horizontal resolution of 0.05x0.05 deg^2, and the wind speed standard deviation at the same heights in five locations. More detailed descriptions are available in the literature [6][8].

3.4 Calculation method

In the Gumbel-Bergström method the reference wind speed V_{ref} is [7, section 4.1 in part 5]:

$$V_{ref} = \beta - \frac{1}{\alpha}\ln(-\ln(F_{e,Vref})) \text{ with } F_{e,Vfref} = 0.98,$$

where the modal value β and the inverse dispersion factor α are the parameters of the Gumbel distribution of extreme wind speed.

The modal value β and the dispersion factor 1/α are given by:

$$\beta = A(\ln M)^{\frac{1}{k}} \text{ and } \frac{1}{\alpha} = \frac{A}{k}(\ln M)^{\frac{1}{k}-1},$$

where the scale factor A and the shape factor k are the parameters of the parent Weibull distribution of wind speed and M is the number of independent wind speeds.

The scale factor A and the shape factor k are calculated from the wind speed statistics [6, chapter 6] by using:

$$\left(\frac{s}{m}\right)^2 = \frac{\Gamma\left(1+\frac{2}{k}\right)}{\Gamma^2\left(1+\frac{1}{k}\right)} - 1 \text{ and } \frac{A}{m} = \frac{1}{\Gamma\left(1+\frac{1}{k}\right)},$$

where s is the standard deviation of the wind speed in a given period and m is the average wind speed in that period; $\Gamma(.)$ indicates the Gamma function.

The number of independent wind speeds M is estimated from:

$$M = \nu_M T$$

with $v_M = 7.3\ 10^{-4}$ Hz (frequency of independent observations) [5] and $T = 3.2\ 10^7$ s (observation period of in this case one year).

In this approach a variation Δm in the average wind speed is found to have a small but opposite impact ΔV_{ref} on the reference wind speed: $\Delta V_{ref} \sim -\Delta m$. The impact of a variation Δs in the wind speed standard deviation is found to be much larger: $\Delta V_{ref} \sim 10\Delta s$.

4. Reference wind speeds

In this section reference wind speeds are discussed as obtained with the method described in sub-section 3.4. These reference wind speeds are valid at the heights of 60, 90, 120 and 150 m above sea level in the period 1997-2002.

The highest reference wind speeds are found to occur near the coast, and the reference wind speed decreases towards the west and the north. This is in contrast to the information published by Korevaar [2] and Verkaik et al. [3], where highest values occur in the north of the region and the extreme values decrease towards the coast and the south (see section 2). Apart from this, the reference wind speeds are 2-3 m/s higher than the values extrapolated from Korevaar's data.

An explanation of this anomaly is found in the underlying averages m and standard deviations s of the wind speed. As expected the highest average wind speed occurs in the north of the region. The averages decrease towards the south and reach the lowest values near the coast. The highest wind speed standard deviation is found north of the Waddeneilanden, and decreases weakly along the coast towards the south and strongly towards the west. Recalling that the wind speed standard deviation is a measure of the variability of the wind speed, this is in agreement with the notion that the greater the distance from the shore the smaller the variability of the wind speed.

The resulting map of the Weibull scale parameter A qualitatively corresponds to the map of the average wind speed m in the sense that the highest value of A occurs in the north of the region, whereas A decreases towards the south and reaches the lowest values near the coast. The resulting map of the Weibull scale parameter k has a different structure in the sense that the minimum value of 2.0 is found along the coast, it rapidly reaches the value 2.2 at a small distance from the coast and increases further with distance from the coast until a maximum value of about 2.5 is reached in the north of the region.

Together the values of A and k collaborate to produce the value of the reference wind speed V_{ref}, where, recalling from section 2, the value of V_{ref} roughly is proportional to A for a fixed value of k but the actual value of V_{ref} is higher the lower k is. As a result near the coast the generally lower value of A in combination with the lower value of k yield a large value of V_{ref}, and vice versa in the north of the region.

5. Conclusions

Reference wind speeds over the Dutch part of the North Sea have been determined by employing the Gumbel-Bergström method in combination with wind speed statistics from the Offshore Wind Atlas of the Dutch part of the North Sea. An anomaly in the so determined reference wind speeds is found in the sense that the highest extreme values occur near the coast, and the extreme values decrease towards the west and the north. This has to do with the near coastal regions in the Offshore Wind Atlas having a much lower wind speed variability than the regions in the north.

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Abstract

- Reference wind speed over the Dutch part of the North Sea has been determined by using the Gumbel-Bergström method and wind data from the Offshore Wind Atlas.
- An anomaly in the so determined reference wind speeds is found.
- This anomaly is caused by the near coastal regions in the Offshore Wind Atlas having a much lower wind speed variability than the regions in the north.

Objectives

- To date sites in the Dutch part of the North Sea are evaluated for wind farm development.
- According to the standard IEC61400-3 site assessment must include the reference wind speed, which is the extreme 10 minute average wind speed at turbine hub height with a recurrence period of 50 years.

Method

- Gumbel-Bergström reference wind speed from Weibull A and k

$$V_{ref} = \beta - \frac{1}{\alpha}\ln(-\ln(0.98))$$

$$\beta = A\left(\ln(v_M T)\right)^{\frac{1}{k}}$$

$$\frac{1}{\alpha} = \frac{A}{k}\left(\ln(v_M T)\right)^{\frac{1}{k}-1}$$

- Weibull A and k from st.dev. s and mean m in Offshore Wind Atlas

$$\frac{\Gamma\left(1+\frac{2}{k}\right)}{\Gamma^2\left(1+\frac{1}{k}\right)} = \left(\frac{s}{m}\right)^2 + 1$$

$$A = \frac{m}{\Gamma\left(1+\frac{1}{k}\right)}$$

Results

Anomaly

- The highest reference wind speeds are found to occur near the coast, and the reference wind speed is found to decrease towards the west and the north.
- This is in contrast to published information where highest reference wind speeds occur in the north of the region and the values decrease towards the coast and the south.
- Apart from this, the reference wind speeds are found to be 2-3 m/s higher than the values extrapolated from published data.

Explanation

- As expected the highest average wind speed is found far offshore in the north. The averages decrease towards the south and reach the lowest values near the coast.
- The highest wind speed standard deviation is found north of the Waddeneilanden, and decreases weakly along the coast towards the south and strongly towards the west. This is in agreement with the notion that the greater the distance from the shore the smaller the variability of the wind speed.
- The resulting map of the Weibull scale parameter A qualitatively corresponds to the map of the average wind speed in the sense that the highest value occurs in the north of the region, whereas it decreases towards the south and reaches the lowest values near the coast.
- The resulting map of the Weibull scale parameter k has a different structure in the sense that the minimum value of 2.0 is found along the coast, it rapidly reaches the value 2.2 at a small distance from the coast and increases further with distance from the coast until a maximum value of about 2.5 is reached in the north of the region.
- Together the values of A and k collaborate to produce the reference wind speed, where the value roughly is proportional to A for a fixed value of k but the actual value is higher the lower k is. As a result near the coast the generally lower value of A in combination with the lower value of k yield a large value of the reference wind speed, and vice versa in the north of the region.

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Summary and Conclusions

- Reference wind speeds over the Dutch part of the North Sea have been determined by employing the Gumbel-Bergström method in combination with wind speed statistics from the Offshore Wind Atlas of the Dutch part of the North Sea.
- An anomaly in the so determined reference wind speeds is found in the sense that the highest extreme values occur near the coast, and the extreme values decrease towards the west and the north.
- The anomaly in the so determined reference wind speed is caused by the near coastal regions in the Offshore Wind Atlas having a much lower wind speed variability than the regions in the north.