Norwegian University of Science and Technology

Faculty of Engineering Science and Technology
Department of Energy and Process Engineering

EPT-P-2014-117

NTNU

PROJECT WORK

for

student Ingunn Sletvold Øistad

Autumn 2014

Site analysis of the Titran Met-masts

Site-analyse av Met-master på Titran

Background and objective

The wind measuring station at Titran, Frøya, offers an opportunity for measuring characteristic of both "on-shore" wind and "off-shore" wind – depending on the wind direction. The shortest distance to the shore is about 300 meter when the wind direction is southerly thus enabling Off-shore wind to be measured for heights above about 30 meters.

The wind measuring station has two 100 meter high met-masts equipped with ultrasonic anemometers. Measurements have been done for several years such that there exist a considerable data-bank of time-series of wind data.

For the evaluation of the usefulness of the met-masts there is a need to do a Site analysis of the wind measuring station, in order to distinguish measured wind parameters as representative for either On-shore or Off-shore wind. Another purpose for the Site analysis is for evaluating the site for a certification (by DNV-GL) as a reference for Ocean observation buoys (wind, waves and sea current) that can be tested in the vicinity of the wind station.

The Site evaluation shall be done following the "MEASNET 2009 – Evaluation of site-specific wind conditions" standard. MEASNET is a network international measurement institutes, which have been established to harmonise wind energy-related measurement procedures.

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The project work comprises 15 ECTS credits.

The work shall be edited as a scientific report, including a table of contents, a summary in Norwegian, conclusion, an index of literature etc. When writing the report, the candidate must emphasise a clearly arranged and well-written text. To facilitate the reading of the report, it is important that references for corresponding text, tables and figures are clearly stated both places.

By the evaluation of the work the following will be greatly emphasised: The results should be thoroughly treated, presented in clearly arranged tables and/or graphics and discussed in detail.

The candidate is responsible for keeping contact with the subject teacher and teaching supervisors.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

According to "Utfyllende regler til studieforskriften for teknologistudiet/sivilingeniørstudiet ved NTNU" § 20, the Department of Energy and Process Engineering reserves all rights to use the results and data for lectures, research and future publications.

The report shall be submitted to the department in 3 complete, bound copies.

An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

Submission deadline: *December 19, 2014.*

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
X☐ Field work

Department for Energy and Process Engineering, 22 November 2014.

Olav Bolland	Lars Sætran
Department Head	Supervisor

Co-Supervisor(s): Lars M Bardal

Sammendrag

Dette arbeidet er gjort i forbindelse med en prosjektoppgave på Norges teknisk-naturvitenskapelige universitet (NTNU) og inneholder en site-analyse som beskriver vindforholdene på Titran, Frøya. Hensikten med arbeidet er å karakterisere og evaluere de målte vindparametrene og vurdere om de er representative for ”on-shore” eller ”off-shore” vind, altså vind på eller utenfor kysten.

Site-analysen har blitt utarbeidet i tråd med retningslinjer gitt av MEASNET (Measuring Network of Wind Energy Institutes), som er et internasjonalt nettverk for vindmåleinstitutter. Data med tidsserier for de målte parametrene er presentert og vurdert, og det er gjort en site-inspeksjon for å kartlegge omkringliggende og topografiske forhold. Aktuelle bilder og tabeller er gitt i appendiks, og avvik fra retningslinjene er gitt i et eget avsnitt.

For å kunne vurdere og forutsi langtids vindforhold på Titran er målinger fra en regional værstasjon på Sula, som ligger omkring 20 kilometer nord for Titran, blitt evaluert. Programvare for vindanalyse har blitt benyttet for å vurdere vinddata fra Titran og sammenligne dem med langtidsdata. Det ble funnet en sammenheng mellom vindmålingene for de to lokasjonene, som indikerer at data fra værstasjonen på Sula kan bli brukt for å forutsi forholdene på Titran. En korrelasjon for en overlappende toårsperiode ble benyttet for å ekstrapolere målingene fra Titran til en 15-årsperiode med tilgjengelig data fra værstasjonen på Sula.

Executive summary

This report provides an analysis of the site-specific wind conditions at Titran, Frøya. The work is conducted as a student project thesis at the Norwegian University of Science and Technology (NTNU) with the purpose of characterising the measured wind parameters and evaluating the representativeness for "on-shore" or "off-shore" wind, i.e. wind conditions on or outside the coast.

The site analysis has been performed following a guideline for wind-site evaluations, carried out by MEASNET (Measuring Network of Wind Energy Institutes). Data containing time series of measured wind parameters are presented and evaluated, and a site inspection has been carried out. Relevant photos and tables are given in the appendices, and deviations from the guideline are provided in a separate section.

In order to assess long-term wind conditions at Titran, data from a regional met station located at Sula, approximately 20 kilometres north of Titran, have been evaluated. Wind analysis software has been used to assess the on-site measurements and to compare them to the long-term data. It was found a corresponding correlation between the two locations, meaning that data from the met station may be utilised to predict the wind conditions at Titran. A relationship for a concurrent two-year period was used to extrapolate the on-site measurements to a 15-year period, for which data from Sula met station are available.

Contents

Appendix

1 Introduction

Skipheia wind measuring station at Titran contains two 100 meter met masts providing data collected by ultrasonic anemometers. The site is located at the west end of Frøya, which is exposed to winds both from the Norwegian Sea and the mainland. It is therefore of interest to evaluate the usefulness of the measurements, in order to characterise the wind conditions as representative for "on-shore" and "off-shore" wind, depending on the wind direction. In addition, it is desired to evaluate the site for a certification as a reference station for ocean observation buoys measuring wind, waves and sea current.

This work contains a site-analysis of the wind measuring station in accordance with a guideline provided by the Measuring Network of Wind Energy Institutes (MEASNET). Wind data for a two-year period are presented and evaluated, and compared to long-term data from a regional weather station. In the end, the long-term data are used for extrapolation of the on-site short-term measurements to a period of 15 years.

2 Project information and input data

2.1 Site description

The site was inspected on October the 14th, 2014, and is located on the coast of Mid-Norway, more specifically at the west end of the island Frøya. The measurement station is found at Skipheia, near the village of Titran, approximately 110 kilometres in linear distance from Trondheim. Depending on the orientation, the distance from the measurement location to the shoreline varies from 300 meters to around three kilometres. In a narrow section northeast the distance to the shoreline is approximately 20 kilometres. Maps showing the location of the test site are given in Figure 1, Figure 2 and in Appendix A.

Depending on the wind direction, the test site is exposed to both land breezes and maritime winds, and is hence providing characteristics for both “on-shore” and “off-shore” wind conditions, where “on-shore” means on the shore and “off-shore” means outside the shore. As seen from the contour lines in Figure 2, the landscape is relatively flat. The vegetation present is mainly heather and moss, and there are no trees. There are also no nearby obstacles which are assumed to influence the wind measurements. The local topography is typically characterised by small hills with an intermediate distance of 100-500 meters [1] [2]. Larger-scale maps and photo documentation of the site are found in Appendix A.

The wind measurement station is containing three masts, as shown in Figure 2. Masts 2 and 4 are 100 meters high, whereas Mast 3 is 45 meters. Both 100 meter masts are equipped with ultrasonic anemometers, but in the present work, Mast 2 is the only one considered. It is located on the geographical coordinates 63.66638N and 8.34251E, approximately 20 meters above sea level. A more thorough description of the mast will be given in section 2.2. Figure 3 indicates how the three masts are positioned relative to each other, showing intermediate distances and orientations.

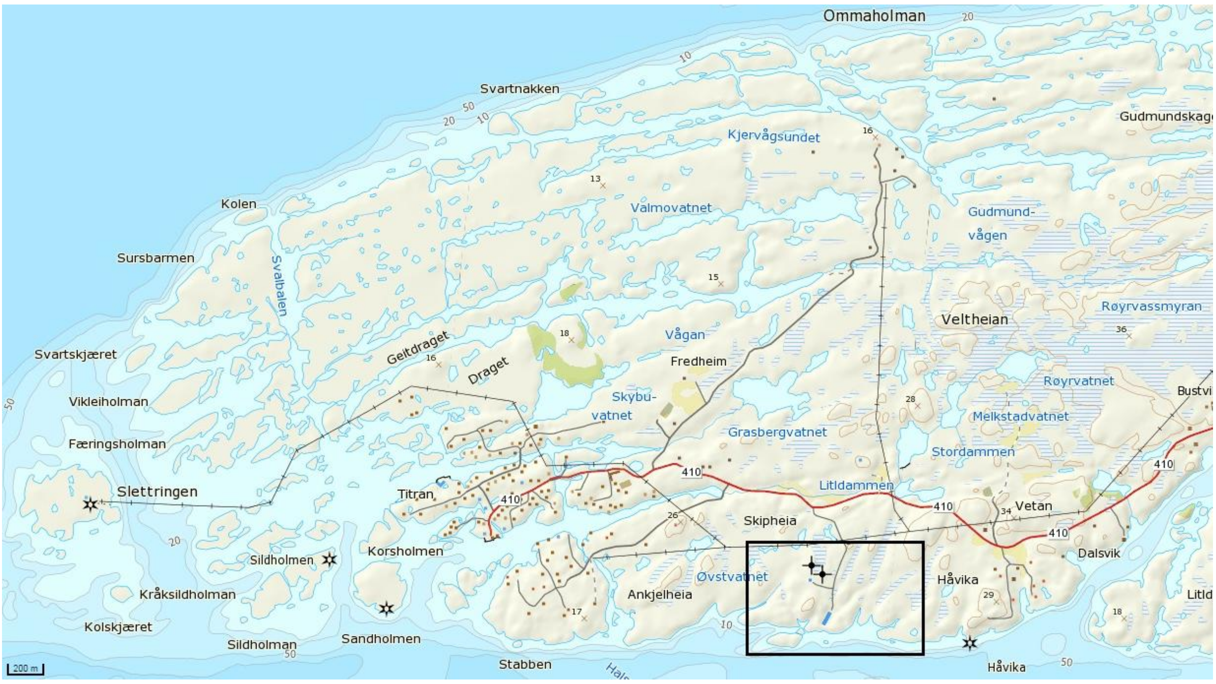

Figure 1 Map of the western part of Frøya

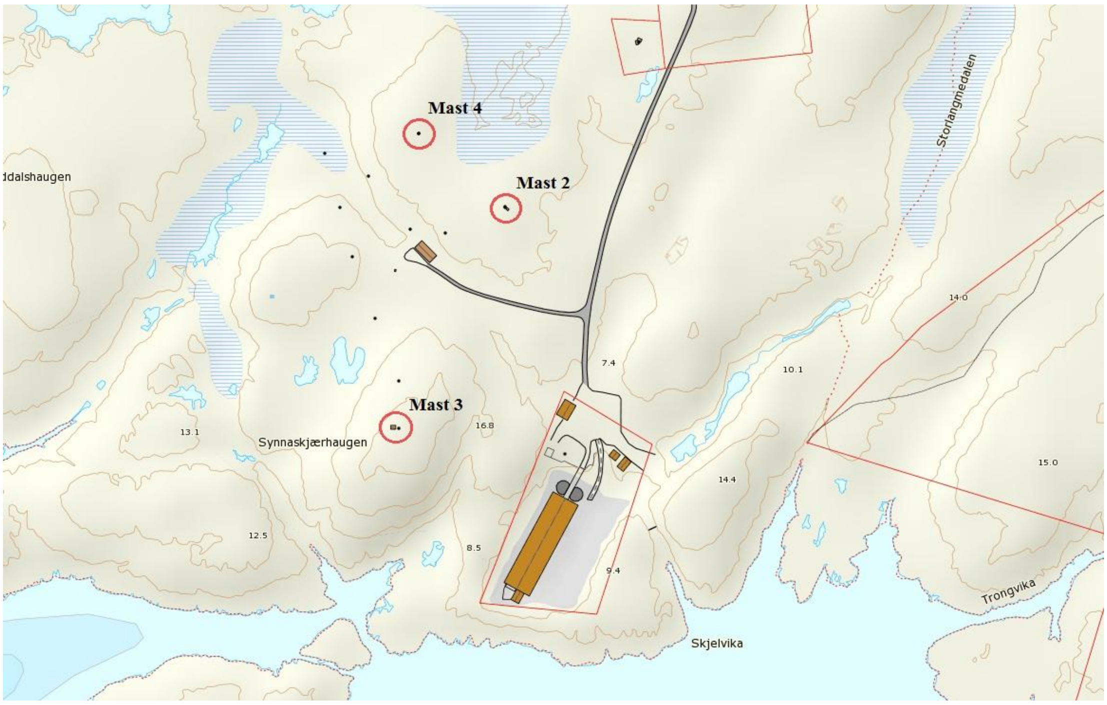

Figure 2 Map with contour lines and mast positions

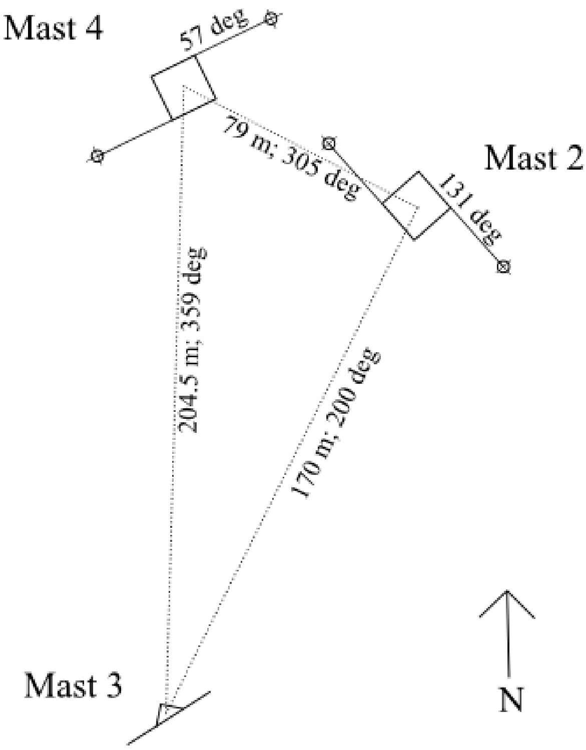

Figure 3 Mast positions and orientations

2.2 Meteorological input data

Here the meteorological input data relevant for the site analysis are presented. The evaluation is mainly based on the short-term onsite measurement data, which is described thoroughly in section 2.2.1. In addition, long-term data from a regional weather station are considered to help assess the long-term onsite wind conditions. These data are presented in section 2.2.2. Table 1 gives an overview of the relevant meteorological data.

Data source	Data type	Distance from Skipheia station; Longitude, latitude	Available time period	Sampling frequency
Mast 2, Skipheia	Short-term onsite measurement	– ; 63.66638N, 8.34251E	2009-11-18 – 2014-09-30	10 min. averages
Sula weather station	Long-term regional weather measurement	~21 km (linear distance); 63.8467N, 8.4667E	1975 – 2014	Varying; from values every six hours to every hour

Table 1 Overview of meteorological input data

2.2.1 Wind measurement at Skipheia measurement station

The relevant measurements of Mast 2 at Skipheia started on the 18th of November 2009 and are still ongoing. At the time of this assessment, slightly less than 58 months of data were available, spanning the period 2009-11-18 – 2014-09-30. However, due to significant recurring gaps in the data coverage of the second half of the time period, only the first half of the data is considered in the current analysis. In order to avoid seasonal biasing of data and results, the evaluated time period is reduced to two full years, from 2009-11-18 until 2011-11-17.

Mast 2 at Skipheia station was raised in 1980 and has since 1981 been equipped with various wind measuring instruments, e.g. cup anemometers and wind vanes. Today six pairs of Gill WindObserver II 2D ultrasonic anemometers are installed on the mast all together, at heights of 10, 16, 25, 40, 70 and 100 meters, respectively. In addition, one Campell Scientific 109 temperature probe is mounted at each height, as well as at two meters above ground level near the mast. A Lambrecht rain sensor is used to measure the precipitation, and a Campbell Scientific CR3000 Micrologger is logging the data.

The mast is supported by guy wires, and the measurement equipment is installed and managed by qualified staff from NTNU. Table 2 gives an overview of the ultrasonic anemometers installed on the mast, and the mean availabilities for the entire available time period (2009-11-18 – 2014-09-30). "Geographical orientation" gives the orientation of the anemometer booms relative to the geographical north (i.e. 0°), and "Southeast" and "Northwest" mean 131° and 311°, respectively. The orientation of the booms can also be seen in Figure 4. The serial numbers of the respective anemometers are not known.

Short name	Geographical orientation	Logger channel	Height above ground [m]	Mean availability
UA1	Southeast	1	10	99.8
UA2	Northwest	2	10	88.6
UA3	Southeast	3	16	97.2
UA4	Northwest	4	16	84.5
UA5	Southeast	5	25	99.8
UA6	Northwest	6	25	99.8
UA7	Southeast	7	40	99.8
UA8	Northwest	8	40	84.1
UA9	Southeast	9	70	74.6
UA10	Northwest	10	70	99.7
UA11	Southeast	11	100	99.8
UA12	Northwest	12	100	99.8

Table 2 Anemometer properties

The anemometers are mounted on square-cross-sectional booms reaching 2.5 meters out from the tower, which has a quadratic climbable lattice shape and a ground surface area of 1 m^2. Figure 4 shows a sketch of the mast including principle dimensions of the tower and the instrument mounting fixtures. In addition to the orientation of the booms, there is a displacement between the geographic north and the anemometer north of 221°. The red arrows in Figure 4 show the northerly directions on the anemometers, pointing southwest (221°) and northeast (41°), respectively. Information regarding mast, boom and anemometer directions was provided by NTNU and was to some extent verified during the site inspection. A summary of the measurement features of the mast is given in Table 3, and photo documentation of the mast is found in Appendix A.

Mast features – Mast 2 Skipheia	
Mast coordinates	63.66638N, 8.34251E Altitude: 20 meters above sea level
Time period with available data	2009-11-18 – 2014-09-30
Sensor types	Gill WindObserver II ultrasonic anemometers (12 pcs) Campell Scientific 109 temperature probe (7 pcs)
Data logging system	Data logger: Campbell Scientific CR3000 Micrologger Averaging period: 10 minutes Sampling rate: 1 Hz
Mast type	Climbable lattice tower (1x1 m^2), 100 meters

Table 3 Mast features

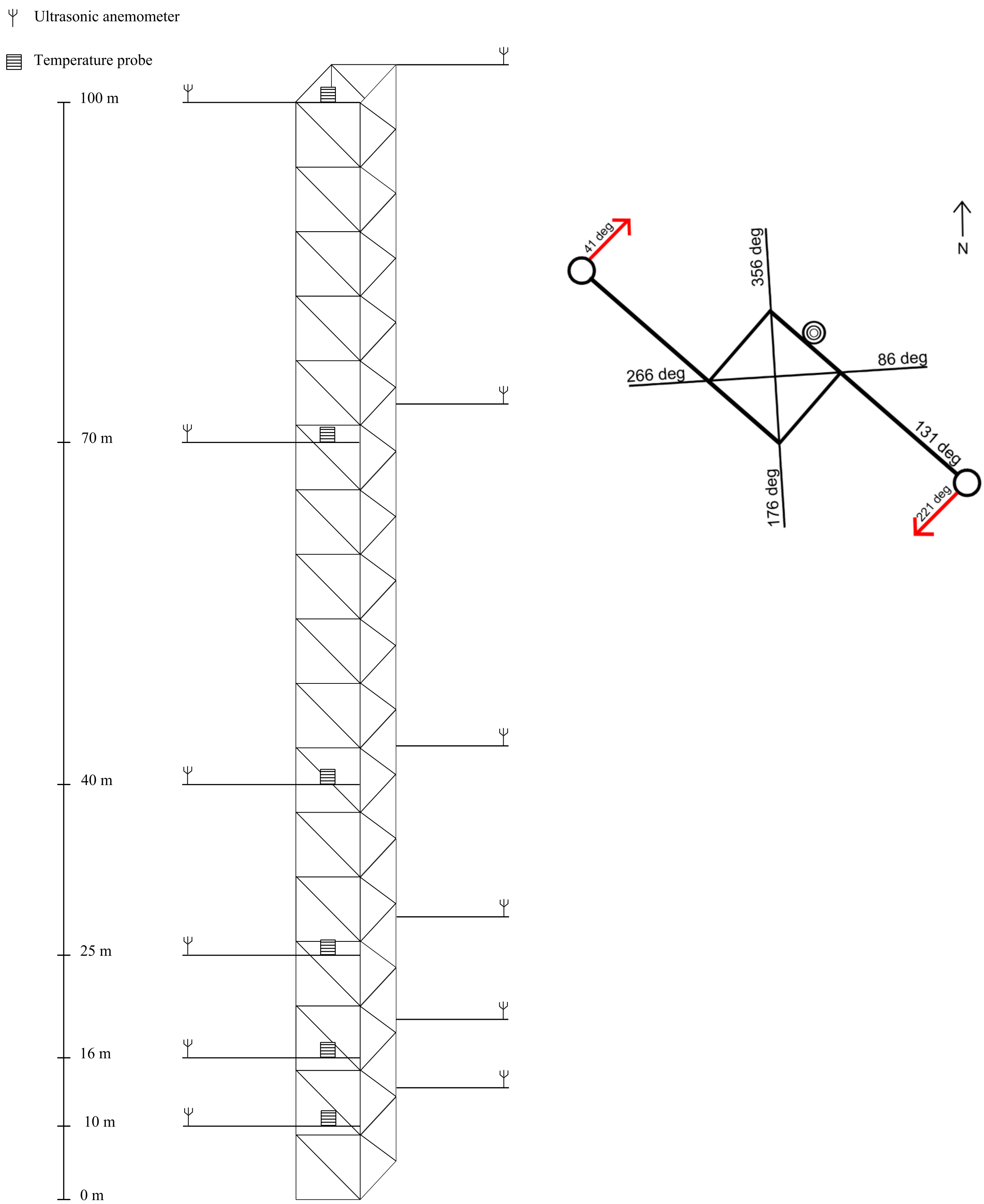

Figure 4 Left: Sketch of Mast 2 with anemometers and temperature sensors (see Figure A6)
Right: Top view of mast showing anemometers, temperature sensor and directions

According to the MEASNET guideline [3], a log book containing all important events during the measurement period shall be included in the site analysis. During the measurement period of almost five years, there have been power supply problems, equipment defects and replacement of anemometers, but none of these events are documented.

2.2.2 Long-term data from Sula meteorological measuring station

In order to carry out a long-term assessment of the wind conditions at Skipheia, data from Sula meteorological measurement station have been evaluated. The met station is found in the island group with the same name, which similarly to Skipheia lies in the municipality of Frøya (see Table 1). The map in Appendix A shows the southernmost part of Sula, located north from the mainland of Frøya. The weather station is found approximately five meters above sea level. No inspection of the long-term station has been carried out, and it is not known to what extent the surroundings are assumed to affect the measurements.

The long-term data from Sula contains information on air temperature and pressure, wind speed (ten meters above the ground) and wind direction from the start of 1975 until the end of 2013. The sampling frequency varies from every six hours to every hour. A complete overview of the time steps for the available long-term data is given in Table 4.

Time period	Times with data
1975-01-01 – 1995-12-31	01:00, 07:00, 13:00, 19:00
1996-01-01 – 1997-11-30	01:00, 07:00, 10:00, 13:00, 19:00, 22:00
1998-05-12 – 2013-12-31	00:00 – 23:00, every hour

Table 4 Time period and frequency for the data from Sula met station

To get a best possible picture of the wind conditions at Sula, data from the period with every-hour measurements were used. Like for the Skipheia data, the time period was limited to contain a given number of whole years to avoid seasonal biasing, in this case 15 years (1998-11-18 – 2013-11-17).

3 Data evaluation procedure

The evaluation of the wind resources at the current site is primarily based on data measured at the Skipheia met mast. As previously mentioned, two full years of measured data are considered to avoid seasonal biasing. These are evaluated in detail and also, in order to assess the site-specific long-term wind conditions, compared and correlated with long-term measurements from Sula met station. The data evaluation and processing will be presented in the following sections.

3.1 Evaluation of and corrections to the Skipheia mast data

3.1.1 Preparation of the measurement data

The measured data from the mast were provided as text files containing ten-minute averaged measurements for wind speed, wind direction, air temperature, standard deviations for speed and direction, and availability for the anemometers. Signals are sent from the measurement instruments to the data logger with a sampling rate of 1 Hz, and from the data logger to a computer running the software LoggerNet 3.4.1, developed by Campell Scientific. Finally, the data are averaged into ten-minute intervals. NTNU is the only institution processing the data, including complete measurement installation, operation and data evaluation. Data integrity can therefore be ensured according to [3]. The measurement procedure shows a clear and reproducible chain of steps.

According to the anemometer product specification [4], the wind speed measurements have an accuracy of ±2% at 12 m/s and an offset of ±1 m/s, whereas the direction measurements have an accuracy of ±2 °. Any over- or under estimation of speed and direction is therefore assumed to be negligible, and will not be made any corrections for.

The anemometers do not contain any moving parts or user-serviceable parts requiring maintenance. In addition, there are no calibration adjustments, so the unit is designed not to require re-calibration within its lifetime. The product specification also states that no site calibration is required. However, the manufacturer provides a software to perform an integrity check in order to discover any faults on the anemometers, and to confirm zero calibration [4]. It is known that an integrity check was performed for some of the anemometers used at Skipheia, but no documentation can confirm this.

3.1.2 Combining the anemometer data

As described earlier, the mast has two anemometers at each respective height. They are mounted with an orientation difference of 180°, and will hence perceive mismatching wind parameters due to tower disturbance. Figure 5 shows the ratio of the wind speed sensors as a function of wind direction. A peak can be observed at approximately 120° and a dip at approximately 300°. The graph in Figure 5 corresponds to the expected tower distortion effect on the anemometers, caused by wind shading. To handle this, a MATLAB code was used to combine the data from the two respective anemometers in each time step, choosing the one *not* disrupted by the tower (i.e. the upstream anemometer). The 360° wind direction sector was split in two, with the anemometers mounted on the southeast (131°) oriented booms covering 41° to 221°, and the anemometers on the northwest (311°) oriented booms the remaining 180°.

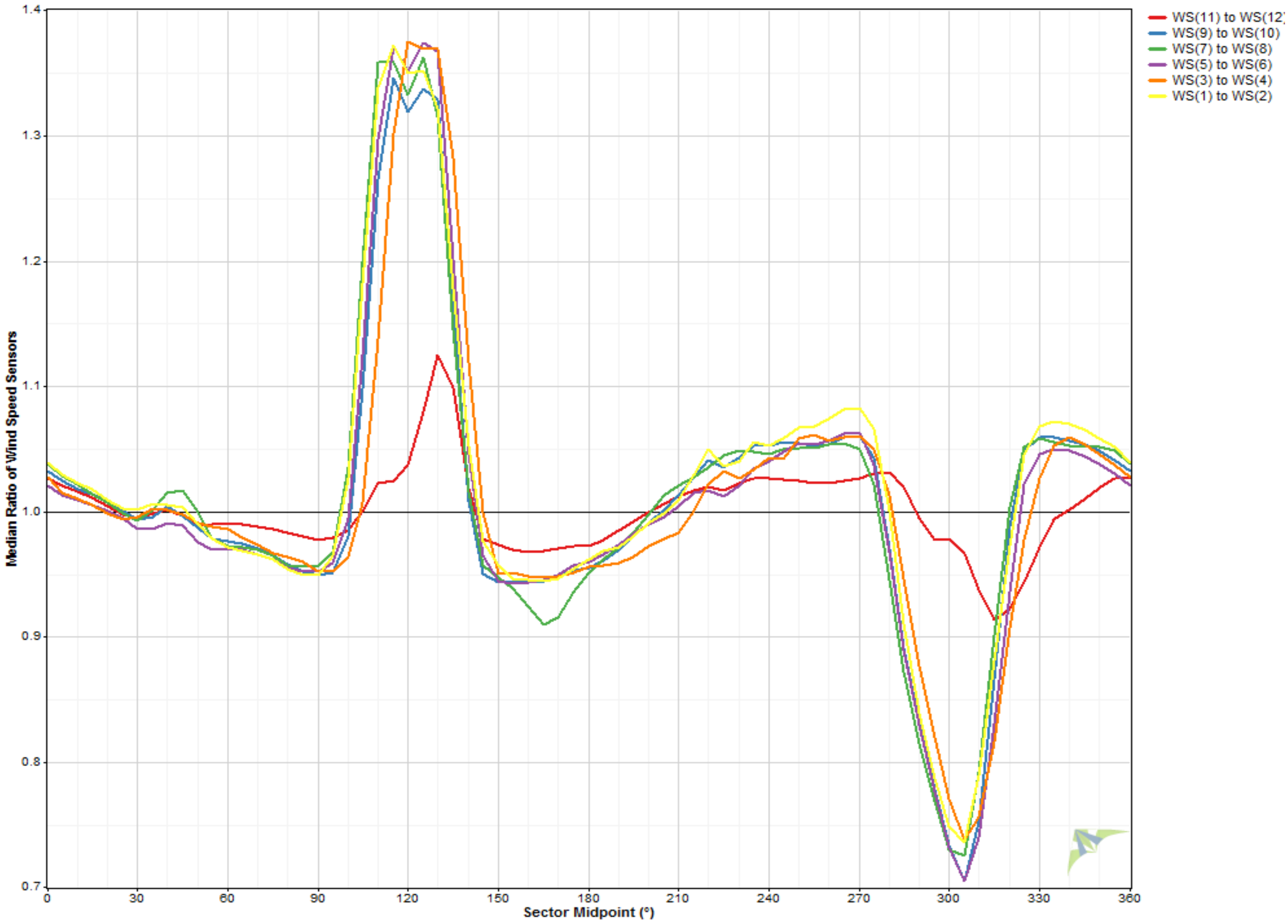

Figure 5 Wind speed ratio relative to wind direction

After combining the measurements for the 12 anemometers, the data set contained one value for wind speed and one for wind direction at each height in every time step. The new data file was loaded into Windographer, which is a software package developed by the renewable energy consulting company AWS Truepower [5]. It imports raw data files and gives the user a wide range of possibilities and options for wind data analysis. Windographer can be used for data measured by met towers, SoDARs or LiDARs and provides high-quality interactive graphics, quality control capabilities, statistical analyses and more. After loading the combined data into Windographer, a flagging rule was applied to filter out the anemometer data of availabilities below 90 %. Analysing tools were then used to present and assess the on-site measurements, as given in section 3.1.3.

3.1.3 Presentation of the short-term data

Here the two-year period of measurement data from the Skipheia mast is presented. The section includes wind speed, wind direction, temperature, turbulence and wind shear exponent data shown graphically. Appendix B contains the data presented in tabular format, as required by [3]. Since there are no intended wind turbines on the site, all data are associated only to the met-mast position.

3.1.3.1 *Wind speed*

Figure 6 shows a frequency histogram of the wind speed at 100 meters with a bin-width of 1 m/s, best fit to a Weibull distribution with parameters k = 1.80 and c = 9.01 m/s. The dimensionless Weibull k factor reflects the breadth of the distribution; the broader the distribution, the lower the k value. The Weibull c value is a scale factor related to the average wind speed [5].

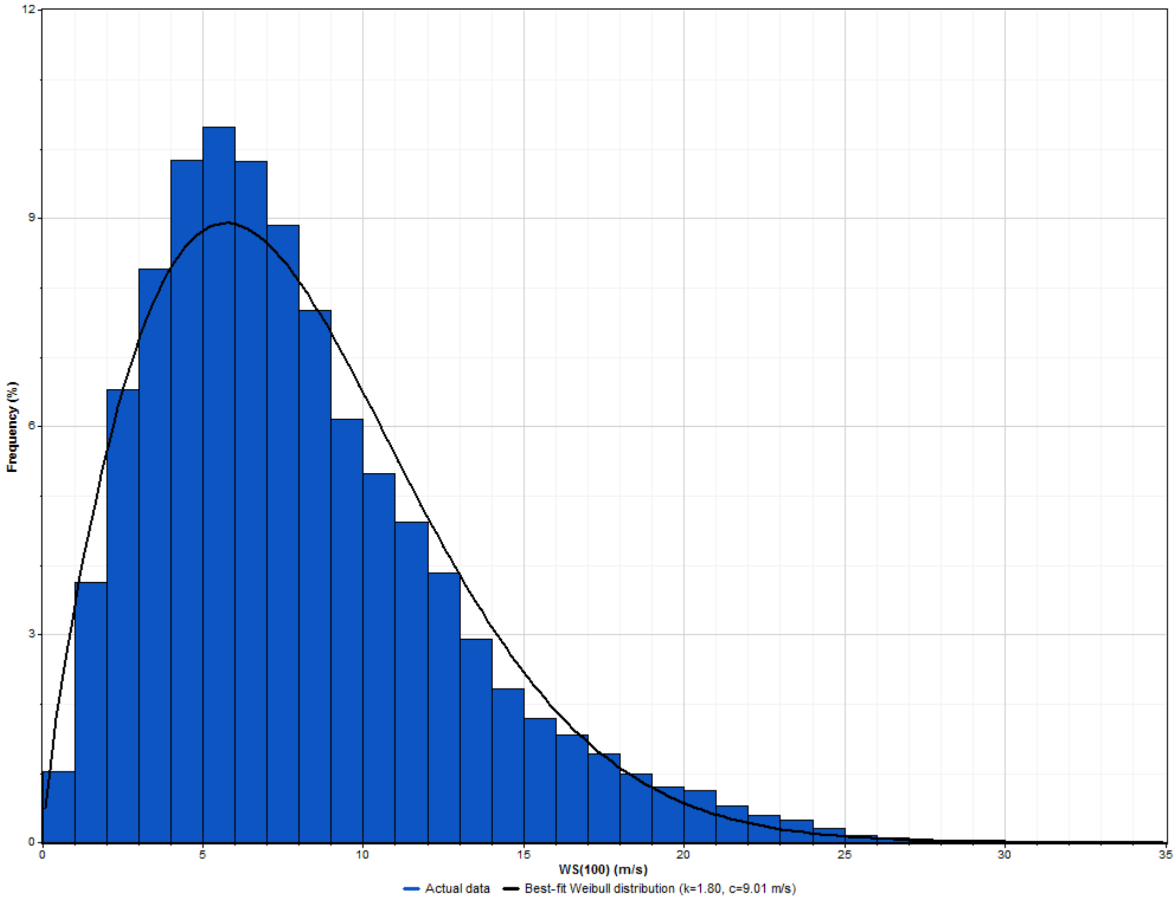

Figure 6 Wind speed frequency histogram at 100 m compared to best-fit Weibull distribution

Figure 6 corresponds to the table below, presenting mean-, maximum-, minimum- and standard deviation values of the wind speed for the two-year measurement period. The values for each month are given in Table B1.

Mean [m/s]	7.987
Minimum [m/s]	0.085
Maximum [m/s]	31.217
Standard deviation [m/s]	4.682

Table 5 Wind speed values for the complete time period

3.1.3.2 *Wind direction*

As mentioned in the site description, the distance from the test-site to the ocean varies from 300 meters to approximately three kilometres, depending on the direction. Therefore, it is interesting to evaluate the wind direction detected by the mast, in order to distinguish the measured parameters as representative for off-shore or on-shore wind. Figure 7 shows a wind rose for all heights for the two-year period. Each sector represents 30°, with the first sector centred on geographic north.

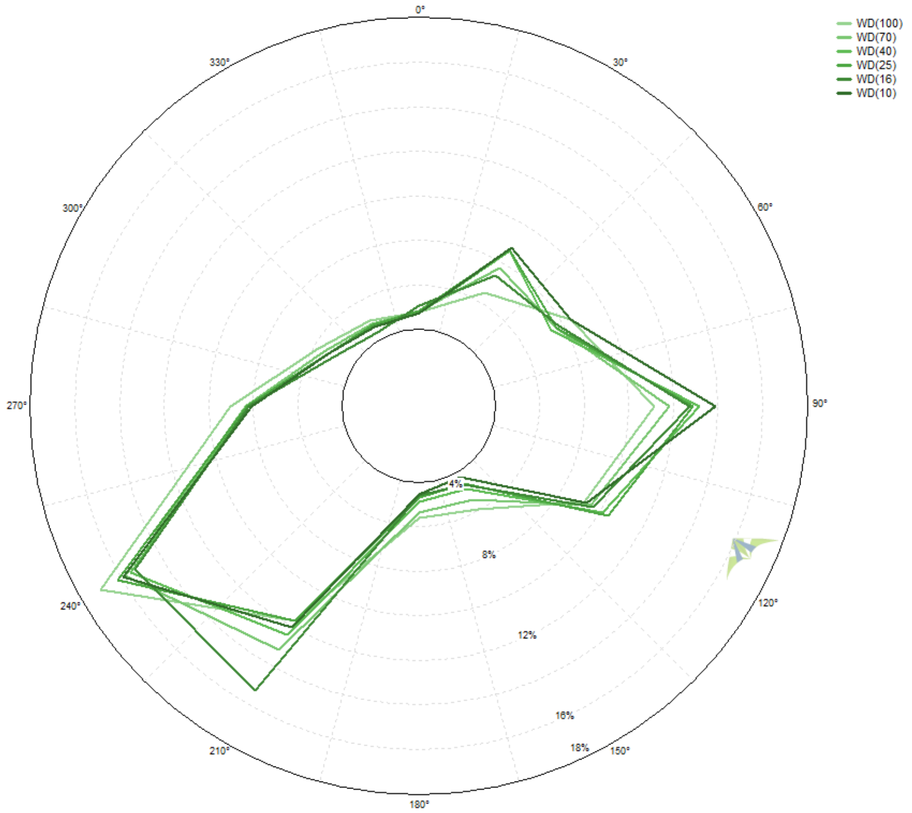

Figure 7 Wind rose showing the wind direction frequency for all six heights

In the figure above, it can be seen that the two sectors with midpoints 210° and 240° (i.e. winds from southwest), respectively, represent the bulk of the wind direction distribution (approximately 30 %). Another notable orientation is east-southeast, representing approximately 20 %. Going back to the map in Figure 1, the southwest frequency bulk implies winds from the Norwegian Sea, whereas the winds coming from east-southeast primarily have travelled over land. From approximately 235° via north to 50°, the west end of Frøya is exposed to nearly undisturbed maritime winds [1], which implies that these measurements are representative for off-shore conditions. An overview describing the various directions is given in Table 6.

Direction	Description
0°-40°	The distance to the sea is 3-5 km
40°-100°	Wind that has passed the northeast part of Frøya for up to 25 km
100°-190°	Wind comes from inland, but have passed sea for the last 10 km
190°-270°	The sector with the most frequent wind direction and the highest average wind speeds. The distance to the sea varies from 300 m to 3 km
270°-360°	Maritime wind that have passed land for about 3 km

Table 6 Classification of wind direction sectors [1]

For a detailed frequency distribution, the method of bins with bin-width 1 m/s and sector-width 30° is used for the 100 meter measurements. Each direction sector is represented by a stack of bars, with one bar for each bin, where the bar length indicates frequency. The graphical result is shown in Figure 8 and the values in Table B3.

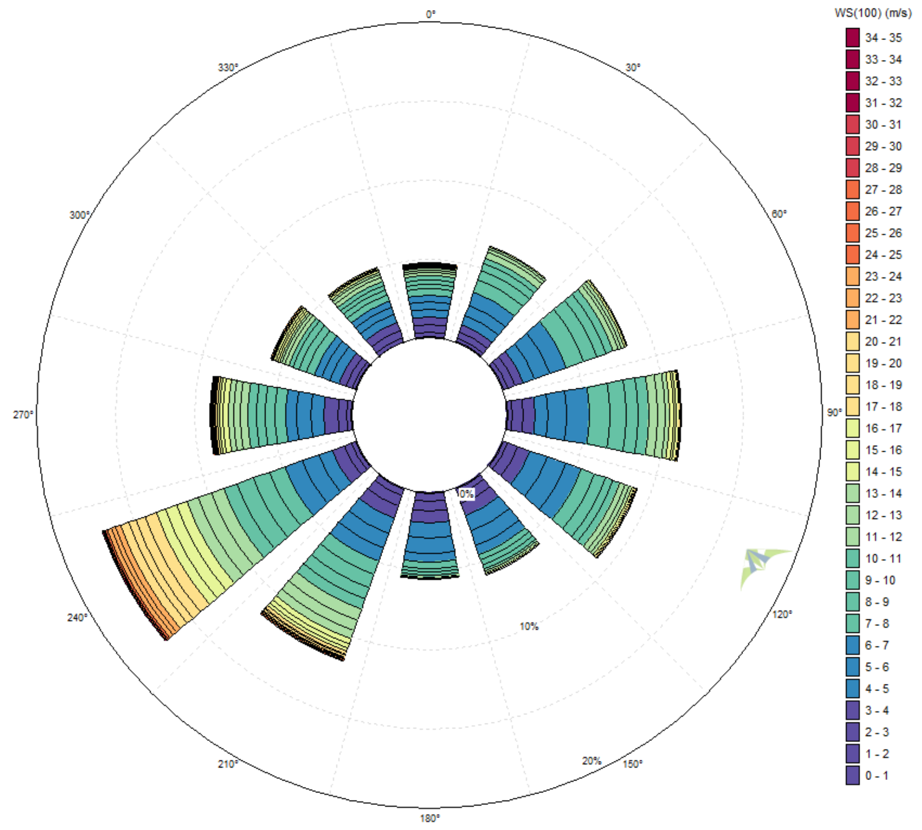

Figure 8 Direction frequency using method of bins; bin-width 1 m/s and sector-width 30°

For all the 12 direction sectors, the blue and darker green bars are the dominating ones, meaning wind speeds around 4-11 m/s. In the sector with midpoint at 240° the higher-speed bars (from 11 m/s and up) are longer than in the remaining eleven sectors, implying greater exposure to increased wind speeds in this sector. This is assumed to be related to winds coming in from the ocean and the relatively short distance to the shore.

3.1.3.3 Turbulence

Turbulence analysis is valuable to see how the turbulence in the wind varies with a given parameter, e.g. wind speed, wind direction or month. The turbulence intensity is a dimensionless number defined as the standard deviation of the wind speed divided by the mean wind speed for a particular time step. The data set for the Skipheia mast contains ten-minute time steps, each of which has a turbulence intensity value. The value below which 90 % of these values fall is known as the representative turbulence intensity.

The blue curve in Figure 9 shows the representative turbulence intensity at 100 meters height, decreasing with the increase of wind speed. For sufficiently high wind speeds, the turbulence intensity is expected to approach constant values [6], which is also the case in the current case. The green curve shows the mean turbulence intensity as a function of wind speed.

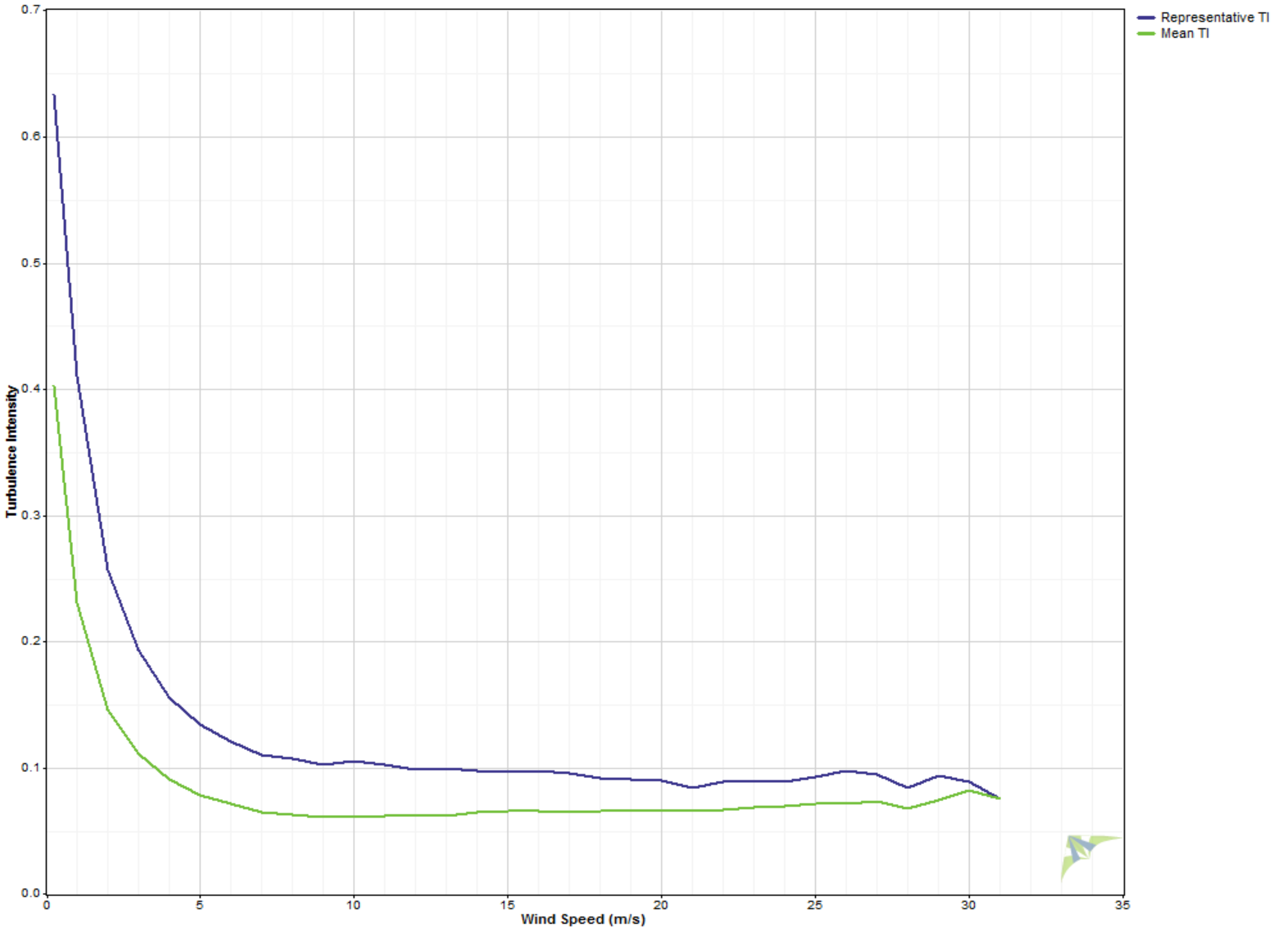

Figure 9 Representative and mean turbulence intensities as functions of wind speed at 100 m

IEC [4] defines four turbulence categories based on mean turbulence intensity at a wind speed of 15 m/s as defined in Table 7. For the current case, the mean turbulence intensity at 15 m/s is 0.07, which falls under category C. The representative turbulence intensity is 0.10. A graphical comparison of the representative turbulence intensities of the respective categories and the mast is shown in Figure B1 in the appendix.

IEC [4] recommends an inverse linear function to describe the decaying behaviour, but as an alternative Rodrigues et al. [6] present an exponential decay function, and find that the turbulence intensity in their analysis approaches asymptotic behaviour at wind speeds between 7 m/s and 10 m/s. This seems to be the case at Skipheia too, according to Figure 9, and may show that the reference value at 15 m/s is an overestimate also here.

Category	Mean TI at 15 m/s
S	> 0.16
A	0.14-0.16
B	0.12-0.14
C	0-0.12

Table 7 Turbulence categories defined in IEC 61400-1 ed. 3

In general, it is obvious that wind conditions at a given location are influenced by surroundings and nearby obstacles. At the west end of Frøya the landscape is relatively flat; see section 2.1 and Appendix A. The vegetation is dominated by heather and moss, and near the sea, there are large rocky areas with no vegetation at all. In addition, there are no nearby obstacles of significant heights, except for the other measurement masts, but these are assumed not to disturb the wind conditions at the top of Mast 2. As stated by Heggem [1], the turbulence is not affected by the mast construction itself outside the mast shade sector. The shade issue is solved by always choosing the anemometer upstream of the mast, as described in section 3.1.1. The turbulence intensity is therefore assumed to be independent of wind direction. The small variations of mean- and representative turbulence intensity as a function of wind direction are shown in Figure 10.

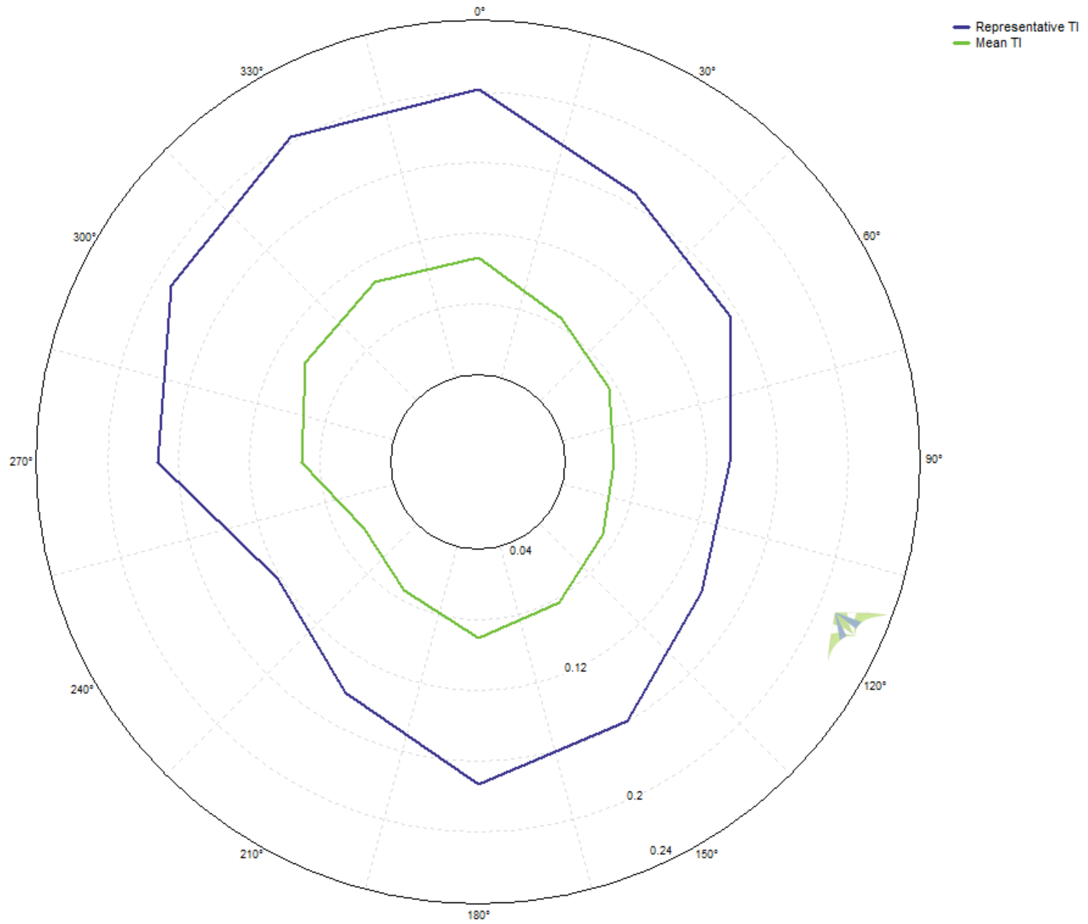

Figure 10 Turbulence intensity versus wind direction at 100 m

Surface roughness is known to have an influence on turbulence, but as the distance to the ground increases, this influence decreases. For surface roughness corresponding to vegetation mainly of heather and moss, the turbulence influence at a height of 100 meters is assumed to be zero. Another factor which might have a greater impact on the turbulence is thermal changes experienced by the wind when passing the warmer Gulf Stream outside the coast [1].

3.1.3.4 Wind shear

The wind shear describes how the wind velocity (speed and direction) changes with height above ground. According to boundary layer theory, the wind speed tends to increase with increasing distance to the ground, until it reaches the frees-stream speed of the undisturbed flow. As described in section 2.2.1, the relevant met mast has anemometers at heights of 10, 16, 25, 40, 70 and 100 meters, which provides a good foundation for wind shear analysis.

To characterise the measured wind speed profile, the power law is applied, containing a parameter called the power law exponent (or simply the wind shear exponent), α. This exponent gives the rate at which the wind speed changes with height above ground. As for the turbulence intensity, the value of the wind shear exponent approaches asymptotic behaviour for sufficiently high wind speeds. But unlike the turbulence intensity it follows an ascending rather than a decaying function.

The wind speed profile has an exponential shape with the wind speed approaching free-stream speed as the distance to the ground increases, as in Figure 11, showing the mean wind speed profile for the complete two-year period. However, it is assumed more relevant to look at the wind shear exponent in the respective direction sectors rather than an averaged wind speed profile for all directions, due to varying ground surface conditions and hence significant variations in wind speed profile in the different directions. The greater value of α, the less steep slope of the exponential velocity function.

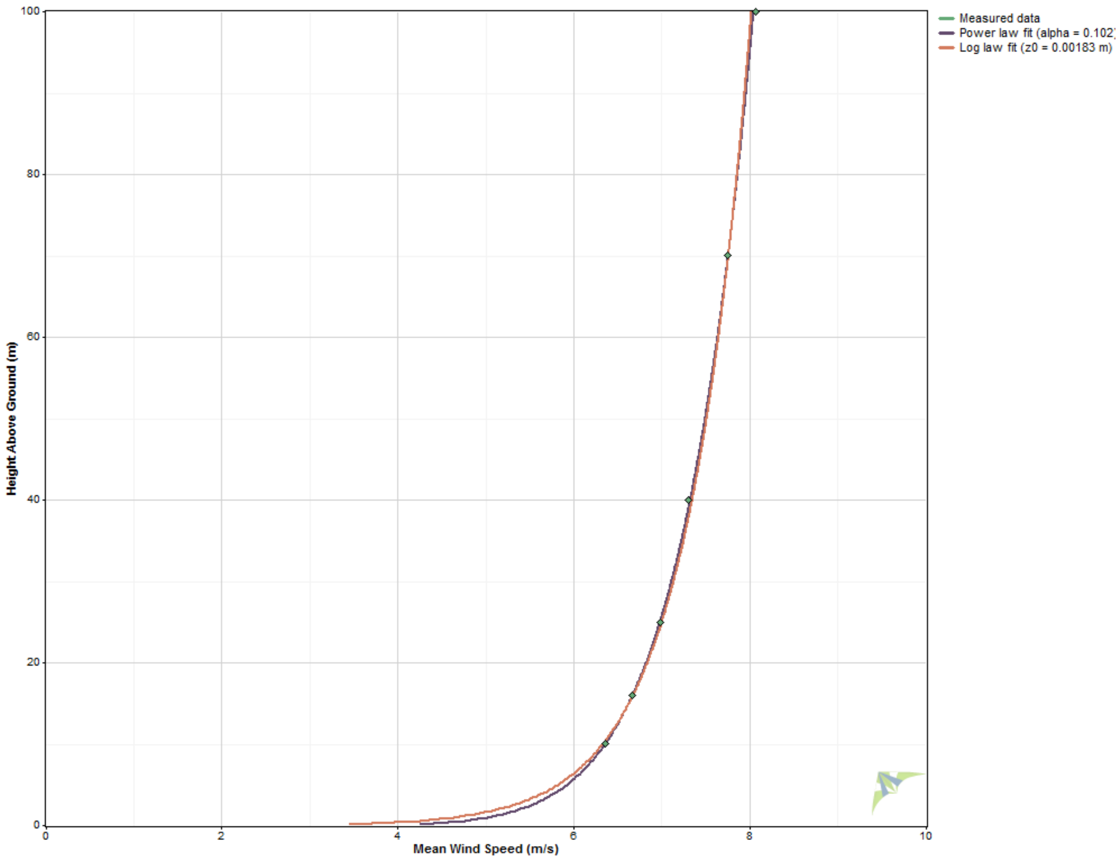

Figure 11 Mean wind speed as function of height above ground

The mast is exposed to winds which have been travelling both over sea and over land, and the wind shear will therefore vary depending on the wind direction. In addition, there are topographical variations. Figure 12 illustrates the value of α as a function of the wind direction detected by the top anemometers.

The wind shear exponent shows remarkably small values in sectors of midpoints 30°, 120° and 210°, respectively. This indicates that winds from these directions have relatively steep wind profile slopes and hence travel over smoother and less disturbing surfaces before reaching the measurement point, compared to winds from the remaining directions. According to Figure 1, the mentioned sections represent a large variation in distances from the mast to the shoreline. Southward, the distance is around 300 meters, whereas winds from the northeast direction travel over roughly 20 kilometres of land before reaching the measurement point. Despite the relatively flat surface of the mast surroundings, small variations in the topography prove to have a significant impact on the wind speed profile.

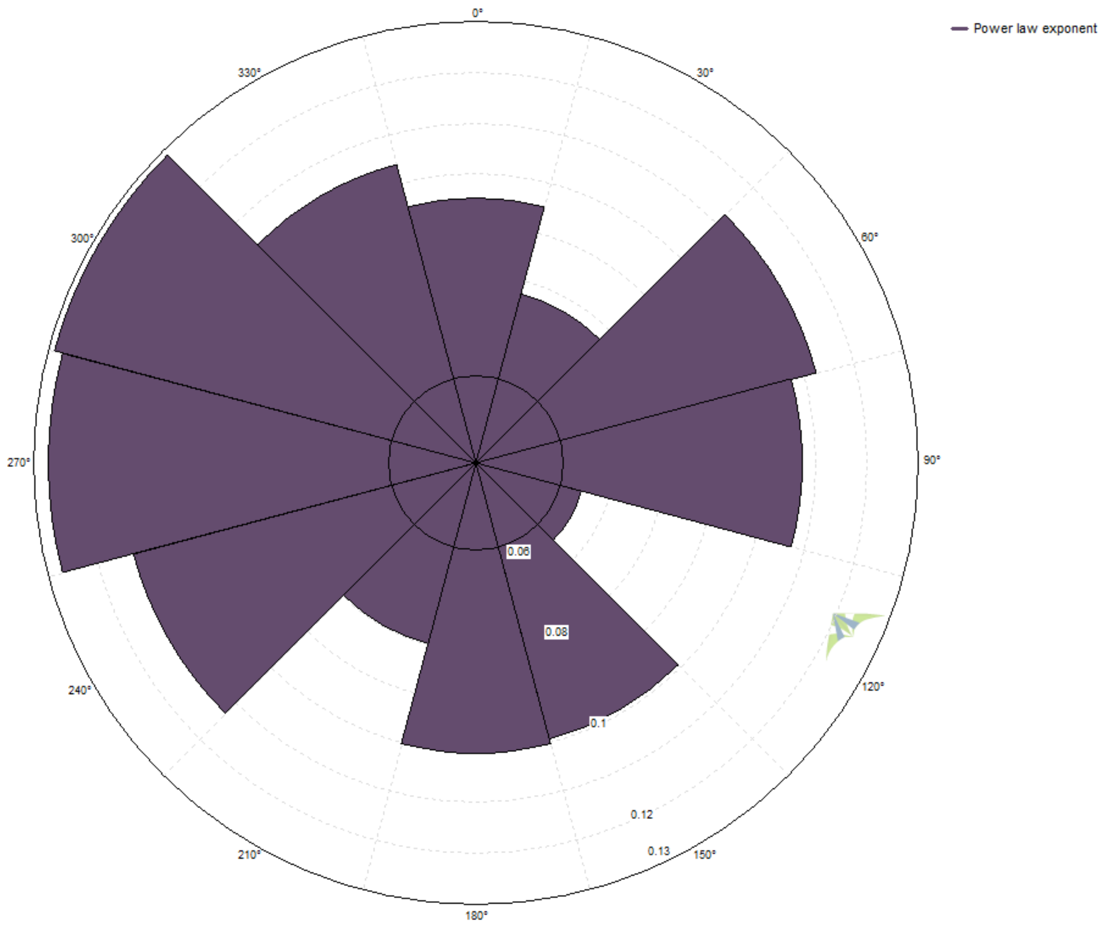

Figure 12 Wind shear exponent, α, as function of wind direction at 100 m; bin-width 30°

Table B10 in the appendix gives values for α depending on both wind speed and wind direction. A summary is provided below. The actual minimum in Table B10 is below zero, but as the wind speed is assumed to increase with height above the ground in the current case, the negative values of α (occurring in the first two wind-speed bins) are neglected.

	α	Wind speed bin; Wind direction sector
Mean	0.084	-
Maximum	0.268	16-17 m/s; 45-75°
Minimum	0.001	1-2 m/s; 15-45°

Table 8 Mean, maximum and minimum values for α using the method of bins; bin width 1 m/s and sector-width 30°

3.2 Long-term data from Sula met station

3.2.1 Preparation of the long-term data

As mentioned in section 2.2.2, the applied measurements from Sula met station contains 15 full years of data, with values given every hour from 1998-11-18 until 2013-11-17. The data were retrieved from the website of the Norwegian Meteorological Institute [8], containing free-access weather- and climate data for met stations all over Norway. The measurements were downloaded as text files and modified for use in Windographer.

From May 1998, Sula met station was automated and provided values for air temperature and pressure, wind speed and wind direction every hour. For uncertainty assessment, each measurement in every time step should be provided with a number describing the measurement quality. A table explaining the levels of quality is given below. For the mentioned 15-year data period, measurements from 1998-11-18 through 2005-04-30 are mainly of quality level 2, whereas the rest primarily contains data of quality level 0.

Explanation	Level
OK	0
OK	1
Slightly uncertain	2
Slightly uncertain	3
Slightly uncertain	4
Very uncertain	5
Very uncertain, model data	6
Erroneous	7
No access/very uncertain, model data	x

Table 9 Quality information for the data from Sula met station [8]

In the data periods with qualities of mainly 2 and 0, respectively, there are shorter periods with lower qualities (3 or greater), no quality information or no data at all (gaps). This increases the uncertainty of the measurements and must be considered when evaluating the data. Beyond the automation in 1998, no information regarding the history of the station is found, and it is not known what kinds of instruments the met station is equipped with.

To ensure a certain quality level of the long-term data, flag rules were applied in Windographer, leaving out data of lower quality than level 2. This limit was chosen to retain a sufficient number of data points to represent the time period, but at the same time keep up the quality level. Leaving out level 2 as well would have nearly halved the amount of data. The flagging excludes some data points for wind speed, air temperature and air pressure measurements, primarily in the period spanning the start of 2005 until March 2007.

3.2.2 Presentation of the long-term data

This section gives a brief presentation of the data from the met station to provide a rough picture of the wind conditions at Sula. A more thorough comparison to the on-site measurements is carried out in section 4. As mentioned in section 2.2.2, it is not known to what extent the surroundings of the met station are assumed to affect the wind measurements. However, the long-term data are assumed to give indications of the wind conditions at Skipheia. Figure 13 and Figure 14 show the monthly wind speed and the wind direction frequencies, respectively, for the two locations in the overlapping period (2009-11-18 – 2011-11-17).

When comparing the wind speeds at the two locations, the difference in measurement heights needs to be considered. As a consequence of surface roughness and boundary layer flow behaviour, the wind speed at 100 metres will be closer to the magnitude of the undisturbed flow than the one at 10 metres will. The on-site measurements from Skipheia are ten-minute-averaged data, and therefore assumed to give a more accurate picture of the wind conditions than the every-hour values from Sula, but the two curves still show reasonable accordance, with height differences taken into account. A summary of the wind speed measurements for the two data sets is given in Table 10. It shows that the wind speed at the top of the Skipheia mast lies slightly above the wind speed measured at Sula, as expected.

Parameter	**Skipheia**	**Sula**
Mean wind speed [m/s]	7.987	6.487
Minimum wind speed [m/s]	0.085	0.000
Maximum wind speed [m/s]	31.217	28.100
Std. dev. for wind speed [m/s]	4.682	3.954

Table 10 Summary of wind speed and temperature measurements for the two stations

As for the Skipheia site, Sula is exposed to winds coming in both from the sea and from the inland. The dominating wind directions are west-southwest and southeast, not unlike the situation at Skipheia, as seen in Figure 14.

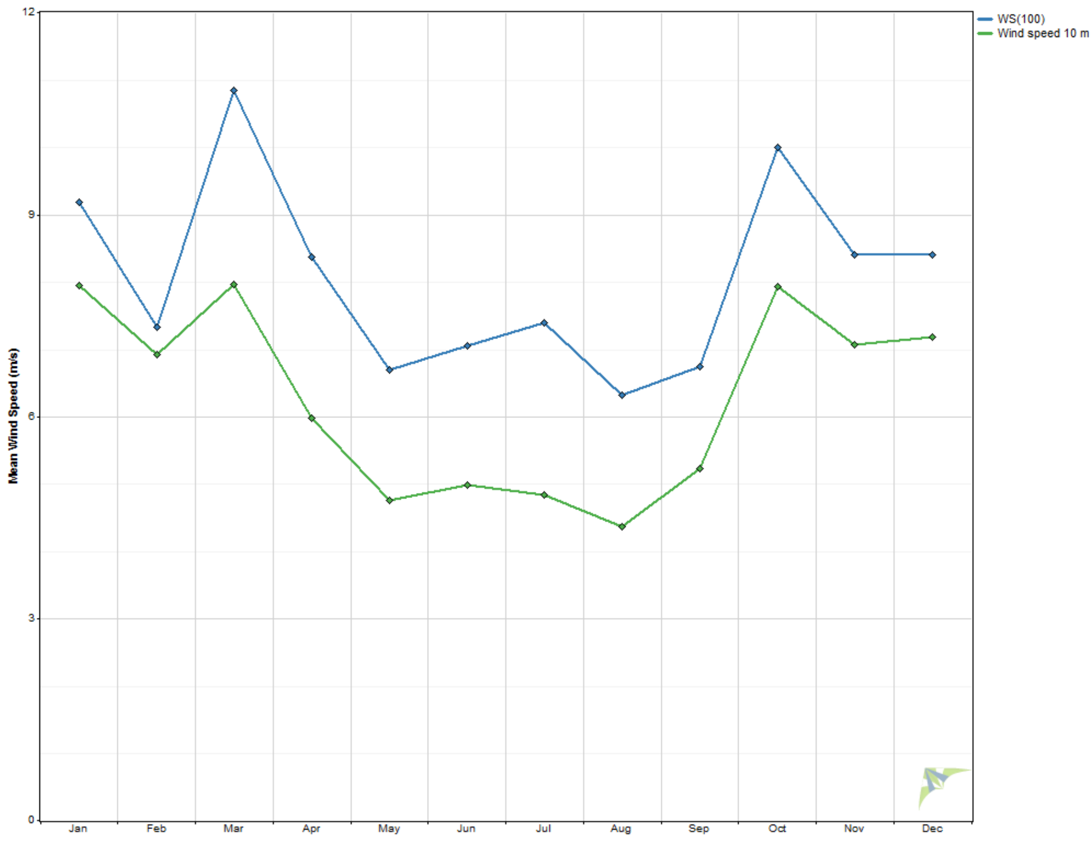

Figure 13 Monthly wind speed for Skipheia (100 m) and Sula (10 m) for the overlap period

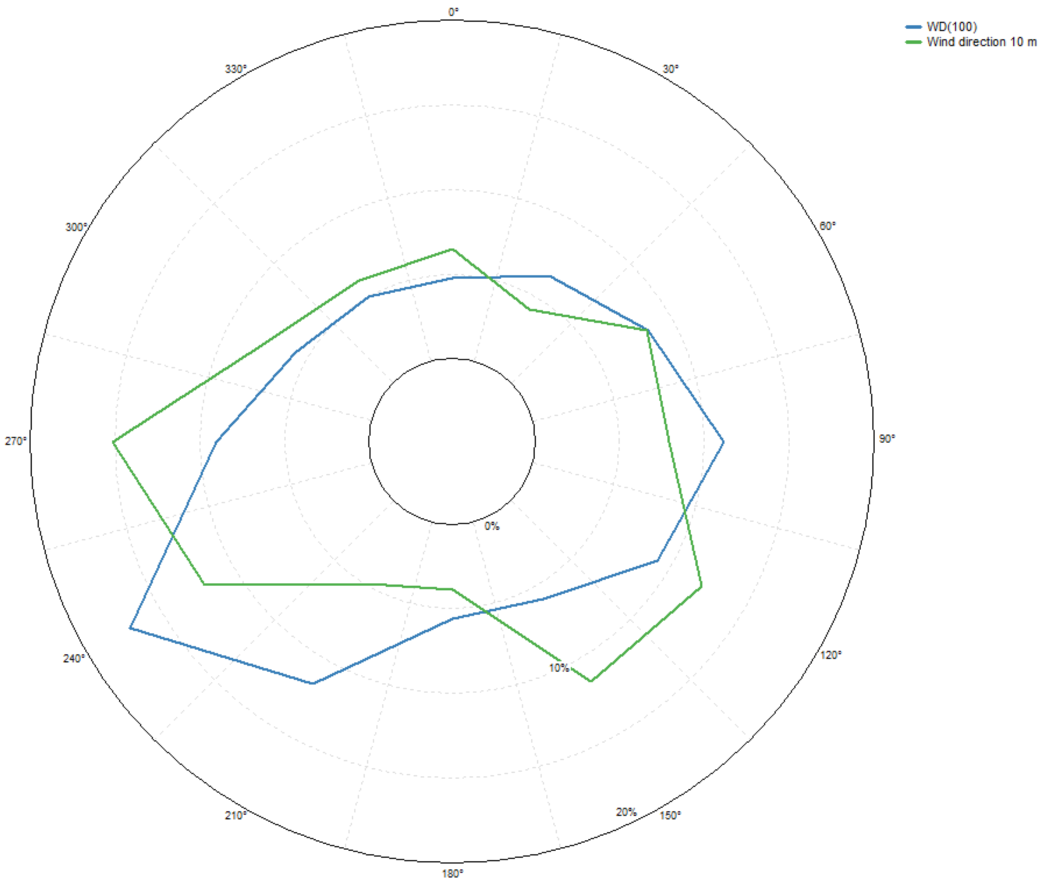

Figure 14 Wind direction frequencies for Skipheia (100 m) and Sula (10 m) for the overlap period

4 Comparison of the on-site data with the met station data

In order to conduct a long-term estimate of the wind conditions measured on site, a thorough comparison of short-term and long-term data is required. Data from national meteorological stations are commonly used for this purpose, as in the current case. In addition, computed time series such as re-analysis data are found helpful and important. Re-analysis is done by creating an unchanging data assimilation scheme used on an extended time period of data, and provides a dynamically consistent estimate of the wind conditions at each time step [9]. However, only long-term meteorological data will be considered here.

4.1 Comparison using the Measure-Correlate-Predict method

The measure-correlate-predict method (MCP) is commonly used to analyse the relationship between wind data measured in a concurrent period at two different locations; a target site (Skipheia) and a reference site (Sula). This relationship is then applied in a statistical process to synthesise and predict target site data from the reference site measurements, for time steps in which target data are absent. The method is typically used to lengthen or to fill gaps in the target data set [5].

4.1.1 Evaluation of the compliance between the data sets

In the present work the “Measure Correlate Predict” function in Windographer has been used to compare the two relevant sites. One-hourly means were calculated from the wind speed and wind direction data from the target site and compared to the concurrent data for the met station. The scatter plots for wind speed and wind direction using the Variance Ratio distribution [10] are shown in the two graphs below, and tell us to what extent the respective wind speed and wind direction measurements correspond to each other. The choice of distribution algorithm was based on a performance test integrated in Windographer, calculating error statistics for several algorithms in terms of wind speed.

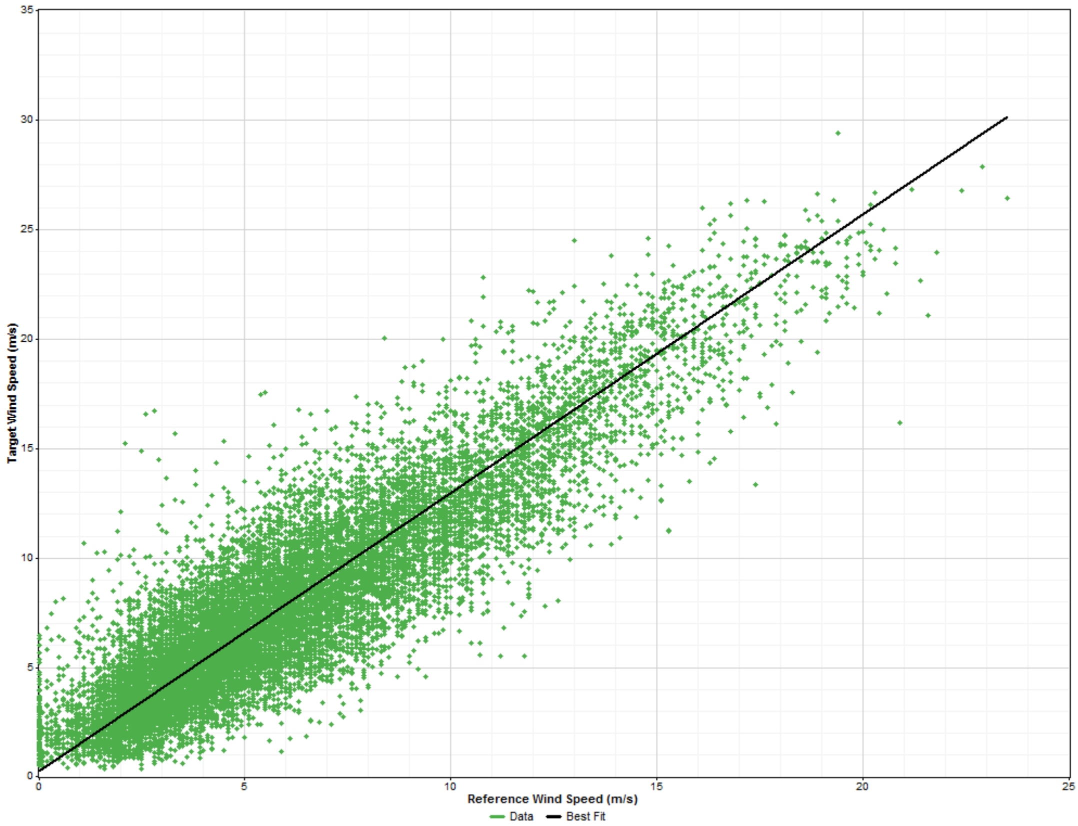

Figure 15 Comparison of one-hourly wind speeds between Skipheia (100 m) and Sula (10 m) for all wind directions

Figure 15 demonstrates the correspondence between the wind speeds measured at the two locations. Despite the significant scatter, it is clear that the measurements have been carried out in a common regional wind field, as the data seem to pursue the same path. That makes it sensible to extrapolate the short-term on-site data to long-term using reference data from the met station. Reasons for the scatter might be e.g. thermal- and roughness effects.

The sensibility of extrapolating the on-site data using the met station measurements is strengthened by evaluating Figure 16, showing accordance between the wind direction measurements. Some non-linearities are visible, but they are assumed to be due to local and regional influences, and hence ignored.

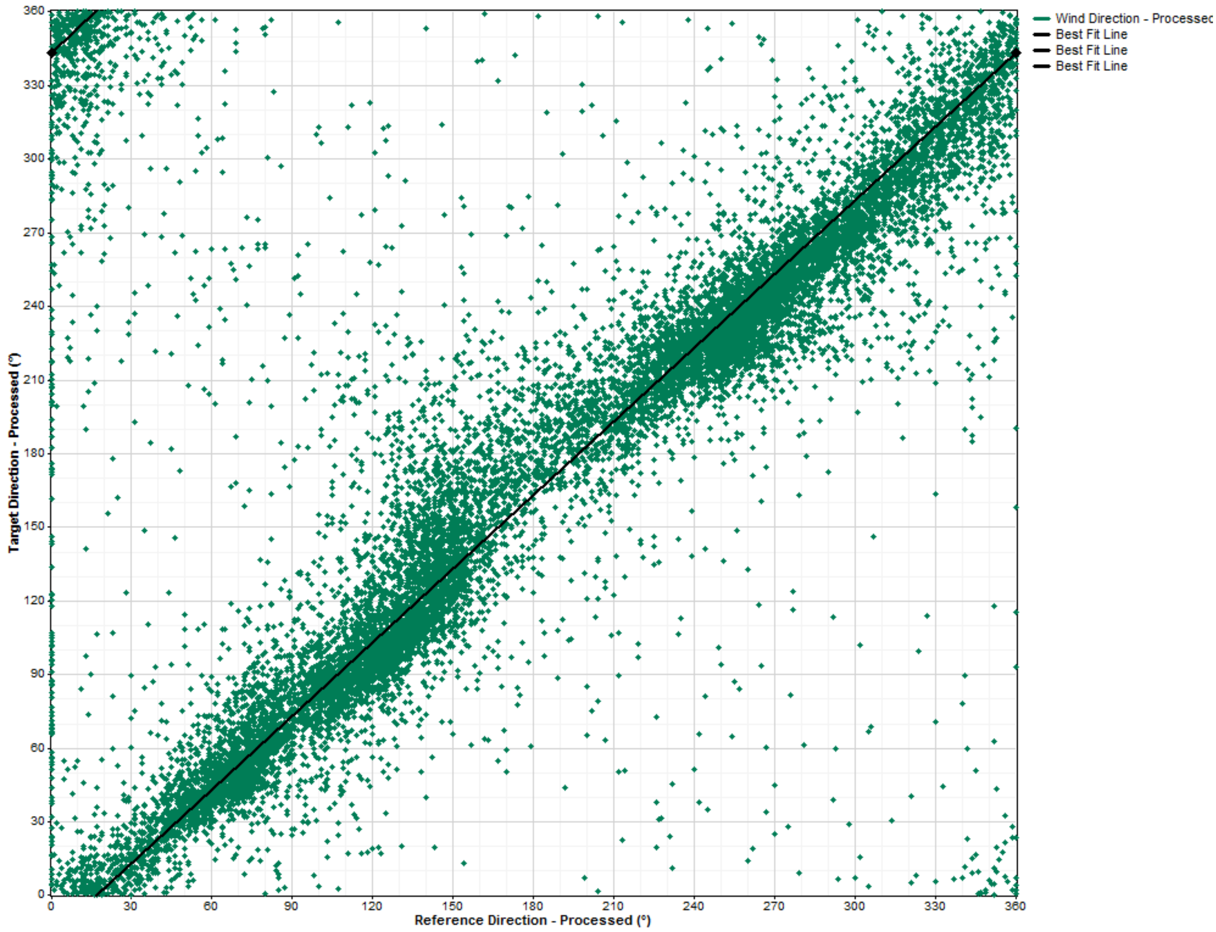

Figure 16 Comparison of one-hourly wind directions between Skipheia (100 m) and Sula (10 m)

4.1.2 Extrapolation of the on-site measurements

As mentioned in the previous section the MCP method uses the relationship between the data sets in a concurrent period to extrapolate the short-term measurements, in this case to the entire 15-year period of the reference data. The results of the extrapolation for wind speed and wind direction are shown in the two following figures, where the blue line represents the one-hour-averaged measurements at Skipheia, the green line shows the wind data from Sula and the red line is the final, synthesised data.

For the wind speed profiles in Figure 17, the shape of the curve for the synthesised data follows the form of the reference data curve, but at the wind speed level of the target data. This shows that the difference in measurement heights is taken into account when obtaining the correlation and performing the extrapolation.

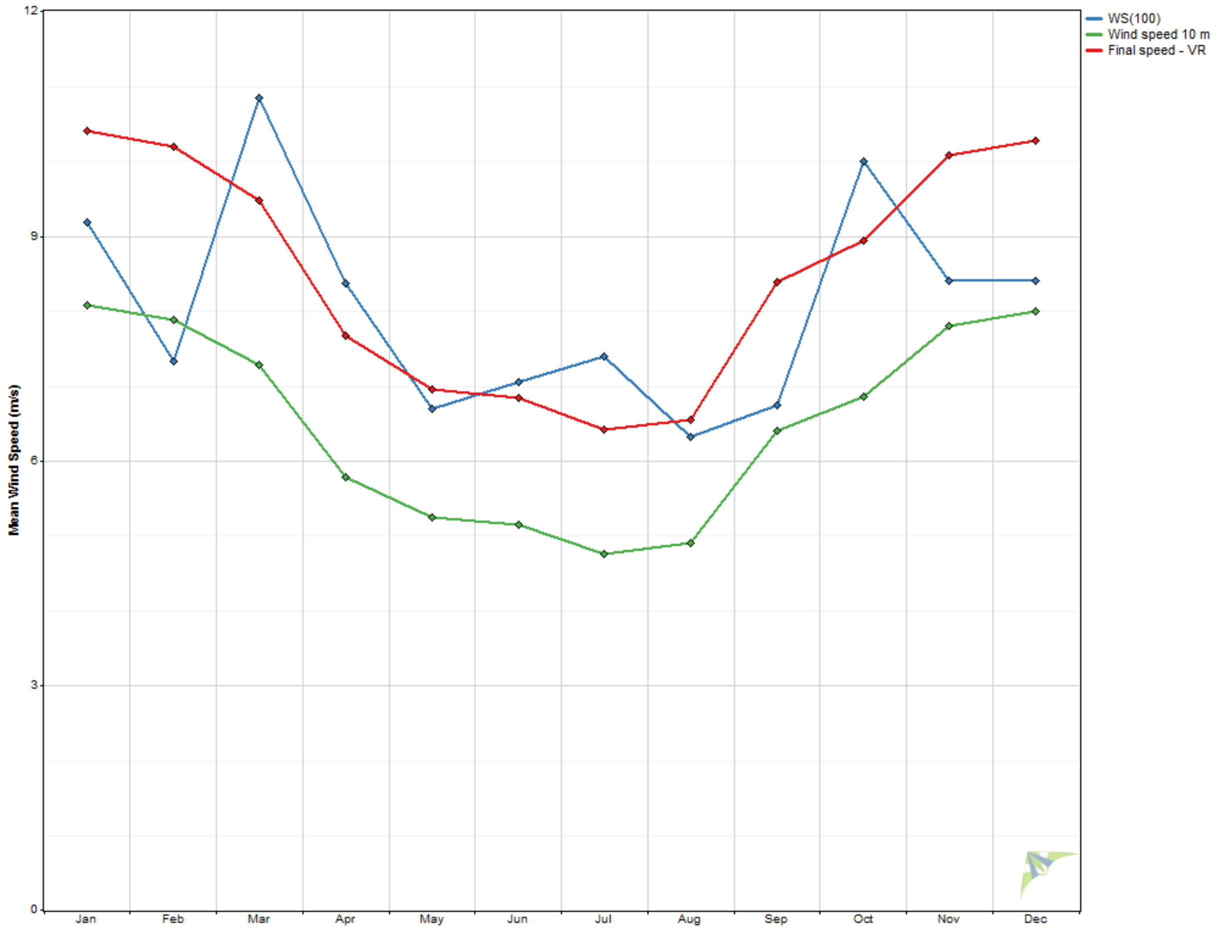

Figure 17 Monthly wind speed profiles for the target (blue), reference (green) and synthesised (red) data

The final, synthesised wind direction frequency for the 15-year period corresponds relatively well to the original short-term target data, as visualised in Figure 18. It can be noted that the proportion of winds from the prevailing direction region is slightly lower than for the initial data set.

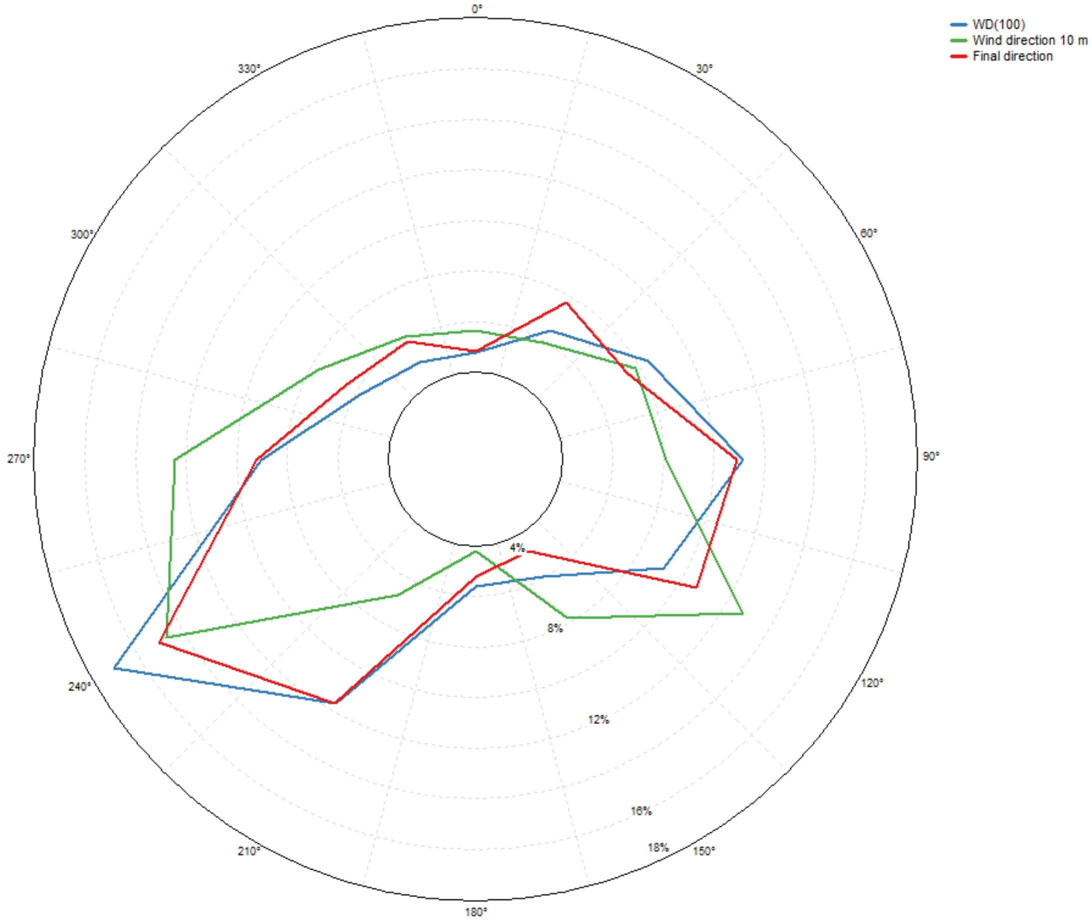

Figure 18 Wind direction frequencies for the target (blue), reference (green) and synthesised (red) data

Overall, extrapolation of the short-term data using the MCP method seems to give a reasonable picture of the long-term wind conditions at Skipheia. However, it is preferable to have several long-term measurements available when performing an extrapolation, to enhance the integrity of the results. The scatter plots in Figure 15 and Figure 16 also show significant scatter, but it is clear that the measurements are carried out in a common regional wind field.

5 Uncertainty analysis

Some uncertainties related to the measurements and results have already been discussed in the text. A more thorough uncertainty analysis would have been conducted if a wind farm development was intended. The list below gives an overview of the aspect which might be of significance in the present work.

Uncertainty aspects:

- Gaps in the measurement period, both for Titran and Sula
- Uncertainties related to the measurement equipment; sensors and installation
- The minimum temperature values show unrealistic behaviour, see Table B7
- Low quality in the long-term measurements
- No information regarding measurement instruments at Sula
- No information regarding the nearby surroundings of Sula met station
- Uncertainties related to the MCP method

6 Deviations to the MEASNET Guideline 'Evaluation of Site Specific Wind Conditions'

There are some deviations to the guideline, including missing documentation, data and assessment results. In addition, no results are provided for any intended wind turbines. The missing parameters and results are provided below.

Missing measurement documentation:

- Documentation of calibrations for the sensors
- Serial number of the anemometers
- A log book recording all important events during the measurement period; including a listing of all maintenance activities that occurred during the measurement period

Missing measurement data:

- Flow inclination
- Air pressure
- Humidity

Missing assessment results:

- Air density
- Flow inclination
- Wind field modelling
- Extreme winds

7 Summary

This work contains a wind-site analysis of Titran, located at the west end of Frøya. Two years of wind measurements are presented and evaluated, and found to be relevant for both off-shore and on-shore wind conditions. Applying the measure-correlate-predict method and 15 years of data from a regional met station located roughly 20 kilometres north from Titran, the short-term measurements have been extrapolated to a longer period.

8 References

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Appendix A

Maps

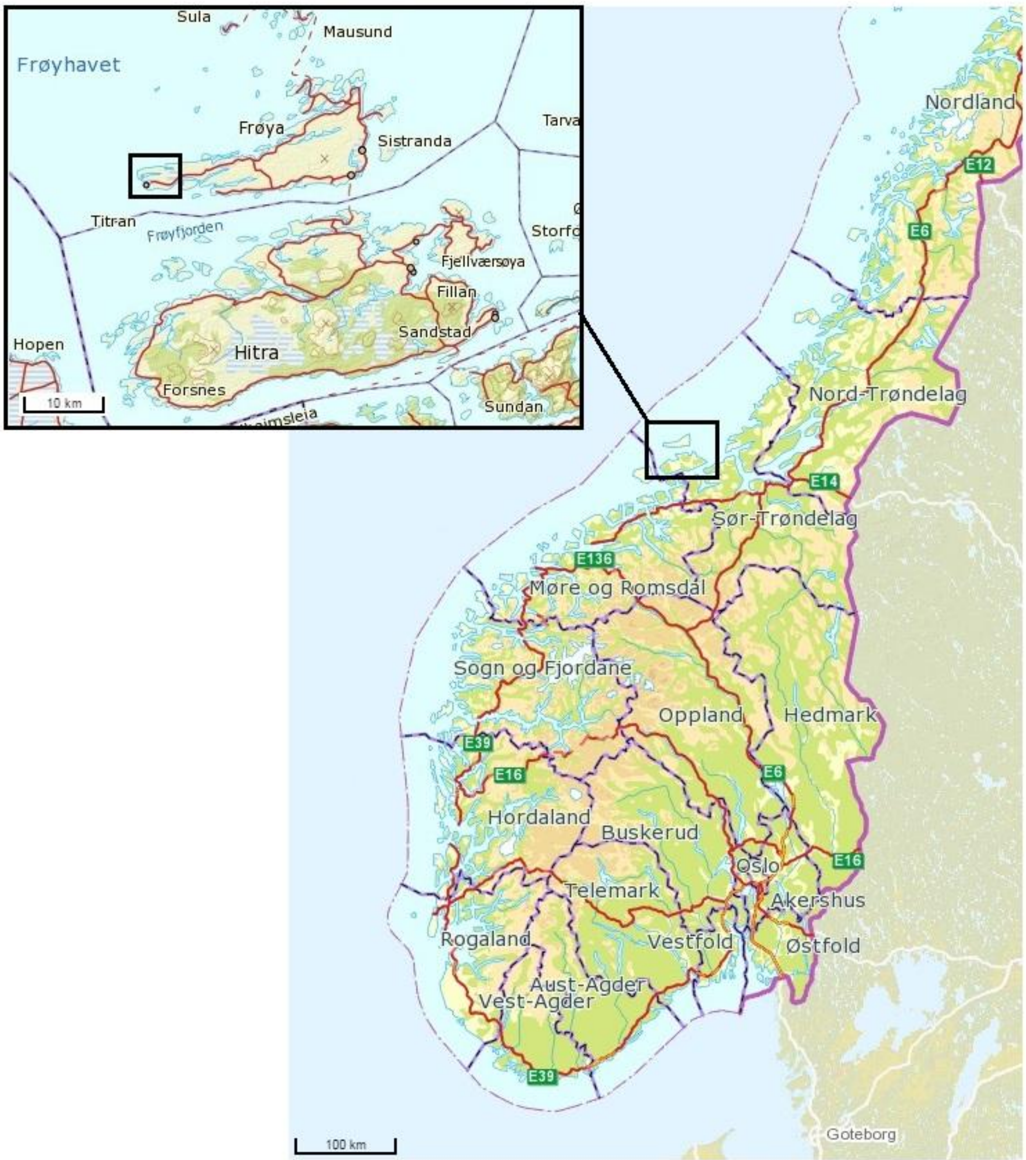

Figure A1 The location of the measurement site

Photo documentation of the mast surroundings

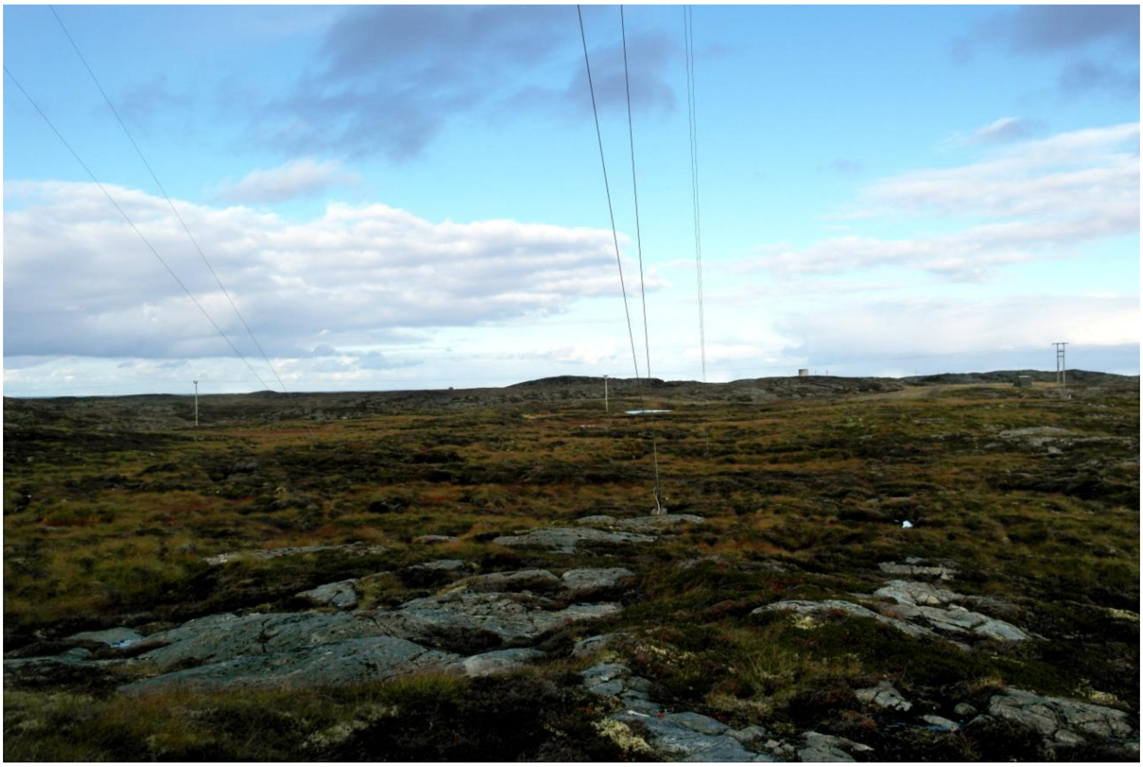

Figure A2 North

Figure A3 East

Figure A4 South

Figure A5 West

Photo documentation of the mast

Figure A6 The mast showing the six measurement heights

Appendix B

Short term data presentation

Month	Mean [m/s]	Minimum [m/s]	Maximum [m/s]	Standard deviation [m/s]
January	9.177	0.347	30.150	4.751
February	7.326	0.396	22.622	3.792
Mars	10.843	0.217	31.217	6.386
April	8.371	0.179	25.296	4.772
May	6.694	0.190	26.051	3.877
June	7.045	0.127	24.720	4.051
July	7.388	0.148	25.838	3.740
August	6.310	0.085	18.293	3.559
September	6.738	0.130	24.276	4.341
October	9.994	0.375	27.893	5.417
November	8.401	0.208	25.234	4.502
December	8.408	0.351	24.583	4.403
Complete period	7.987	0.085	31.217	4.682

Table B1 Mean, minimum, maximum and standard deviation values of the wind speed at 100 m for each month and the complete measurement period

Direction sector	Weibull k-parameter	Weibull c-parameter [m/s]	Frequency [%]
345° - 15°	1.685	7.964	4.78
15° - 45°	2.356	7.858	6.48
45° - 75°	2.396	7.966	8.41
75° - 105°	2.192	8.704	11.11
105° - 135°	2.069	7.769	9.12
135° - 165°	2.073	6.195	5.88
165° - 195°	2.071	5.798	5.56
195° - 225°	1.883	9.746	11.65
225° - 255°	1.995	12.857	17.11
255° - 285°	1.821	9.331	9.04
285° - 315°	1.823	8.760	5.81
315° - 345°	1.830	7.972	5.04
All data	1.797	9.005	100.00

Table B2 Sectoral Weibull k- and c- parameters and frequency distribution at 100 m; sector width 30°

Bin Endpoints (m/s)		Frequency of 'WS(100)' (%) vs, 'WS(100)' and 'WD(100)'												
Lower	Upper	345° - 15°	15° - 45°	45° - 75°	75° - 105°	105° - 135°	135° - 165°	165° - 195°	195° - 225°	225° - 255°	255° - 285°	285° - 315°	315° - 345°	All
0	1	0.097	0.075	0.082	0.079	0.083	0.075	0.096	0.118	0.083	0.087	0.08	0.069	1.023
1	2	0.253	0.25	0.288	0.319	0.292	0.342	0.462	0.429	0.31	0.311	0.247	0.248	3.752
2	3	0.496	0.389	0.491	0.634	0.669	0.617	0.611	0.662	0.495	0.563	0.409	0.5	6.535
3	4	0.469	0.487	0.581	0.755	0.832	0.859	0.814	0.808	0.783	0.833	0.495	0.554	8.268
4	5	0.53	0.641	0.726	0.87	1.177	1.018	0.955	1.011	0.923	0.879	0.564	0.537	9.832
5	6	0.459	0.645	1.031	1.188	1.218	0.95	0.916	0.959	1.088	0.849	0.545	0.469	10.315
6	7	0.396	0.901	1.121	1.390	1.046	0.61	0.604	0.926	1.181	0.735	0.516	0.389	9.815
7	8	0.414	0.853	1.121	1.305	0.916	0.4	0.368	0.889	1.038	0.641	0.53	0.42	8.894
8	9	0.29	0.598	0.91	1.056	0.746	0.316	0.258	0.907	1.108	0.619	0.507	0.35	7.666
9	10	0.271	0.475	0.604	0.765	0.495	0.266	0.152	0.732	1.069	0.591	0.379	0.298	6.096
10	11	0.264	0.387	0.488	0.698	0.451	0.169	0.147	0.722	0.884	0.534	0.314	0.254	5.310
11	12	0.196	0.37	0.345	0.559	0.391	0.114	0.072	0.755	0.825	0.468	0.278	0.246	4.617
12	13	0.175	0.221	0.238	0.447	0.239	0.063	0.043	0.699	0.901	0.423	0.215	0.219	3.884
13	14	0.117	0.116	0.19	0.307	0.182	0.037	0.031	0.526	0.771	0.365	0.128	0.169	2.939
14	15	0.078	0.046	0.131	0.212	0.129	0.009	0.022	0.368	0.693	0.292	0.123	0.118	2.222
15	16	0.052	0.012	0.045	0.187	0.088	0.011	0.006	0.266	0.705	0.224	0.124	0.078	1.796
16	17	0.039	0.007	0.022	0.173	0.081	0.013	0	0.214	0.68	0.167	0.117	0.04	1.554
17	18	0.044	0.007	0.001	0.1	0.04	0.004	0	0.146	0.718	0.123	0.069	0.035	1.287
18	19	0.03	0.001	0	0.037	0.015	0.009	0	0.125	0.606	0.076	0.058	0.025	0.982
19	20	0.033	0	0	0.004	0.011	0.001	0	0.106	0.527	0.067	0.037	0.011	0.798
20	21	0.038	0	0	0.007	0.019	0	0	0.072	0.53	0.051	0.033	0.003	0.753
21	22	0.022	0	0	0.007	0.003	0	0	0.063	0.361	0.047	0.022	0.004	0.53
22	23	0.012	0	0	0.009	0	0	0	0.055	0.267	0.038	0.011	0	0.393
23	24	0.001	0.001	0	0.001	0	0	0	0.048	0.244	0.019	0.009	0	0.324
24	25	0.001	0.001	0	0	0	0	0	0.03	0.161	0.015	0.002	0	0.21
25	26	0	0	0	0	0	0	0	0.008	0.084	0.015	0	0	0.107
26	27	0	0	0	0	0	0	0	0.003	0.051	0.006	0.002	0	0.062
27	28	0	0	0	0	0	0	0	0.001	0.015	0.006	0	0	0.021
28	29	0	0	0	0	0	0	0	0.001	0.004	0	0	0	0.006
29	30	0	0	0	0	0	0	0	0.001	0.003	0	0	0	0.004
30	31	0	0	0	0	0	0	0	0	0.002	0	0	0	0.002
31	32	0	0	0	0	0	0	0	0	0.001	0	0	0	0.001
32	33	0	0	0	0	0	0	0	0	0	0	0	0	0
33	34	0	0	0	0	0	0	0	0	0	0	0	0	0
34	35	0	0	0	0	0	0	0	0	0	0	0	0	0
All		4.775	6.483	8.415	11.110	9.124	5.884	5.556	11.650	17.113	9.042	5.813	5.036	100

Table B3 Detailed frequency distribution at 100 m using the method of bins; bin-width 1 m/s and sector-width 30°

Hour of day	Mean wind speed [m/s]
00:00 - 01:00	8.04
01:00 - 02:00	8.00
02:00 - 03:00	8.01
03:00 - 04:00	8.04
04:00 - 05:00	7.97
05:00 - 06:00	8.04
06:00 - 07:00	8.02
07:00 - 08:00	8.06
08:00 - 09:00	8.00
09:00 - 10:00	7.95
10:00 - 11:00	7.88
11:00 - 12:00	7.97
12:00 - 13:00	7.90
13:00 - 14:00	7.84
14:00 - 15:00	7.89
15:00 - 16:00	8.02
16:00 - 17:00	8.03
17:00 - 18:00	8.10
18:00 - 19:00	8.00
19:00 - 20:00	8.01
20:00 - 21:00	7.95
21:00 - 22:00	7.93
22:00 - 23:00	8.00
23:00 - 24:00	8.05

Table B4 Daily pattern of average wind speed at 100 m

Season	Mean wind speed [m/s]
Winter (Dec-Feb)	8.30
Spring (Mar-May)	8.64
Summer (Jun-Aug)	6.91
Autumn (Sep-Nov)	8.38

Table B5 Seasonal pattern of average wind speed

Mean [°C]	6.3
Minimum [°C]	-29.6
Maximum [°C]	24.5

Table B6 Mean, minimum and maximum values for air temperature at 100 m for the complete two-year period

Month	Mean [°C]	Minimum [°C]	Maximum [°C]
January	1.1	-8.7	9.1
February	-0.7	-13.8	10.3
Mars	2.0	-29.6	9.7
April	5.8	-0.5	17.2
May	7.4	-0.3	21.9
June	9.5	-5.1	21.6
July	12.1	-29.6	24.5
August	13.1	8.1	23.0
September	10.9	-29.6	20.0
October	8.5	-8.0	20.3
November	2.1	-8.2	13.2
December	0.3	-8.6	9.9
All	6.3	-29.6	24.5

Table B7 Mean, minimum and maximum values for air temperature at 100 m for each month

Comment to Table B6 and Table B7: The minimum (and hence the mean) values of the temperature show abnormal behaviour, as they approach negative 30°C in summer and autumn. It is the case for the temperature sensors at all seven heights and should be taken into consideration.

Bin endpoints [m/s]		Mean TI	Std. dev. of TI	Representative TI
Lower	Upper			
2.5	3.0	0.12	0.07	0.20
3.0	4.0	0.10	0.06	0.17
4.0	5.0	0.08	0.05	0.14
5.0	6.0	0.07	0.04	0.13
6.0	7.0	0.07	0.04	0.12
7.0	8.0	0.06	0.04	0.11
8.0	9.0	0.06	0.03	0.10
9.0	10.0	0.06	0.03	0.10
10.0	11.0	0.06	0.03	0.10
11.0	12.0	0.06	0.03	0.10
12.0	13.0	0.06	0.03	0.10
13.0	14.0	0.06	0.03	0.10
14.0	15.0	0.07	0.02	0.10
15.0	16.0	0.07	0.02	0.10
16.0	17.0	0.07	0.03	0.09
17.0	18.0	0.06	0.02	0.09
18.0	19.0	0.07	0.02	0.09
19.0	20.0	0.07	0.02	0.09
20.0	21.0	0.07	0.02	0.09
21.0	22.0	0.07	0.02	0.09
22.0	23.0	0.07	0.02	0.09
23.0	24.0	0.07	0.02	0.09
24.0	25.0	0.07	0.02	0.09
25.0	26.0	0.07	0.02	0.09
26.0	27.0	0.07	0.02	0.10
27.0	28.0	0.07	0.02	0.09
28.0	29.0	0.07	0.01	0.08
29.0	30.0	0.07	0.01	0.09
30.0	31.0	0.08	0.01	0.09
31.0	32.0	0.08	0.00	0.08
32.0	33.0			

Table B8 Mean, standard deviation and representative values for turbulence intensity versus wind speed at 100 m; bin-width 1 m/s

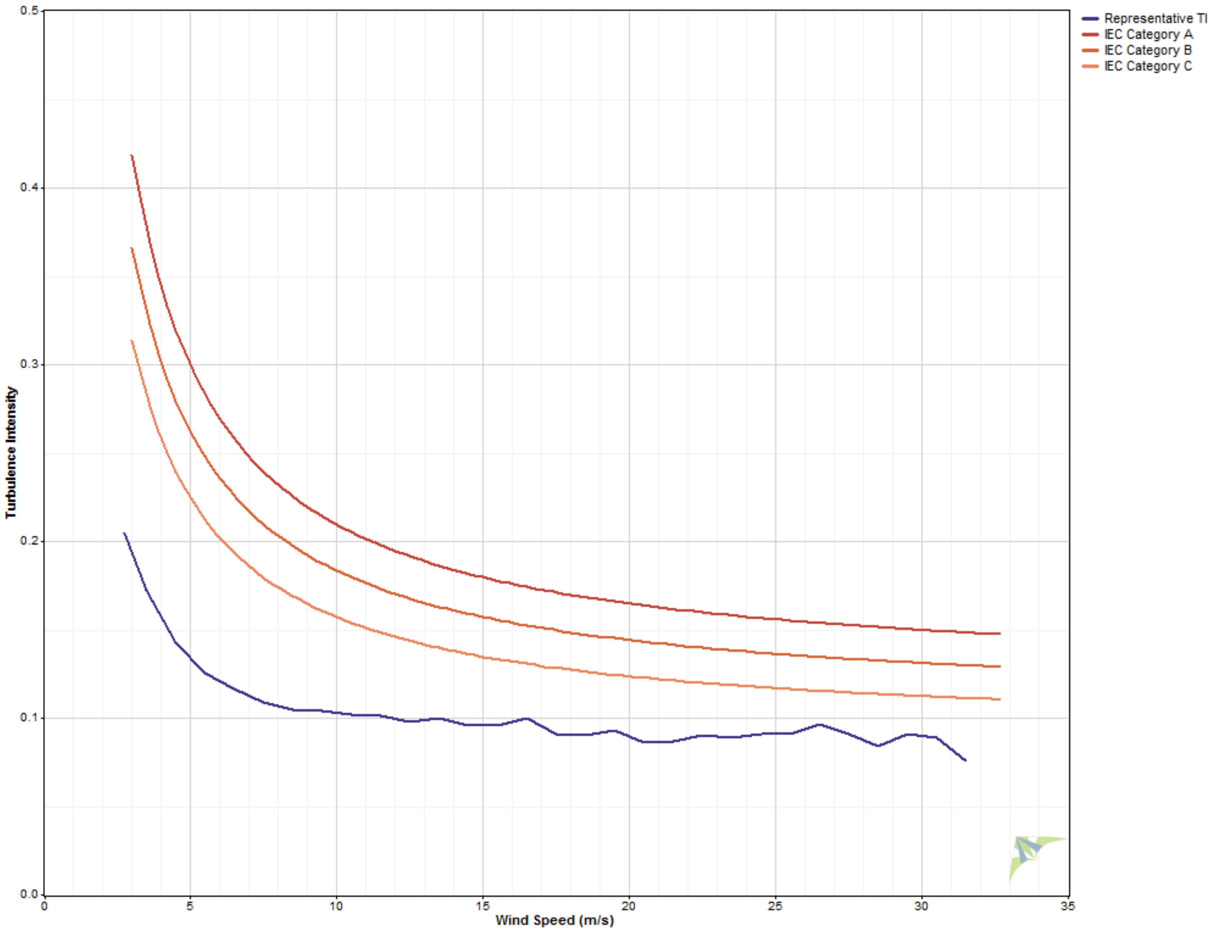

Figure B1 Representative turbulence intensity versus wind speed at 100 m compared to representative turbulence intensity according to IEC 61400 ed. 3

Sector midpoint [°]	Mean TI	Std. dev. of TI	Representative TI
0	0.11	0.07	0.20
30	0.09	0.06	0.17
60	0.08	0.06	0.16
90	0.07	0.05	0.13
120	0.07	0.05	0.14
150	0.08	0.06	0.16
180	0.09	0.06	0.17
210	0.07	0.05	0.14
240	0.07	0.04	0.12
270	0.09	0.06	0.17
300	0.10	0.07	0.19
330	0.11	0.07	0.20

Table B9 Representative turbulence intensity versus wind direction at 100 m; sector-width 30°

	Power Law Exponent, α, by Direction Sector and WS(100)											
WS(100) [m/s]	**345° - 15°**	**15° - 45°**	**45° - 75°**	**75° - 105°**	**105° - 135°**	**135° - 165°**	**165° - 195°**	**195° - 225°**	**225° - 255°**	**255° - 285°**	**285° - 315°**	**315° - 345°**
0 – 1	-0.141	-0.222	-0.24	-0.27	-0.221	-0.294	-0.259	-0.253	-0.258	-0.191	-0.209	-0.238
1 - 2	0.025	0.001	-0.058	-0.097	-0.089	-0.082	-0.043	-0.031	-0.001	0.016	0.054	0.053
2 - 3	0.034	0.019	0.011	0	-0.025	-0.002	0.037	0.065	0.057	0.046	0.049	0.064
3 - 4	0.055	0.041	0.06	0.041	0.011	0.028	0.064	0.091	0.072	0.061	0.091	0.078
4 - 5	0.079	0.06	0.071	0.08	0.039	0.066	0.089	0.112	0.088	0.076	0.109	0.091
5 - 6	0.092	0.064	0.082	0.104	0.057	0.098	0.088	0.101	0.107	0.095	0.113	0.098
6 - 7	0.105	0.067	0.098	0.113	0.071	0.127	0.121	0.093	0.11	0.12	0.125	0.124
7 - 8	0.102	0.08	0.117	0.124	0.08	0.135	0.152	0.074	0.123	0.13	0.142	0.117
8 - 9	0.106	0.075	0.124	0.136	0.085	0.168	0.148	0.066	0.124	0.138	0.148	0.12
9 - 10	0.11	0.074	0.123	0.149	0.094	0.16	0.127	0.07	0.128	0.139	0.154	0.111
10 - 11	0.108	0.102	0.144	0.128	0.096	0.161	0.141	0.063	0.133	0.141	0.147	0.121
11 - 12	0.103	0.112	0.151	0.124	0.08	0.147	0.114	0.052	0.123	0.148	0.145	0.11
12 - 13	0.1	0.112	0.153	0.114	0.076	0.156	0.111	0.065	0.117	0.147	0.144	0.112
13 - 14	0.103	0.114	0.148	0.099	0.077	0.141	0.138	0.091	0.115	0.143	0.132	0.115
14 - 15	0.103	0.092	0.144	0.079	0.073	0.097	0.155	0.092	0.11	0.143	0.132	0.092
15 - 16	0.106	0.105	0.183	0.074	0.073	0.118	0.123	0.114	0.112	0.147	0.128	0.092
16 - 17	0.108	0.123	0.268	0.069	0.077	0.133		0.109	0.122	0.145	0.126	0.09
17 - 18	0.107	0.112		0.062	0.07	0.154		0.106	0.116	0.14	0.12	0.095
18 - 19	0.106	0.111		0.086	0.069	0.156		0.084	0.115	0.141	0.117	0.094
19 - 20	0.107			0.133	0.059	0.132		0.088	0.109	0.143	0.124	0.096
20 - 21	0.107			0.089	0.073			0.082	0.108	0.136	0.118	0.093
21 - 22	0.105			0.062	0.07			0.085	0.109	0.135	0.118	0.096
22 - 23	0.106			0.054				0.088	0.104	0.134	0.119	
23 - 24	0.133	0.106		0.062				0.08	0.1	0.132	0.126	
24 - 25	0.108	0.113						0.077	0.099	0.124	0.119	
25 - 26								0.083	0.103	0.126		
26 - 27								0.09	0.102	0.123	0.114	
27 - 28								0.098	0.095	0.118		
28 - 29									0.106			
29 - 30									0.105			
30 - 31									0.099			
31 - 32									0.123			
32 - 33												
33 - 34												
34 - 35												

Table B10 Wind shear exponent by direction sensor and wind speed at 100 m using the method of bins; bin-width 1 m/s and sector-width 30°