CHALMERS

Hönö Wind Resource Assessment

A statistical report on Chalmers wind turbine station data

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Division of Electric Power Engineering
Department of Energy & Environment
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Cover picture photographed at Chalmers wind turbine station in Hönö during summer 2013.

శ్వసన: స్పర్శన: వాయు: మాతరిశ్వ: సదాగతి:

పృషదశ్వ: గంధవ: గంధవా: అనిల:

ఆశుగ: సమీర: మారుత:మరుత: జగత్ప్రాణ:

సభస్వ: వాత: పవన: పావమాన: ప్రభఞ్జన:

Different names for wind in Sanskrit written in Telugu script. The above names in English script can be written as

Svasanah Sparsanah Vayuh Maatarishwah Sadagatih

Prushadaswah Gandhavah Gandhavaah Anilah

Aasuguh Sameerah Maaruthah Maruthah Jagatpraanah

Sabhaswah Vathah Pavanah Paavamaanah Prabhanjanah

To my parents...

Preface

This report concerns documentation of the anemometer installations and analysis of wind data acquired from the Chalmers wind turbine station located north-west of Göteborg, in an island Hönö, within the Öckerö archipelago.

Acknowledgements

First and foremost, I would like to express my sincere gratitude to my supervisor Magnus Ellsén for believing in me and giving me the opportunity to perform this project. He was very patient and supportive through out. Discussions with him helped me to gain innumerable knowledge on wind engineering. I would like to thank Professor Ola Carlson for providing the financial support for this project. I would like to thank Asst. Professor Peiyuan Chen for his support during this project. I would also like to acknowledge the support and help from my sister Saipriya Thalluri and brother-in-law Dr.Gopala Krishna Thalluri throughout my Master studies and also during this project. I also would like to thank my friends Ajay, Murali Kommuri, Naga VishnuKanth, Seshendra, Swathi Kiranmayee for their cooperation and support. Furthermore, I would like to thank everyone at the division of electric power engineering for providing with a very good working environment.

Sai Venkata Ganesh Koushik Madapati
Göteborg, Sweden, 2014

Contents

Nomenclature

Abbreviations

DAV	Data Availability
DNA	Data Not Available
NA	Not Applicable
TI	Turbulence Intensity
WDM	Wind Direction from Gill Wind Master anemometer
WDO	Wind Direction from Gill Wind Observer anemometer
WDX	Wind Direction from Vaisala sensor
WSM	Wind Speed from Gill Wind Master anemometer, also used synonymous to WSM anemometer
WSO	Wind Speed from Gill Wind Observer anemometer, also used synonymous to WSO anemometer
WST	Wind Speed from Theis anemometer, also used synonymous to WST anemometer
WSX	Wind Speed from Vaisala sensor, also used synonymous to WXT510 anemometer

Symbols

C	Scale factor of Weibull probability distribution function, ms^{-1}
K	Shape factor of Weibull probability distribution function, dimension-less

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Chapter 1

Introduction

1.1 Description of the site

The Chalmers wind turbine owned by the department of energy and environment and division of electric power engineering, Chalmers University was started/installed in 1984. It is located on the island Hönö within Öckerö community which is situated about 15 kilometres north-west of Göteborg. At the site there is an experimental 30 kW wind turbine along with two meteorological masts. This site serves as a demonstration facility for various wind power related studies. Every year students of electric power engineering Masters program visit this site as a part of their curriculum to perform wind power calculations. Many candidate workers also perform wind power studies on the data acquired from the Chalmers wind turbine station. This site is open for general public during Göteborg science festival (Vetenskapsfestivalen), where people meet wind power experts and learn various aspects of wind power. This wind turbine station is managed by Magnus Ellsén.

Bird's eye view of the Chalmers wind turbine station is shown in Figure 1.1. Meteorological mast-1 is located on the north-west of Chalmers turbine. North of the site is relatively open, with the sea water towards Öckerö island. Towards north-east of the site, at about 150 meters distance there is a 660kW Vestas commercial wind turbine. Different anemometers at the site and their corresponding heights are shown in Table 1.1. The heights of the anemometers are with reference to the Chalmers wind turbine base plate. Map of Hönö and its surrounding geography is shown in Appendix A.

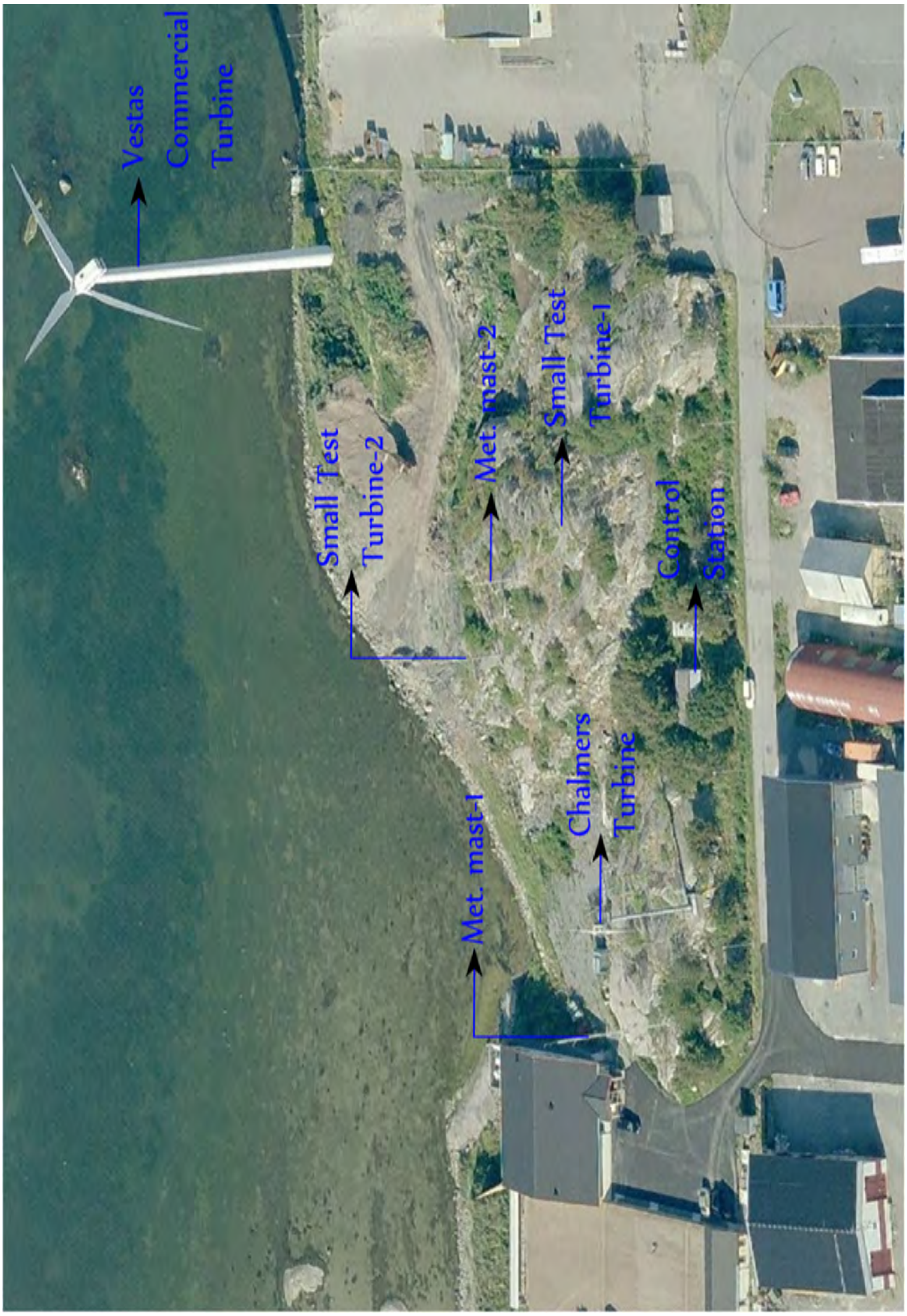


Figure 1.1: Bird view of the Chalmers wind turbine site (Source: Bing Maps)

Table 1.1: Description of different anemometers

Manufacturer Type	Acronym	Height [m]	Mast	Boom orientation	Mast wake sector
Vaisala, WXT510/520	WSX	10	2	240°	50°-90°
Thies	WST	18.5	1	$\sim 318°$	100°-150°
Gill, Wind observer	WSO	18.5	1	$\sim 317°$	110°-142°
Gill, Wind master	WSM	28	1	NA	NA
Thies	WSNA	20	Nacelle	NA	NA

1.2 Meteorological Mast-1

Figure 1.2: Meteorological mast-1, Wind Master on top spar, Wind Observer on a 3 meter boom, Cup anemometer on 1.4 meter boom and also 6 guy wires that support mast-1

Lattice mast-1 has a triangular foot print. There are 6 guy wires that support the lattice mast-1, 3 guy wires above 18.5 meters and 3 guy wires below 18.5 meters of height. These guy wires hang from the vertices of the masts along the vertex and are clamped to the ground. Meteorological mast-1 has 3 anemometers installed at different heights. WST is the mechanical cup anemometer manufactured by Theis and is installed on a boom at about 20 meters height with respect to the Chalmers wind turbine base plate. The length of WST boom is approximately 1.4 meters. It is one of the old anemometers which is in use since several years. It is interfaced to the measurement computer by a LabView program and has a sample acquisition rate of 1 Hz. This anemometer is out of operation from November 2012.

Figure 1.3: WSO and WST on their booms at about 20 m pointing towards Northwest about 318° pointing towards Öckerö community church, Tangential view from the mast-1

WSO is a sonic anemometer manufactured by Gill instruments and is installed on a boom around the same height as WST, it came into operation since the end of September 2012. It has a sample acquisition rate of 10 Hz and was at first interfaced to the measurement computer by a logging program, WindView from Gill instruments. Later, the interface to WSO was implemented in the LabView measurement system. These two anemometer's booms are aligned towards Northwest direction approximately 318° with respect to the mast-1 and are at about the hub height of the Chalmers wind turbine. Figure 1.3 shows the actual view of the two anemometers from the point their booms originate from the mast. There is a slight difference in the orientation of WSO boom and WST boom with respect to mast-1 which can be seen from Figure 1.4. For simplicity, it is assumed that the orientation of these two anemometers is the same while deriving anemometer correction factors.

Figure 1.4: WSO and WST on their booms, view from WSO. In the background is Chalmers wind turbine and buildings towards Hönö ferry station

Meteorological mast-1 is also equipped with another sonic anemometer, WSM manufactured by Gill instruments which is installed on the top of lattice mast-1 at a height of about 28.5 meters as shown in the Figure 1.2. This sensor has a sample acquisition rate of 20 Hz and was also first interfaced to the measurement computer by a logging program, WindView from Gill instruments and was later replaced by LabView measurement system. WindMaster anemometer is shown in the Figure 1.5.

Figure 1.5: Gill wind master anemometer (source: Gill Instruments)

1.2.1 Factors Effecting Anemometer Readings

Figure 1.6 shows the top view schematic of WST installation on met. mast-1 and sectors around it. WST in Sector-1 (S1) could experience turbulence from nearby Vestas wind turbine. Towards North and north west the terrain is largely free from obstacles with sea water towards Öckerö. Sector-2 (S2) is a disturbed sector, considering the data recorded by WST. This is because the wind blowing in this sector hits initially WSO before reaching WST. This turbulence can contribute to erroneous data recordings in WST. Sector-3 (S3) contains buildings of height about 11 meters, which may cause turbulence in WST readings. Sector-4 (S4) would experience wake effect due to met. mast-1 lattice tower. In addition to the disturbed sectors, WST could experience friction during lower wind speeds.

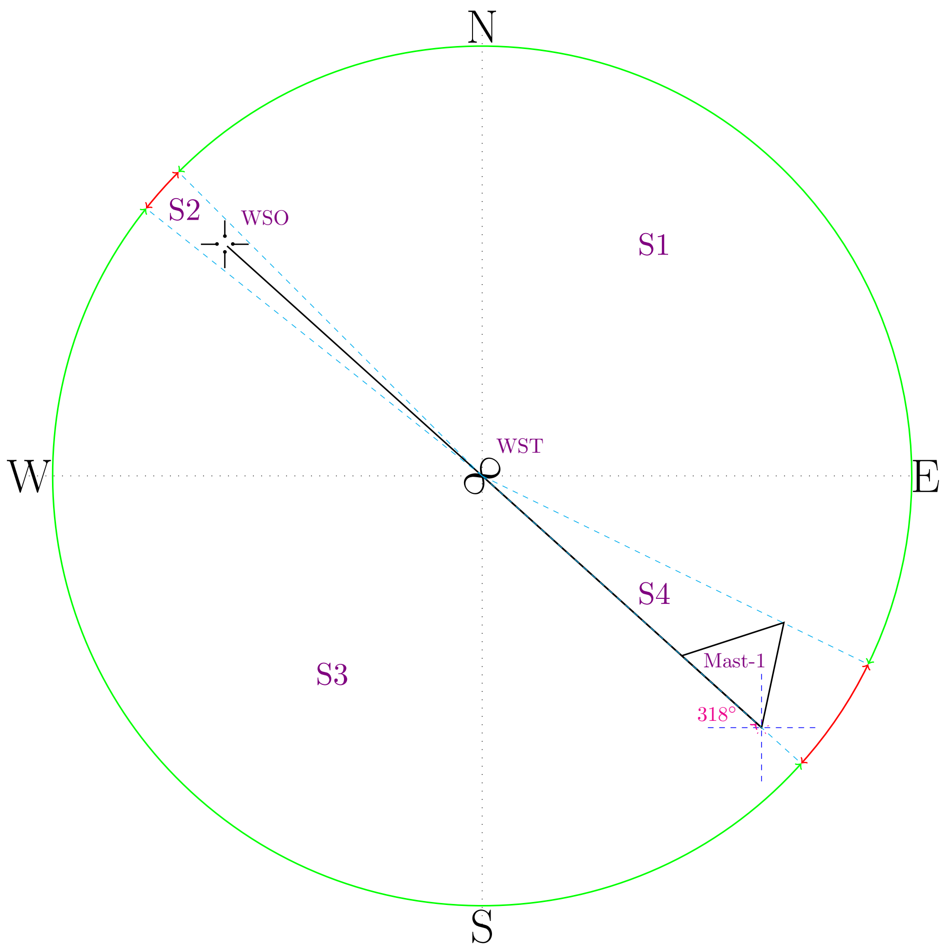


Figure 1.6: Top view schematic of sectors around WST anemometer

WSO anemometer would also have similar disturbed sectors as WST, except that its mast wake sector would be less than WST and it do not have friction effect. The 3 top guy wires hanged from mast-1 could also interfere with the readings of WSO and WST.

1.3 Meteorological Mast-2

Figure 1.7: Meteorological mast-2, Vaisala weather transmitter at around 9 meters, 3 guy wires that support mast-2 and at the back to left: sea water towards Öckerö and to right sea water towards Björkö and Hisingen

In addition to meteorological mast-1 there is another meteorological mast (mast-2) which has one weather transmitter sensor (WXT510). The weather sensor is mounted on a 1.4 meter boom at about 9 meters height. The boom is mounted towards south-west at approximately 240° with respect to mast-2 as shown in the Figure 1.7. The lattice mast-2 also has a triangular foot print and similar dimensions, but not the same height as mast-1. There are three guy wires that support the lattice mast-2. These guy wires hang from a height below the wind sensor. This sensor is manufactured by Vaisala corporation. This is a combined sensor measuring six different weather parameters- wind speed, wind direction, barometric pressure, temperature, rainfall and relative humidity. Wind speed and direction are measured by ultrasonic signals sent between three transmitters. This sensor does not have moving parts which making it maintenance free [1]. Figure 1.7 shows the Vaisala weather transmitter sensor installed on mast-2. This sensor is in use from past several years.

1.3.1 Factors Effecting WXT510 Readings

WSX sensor could experience turbulence from near-by buildings and trees due to its lower height. The terrain towards North and few parts of north-east sector are obstacle free and therefore the readings from these directions are expected to be less disturbed. Figure 1.8 shows the top view schematic of sectors around WSX anemometer. Sector-1 (S1) is in the mast wake of mast-2. Part of Sector-2 (S2) is under the wake of Vestas turbine. Sector-3 (S3) is mostly undisturbed with water towards Öckerö island. Sector-4 (S4) contains buildings which would effect the sensor readings.

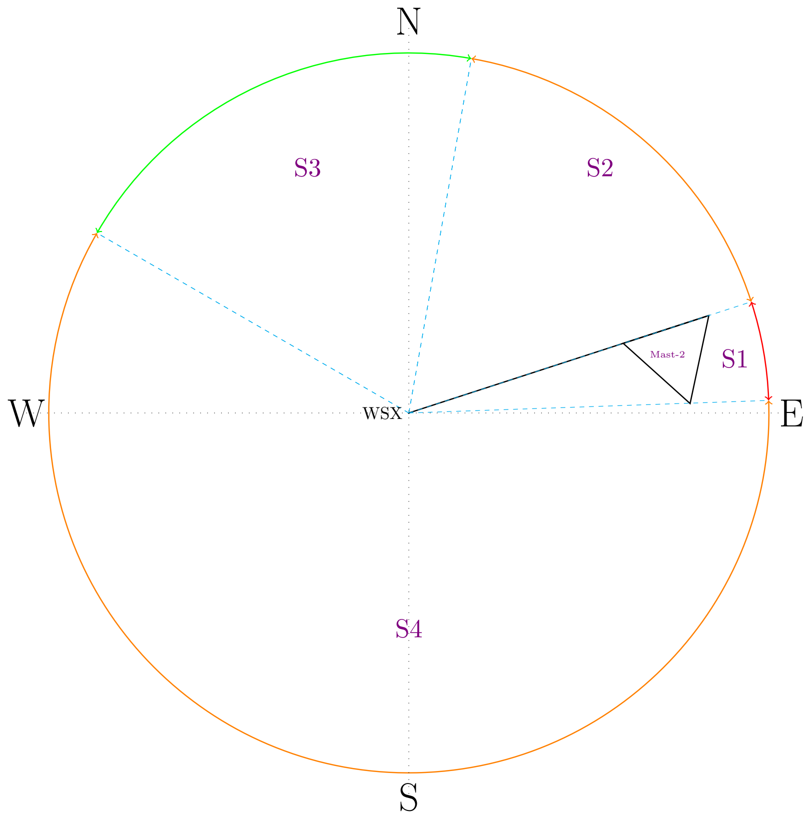


Figure 1.8: Top view schematic of sectors around WSX anemometer

1.4 Wind Data Correction

Raw data is acquired from the measurement computer located in the control station at the Hönö . The readings are monitored by Magnus Ellsén, remotely from the division of electric power engineering. As mentioned in the above sections, the wind readings are disturbed in different sectors for different anemometers. Hence, the following corrections are applied to the raw data of different anemometers

1.4.1 WST Correction

1.4.1.1 Friction Calibration

The raw data from WST anemometer is of 1 Hz precision. The raw data from WSO anemometer is of 10 Hz precision. WSO data is processed to have 1 Hz precision. The data from both these anemometers is compared to calibrate WST anemometer. Table C.1 shows the impact of friction on WST readings during low wind speeds. A calibration factor for WST friction is obtained which is given in Section 2.1.1.

1.4.1.2 Mast wake correction

Calibrated WST data is compared to processed WSM data of 1 Hz precision to identify the mast wake sector of WST, which is given in Section 2.2. The samples within the mast wake sector for both the anemometers are then discarded and a correction factor of WST is calculated. The correction factor thus obtained is applied to 1 Hz WST data and the statistics are presented. The correction factor for WST anemometer is given in Chapter 2.

1.4.2 WSO Correction

1.4.2.1 Mast wake correction

The raw data from WSO anemometer is of 10 Hz precision. To identify the mast wake sector of WSO, the raw data is converted to 1 Hz precision and then compared to WSM data which also have 1 Hz precision. The samples that lies within the mast wake sector are discarded for both the anemometers and a correction factor for WSO anemometer within the mast wake sector is calculated. The correction factor obtained is applied to the 10 Hz WSO data, and the statistics are presented. The correction factor for WSO anemometer is given in Chapter 3.

1.4.3 WSX Correction

1.4.3.1 Mast wake correction

The raw data from WXT510 sensor is of 1 Hz precision. This data is compared to processed WSM data to identify the mast wake sector. The samples within the mast wake sector is discarded for both the anemometers and a correction factor of WSX within mast wake sector is then calculated. The correction factor thus obtained is applied to 1 Hz WXT510 data and the statistics are presented. The correction factor for WXT510 anemometer is given in Chapter 4.

WST anemometer do not have wind direction sensor. Wind direction readings from the WXT510 weather sensor are used in conjugation with WST wind speed readings to present WST statistics. The vertical heights of these anemometers are different also the placement of these two weather sensors are different. This could lead to slight differences in wind rose sectors and mast wake sectors. In wind statistics evaluation, 10 minute average data is considered. This resolution is the standard resolution that is followed in many wind resource assessment reports published.

1.5 Wind Statistics Evaluation

To present the statistics of wind data, the following parameters are calculated from the measurement data files. Their mathematical formulation is as follows

Turbulence intensity is defined as the ratio of standard deviation of wind speed to the mean value of wind speed. It is expressed mathematically as [2]

$$ti = \frac{\sigma}{\omega} \tag{1.1}$$

where:
σ is the standard deviation of wind speed
ω is the mean wind speed

Matlab program that calculates 10 minute average turbulence intensity vector from vector of one second wind speed values is given in Section I.1.

Weibull distribution is a probability distribution function that models the wind speed distribution at a given site. It is characterised by two parameters scale factor (C) and shape factor (K). Weibull function for a wind speed of ω is mathematically expressed as [3]

$$f(w) = \frac{K}{C}(\frac{\omega}{C})^{K-1} \times exp[-(\frac{w}{C})^K] \tag{1.2}$$

$$C = \frac{\omega}{\gamma(1+\frac{1}{K})} \tag{1.3}$$

Scale factor and shape factors defines the nature of Weibull distribution plot. Scale factor determines how windy the given site is. Scale factor is measured in m/s. Shape factor is a dimension less parameter that determines the wind variations. K=1,2,3 corresponds to high, moderate and consistent winds respectively [4]. To obtain a the above parameters in Matlab, a built in function *wblfit* is used. The input to this function is wind speed data and the output is shape and scale factor. Matlab program that plots wind speed distribution and Weibull probability distribution function from a vector of wind speed values is given in Section I.2.

Data availability is calculated based on the following mathematical expression

$$D = \frac{\text{Recorded 10 mins. data in the interval}}{\text{Total 10 mins. in the interval}} \times 100 \tag{1.4}$$

1.6 Meteorological Statistics from WXT510

1.6.1 Data Availability

Negative data availability represents the unavailability of data or non-existence of anemometers. One minute averages are considered for the meteorological data analysis. The bar graphs showing the statistics could be misleading when the data availability is low, therefore data availability should be taken into account while evaluating the statistics. In the caption of the bar graphs a hyper link is given which points towards its respective data availability (DAV).

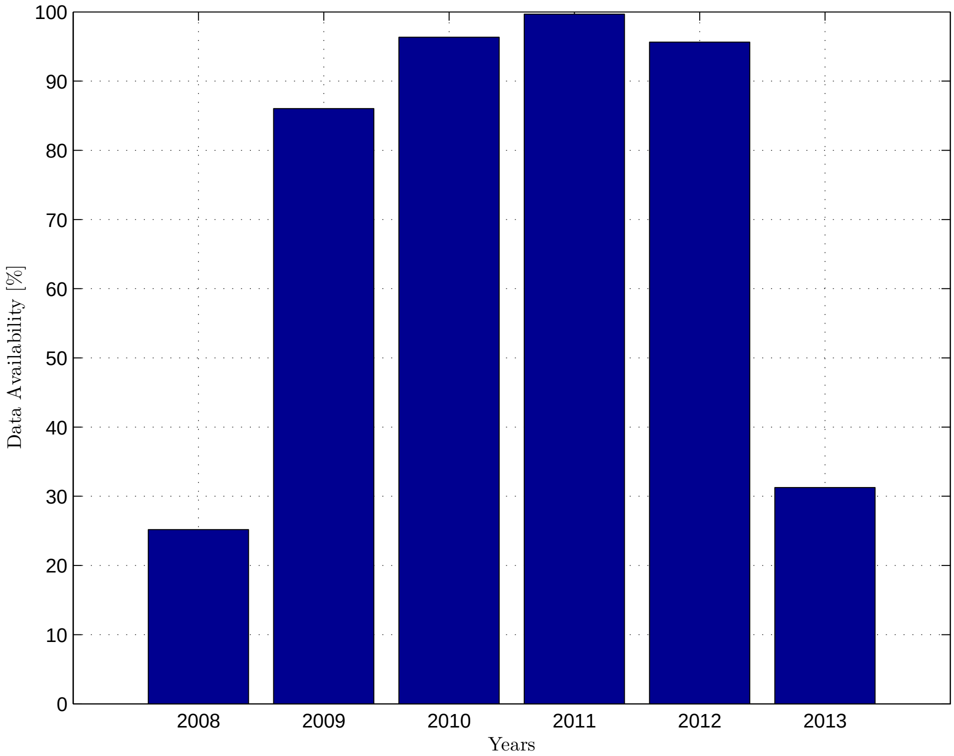


Figure 1.9: Data availability of meteorological data from WXT510 for different years

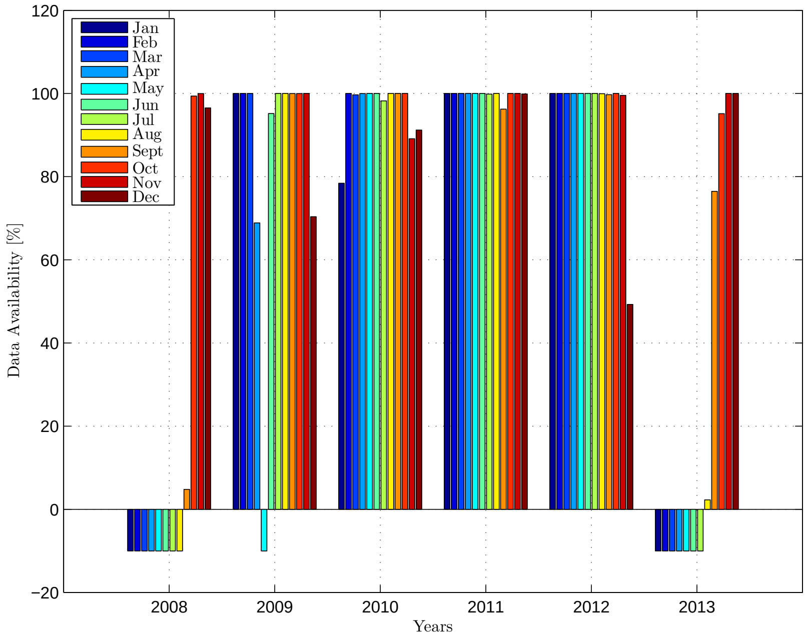


Figure 1.10: Data availability of meteorological data for different years

1.6.2 Precipitation

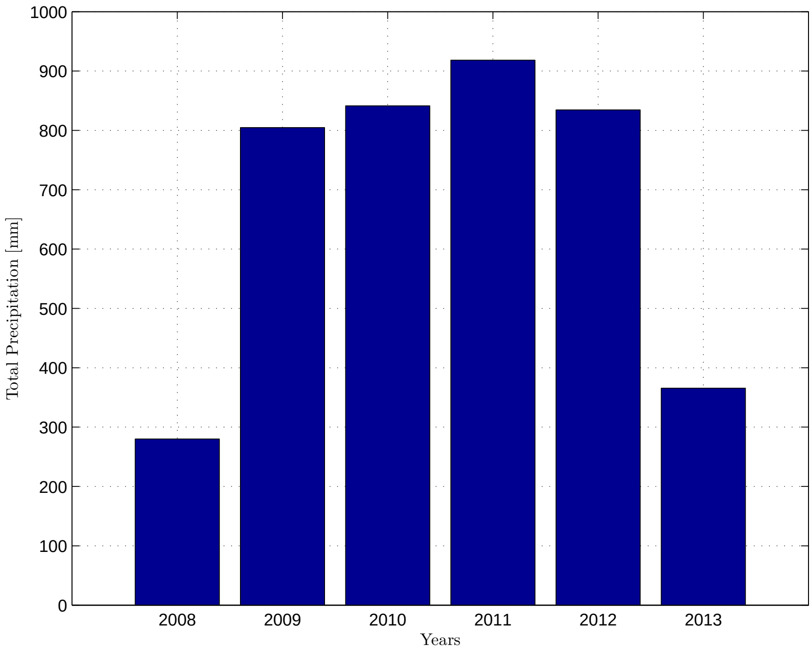


Figure 1.11: Total precipitation for different years; DAV: 1.9

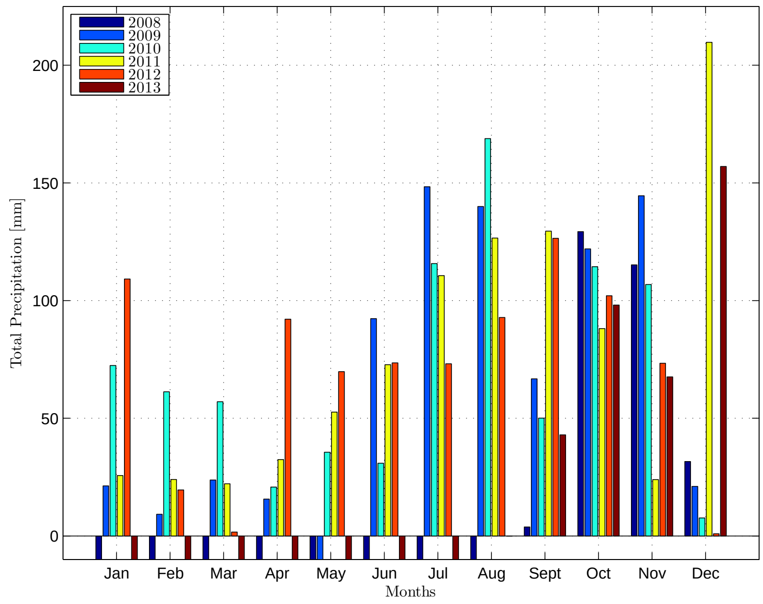


Figure 1.12: Total precipitation for different years and months; DAV: 1.10

1.6.3 Air Temperature

Figure 1.13: Temperature variation for different years; DAV: 1.9

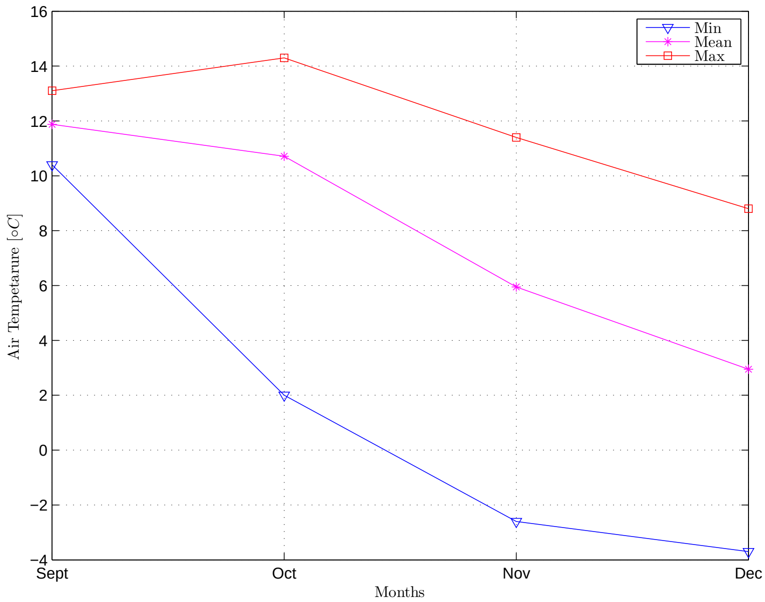


Figure 1.14: Temperature variation for different months during 2008; DAV: 1.10

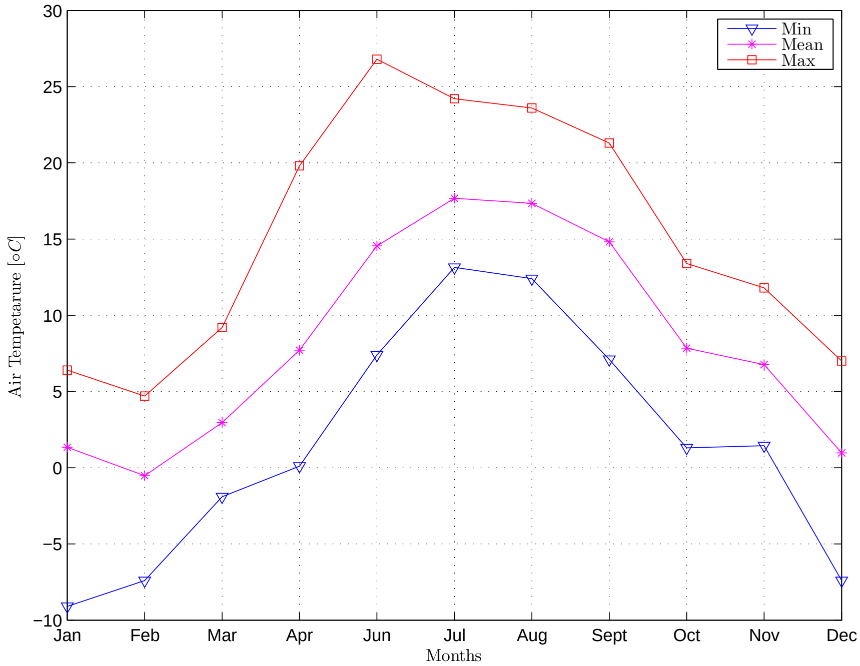


Figure 1.15: Temperature variation for different months during 2009; DAV: 1.10

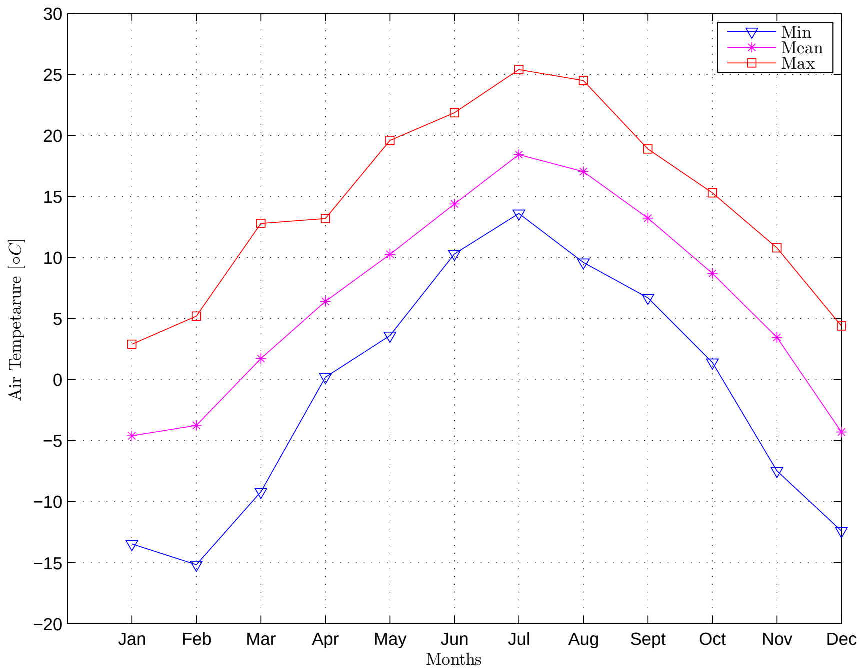


Figure 1.16: Temperature variation for different months during 2010; DAV: 1.10

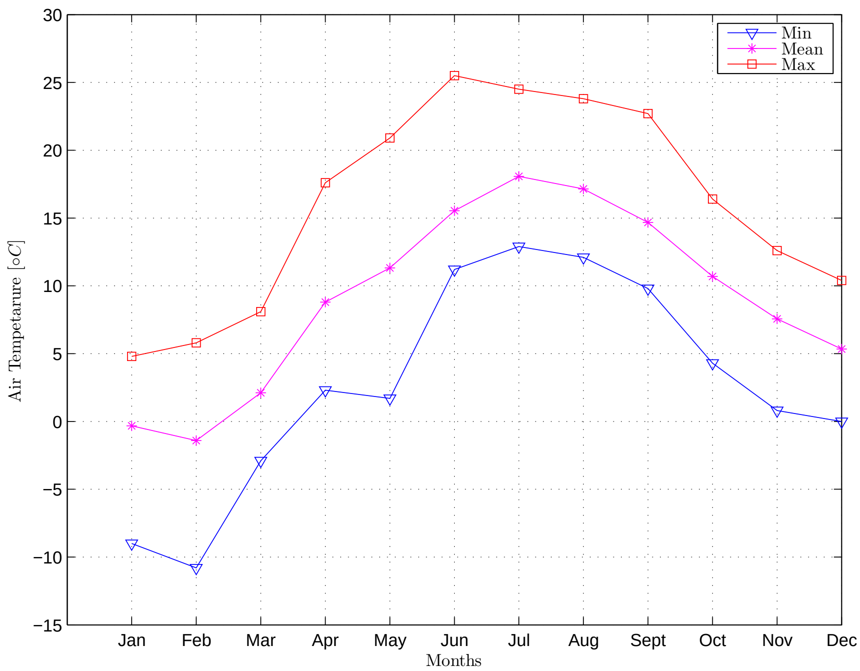


Figure 1.17: Temperature variation for different months during 2011; DAV: 1.10

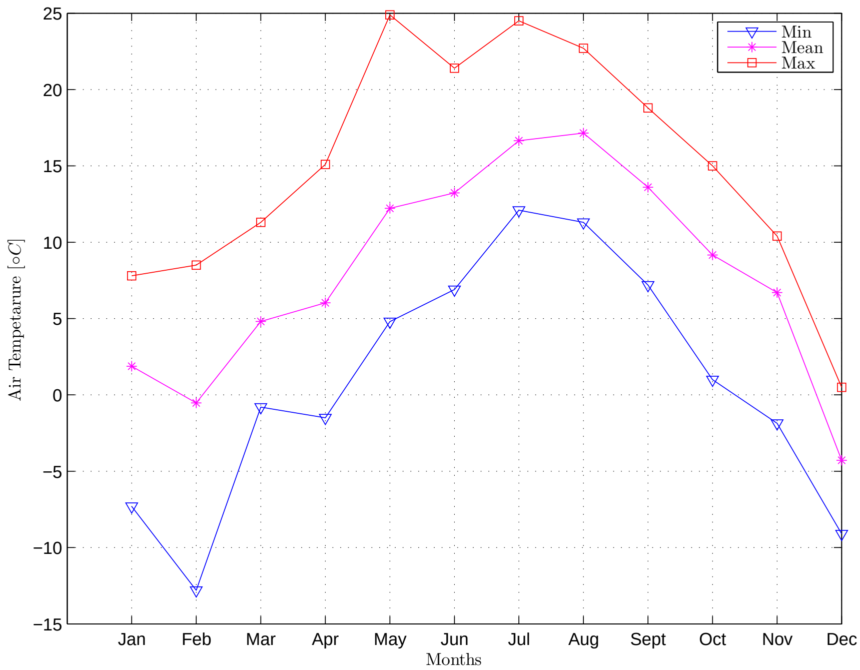


Figure 1.18: Temperature variation for different months during 2012; DAV: 1.10

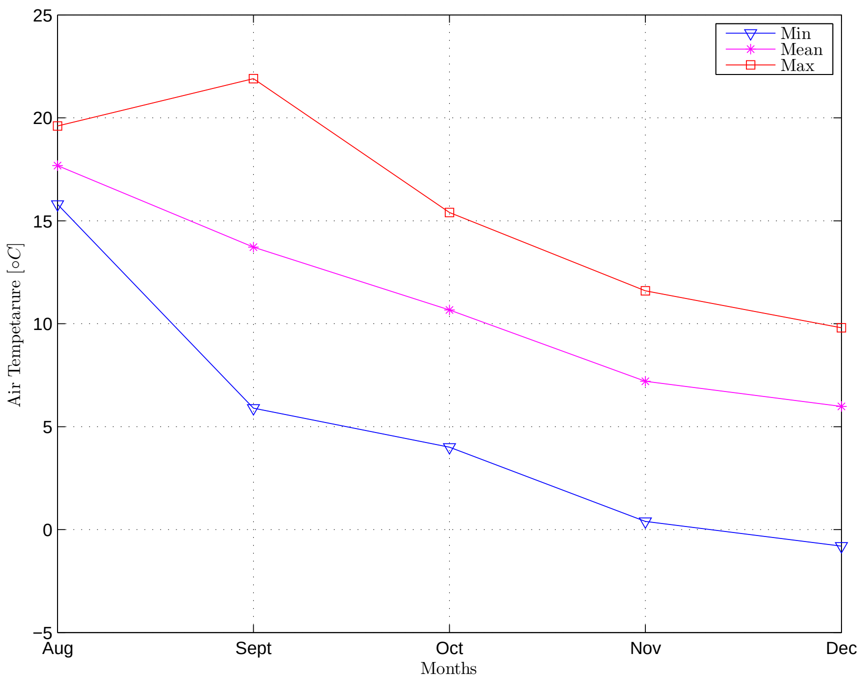


Figure 1.19: Temperature variation for different months during 2013; DAV: 1.10

1.6.4 Air Pressure

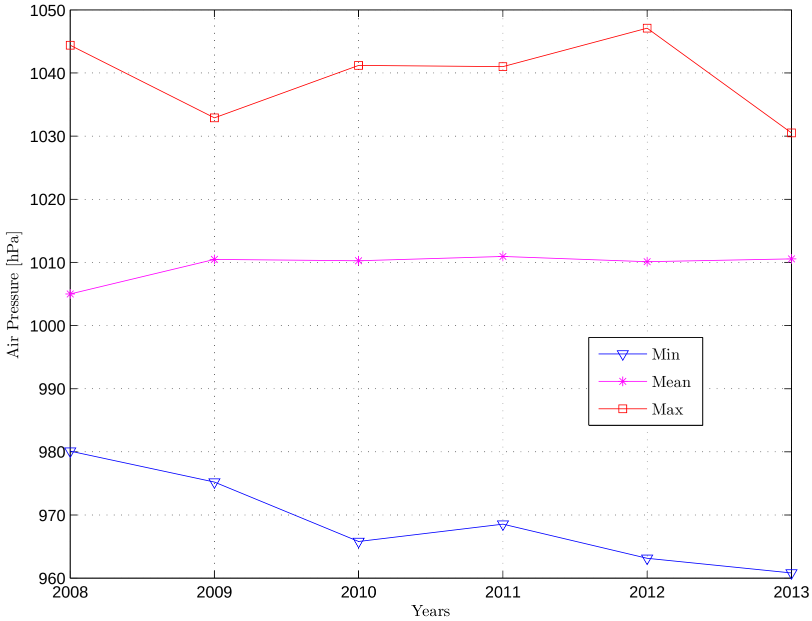


Figure 1.20: Air Pressure variation for different years; DAV: 1.9

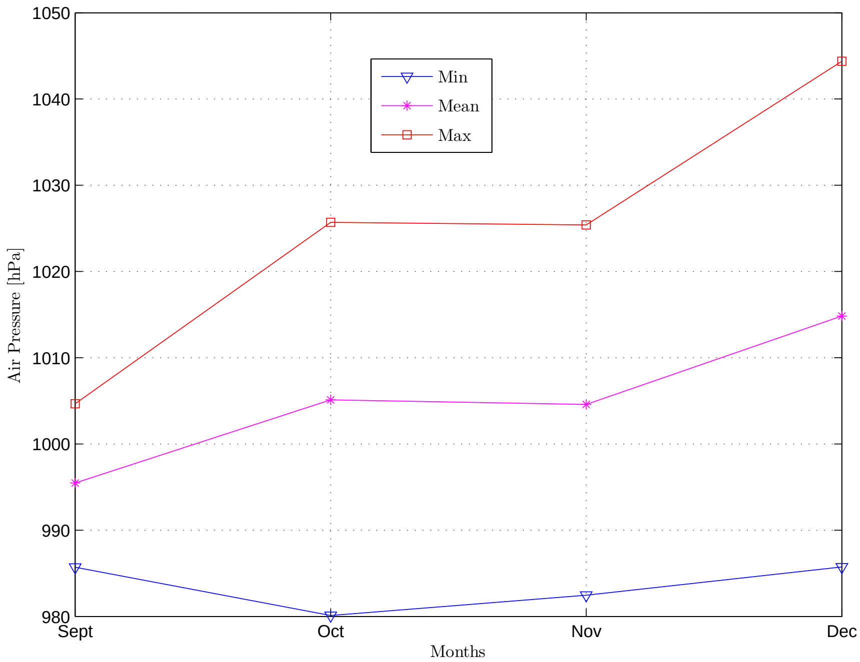


Figure 1.21: Air Pressure variation for different months during 2008; DAV: 1.10

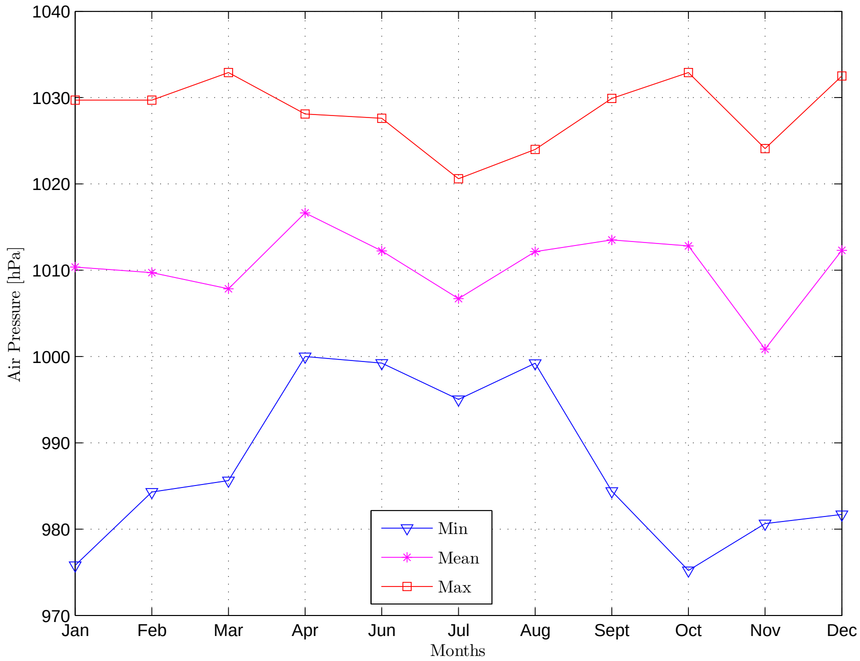


Figure 1.22: Air Pressure variation for different months during 2009; DAV: 1.10

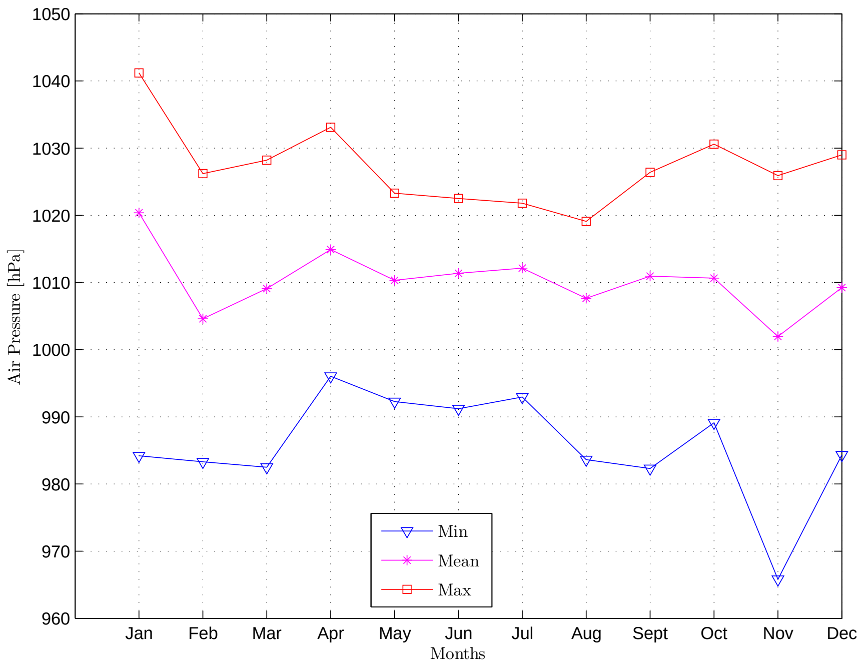


Figure 1.23: Air Pressure variation for different months during 2010; DAV: 1.10

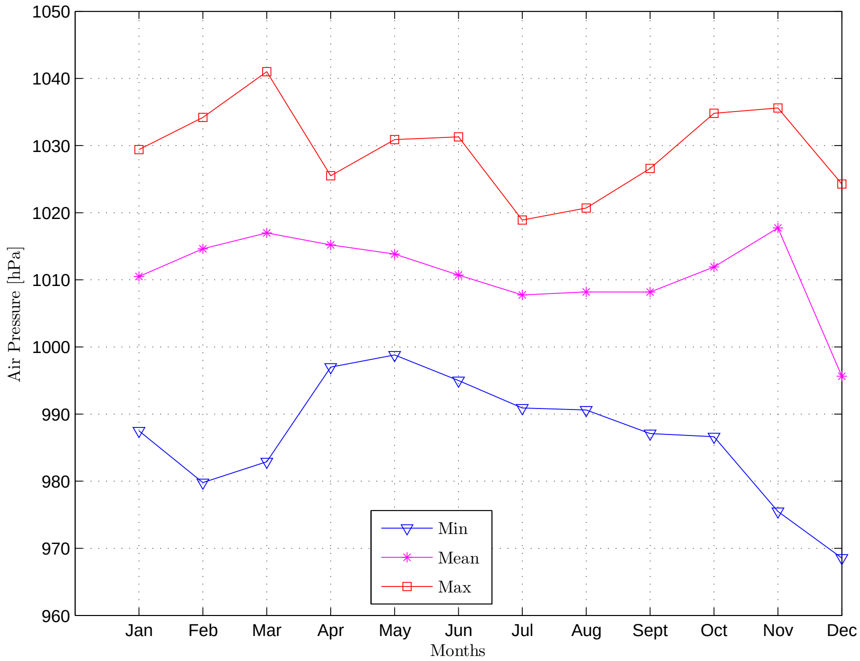


Figure 1.24: Air Pressure variation for different months during 2011; DAV: 1.10

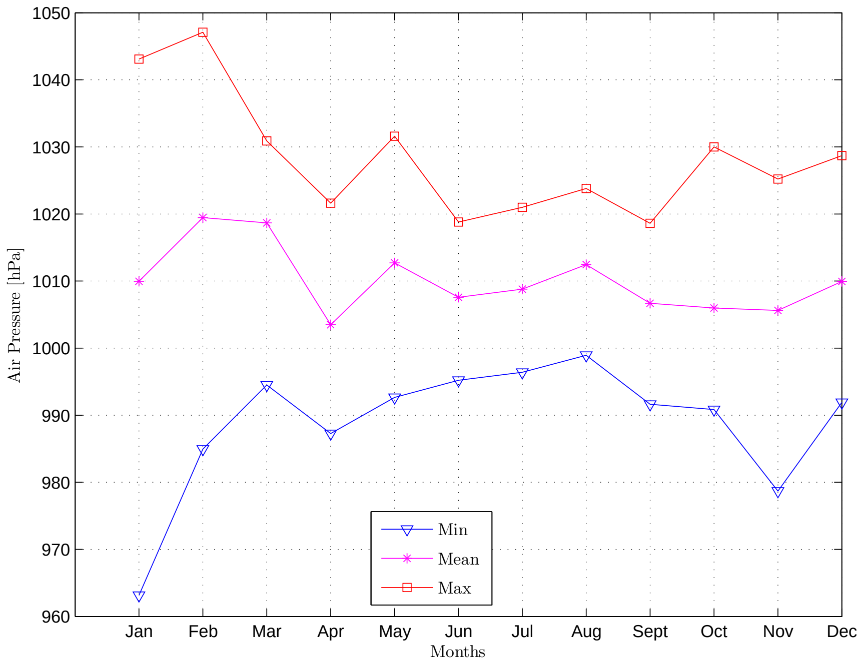


Figure 1.25: Air Pressure variation for different months during 2012; DAV: 1.10

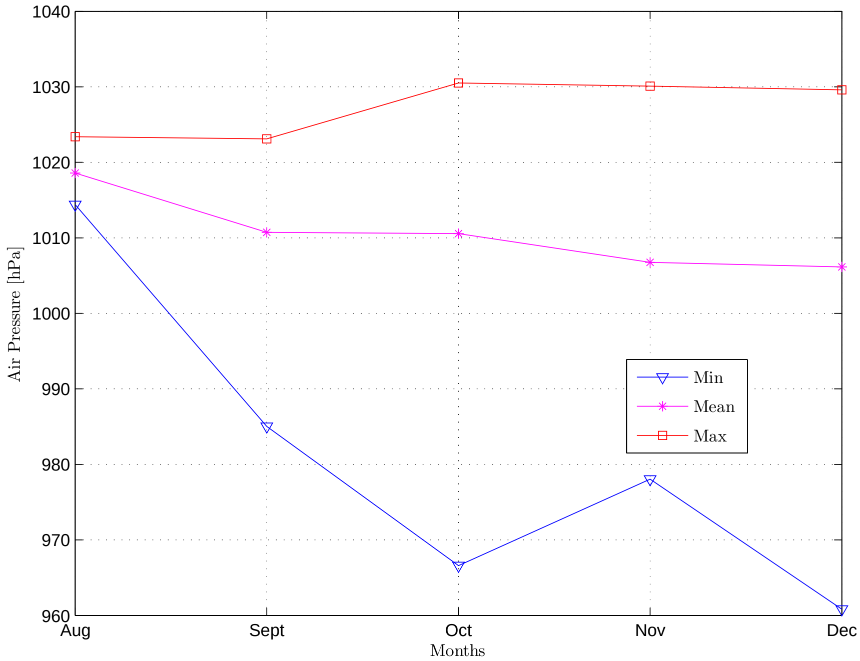


Figure 1.26: Air Pressure variation for different months during 2013; DAV: 1.10

1.6.5 Relative Humidity

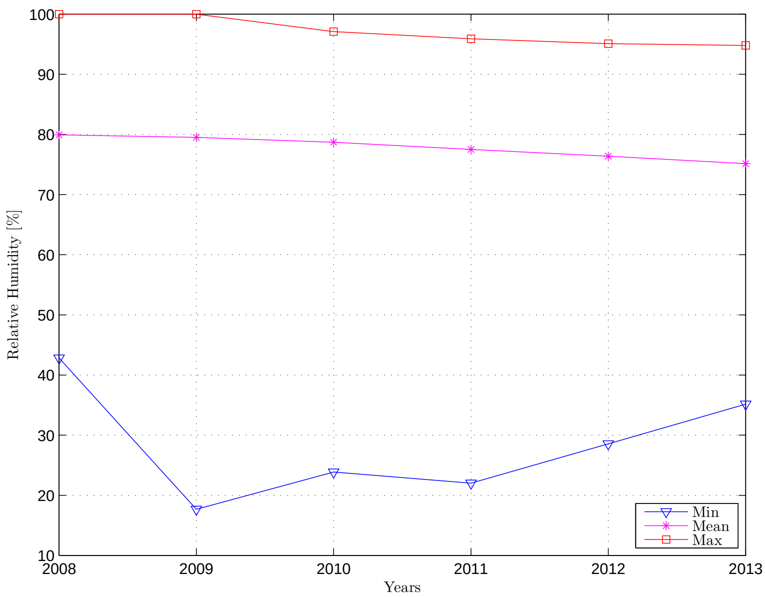


Figure 1.27: Relative humidity variation for different years; DAV: 1.9

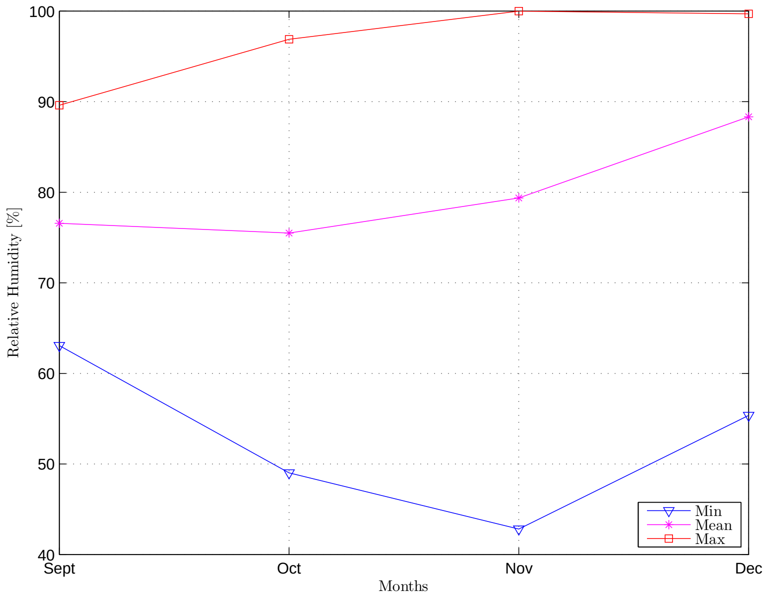


Figure 1.28: Relative humidity for different months during 2008; DAV: 1.10

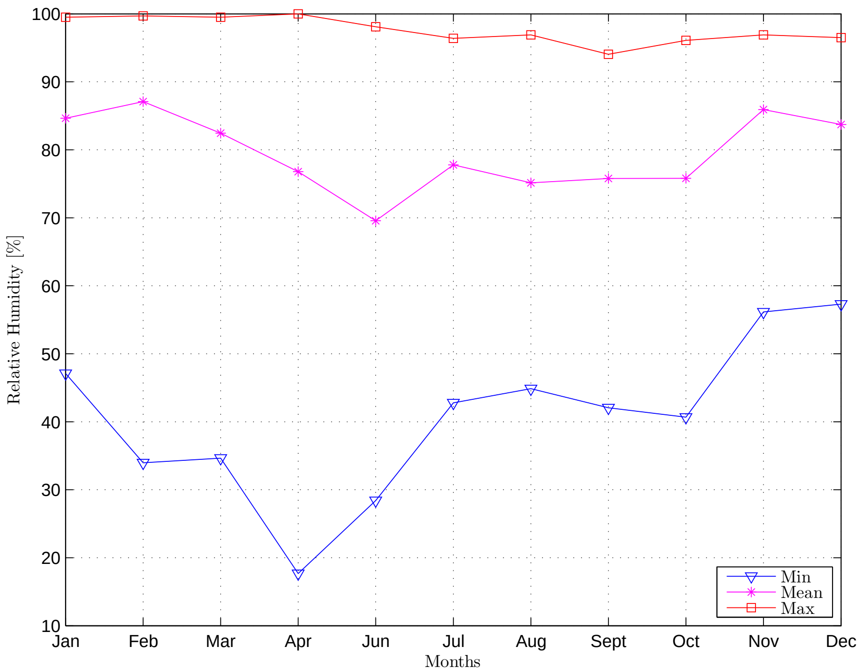


Figure 1.29: Relative humidity for different months during 2009; DAV: 1.10

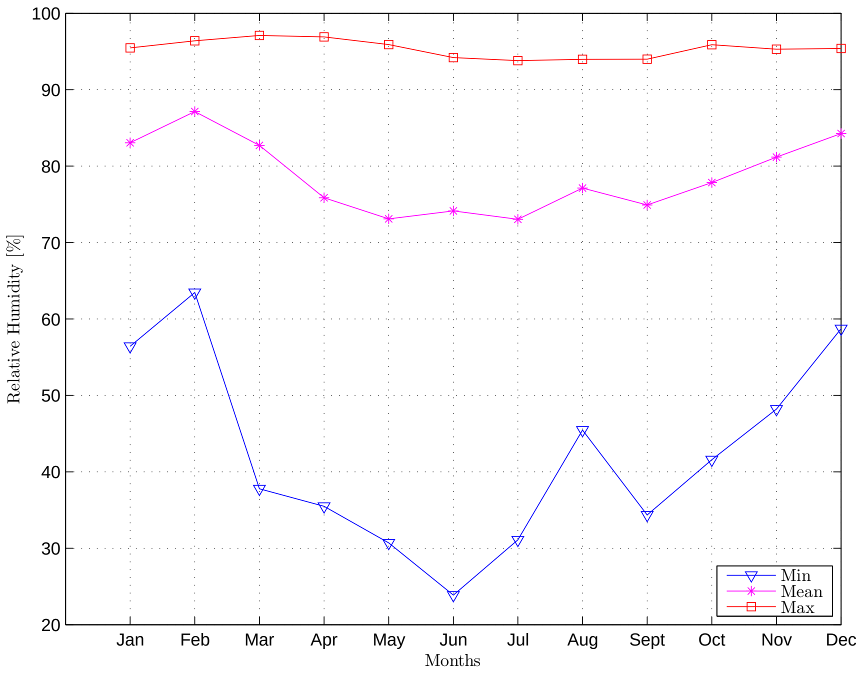


Figure 1.30: Relative humidity for different months during 2010; DAV: 1.10

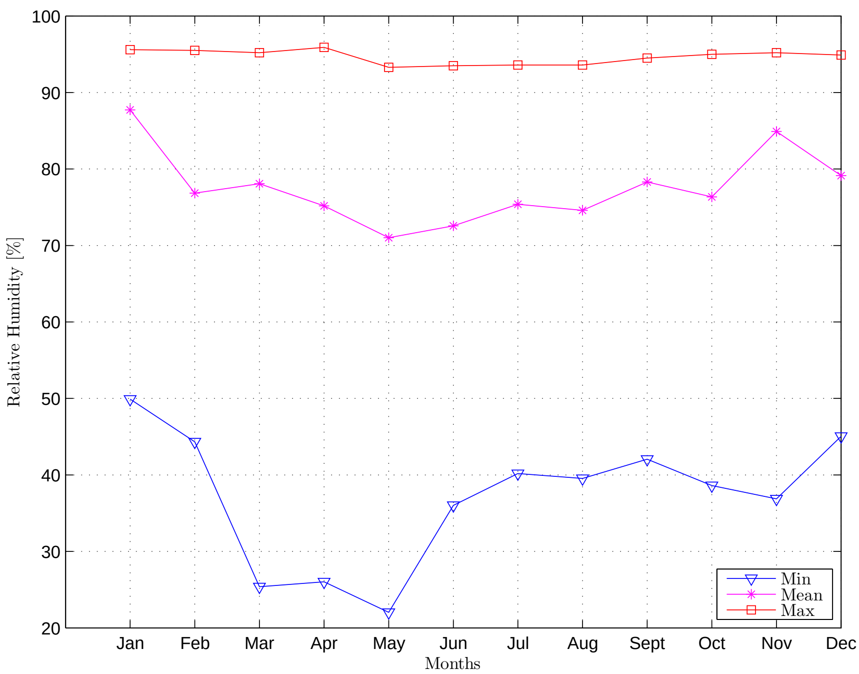


Figure 1.31: Relative humidity for different months during 2011; DAV: 1.10

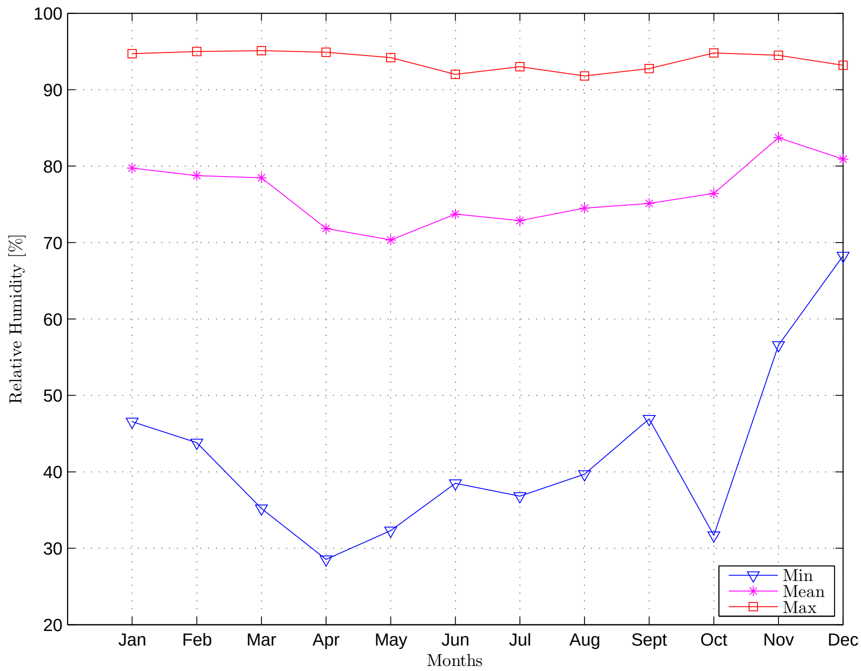


Figure 1.32: Relative humidity for different months during 2012; DAV: 1.10

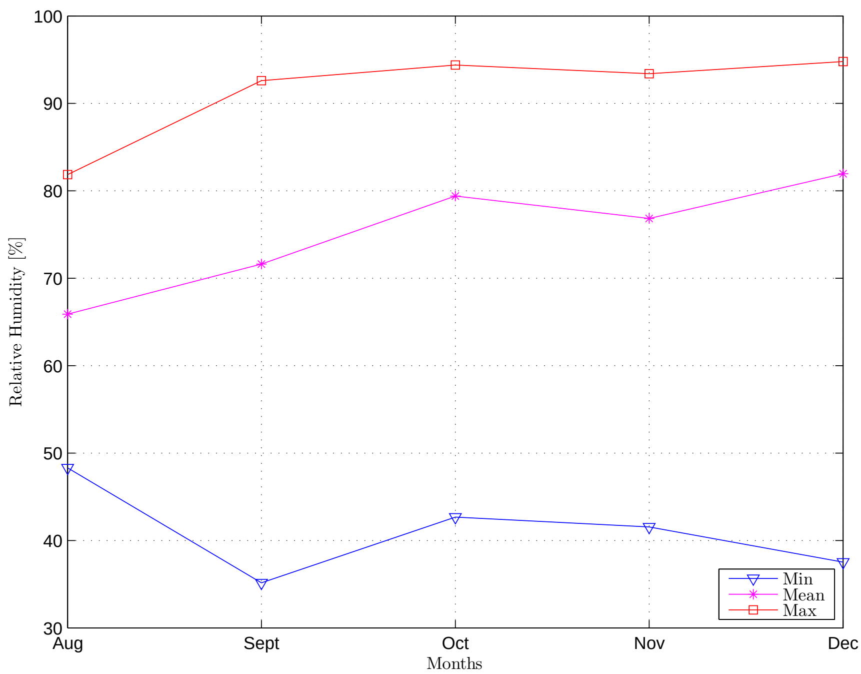


Figure 1.33: Relative humidity for different months during 2013; DAV: 1.10

1.7 Wind Statistics

Negative wind data availability in the bar graphs represents the unavailability of data or non-existence of anemometers. In the caption of the bar charts is the link to respective data availability bar graphs. Table 1.2 shows the wind speed mean of different anemometers for different years. DNA represents data non-availability, DAV represents data availability.

Table 1.2: Mean wind speed and data availability for different years, more detailed month wise statistics given in Tables C.2 C.3

Year	WSM		WSO		WST		WSX	
	DAV	Mean	DAV	Mean	DAV	Mean	DAV	Mean
2008	DNA	DNA	DNA	DNA	13.35	5.83	25.18	5.55
2009	DNA	DNA	DNA	DNA	88.09	5.63	85.2	4.99
2010	DNA	DNA	DNA	DNA	63.9	5.51	96.34	4.82
2011	DNA	DNA	DNA	DNA	99.61	5.82	99.67	4.91
2012	6.4	7.58	6.4	7.07	83.24	5.64	95.64	4.94
2013	51.32	6.64	31.92	5.62	DNA	DNA	31.27	5.35

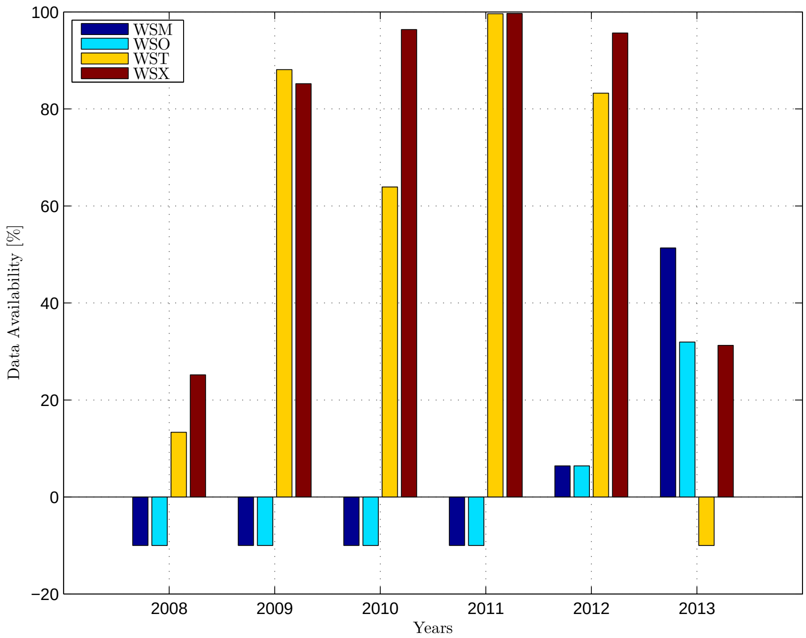


Figure 1.34: Data availability of different anemometers for different years

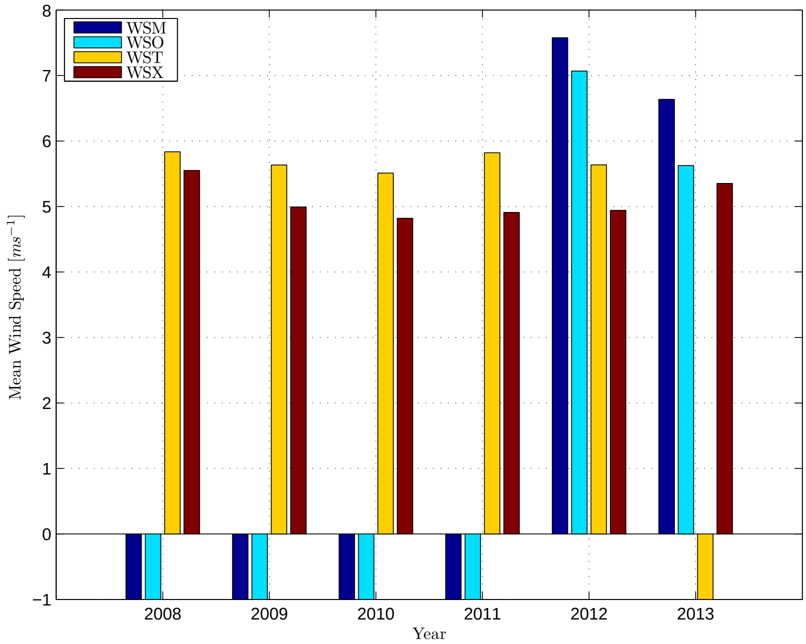


Figure 1.35: Mean wind speed of different anemometers for different years

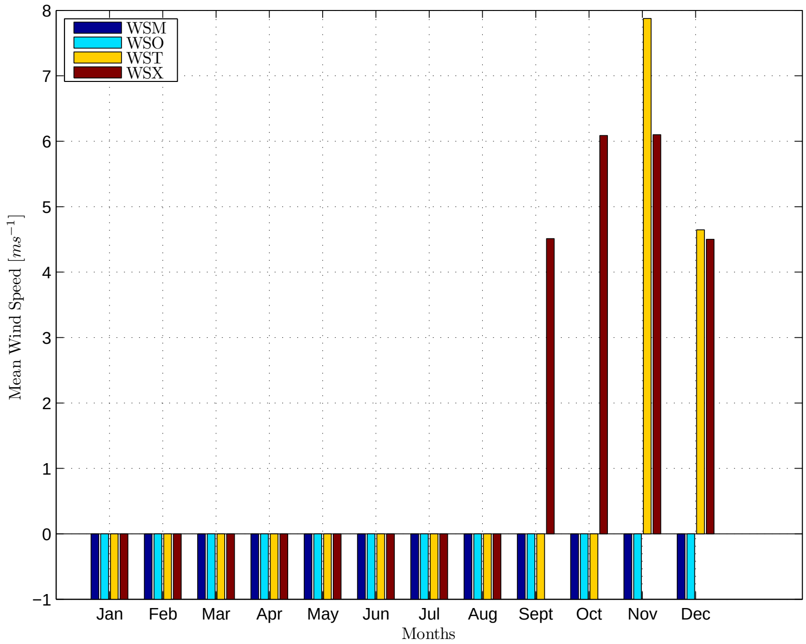


Figure 1.36: Mean wind speed of different anemometers during 2008

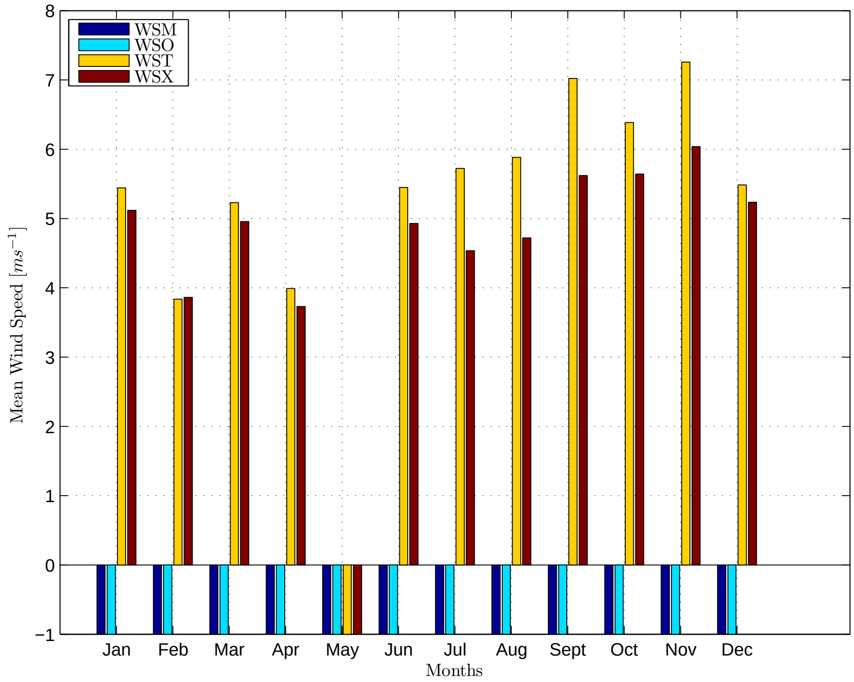


Figure 1.37: Mean wind speed of different anemometers during 2009

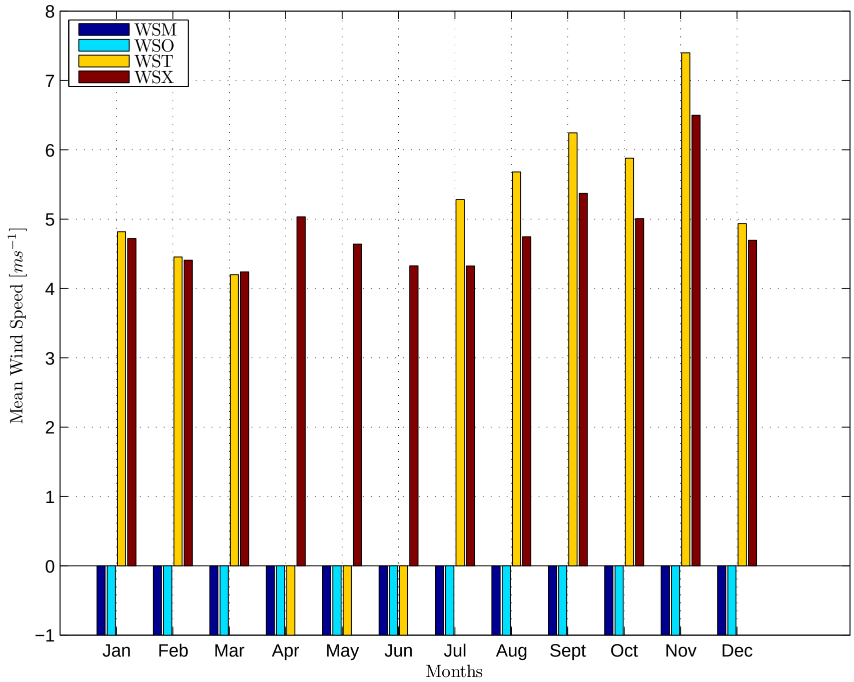


Figure 1.38: Mean wind speed of different anemometers during 2010

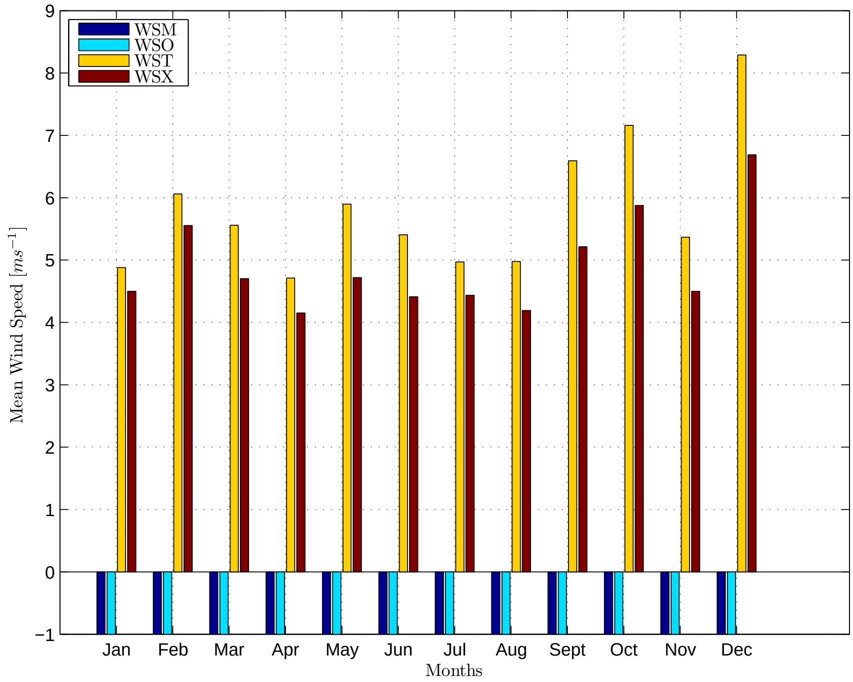


Figure 1.39: Mean wind speed of different anemometers during 2011

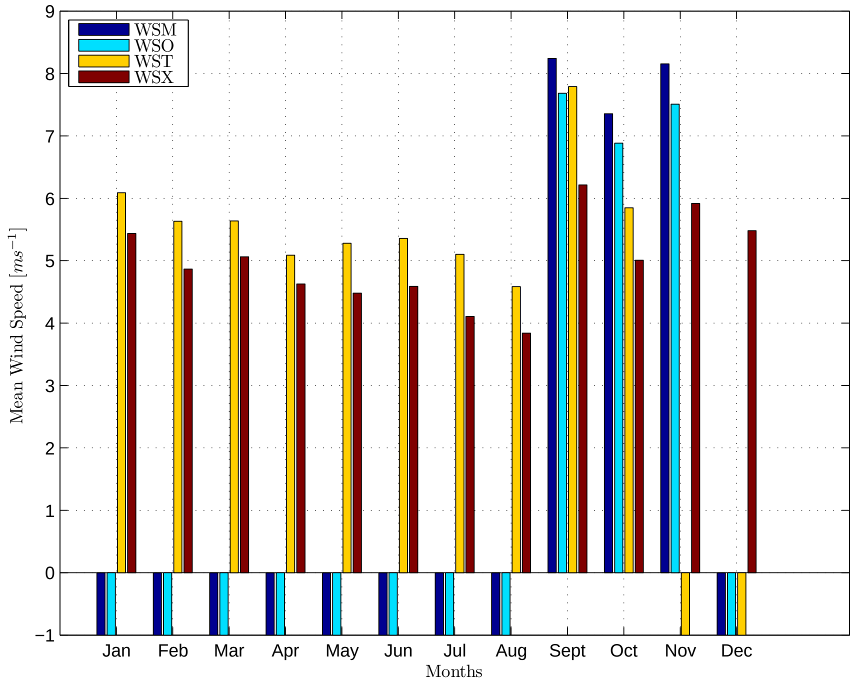


Figure 1.40: Mean wind speed of different anemometers during 2012

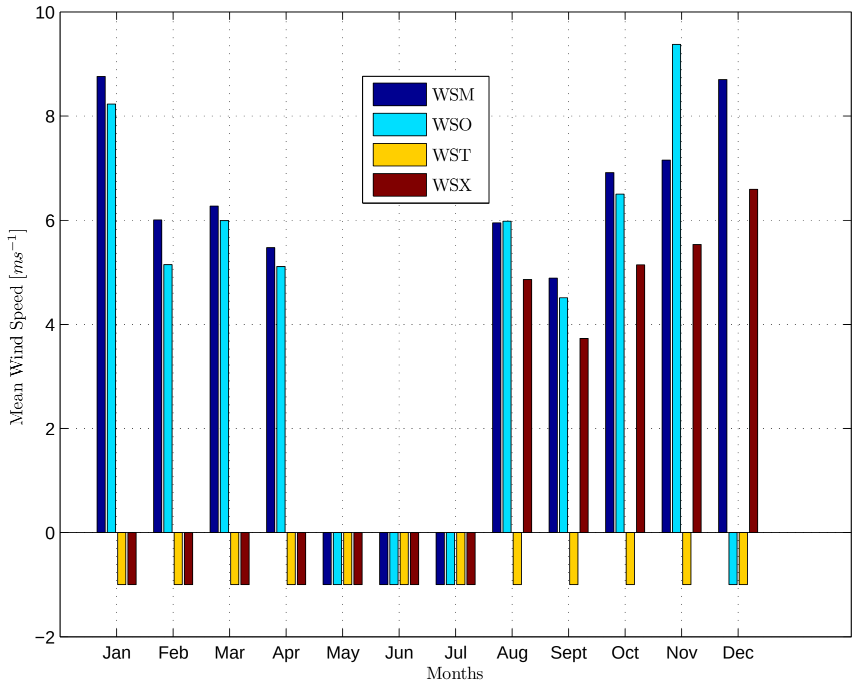


Figure 1.41: Mean wind speed of different anemometers during 2013

1.8 WXT510 Statistics

Matlab program used to obtain the statistics in this section is given in Section I.3

1.8.1 2008 Annual Statistics

Table 1.3: Meteorological parameters, 2008

Month	Air Temperature [°C]			Air Pressure [hPa]			Relative Humidity			Precipitation [mm]
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Total
Sept	10.40	11.88	13.10	985.70	995.47	1004.66	63.08	76.57	89.61	3.80
Oct	2.00	10.71	14.30	980.10	1005.11	1025.70	49.03	75.49	96.89	129.30
Nov	-2.60	5.95	11.40	982.46	1004.58	1025.40	42.82	79.36	100.00	115.18
Dec	-3.70	2.95	8.80	985.75	1014.83	1044.38	55.37	88.32	99.70	31.61

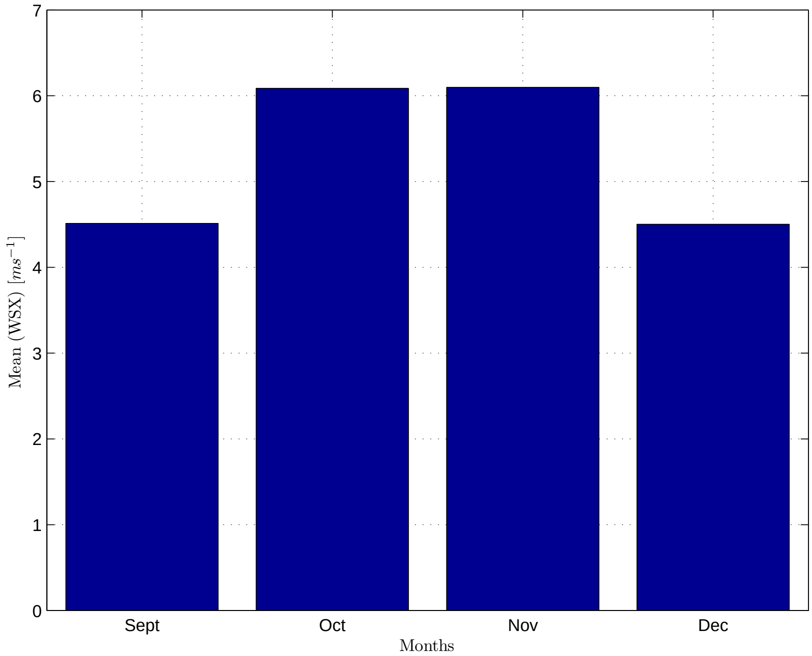


Figure 1.42: Annual wind speed distribution of WSX, 2008

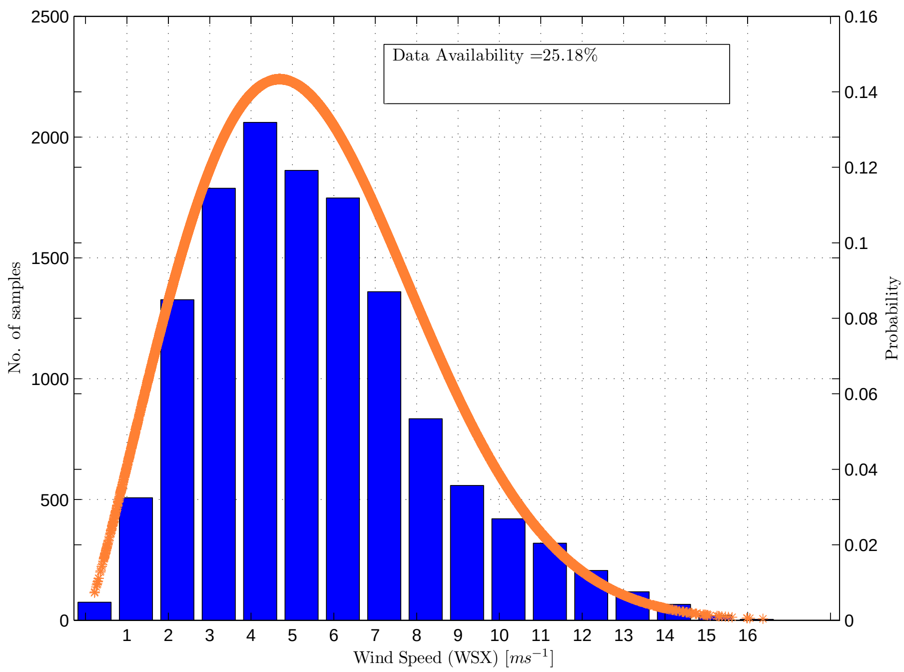


Figure 1.43: Annual wind speed distribution of WSX, 2008

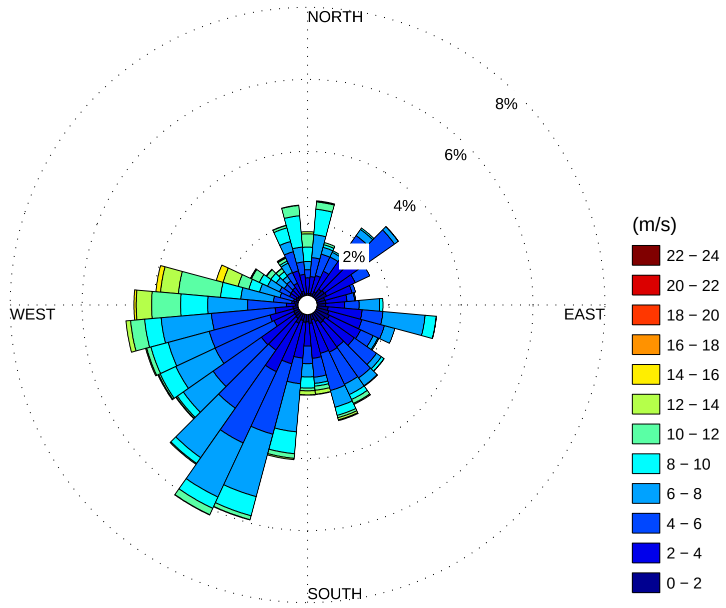


Figure 1.44: Annual wind rose of WSX, 2008

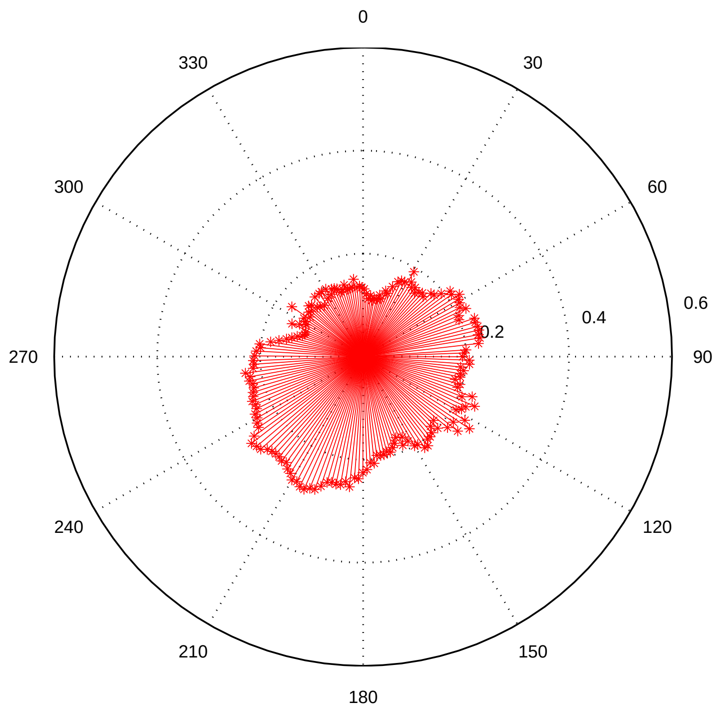


Figure 1.45: Turbulence intensity of WSX, 2008

Table 1.4: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2008

Month	Min	Mean	Max
September	0.20	4.51	13.70
October	0.10	6.09	24.80
November	0.10	6.10	25.10
December	0.10	4.50	25.30

Table 1.5: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2008

Month	Data Availability(%)	Min	Mean	Max	K	C
September	4.79	2.04	4.51	9.27	3.53	5.00
October	99.40	0.22	6.09	14.73	2.72	6.83
November	100.00	0.45	6.10	15.98	2.13	6.91
December	96.53	0.29	4.50	16.37	1.93	5.09

1.8.1.1 2008 Monthly Statistics

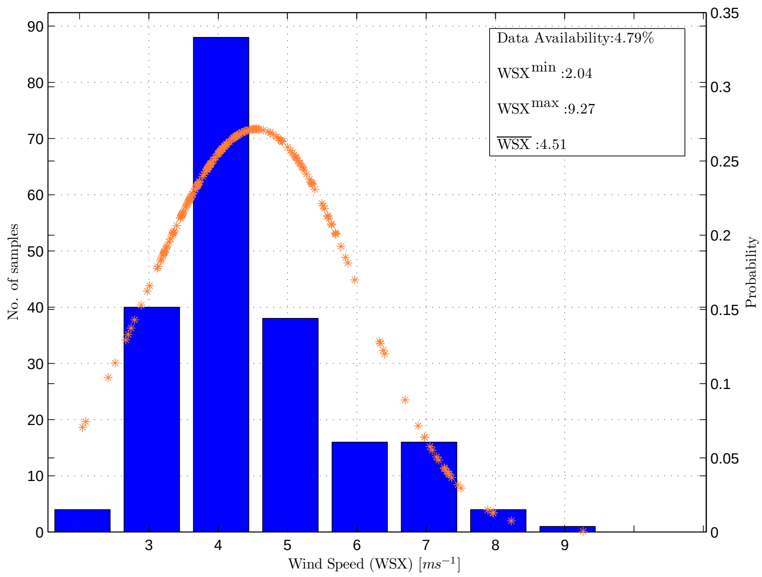


Figure 1.46: September 2008 probability distribution function

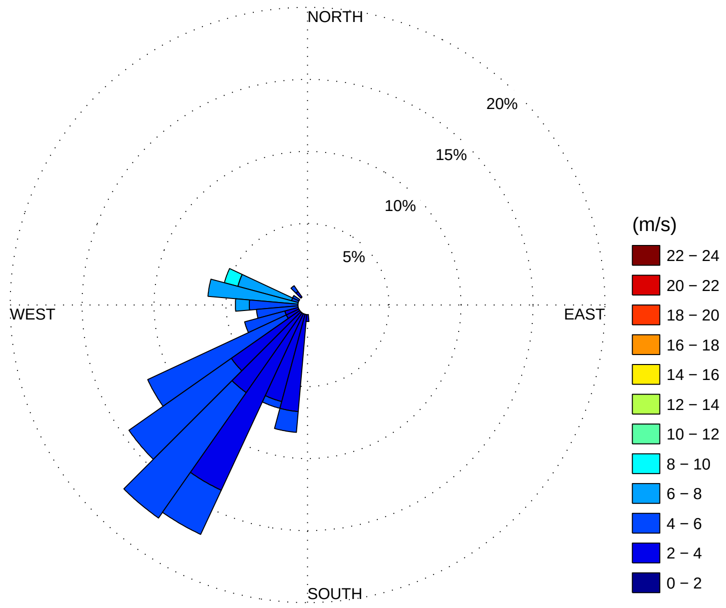


Figure 1.47: September 2008 Wind Rose

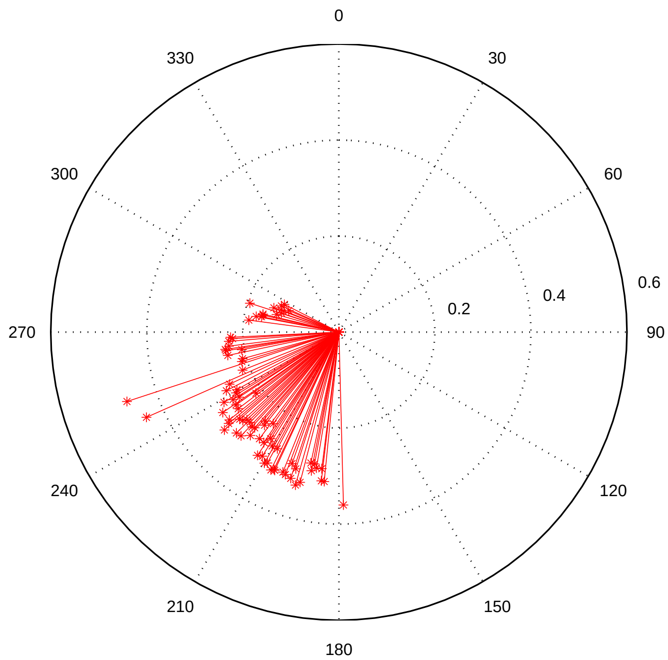


Figure 1.48: September 2008 turbulence intensity

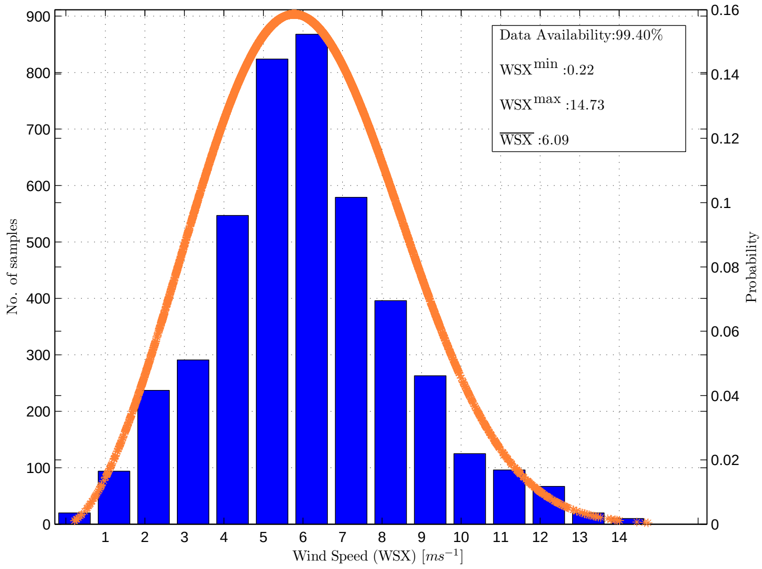


Figure 1.49: October 2008 probability distribution function

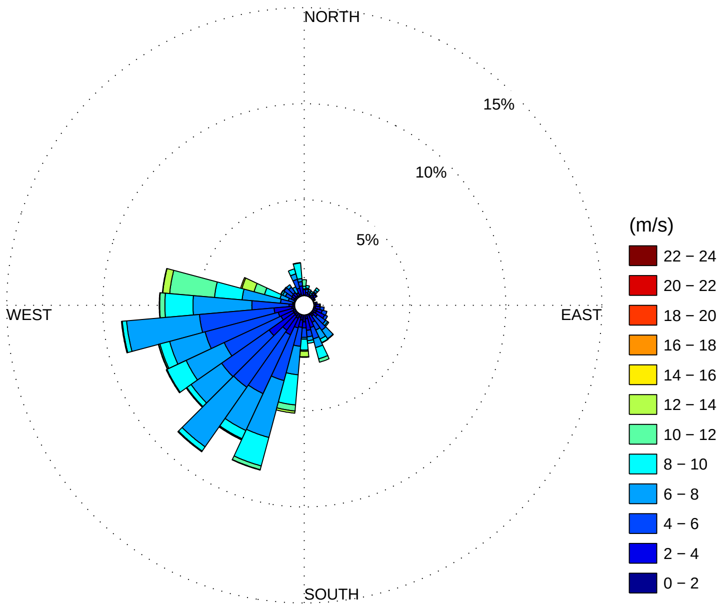


Figure 1.50: October 2008 Wind Rose

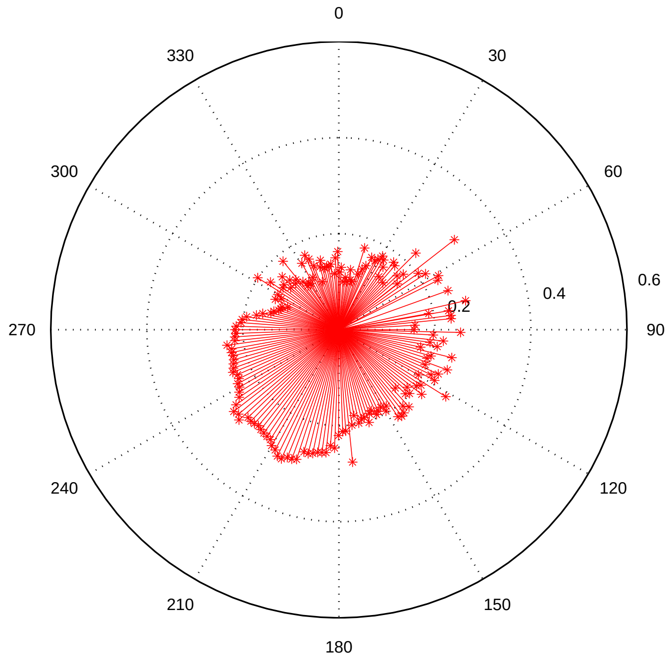


Figure 1.51: October 2008 turbulence intensity

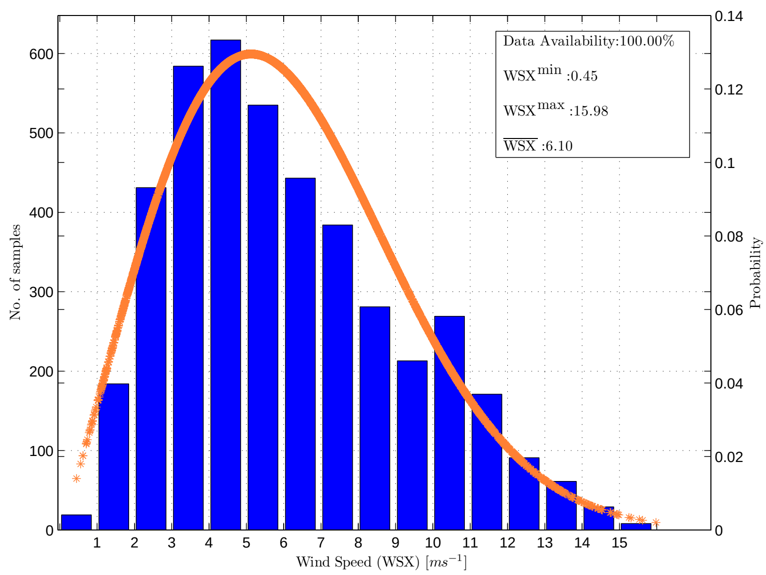


Figure 1.52: November 2008 probability distribution function

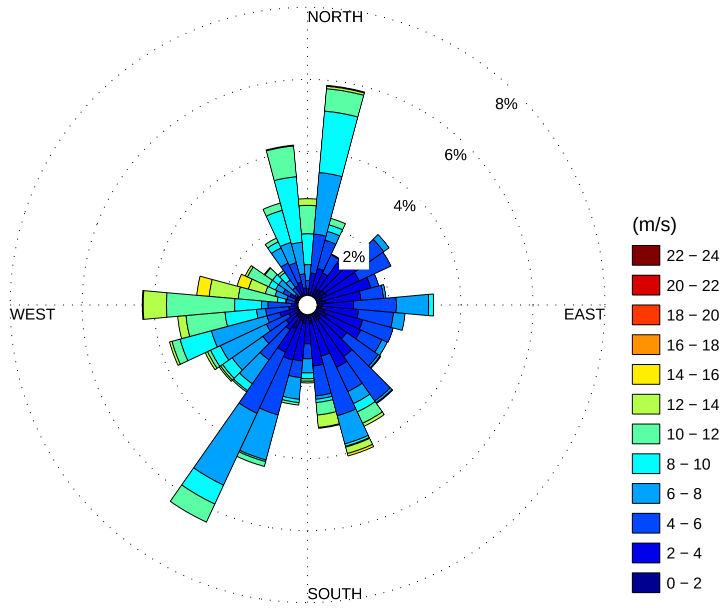


Figure 1.53: November 2008 Wind Rose

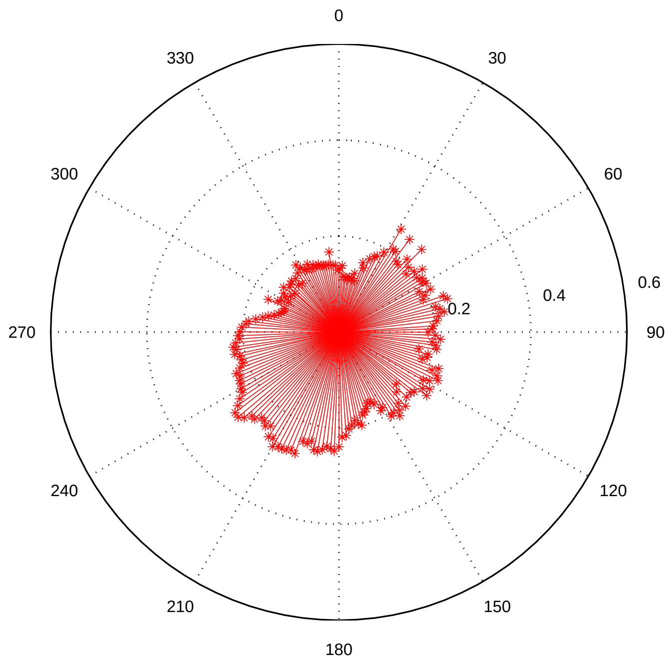


Figure 1.54: November 2008 turbulence intensity

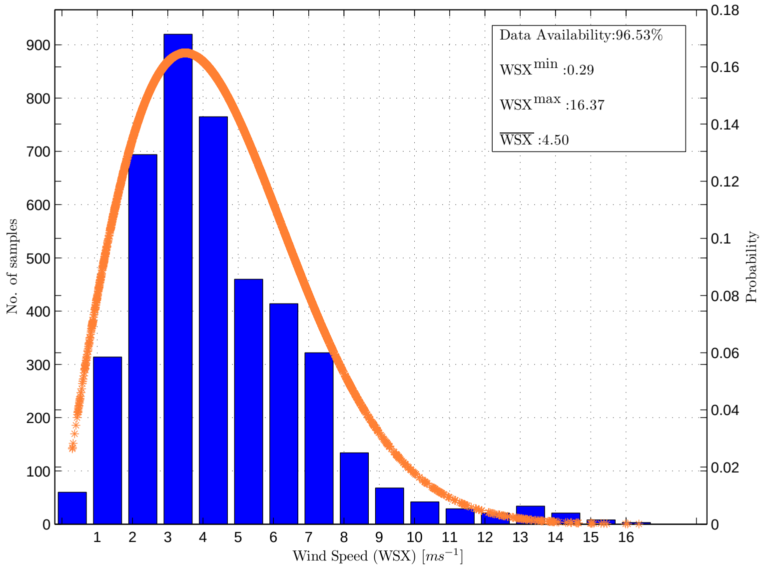


Figure 1.55: December 2008 probability distribution function

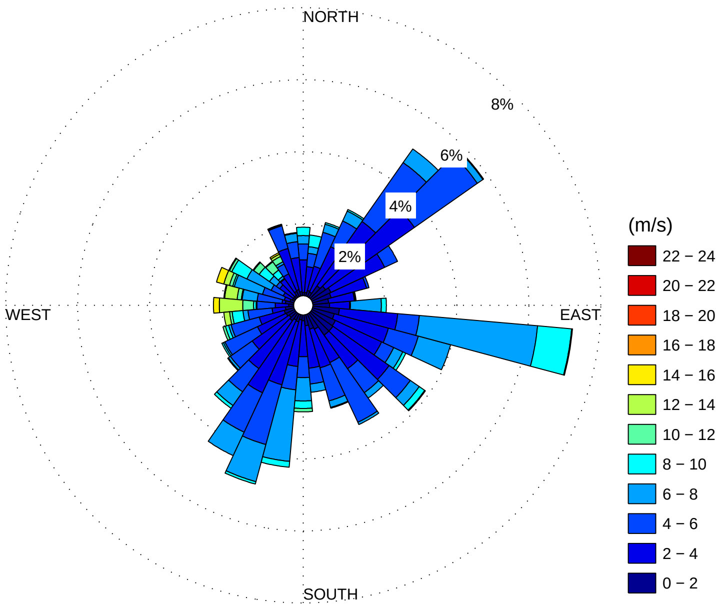


Figure 1.56: December 2008 Wind Rose

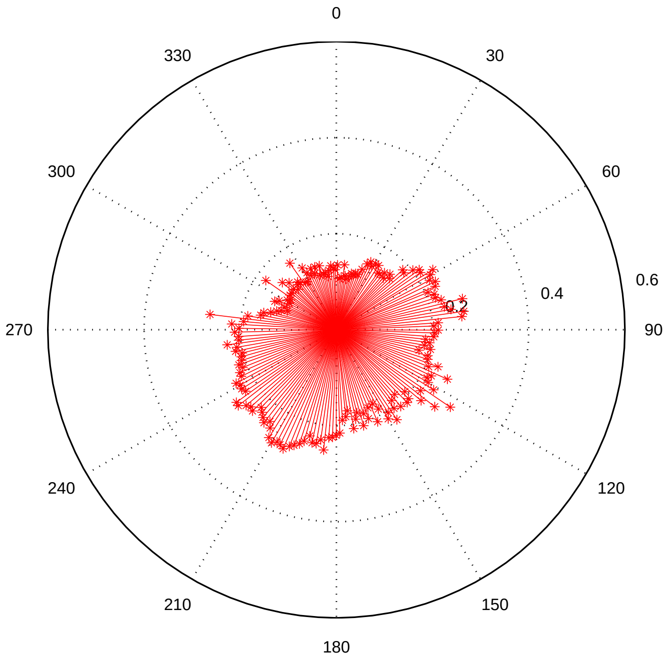


Figure 1.57: December 2008 turbulence intensity

1.8.2 2009 Annual Statistics

Table 1.6: Meteorological parameters, 2009

Month	Air Temperature [°C]			Air Pressure [hPa]			Relative Humidity			Precipitation [mm]
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Total
Jan	-9.10	1.35	6.40	975.80	1010.36	1029.70	47.10	84.65	99.50	21.24
Feb	-7.40	-0.52	4.70	984.30	1009.72	1029.70	33.96	87.10	99.70	9.19
Mar	-1.90	2.96	9.20	985.62	1007.85	1032.90	34.65	82.44	99.49	23.80
Apr	0.10	7.71	19.80	403.34	1016.64	1028.10	17.68	76.77	100.00	15.66
Jun	7.40	14.55	26.80	999.23	1012.24	1027.60	28.41	69.57	98.10	92.33
Jul	13.14	17.67	24.20	995.03	1006.70	1020.60	42.78	77.77	96.39	148.36
Aug	12.40	17.35	23.60	999.22	1012.16	1024.00	44.86	75.15	96.90	139.98
Sept	7.10	14.82	21.30	984.40	1013.51	1029.90	42.06	75.78	94.06	66.74
Oct	1.30	7.84	13.40	975.21	1012.82	1032.90	40.68	75.81	96.10	121.93
Nov	1.44	6.76	11.80	980.65	1000.86	1024.10	56.15	85.92	96.90	144.52
Dec	-7.40	0.98	7.00	981.70	1012.31	1032.50	57.31	83.72	96.50	21.06

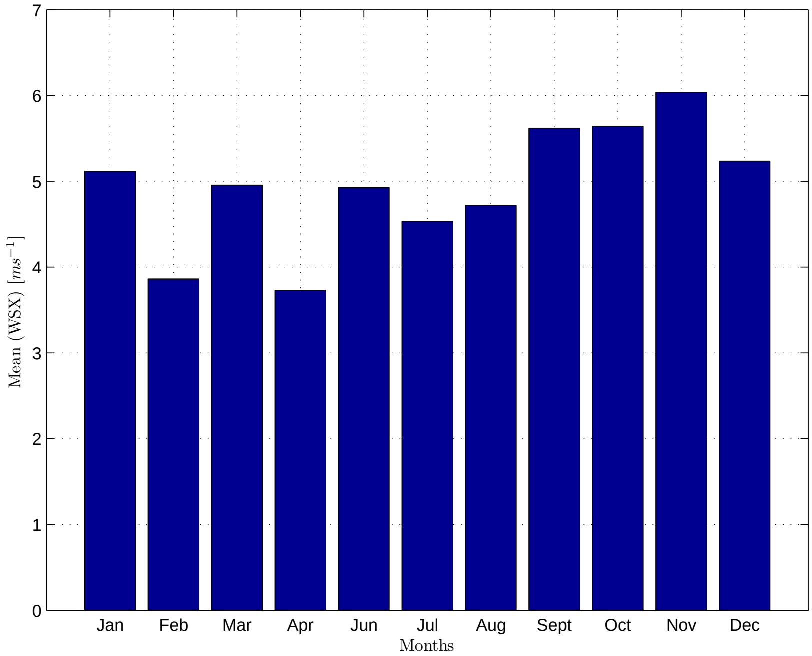


Figure 1.58: Annual wind speed distribution of WSX, 2009

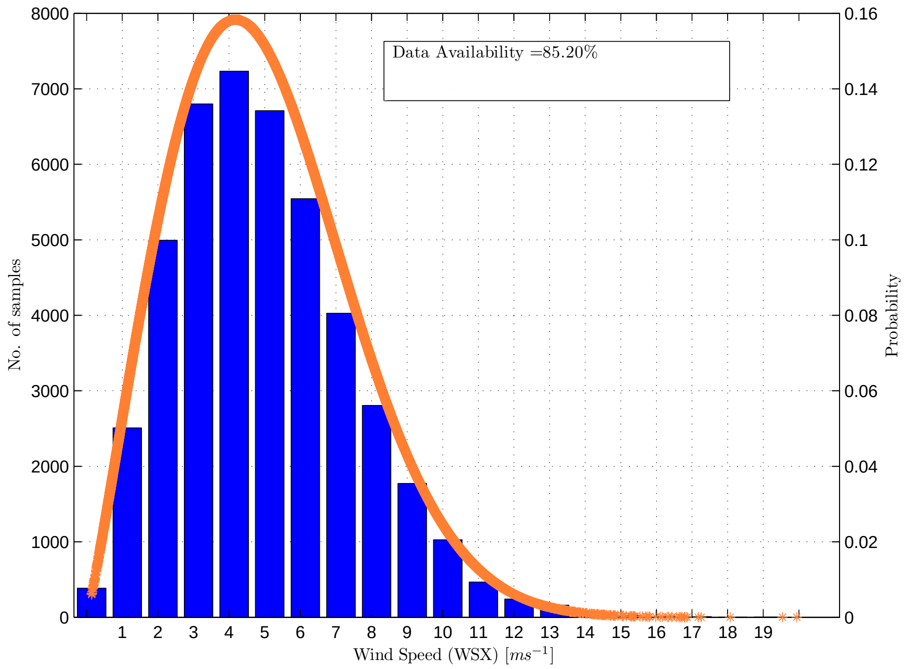


Figure 1.59: Annual wind speed distribution of WSX, 2009

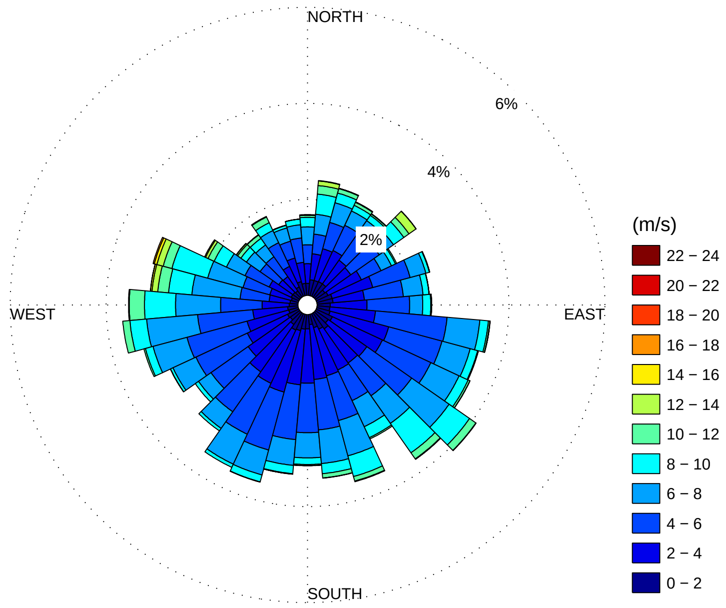


Figure 1.60: Annual wind rose of WSX, 2009

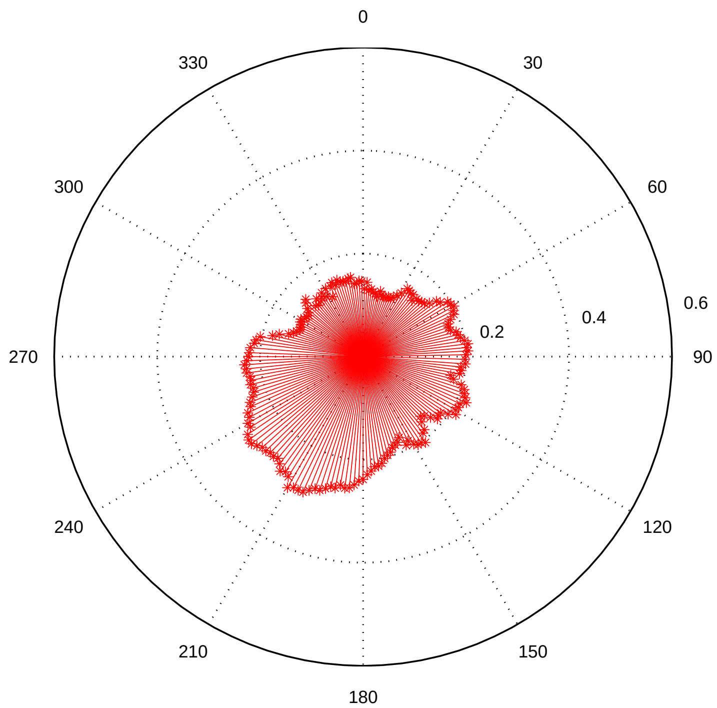


Figure 1.61: Turbulence intensity of WSX, 2009

Table 1.7: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2009

Month	Min	Mean	Max
January	0.10	5.12	28.20
February	0.10	3.86	23.68
March	0.10	4.96	33.50
April	0.10	3.73	26.20
June	0.10	4.93	24.27
July	0.10	4.53	20.37
August	0.10	4.72	18.30
September	0.10	5.62	21.70
October	0.10	5.64	23.50
November	0.20	6.04	21.40
December	0.10	5.24	21.12

Table 1.8: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2009

Month	Data Availability(%)	Min	Mean	Max	K	C
January	100.00	0.14	5.12	13.23	1.93	5.76
February	100.00	0.15	3.86	10.39	2.34	4.36
March	99.96	0.19	4.96	19.94	2.09	5.60
April	58.82	0.22	3.73	15.79	2.09	4.21
June	95.16	0.20	4.93	16.86	2.04	5.57
July	100.00	0.29	4.53	12.89	2.27	5.13
August	100.00	0.24	4.72	13.87	2.31	5.33
September	99.98	0.17	5.62	15.74	2.27	6.34
October	99.98	0.18	5.64	17.25	1.99	6.38
November	100.00	1.75	6.04	14.51	3.29	6.73
December	70.39	0.36	5.24	14.01	2.22	5.93

1.8.2.1 2009 Monthly Statistics

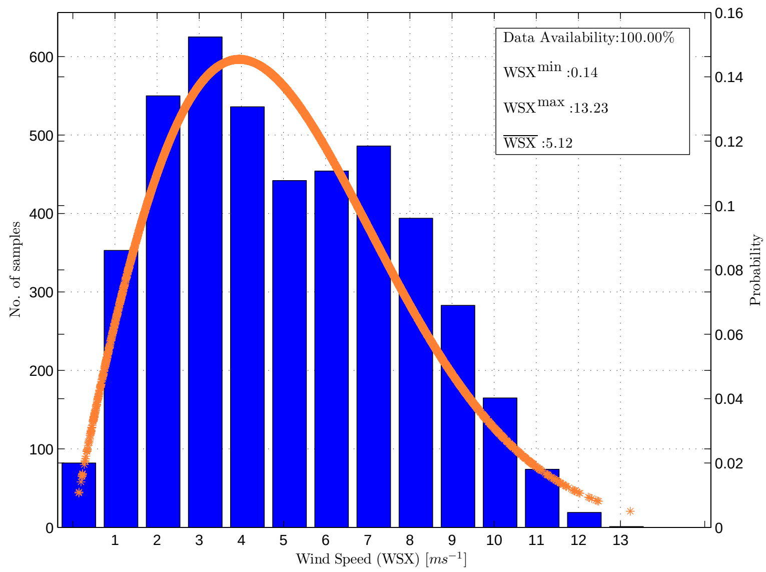


Figure 1.62: January 2009 probability distribution function

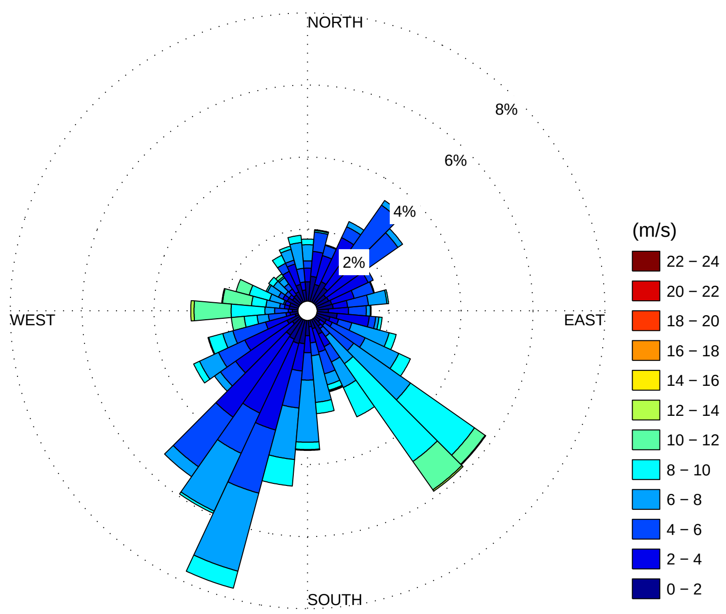


Figure 1.63: January 2009 Wind Rose

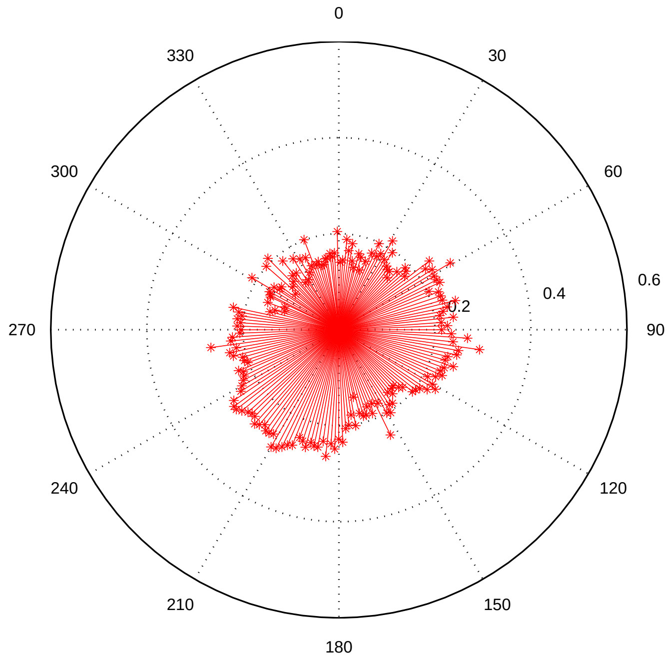


Figure 1.64: January 2009 turbulence intensity

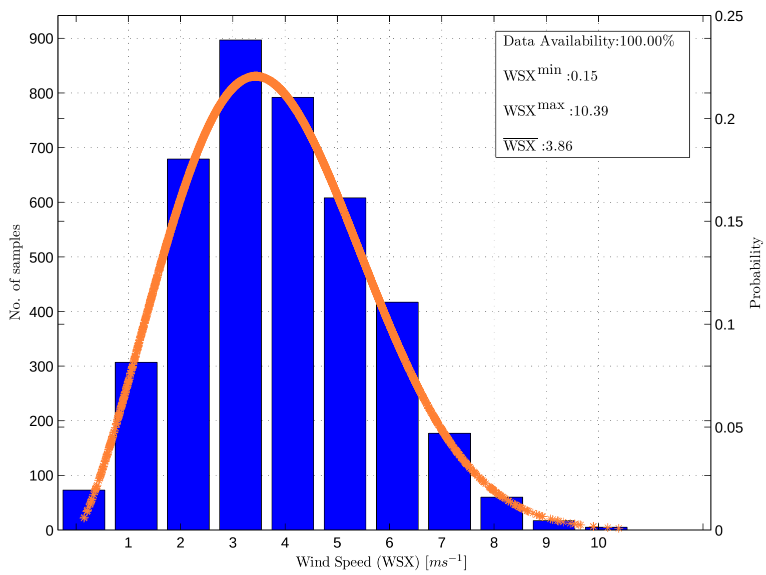


Figure 1.65: February 2009 probability distribution function

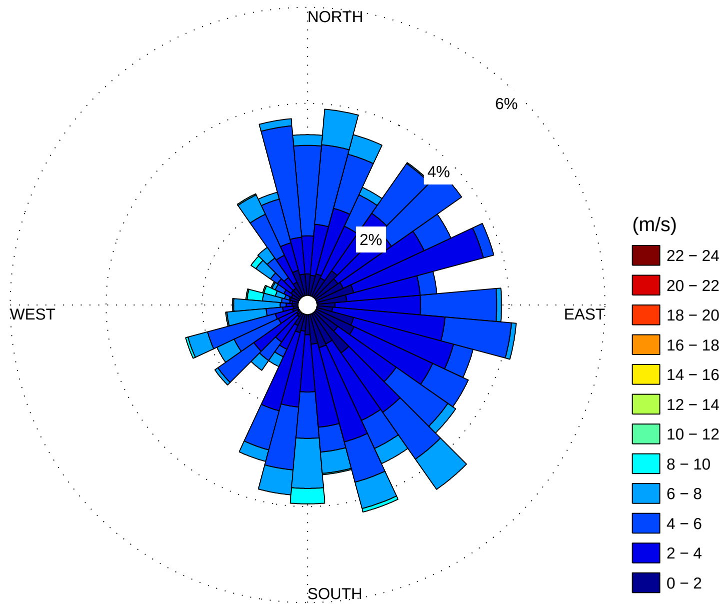


Figure 1.66: February 2009 Wind Rose

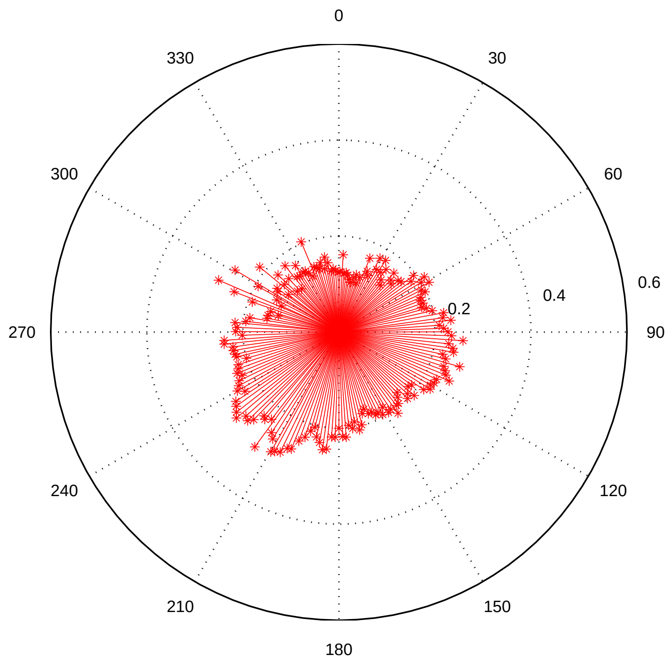


Figure 1.67: February 2009 turbulence intensity

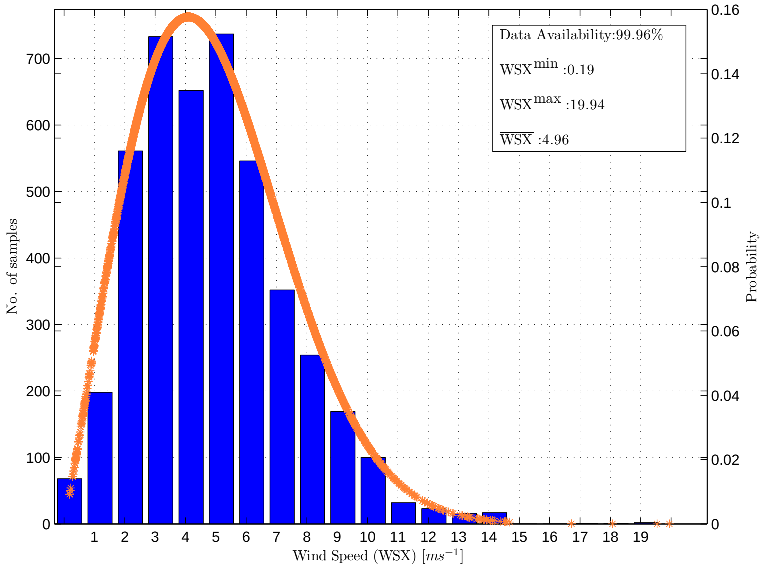


Figure 1.68: March 2009 probability distribution function

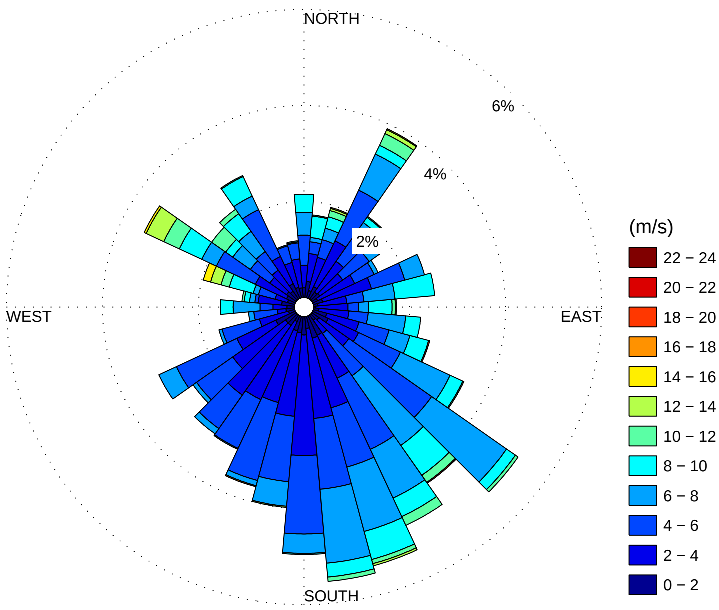


Figure 1.69: March 2009 Wind Rose

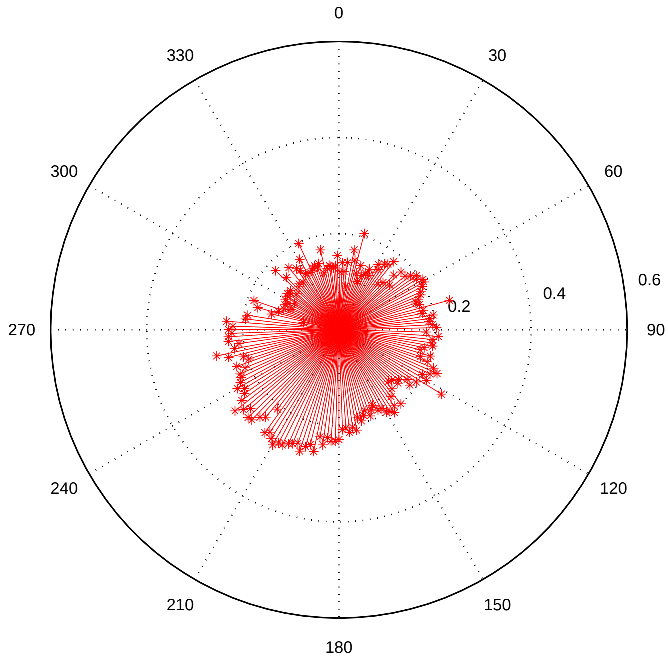


Figure 1.70: March 2009 turbulence intensity

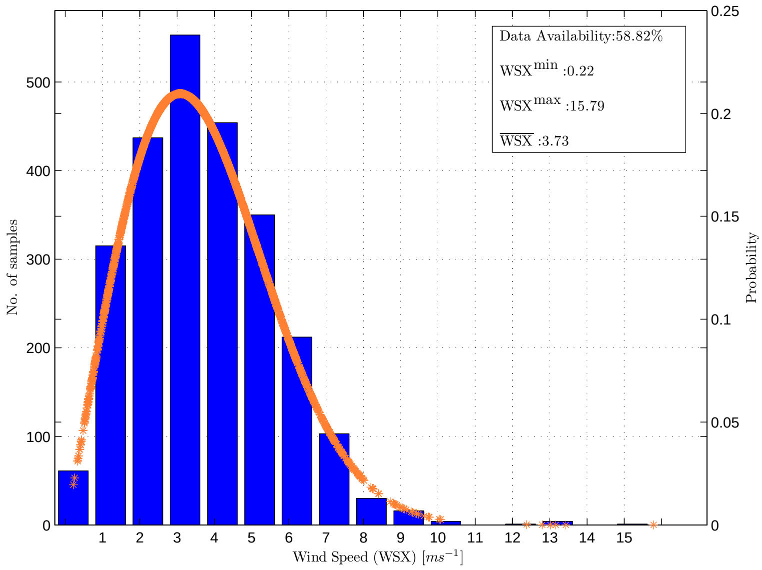


Figure 1.71: April 2009 probability distribution function

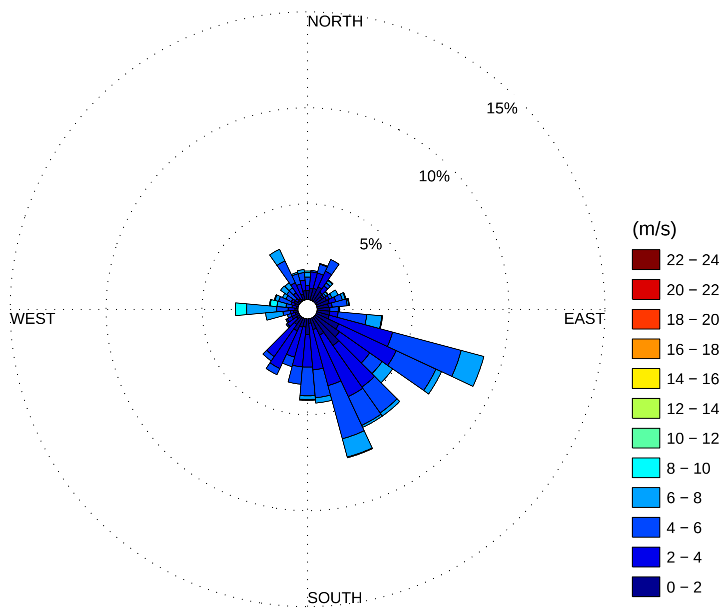


Figure 1.72: April 2009 Wind Rose

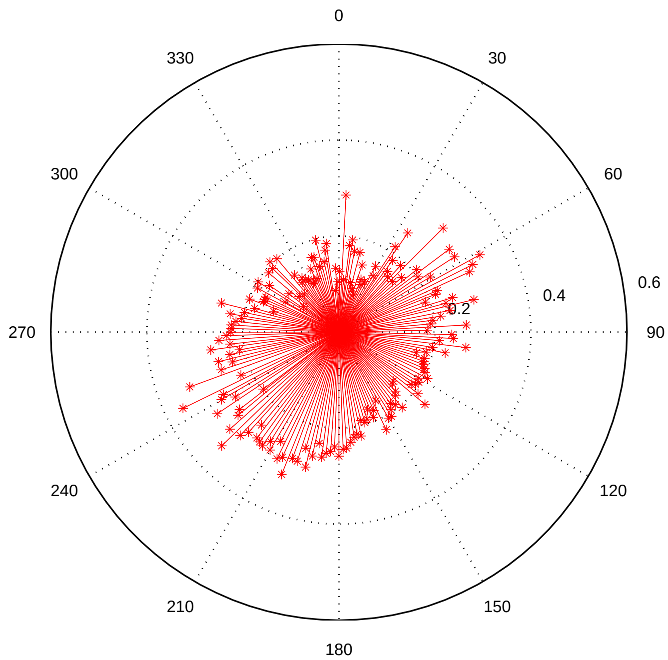


Figure 1.73: April 2009 turbulence intensity

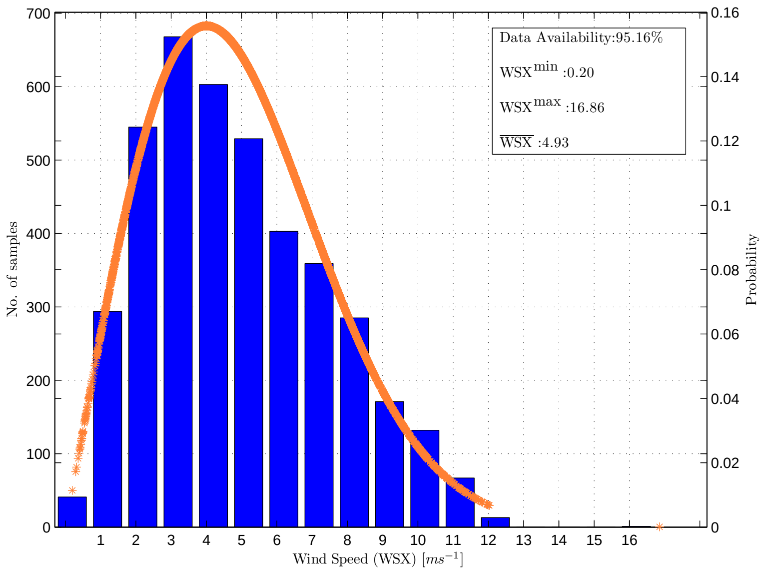


Figure 1.74: June 2009 probability distribution function

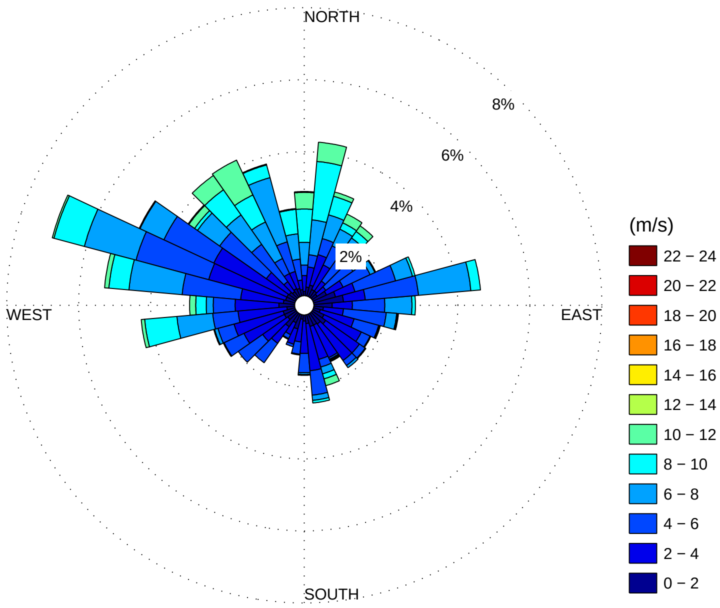


Figure 1.75: June 2009 Wind Rose

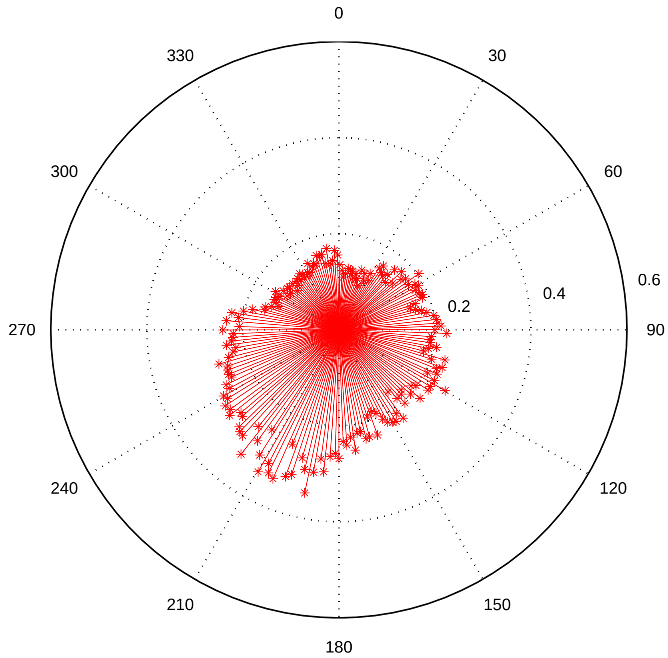


Figure 1.76: June 2009 turbulence intensity

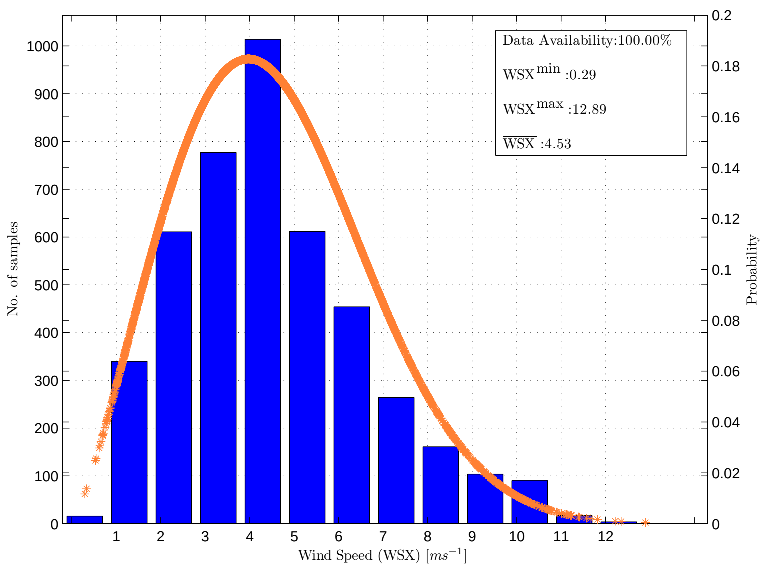


Figure 1.77: July 2009 probability distribution function

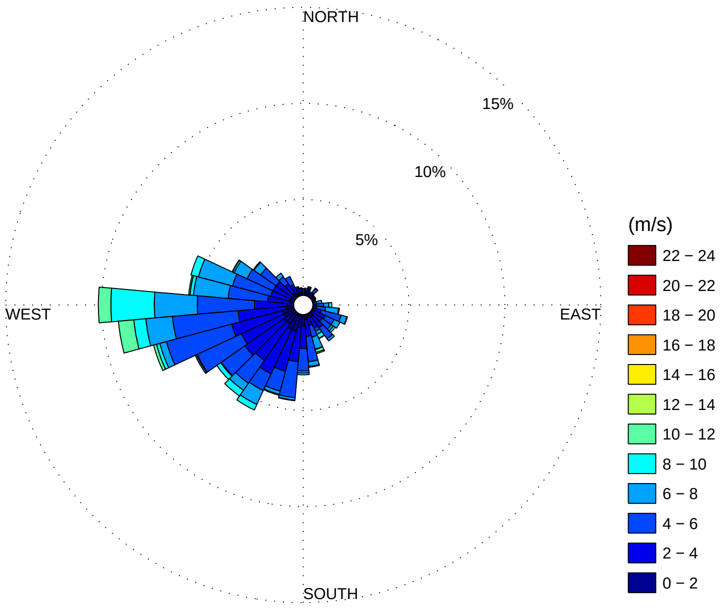


Figure 1.78: July 2009 Wind Rose

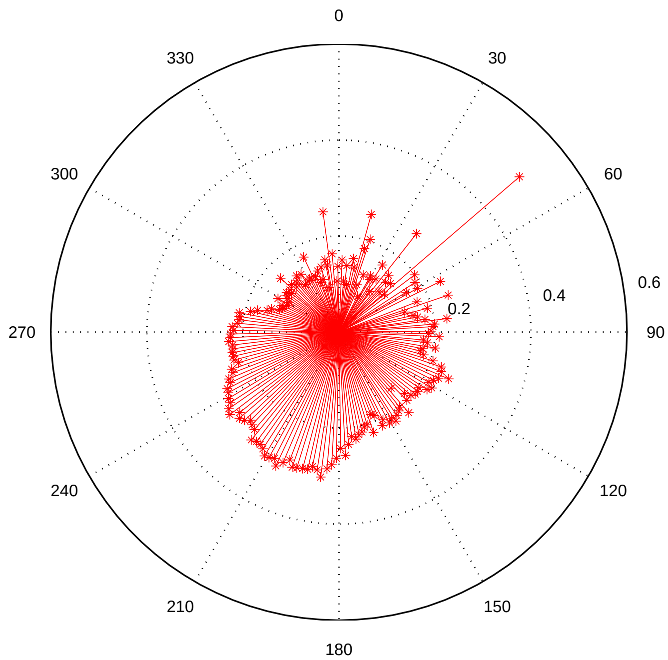


Figure 1.79: July 2009 turbulence intensity

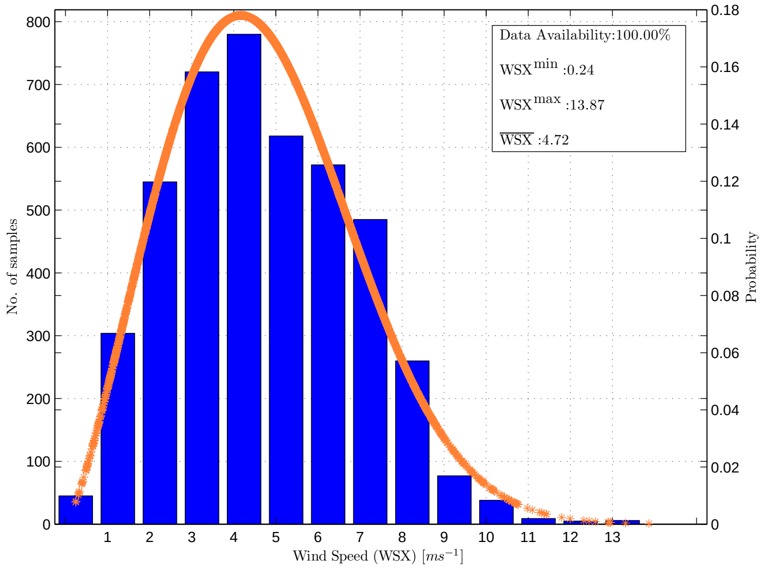


Figure 1.80: August 2009 probability distribution function

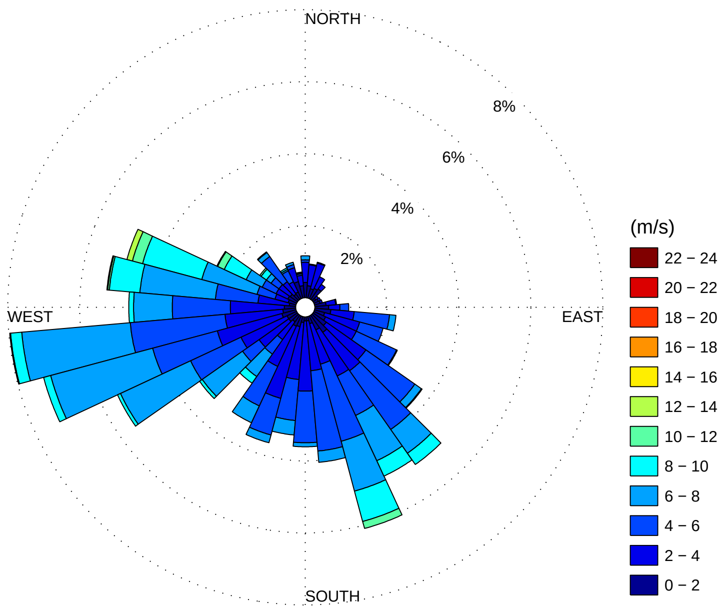


Figure 1.81: August 2009 Wind Rose

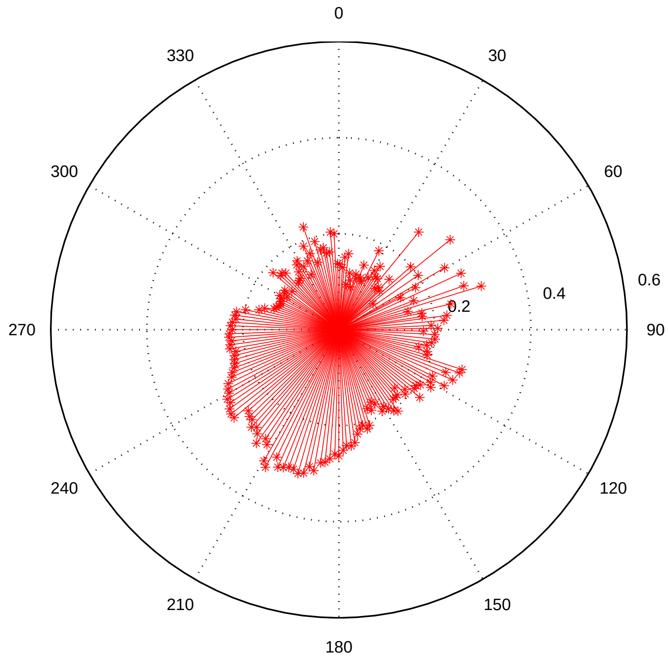


Figure 1.82: August 2009 turbulence intensity

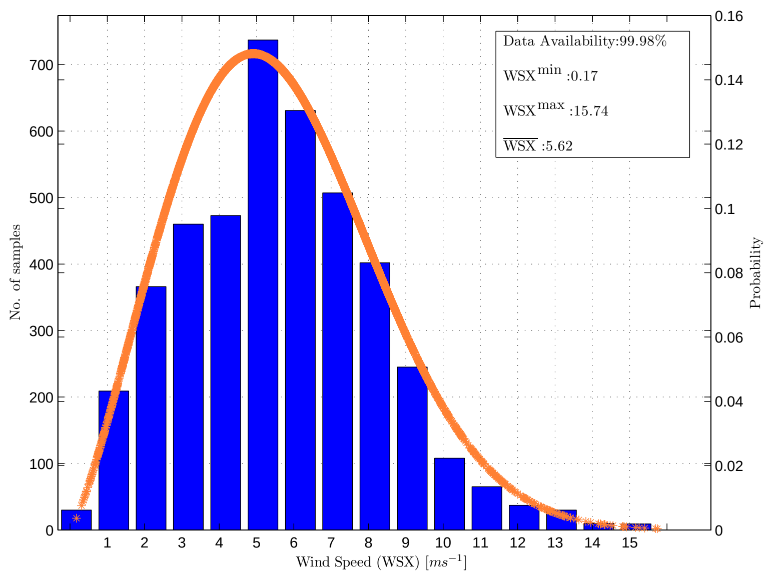


Figure 1.83: September 2009 probability distribution function

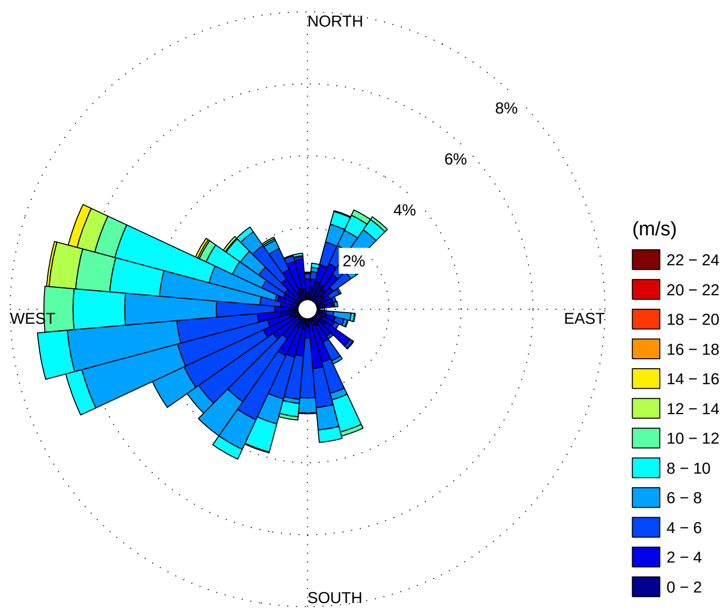


Figure 1.84: September 2009 Wind Rose

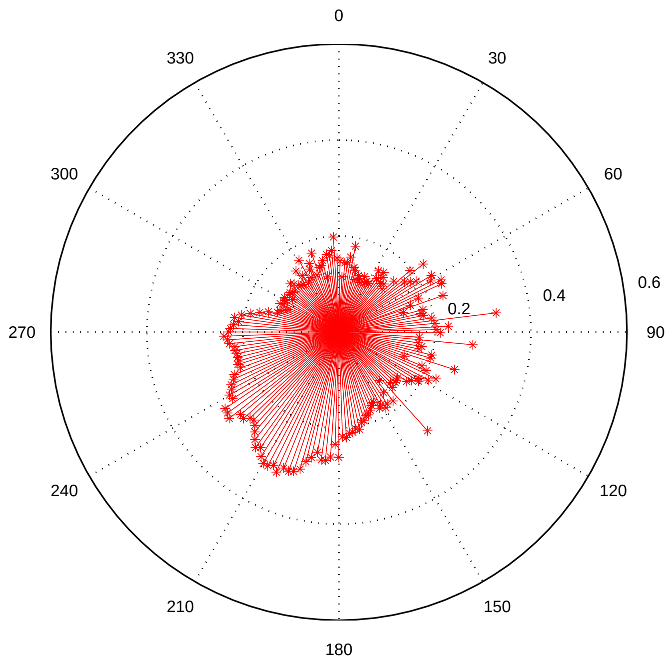


Figure 1.85: September 2009 turbulence intensity

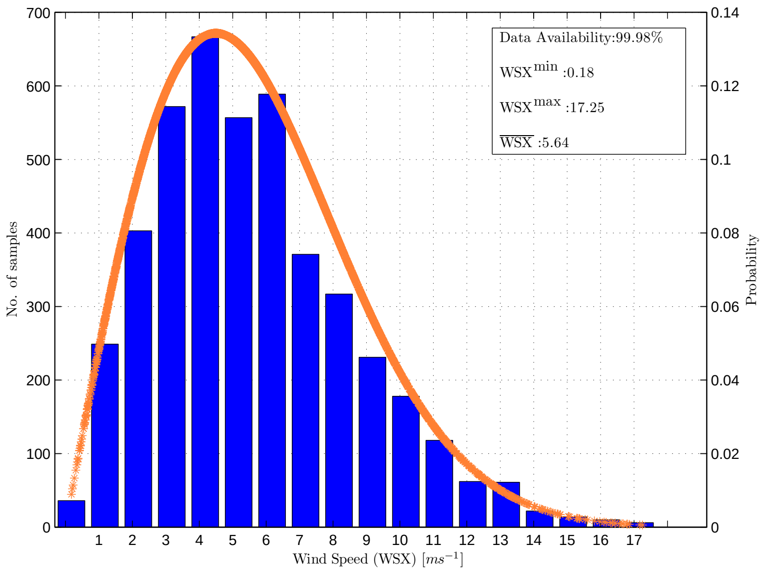


Figure 1.86: October 2009 probability distribution function

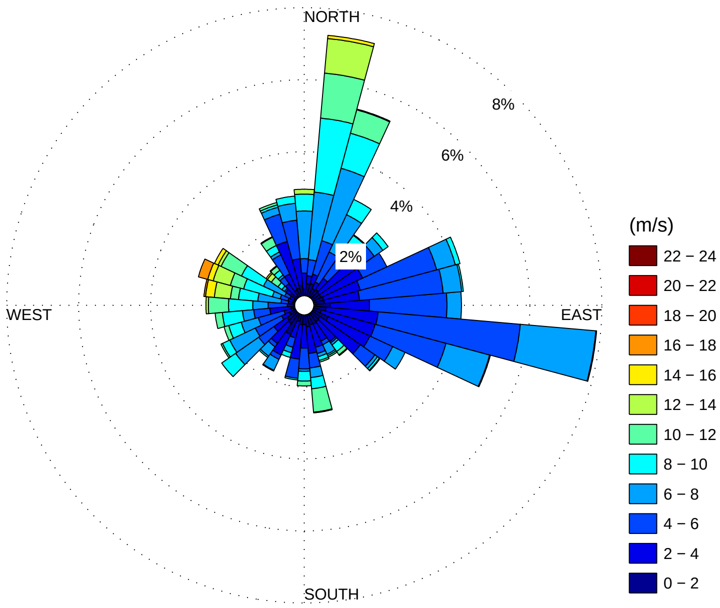


Figure 1.87: October 2009 Wind Rose

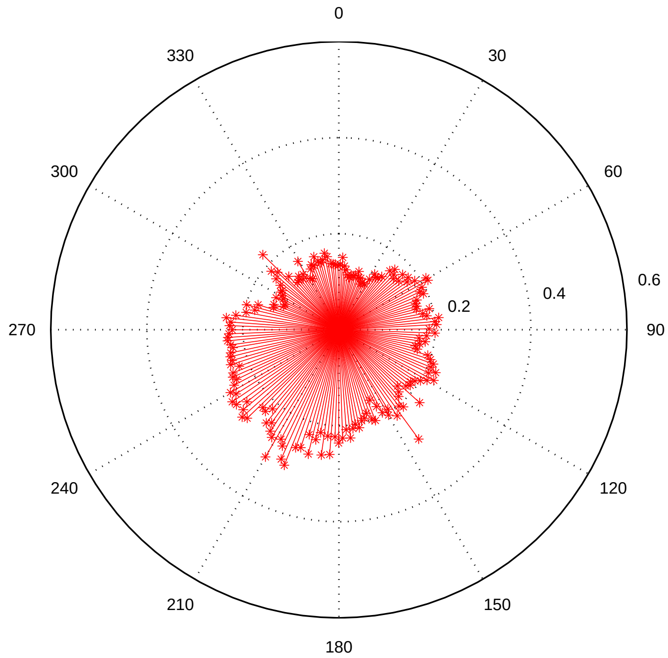


Figure 1.88: October 2009 turbulence intensity

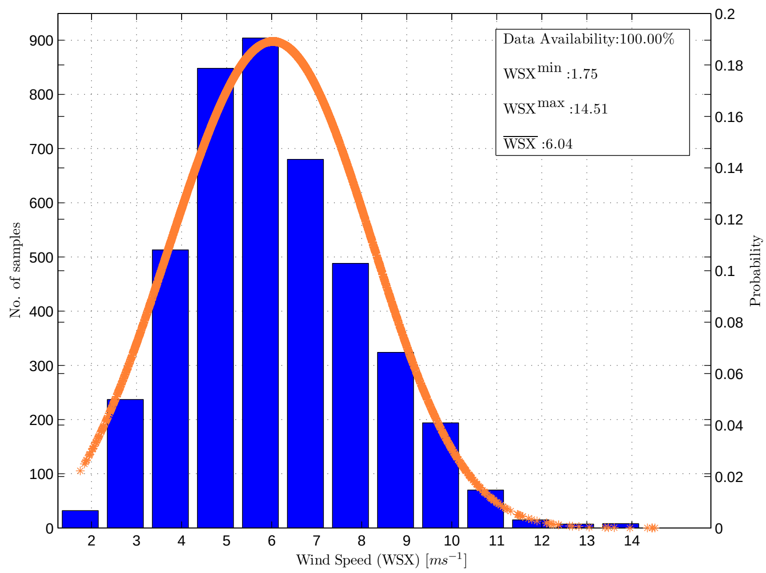


Figure 1.89: November 2009 probability distribution function

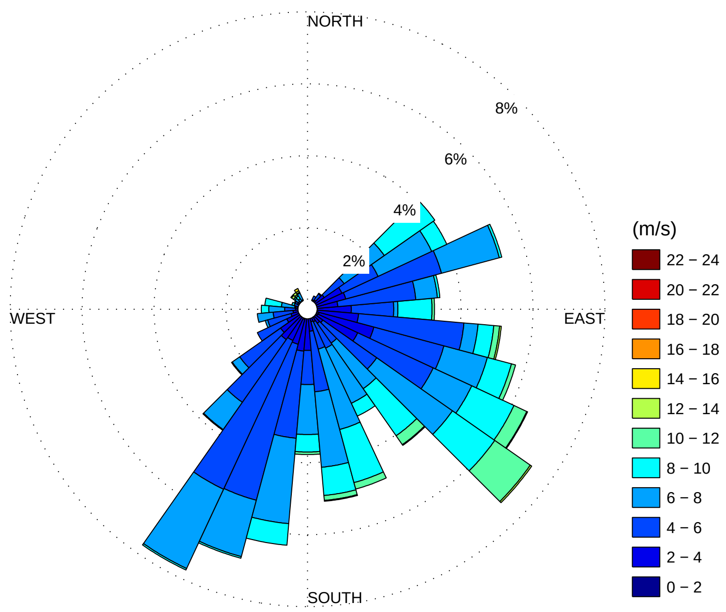


Figure 1.90: November 2009 Wind Rose

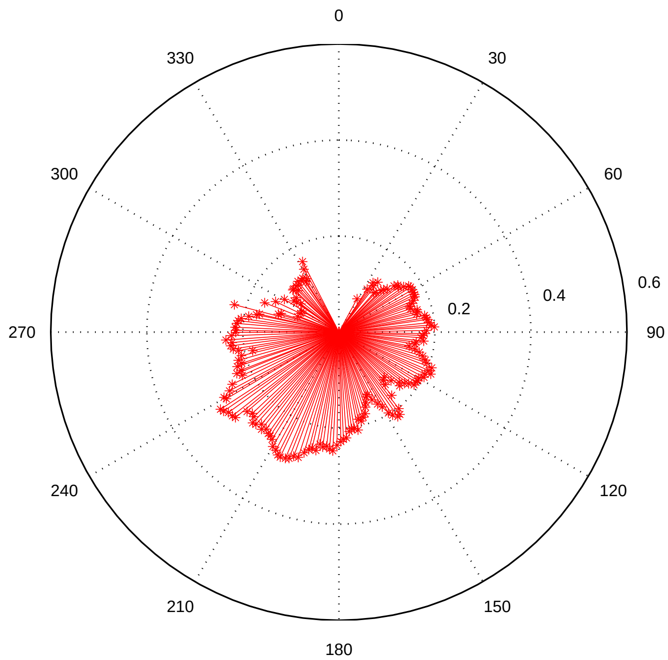


Figure 1.91: November 2009 turbulence intensity

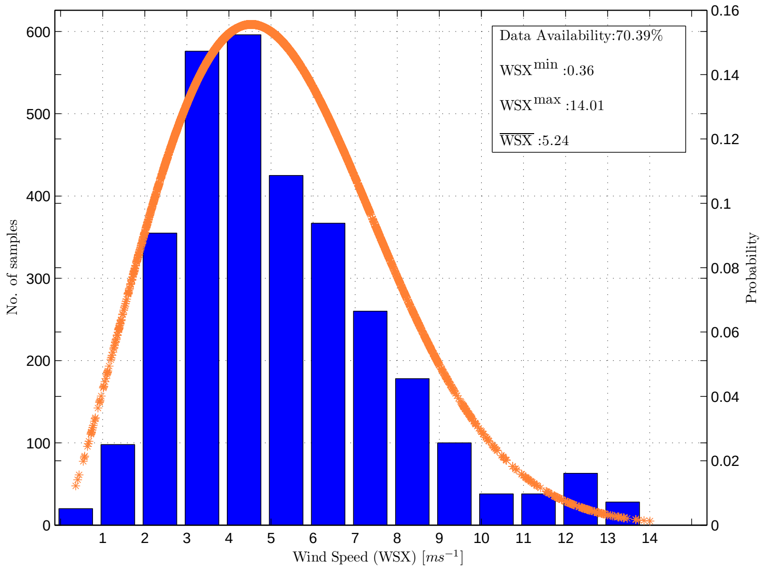


Figure 1.92: December 2009 probability distribution function

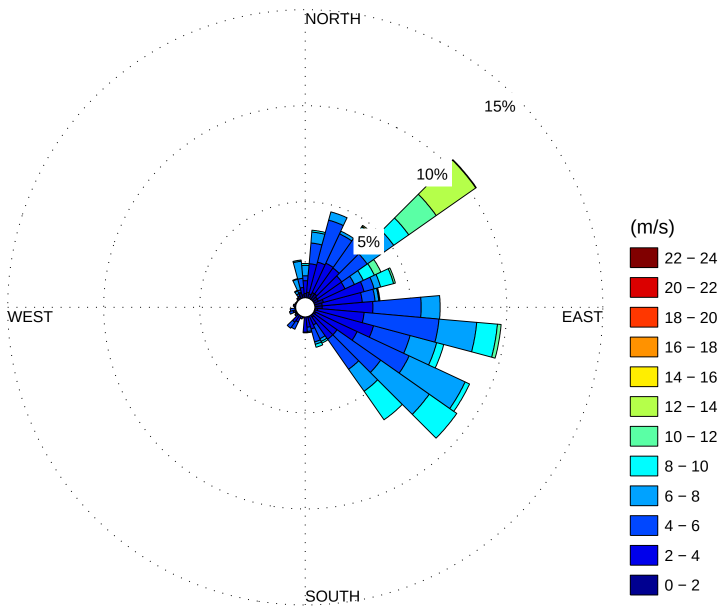


Figure 1.93: December 2009 Wind Rose

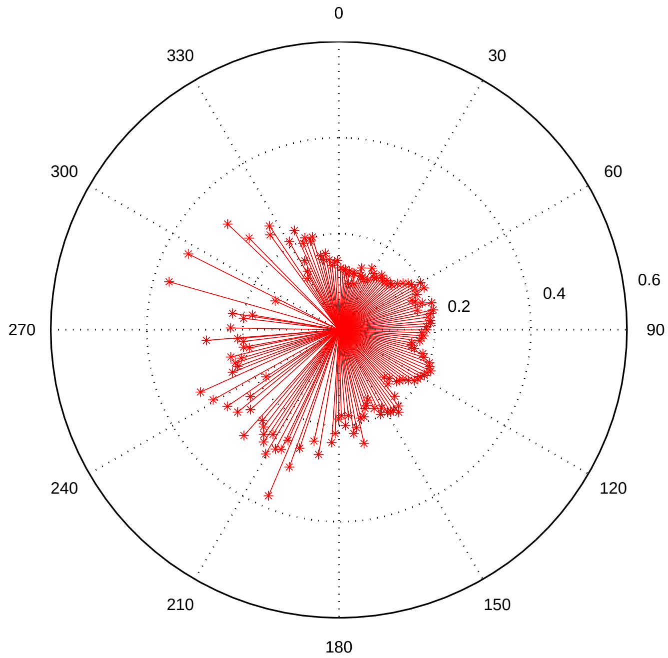


Figure 1.94: December 2009 turbulence intensity

1.8.3 2010 Annual Statistics

Table 1.9: Meteorological parameters, 2010

Month	Air Temperature [°C]			Air Pressure [hPa]			Relative Humidity			Precipitation [mm]
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Total
Jan	-13.46	-4.60	2.90	984.20	1020.36	1041.20	56.42	83.06	95.46	72.42
Feb	-15.17	-3.75	5.20	983.30	1004.60	1026.20	63.47	87.14	96.40	61.23
Mar	-9.20	1.72	12.80	982.50	1009.08	1028.20	37.78	82.71	97.10	57.04
Apr	0.20	6.41	13.20	996.04	1014.91	1033.09	35.50	75.86	96.90	20.78
May	3.60	10.26	19.60	992.28	1010.33	1023.30	30.71	73.10	95.90	35.55
Jun	10.30	14.39	21.86	991.20	1011.38	1022.50	23.87	74.14	94.20	30.86
Jul	13.61	18.43	25.40	992.96	1012.13	1021.80	31.09	73.03	93.80	115.73
Aug	9.60	17.04	24.50	983.61	1007.65	1019.10	45.47	77.13	93.97	168.79
Sept	6.70	13.23	18.90	982.29	1010.93	1026.40	34.36	74.91	94.00	50.09
Oct	1.40	8.70	15.30	989.13	1010.64	1030.60	41.59	77.84	95.88	114.40
Nov	-7.49	3.46	10.80	965.81	1001.96	1025.90	48.21	81.18	95.30	106.86
Dec	-12.40	-4.29	4.40	984.33	1009.24	1029.00	58.72	84.26	95.40	7.64

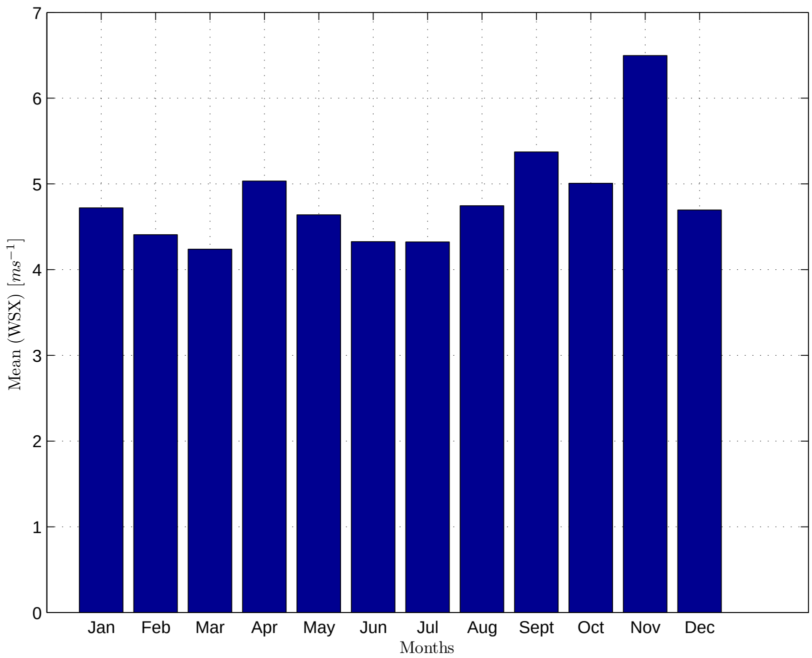


Figure 1.95: Annual wind speed distribution of WSX, 2010

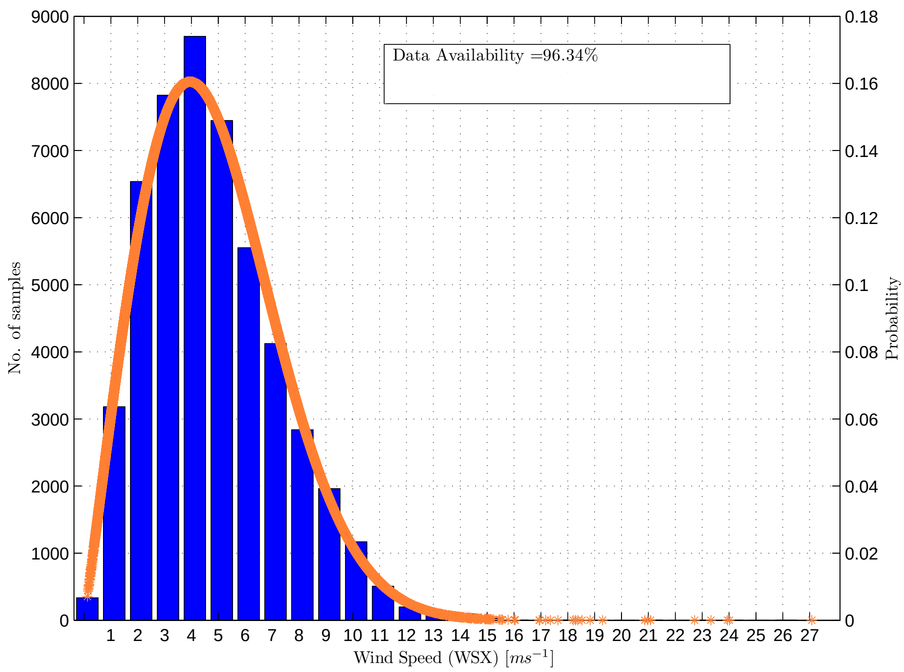


Figure 1.96: Annual wind speed distribution of WSX, 2010

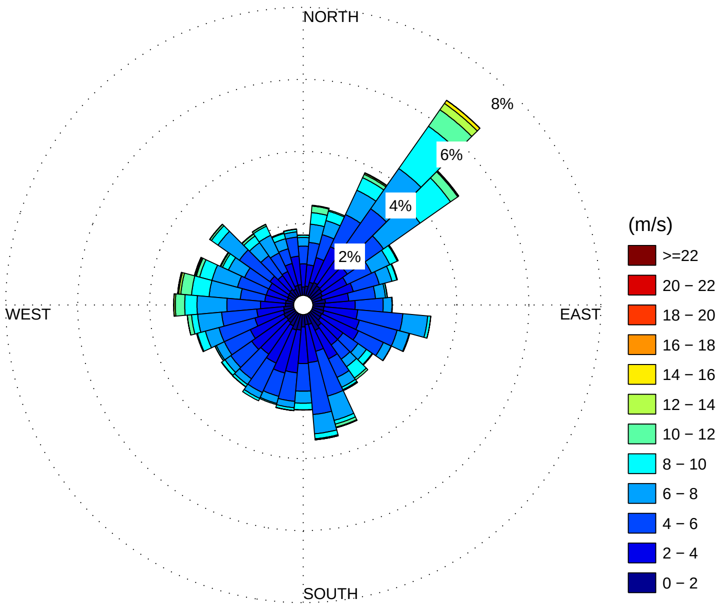


Figure 1.97: Annual wind rose of WSX, 2010

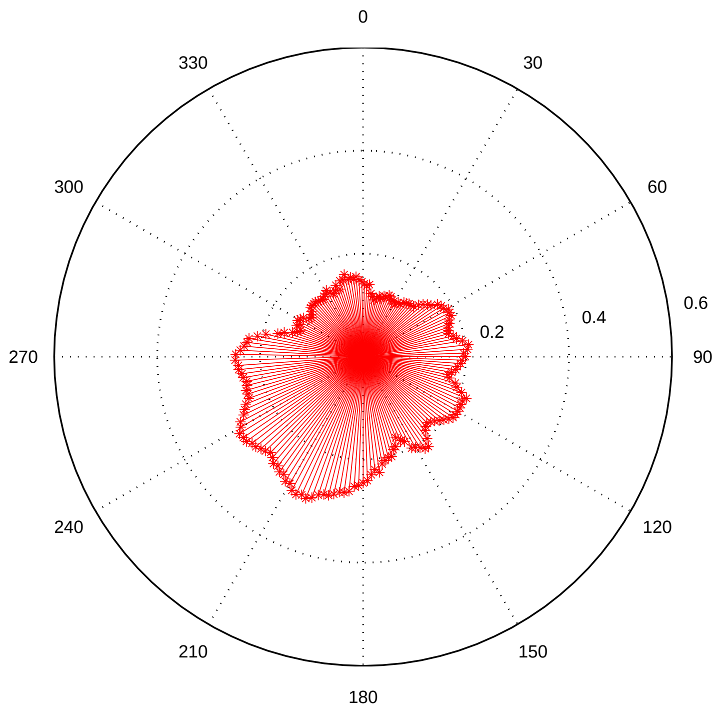


Figure 1.98: Turbulence intensity of WSX, 2010

Table 1.10: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2010

Month	Min	Mean	Max
January	0.10	4.72	22.50
February	0.10	4.41	32.89
March	0.10	4.24	23.70
April	0.10	5.03	20.90
May	0.10	4.64	20.44
June	0.10	4.33	20.60
July	0.10	4.32	24.70
August	0.10	4.75	21.60
September	0.10	5.37	18.90
October	0.10	5.01	31.50
November	0.10	6.50	50.50
December	0.10	4.70	20.20

Table 1.11: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2010

Month	Data Availability(%)	Min	Mean	Max	K	C
January	78.43	0.13	4.72	16.02	2.52	5.31
February	100.00	0.35	4.41	13.12	2.08	4.99
March	99.66	0.26	4.24	10.95	2.49	4.77
April	99.98	0.19	5.03	12.58	2.34	5.68
May	100.00	0.17	4.64	13.44	2.02	5.24
June	100.00	0.25	4.33	12.62	2.07	4.90
July	98.23	0.20	4.32	10.77	2.45	4.88
August	99.98	0.16	4.75	16.04	2.05	5.36
September	100.00	0.30	5.37	13.23	2.28	6.07
October	100.00	0.28	5.01	24.02	1.85	5.65
November	89.12	0.24	6.50	27.08	2.01	7.33
December	91.20	0.21	4.70	12.48	2.03	5.31

1.8.3.1 2010 Monthly Statistics

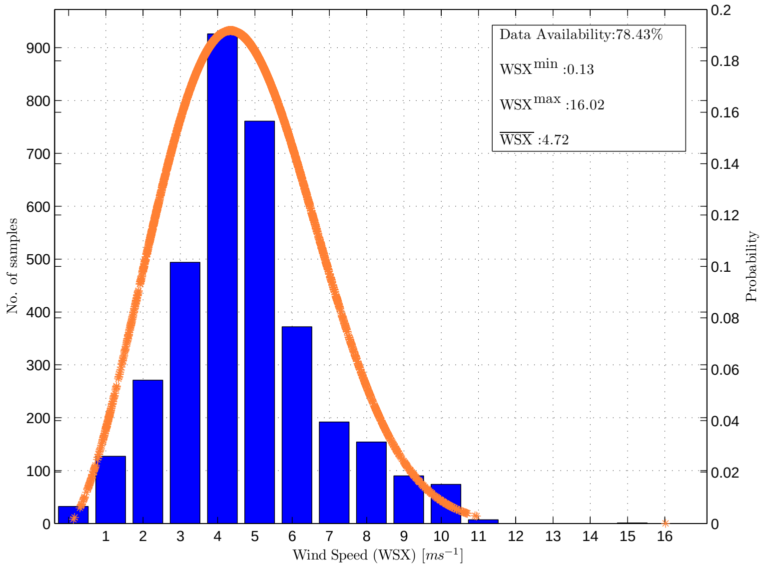


Figure 1.99: January 2010 probability distribution function

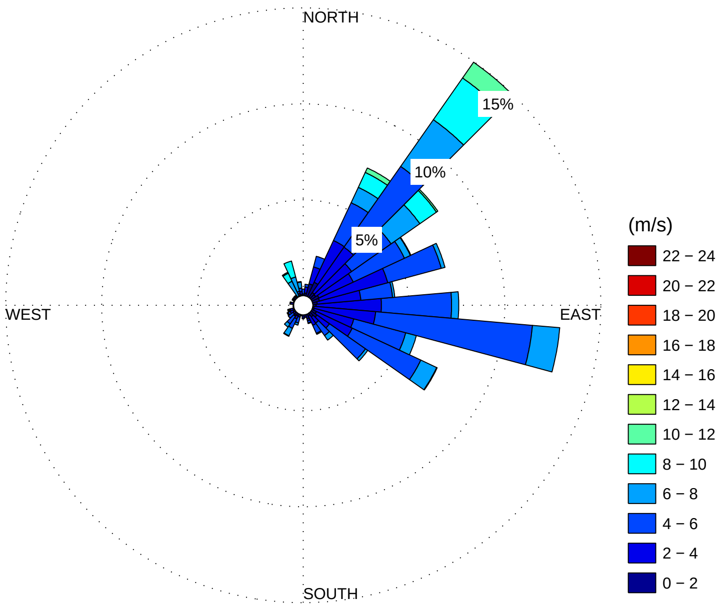


Figure 1.100: January 2010 Wind Rose

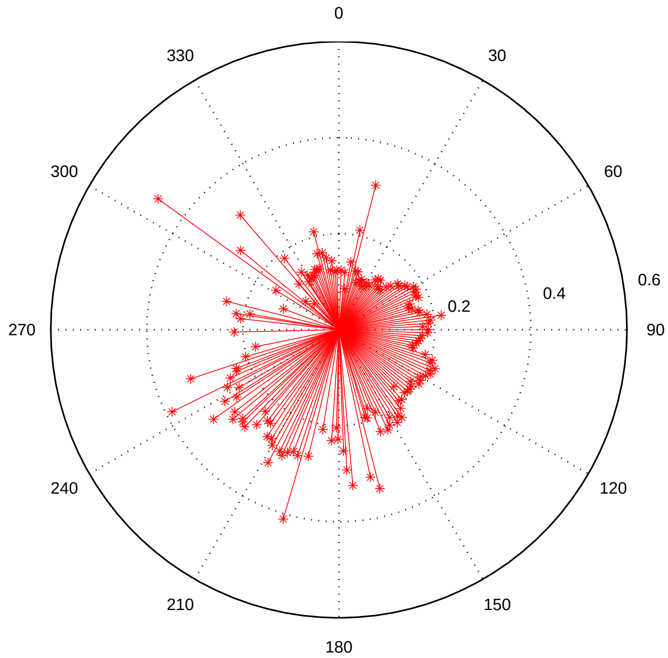


Figure 1.101: January 2010 turbulence intensity

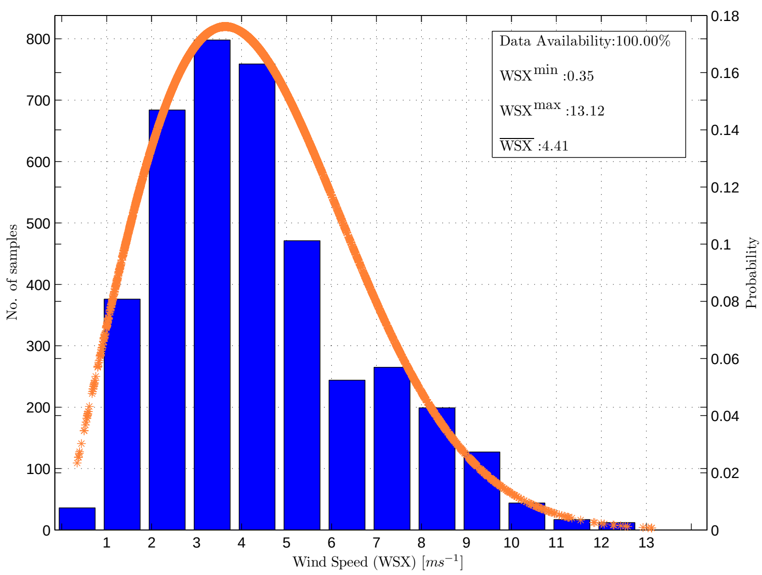


Figure 1.102: February 2010 probability distribution function

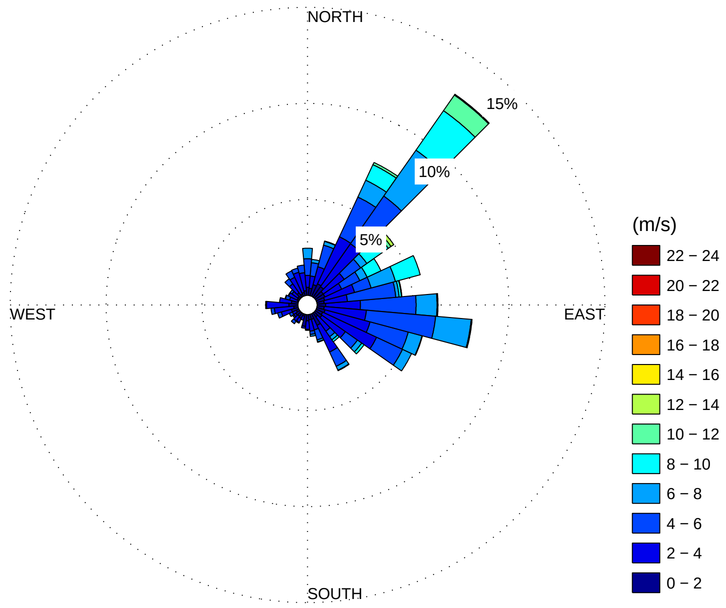


Figure 1.103: February 2010 Wind Rose

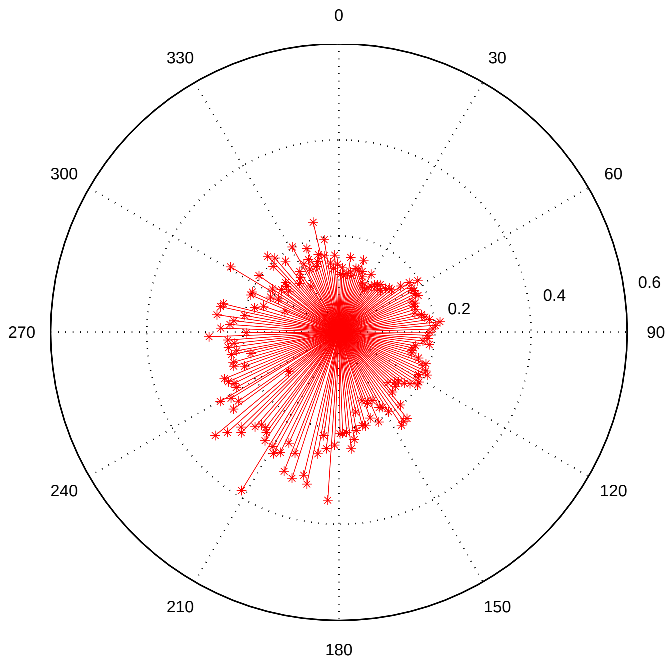


Figure 1.104: February 2010 turbulence intensity

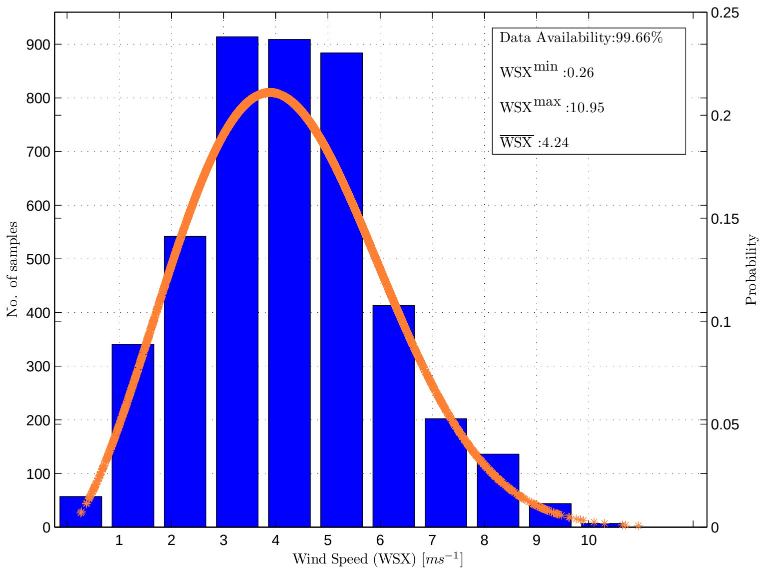


Figure 1.105: March 2010 probability distribution function

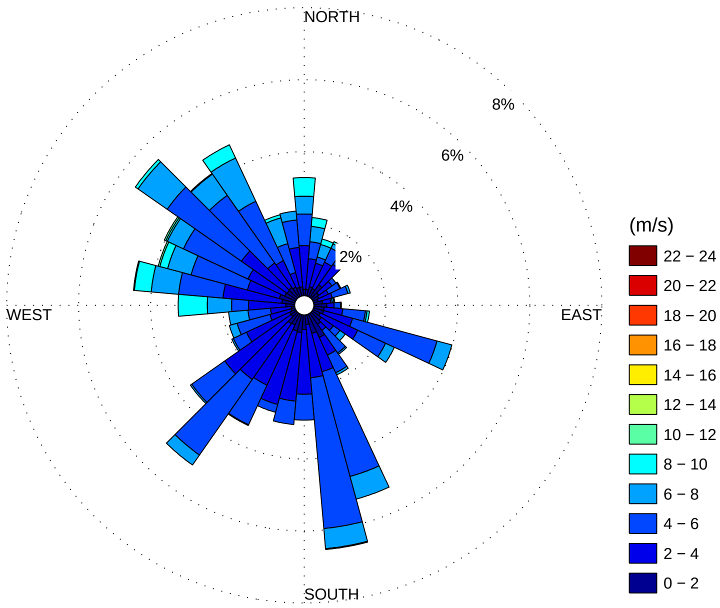


Figure 1.106: March 2010 Wind Rose

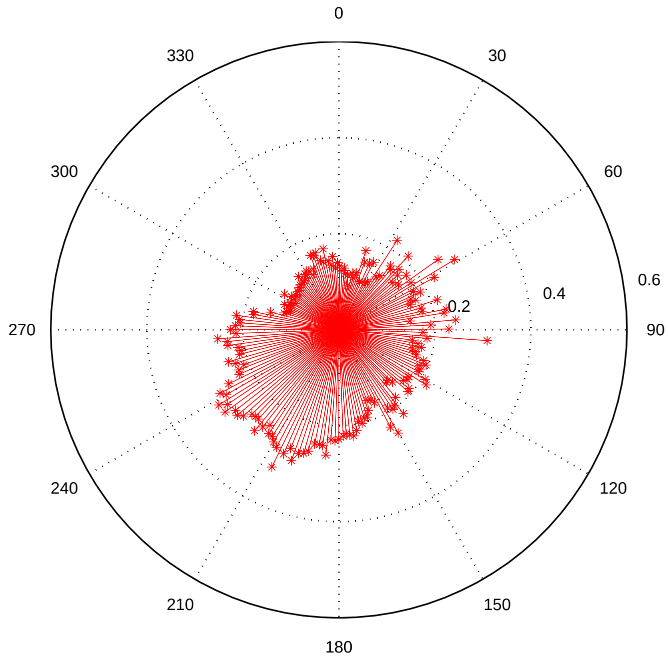


Figure 1.107: March 2010 turbulence intensity

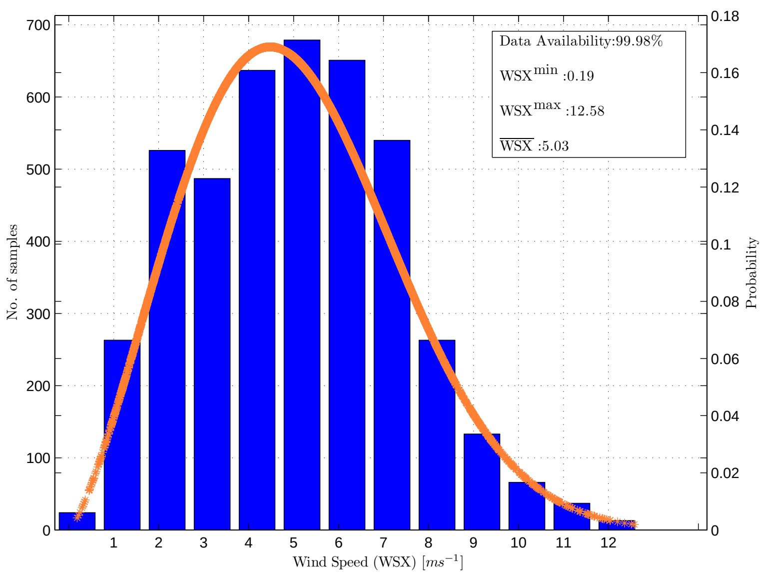


Figure 1.108: April 2010 probability distribution function

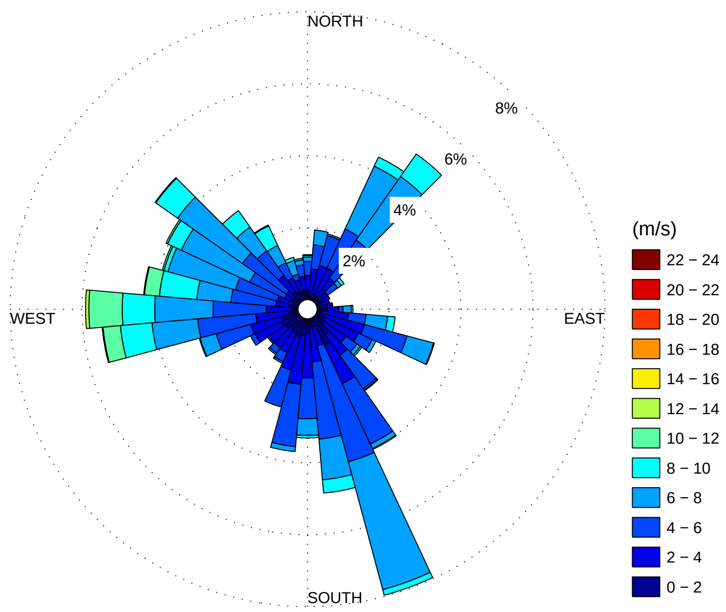


Figure 1.109: April 2010 Wind Rose

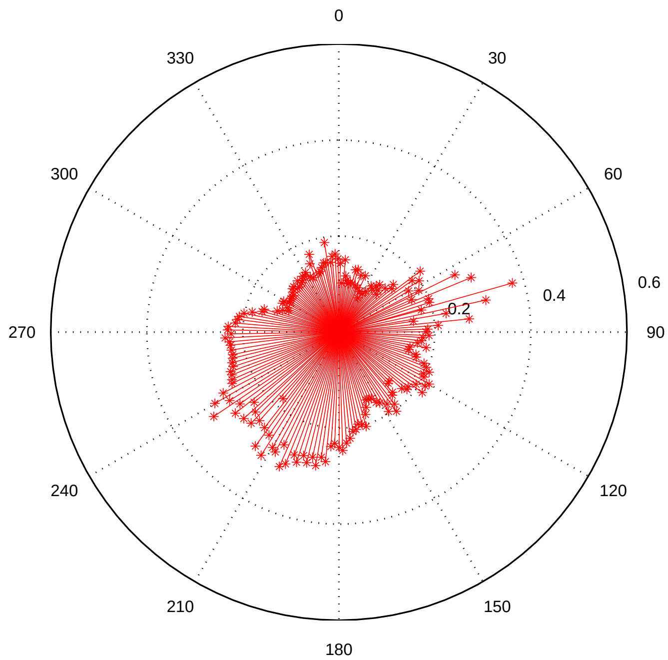


Figure 1.110: April 2010 turbulence intensity

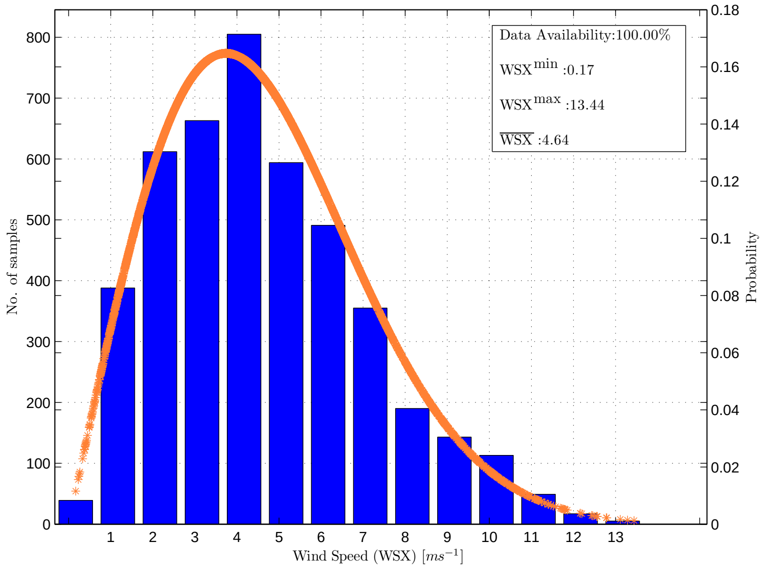


Figure 1.111: May 2010 probability distribution function

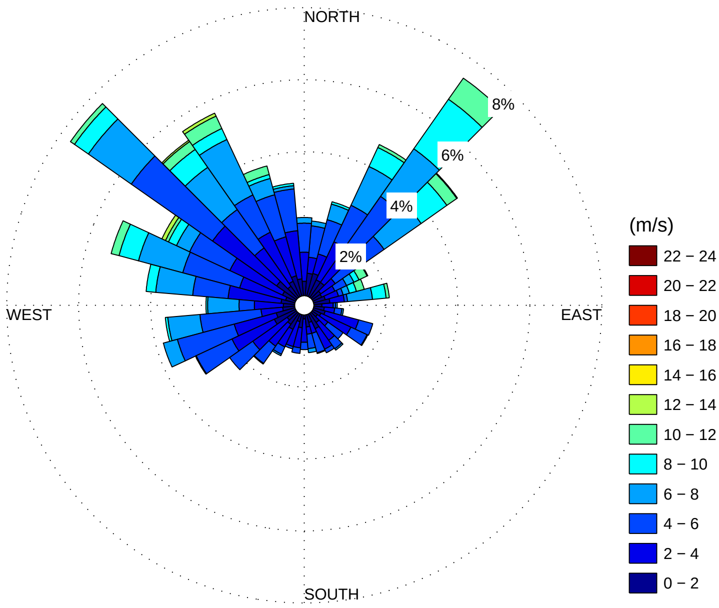


Figure 1.112: May 2010 Wind Rose

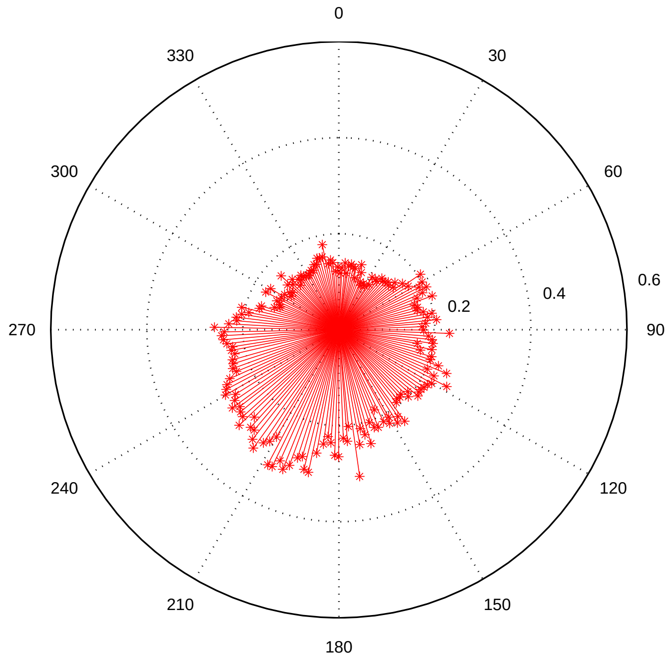


Figure 1.113: May 2010 turbulence intensity

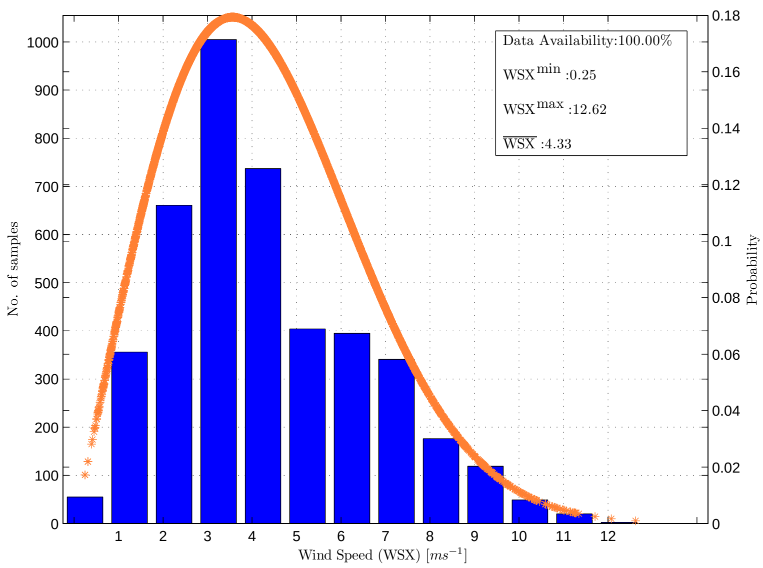


Figure 1.114: June 2010 probability distribution function

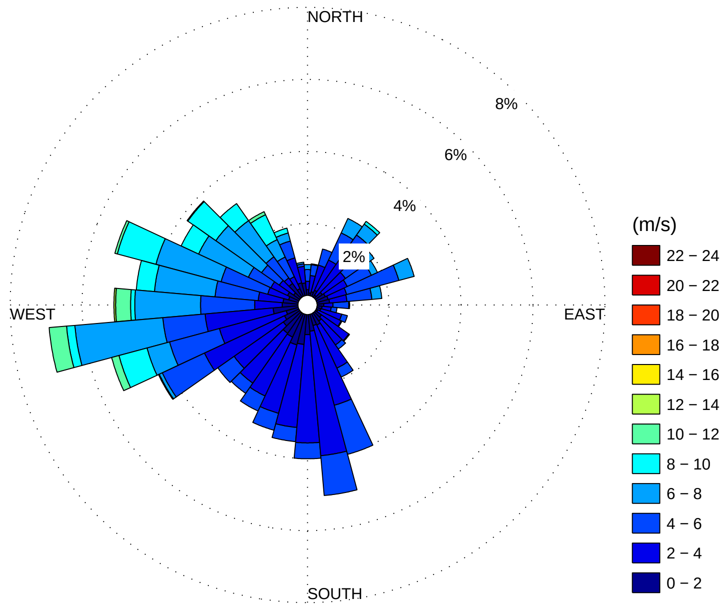


Figure 1.115: June 2010 Wind Rose

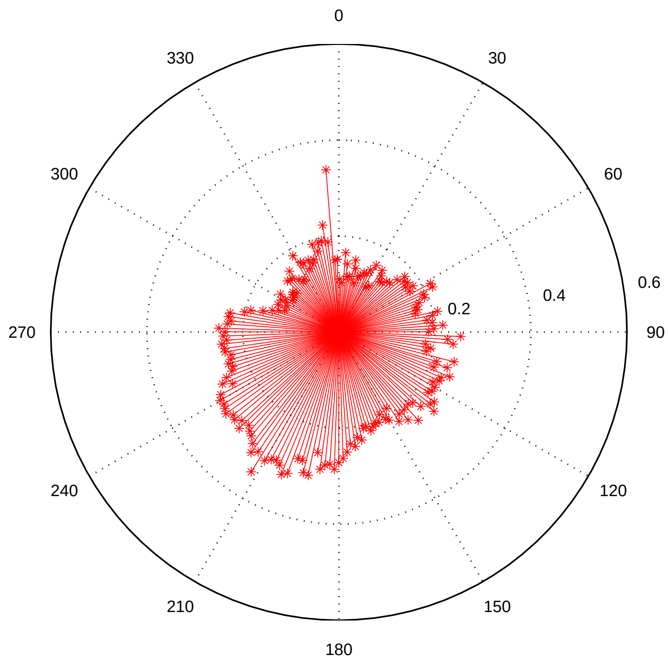


Figure 1.116: June 2010 turbulence intensity

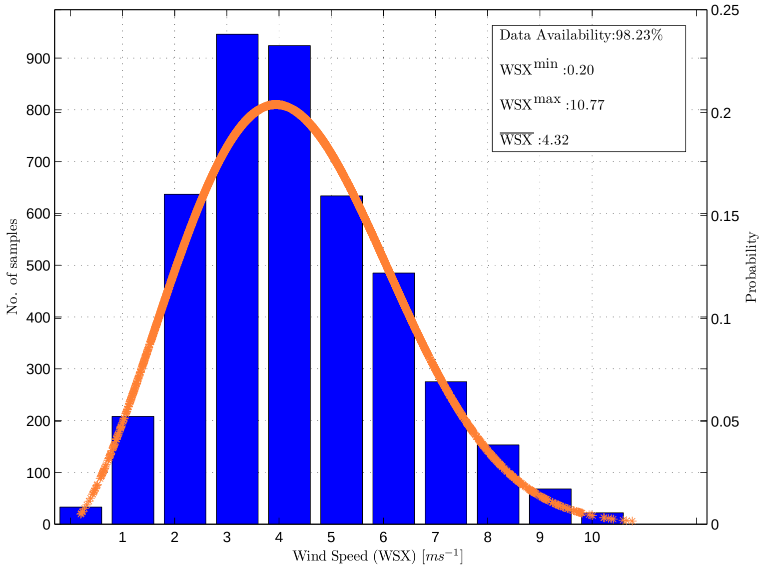


Figure 1.117: July 2010 probability distribution function

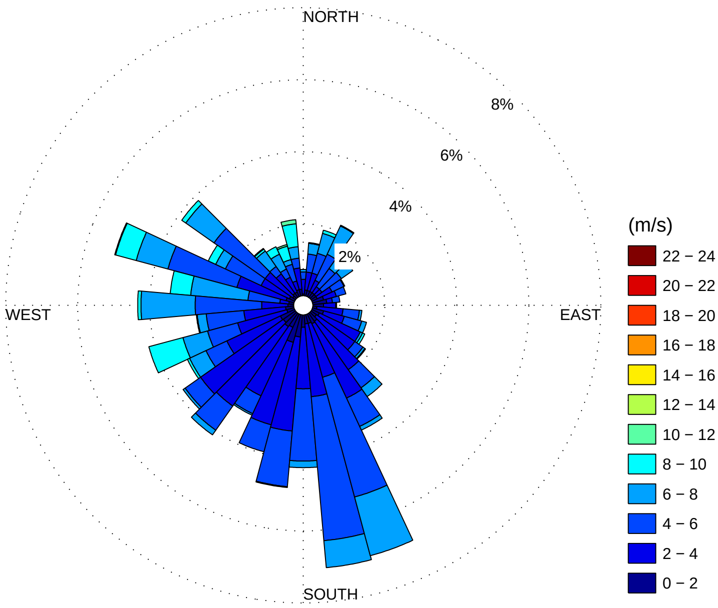


Figure 1.118: July 2010 Wind Rose

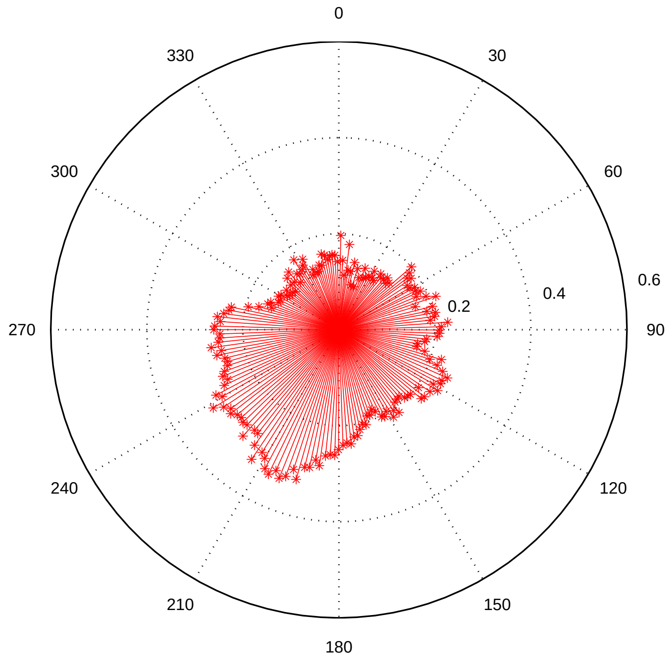


Figure 1.119: July 2010 turbulence intensity

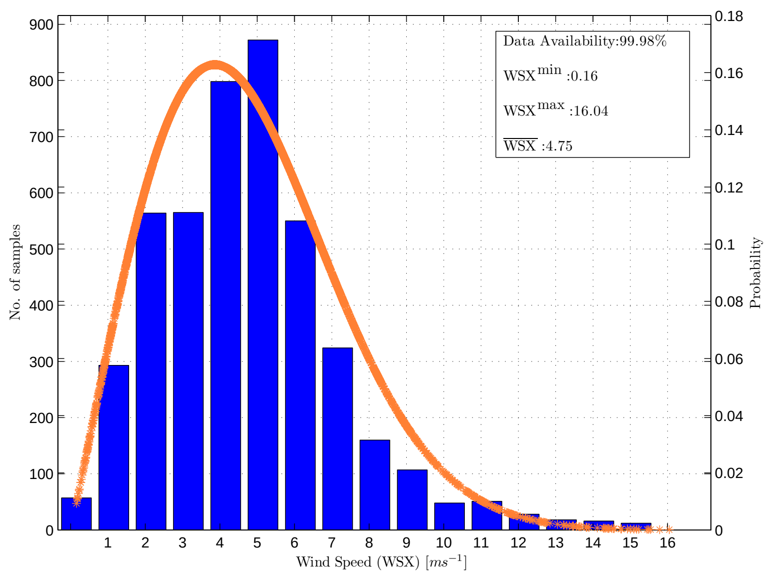


Figure 1.120: August 2010 probability distribution function

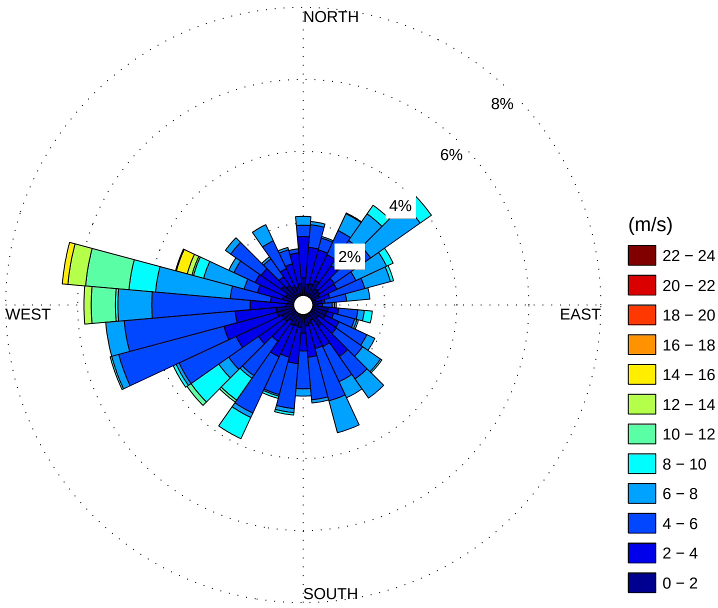


Figure 1.121: August 2010 Wind Rose

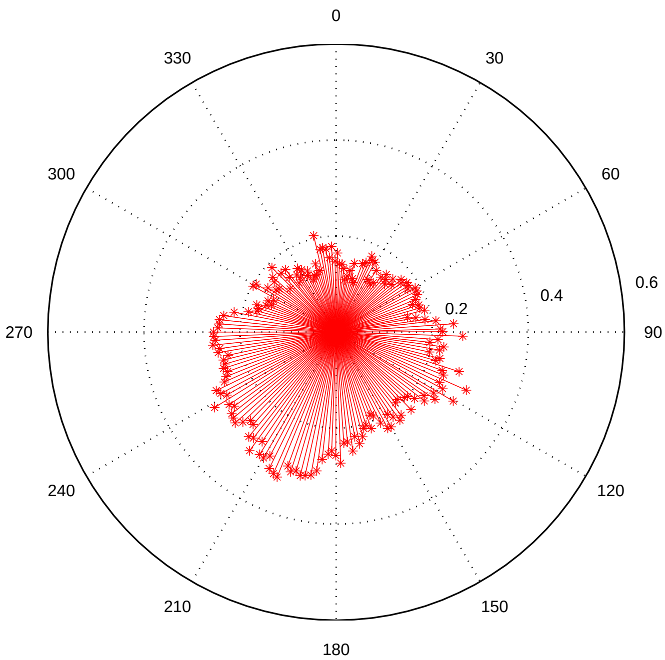


Figure 1.122: August 2010 turbulence intensity

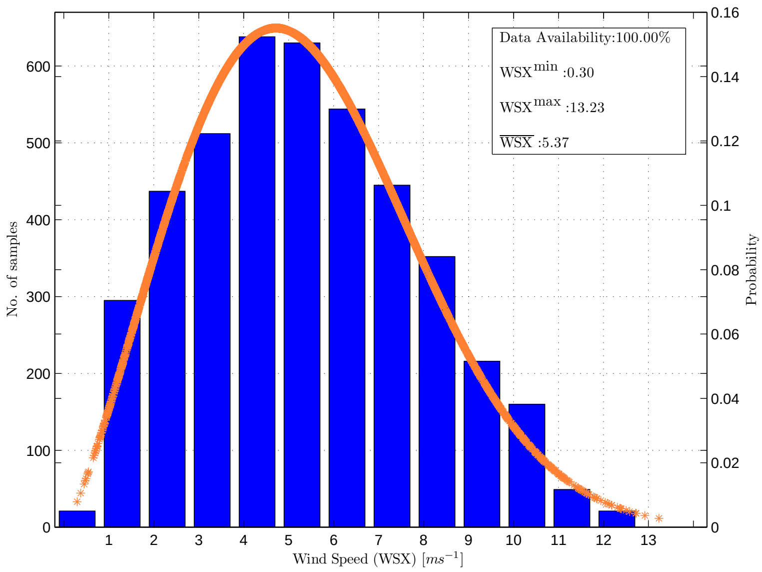


Figure 1.123: September 2010 probability distribution function

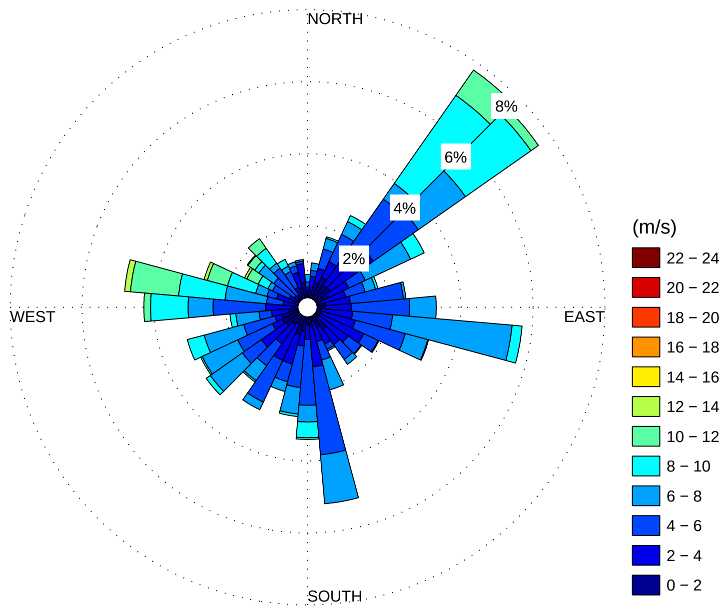


Figure 1.124: September 2010 Wind Rose

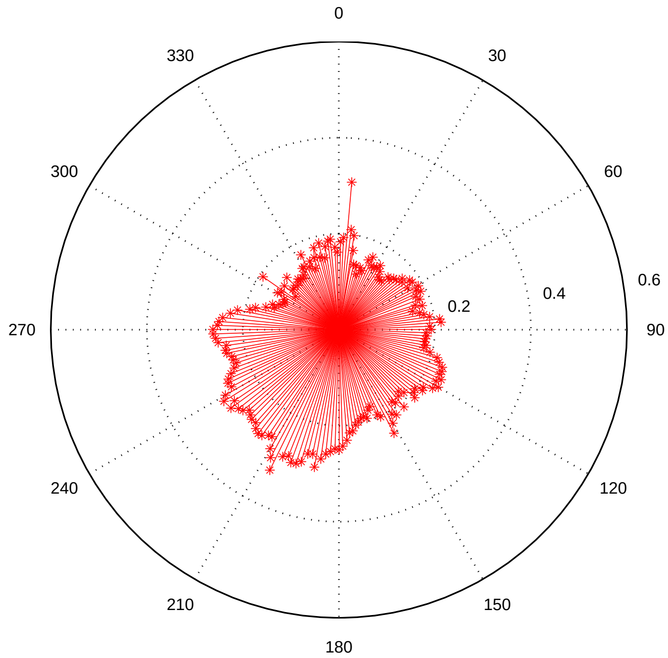


Figure 1.125: September 2010 turbulence intensity

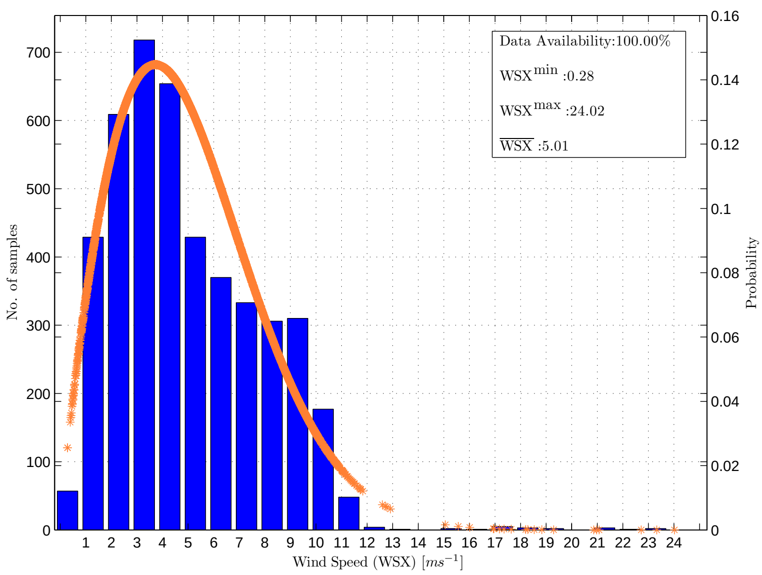


Figure 1.126: October 2010 probability distribution function

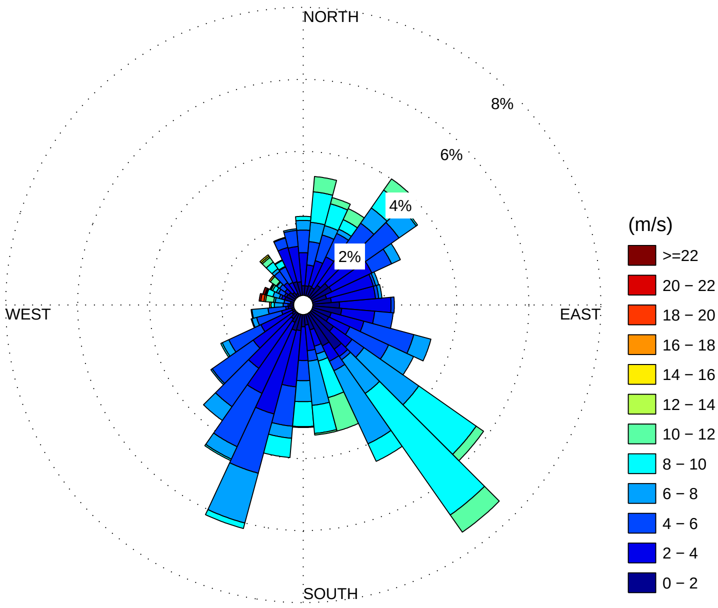


Figure 1.127: October 2010 Wind Rose

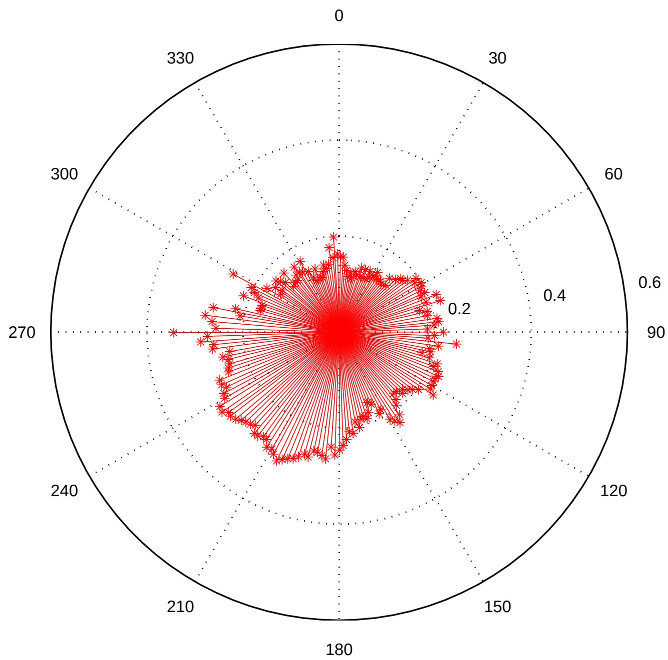


Figure 1.128: October 2010 turbulence intensity

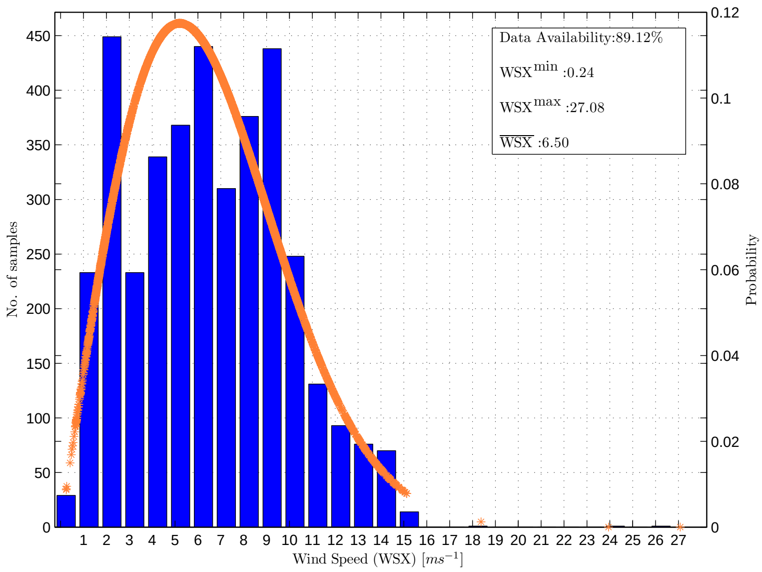


Figure 1.129: November 2010 probability distribution function

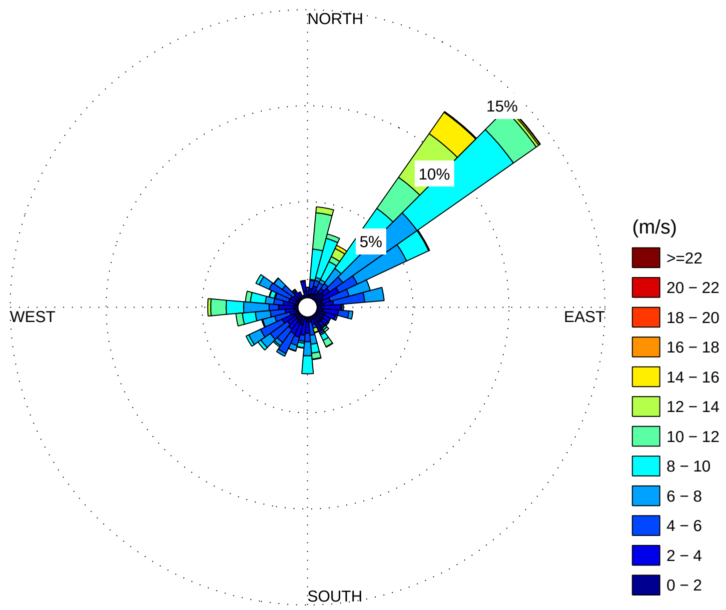


Figure 1.130: November 2010 Wind Rose

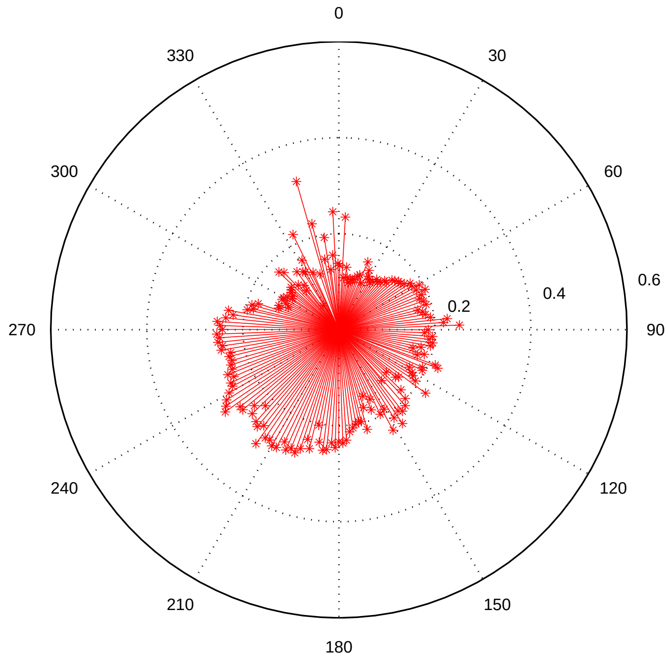


Figure 1.131: November 2010 turbulence intensity

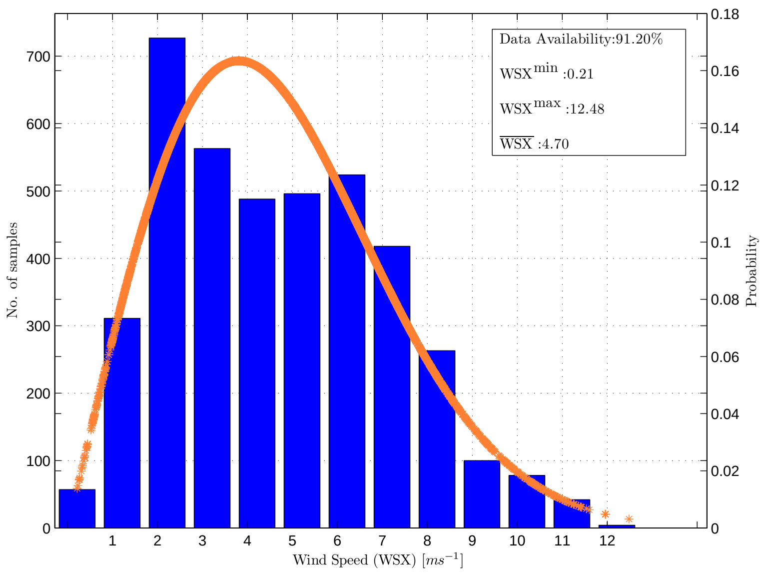


Figure 1.132: December 2010 probability distribution function

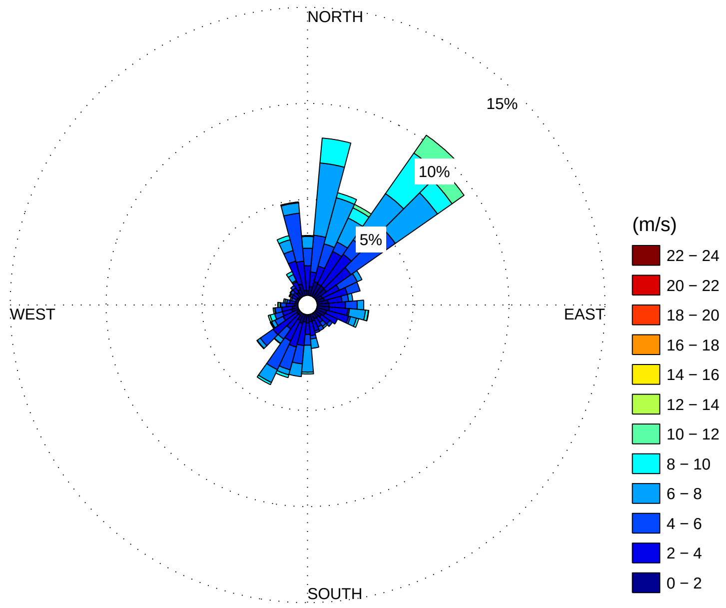


Figure 1.133: December 2010 Wind Rose

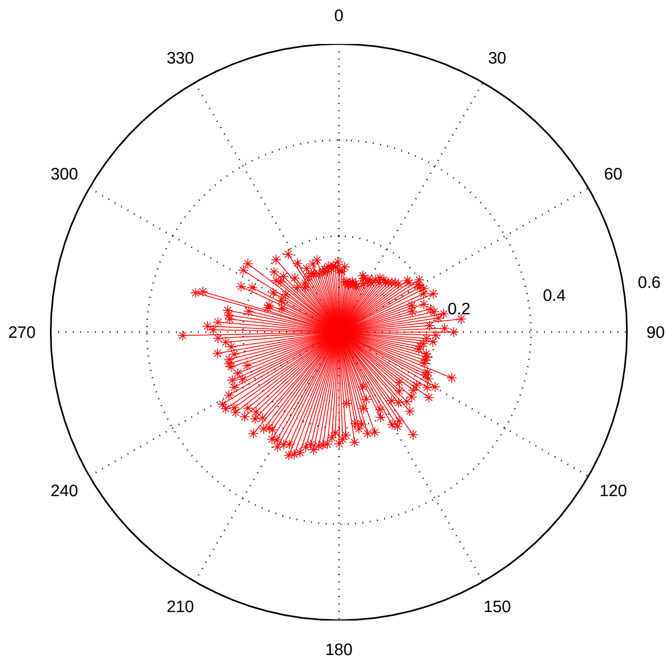


Figure 1.134: December 2010 turbulence intensity

1.8.4 2011 Annual Statistics

Table 1.12: Meteorological parameters, 2011

Month	Air Temperature [°C]			Air Pressure [hPa]			Relative Humidity			Precipitation [mm]
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Total
Jan	-9.00	-0.32	4.80	987.50	1010.49	1029.40	49.92	87.73	95.60	25.68
Feb	-10.80	-1.41	5.80	979.80	1014.63	1034.20	44.32	76.84	95.50	24.02
Mar	-2.90	2.11	8.10	982.90	1016.99	1041.00	25.37	78.07	95.20	22.17
Apr	2.30	8.80	17.60	996.99	1015.20	1025.50	26.02	75.17	95.90	32.46
May	1.70	11.32	20.90	998.80	1013.84	1030.90	22.03	71.02	93.30	52.65
Jun	11.20	15.54	25.50	995.00	1010.70	1031.30	36.02	72.57	93.50	72.77
Jul	12.90	18.07	24.50	990.90	1007.75	1018.90	40.19	75.39	93.59	110.59
Aug	12.10	17.14	23.80	990.60	1008.20	1020.70	39.54	74.59	93.60	126.55
Sept	9.80	14.67	22.70	987.10	1008.18	1026.60	42.07	78.31	94.50	129.49
Oct	4.30	10.70	16.40	986.61	1011.92	1034.80	38.62	76.36	95.00	88.09
Nov	0.80	7.56	12.60	975.49	1017.73	1035.60	36.88	84.90	95.20	23.94
Dec	0.00	5.34	10.40	968.55	995.64	1024.27	45.05	79.14	94.90	209.73

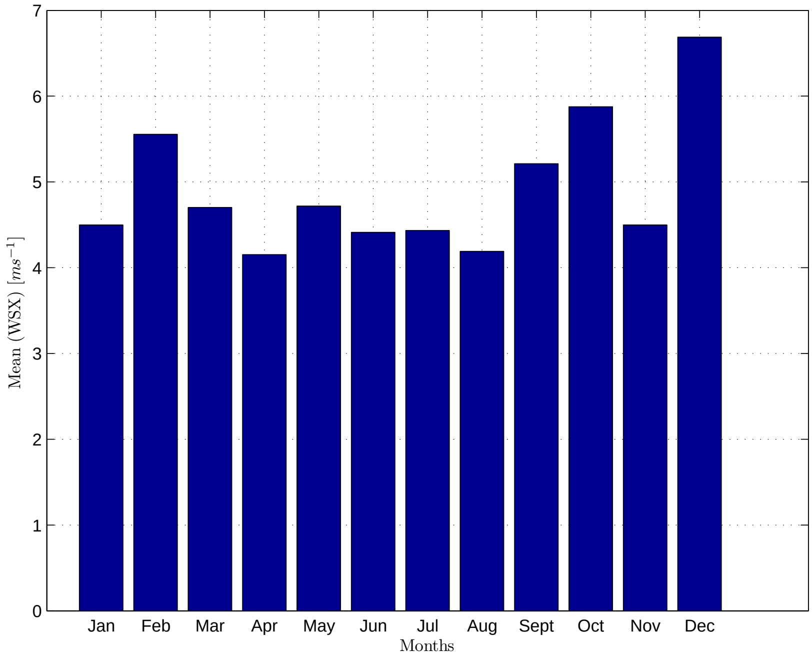


Figure 1.135: Annual wind speed distribution of WSX, 2011

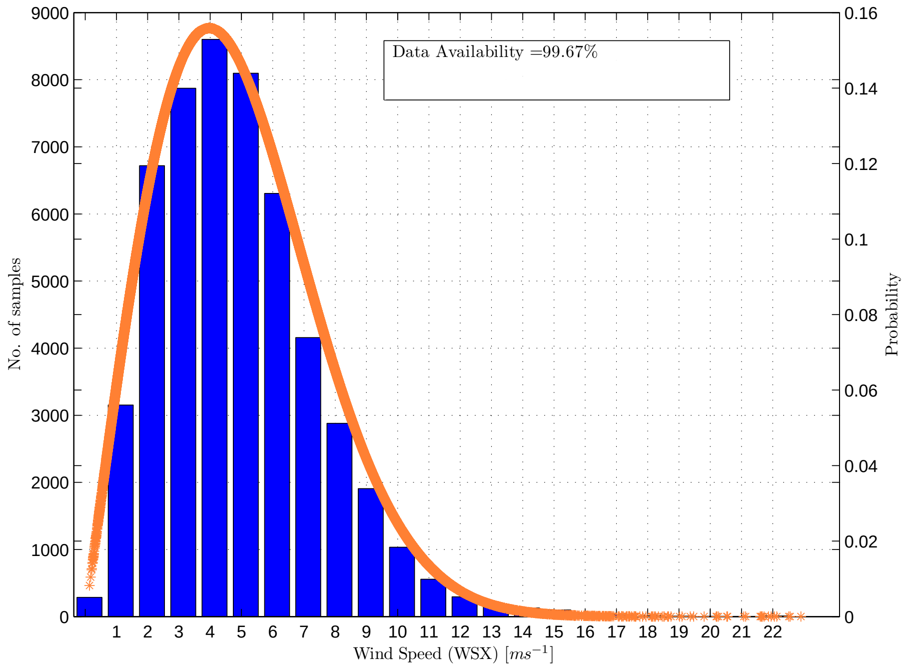


Figure 1.136: Annual wind speed distribution of WSX, 2011

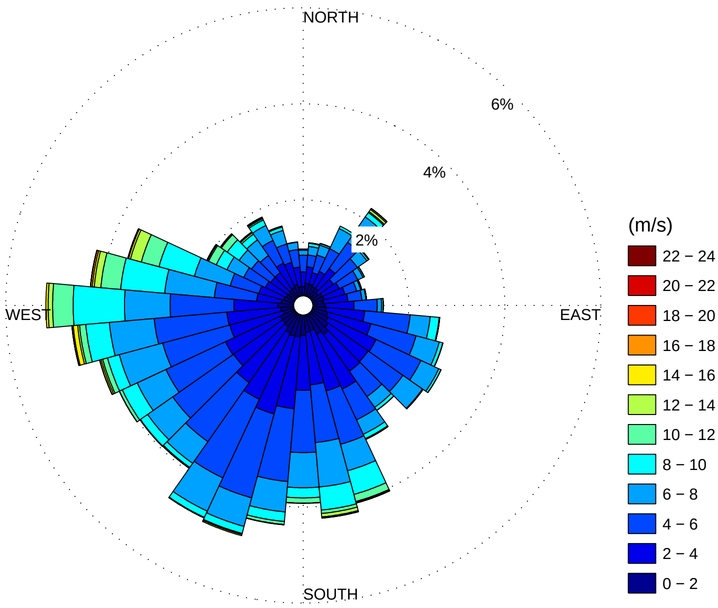


Figure 1.137: Annual wind rose of WSX, 2011

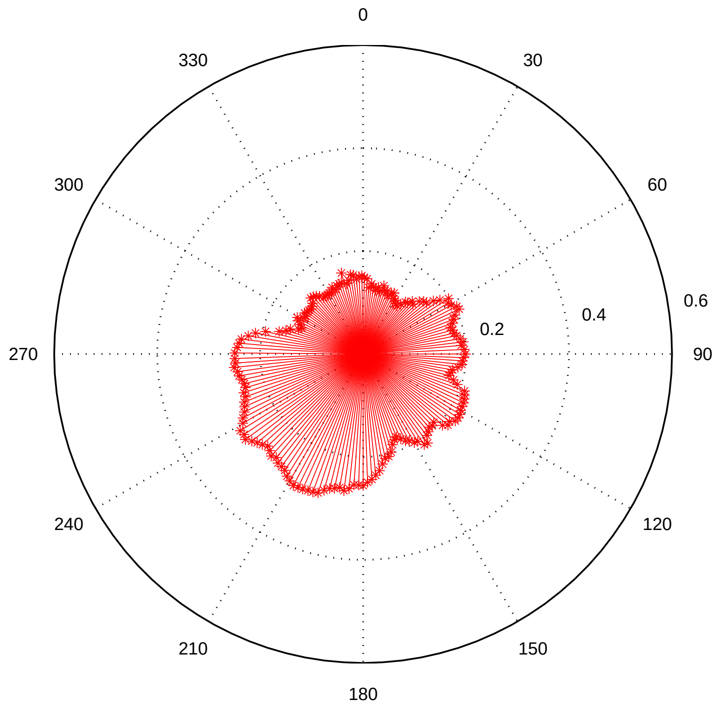


Figure 1.138: Turbulence intensity of WSX, 2011

Table 1.13: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2011

Month	Min	Mean	Max
January	0.10	4.50	38.51
February	0.10	5.55	35.30
March	0.10	4.70	21.05
April	0.10	4.15	21.90
May	0.10	4.72	20.00
June	0.10	4.41	18.00
July	0.10	4.43	15.90
August	0.10	4.19	16.90
September	0.10	5.21	21.00
October	0.10	5.88	20.50
November	0.10	4.50	32.10
December	0.10	6.69	28.60

Table 1.14: Monthly wind speed [ms-1] parameters of 10 min. averaged data, 2011

Month	Data Availability(%)	Min	Mean	Max	K	C
January	100.00	0.14	4.50	21.72	1.88	5.07
February	100.00	0.48	5.55	22.90	2.18	6.29
March	100.00	0.25	4.70	12.90	2.30	5.30
April	100.00	0.17	4.15	15.49	1.72	4.68
May	100.00	0.51	4.72	11.98	2.53	5.32
June	100.00	0.27	4.41	10.97	2.20	5.00
July	99.84	0.26	4.43	9.93	2.45	5.01
August	100.00	0.24	4.19	12.74	2.05	4.74
September	96.23	0.35	5.21	13.24	2.15	5.90
October	100.00	0.59	5.88	13.89	2.56	6.63
November	100.00	0.33	4.50	22.56	1.73	5.08
December	99.89	0.60	6.69	18.34	2.30	7.55

1.8.4.1 2011 Monthly Statistics

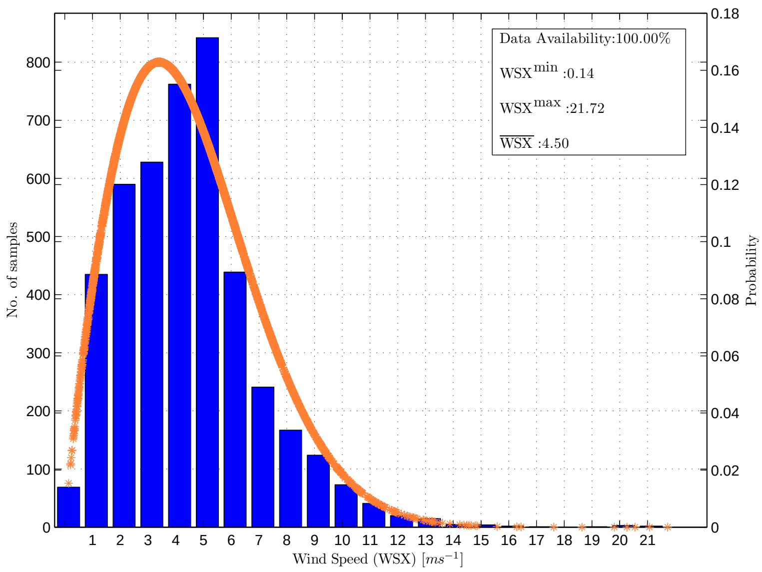


Figure 1.139: January 2011 probability distribution function

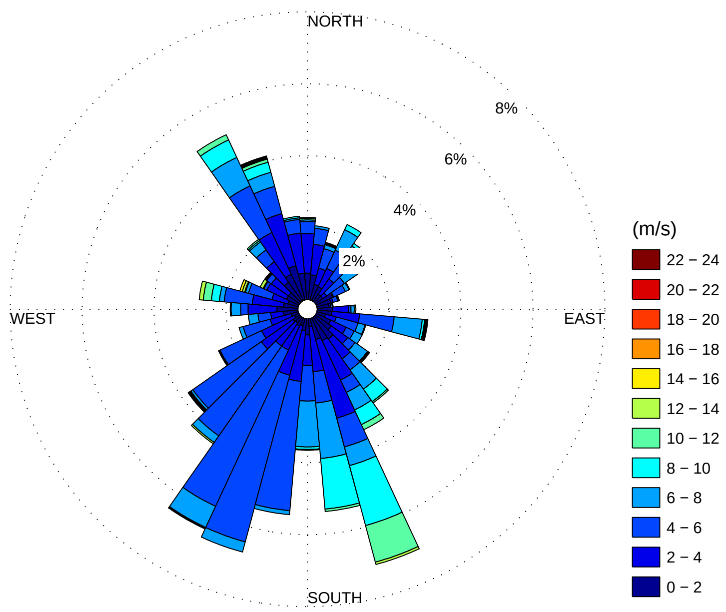


Figure 1.140: January 2011 Wind Rose

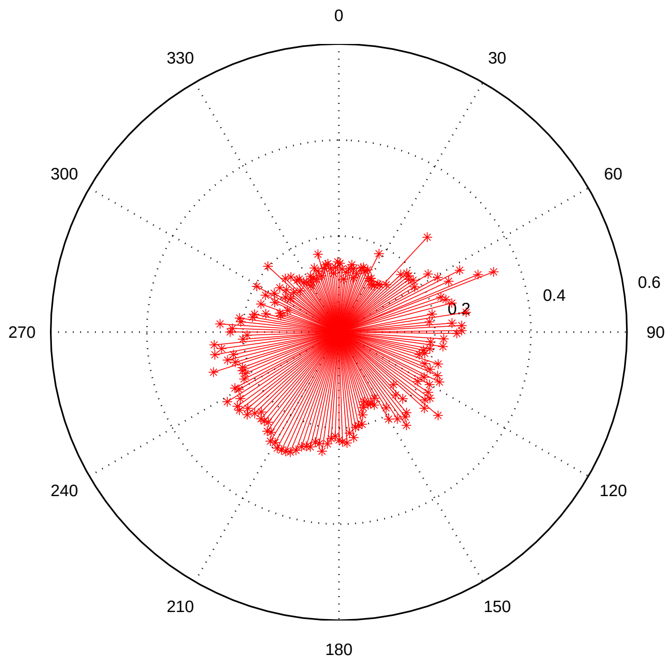


Figure 1.141: January 2011 turbulence intensity

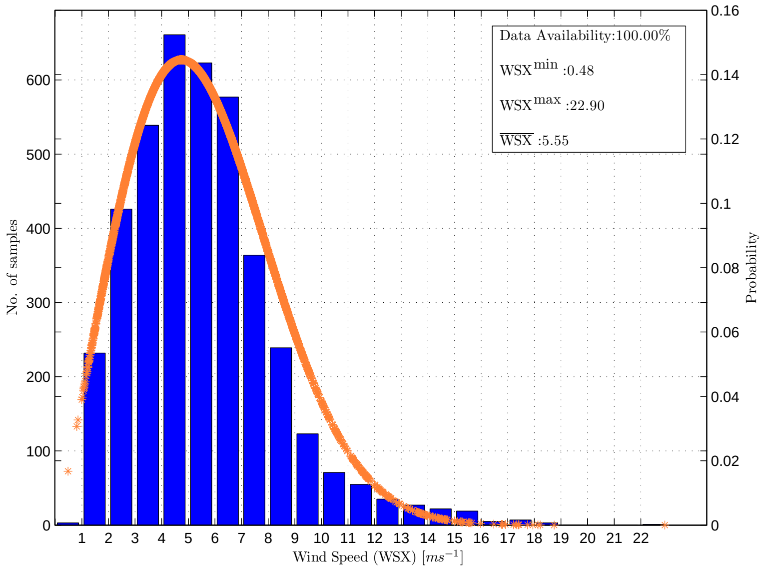


Figure 1.142: February 2011 probability distribution function

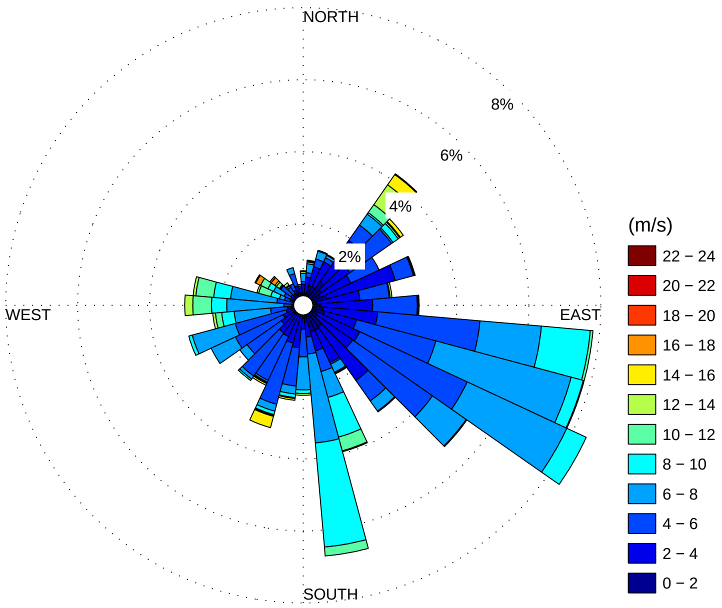


Figure 1.143: February 2011 Wind Rose

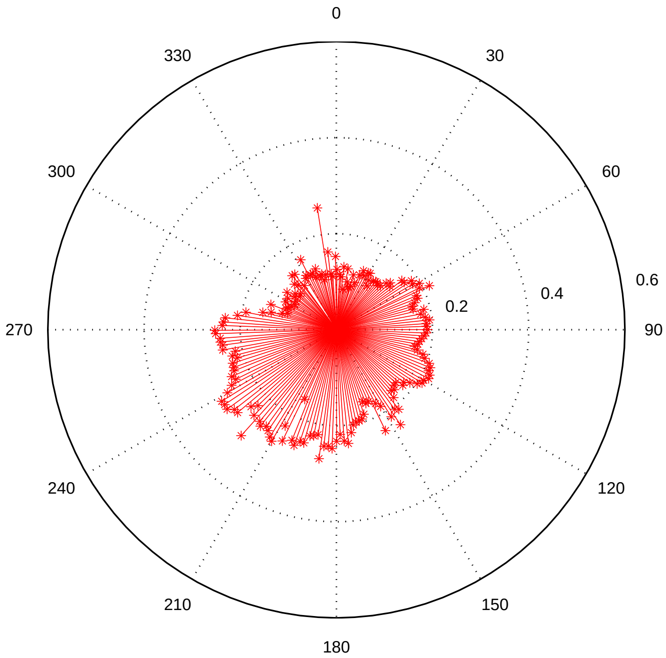


Figure 1.144: February 2011 turbulence intensity

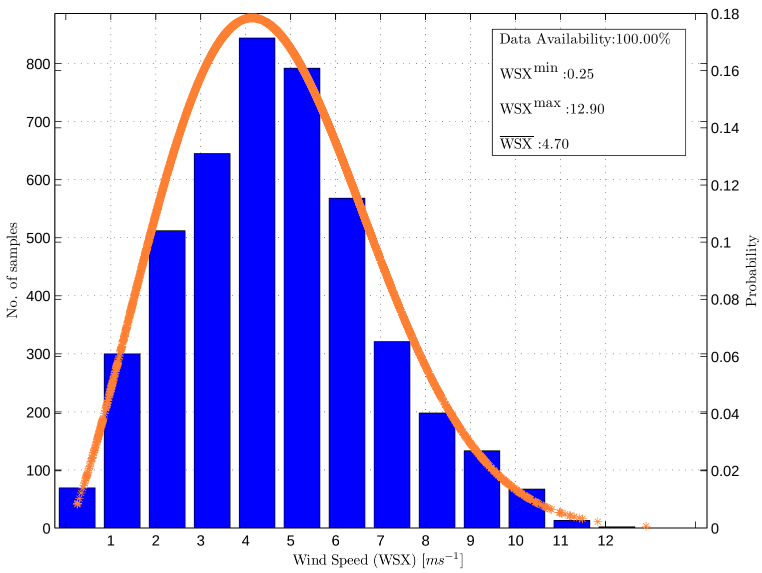


Figure 1.145: March 2011 probability distribution function

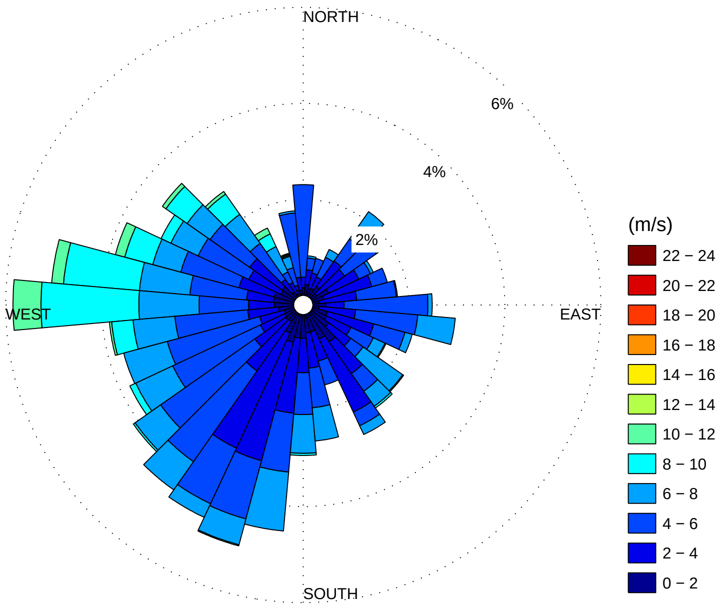


Figure 1.146: March 2011 Wind Rose

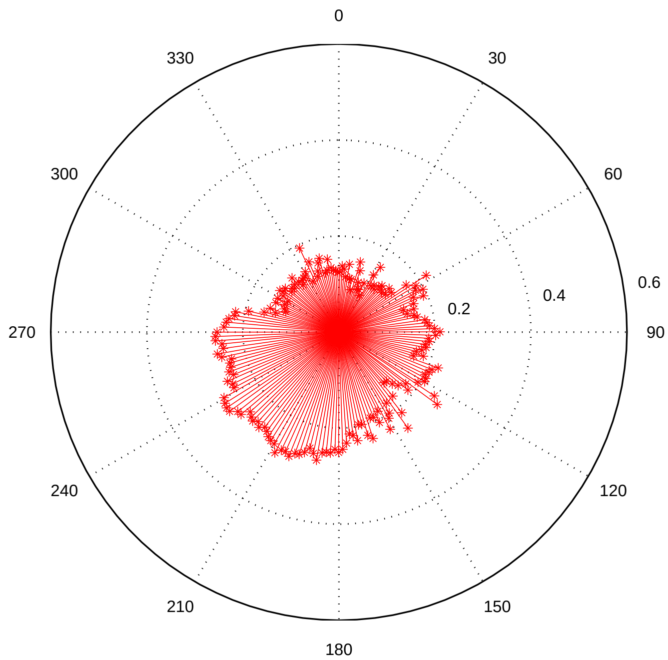


Figure 1.147: March 2011 turbulence intensity

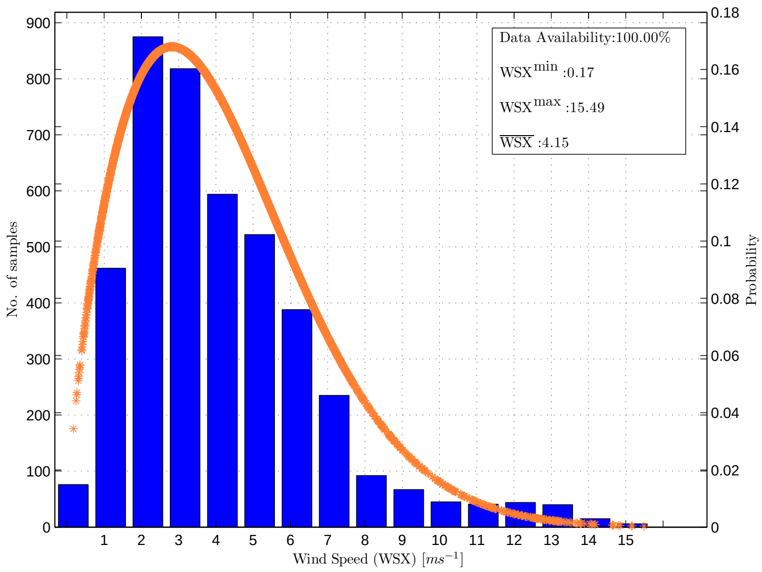


Figure 1.148: April 2011 probability distribution function

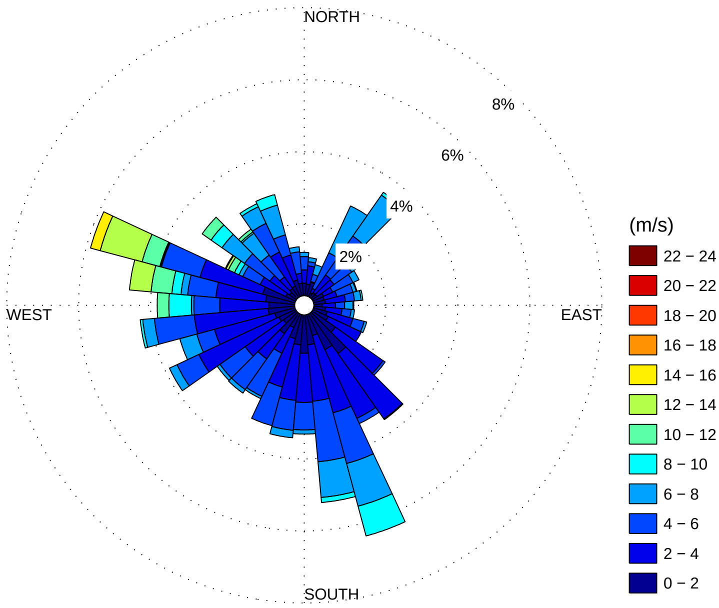


Figure 1.149: April 2011 Wind Rose

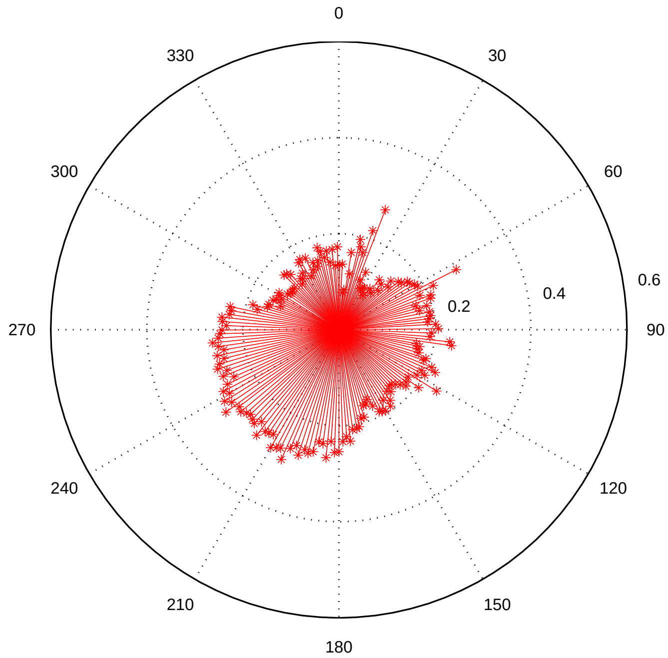


Figure 1.150: April 2011 turbulence intensity

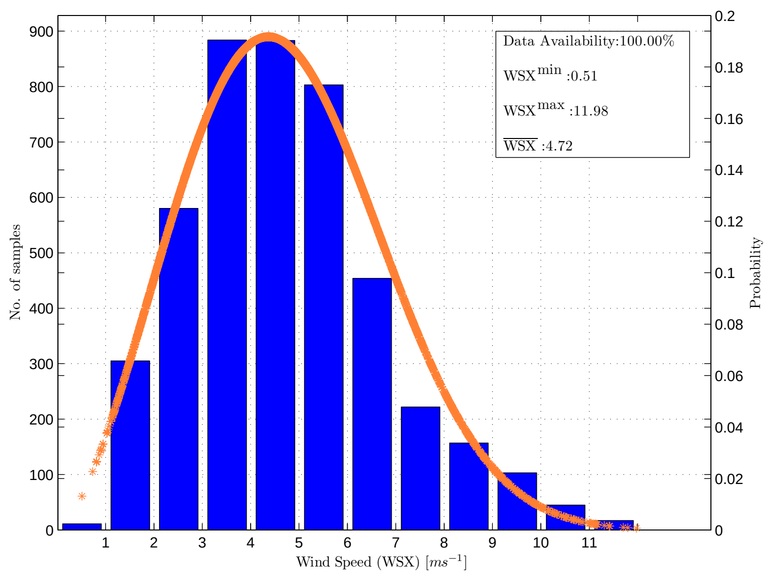


Figure 1.151: May 2011 probability distribution function

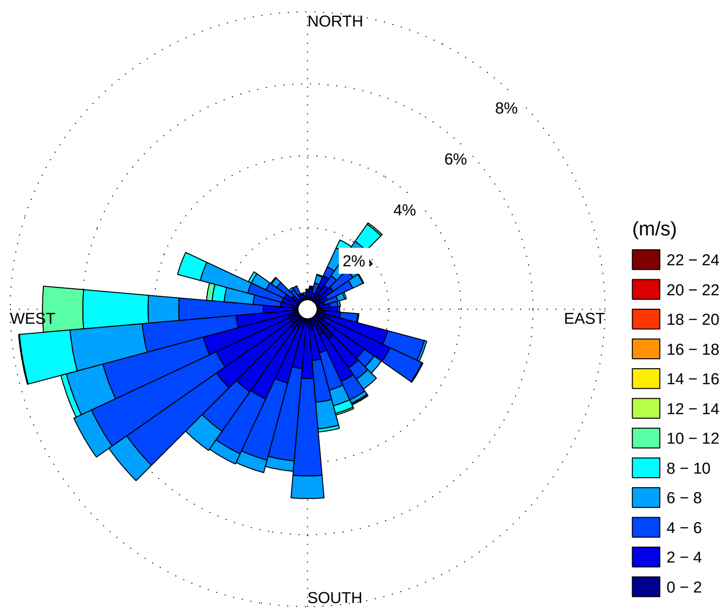


Figure 1.152: May 2011 Wind Rose

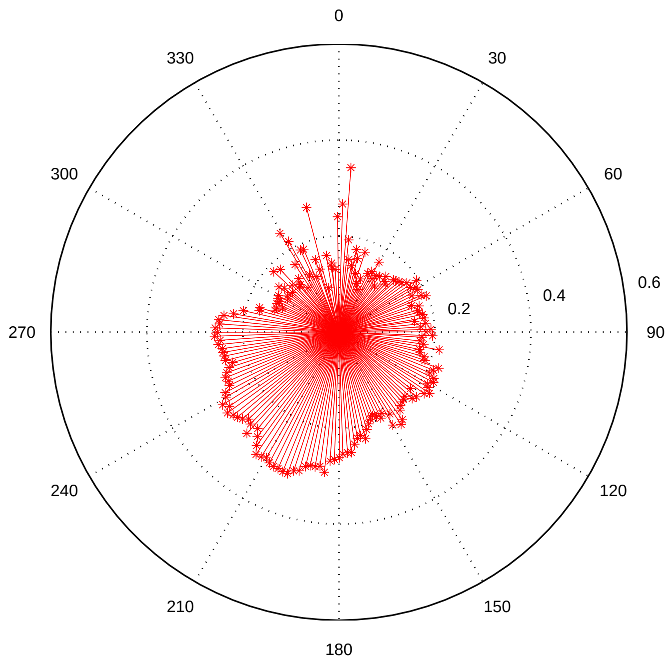


Figure 1.153: May 2011 turbulence intensity

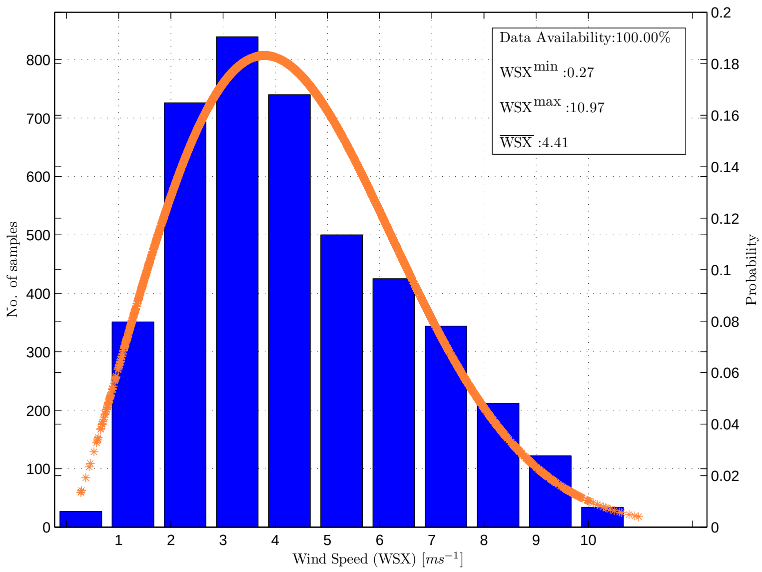


Figure 1.154: June 2011 probability distribution function

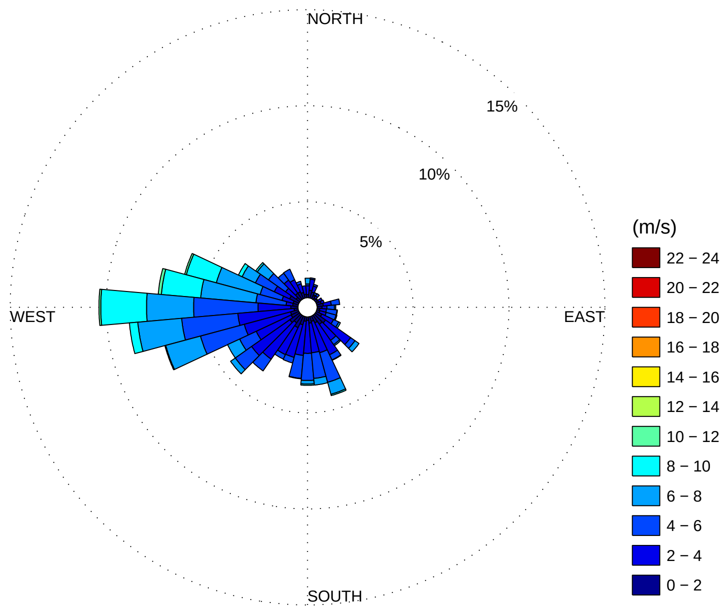


Figure 1.155: June 2011 Wind Rose

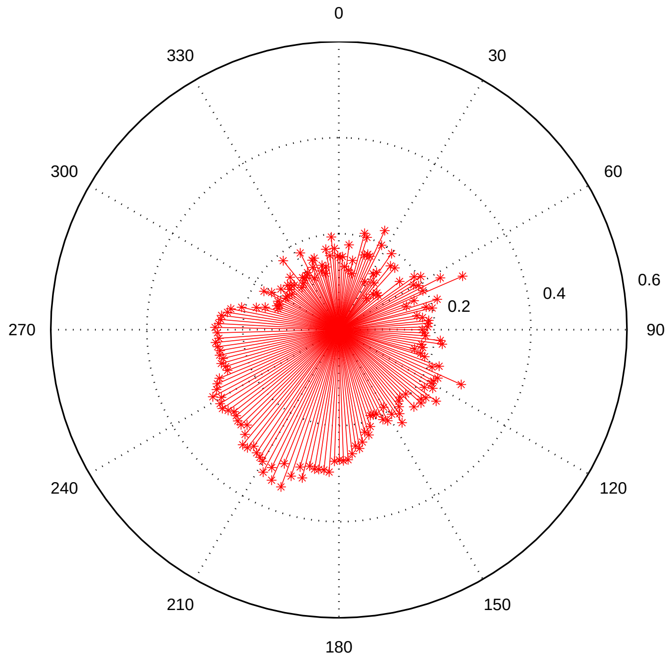


Figure 1.156: June 2011 turbulence intensity

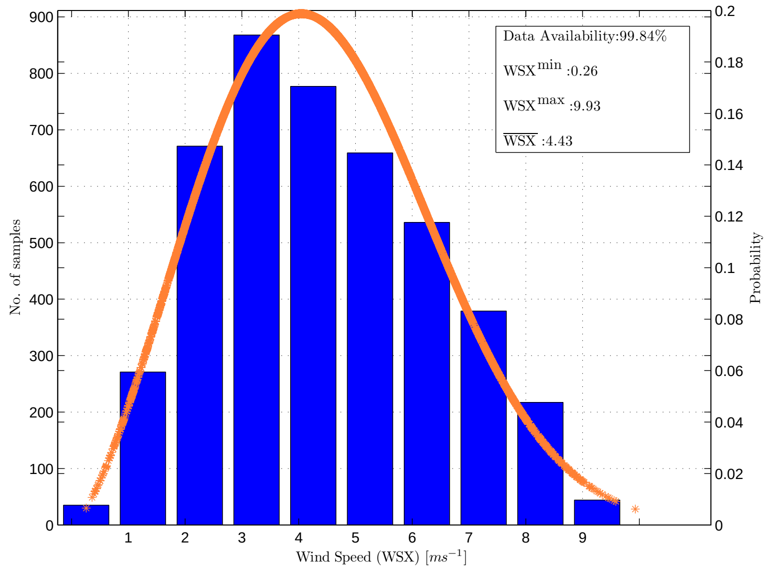


Figure 1.157: July 2011 probability distribution function

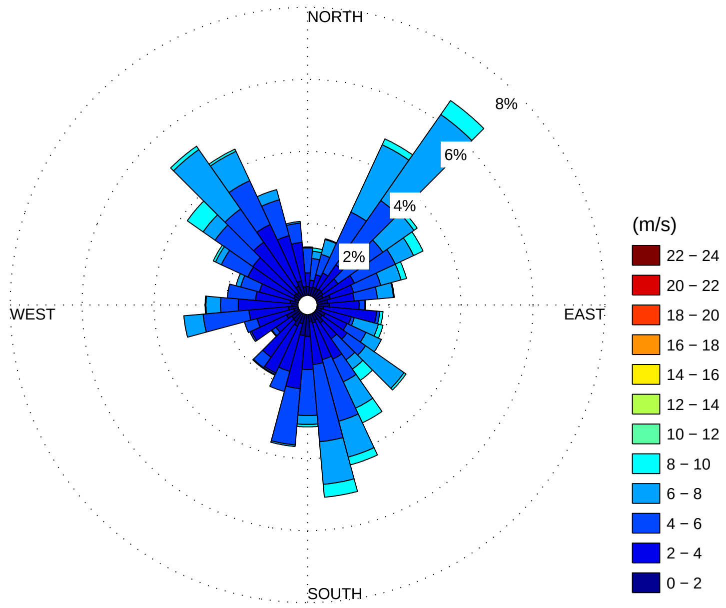


Figure 1.158: July 2011 Wind Rose

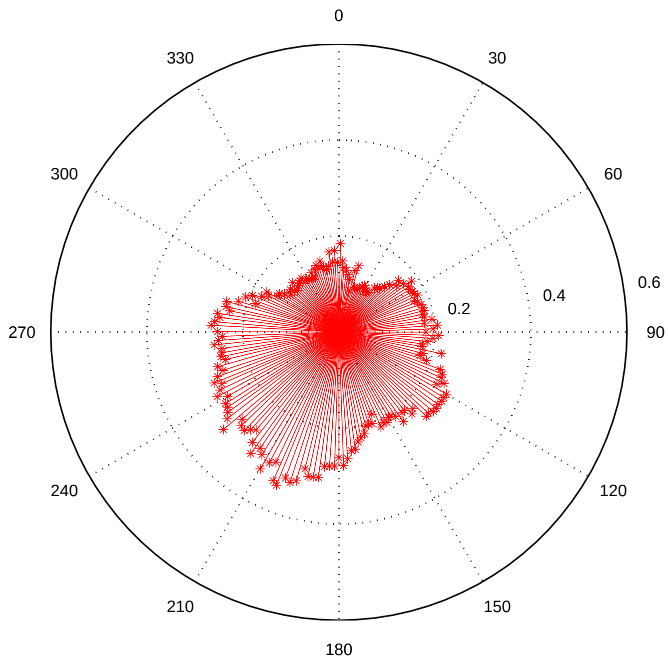


Figure 1.159: July 2011 turbulence intensity

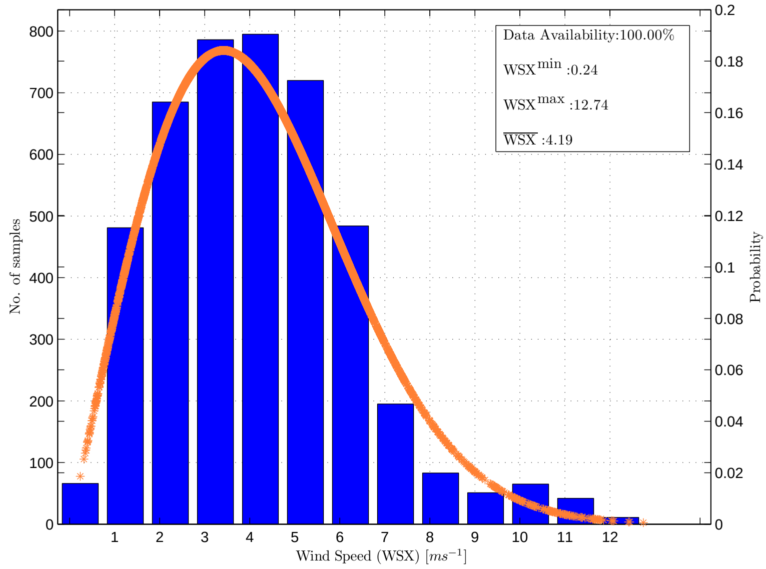


Figure 1.160: August 2011 probability distribution function

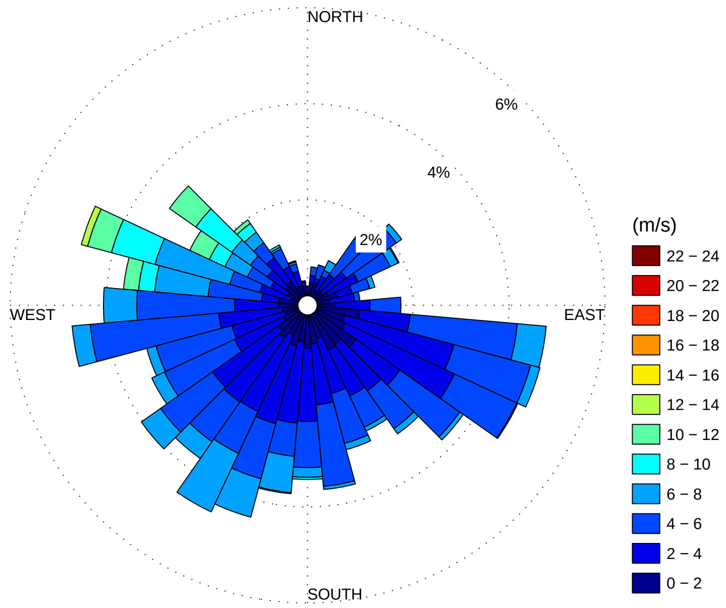


Figure 1.161: August 2011 Wind Rose

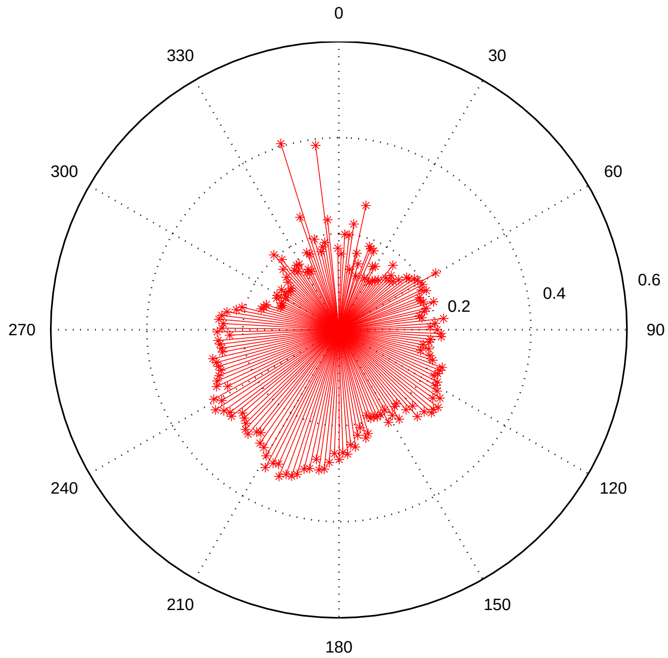


Figure 1.162: August 2011 turbulence intensity

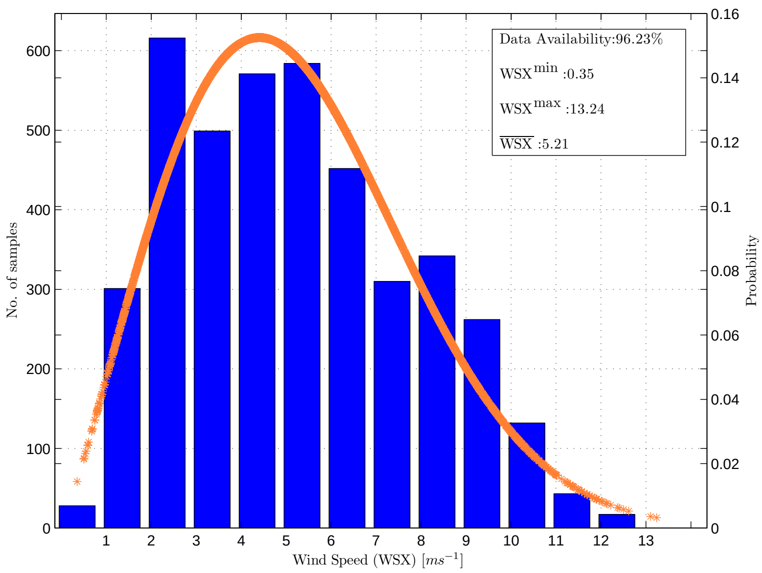


Figure 1.163: September 2011 probability distribution function

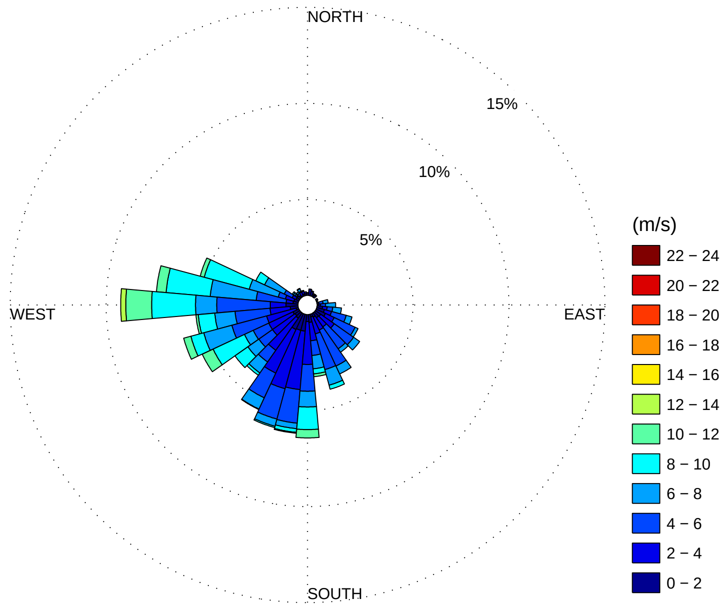


Figure 1.164: September 2011 Wind Rose

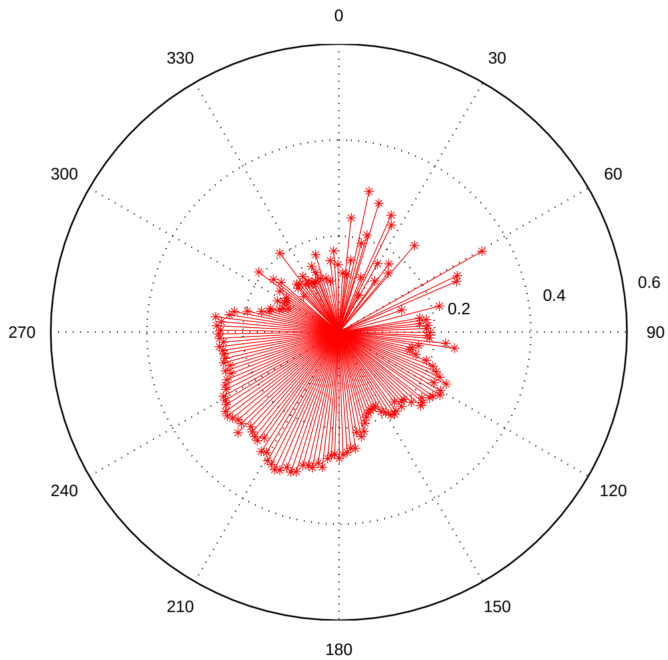


Figure 1.165: September 2011 turbulence intensity

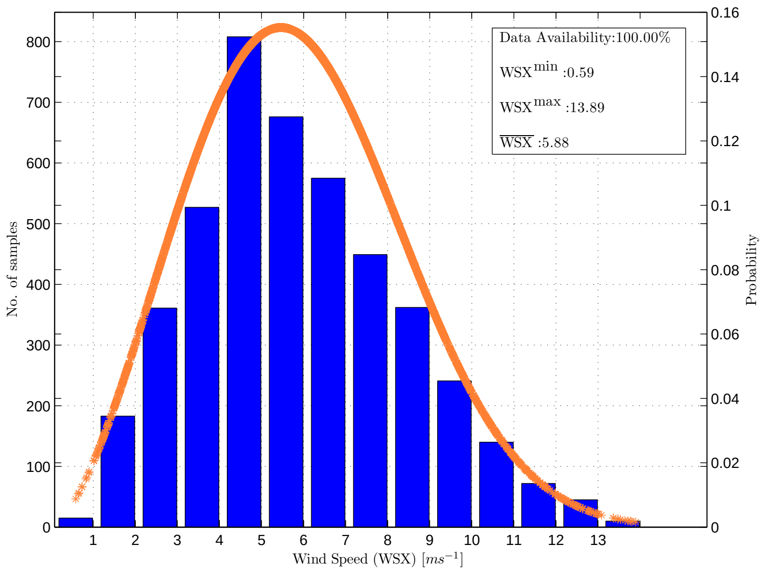


Figure 1.166: October 2011 probability distribution function

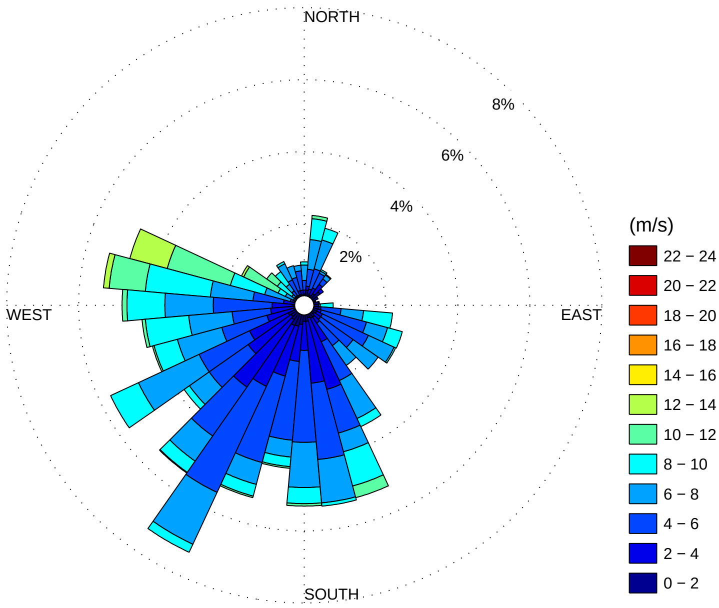


Figure 1.167: October 2011 Wind Rose

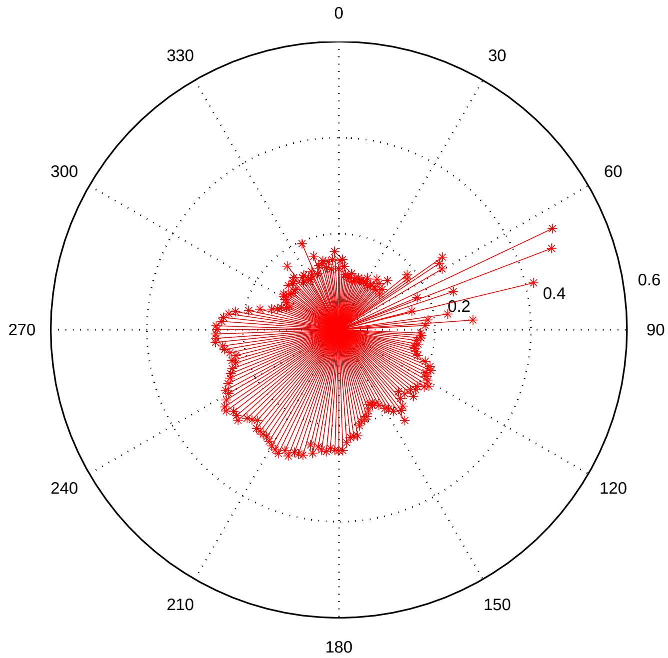


Figure 1.168: October 2011 turbulence intensity

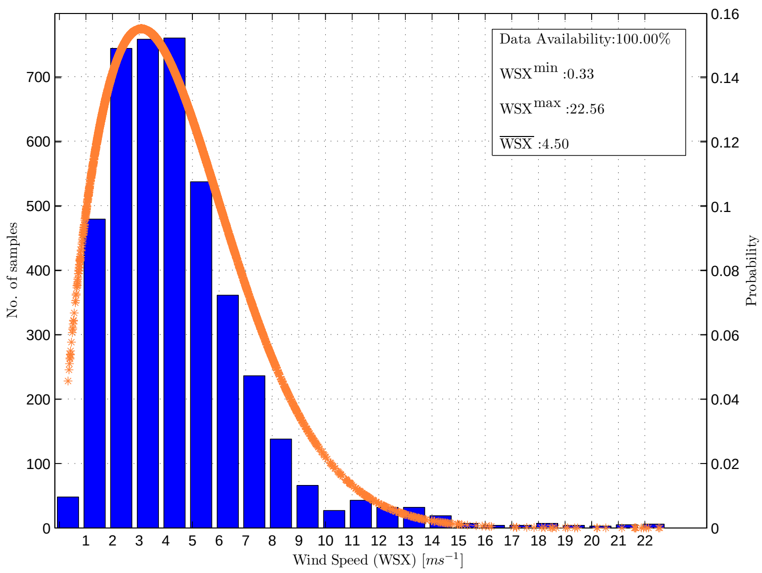


Figure 1.169: November 2011 probability distribution function

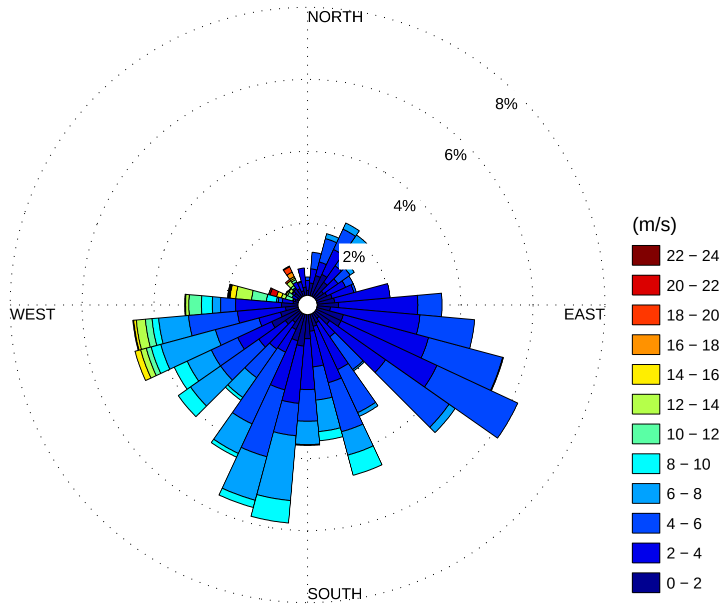


Figure 1.170: November 2011 Wind Rose

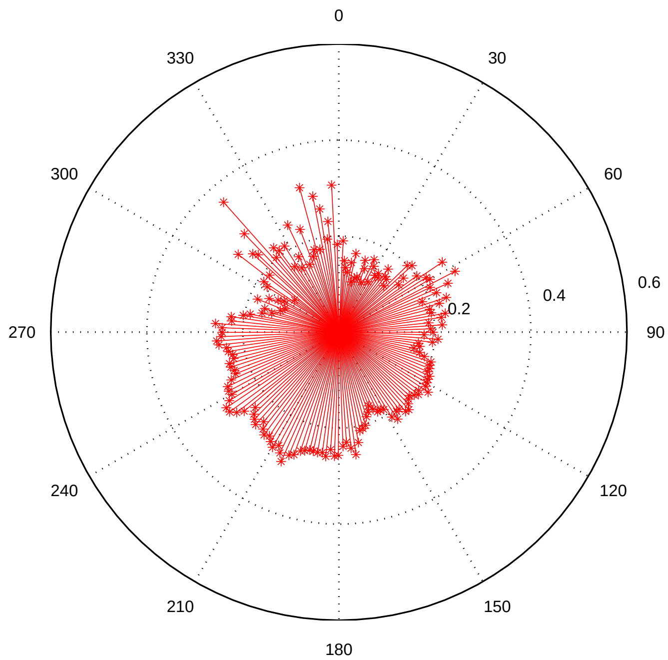


Figure 1.171: November 2011 turbulence intensity

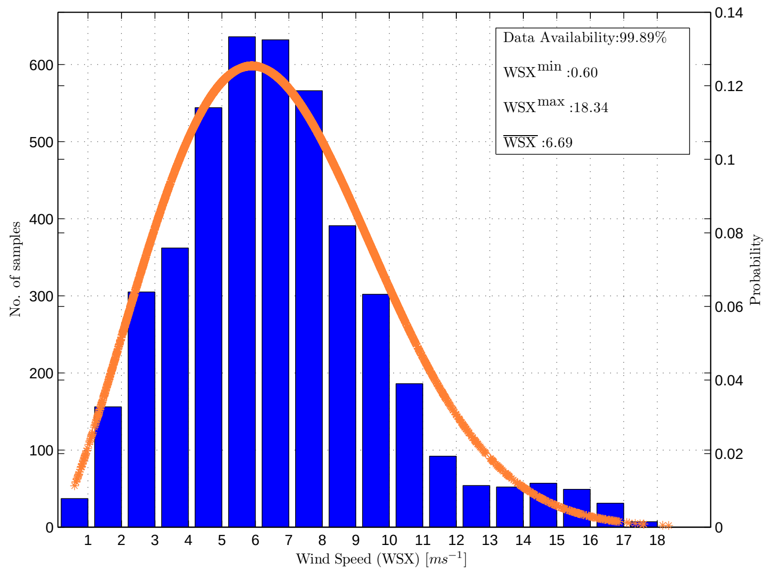


Figure 1.172: December 2011 probability distribution function

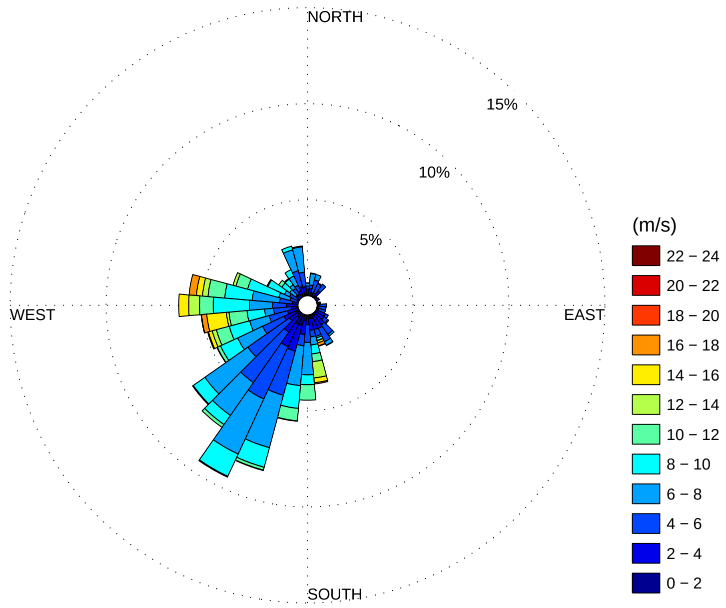


Figure 1.173: December 2011 Wind Rose

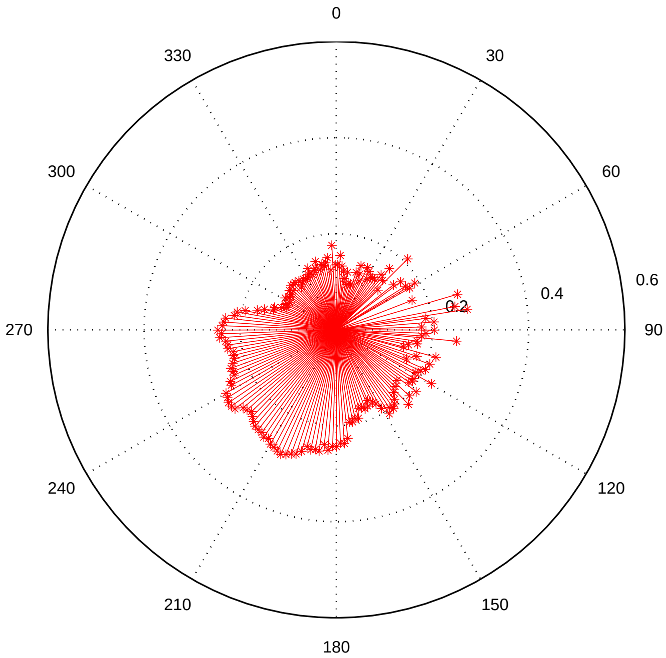


Figure 1.174: December 2011 turbulence intensity

1.8.5 2012 Annual Statistics

Table 1.15: Meteorological parameters, 2012

Month	Air Temperature [°C]			Air Pressure [hPa]			Relative Humidity			Precipitation [mm]
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Total
Jan	-7.30	1.88	7.80	963.13	1009.97	1043.10	46.56	79.74	94.70	109.18
Feb	-12.80	-0.53	8.50	984.94	1019.45	1047.10	43.81	78.75	95.00	19.54
Mar	-0.80	4.81	11.30	994.50	1018.67	1030.90	35.22	78.47	95.10	1.63
Apr	-1.50	6.03	15.10	987.26	1003.48	1021.60	28.55	71.85	94.90	92.09
May	4.80	12.22	24.90	992.66	1012.72	1031.60	32.31	70.33	94.20	69.79
Jun	6.90	13.23	21.40	995.20	1007.58	1018.80	38.50	73.72	92.00	73.53
Jul	12.10	16.65	24.50	996.40	1008.78	1021.00	36.82	72.87	93.00	73.14
Aug	11.30	17.15	22.70	998.93	1012.46	1023.80	39.70	74.49	91.80	92.80
Sept	7.20	13.60	18.80	991.62	1006.68	1018.60	46.91	75.13	92.76	126.47
Oct	1.00	9.16	15.00	990.85	1005.98	1030.00	31.68	76.42	94.80	102.06
Nov	-1.86	6.71	10.40	978.68	1005.62	1025.20	56.58	83.71	94.50	73.37
Dec	-9.10	-4.29	0.50	991.90	1009.93	1028.70	68.28	80.91	93.20	0.90

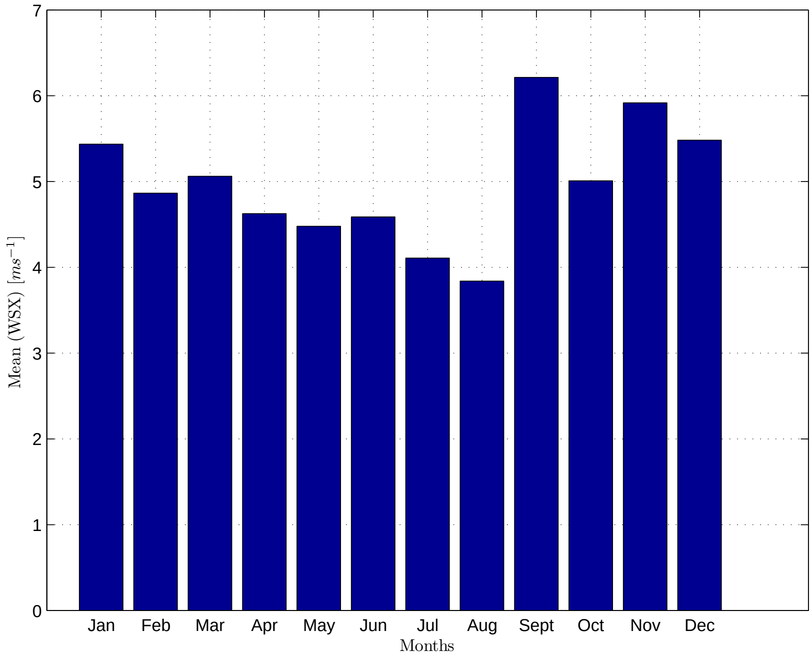


Figure 1.175: Annual wind speed distribution of WSX, 2012

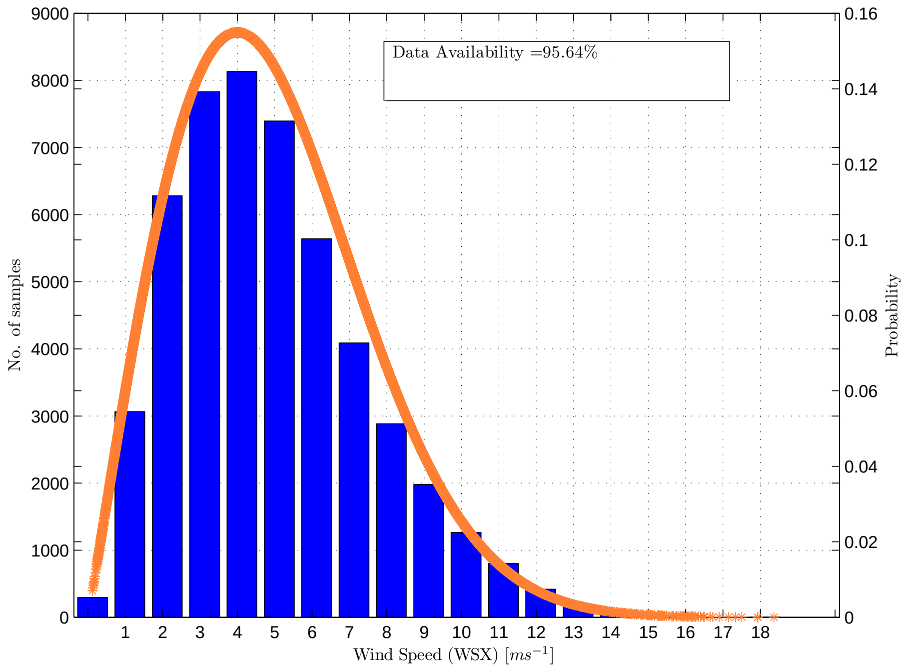


Figure 1.176: Annual wind speed distribution of WSX, 2012

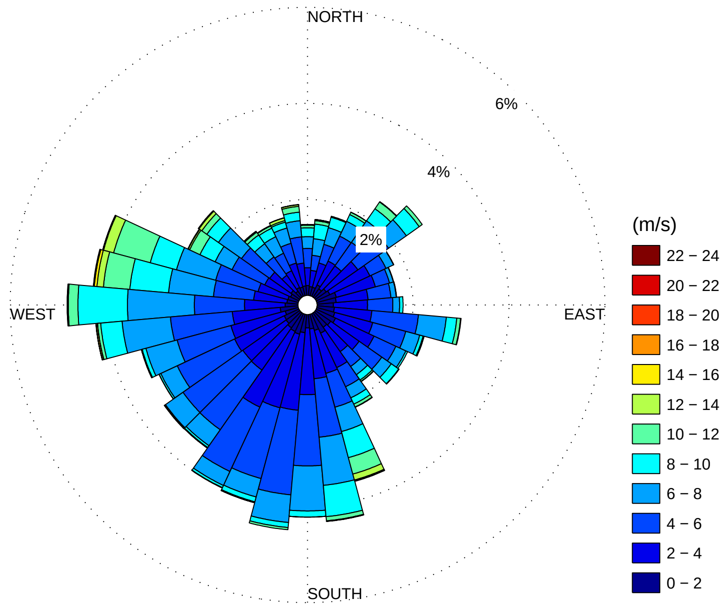


Figure 1.177: Annual wind rose of WSX, 2012

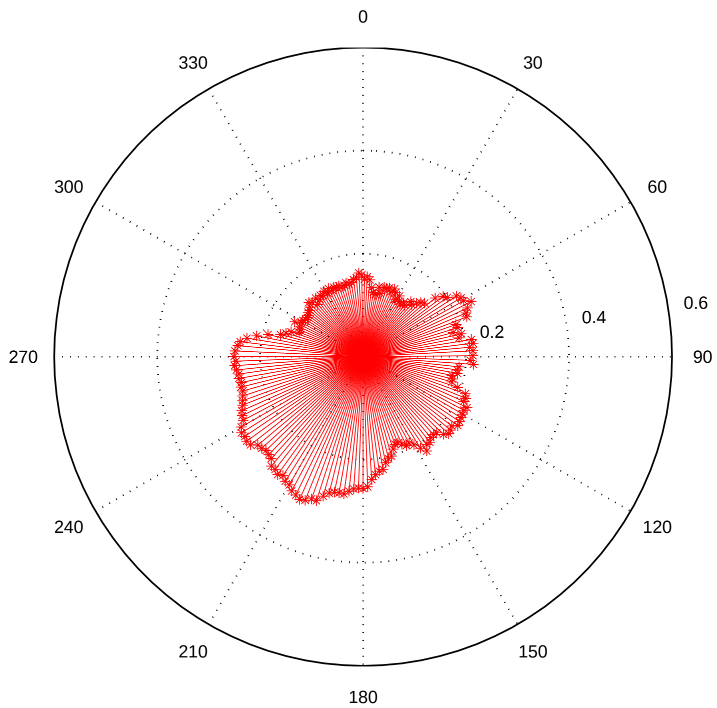


Figure 1.178: Turbulence intensity of WSX, 2012

Table 1.16: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2012

Month	Min	Mean	Max
January	0.10	5.44	25.70
February	0.10	4.87	20.70
March	0.10	5.06	22.50
April	0.10	4.63	37.40
May	0.10	4.48	20.50
June	0.10	4.59	24.10
July	0.10	4.11	18.20
August	0.10	3.84	16.00
September	0.10	6.21	19.40
October	0.10	5.01	25.20
November	0.10	5.92	18.80
December	0.10	5.48	21.53

Table 1.17: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2012

Month	Data Availability(%)	Min	Mean	Max	K	C
January	100.00	0.13	5.44	17.94	1.83	6.13
February	100.00	0.14	4.86	14.54	2.01	5.50
March	100.00	0.24	5.06	15.67	1.83	5.71
April	100.00	0.18	4.63	15.37	2.02	5.23
May	100.00	0.15	4.48	11.85	2.10	5.06
June	100.00	0.20	4.59	12.83	2.29	5.19
July	100.00	0.12	4.11	11.86	2.27	4.64
August	99.96	0.26	3.84	10.89	2.01	4.35
September	99.72	0.80	6.21	14.17	2.69	7.00
October	100.00	0.16	5.01	18.37	1.89	5.66
November	99.56	0.35	5.92	13.34	2.86	6.65
December	49.26	0.33	5.48	12.86	2.17	6.21

1.8.5.1 2012 Monthly Statistics

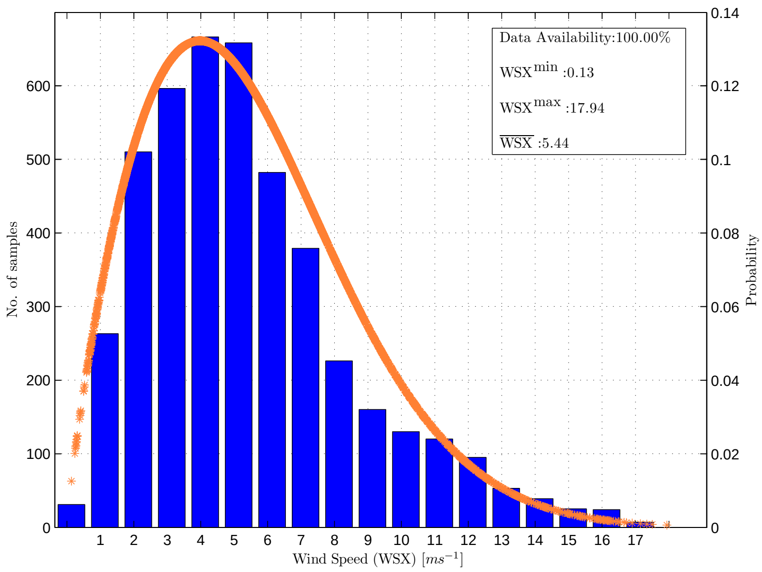


Figure 1.179: January 2012 probability distribution function

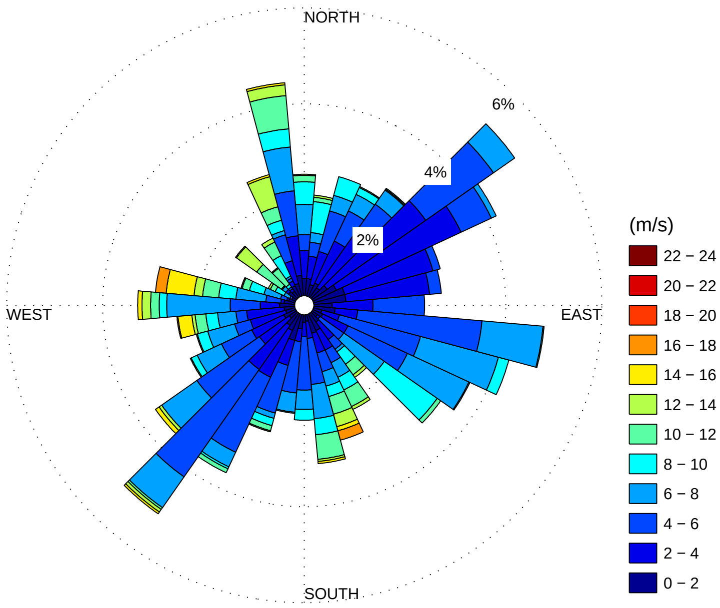


Figure 1.180: January 2012 Wind Rose

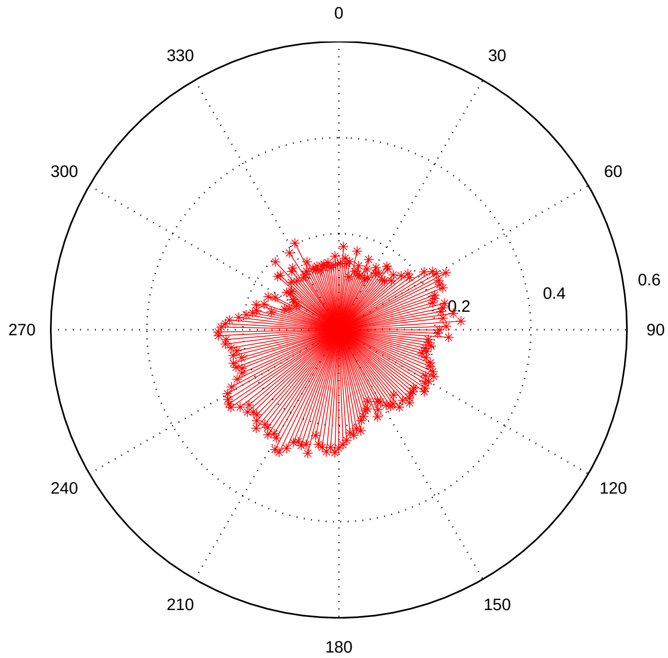


Figure 1.181: January 2012 turbulence intensity

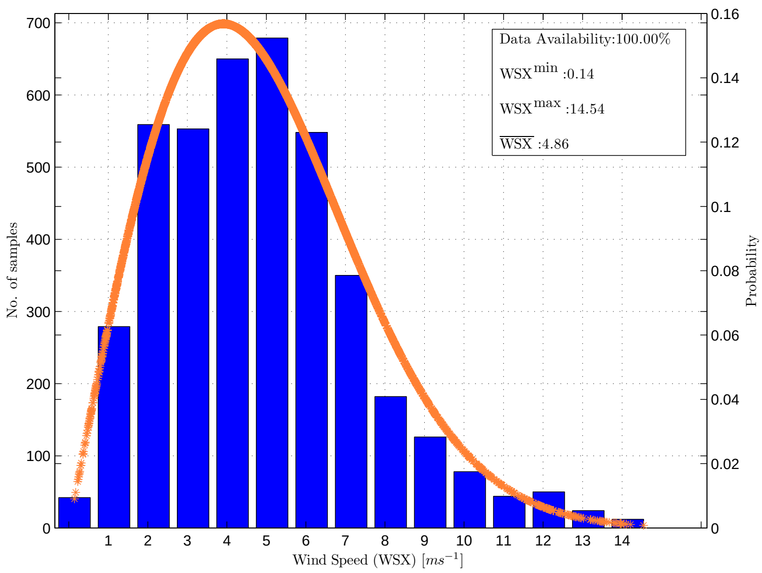


Figure 1.182: February 2012 probability distribution function

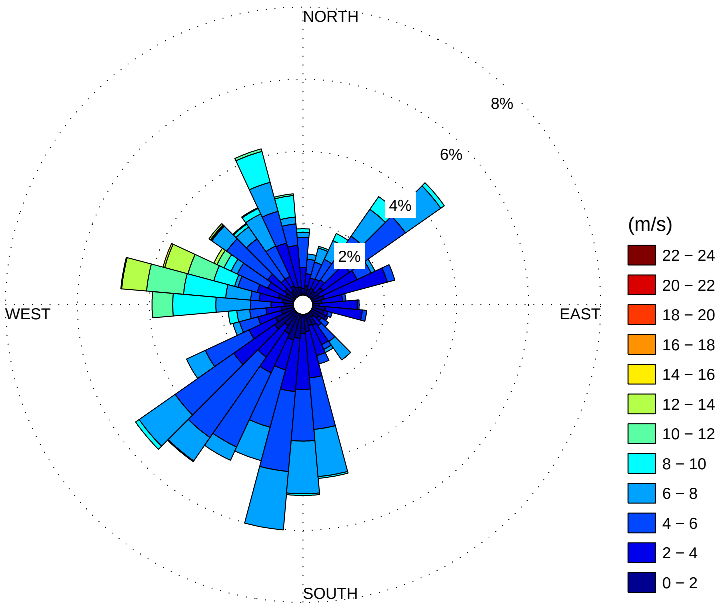


Figure 1.183: February 2012 Wind Rose

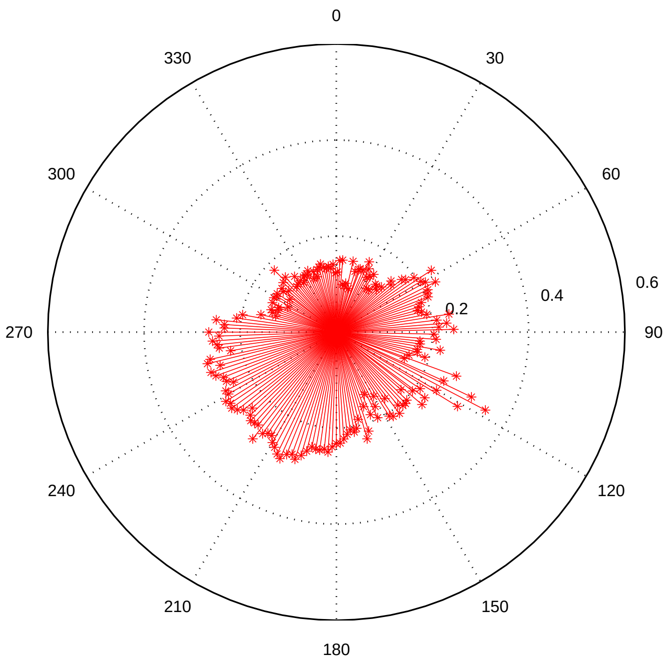


Figure 1.184: February 2012 turbulence intensity

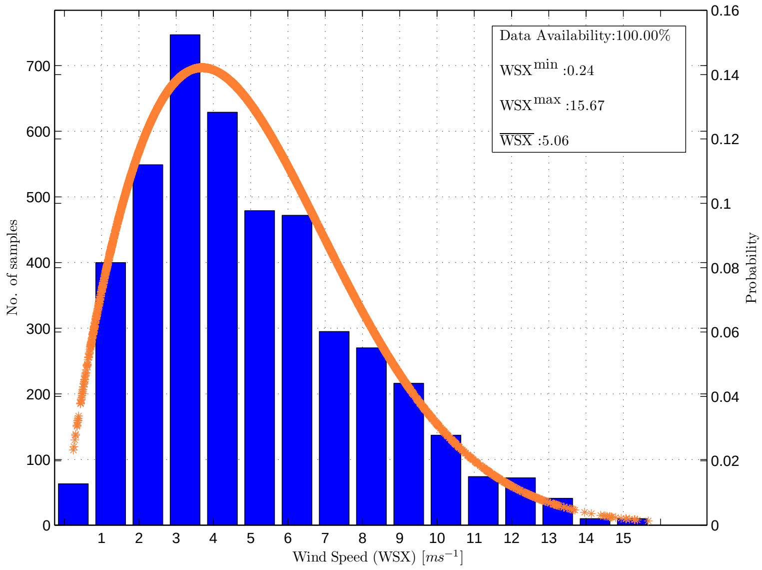


Figure 1.185: March 2012 probability distribution function

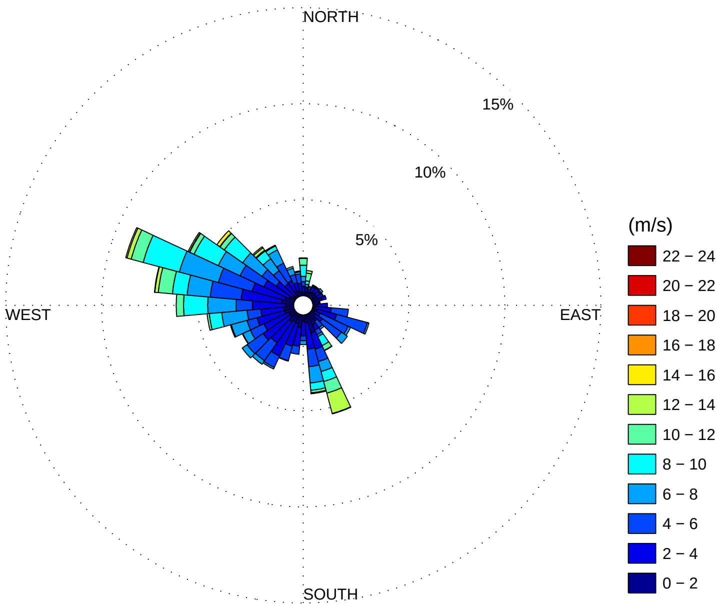


Figure 1.186: March 2012 Wind Rose

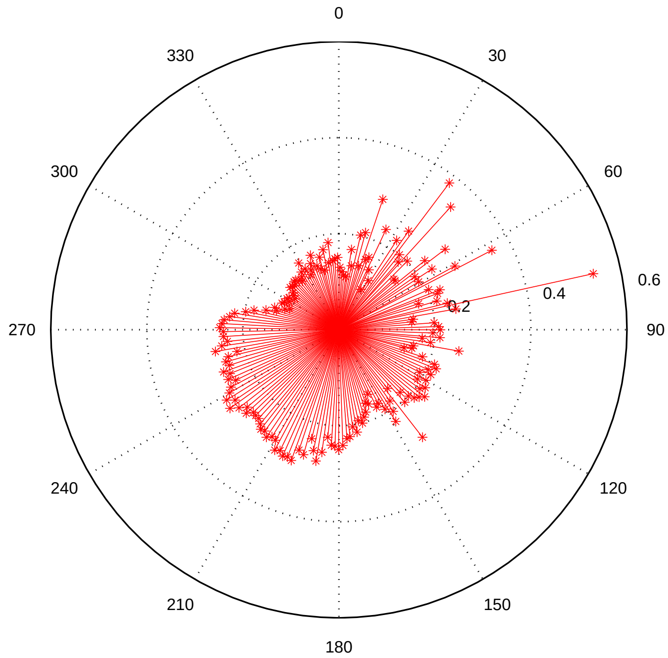


Figure 1.187: March 2012 turbulence intensity

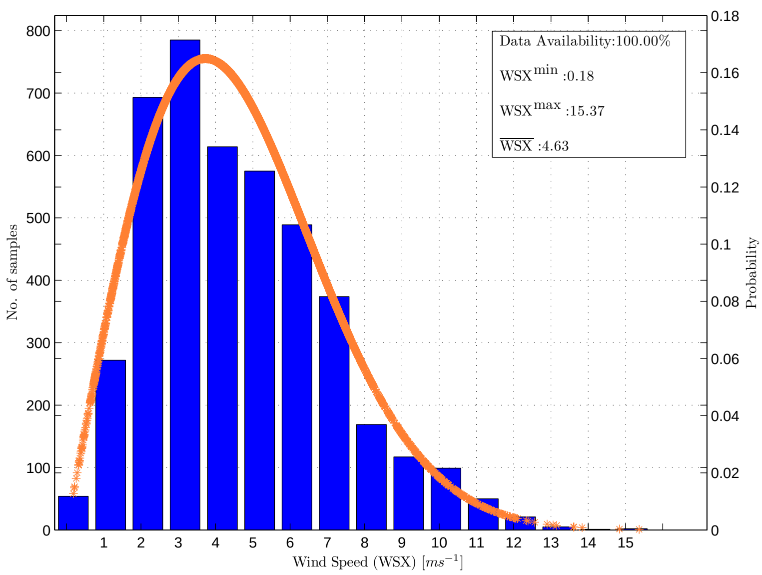


Figure 1.188: April 2012 probability distribution function

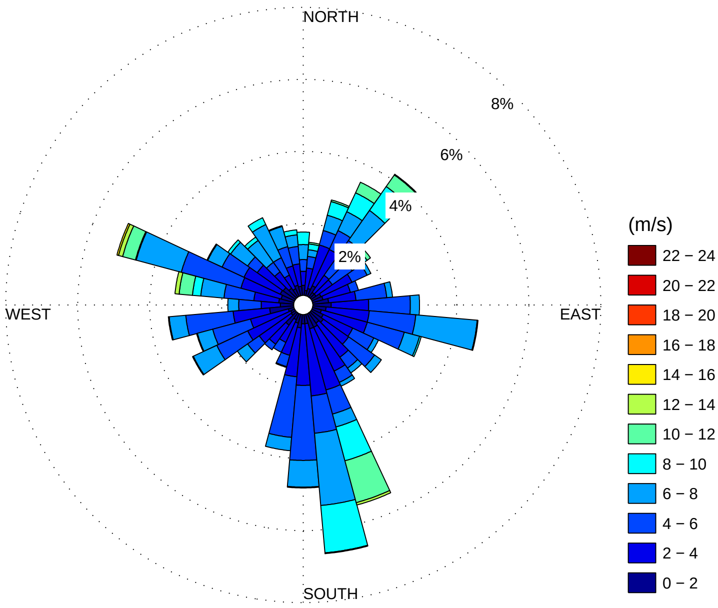


Figure 1.189: April 2012 Wind Rose

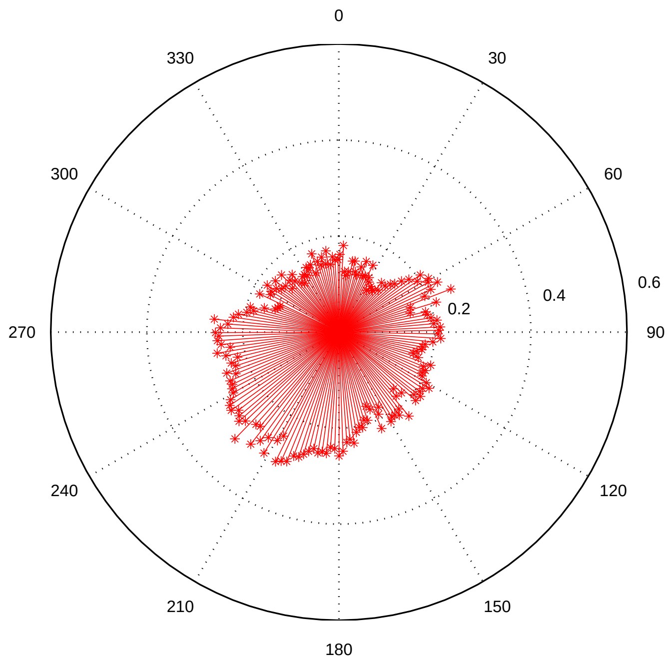


Figure 1.190: April 2012 turbulence intensity

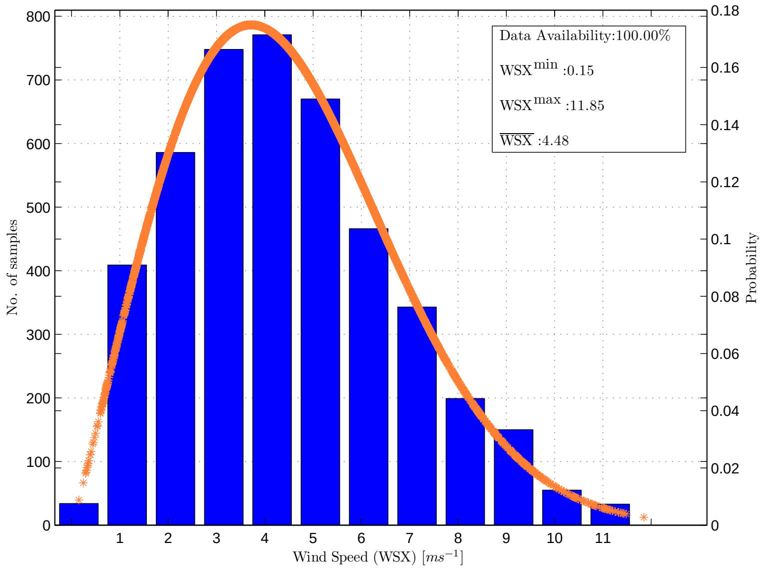


Figure 1.191: May 2012 probability distribution function

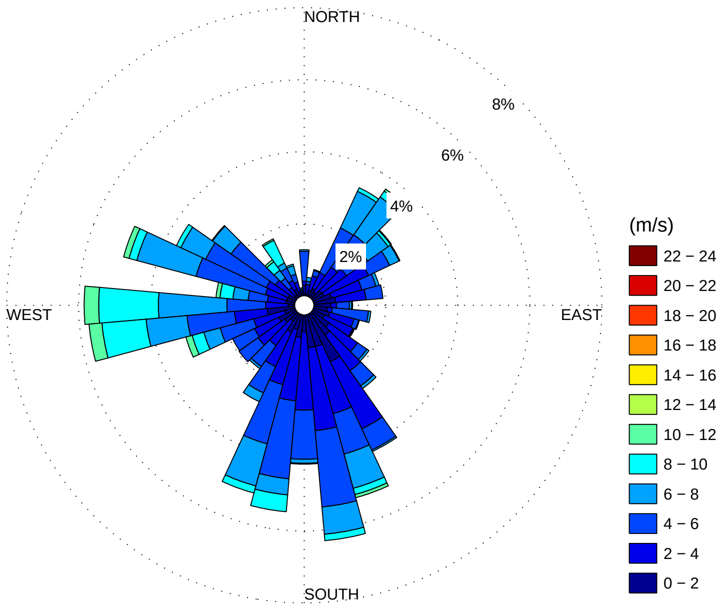


Figure 1.192: May 2012 Wind Rose

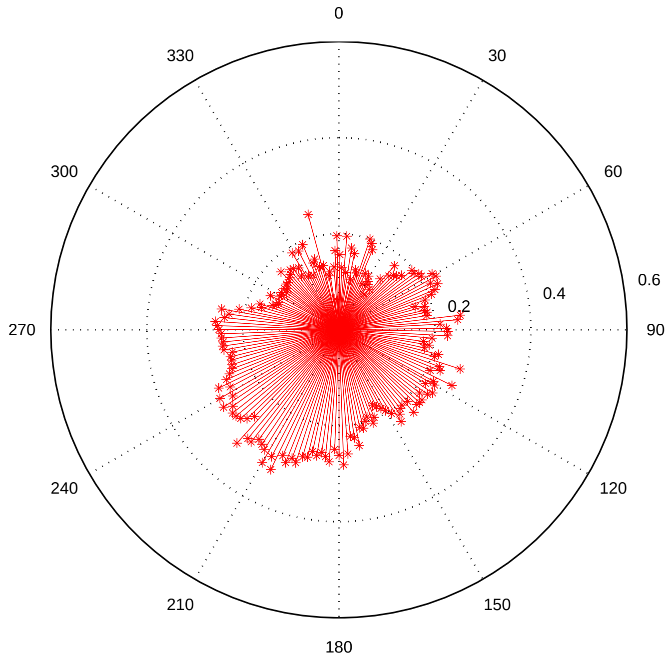


Figure 1.193: May 2012 turbulence intensity

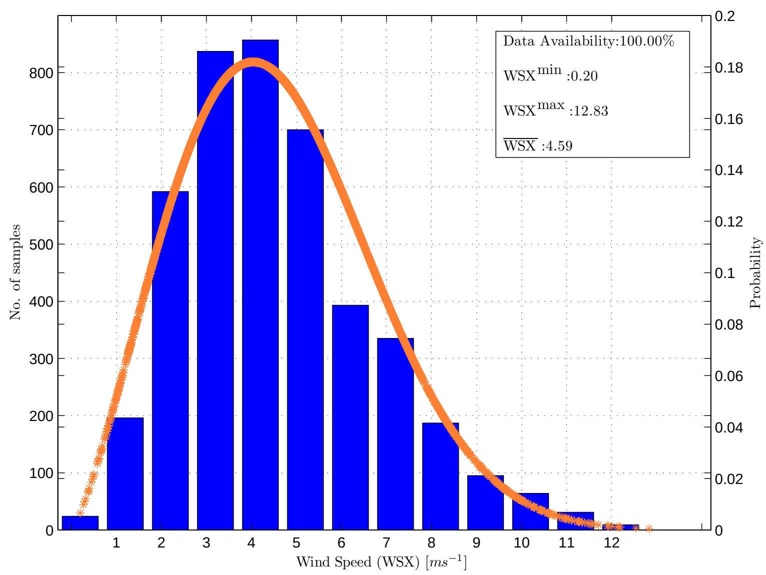


Figure 1.194: June 2012 probability distribution function

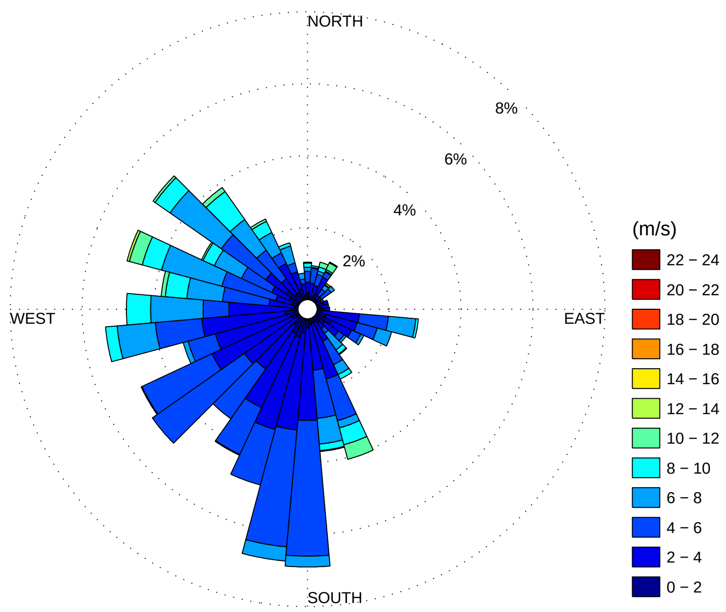


Figure 1.195: June 2012 Wind Rose

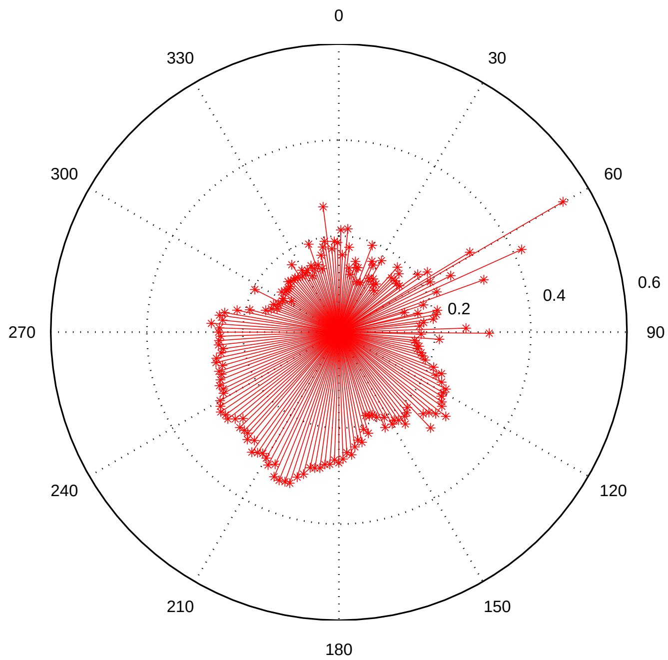


Figure 1.196: June 2012 turbulence intensity

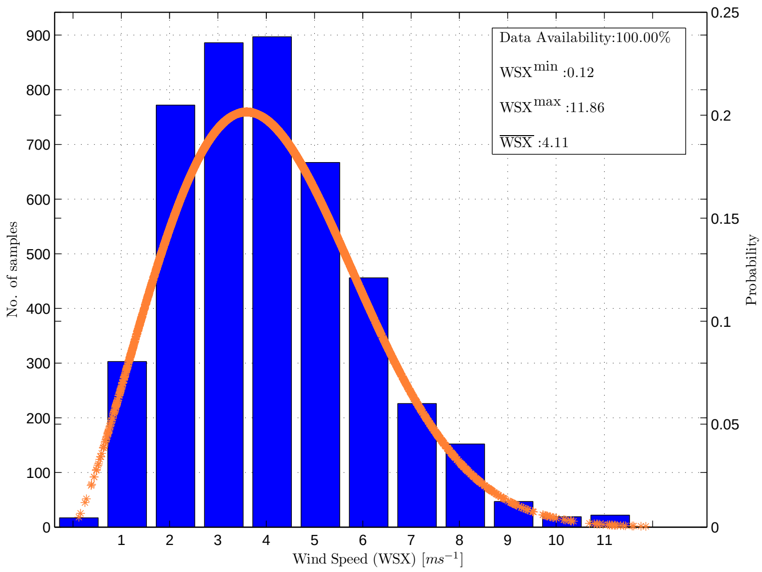


Figure 1.197: July 2012 probability distribution function

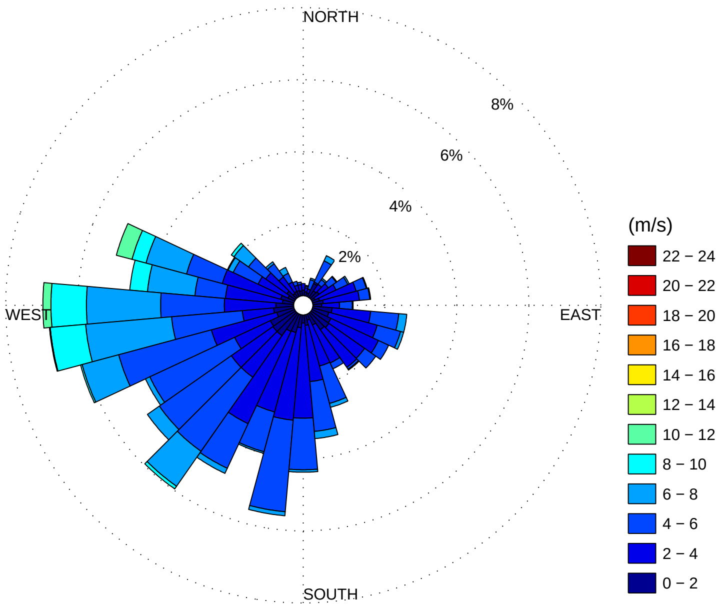


Figure 1.198: July 2012 Wind Rose

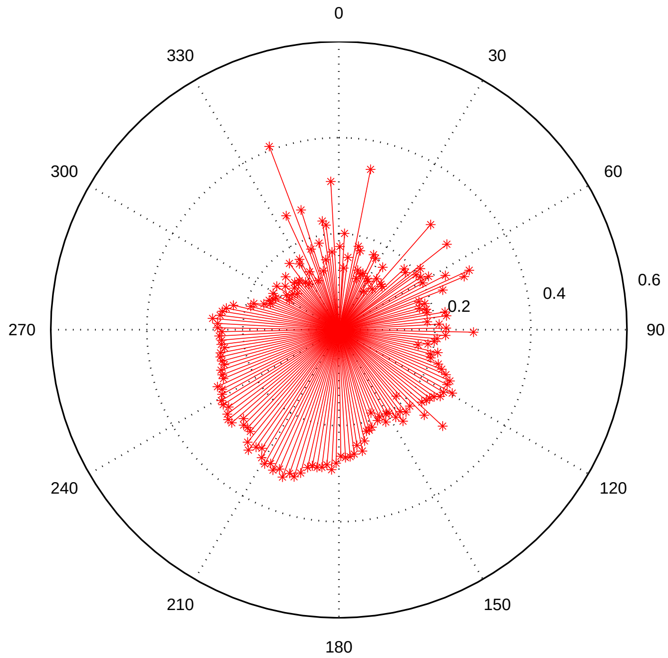


Figure 1.199: July 2012 turbulence intensity

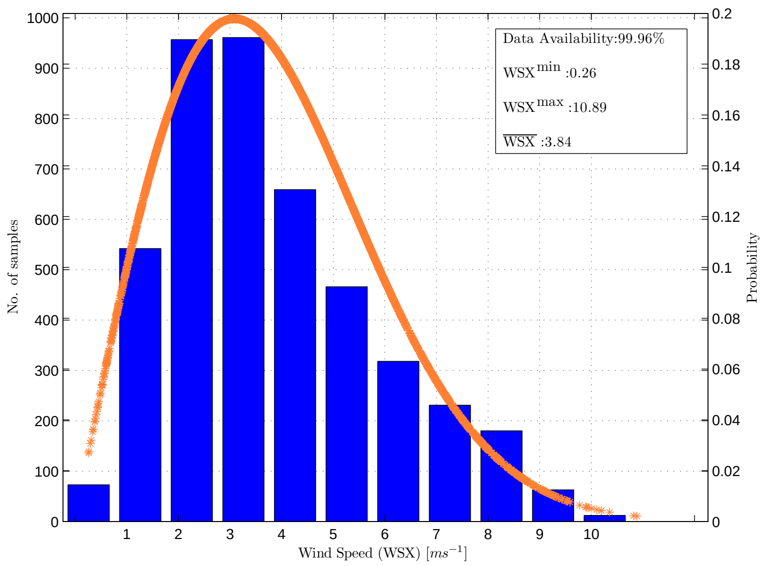


Figure 1.200: August 2012 probability distribution function

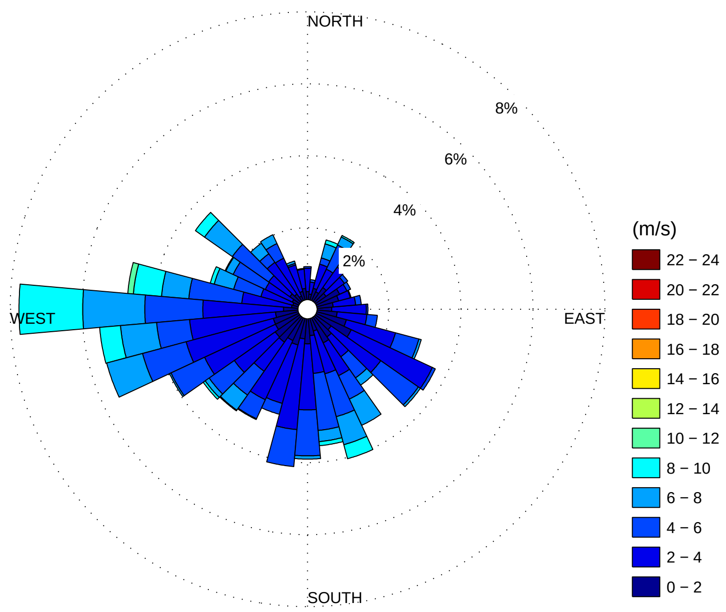


Figure 1.201: August 2012 Wind Rose

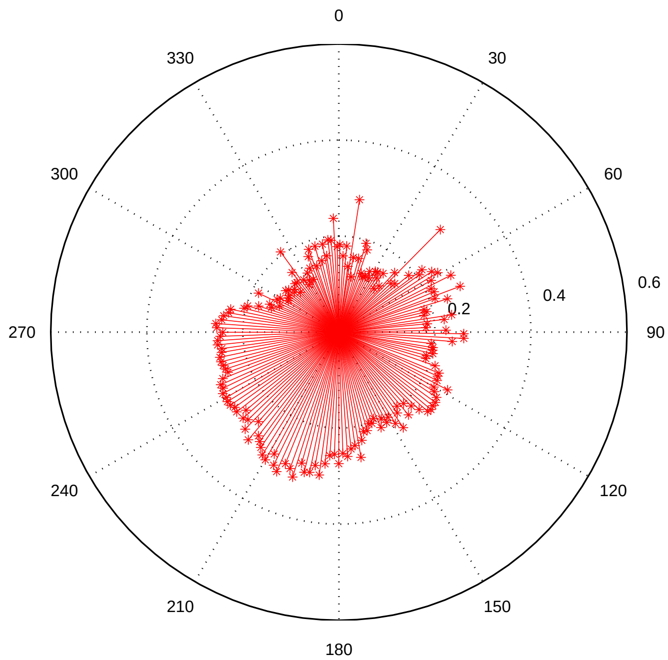


Figure 1.202: August 2012 turbulence intensity

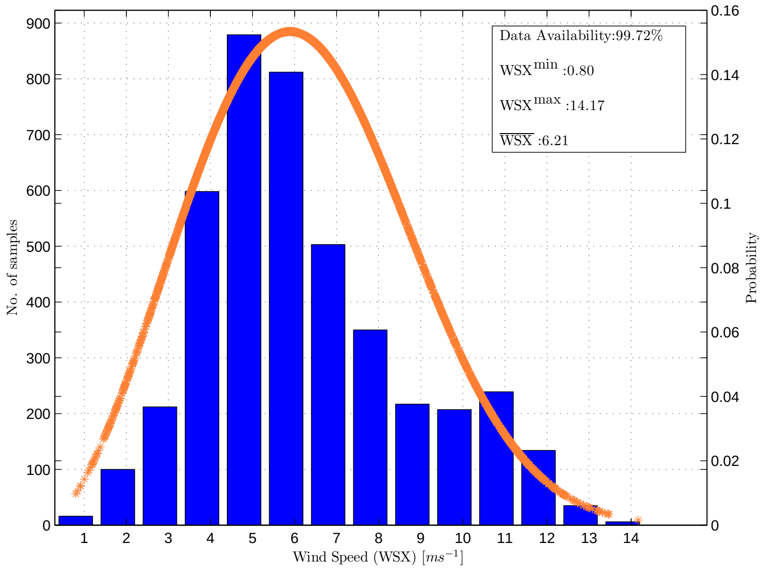


Figure 1.203: September 2012 probability distribution function

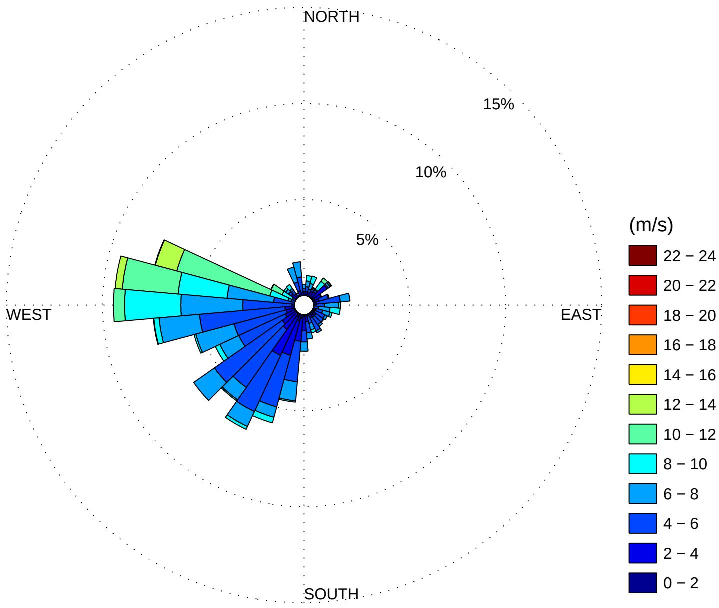


Figure 1.204: September 2012 Wind Rose

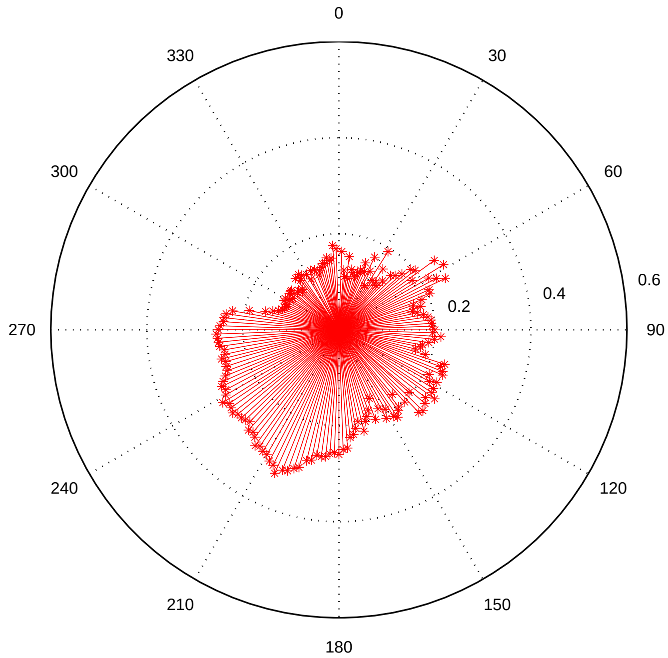


Figure 1.205: September 2012 turbulence intensity

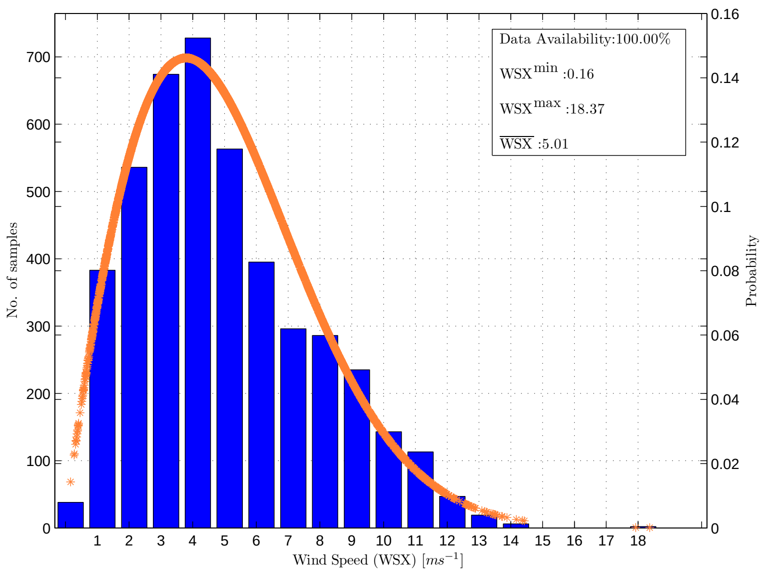


Figure 1.206: October 2012 probability distribution function

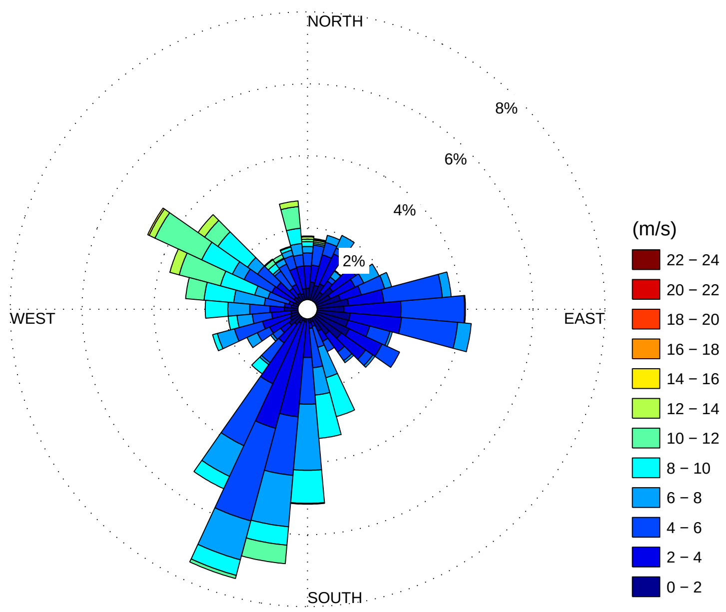


Figure 1.207: October 2012 Wind Rose

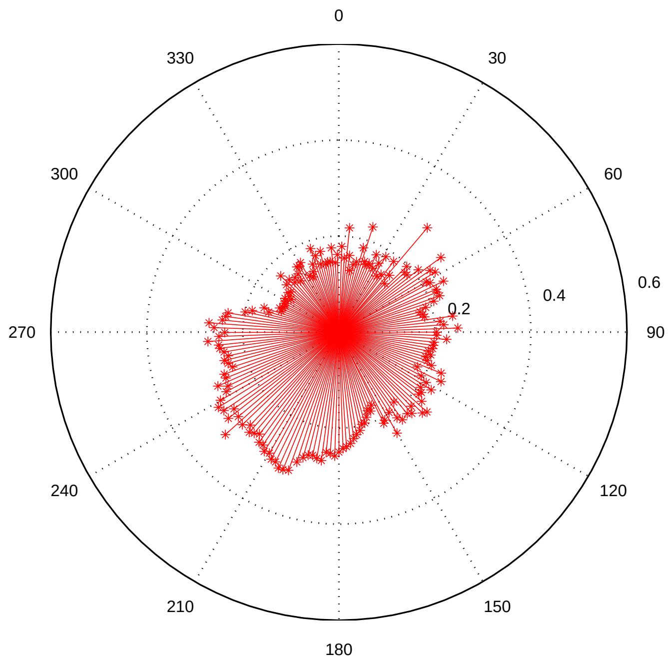


Figure 1.208: October 2012 turbulence intensity

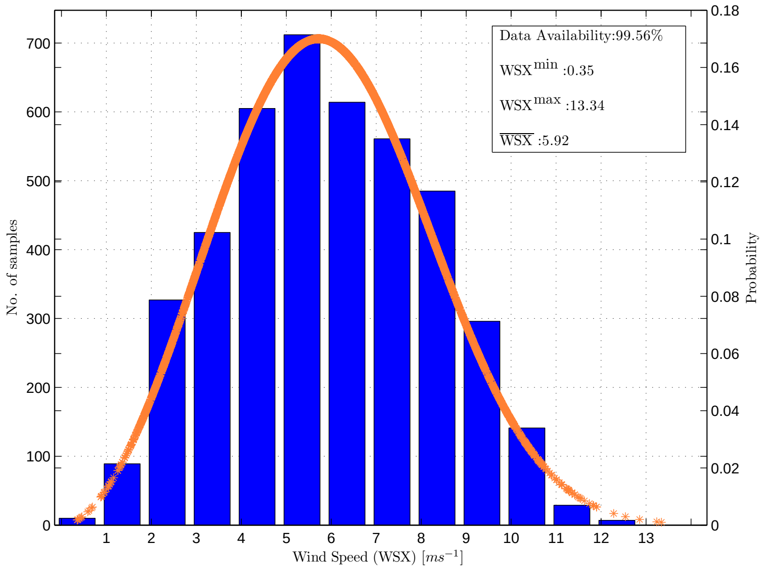


Figure 1.209: November 2012 probability distribution function

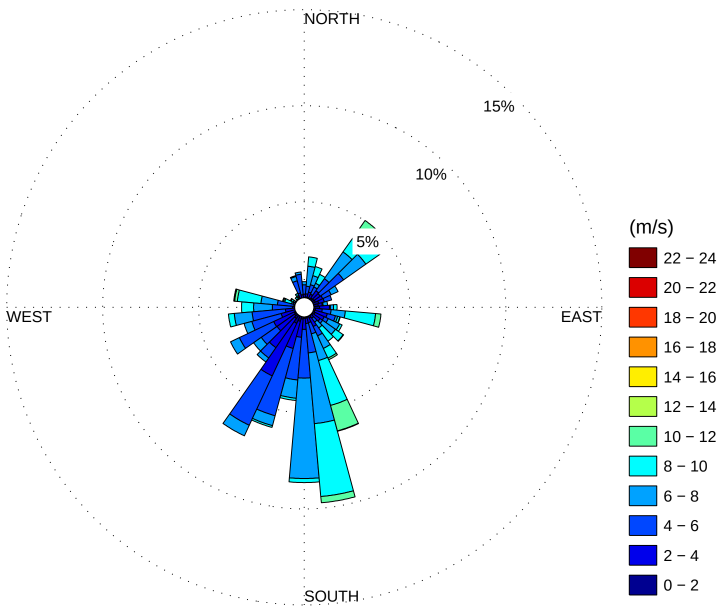


Figure 1.210: November 2012 Wind Rose

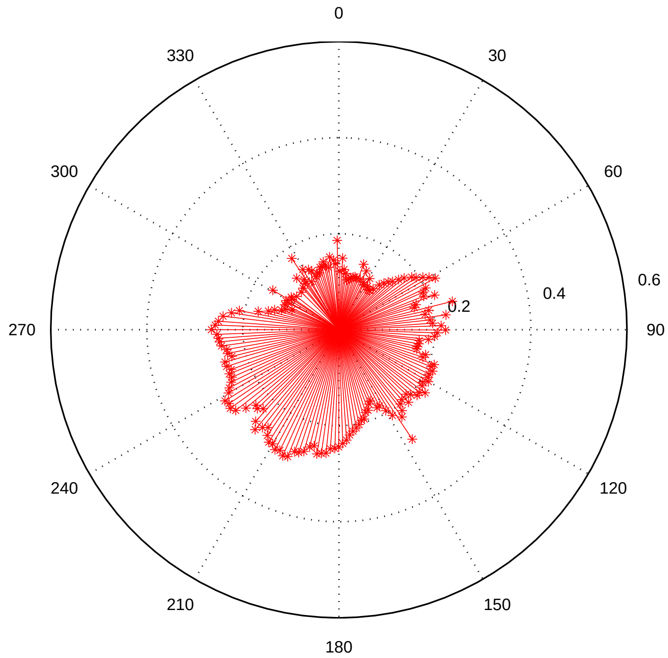


Figure 1.211: November 2012 turbulence intensity

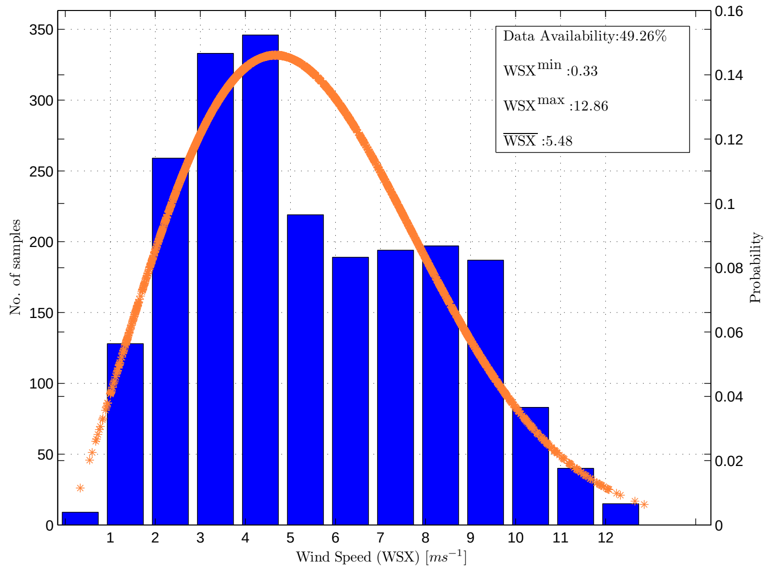


Figure 1.212: December 2012 probability distribution function

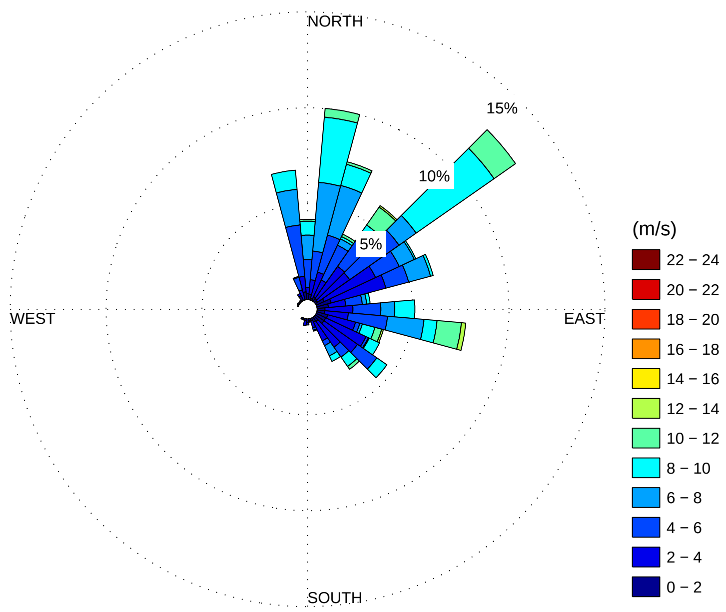


Figure 1.213: December 2012 Wind Rose

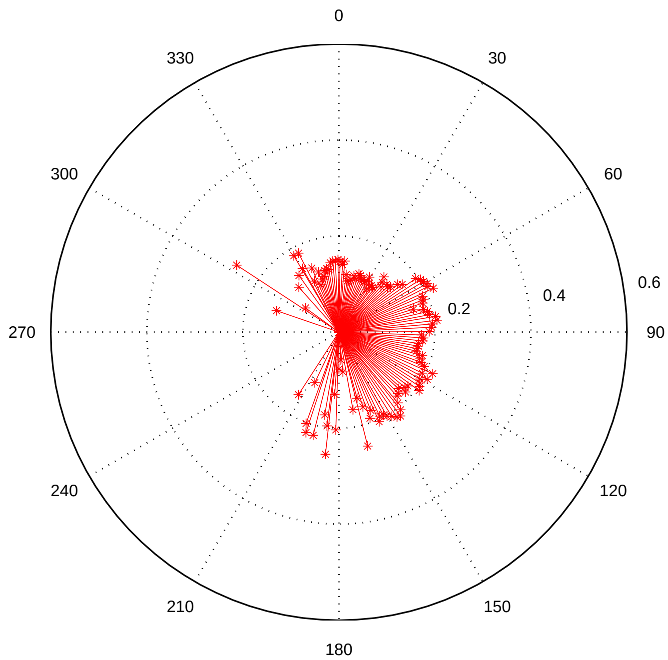


Figure 1.214: December 2012 turbulence intensity

1.8.6 2013 Annual Statistics

Table 1.18: Meteorological parameters, 2013

Month	Air Temperature [°C]			Air Pressure [hPa]			Relative Humidity			Precipitation [mm]
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Total
Aug	15.80	17.68	19.60	1014.40	1018.59	1023.40	48.30	65.89	81.86	0.00
Sept	5.90	13.72	21.90	985.04	1010.74	1023.10	35.16	71.62	92.60	42.96
Oct	4.00	10.67	15.40	966.60	1010.57	1030.50	42.68	79.41	94.40	98.08
Nov	0.40	7.20	11.60	978.04	1006.76	1030.10	41.55	76.84	93.40	67.57
Dec	-0.80	5.98	9.80	960.82	1006.15	1029.60	37.53	81.95	94.80	157.00

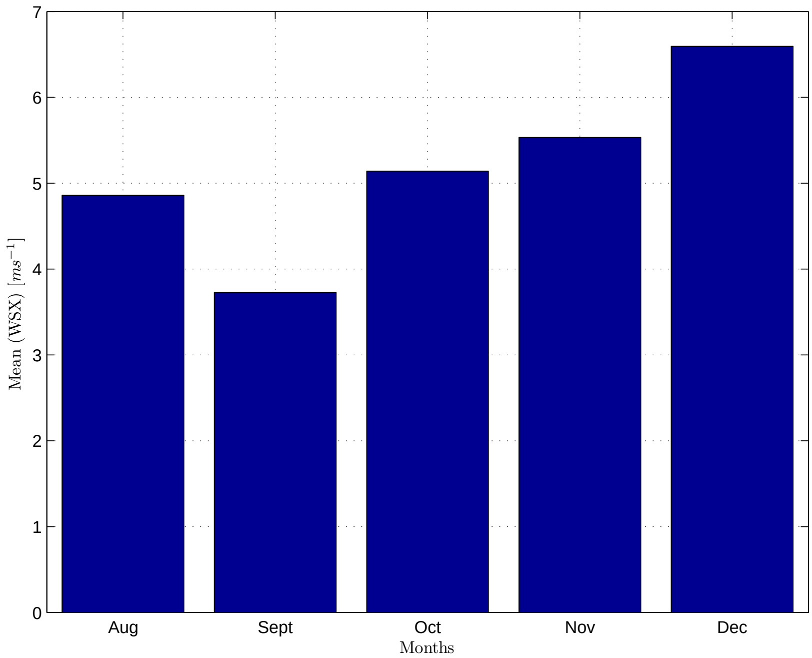


Figure 1.215: Annual wind speed distribution of WSX, 2013

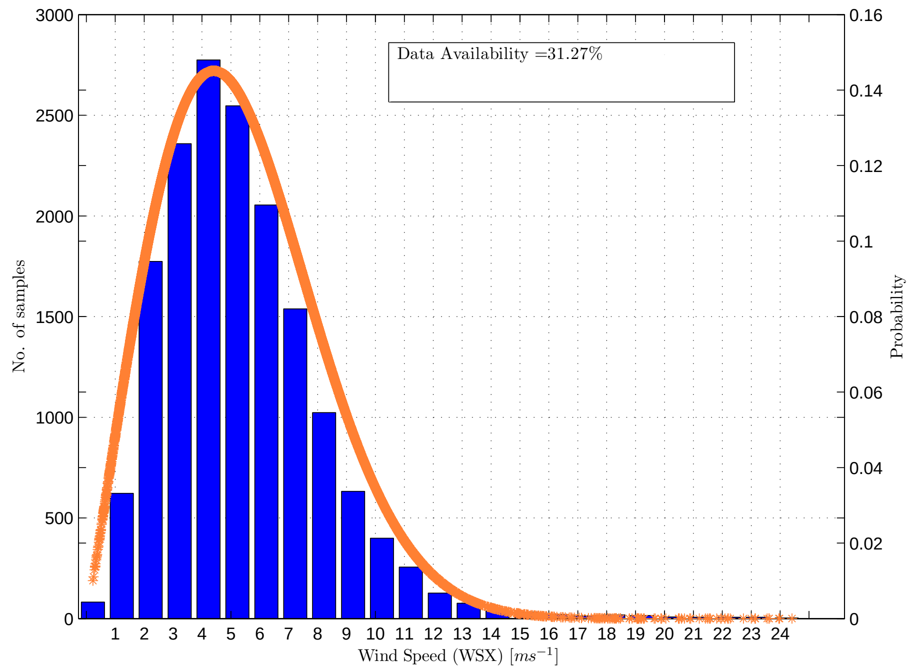


Figure 1.216: Annual wind speed distribution of WSX, 2013

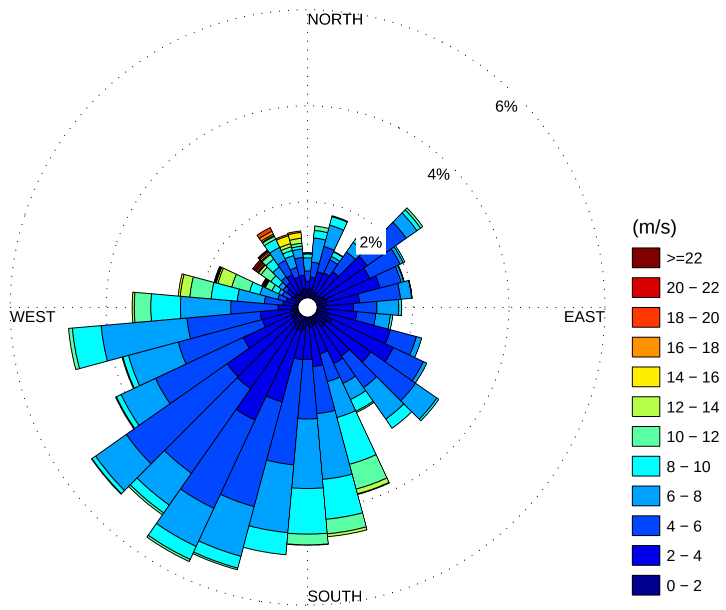


Figure 1.217: Annual wind rose of WSX, 2013

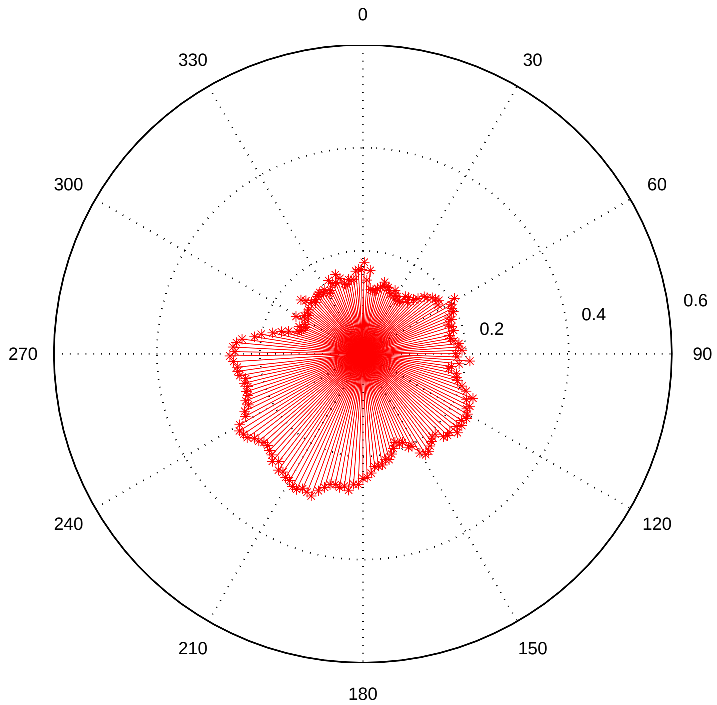


Figure 1.218: Turbulence intensity of WSX, 2013

Table 1.19: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2013

Month	Min	Mean	Max
August	0.20	4.86	11.50
September	0.10	3.73	18.20
October	0.10	5.14	28.60
November	0.10	5.53	20.10
December	0.10	6.60	33.80

Table 1.20: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2013

Month	Data Availability(%)	Min	Mean	Max	K	C
August	2.26	2.04	4.86	7.44	3.71	5.41
September	76.44	0.23	3.73	11.58	2.11	4.22
October	95.14	0.32	5.14	20.59	2.52	5.79
November	100.00	0.30	5.53	14.24	2.27	6.25
December	100.00	0.29	6.60	24.41	2.17	7.46

1.8.6.1 2013 Monthly Statistics

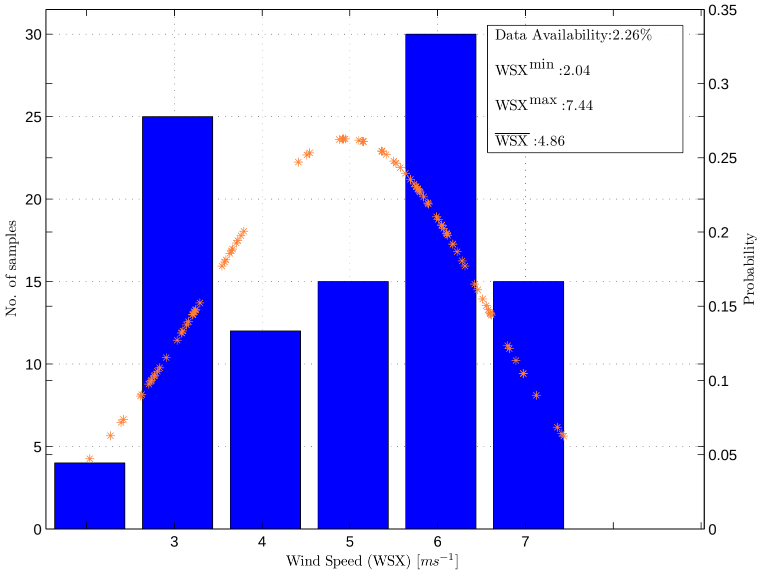


Figure 1.219: August 2013 probability distribution function

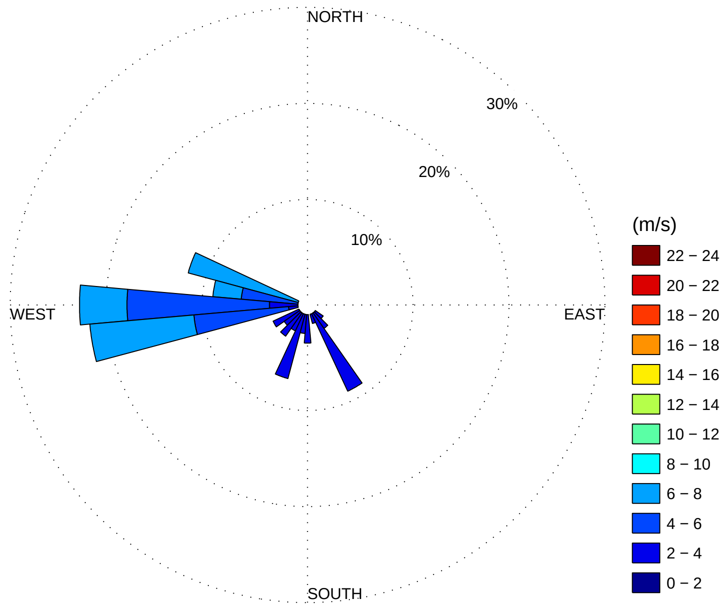


Figure 1.220: August 2013 Wind Rose

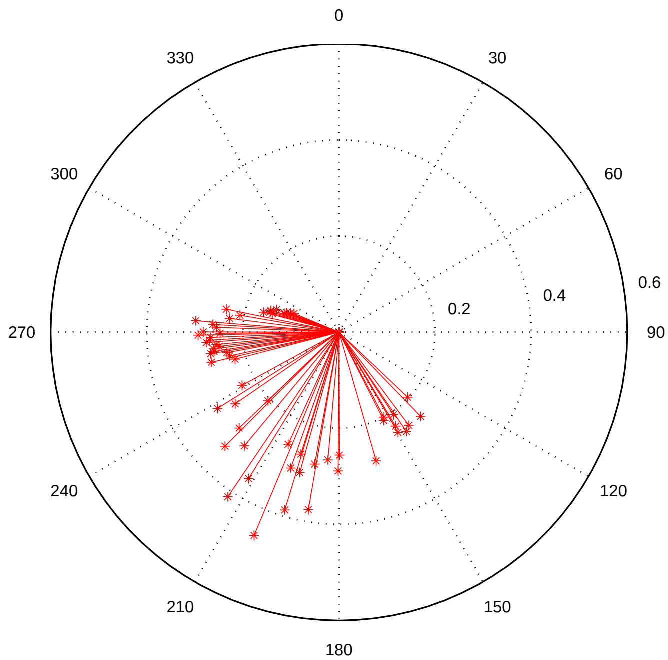


Figure 1.221: August 2013 turbulence intensity

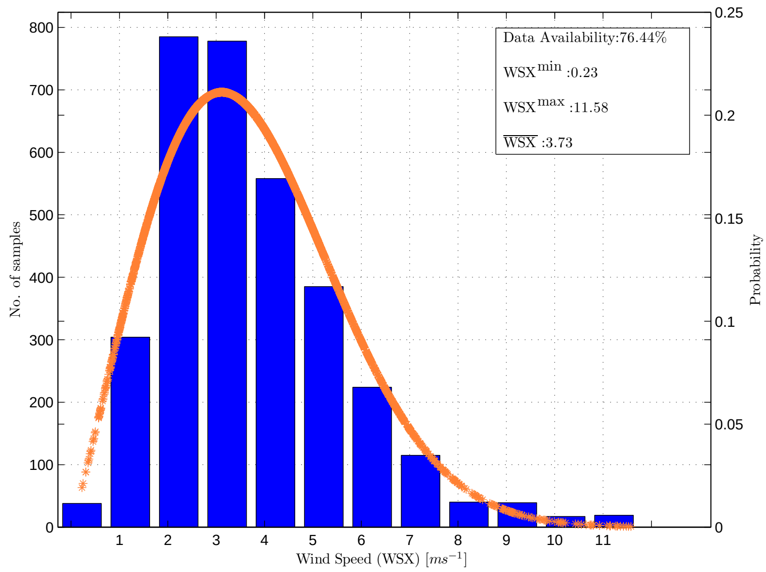


Figure 1.222: September 2013 probability distribution function

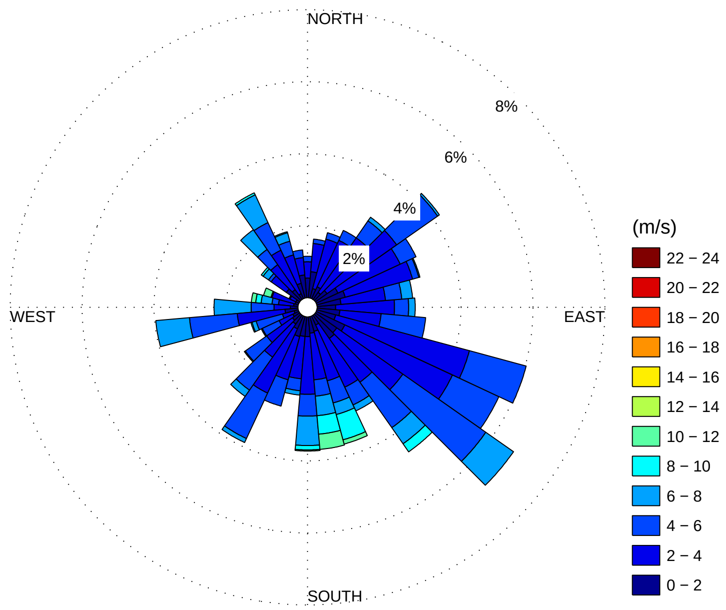


Figure 1.223: September 2013 Wind Rose

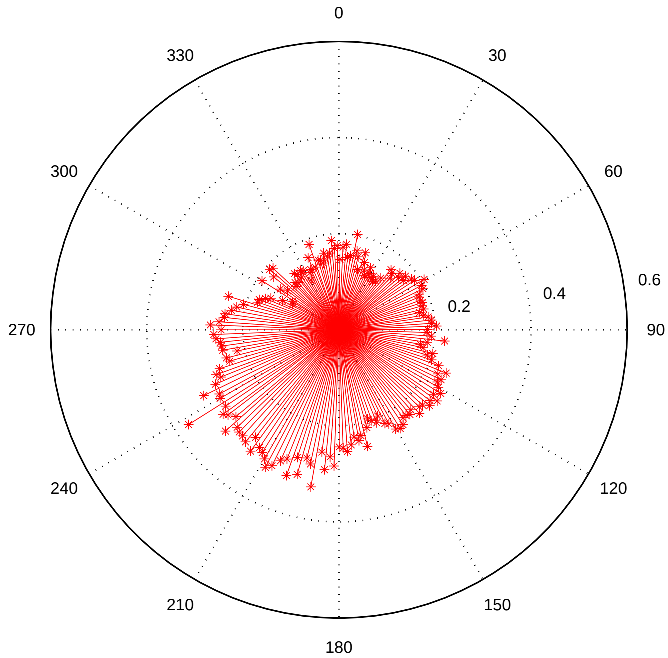


Figure 1.224: September 2013 turbulence intensity

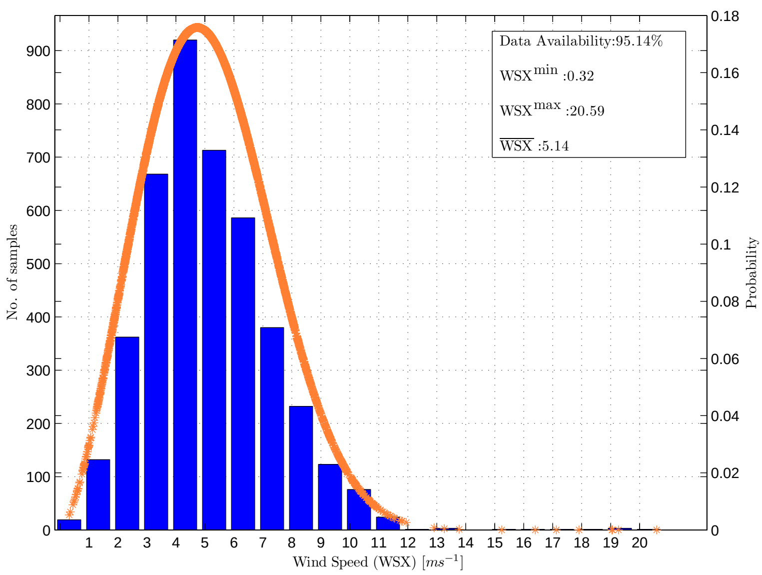


Figure 1.225: October 2013 probability distribution function

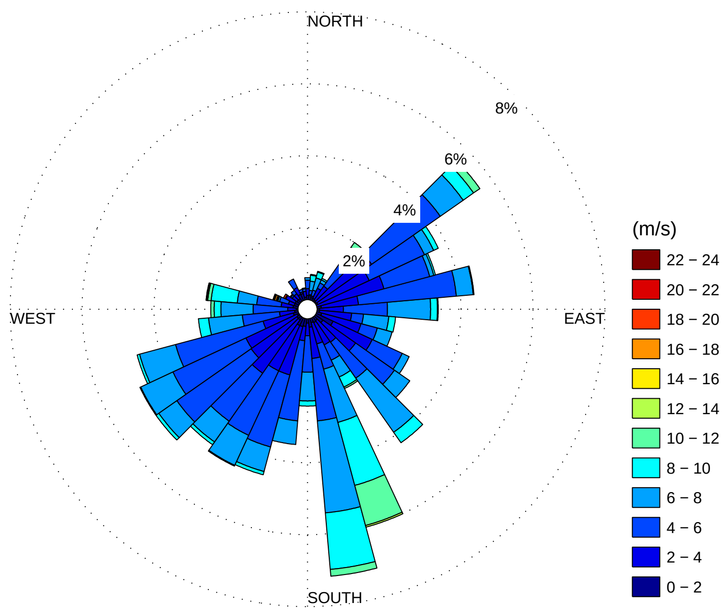


Figure 1.226: October 2013 Wind Rose

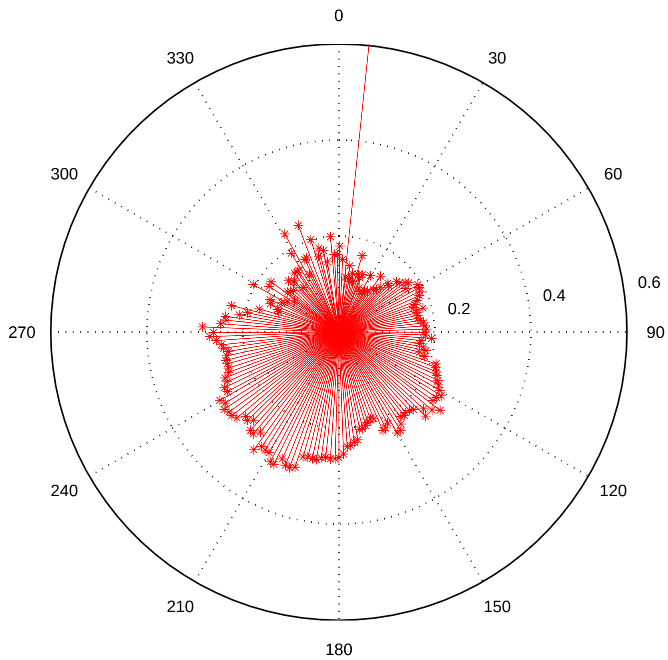


Figure 1.227: October 2013 turbulence intensity

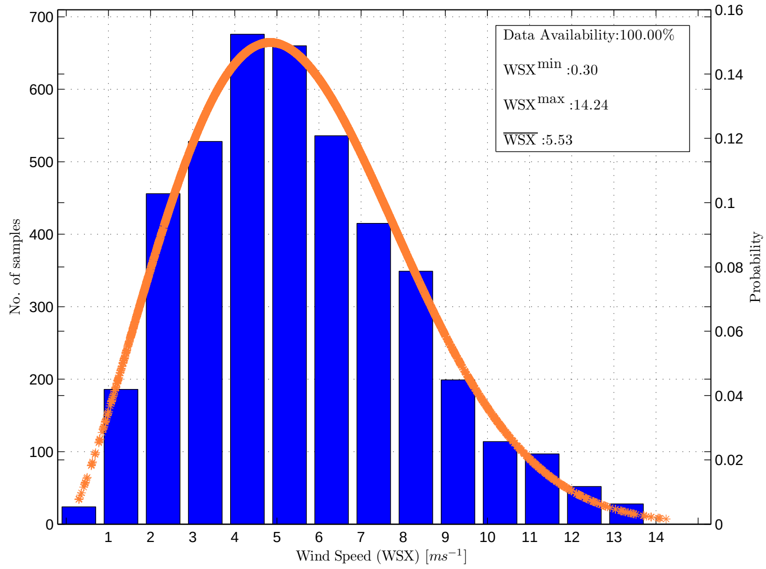


Figure 1.228: November 2013 probability distribution function

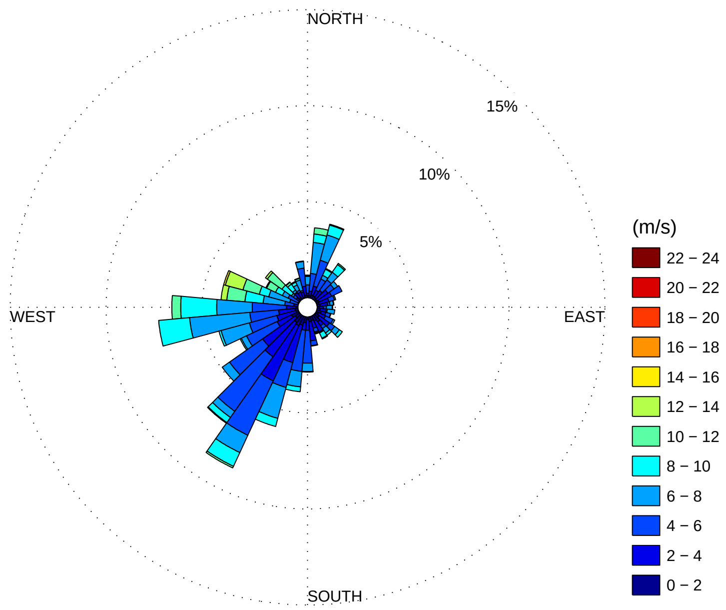


Figure 1.229: November 2013 Wind Rose

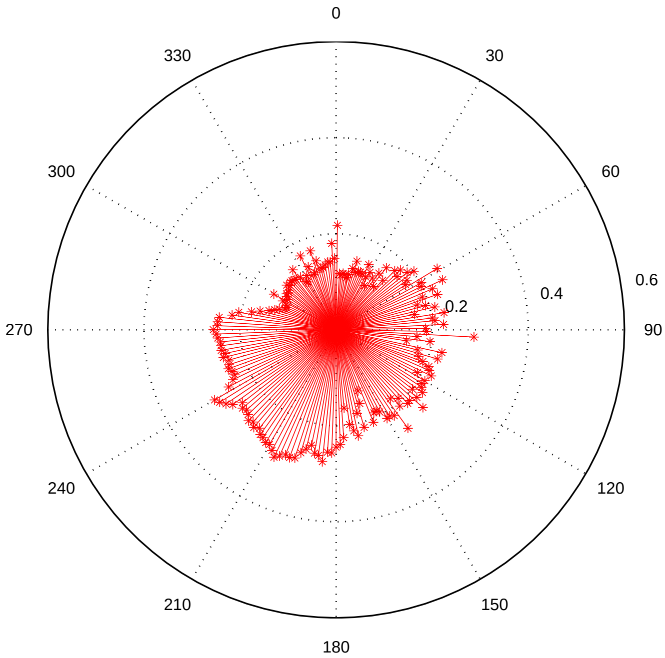


Figure 1.230: November 2013 turbulence intensity

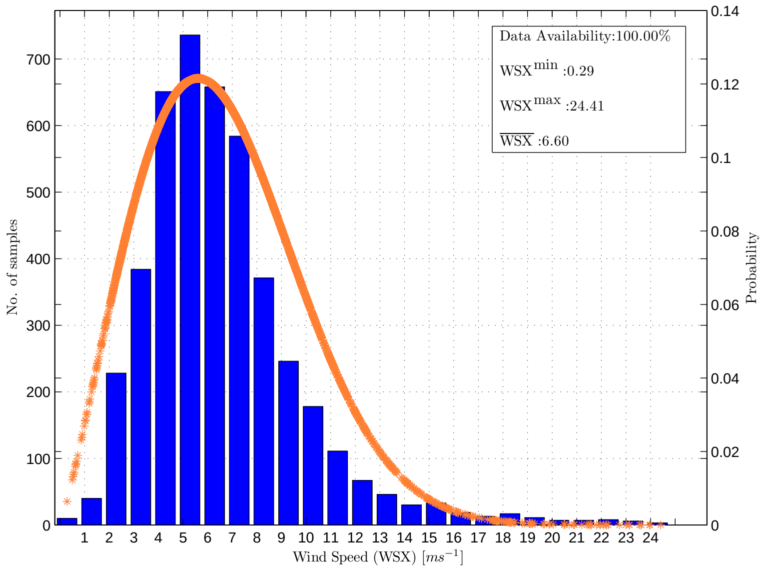


Figure 1.231: December 2013 probability distribution function

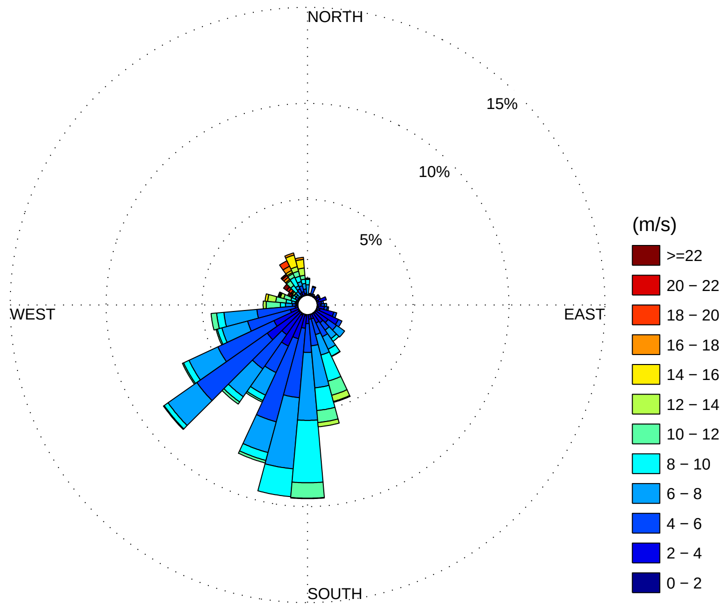


Figure 1.232: December 2013 Wind Rose

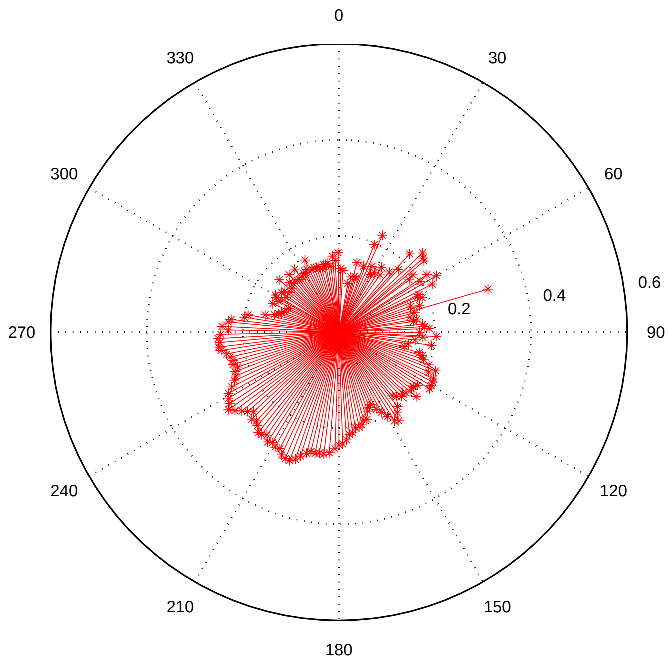


Figure 1.233: December 2013 turbulence intensity

1.9 WST Statistics

Matlab program used to obtain the statistics of WST anemometer is given in Section I.4

1.9.1 2008 Annual Statistics

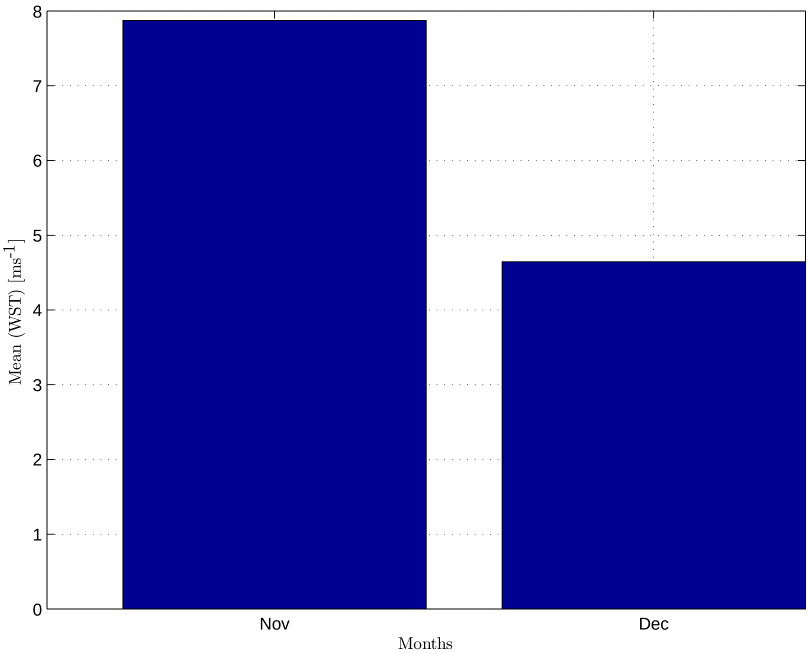


Figure 1.234: Annual wind speed distribution of WST, 2008

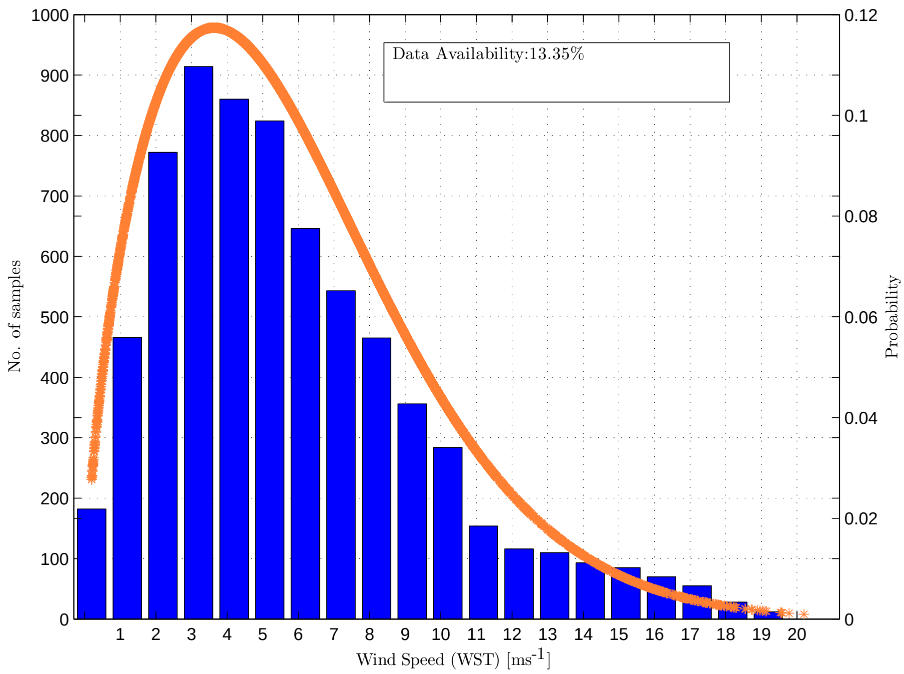


Figure 1.235: Annual wind speed distribution of WST, 2008

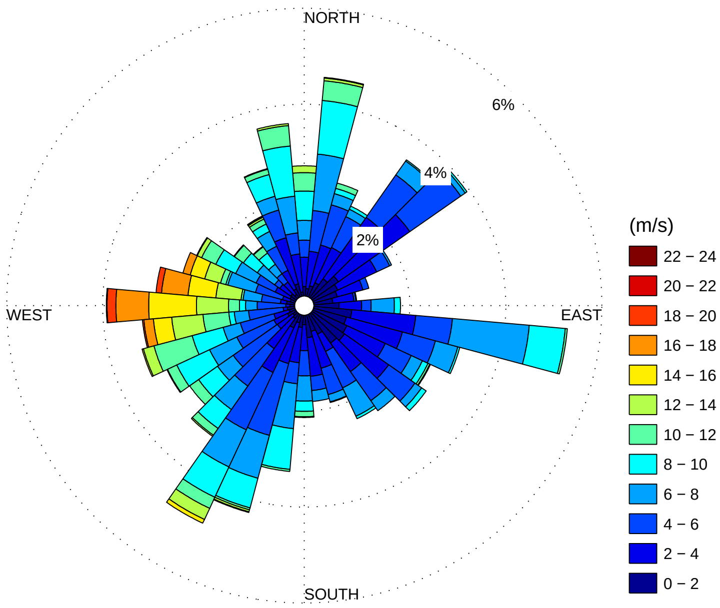


Figure 1.236: Annual wind rose of WST, 2008

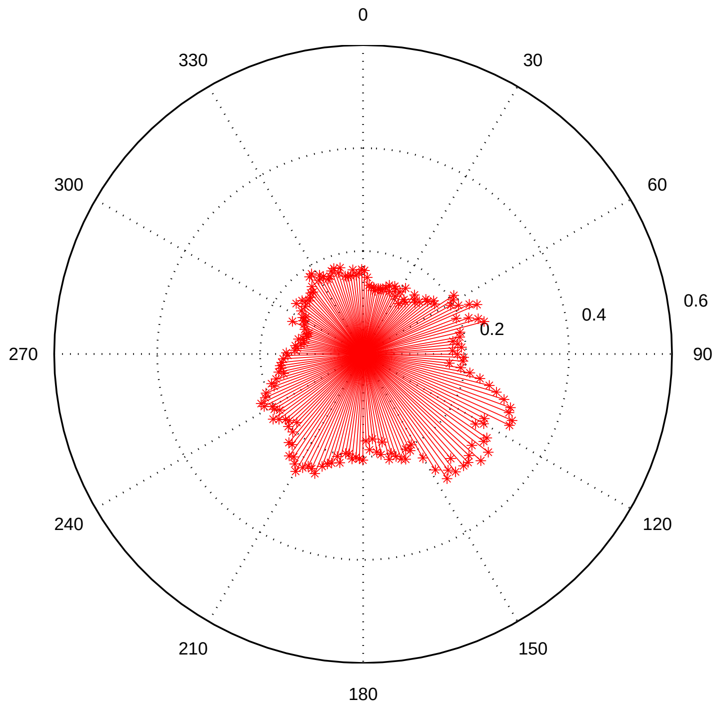


Figure 1.237: Turbulence intensity of WST, 2008

Table 1.21: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2008

Month	Min	Mean	Max
November	0.06	7.87	26.78
December	0.06	4.65	28.80

Table 1.22: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2008

Month	Data Availability(%)	Min	Mean	Max	K	C
November	59.98	0.20	7.87	19.58	2.11	8.88
December	99.55	0.20	4.65	20.20	1.62	5.20

1.9.1.1 2008 Monthly Statistics

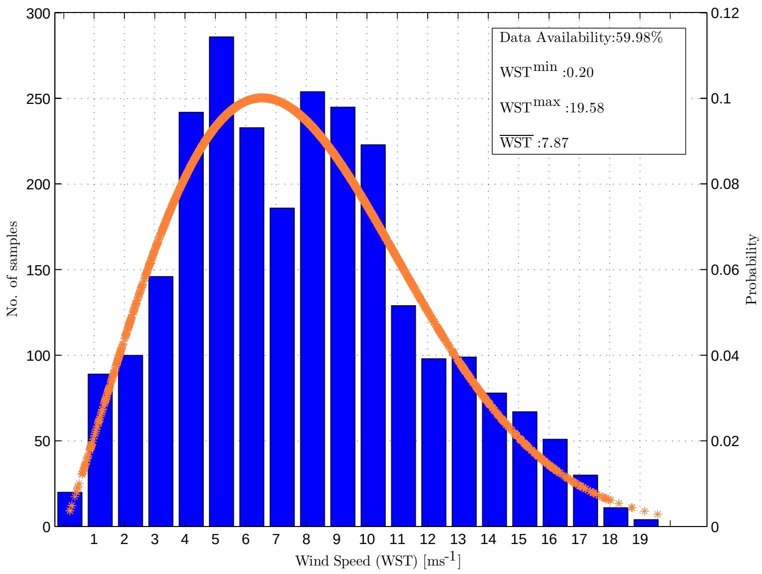


Figure 1.238: November 2008 probability distribution function

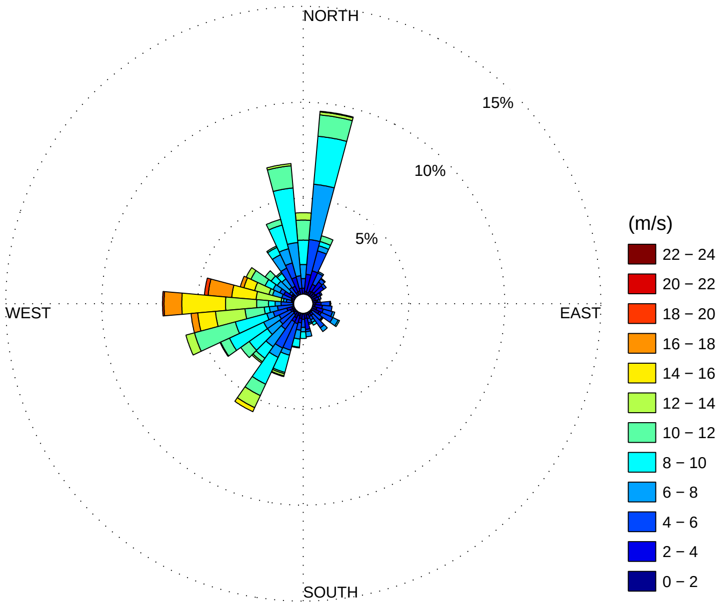


Figure 1.239: November 2008 Wind Rose

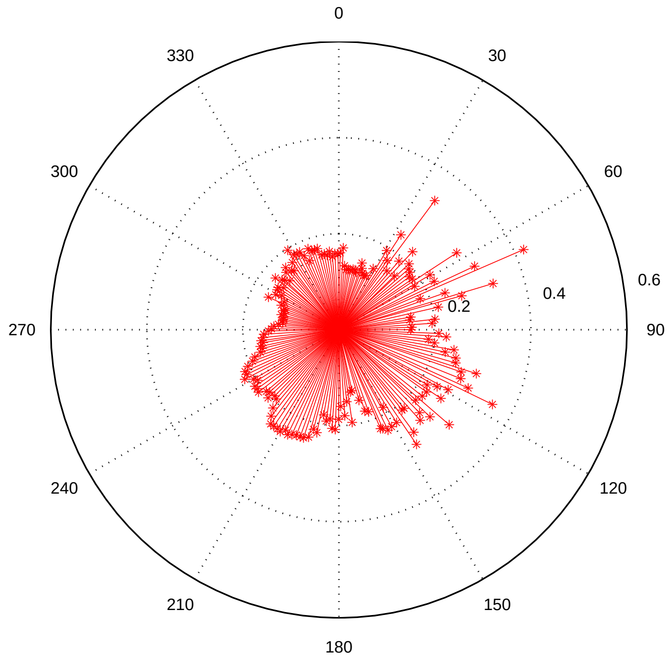


Figure 1.240: November 2008 turbulence intensity

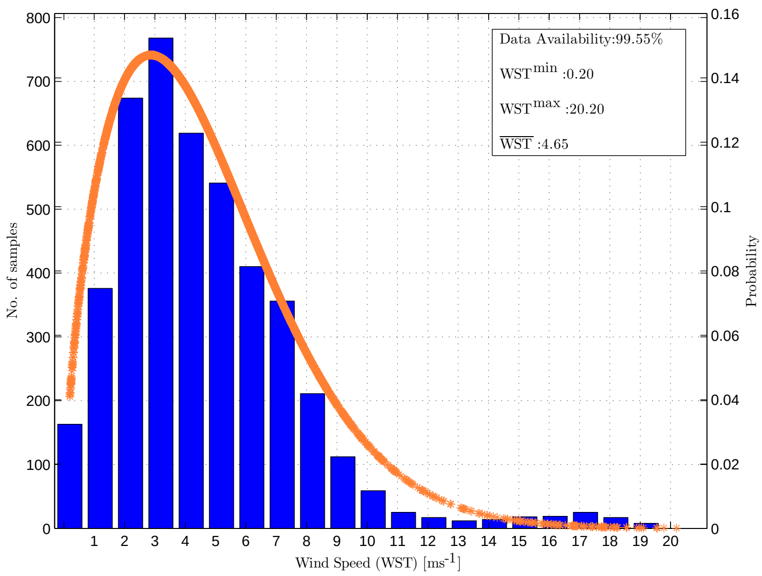


Figure 1.241: December 2008 probability distribution function

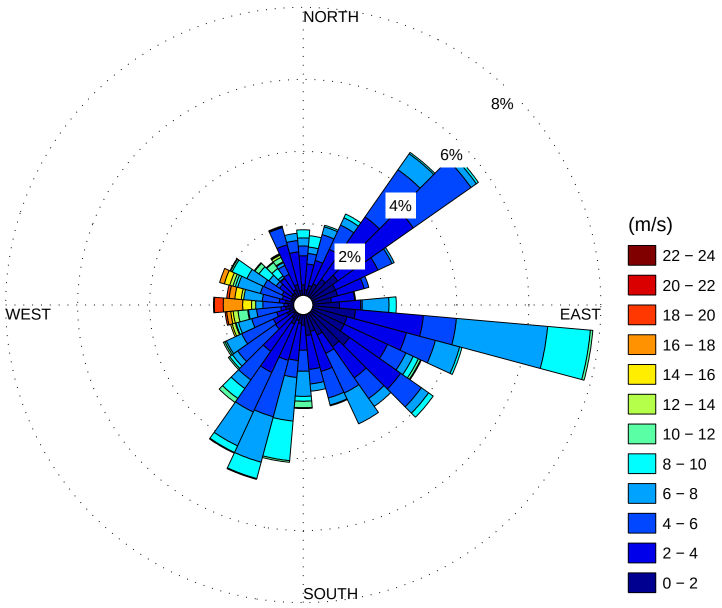


Figure 1.242: December 2008 Wind Rose

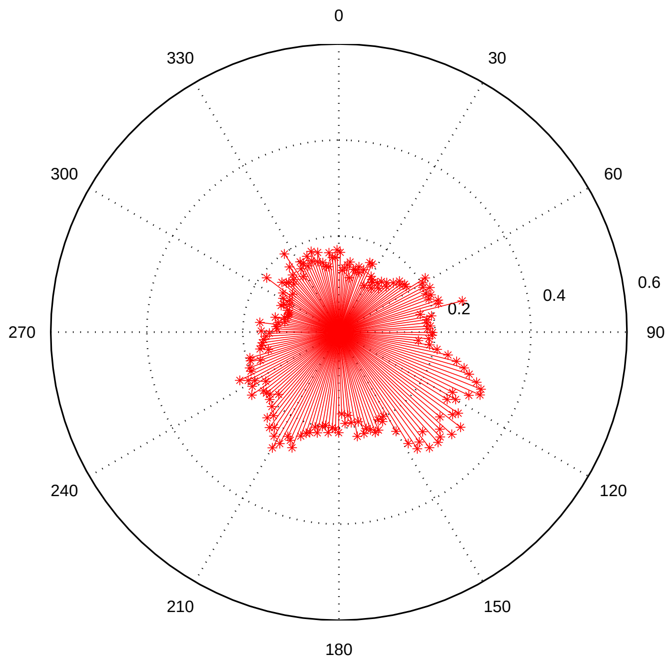


Figure 1.243: December 2008 turbulence intensity

1.9.2 2009 Annual Statistics

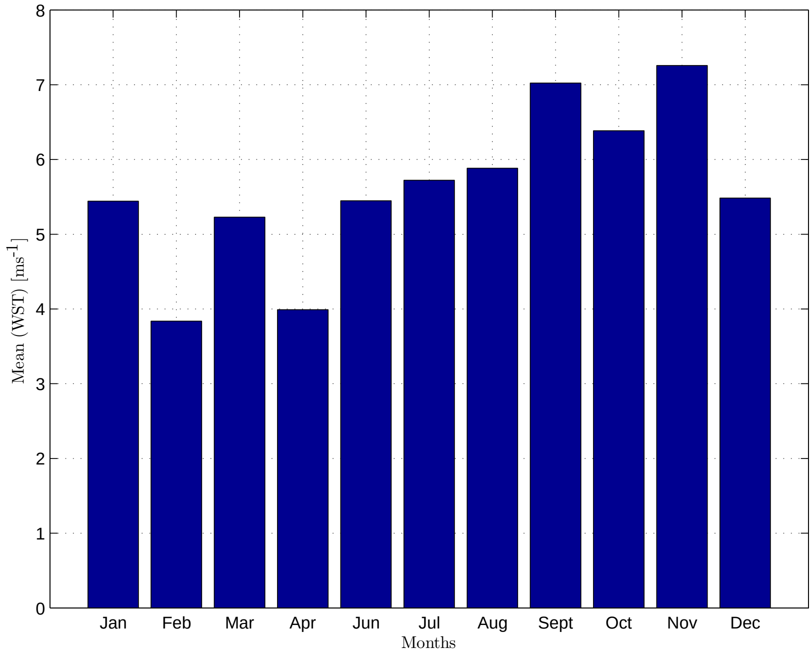


Figure 1.244: Annual wind speed distribution of WST, 2009

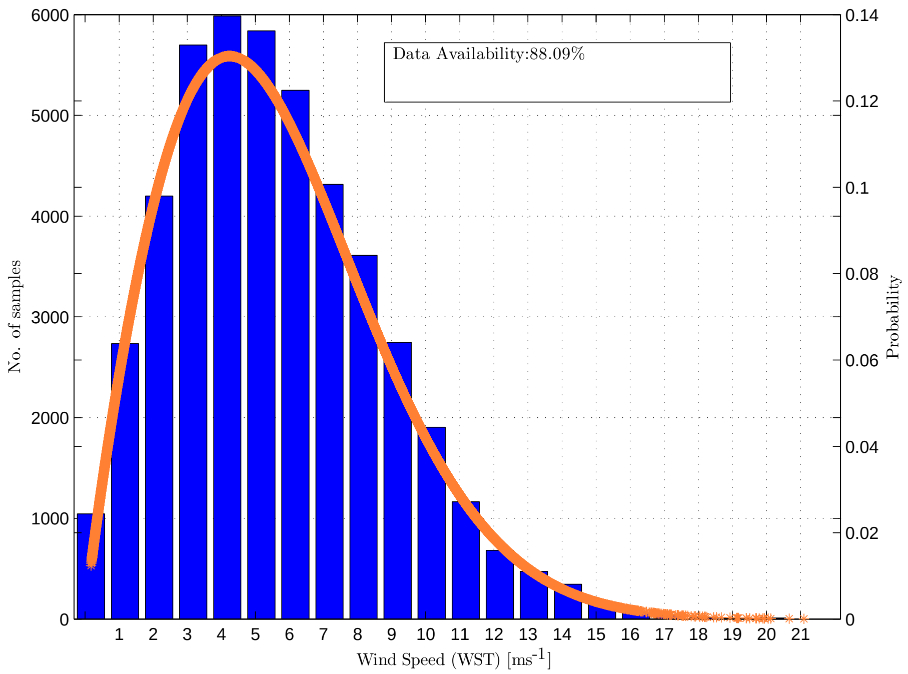


Figure 1.245: Annual wind speed distribution of WST, 2009

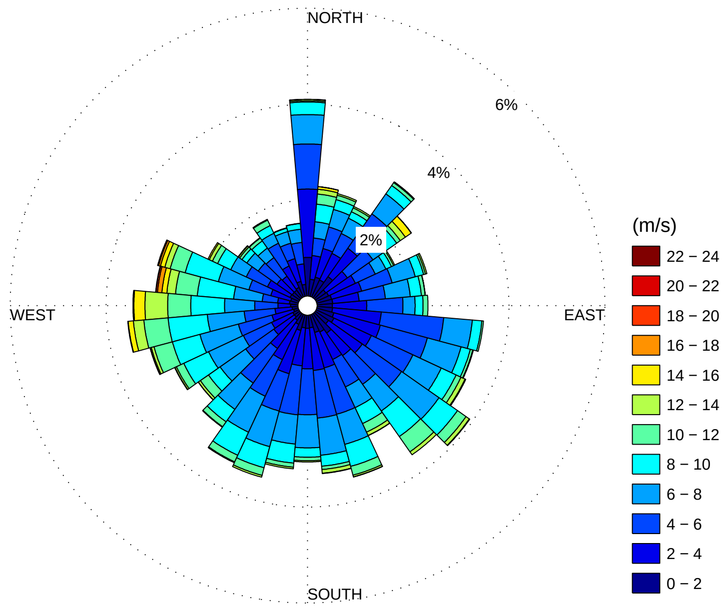


Figure 1.246: Annual wind rose of WST, 2009

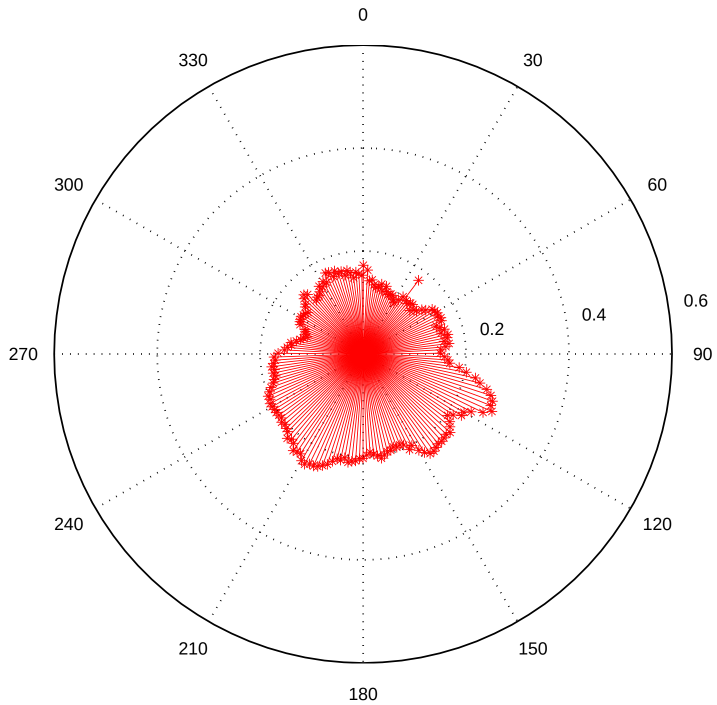


Figure 1.247: Turbulence intensity of WST, 2009

Table 1.23: Monthly wind speed [ms-1] parameters of 1 sec. raw data, 2009

Month	Min	Mean	Max
January	0.06	5.44	23.87
February	0.05	3.84	17.39
March	0.06	5.23	23.15
April	0.06	3.99	17.98
June	0.08	5.45	21.39
July	0.09	5.72	23.44
August	0.07	5.88	20.65
September	0.08	7.02	23.63
October	0.06	6.39	28.48
November	0.31	7.26	25.92
December	0.05	5.48	21.99

Table 1.24: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2009

Month	Data Availability(%)	Min	Mean	Max	K	C
January	99.98	0.19	5.44	15.93	1.61	6.03
February	100.00	0.19	3.84	11.89	1.84	4.31
March	99.15	0.20	5.23	14.97	1.96	5.88
April	94.93	0.20	3.99	13.49	1.88	4.49
June	95.19	0.21	5.45	14.59	1.97	6.15
July	100.00	0.24	5.72	16.26	2.09	6.47
August	100.00	0.21	5.88	15.25	2.12	6.63
September	99.88	0.17	7.02	18.20	2.13	7.90
October	99.96	0.20	6.39	21.10	1.83	7.19
November	100.00	1.28	7.26	16.63	3.28	8.09
December	70.39	0.20	5.48	16.16	1.92	6.20

1.9.2.1 2009 Monthly Statistics

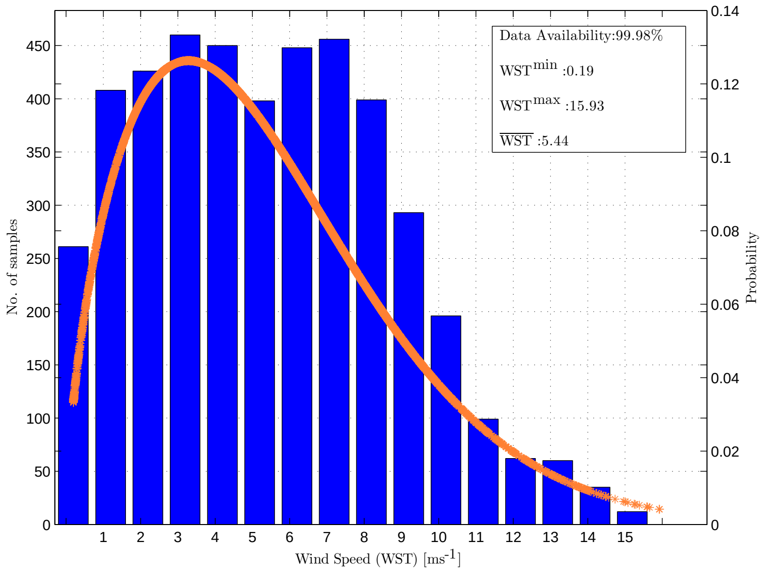


Figure 1.248: January 2009 probability distribution function

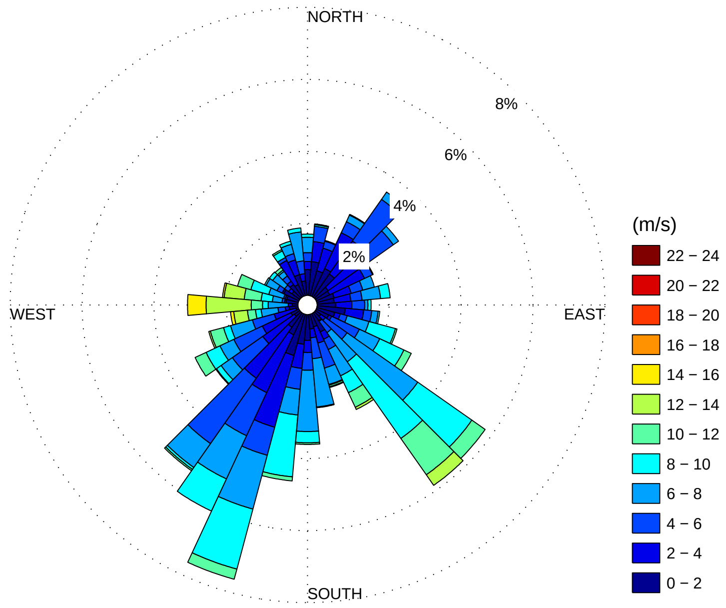


Figure 1.249: January 2009 Wind Rose

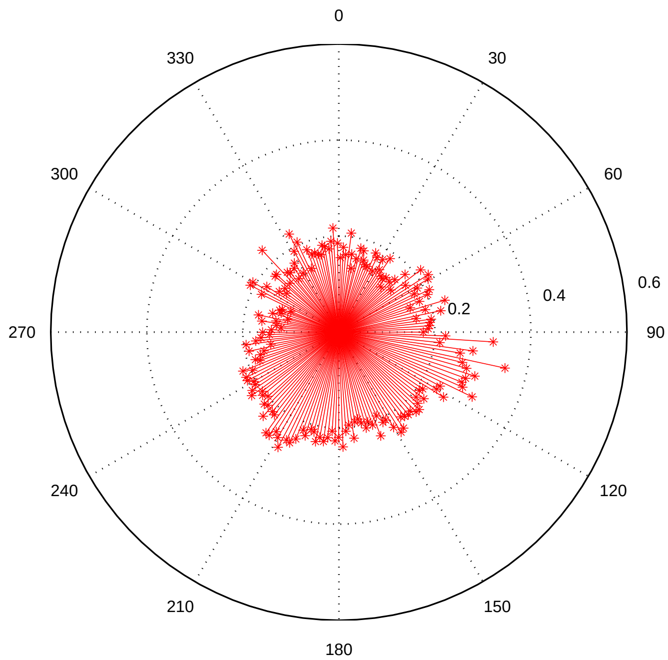


Figure 1.250: January 2009 turbulence intensity

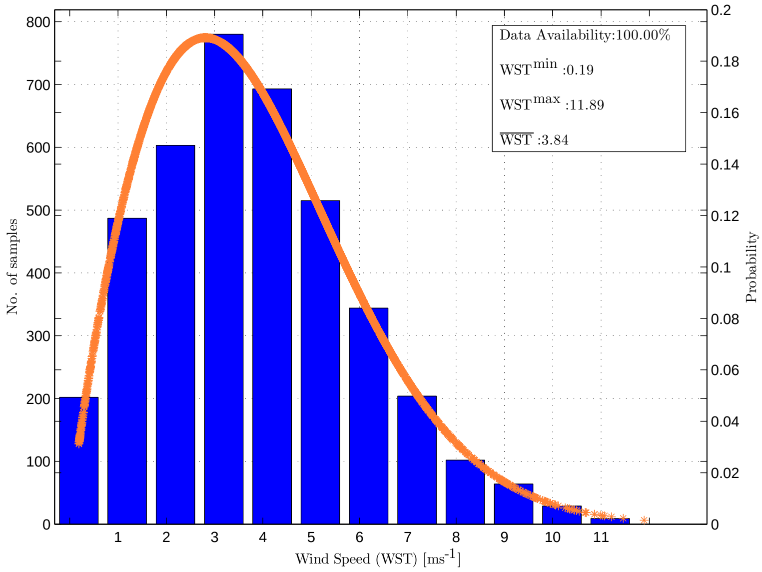


Figure 1.251: February 2009 probability distribution function

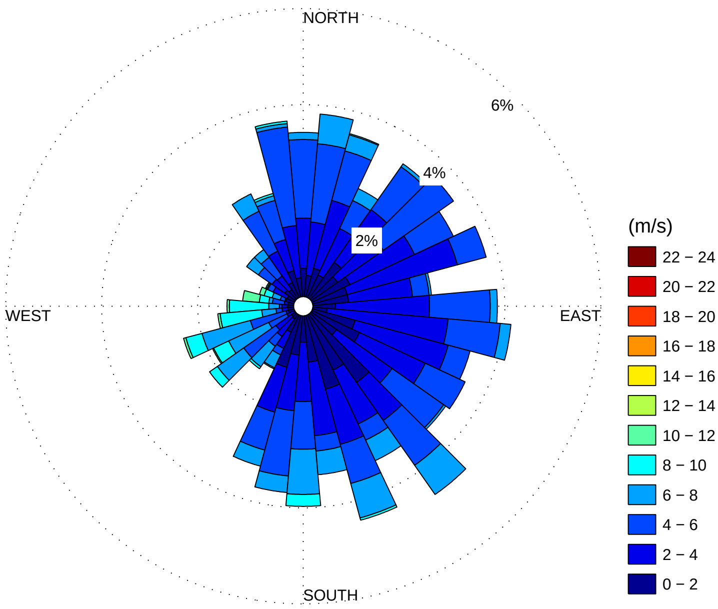


Figure 1.252: February 2009 Wind Rose

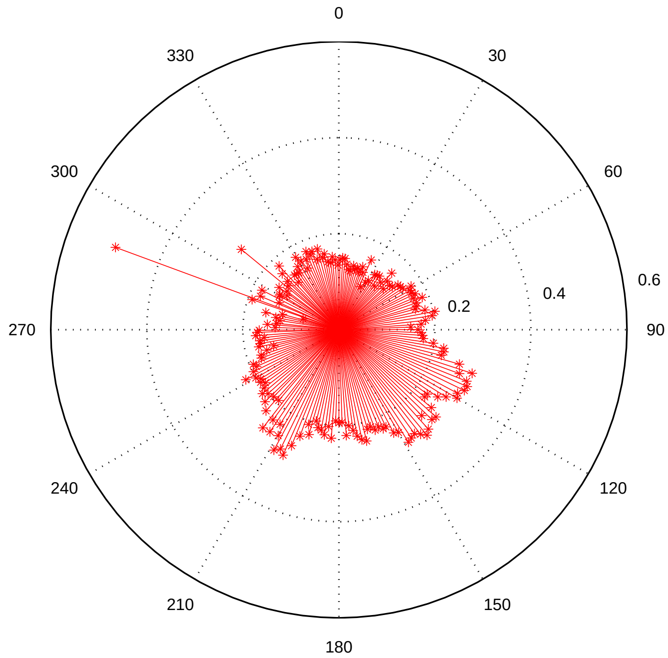


Figure 1.253: February 2009 turbulence intensity

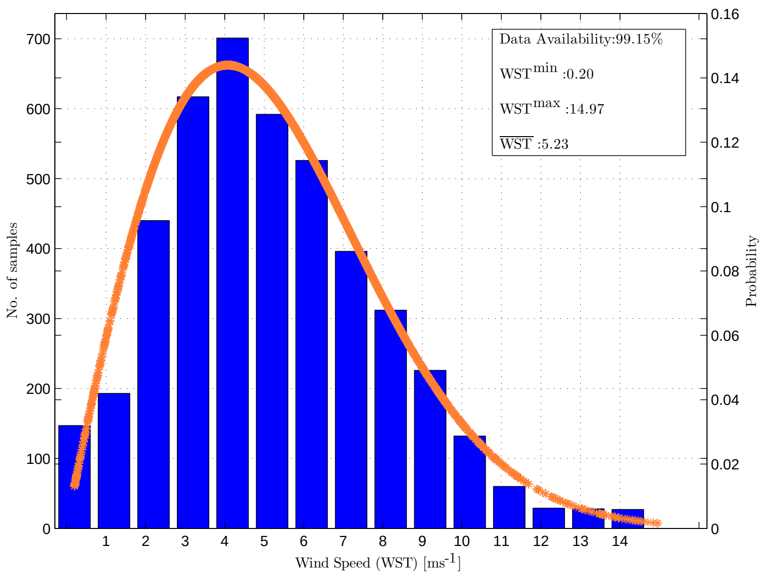


Figure 1.254: March 2009 probability distribution function

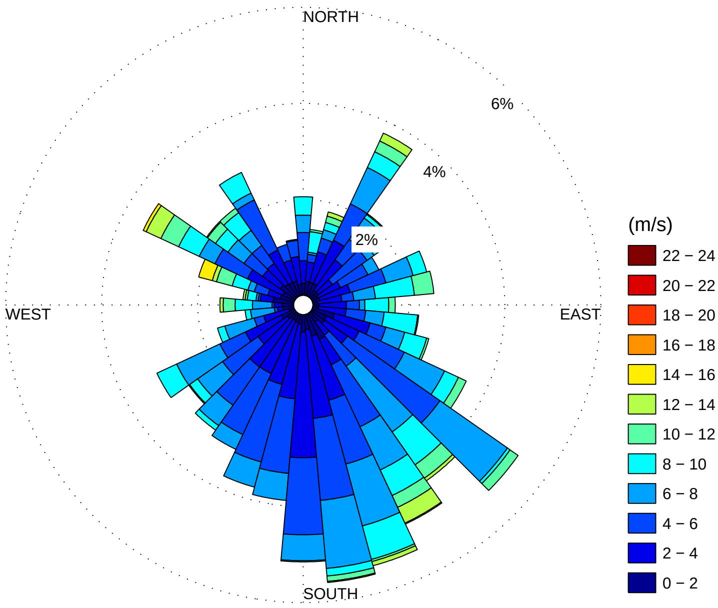


Figure 1.255: March 2009 Wind Rose

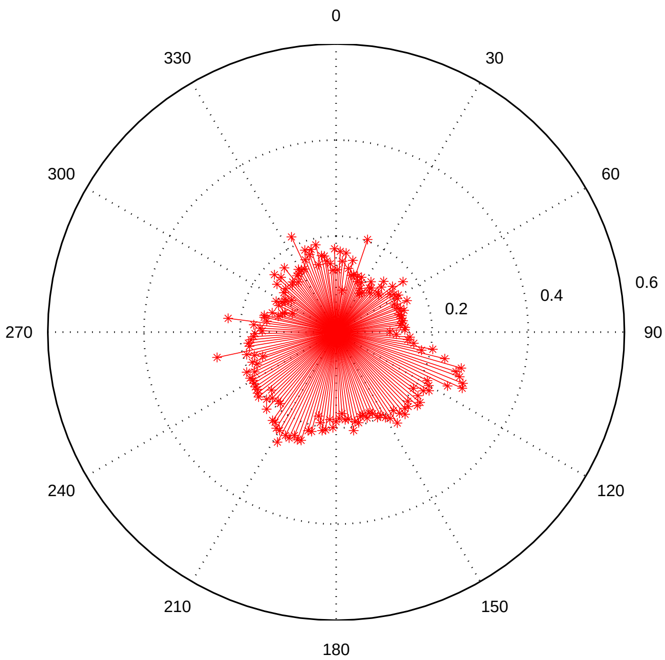


Figure 1.256: March 2009 turbulence intensity

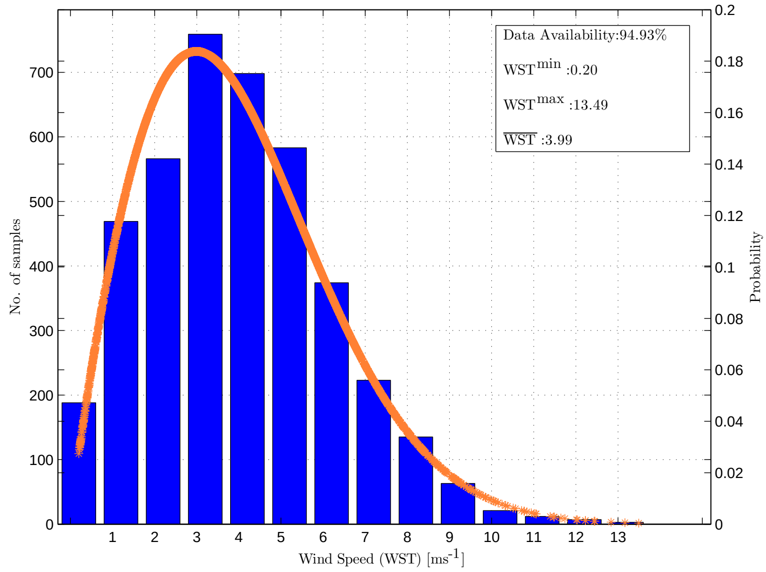


Figure 1.257: April 2009 probability distribution function

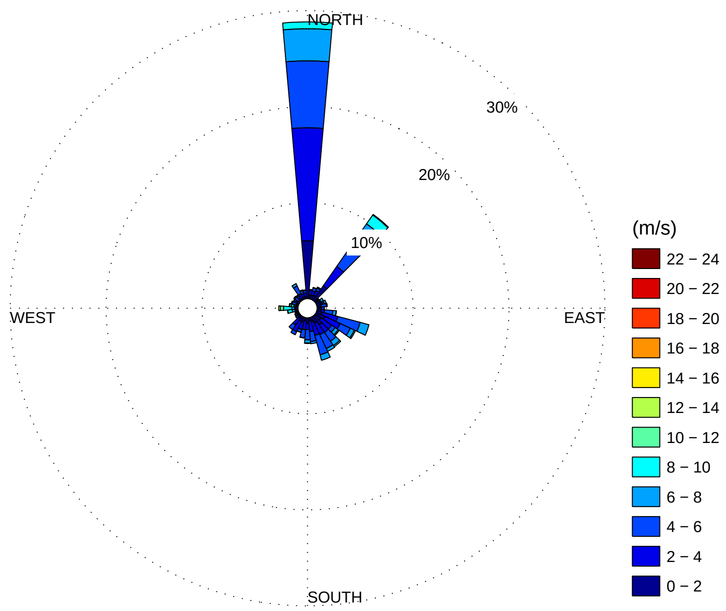


Figure 1.258: April 2009 Wind Rose

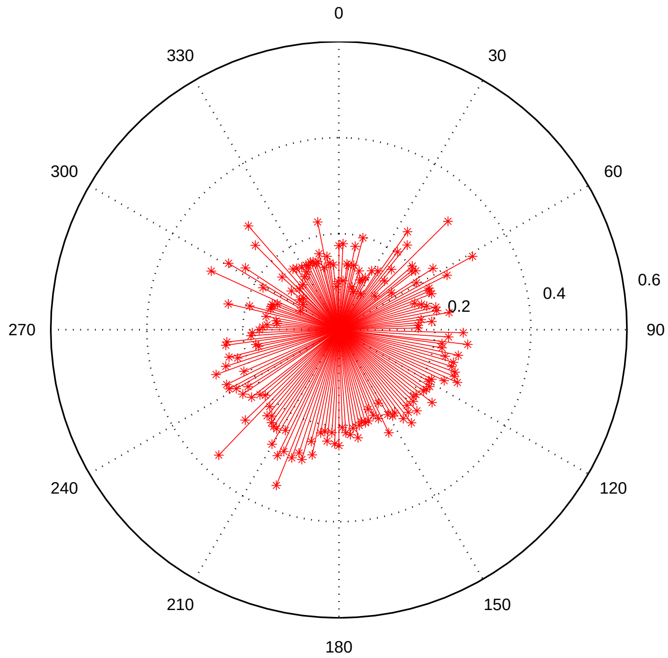


Figure 1.259: April 2009 turbulence intensity

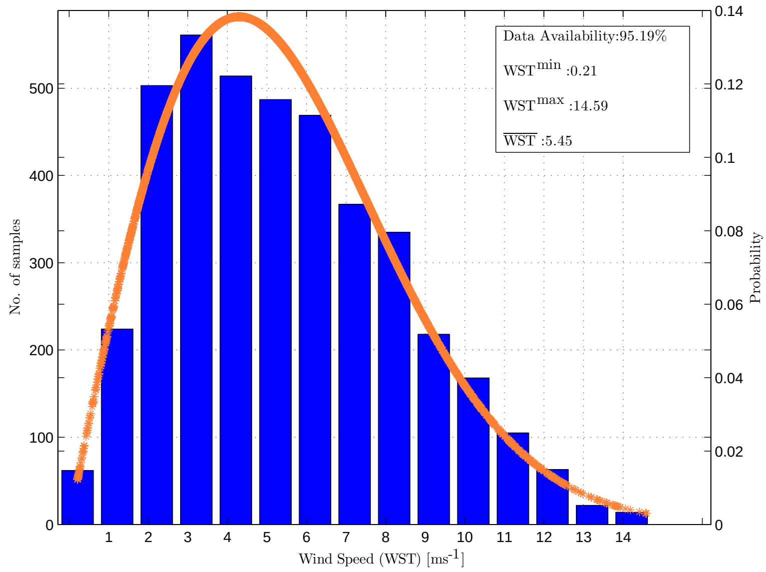


Figure 1.260: June 2009 probability distribution function

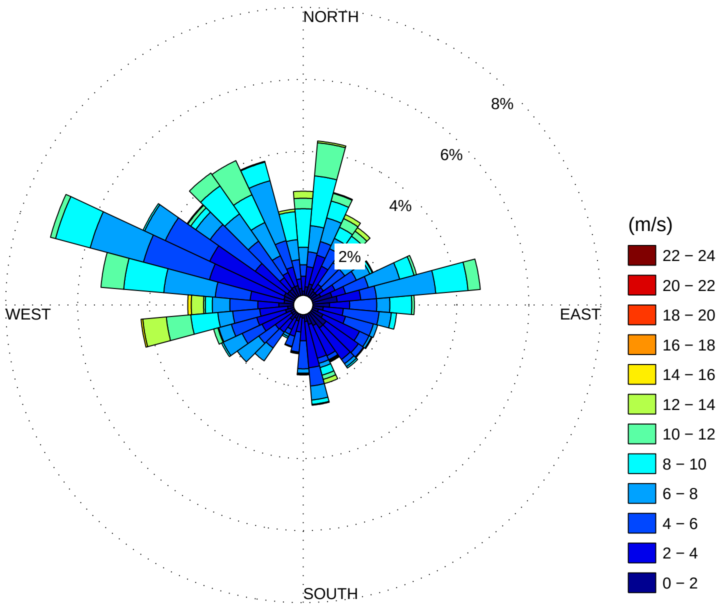


Figure 1.261: June 2009 Wind Rose

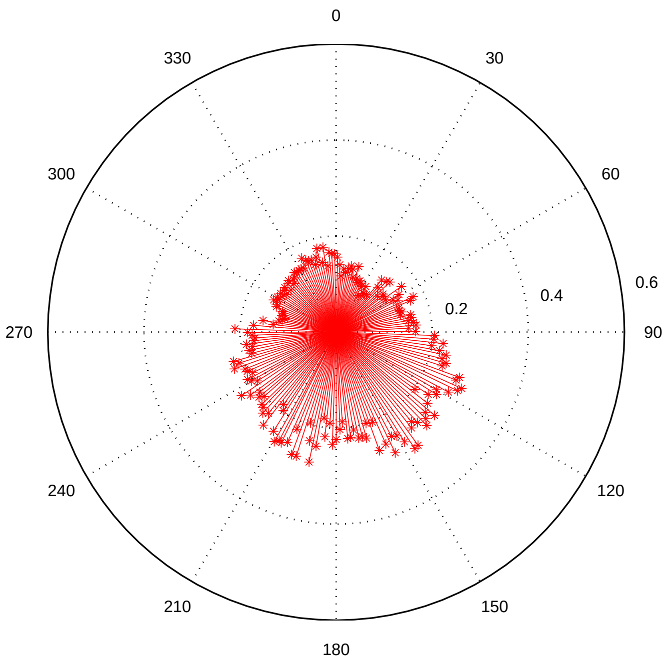


Figure 1.262: June 2009 turbulence intensity

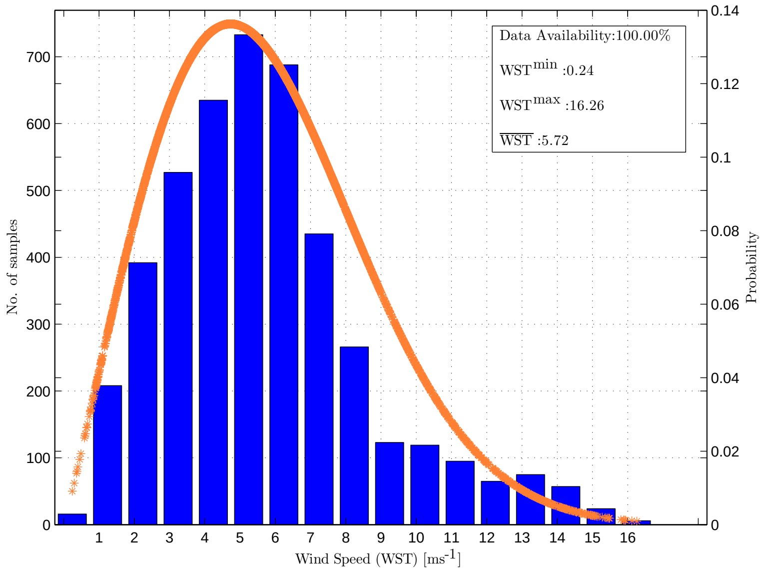


Figure 1.263: July 2009 probability distribution function

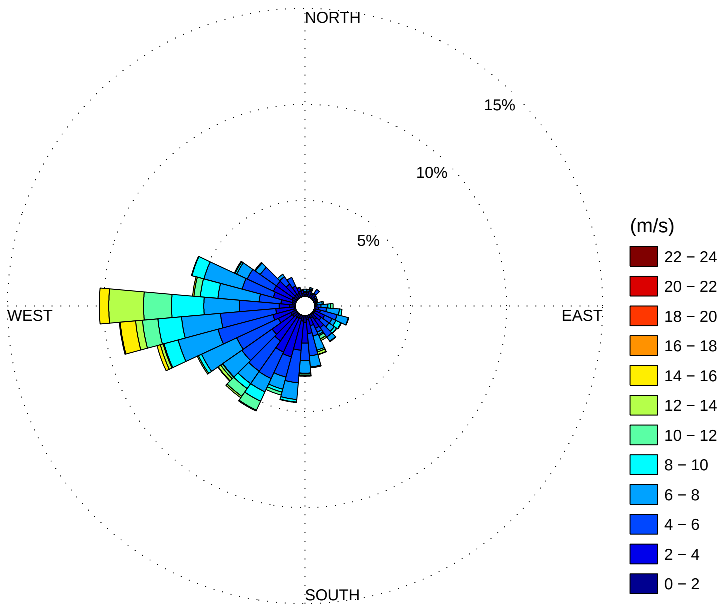


Figure 1.264: July 2009 Wind Rose

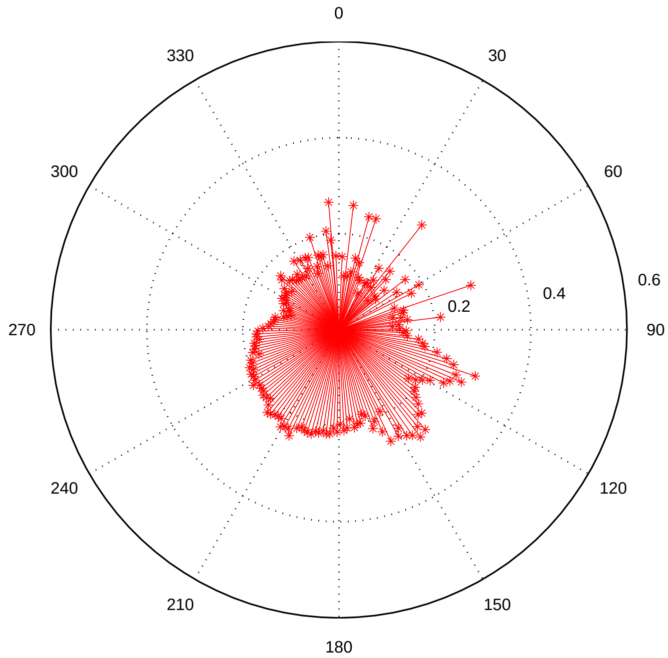


Figure 1.265: July 2009 turbulence intensity

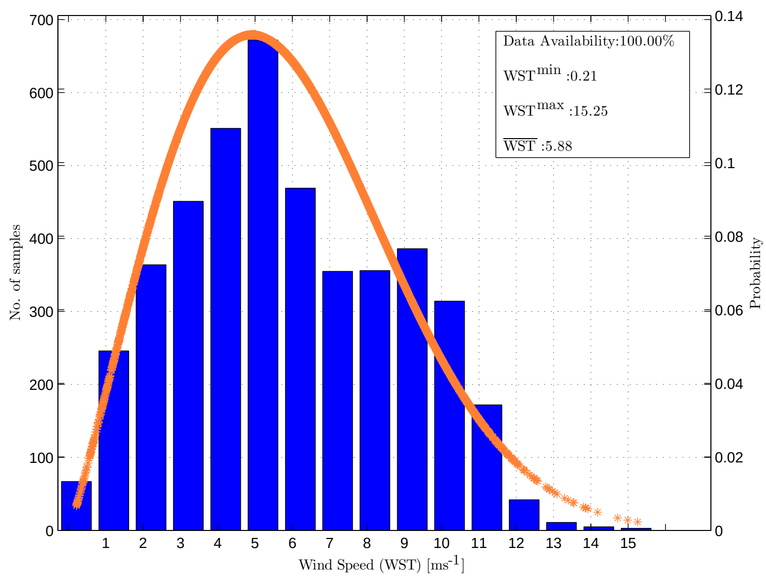


Figure 1.266: August 2009 probability distribution function

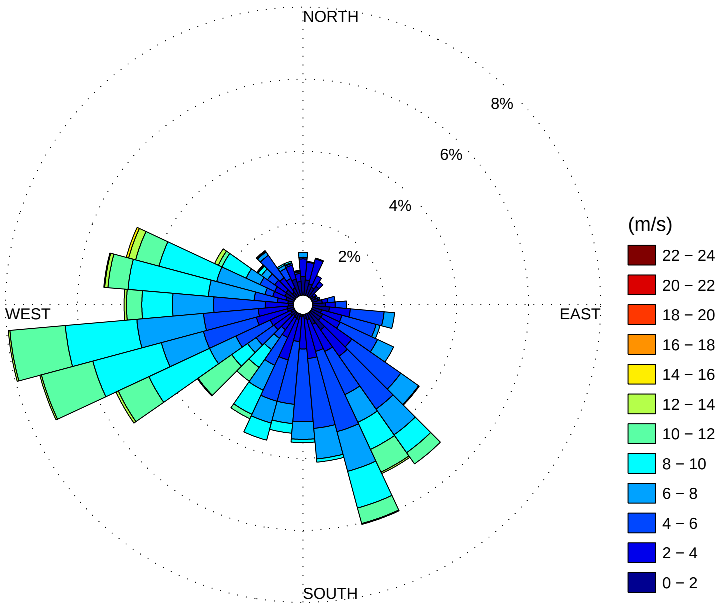


Figure 1.267: August 2009 Wind Rose

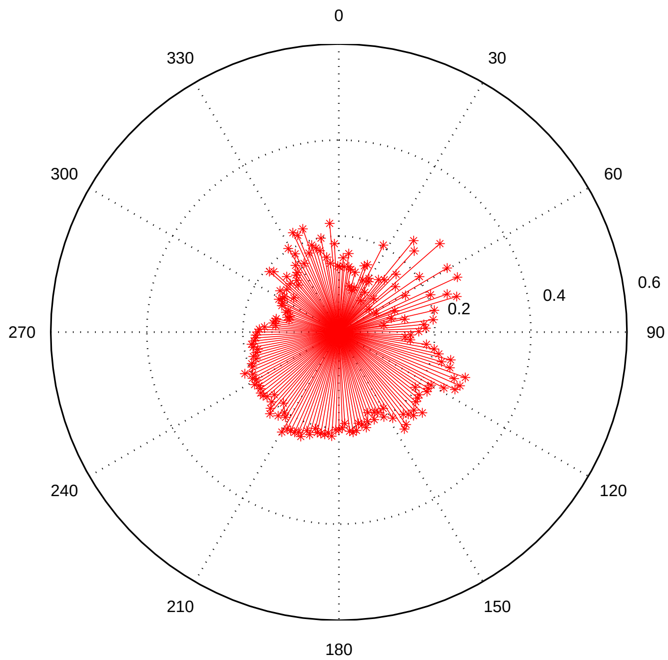


Figure 1.268: August 2009 turbulence intensity

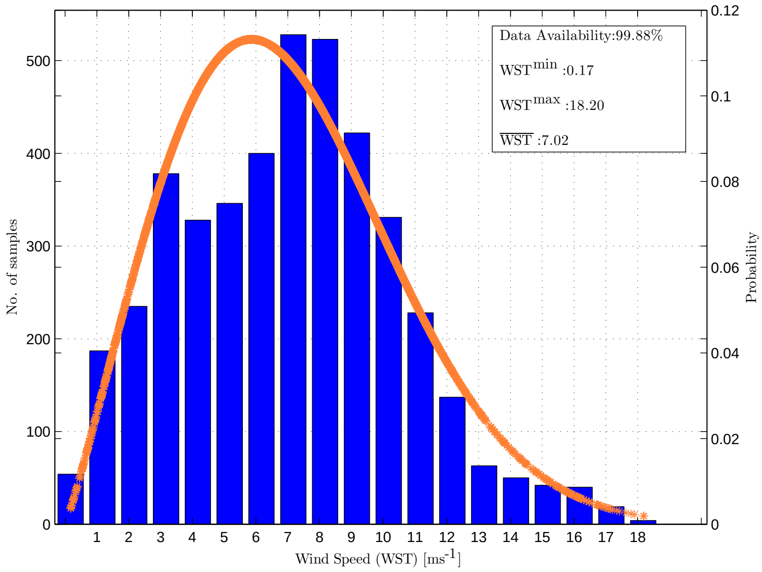


Figure 1.269: September 2009 probability distribution function

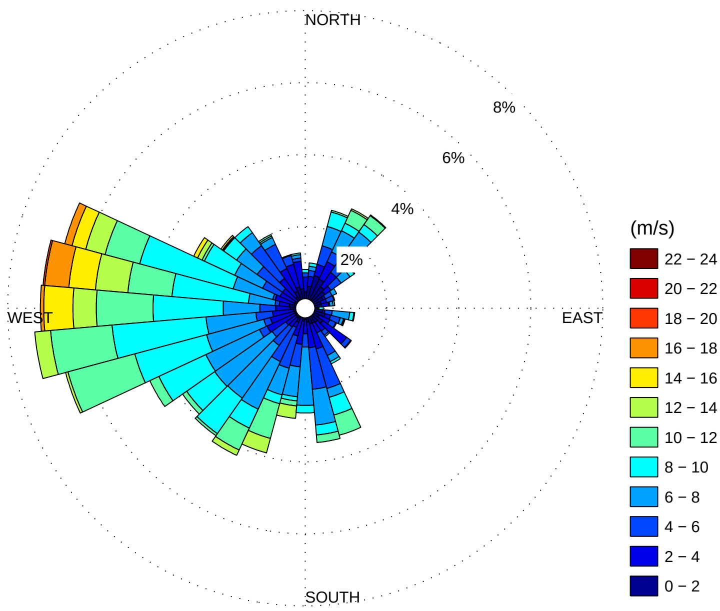


Figure 1.270: September 2009 Wind Rose

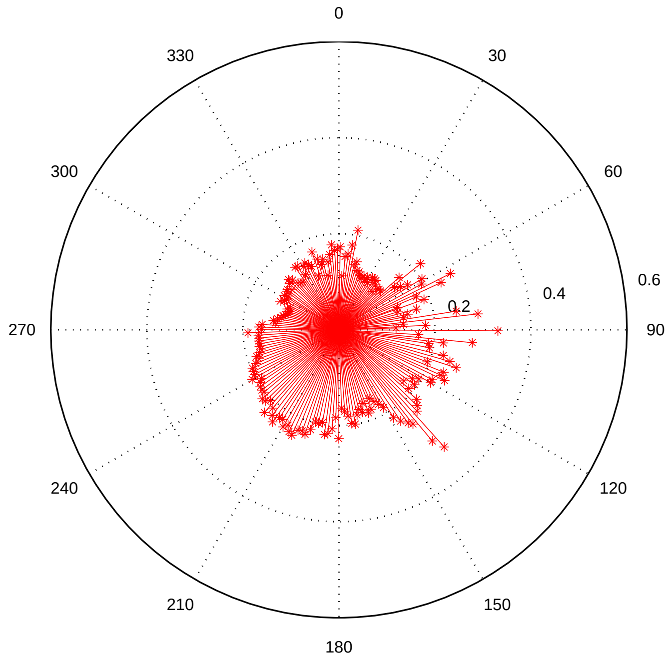


Figure 1.271: September 2009 turbulence intensity

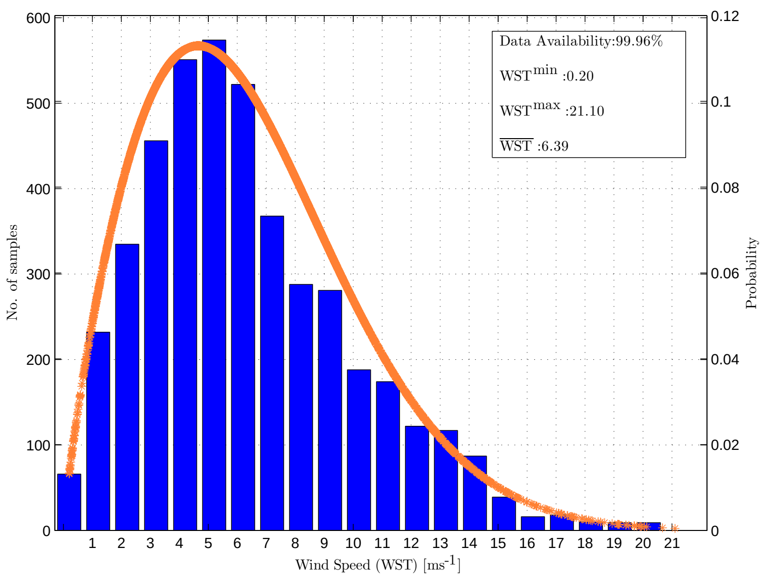


Figure 1.272: October 2009 probability distribution function

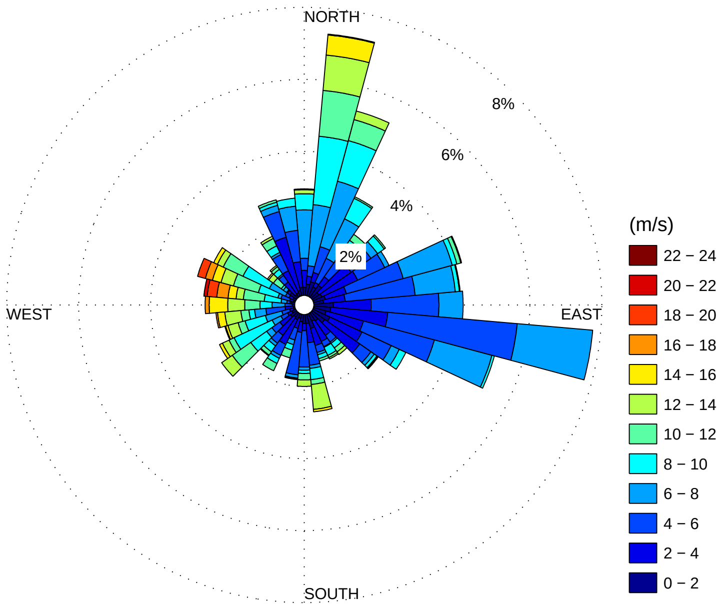


Figure 1.273: October 2009 Wind Rose

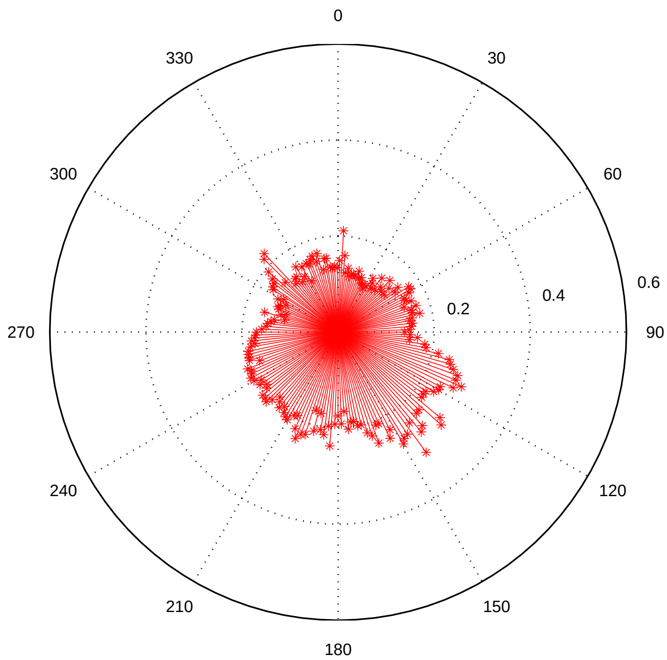


Figure 1.274: October 2009 turbulence intensity

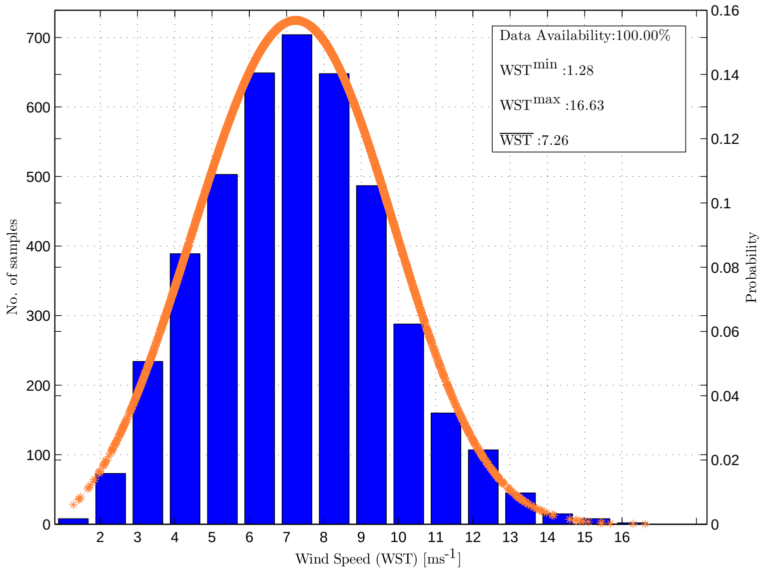


Figure 1.275: November 2009 probability distribution function

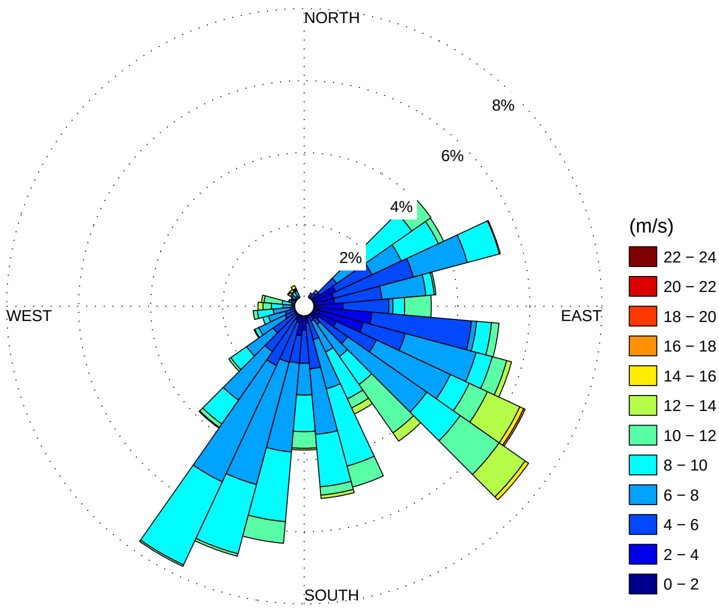


Figure 1.276: November 2009 Wind Rose

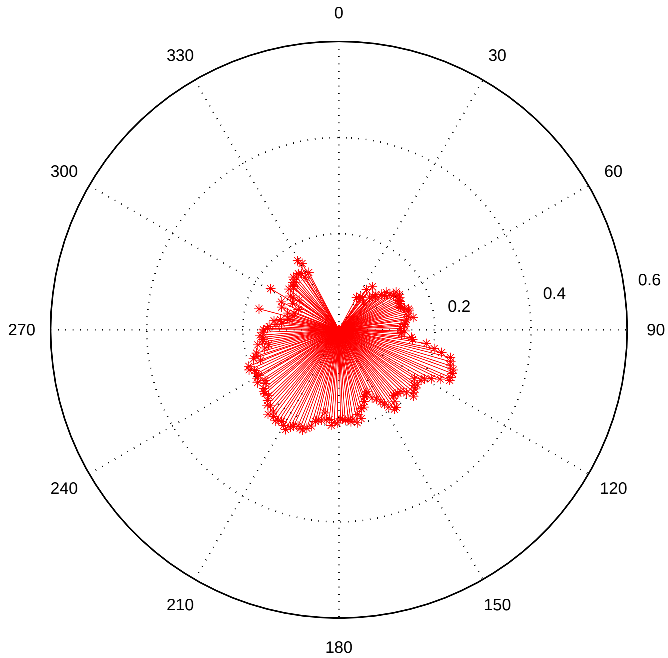


Figure 1.277: November 2009 turbulence intensity

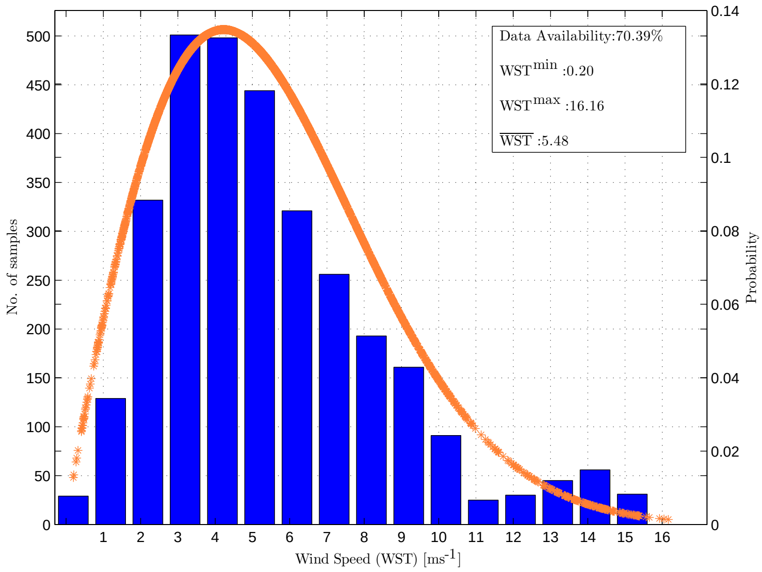


Figure 1.278: December 2009 probability distribution function

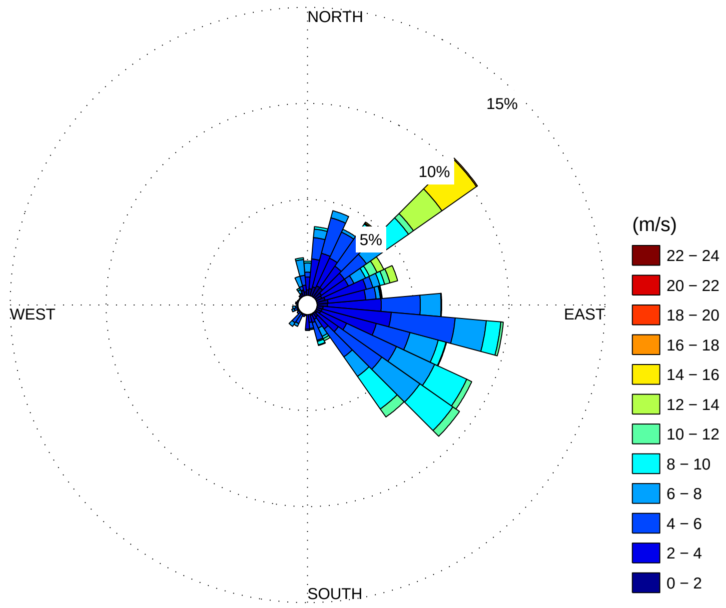


Figure 1.279: December 2009 Wind Rose

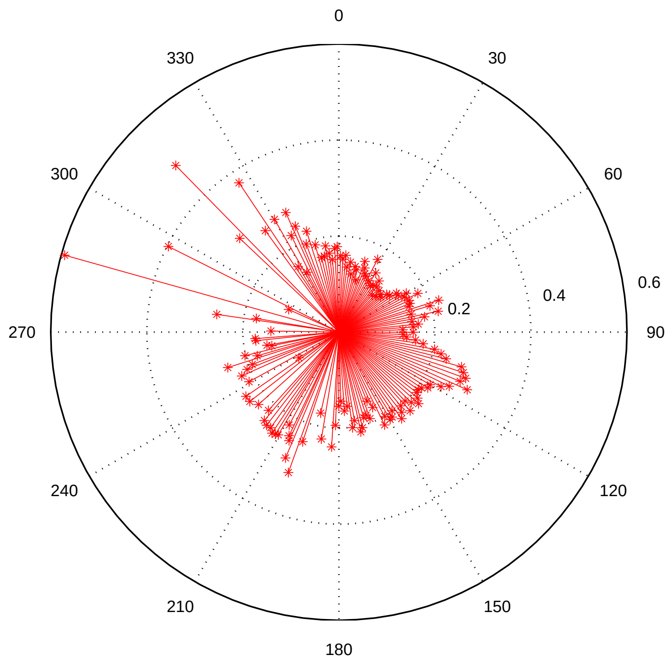


Figure 1.280: December 2009 turbulence intensity

1.9.3 2010 Annual Statistics

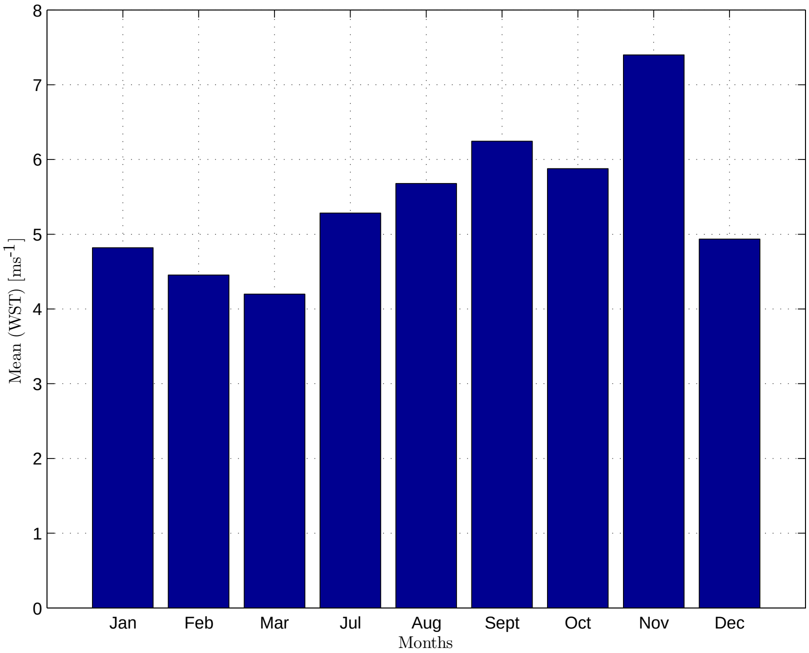


Figure 1.281: Annual wind speed distribution of WST, 2010

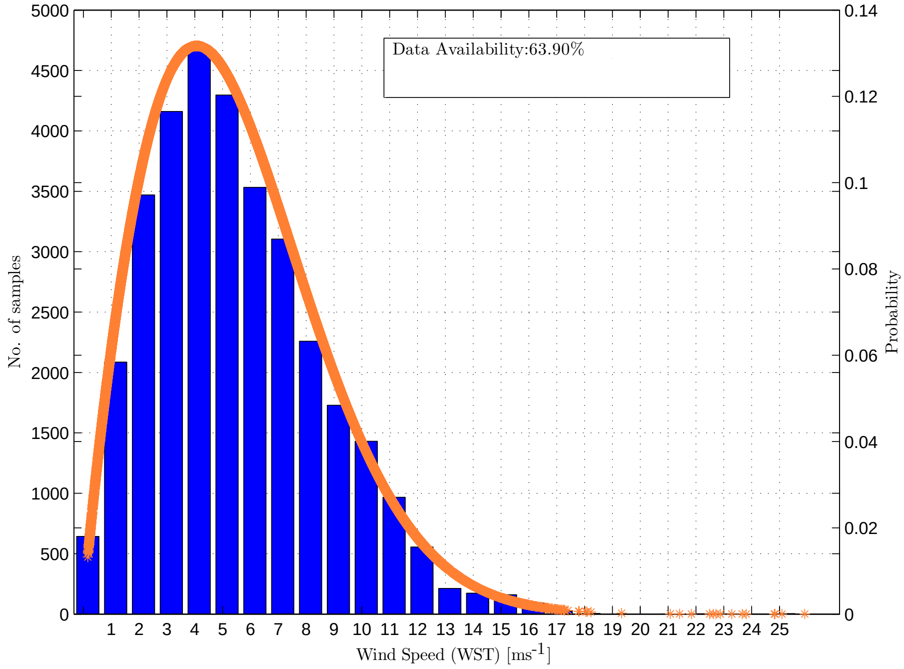


Figure 1.282: Annual wind speed distribution of WST, 2010

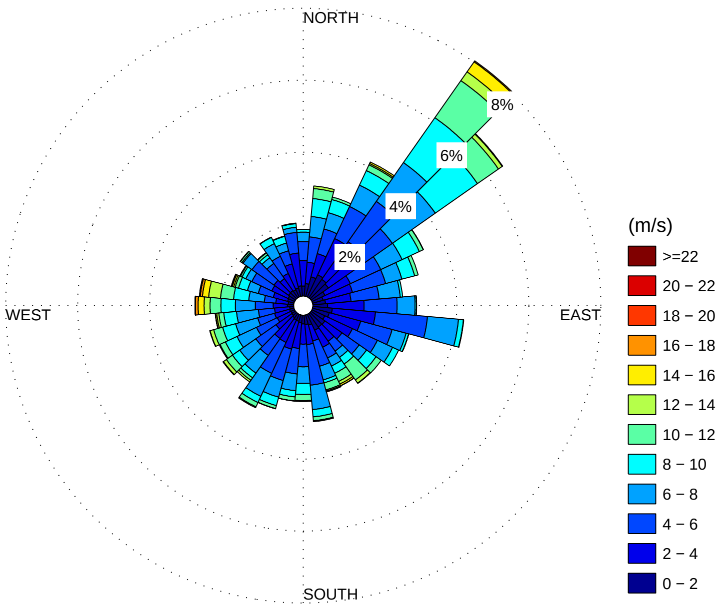


Figure 1.283: Annual wind rose of WST, 2010

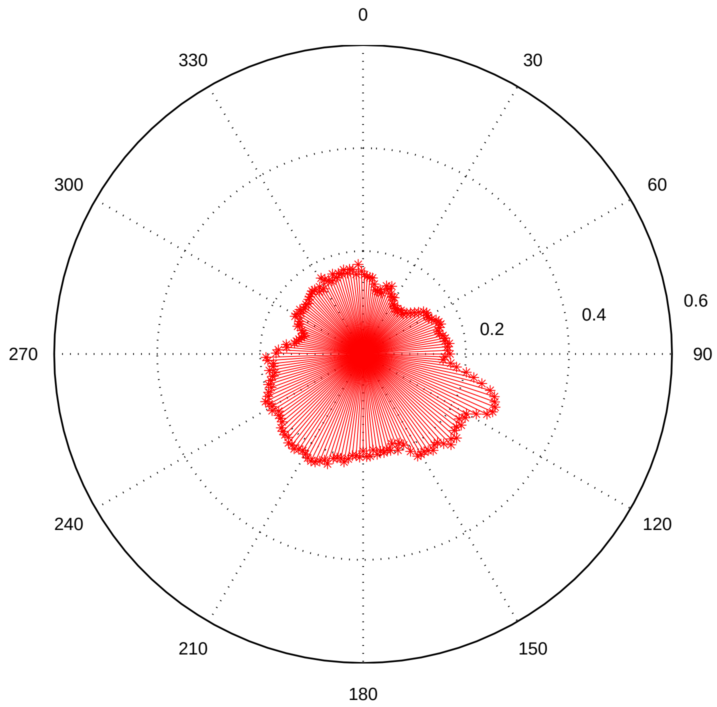


Figure 1.284: Turbulence intensity of WST, 2010

Table 1.25: Monthly wind speed [ms-1] parameters of 1 sec. raw data, 2010

Month	Min	Mean	Max
January	0.05	4.82	20.56
February	0.05	4.45	18.79
March	0.06	4.20	17.54
July	0.09	5.28	19.87
August	0.08	5.68	23.99
September	0.08	6.24	23.38
October	0.07	5.88	33.69
November	0.06	7.40	27.55
December	0.06	4.94	24.44

Table 1.26: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2010

Month	Data Availability(%)	Min	Mean	Max	K	C
January	78.38	0.17	4.82	12.25	2.19	5.43
February	100.00	0.19	4.45	14.56	1.78	5.02
March	56.32	0.16	4.20	12.85	1.96	4.71
July	53.14	0.21	5.28	13.12	2.47	5.95
August	100.00	0.18	5.68	17.81	1.86	6.39
September	100.00	0.23	6.24	15.51	2.19	7.05
October	100.00	0.23	5.88	25.91	1.77	6.60
November	89.12	0.18	7.40	18.04	2.01	8.32
December	91.17	0.19	4.94	17.23	1.83	5.54

1.9.3.1 2010 Monthly Statistics

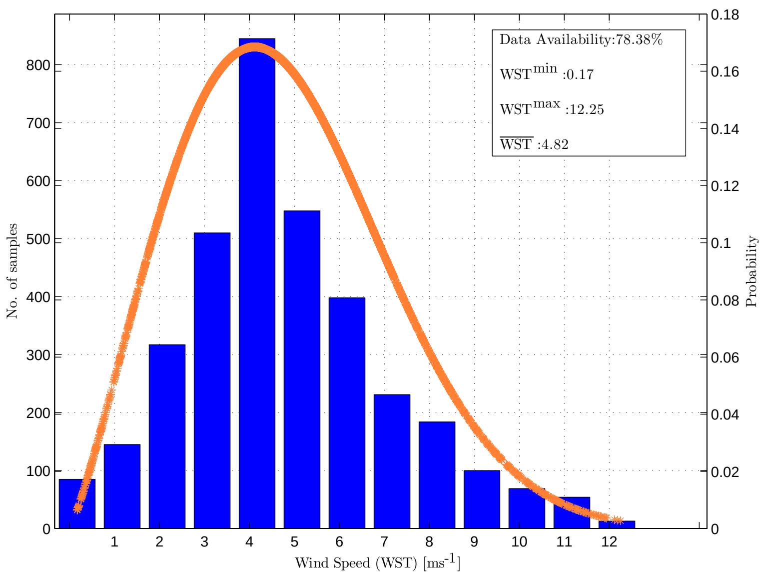


Figure 1.285: January 2010 probability distribution function

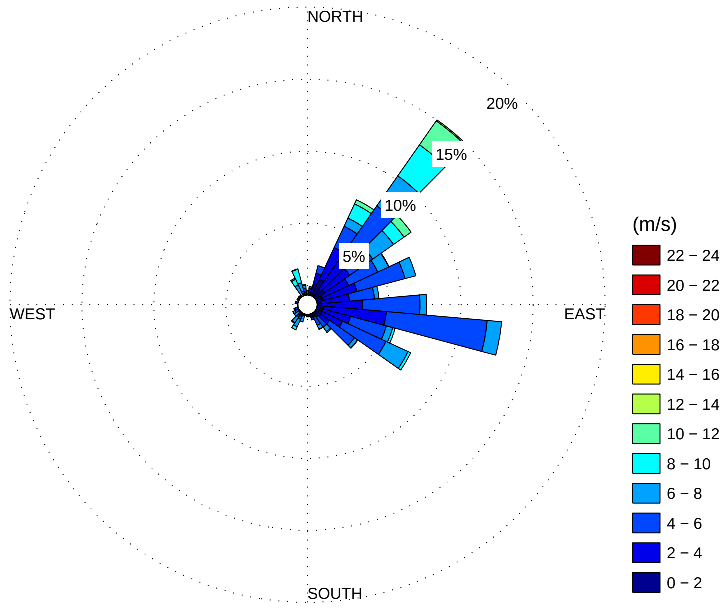


Figure 1.286: January 2010 Wind Rose

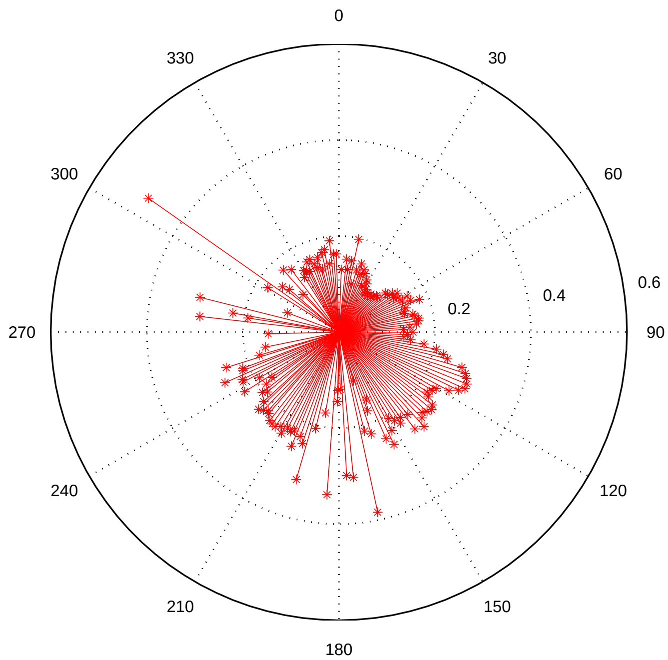


Figure 1.287: January 2010 turbulence intensity

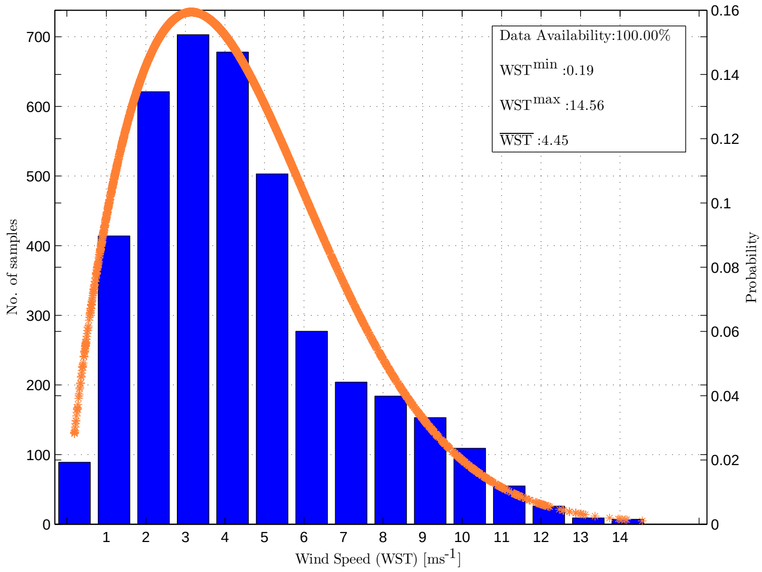


Figure 1.288: February 2010 probability distribution function

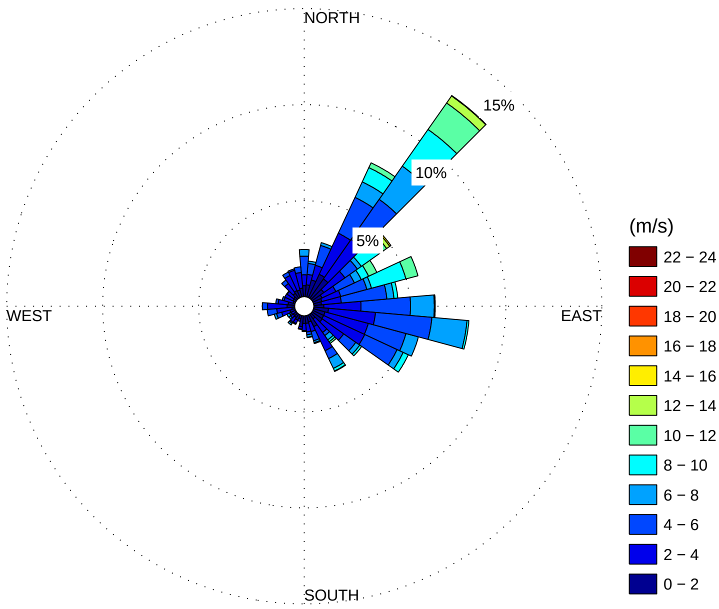


Figure 1.289: February 2010 Wind Rose

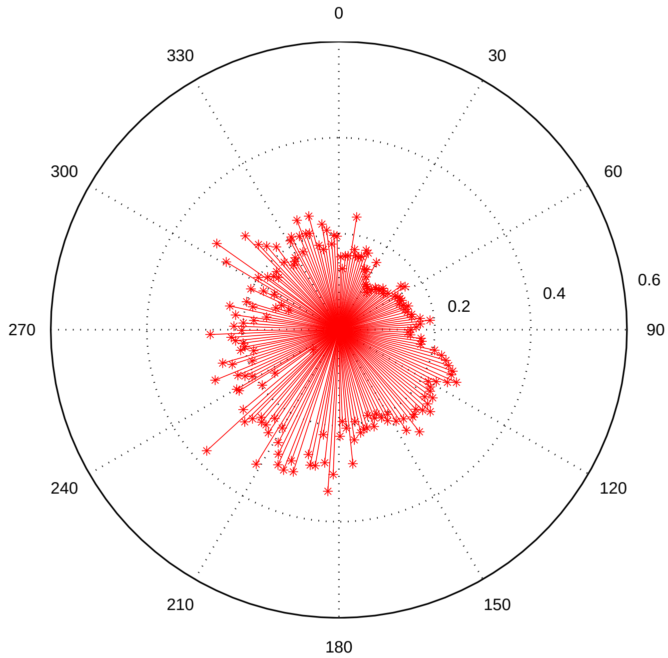


Figure 1.290: February 2010 turbulence intensity

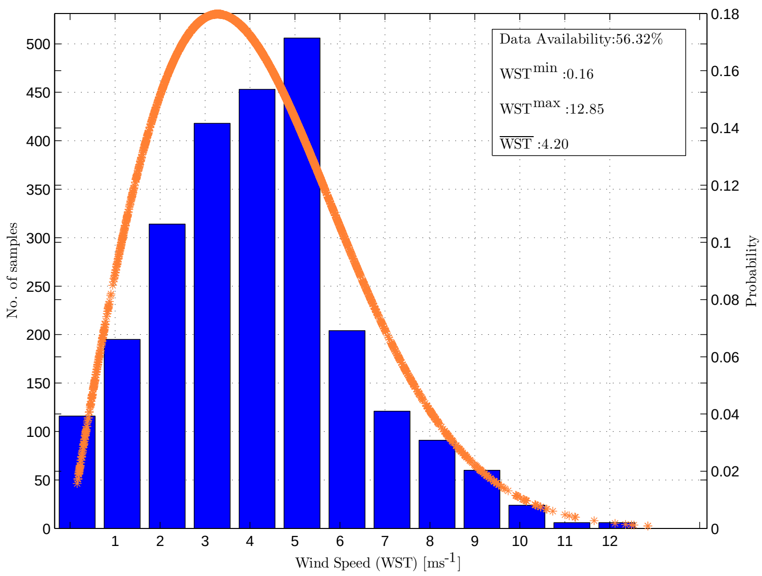


Figure 1.291: March 2010 probability distribution function

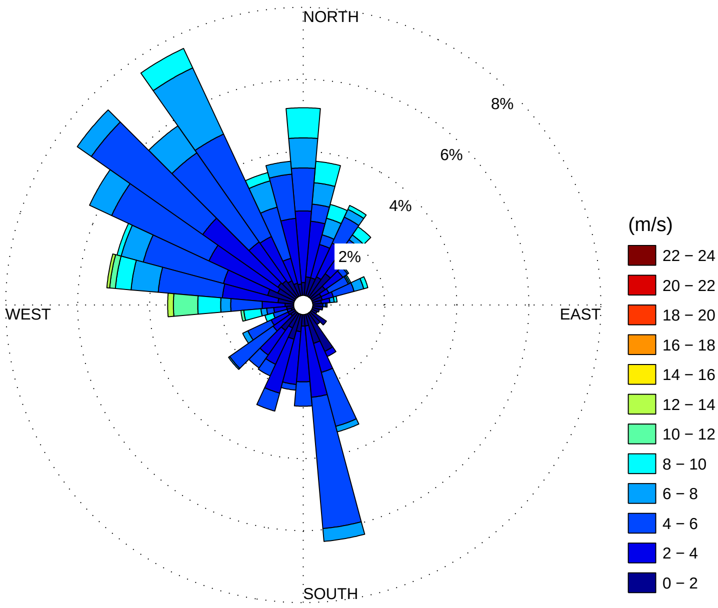


Figure 1.292: March 2010 Wind Rose

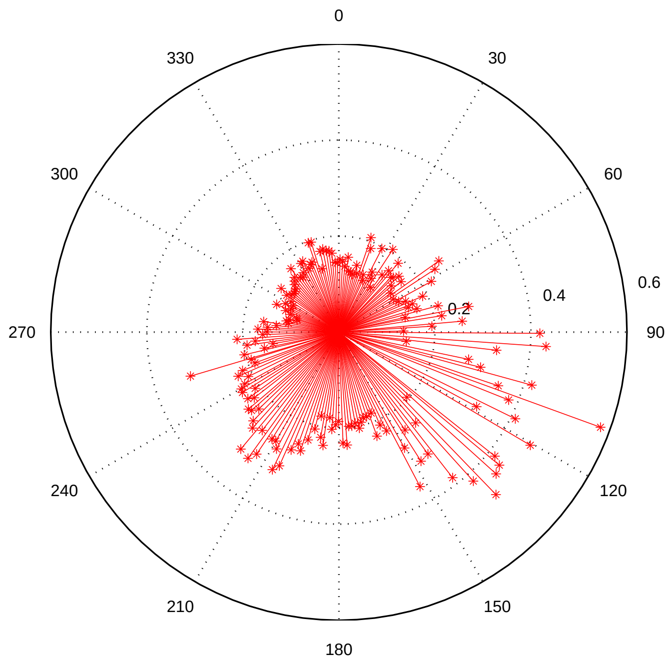


Figure 1.293: March 2010 turbulence intensity

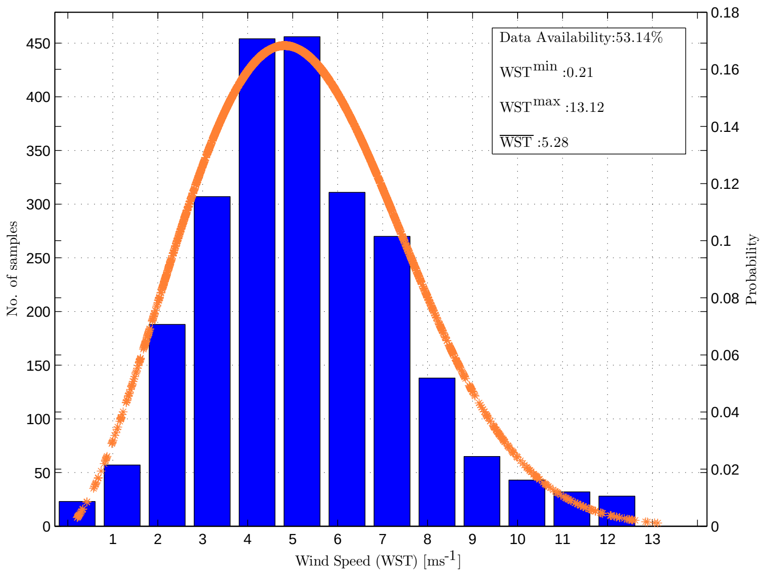


Figure 1.294: July 2010 probability distribution function

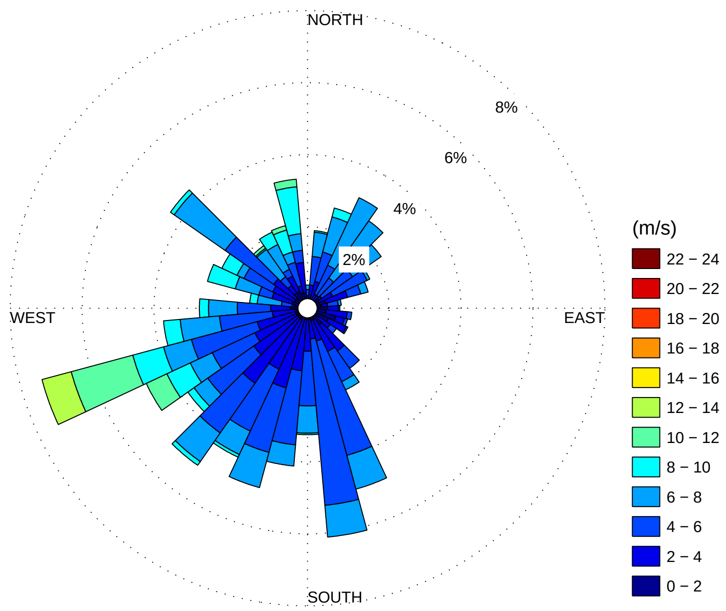


Figure 1.295: July 2010 Wind Rose

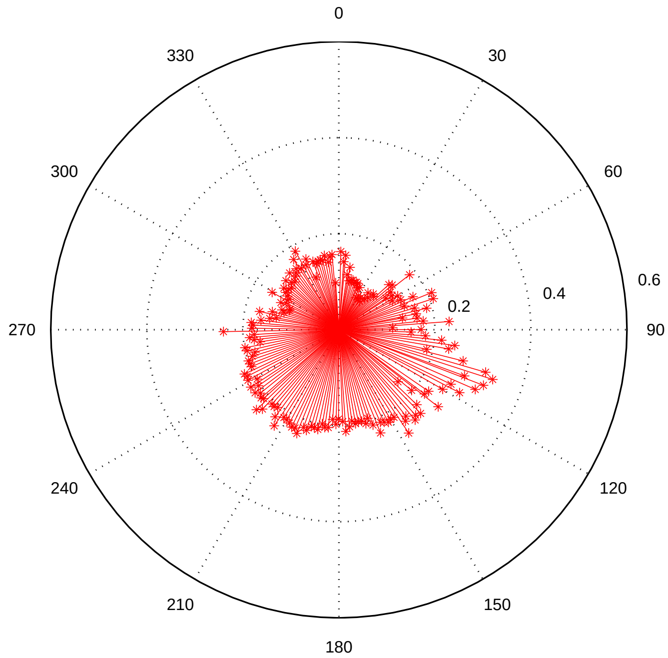


Figure 1.296: July 2010 turbulence intensity

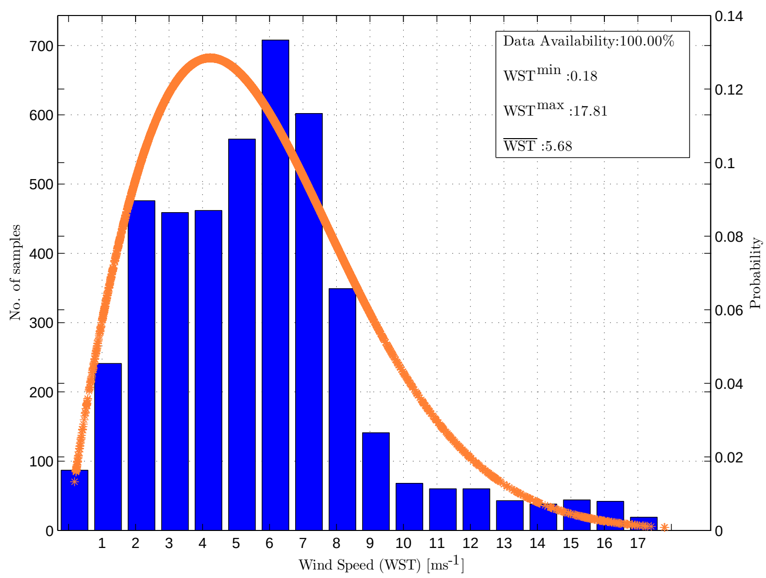


Figure 1.297: August 2010 probability distribution function

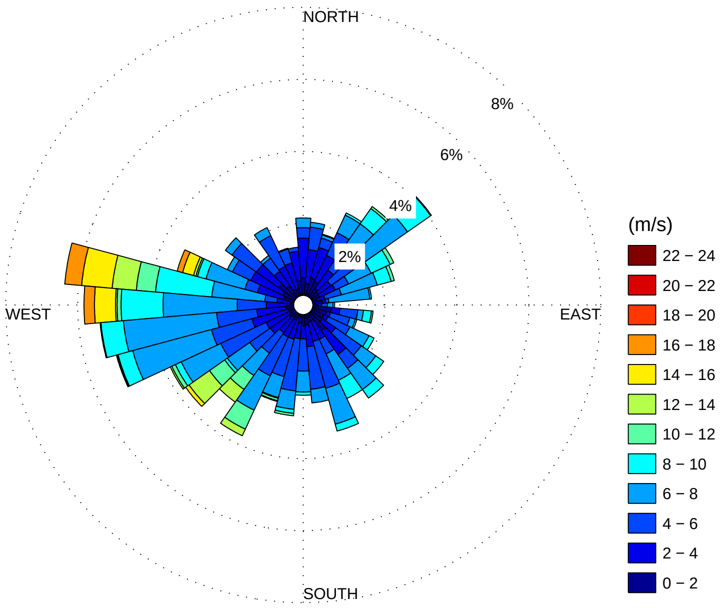


Figure 1.298: August 2010 Wind Rose

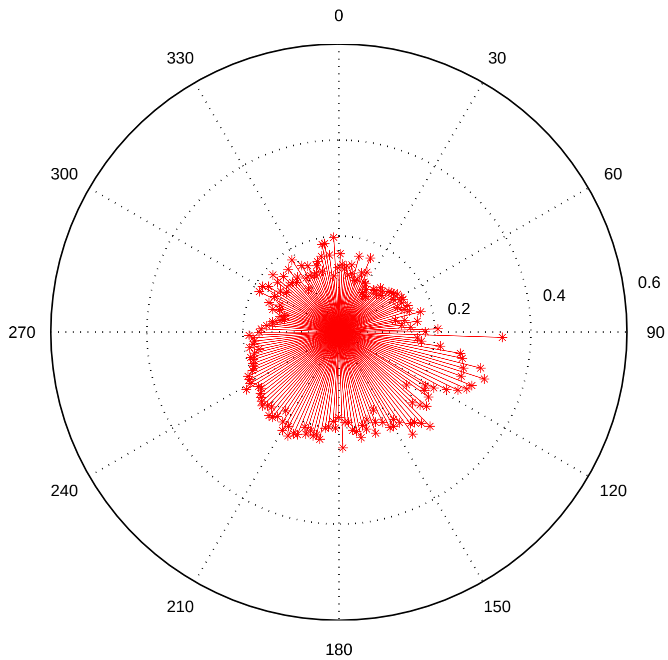


Figure 1.299: August 2010 turbulence intensity

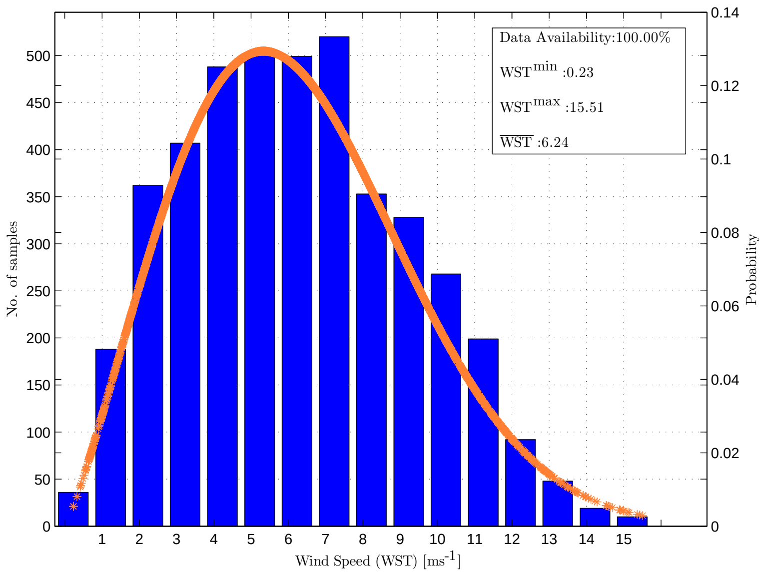


Figure 1.300: September 2010 probability distribution function

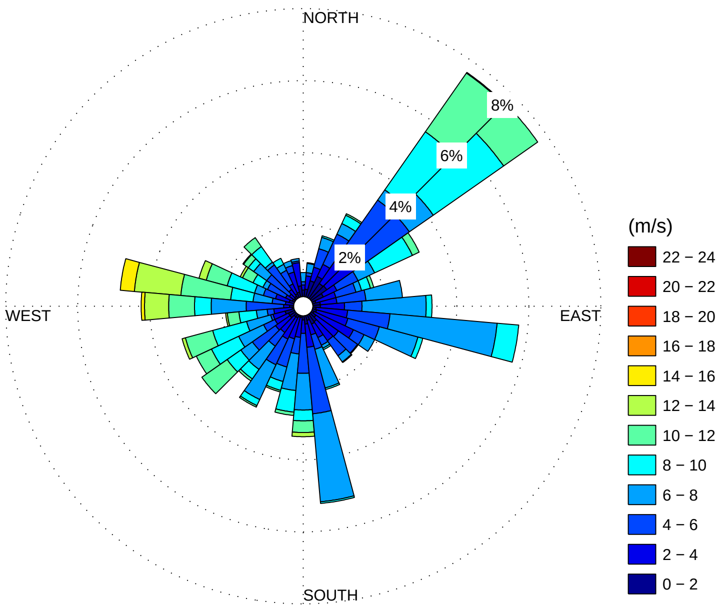


Figure 1.301: September 2010 Wind Rose

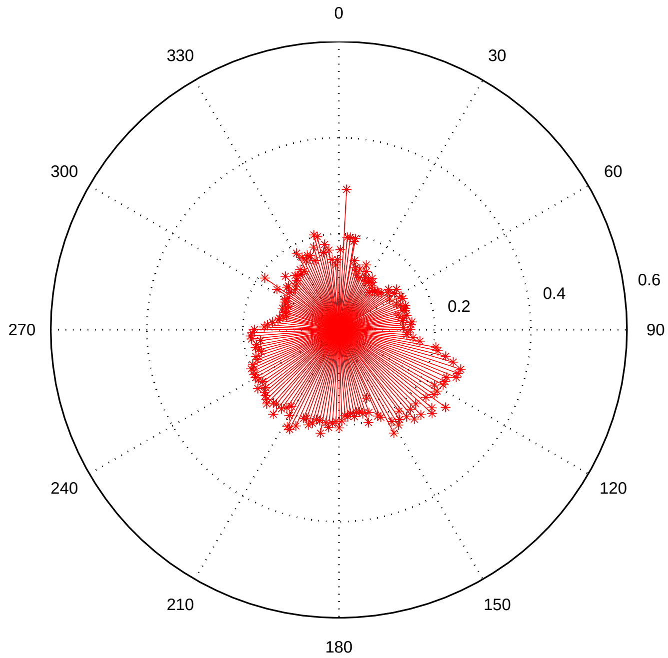


Figure 1.302: September 2010 turbulence intensity

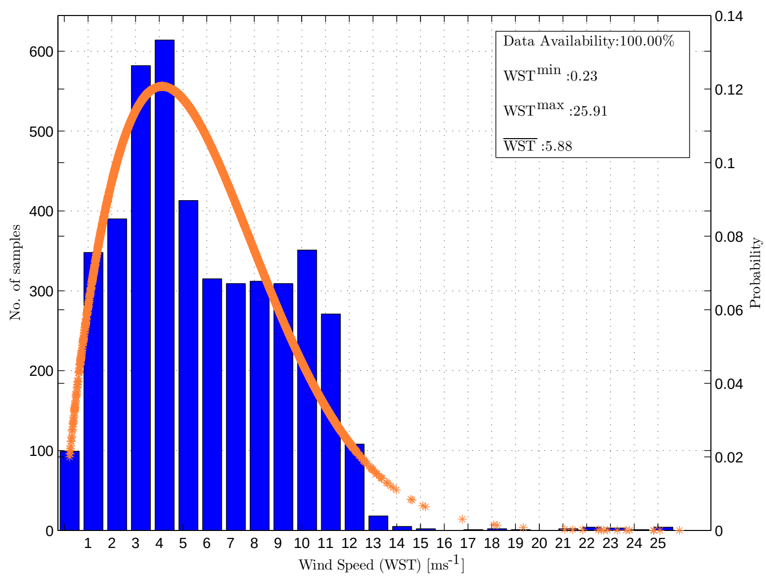


Figure 1.303: October 2010 probability distribution function

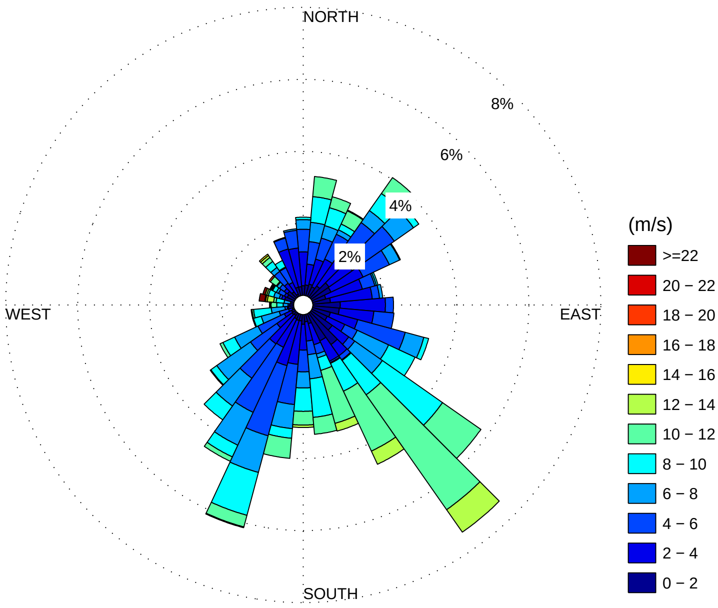


Figure 1.304: October 2010 Wind Rose

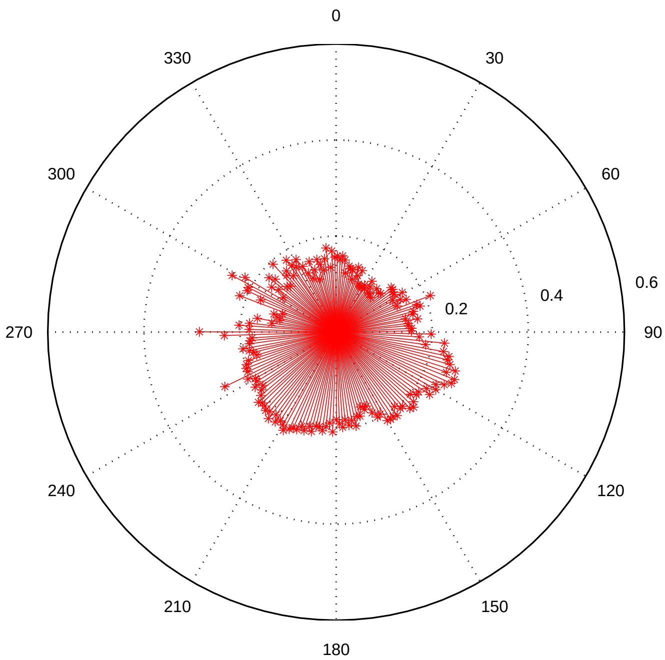


Figure 1.305: October 2010 turbulence intensity

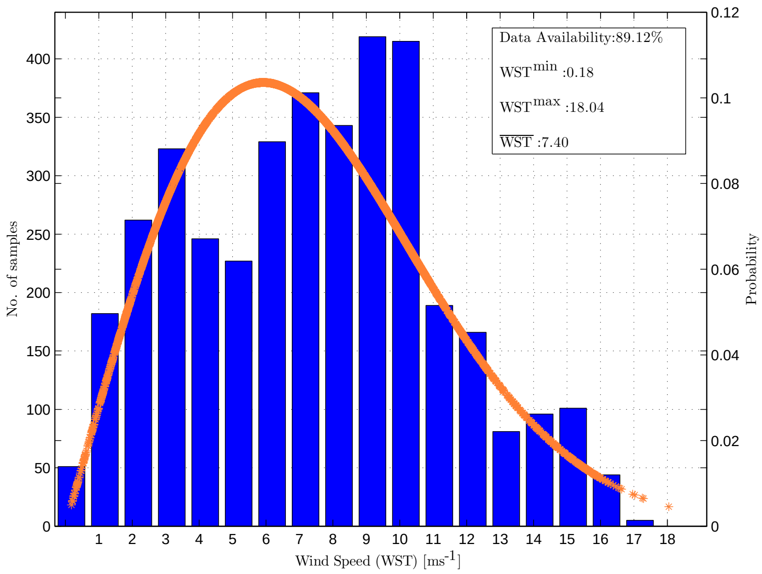


Figure 1.306: November 2010 probability distribution function

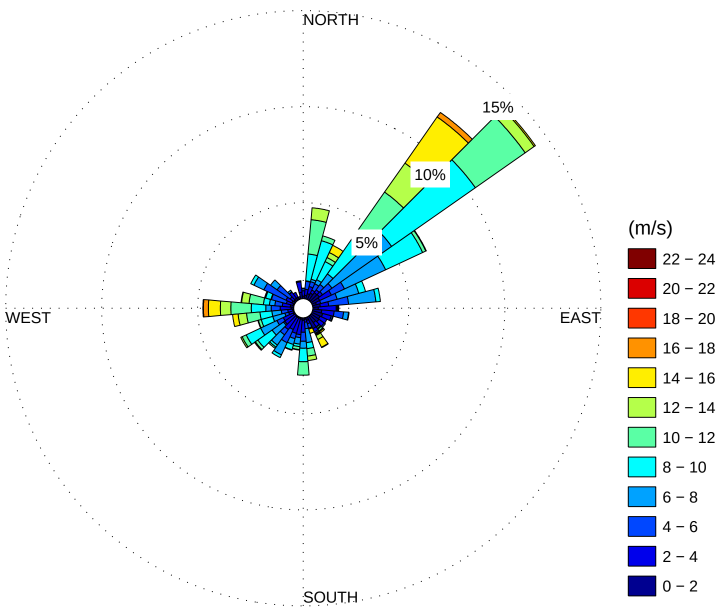


Figure 1.307: November 2010 Wind Rose

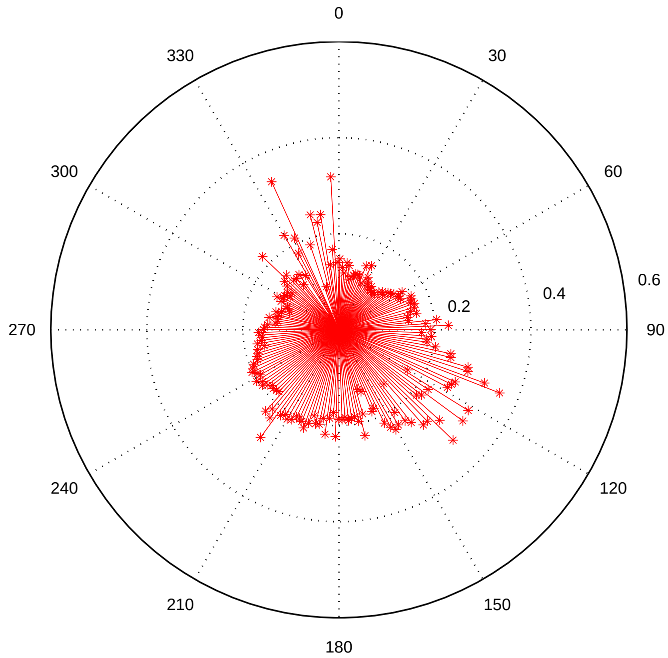


Figure 1.308: November 2010 turbulence intensity

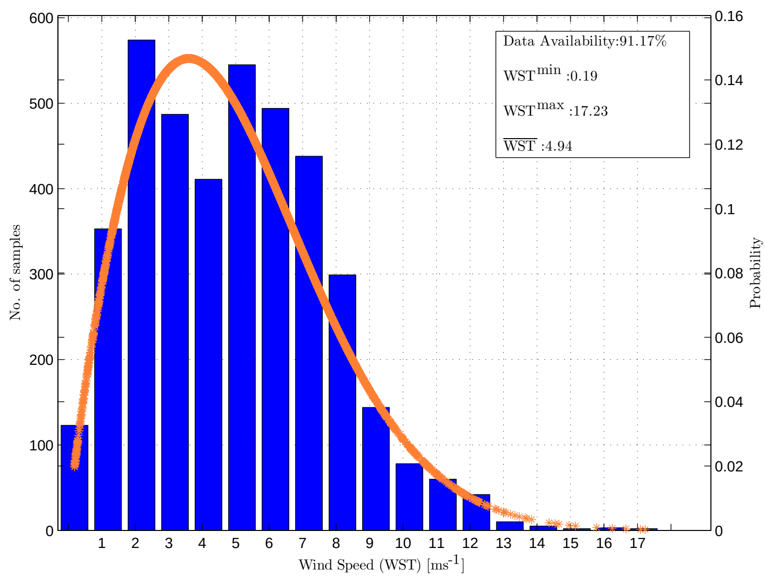


Figure 1.309: December 2010 probability distribution function

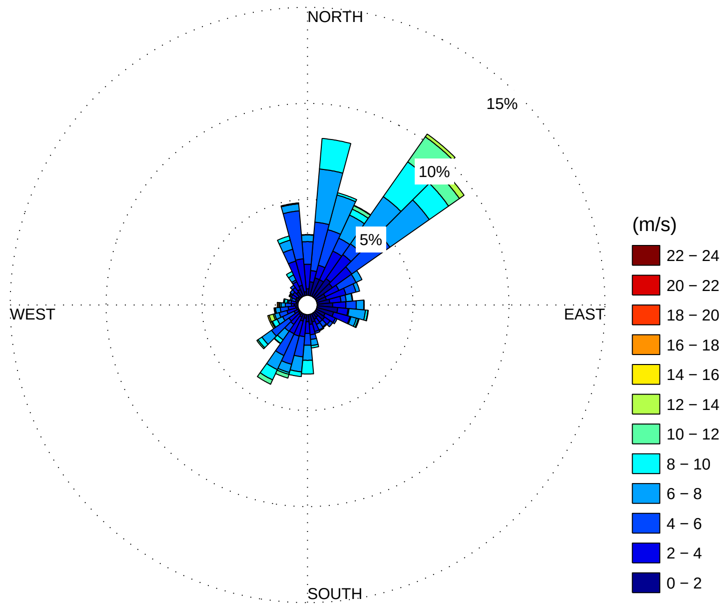


Figure 1.310: December 2010 Wind Rose

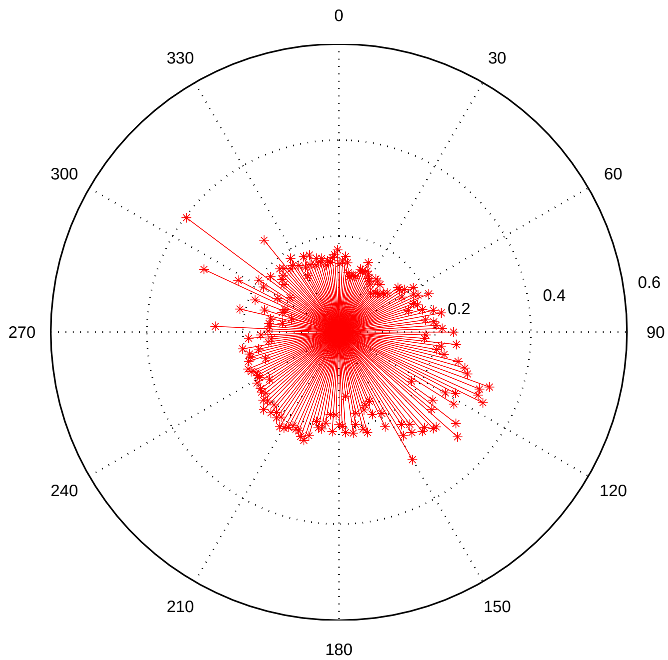


Figure 1.311: December 2010 turbulence intensity

1.9.4 2011 Annual Statistics

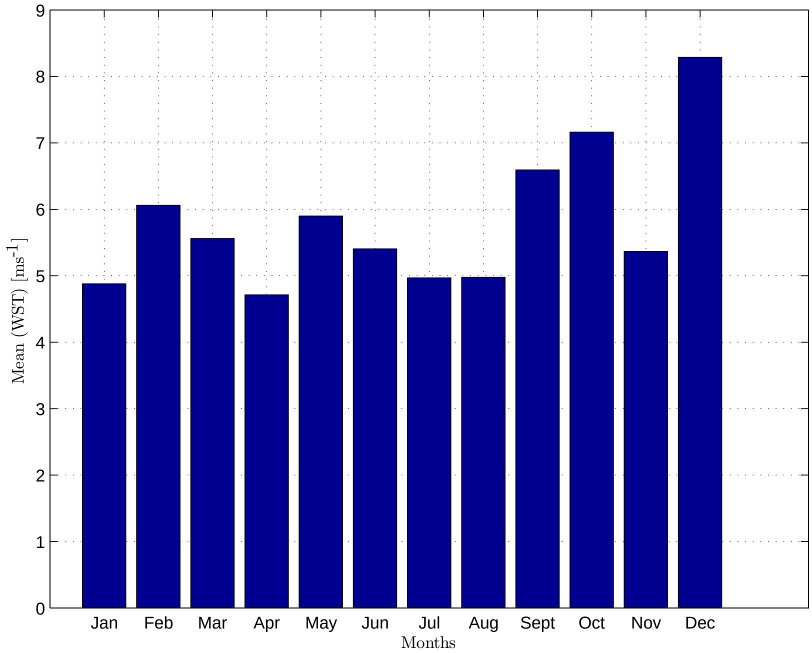


Figure 1.312: Annual wind speed distribution of WST, 2011

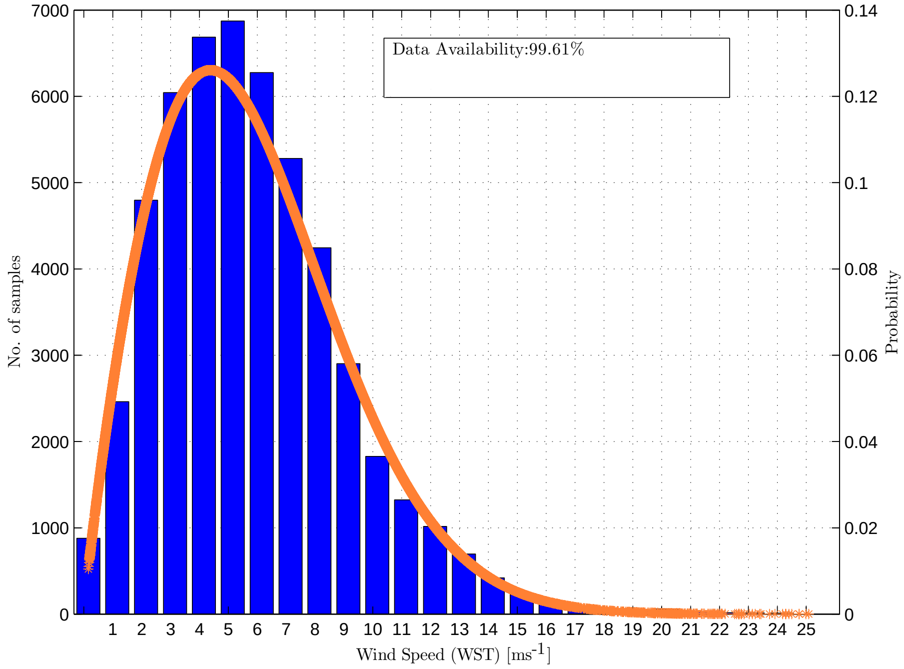


Figure 1.313: Annual wind speed distribution of WST, 2011

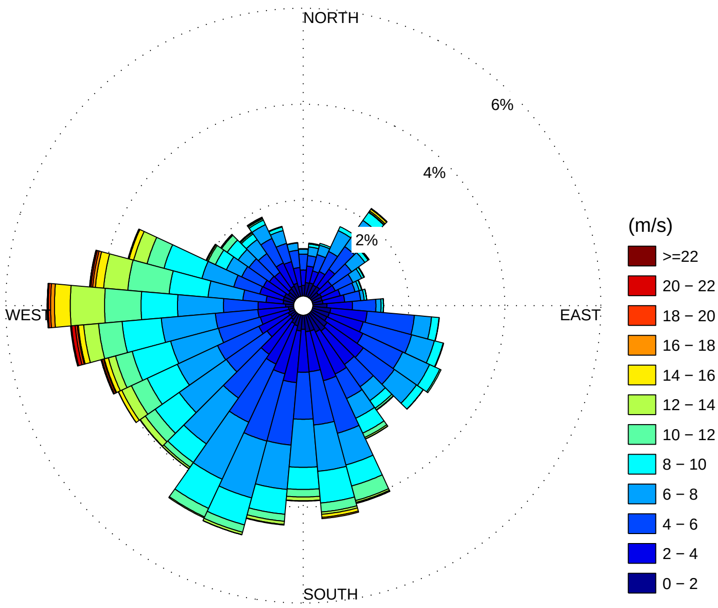


Figure 1.314: Annual wind rose of WST, 2011

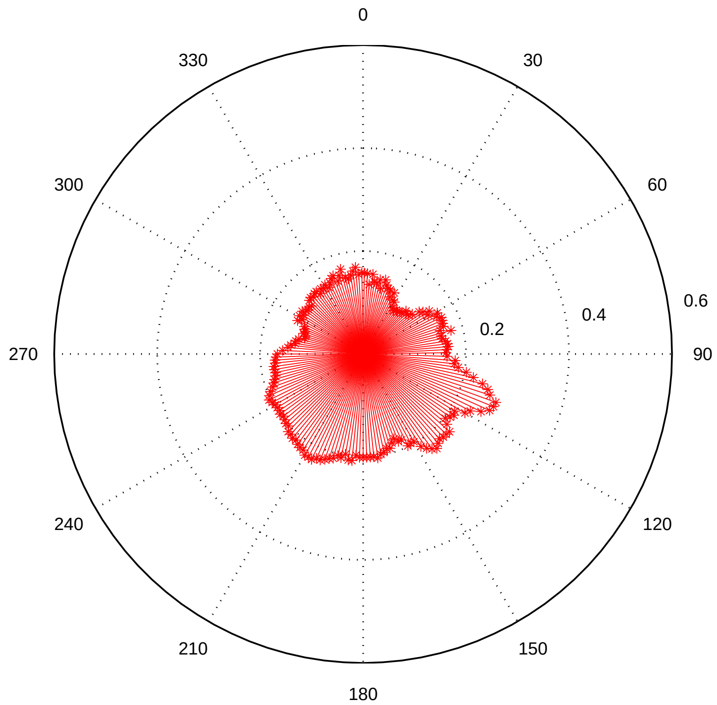


Figure 1.315: Turbulence intensity of WST, 2011

Table 1.27: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2011

Month	Min	Mean	Max
January	0.05	4.88	21.76
February	0.06	6.06	26.26
March	0.06	5.56	21.26
April	0.07	4.71	23.43
May	0.08	5.90	23.78
June	0.10	5.40	20.60
July	0.09	4.97	21.52
August	0.08	4.98	19.06
September	0.09	6.59	24.69
October	0.08	7.16	25.99
November	0.06	5.37	35.36
December	0.20	8.29	34.96

Table 1.28: Monthly wind speed [ms-1] parameters of 10 min. averaged data, 2011

Month	Data Availability(%)	Min	Mean	Max	K	C
January	100.00	0.15	4.88	15.96	1.63	5.40
February	100.00	0.20	6.06	18.86	1.94	6.81
March	100.00	0.19	5.56	15.17	1.99	6.24
April	100.00	0.21	4.71	17.04	1.69	5.29
May	100.00	0.44	5.90	16.20	2.39	6.66
June	100.00	0.23	5.40	14.10	2.06	6.11
July	99.84	0.24	4.97	12.57	2.37	5.61
August	100.00	0.21	4.98	13.71	2.04	5.61
September	95.44	0.22	6.59	17.06	2.04	7.45
October	100.00	0.57	7.16	15.82	2.64	8.06
November	100.00	0.20	5.37	25.09	1.60	6.02
December	99.96	0.39	8.29	24.76	2.15	9.36

1.9.4.1 2011 Monthly Statistics

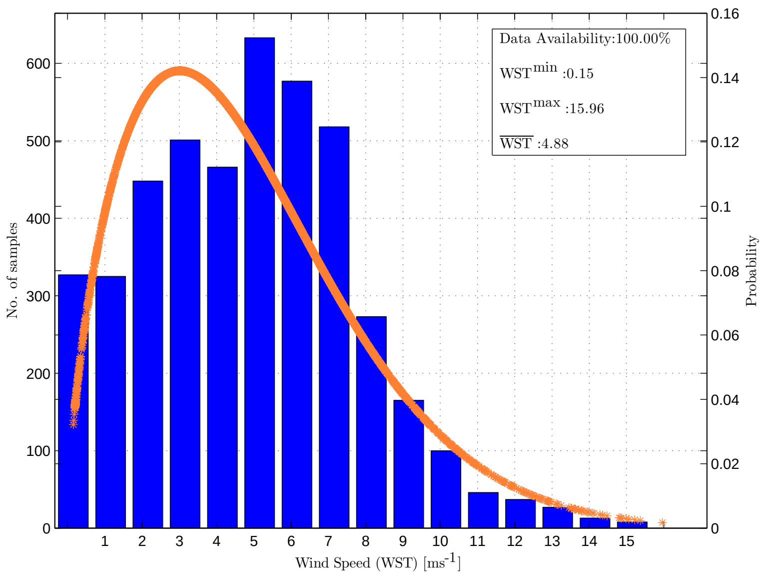


Figure 1.316: January 2011 probability distribution function

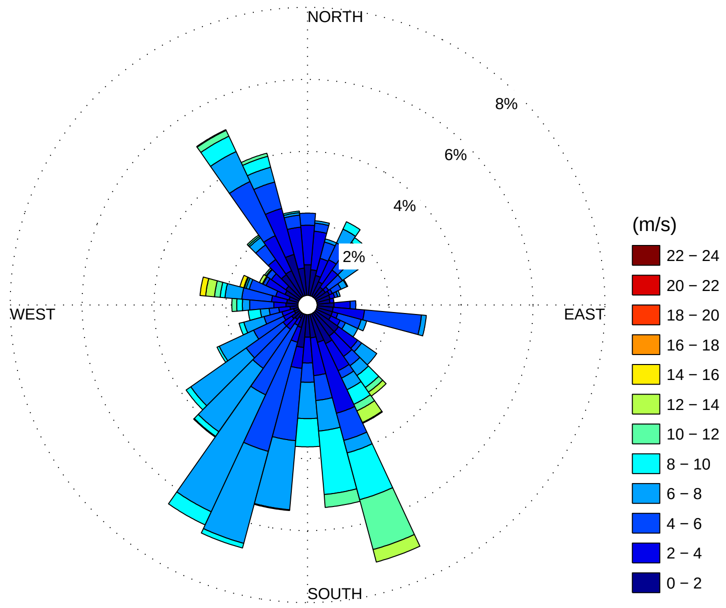


Figure 1.317: January 2011 Wind Rose

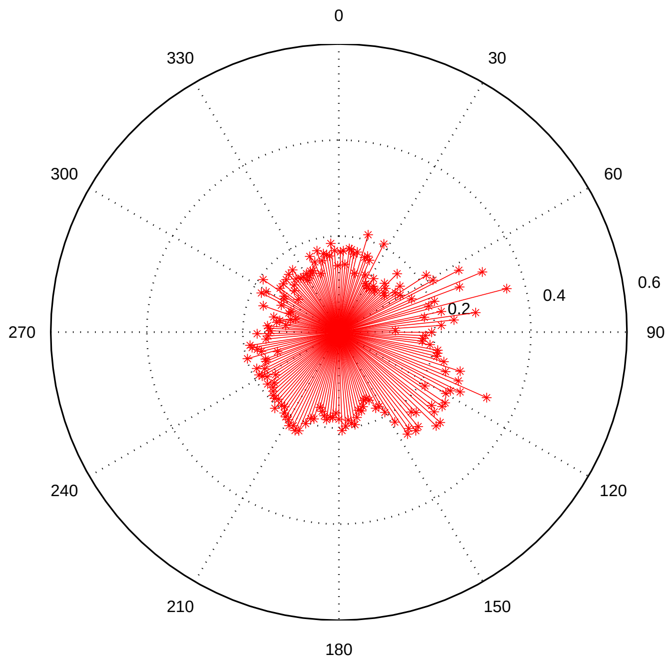


Figure 1.318: January 2011 turbulence intensity

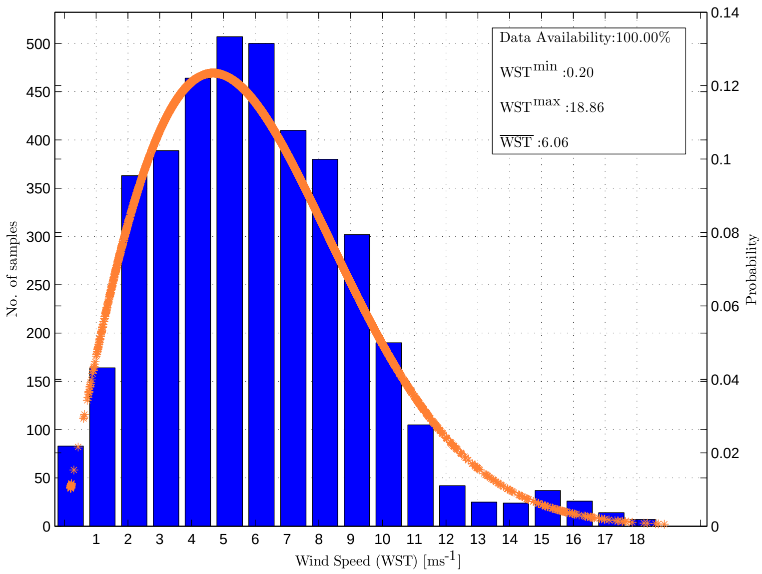


Figure 1.319: February 2011 probability distribution function

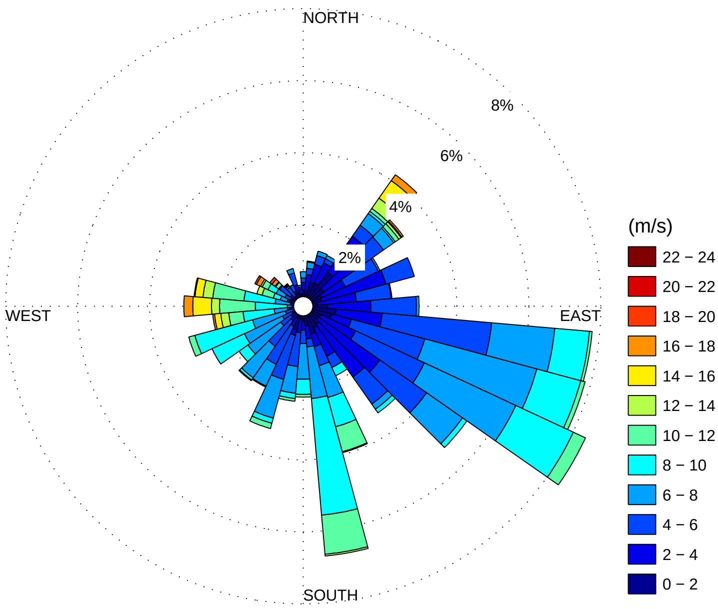


Figure 1.320: February 2011 Wind Rose

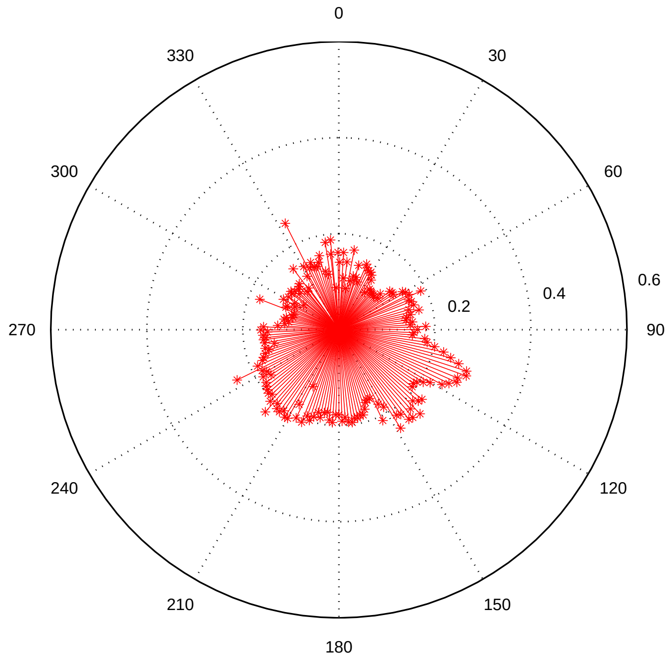


Figure 1.321: February 2011 turbulence intensity

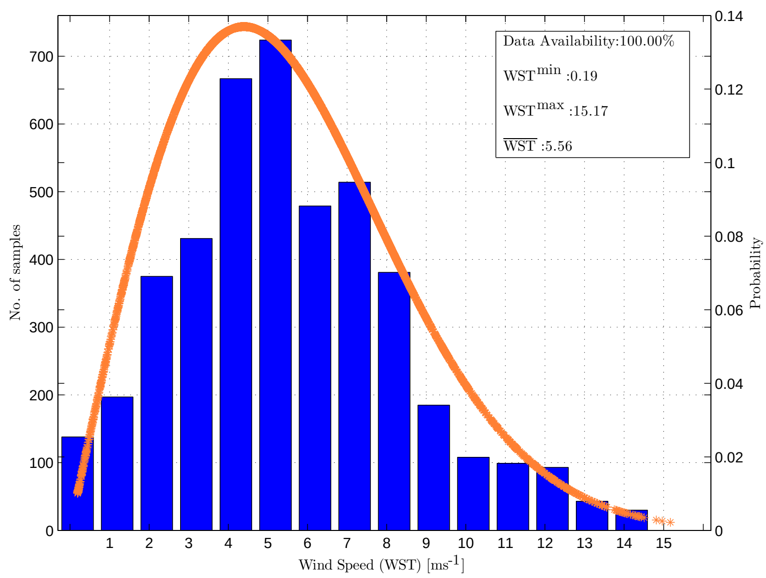


Figure 1.322: March 2011 probability distribution function

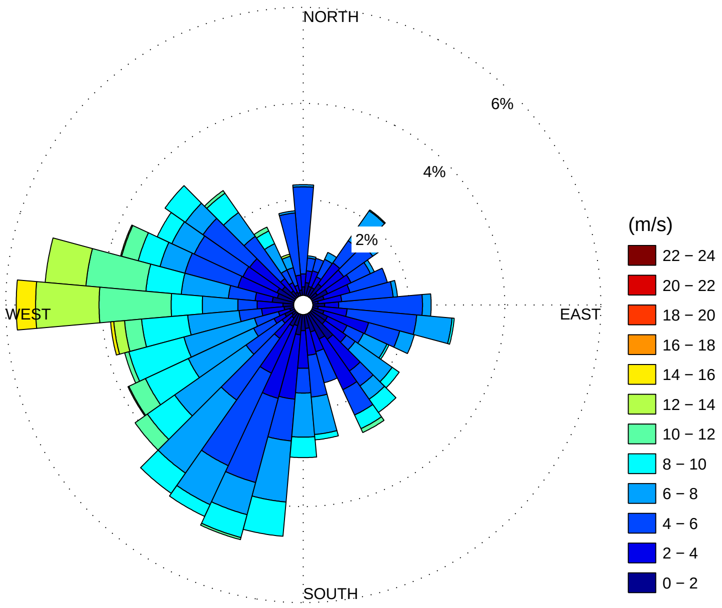


Figure 1.323: March 2011 Wind Rose

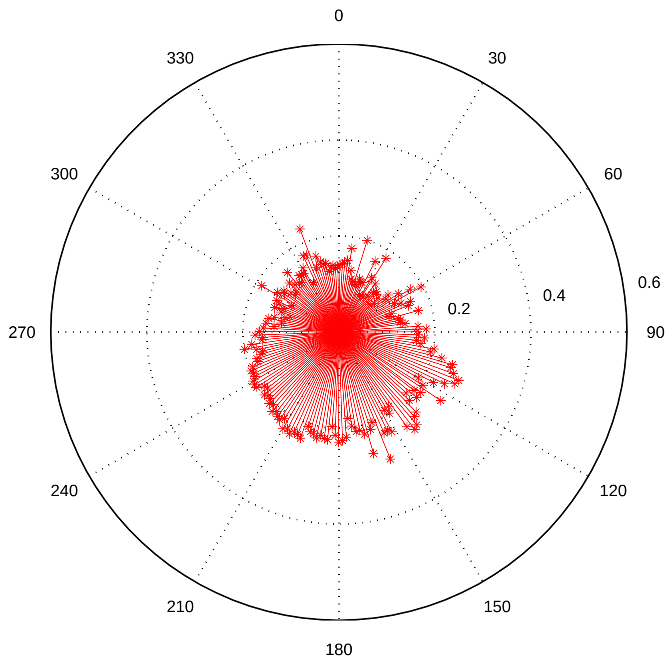


Figure 1.324: March 2011 turbulence intensity

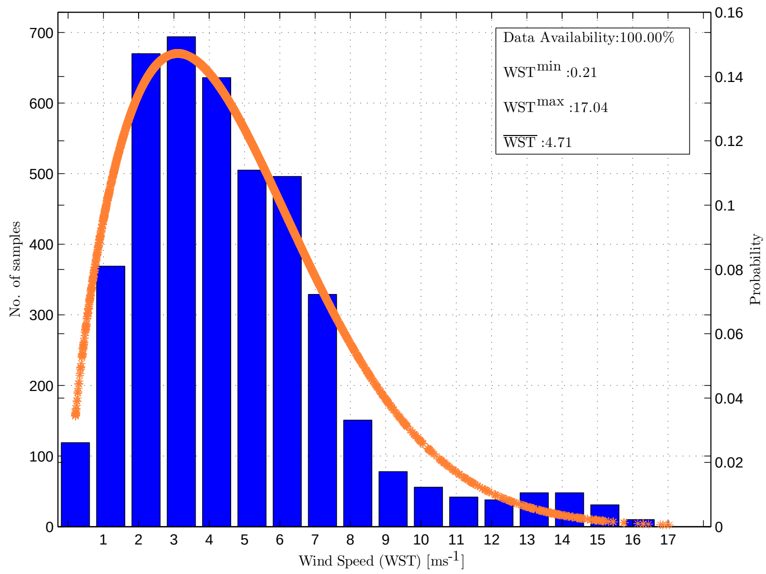


Figure 1.325: April 2011 probability distribution function

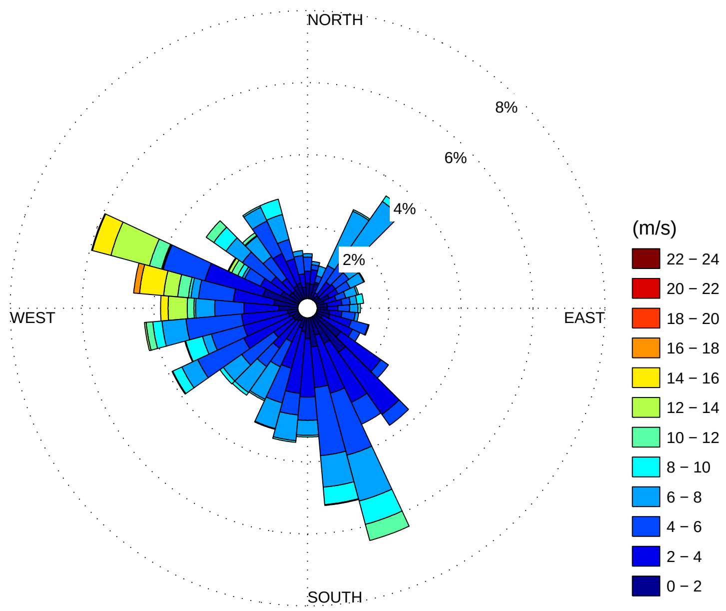


Figure 1.326: April 2011 Wind Rose

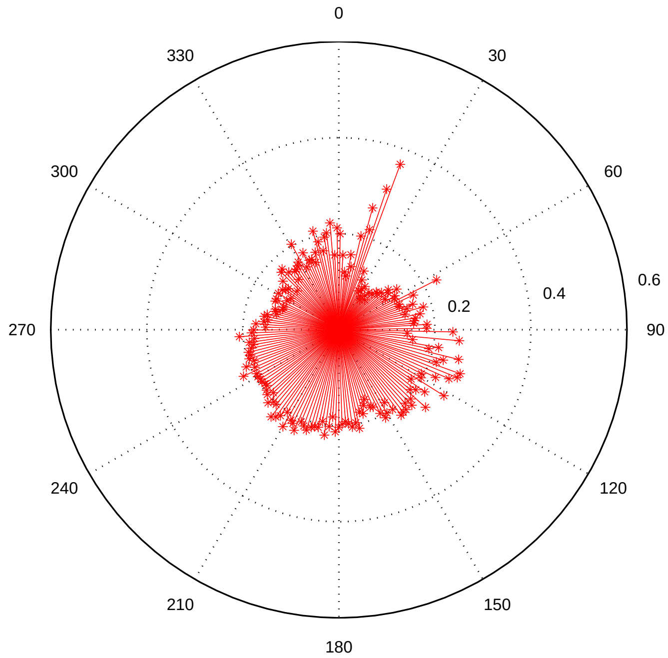


Figure 1.327: April 2011 turbulence intensity

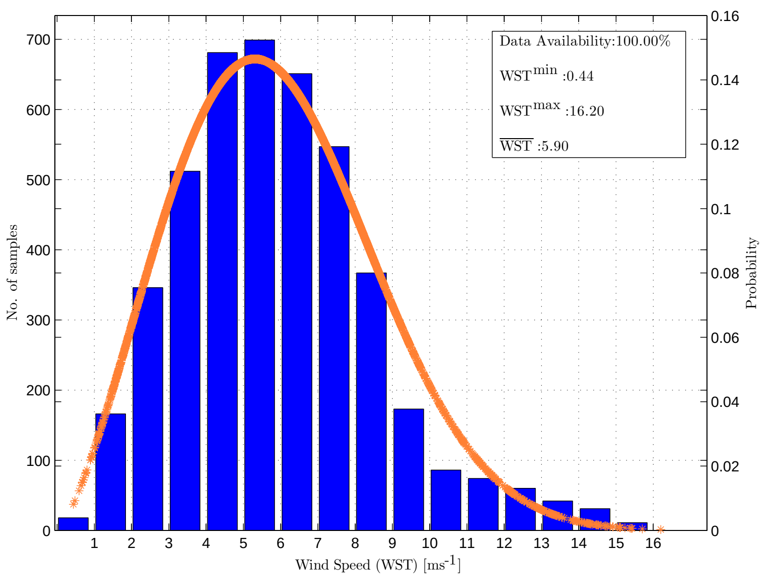


Figure 1.328: May 2011 probability distribution function

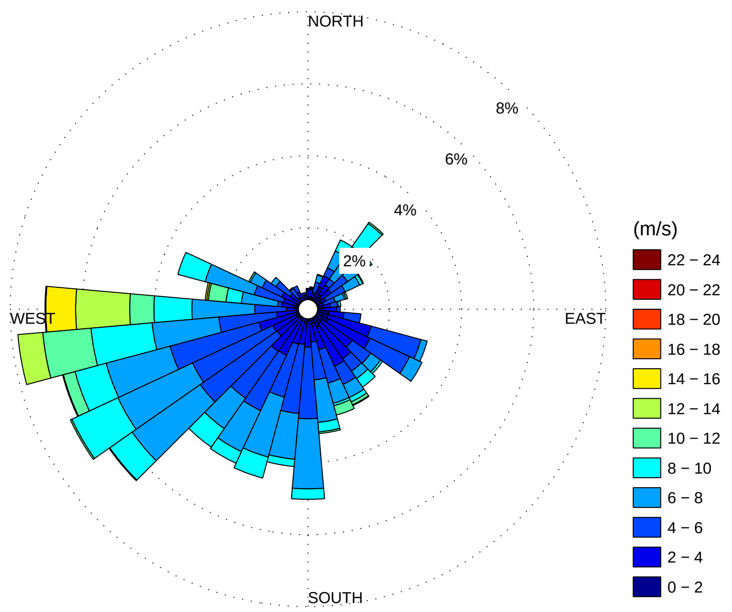


Figure 1.329: May 2011 Wind Rose

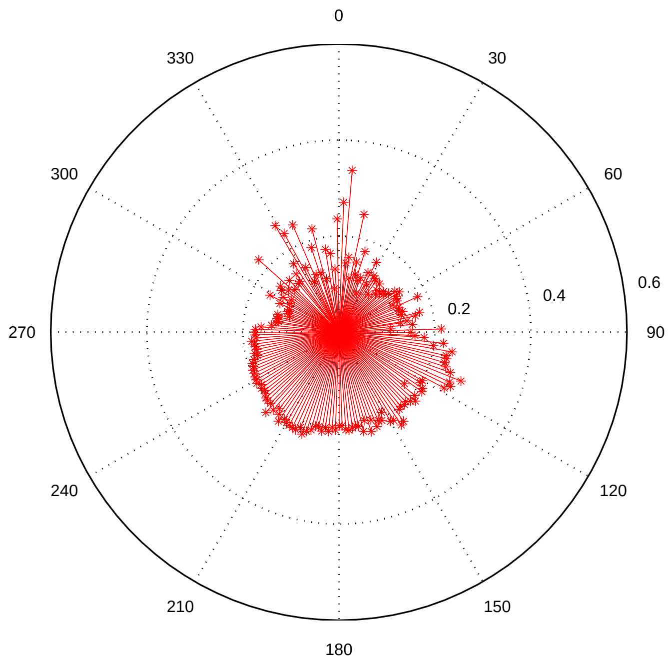


Figure 1.330: May 2011 turbulence intensity

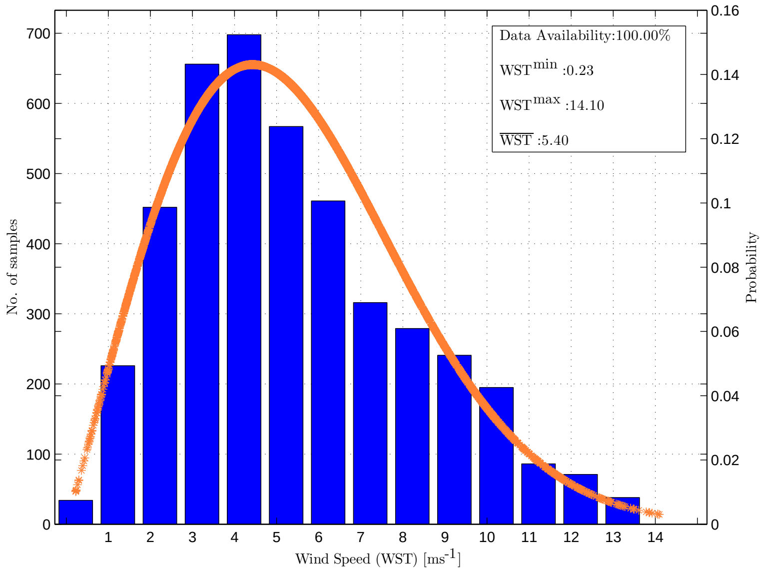


Figure 1.331: June 2011 probability distribution function

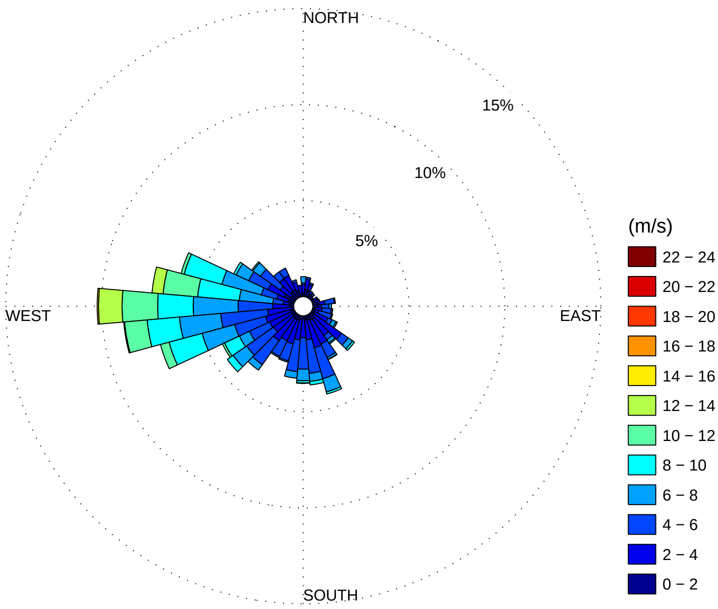


Figure 1.332: June 2011 Wind Rose

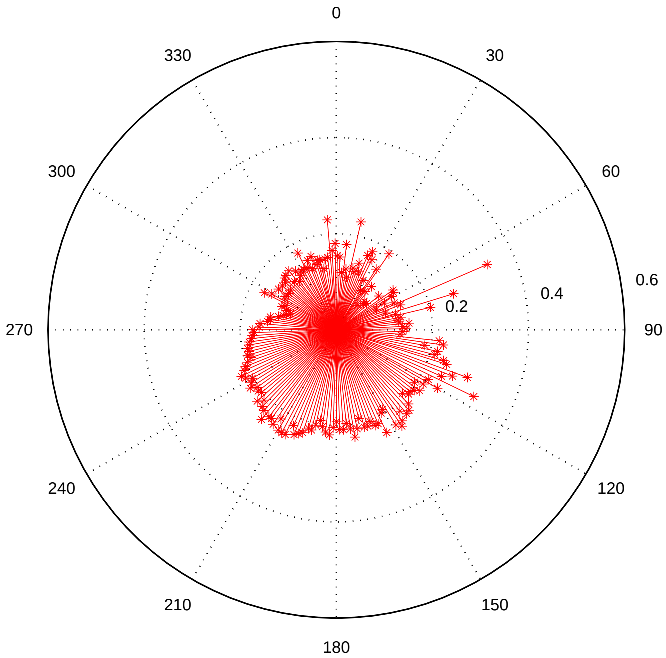


Figure 1.333: June 2011 turbulence intensity

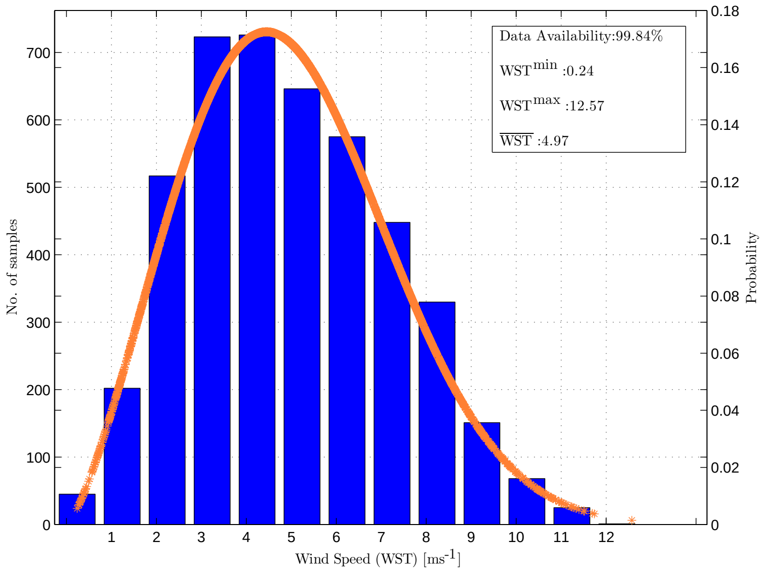


Figure 1.334: July 2011 probability distribution function

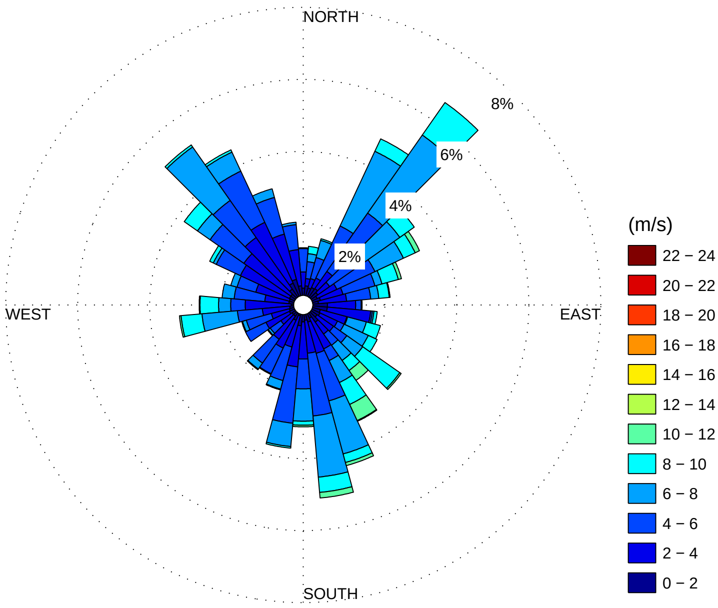


Figure 1.335: July 2011 Wind Rose

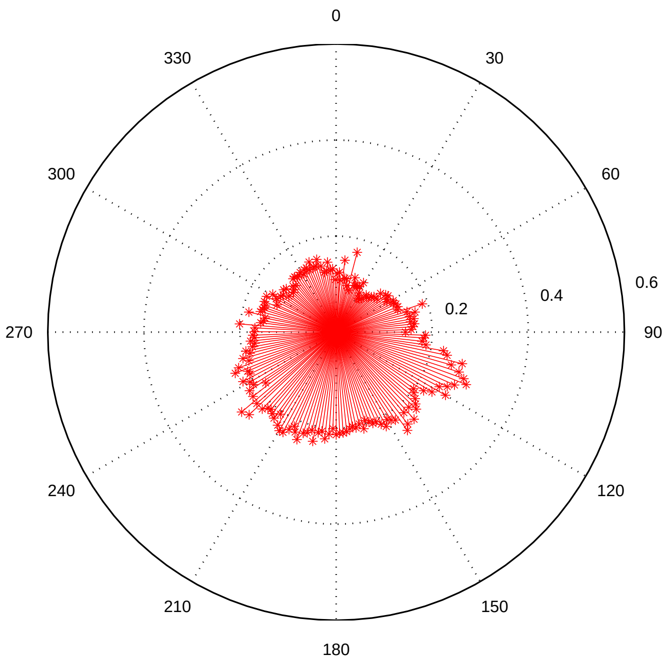


Figure 1.336: July 2011 turbulence intensity

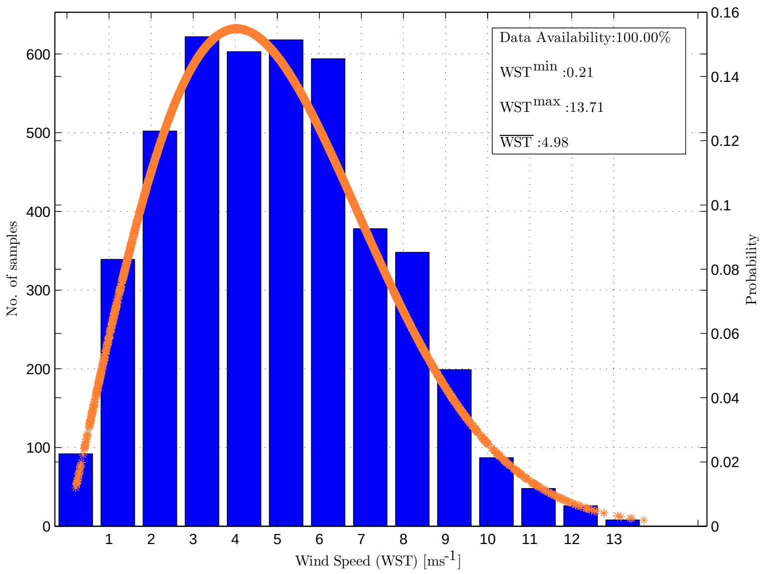


Figure 1.337: August 2011 probability distribution function

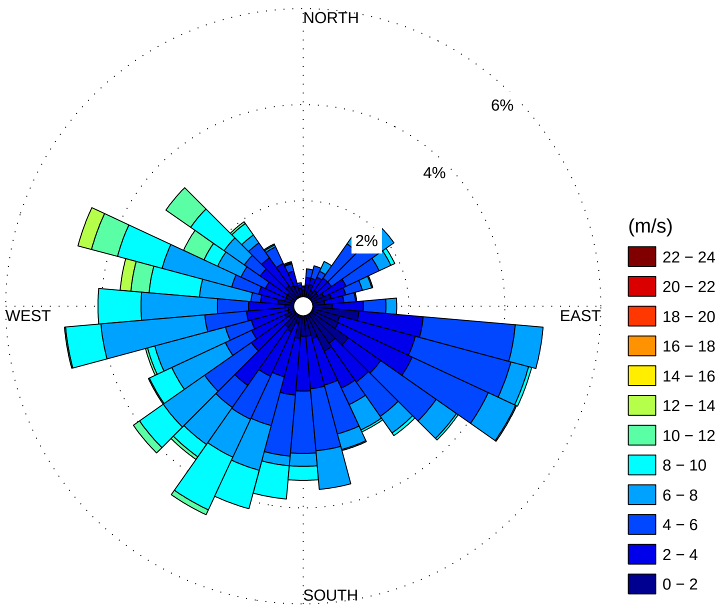


Figure 1.338: August 2011 Wind Rose

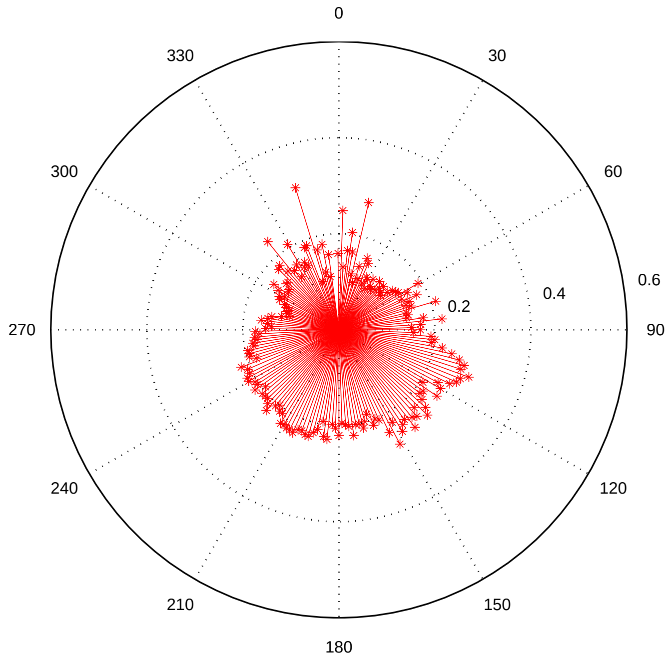


Figure 1.339: August 2011 turbulence intensity

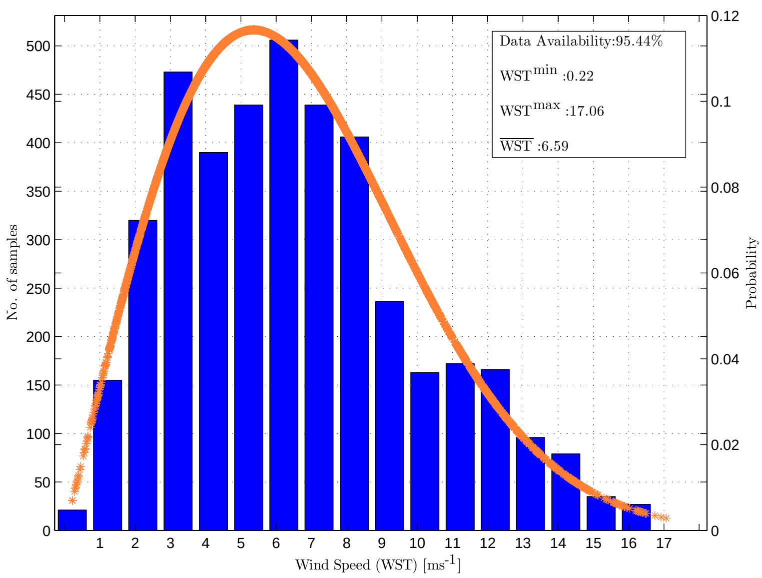


Figure 1.340: September 2011 probability distribution function

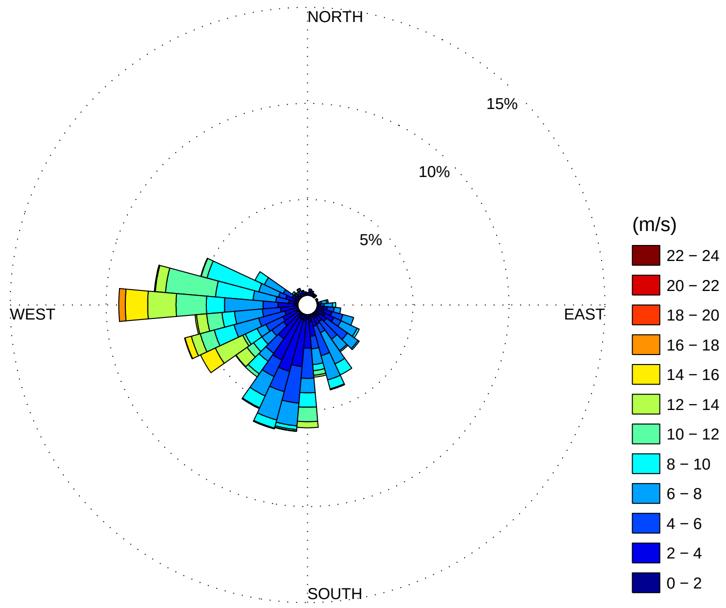


Figure 1.341: September 2011 Wind Rose

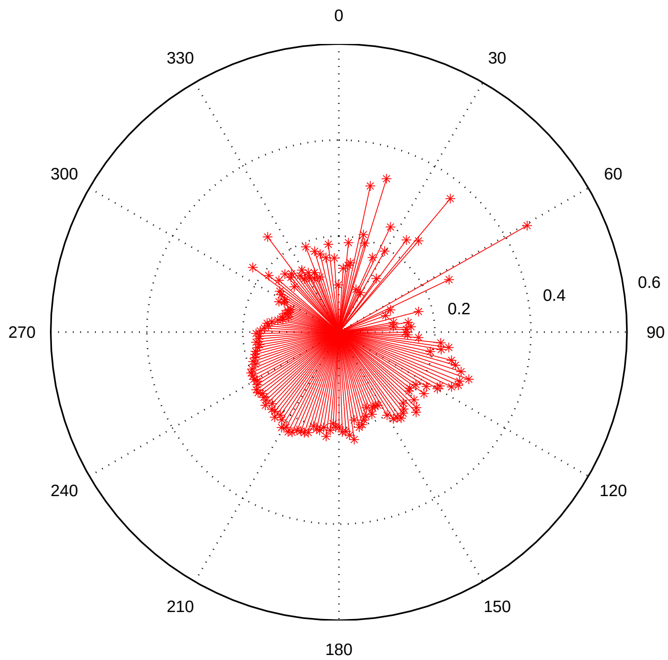


Figure 1.342: September 2011 turbulence intensity

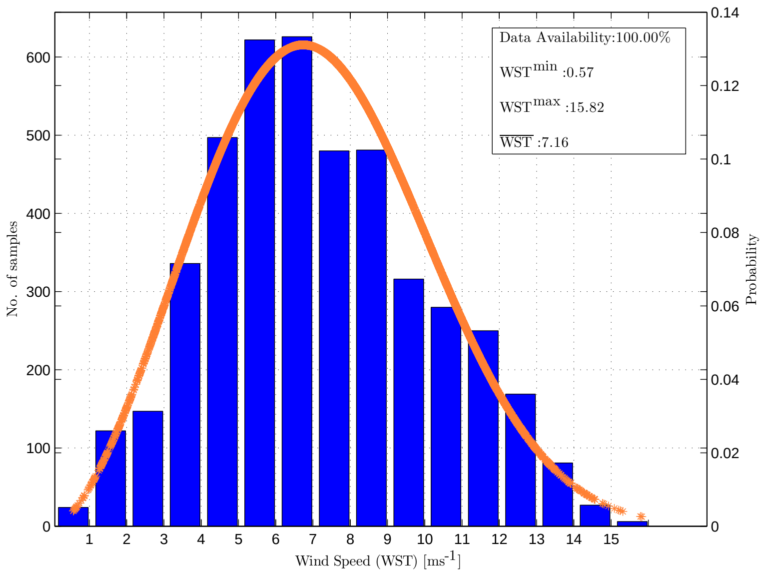


Figure 1.343: October 2011 probability distribution function

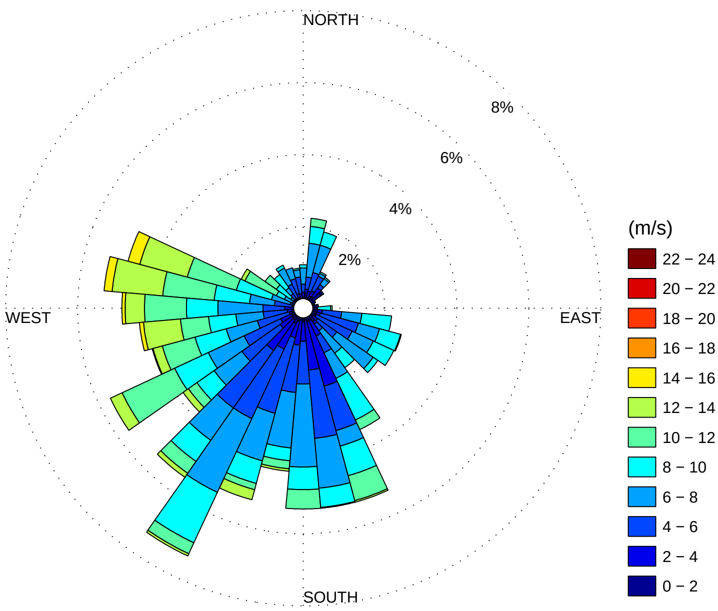


Figure 1.344: October 2011 Wind Rose

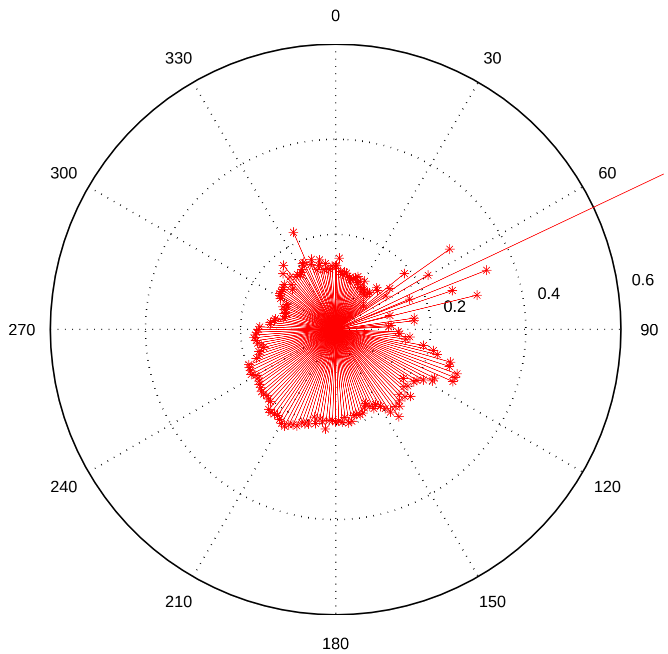


Figure 1.345: October 2011 turbulence intensity

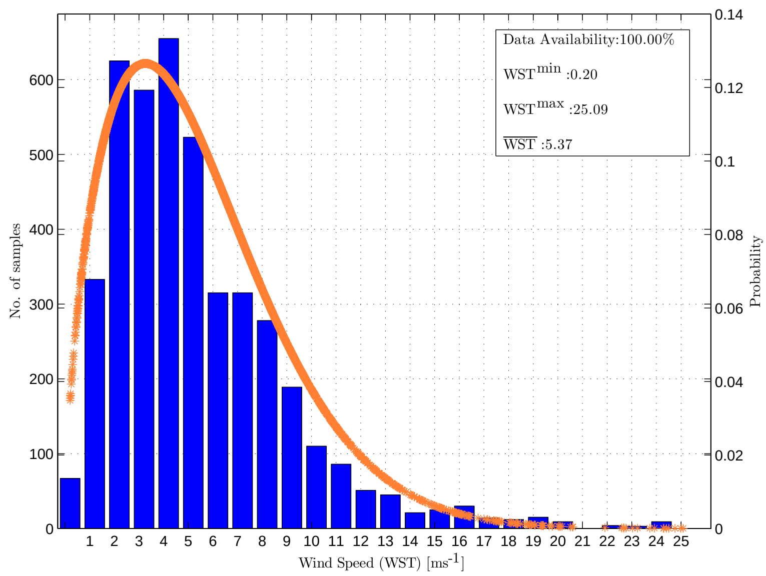


Figure 1.346: November 2011 probability distribution function

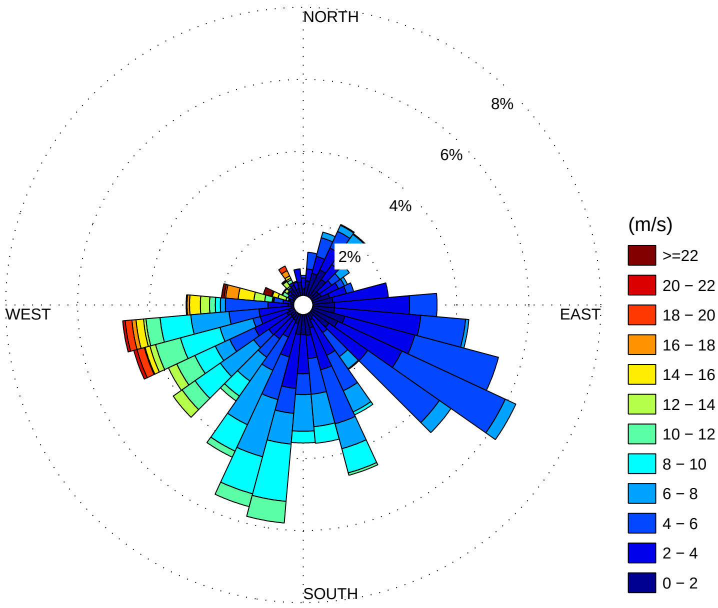


Figure 1.347: November 2011 Wind Rose

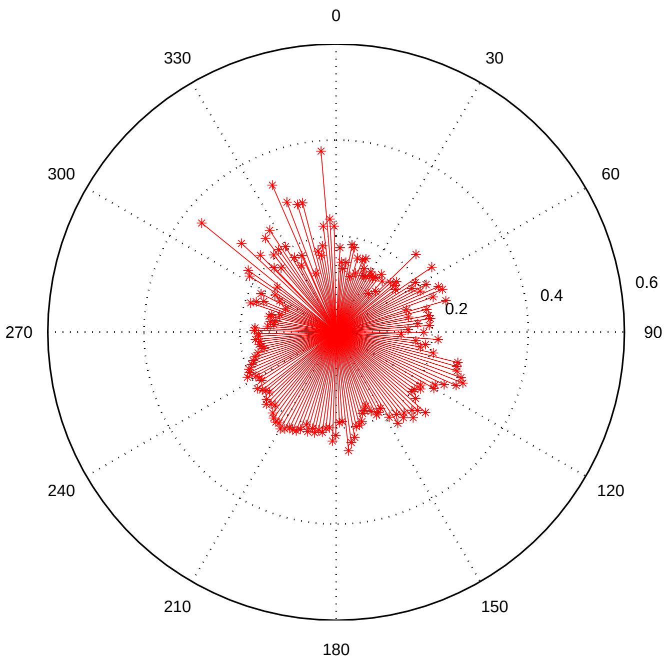


Figure 1.348: November 2011 turbulence intensity

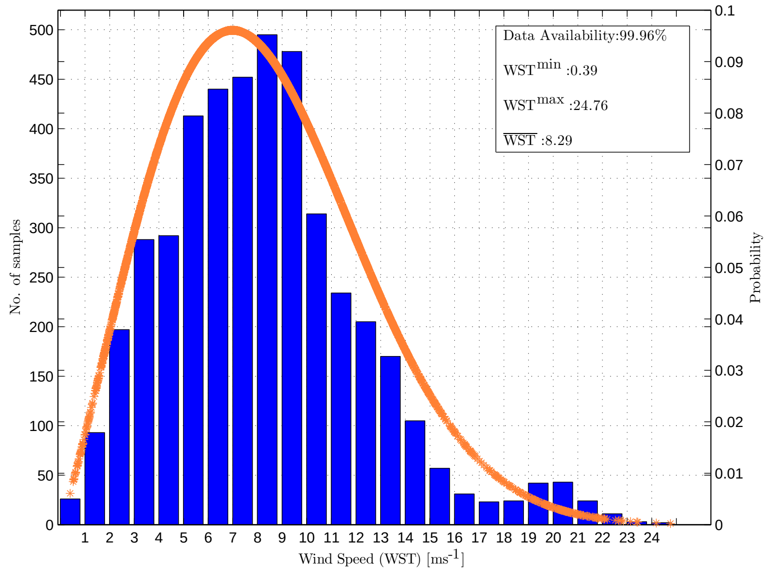


Figure 1.349: December 2011 probability distribution function

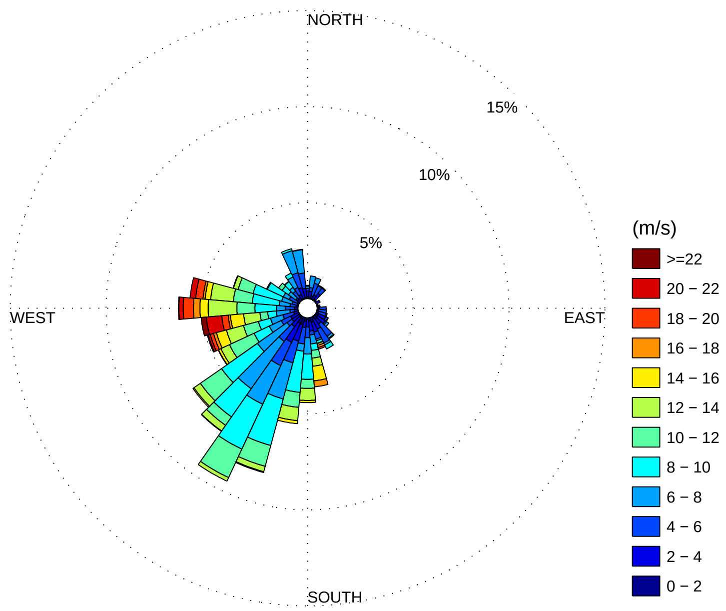


Figure 1.350: December 2011 Wind Rose

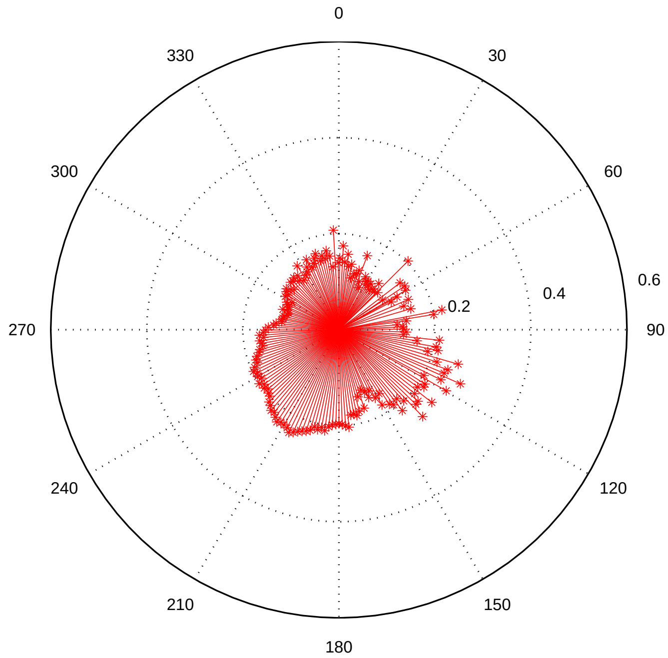


Figure 1.351: December 2011 turbulence intensity

1.9.5 2012 Annual Statistics

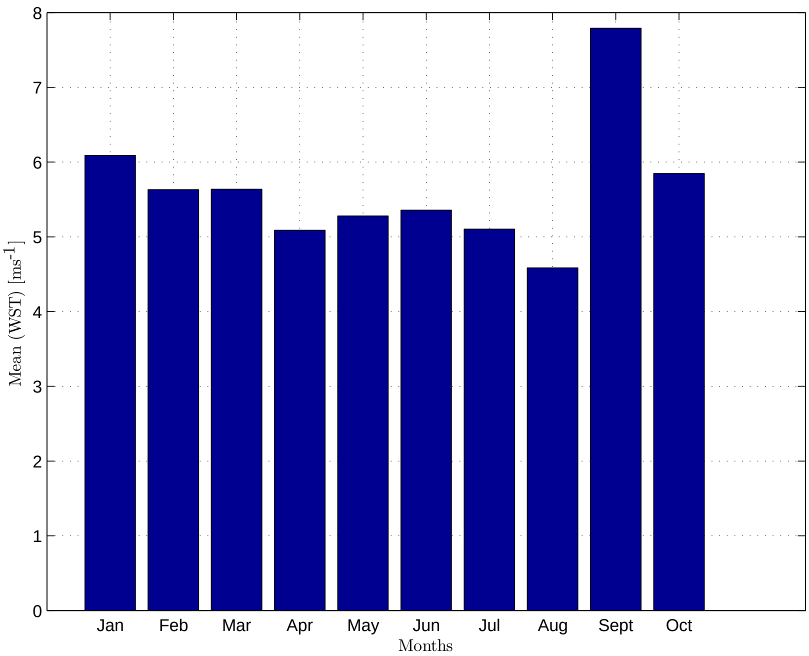


Figure 1.352: Annual wind speed distribution of WST, 2012

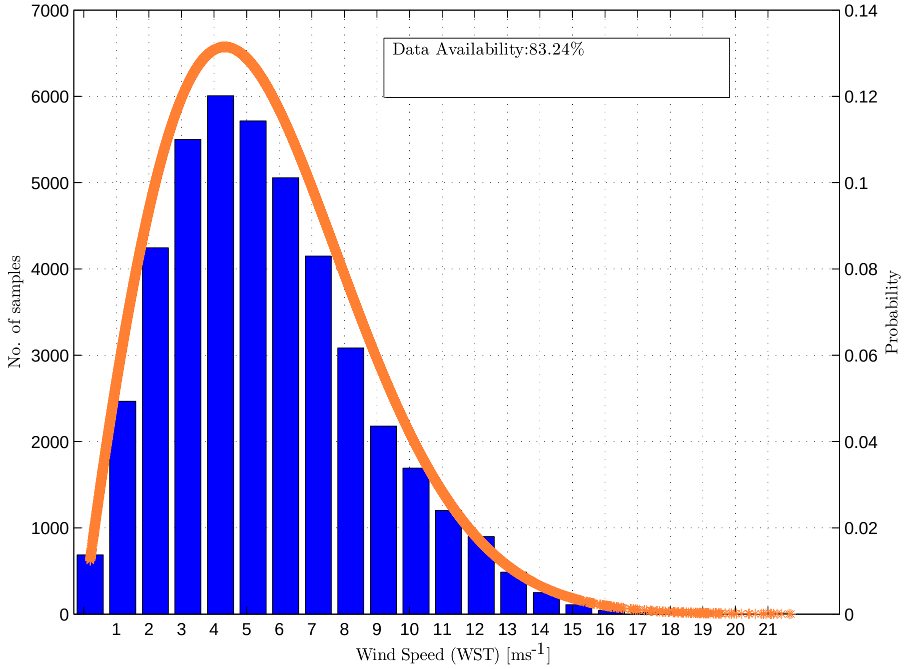


Figure 1.353: Annual wind speed distribution of WST, 2012

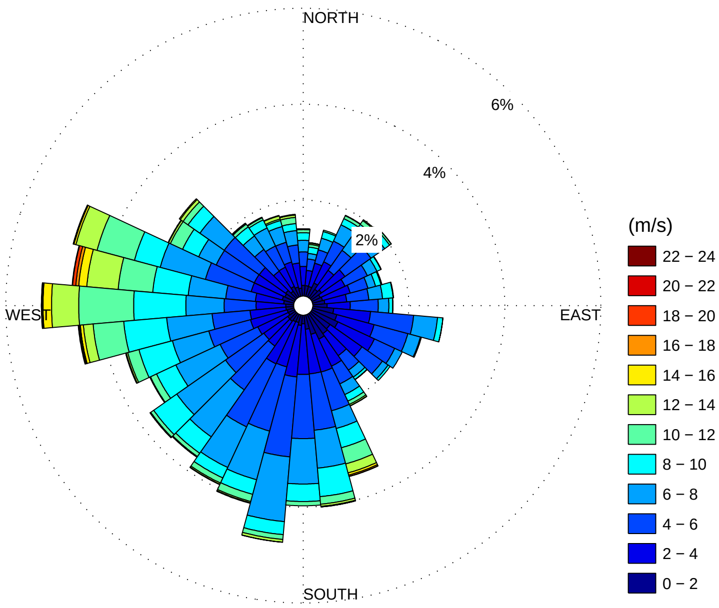


Figure 1.354: Annual wind rose of WST, 2012

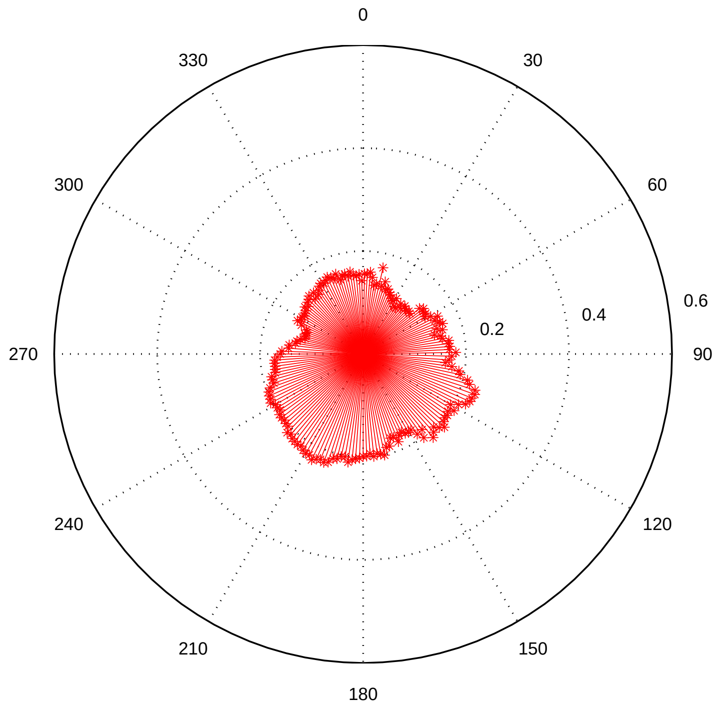


Figure 1.355: Turbulence intensity of WST, 2012

Table 1.29: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2012

Month	Min	Mean	Max
January	0.20	6.09	34.90
February	0.19	5.63	22.86
March	0.21	5.64	22.28
April	0.20	5.09	20.76
May	0.22	5.28	23.09
June	0.22	5.36	19.89
July	0.21	5.10	20.46
August	0.22	4.59	18.78
September	0.19	7.79	21.98
October	0.21	5.85	25.27

Table 1.30: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2012

Month	Data Availability(%)	Min	Mean	Max	K	C
January	99.10	0.20	6.09	21.70	1.72	6.82
February	100.00	0.20	5.63	16.49	1.86	6.33
March	100.00	0.22	5.64	17.66	1.79	6.34
April	100.00	0.22	5.09	16.39	1.96	5.74
May	100.00	0.22	5.28	15.45	1.92	5.95
June	100.00	0.23	5.36	13.77	2.39	6.04
July	100.00	0.23	5.10	15.12	2.08	5.77
August	100.00	0.23	4.59	13.17	1.84	5.18
September	99.75	0.22	7.79	15.51	3.04	8.72
October	100.00	0.23	5.85	18.85	1.85	6.58

1.9.5.1 2012 Monthly Statistics

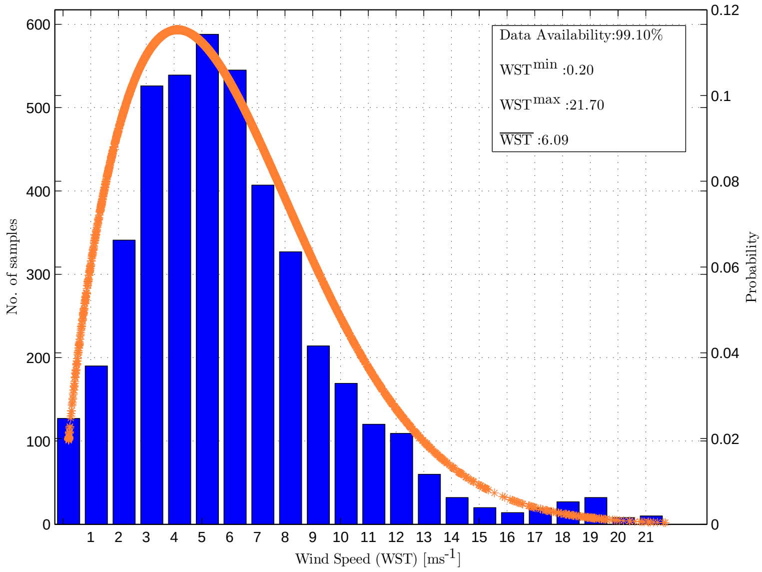


Figure 1.356: January 2012 probability distribution function

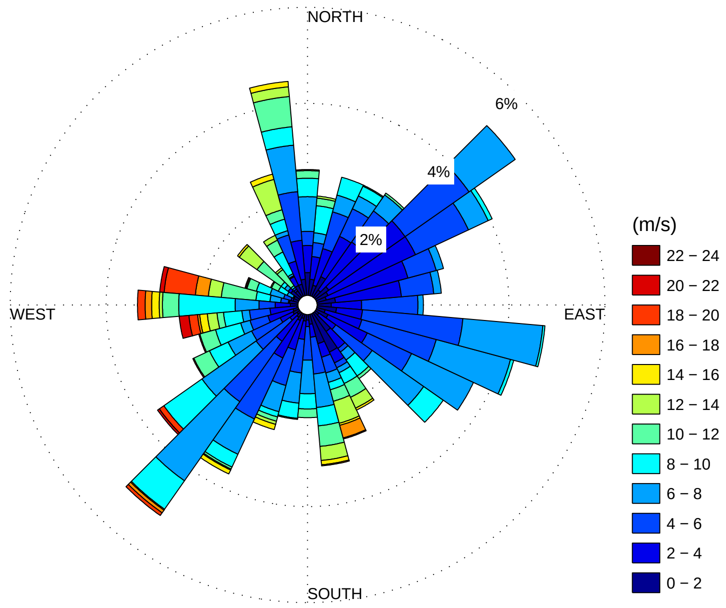


Figure 1.357: January 2012 Wind Rose

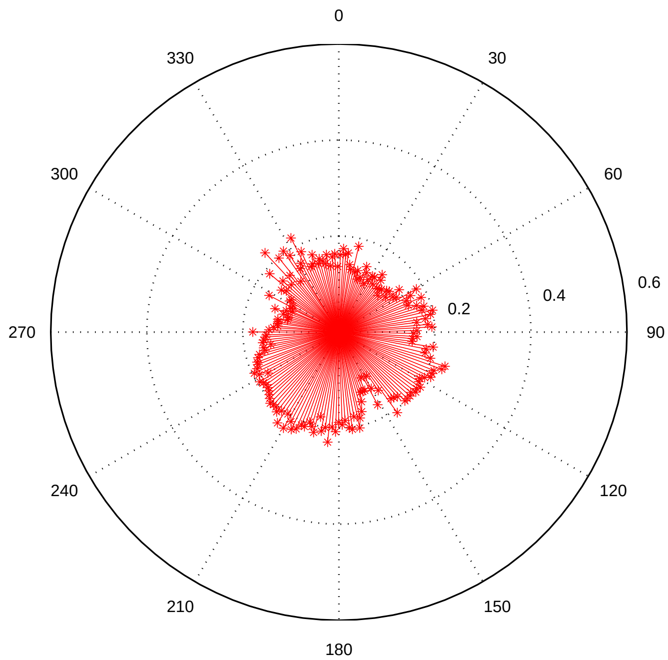


Figure 1.358: January 2012 turbulence intensity

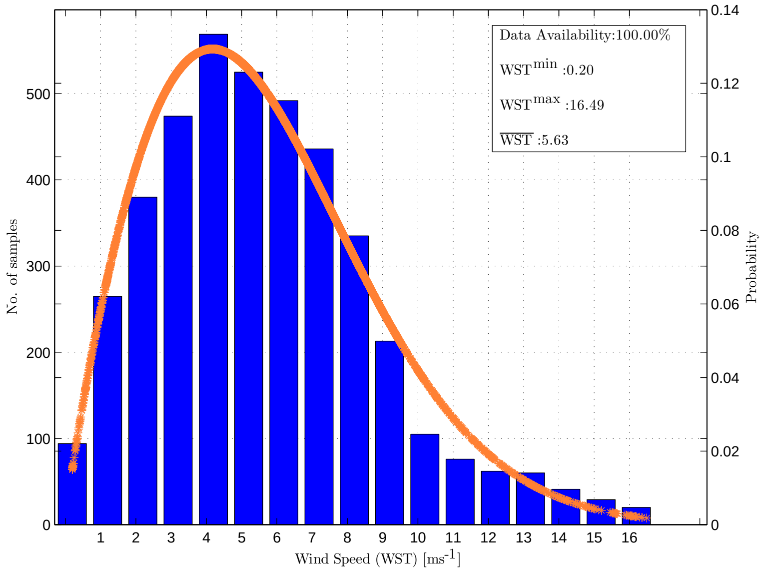


Figure 1.359: February 2012 probability distribution function

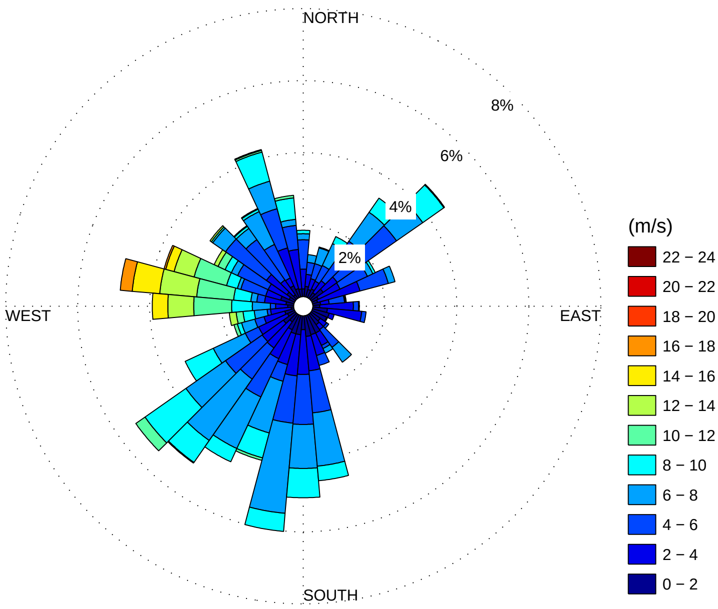


Figure 1.360: February 2012 Wind Rose

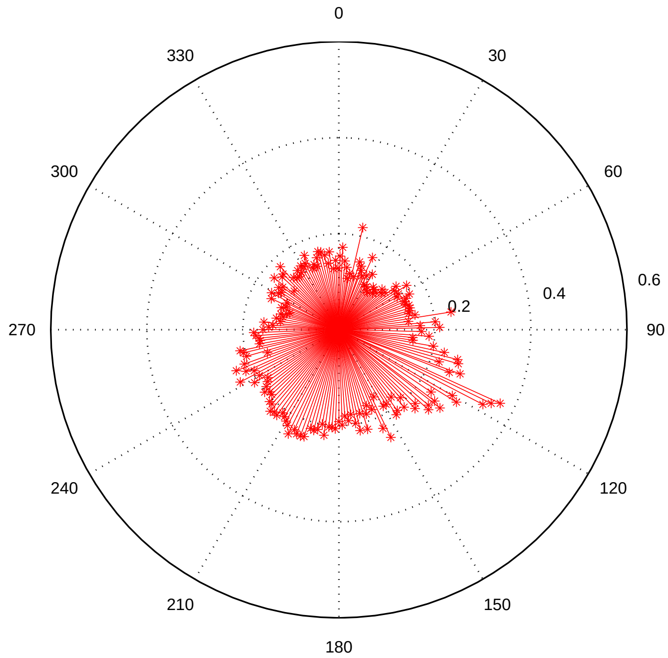


Figure 1.361: February 2012 turbulence intensity

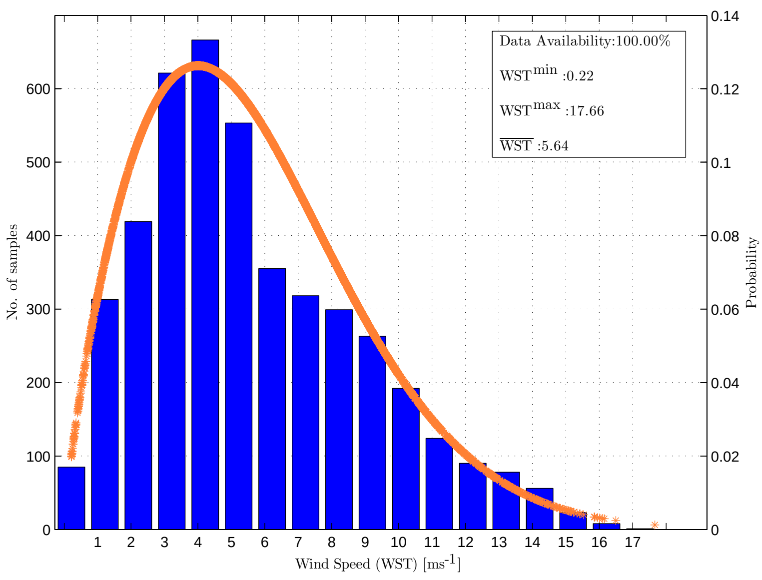


Figure 1.362: March 2012 probability distribution function

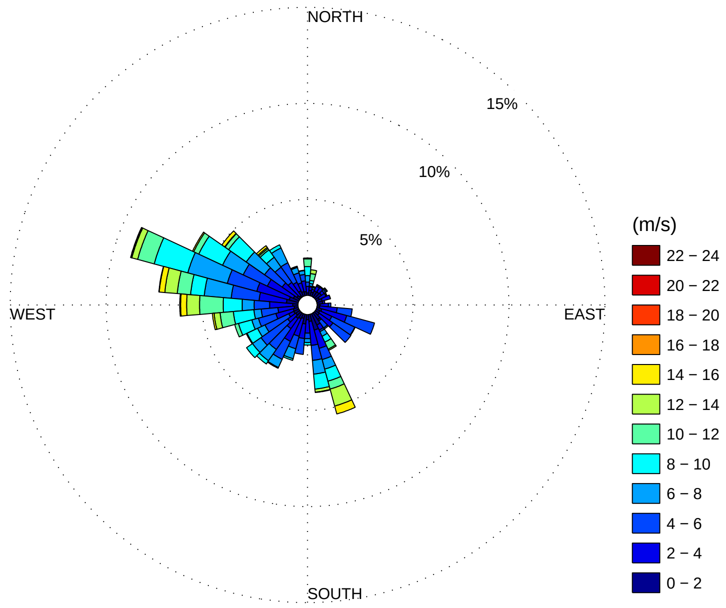


Figure 1.363: March 2012 Wind Rose

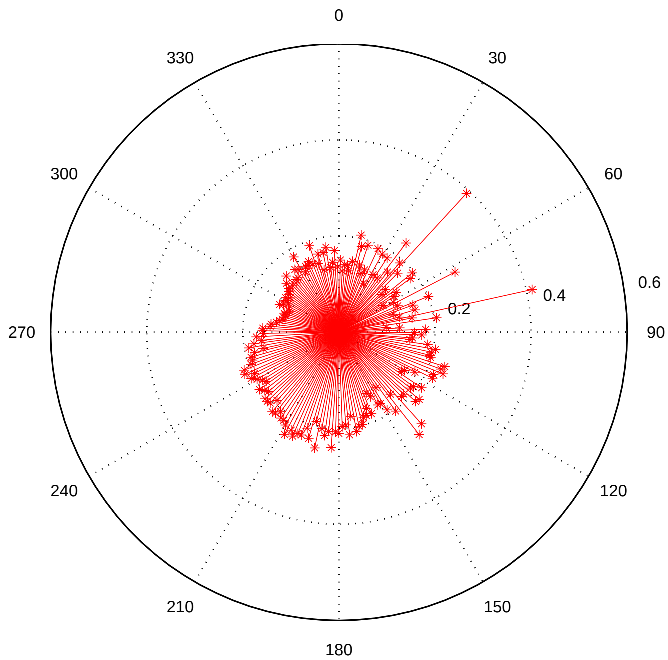


Figure 1.364: March 2012 turbulence intensity

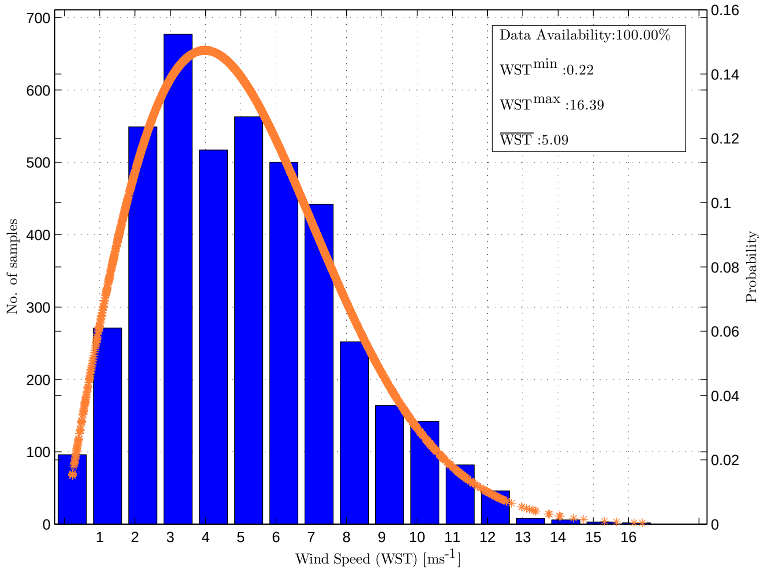


Figure 1.365: April 2012 probability distribution function

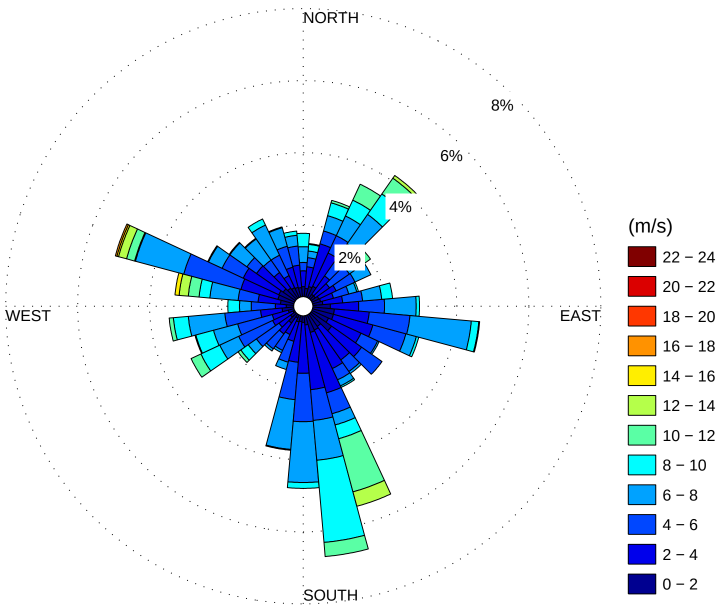


Figure 1.366: April 2012 Wind Rose

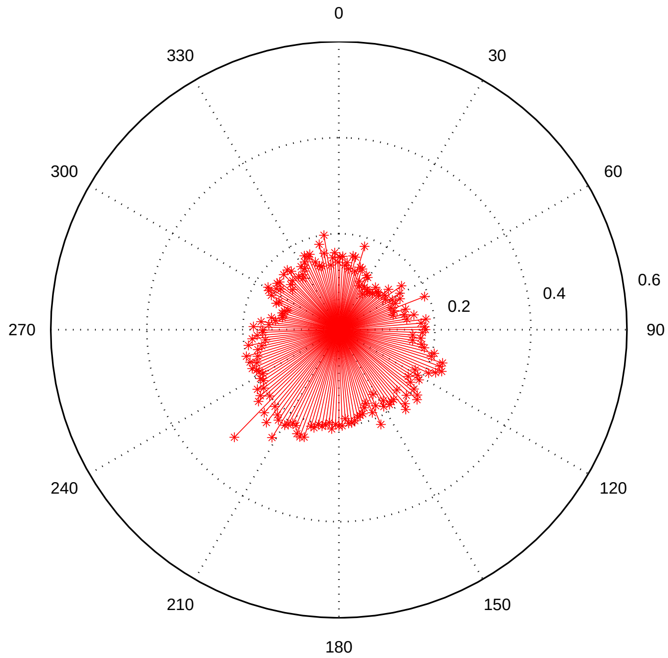


Figure 1.367: April 2012 turbulence intensity

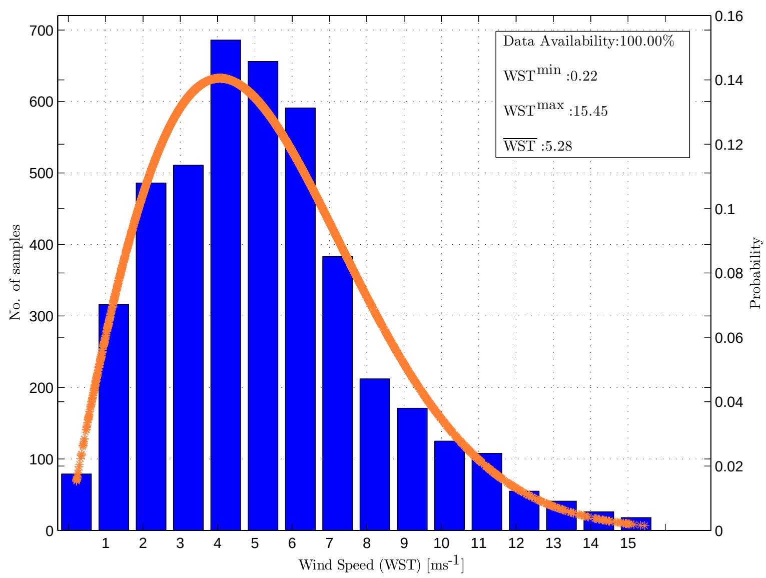


Figure 1.368: May 2012 probability distribution function

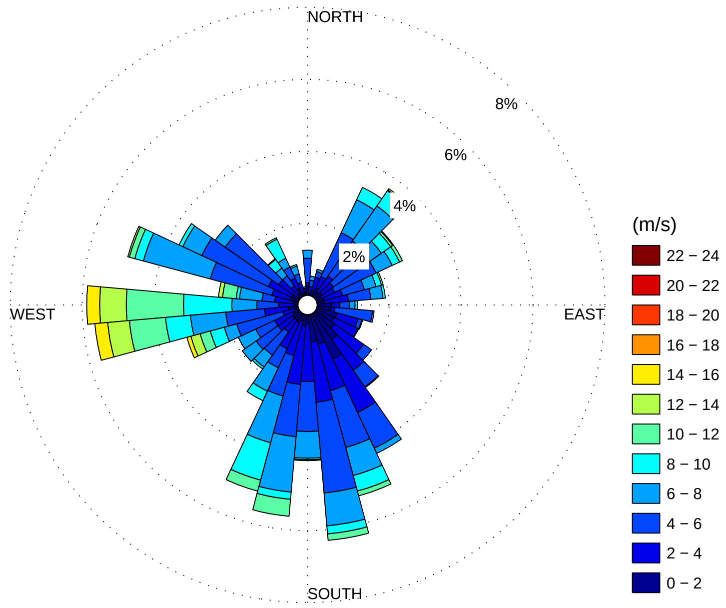


Figure 1.369: May 2012 Wind Rose

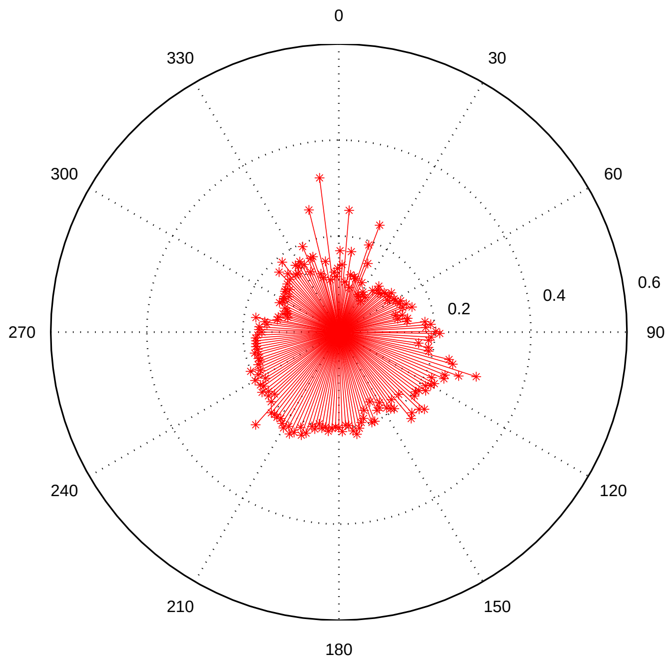


Figure 1.370: May 2012 turbulence intensity

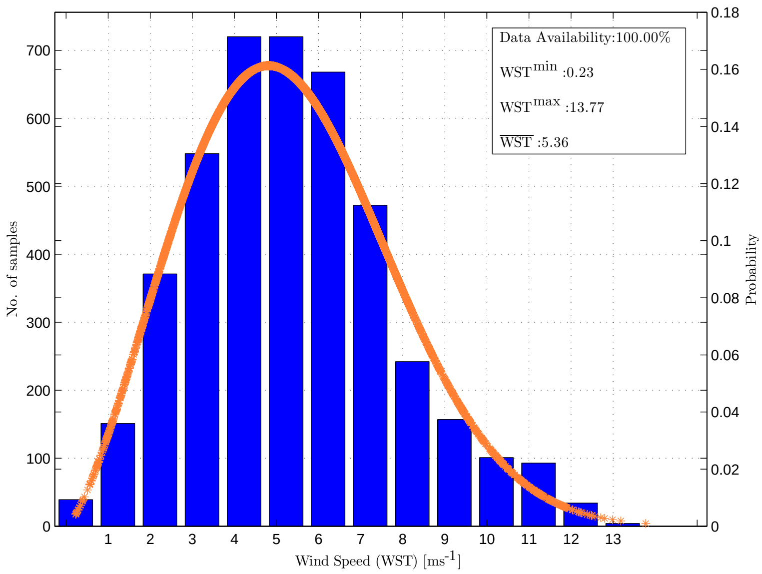


Figure 1.371: June 2012 probability distribution function

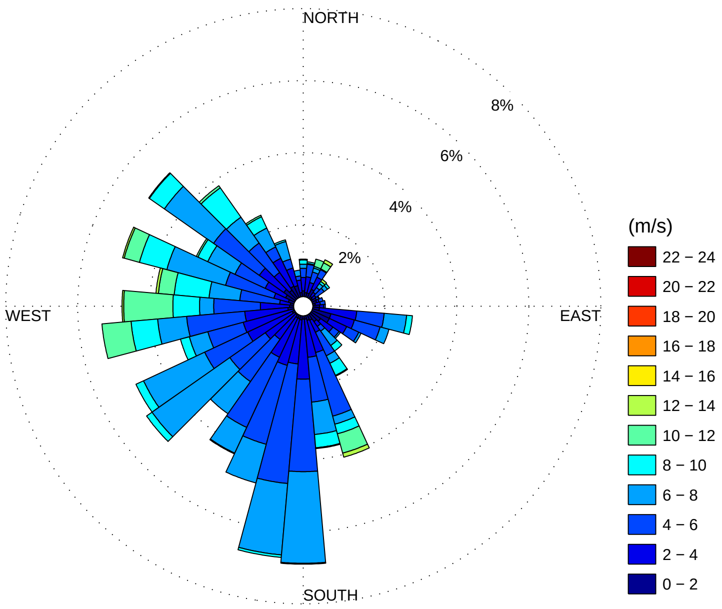


Figure 1.372: June 2012 Wind Rose

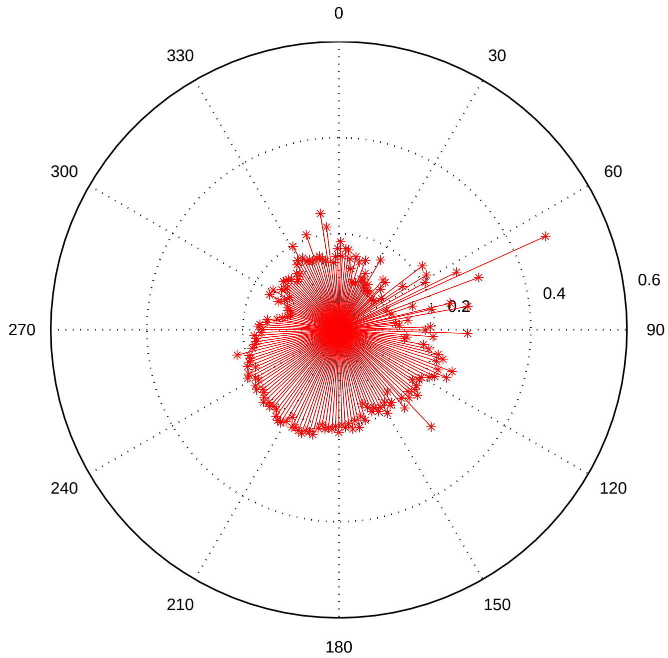


Figure 1.373: June 2012 turbulence intensity

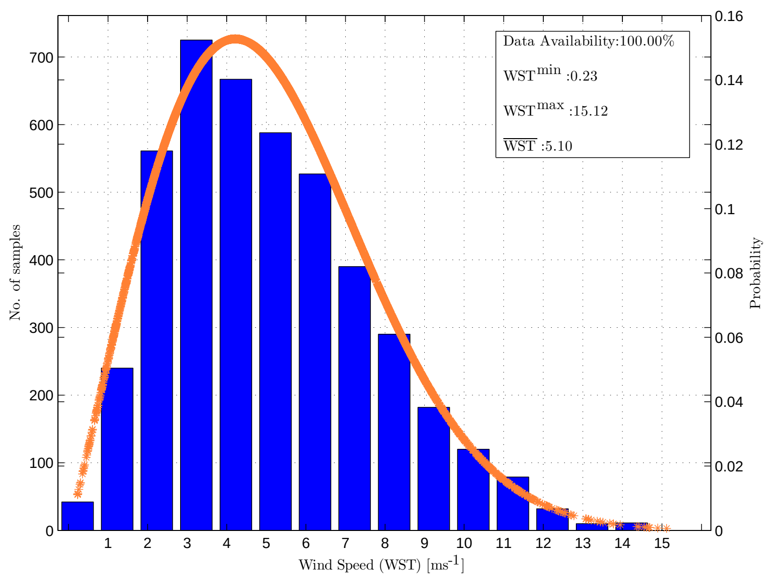


Figure 1.374: July 2012 probability distribution function

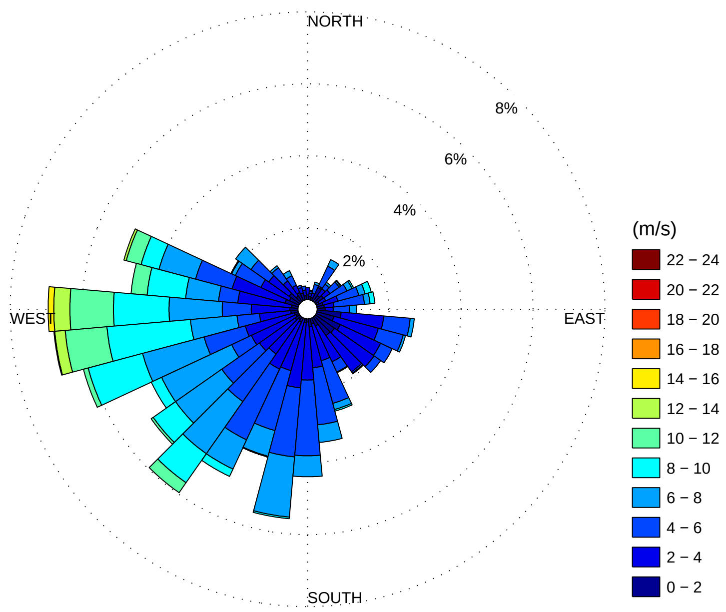


Figure 1.375: July 2012 Wind Rose

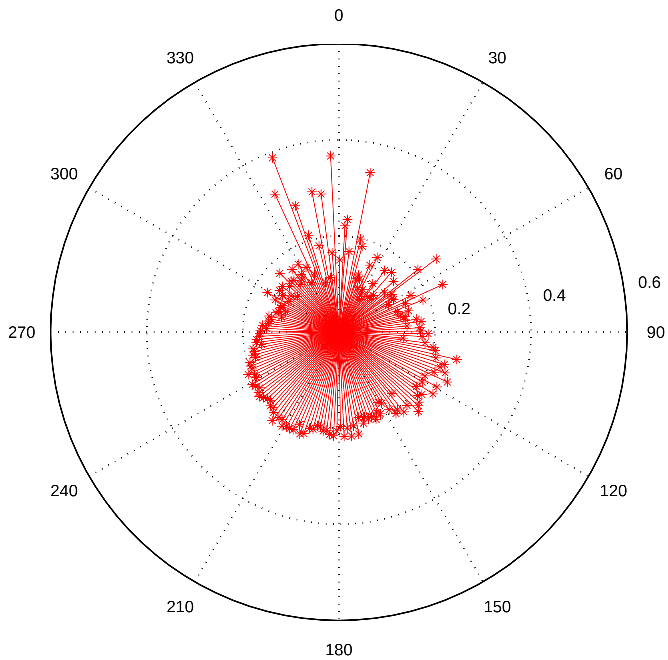


Figure 1.376: July 2012 turbulence intensity

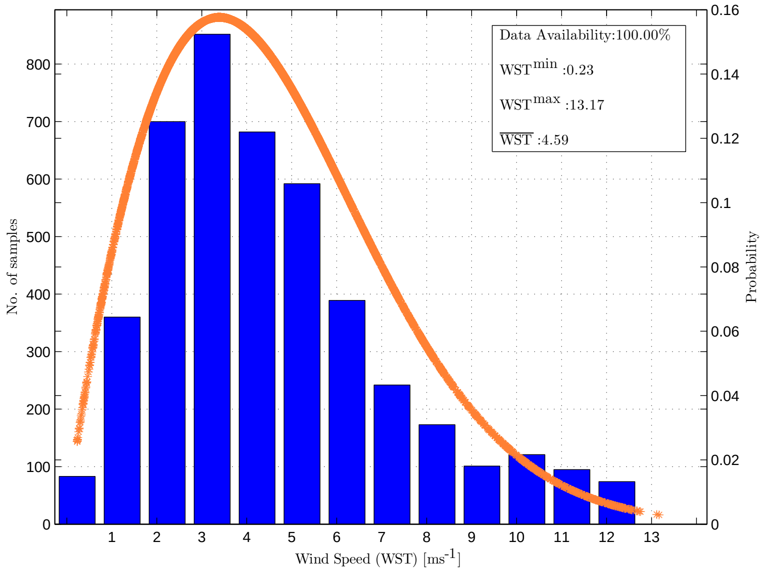


Figure 1.377: August 2012 probability distribution function

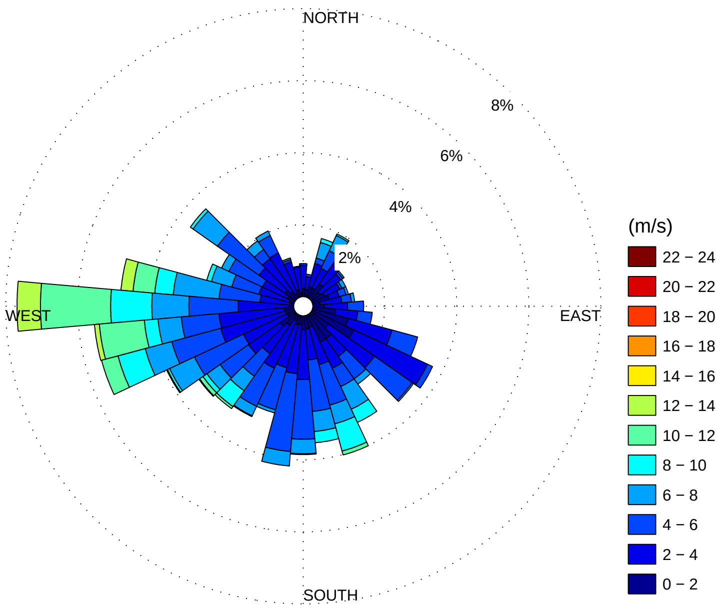


Figure 1.378: August 2012 Wind Rose

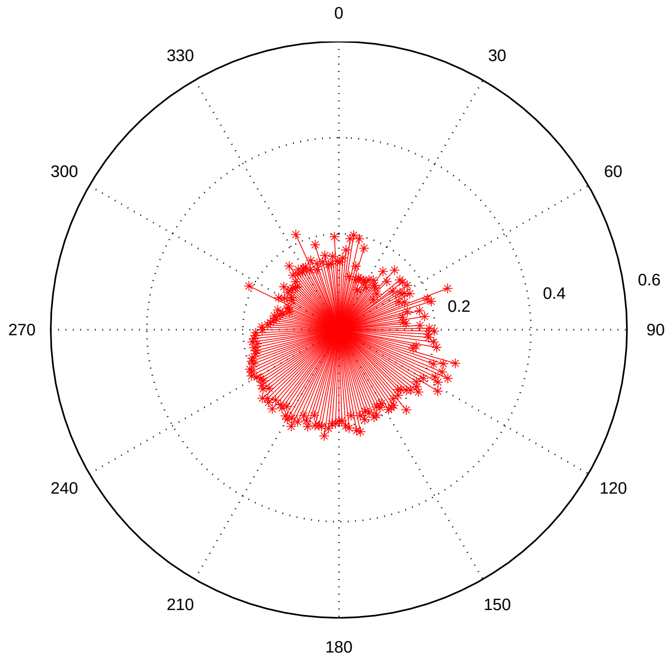


Figure 1.379: August 2012 turbulence intensity

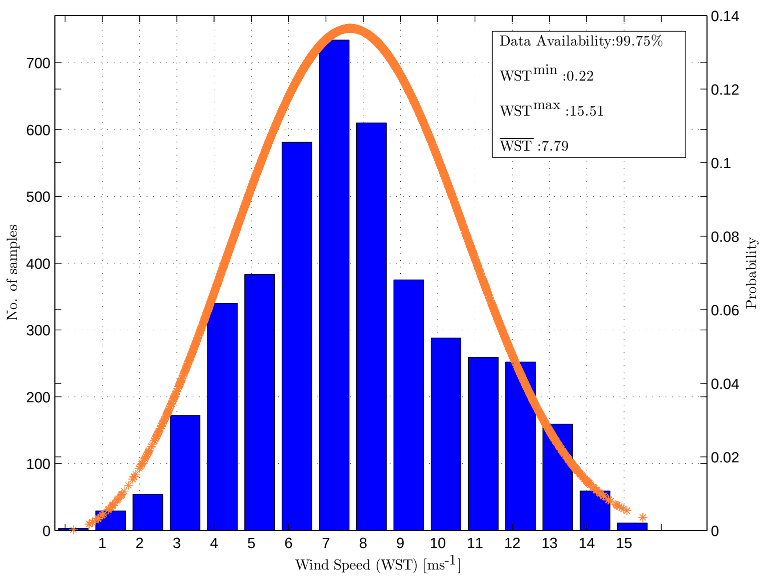


Figure 1.380: September 2012 probability distribution function

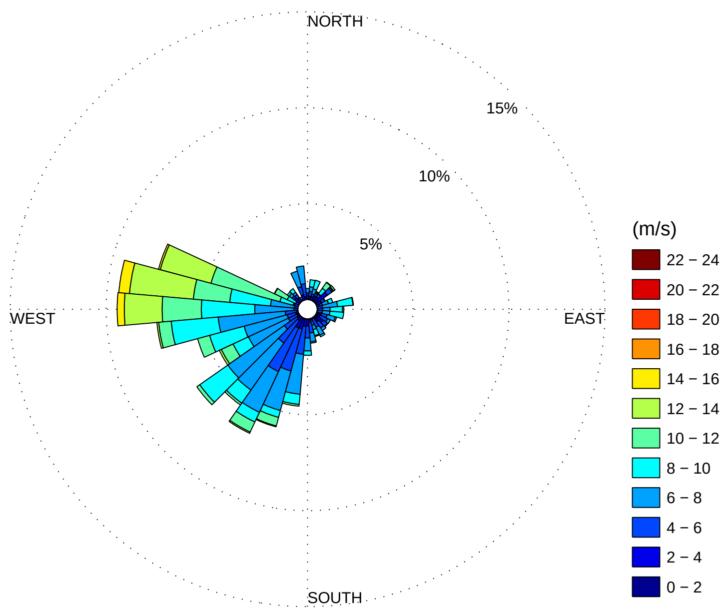


Figure 1.381: September 2012 Wind Rose

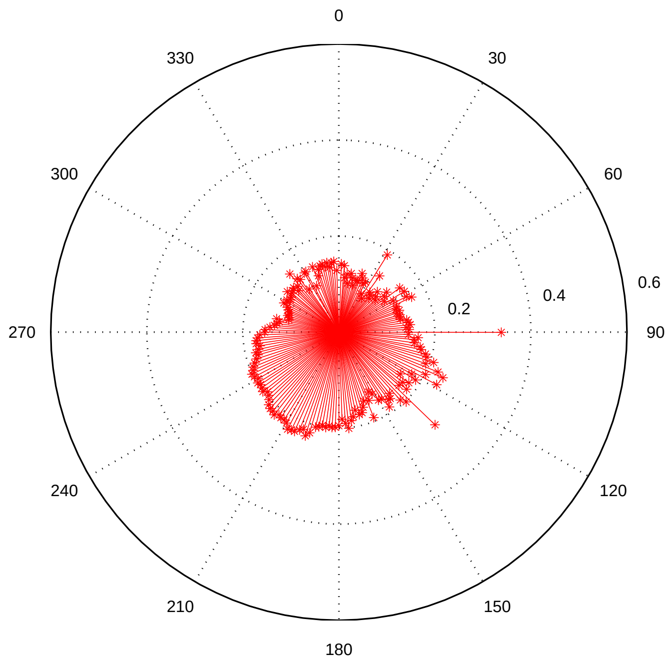


Figure 1.382: September 2012 turbulence intensity

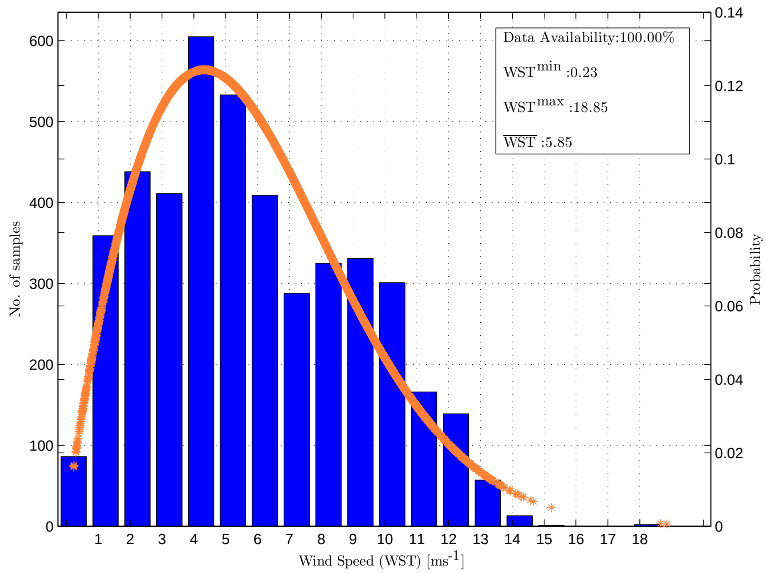


Figure 1.383: October 2012 probability distribution function

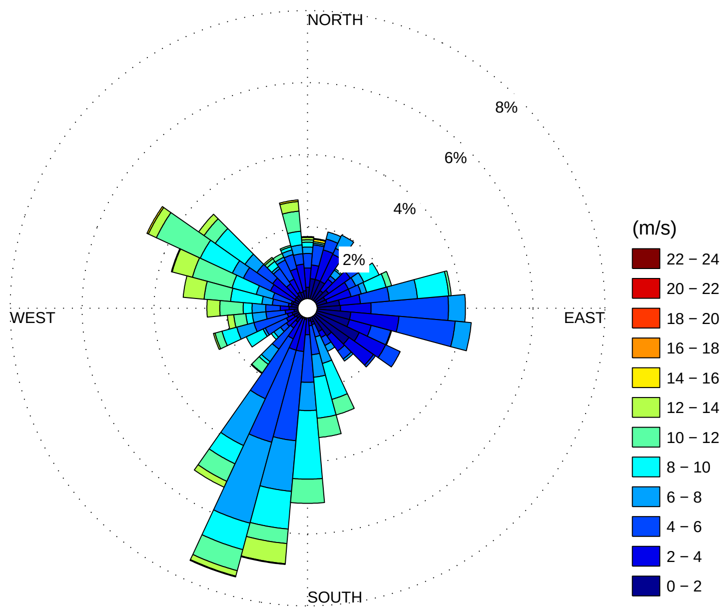


Figure 1.384: October 2012 Wind Rose

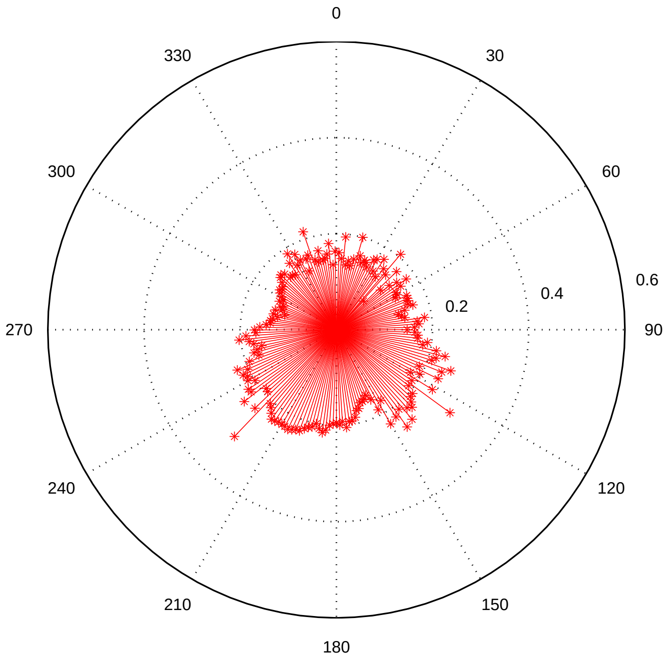


Figure 1.385: October 2012 turbulence intensity

1.10 WSO Statistics

1.10.1 2012 Annual Statistics

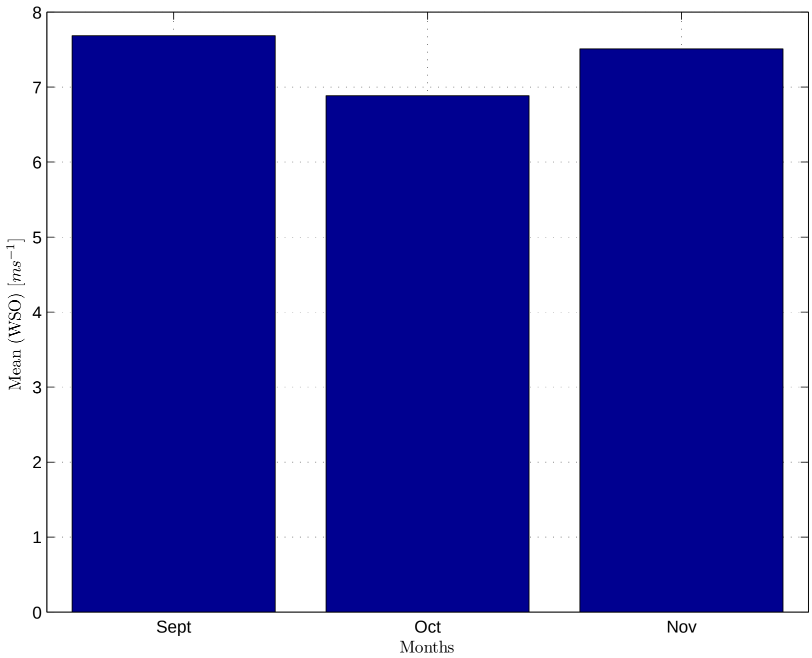


Figure 1.386: Annual wind speed distribution of WSO, 2012

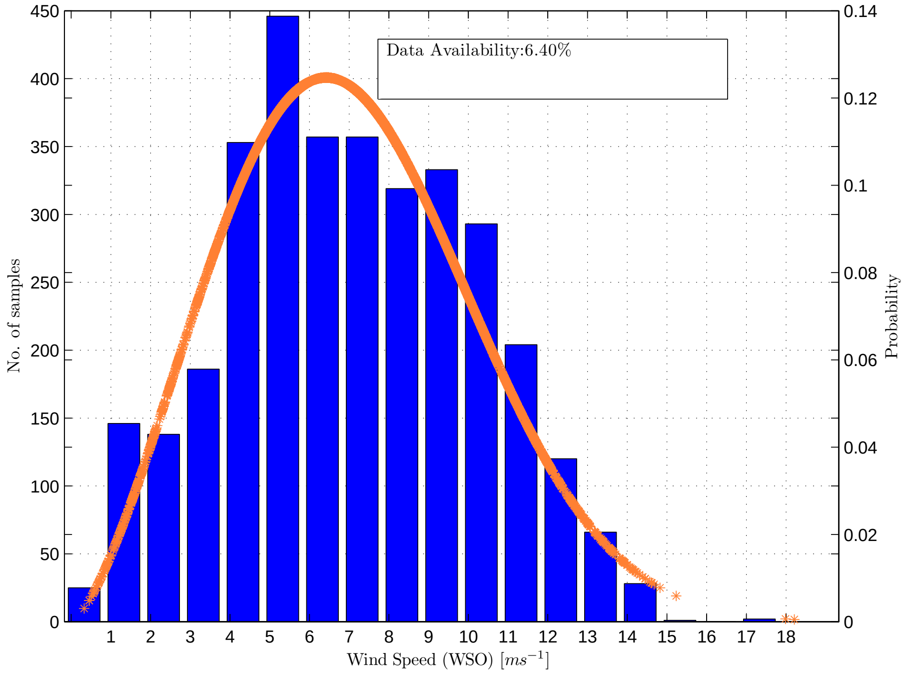


Figure 1.387: Annual wind speed distribution of WSO, 2012

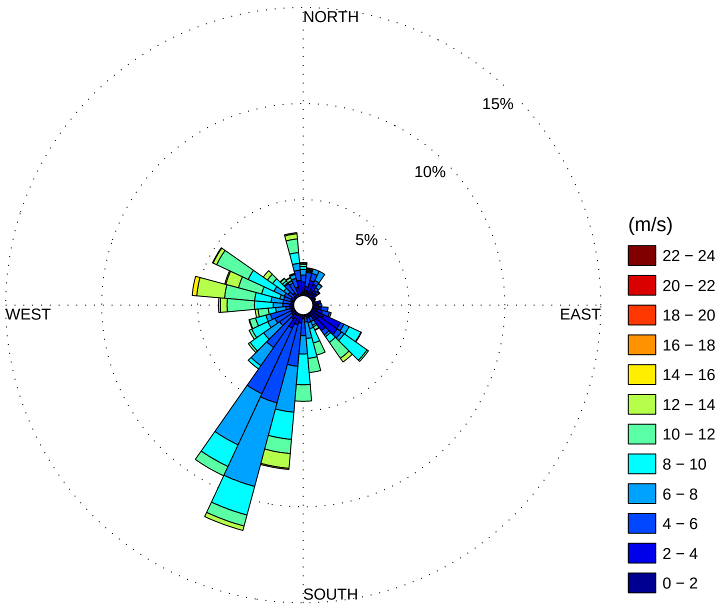


Figure 1.388: Annual wind rose of WSO, 2012

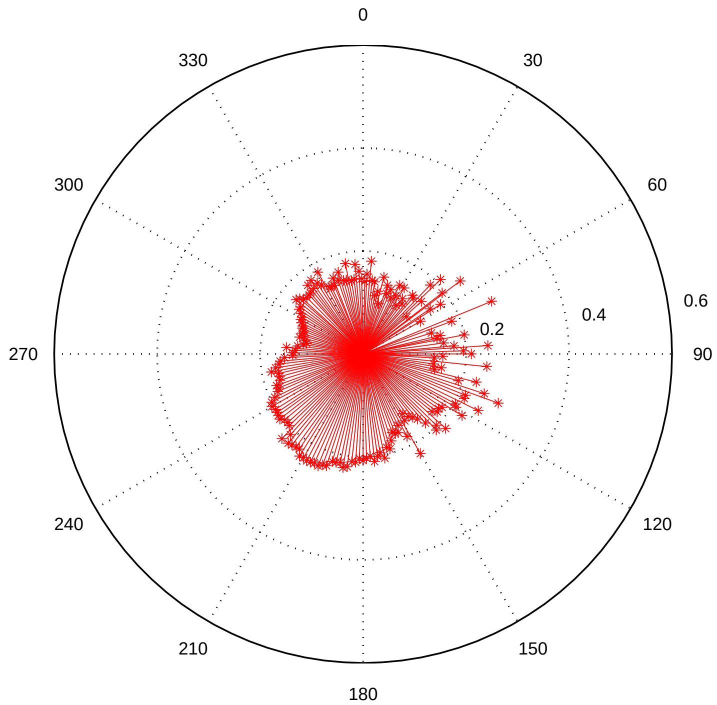


Figure 1.389: Turbulence intensity of WSO, 2012

Table 1.31: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2012

Month	Min	Mean	Max
September	1.13	7.68	20.33
October	0.00	6.88	24.65
November	0.80	7.51	19.14

Table 1.32: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2012

Month	Data Availability(%)	Min	Mean	Max	K	C
September	9.17	3.49	7.68	15.23	3.04	8.60
October	55.65	0.33	6.88	18.21	2.22	7.76
November	11.44	2.26	7.51	13.06	3.69	8.33

1.10.1.1 2012 Monthly Statistics

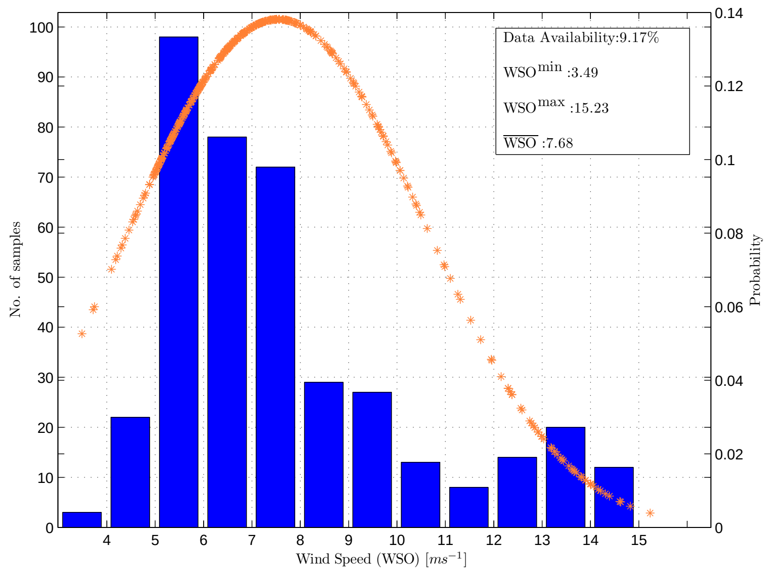


Figure 1.390: September 2012 probability distribution function

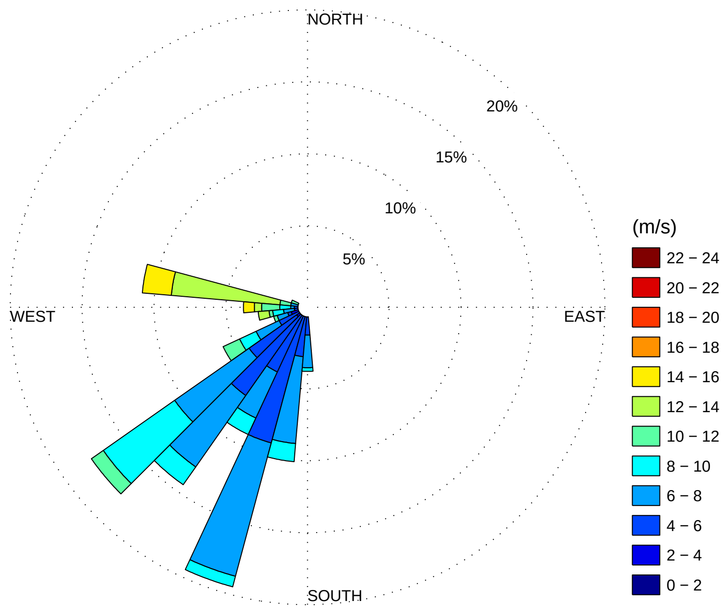


Figure 1.391: September 2012 wind rose

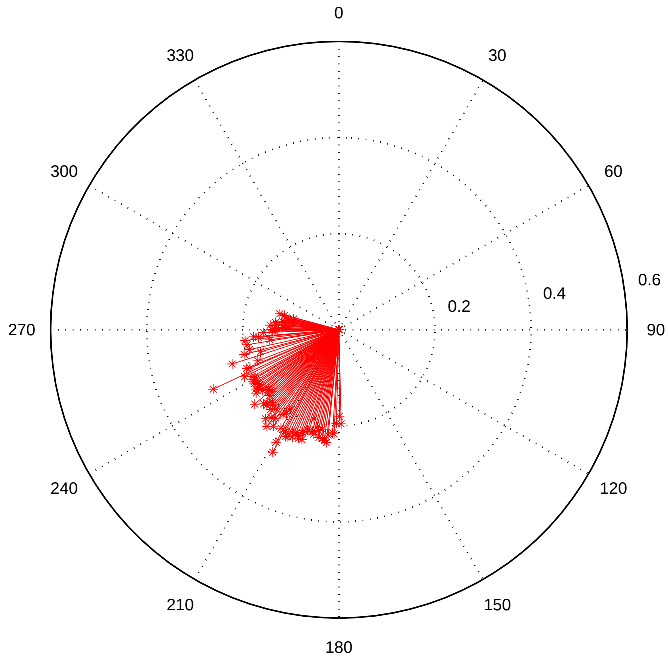


Figure 1.392: September 2012 turbulence intensity

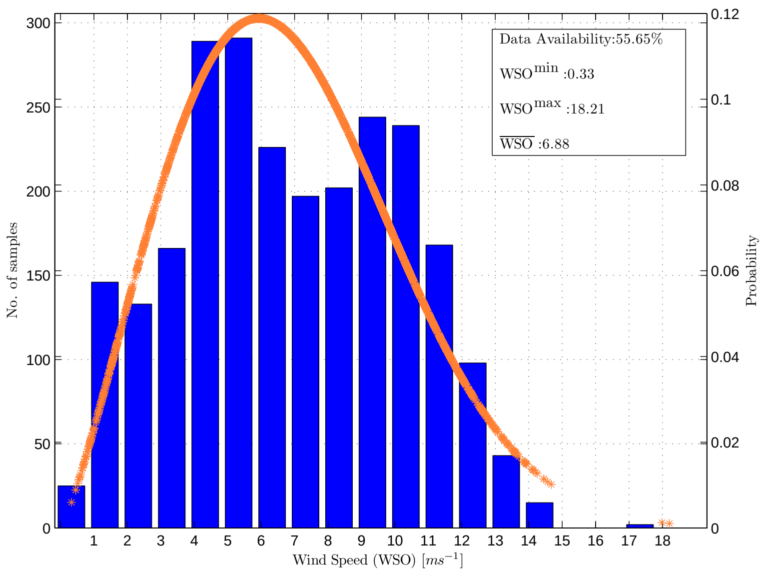


Figure 1.393: October 2012 probability distribution function

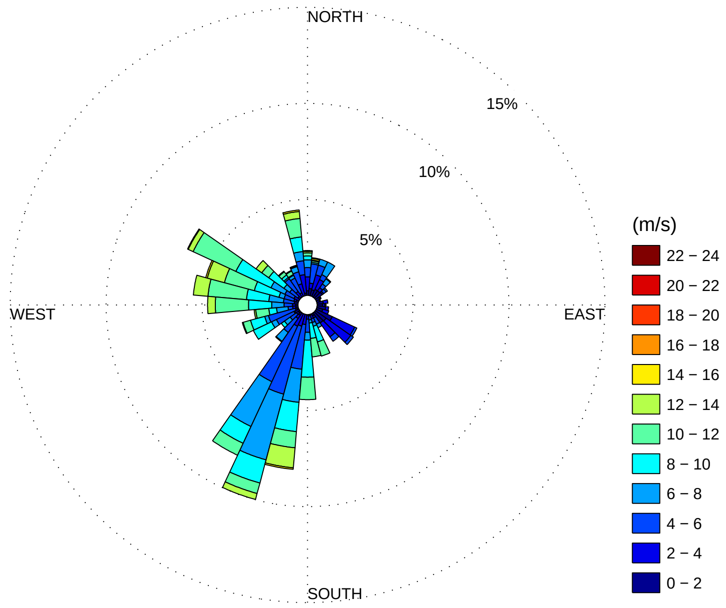


Figure 1.394: October 2012 wind rose

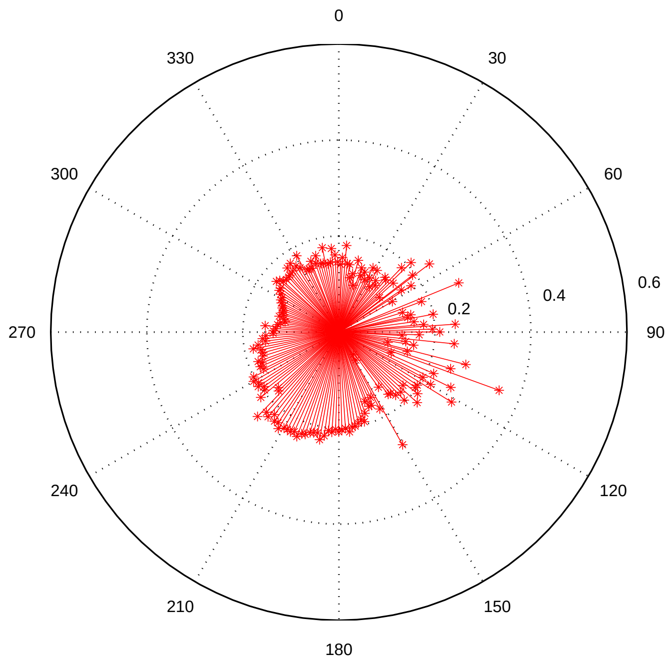


Figure 1.395: October 2012 turbulence intensity

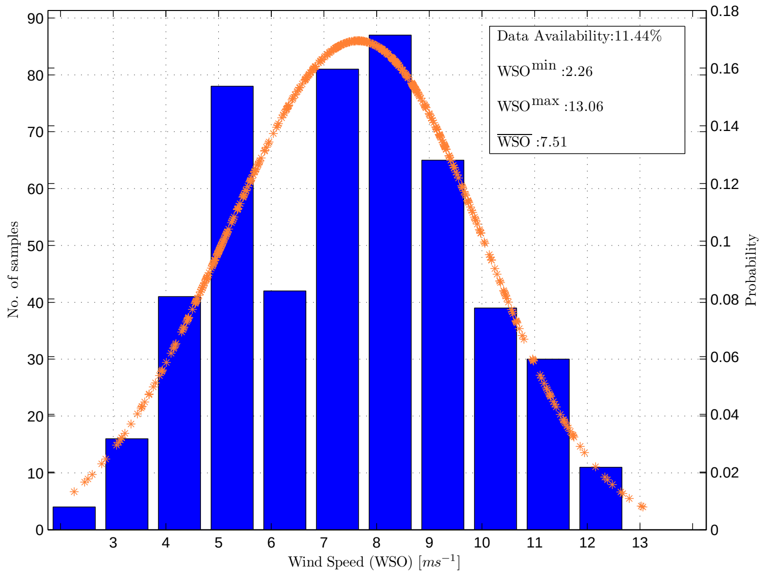


Figure 1.396: November 2012 probability distribution function

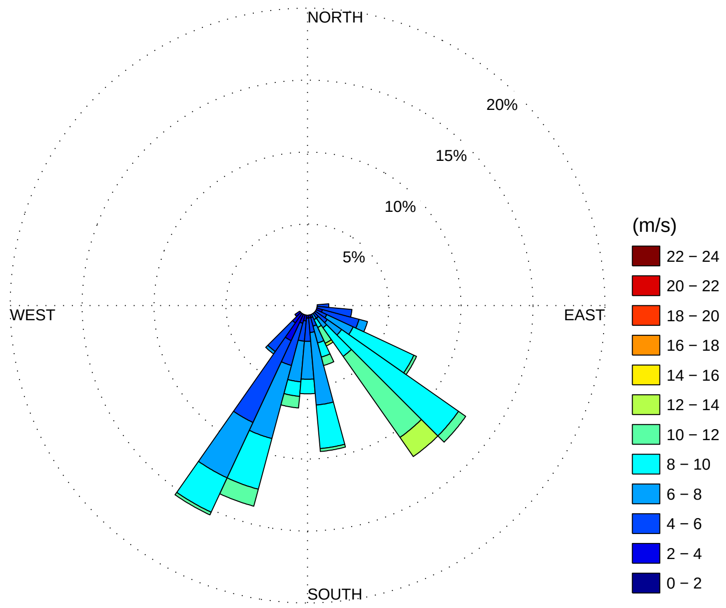


Figure 1.397: November 2012 wind rose

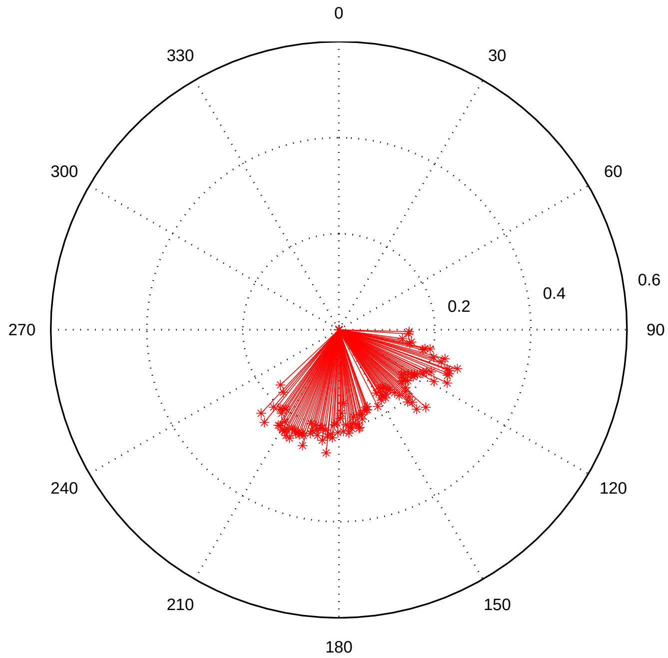


Figure 1.398: November 2012 turbulence intensity

1.10.2 2013 Annual Statistics

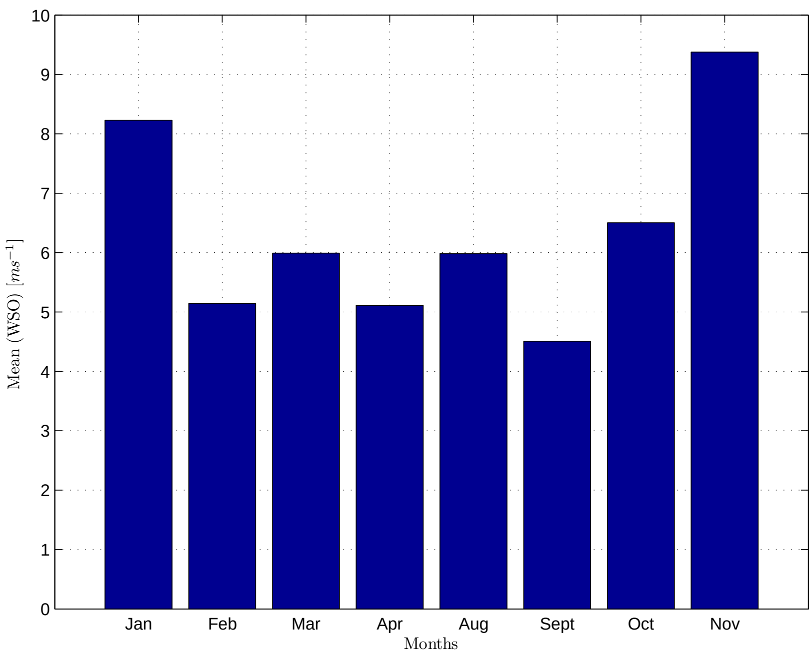


Figure 1.399: Annual wind speed distribution of WSO, 2013

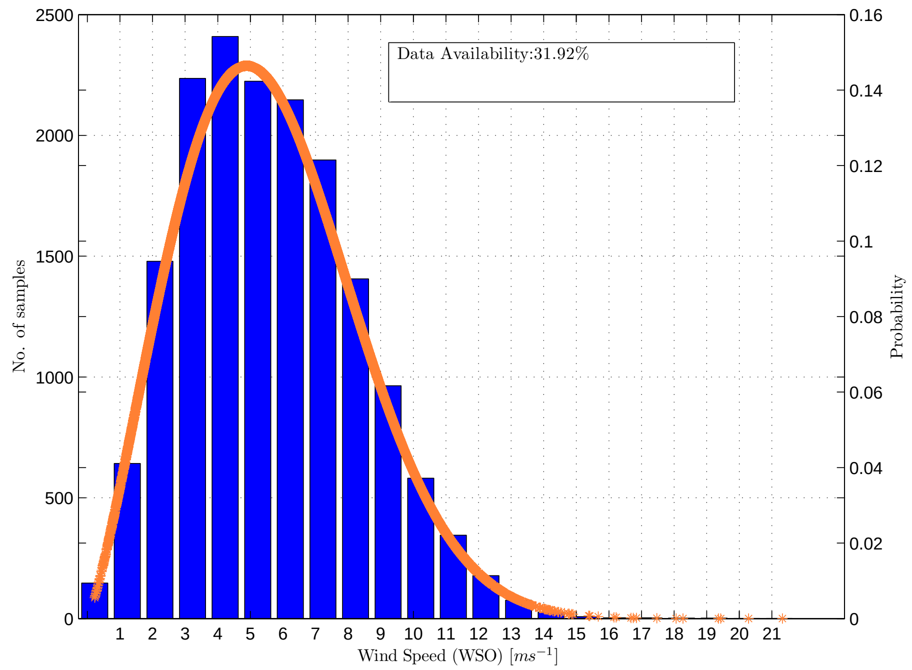


Figure 1.400: Annual wind speed distribution of WSO, 2013

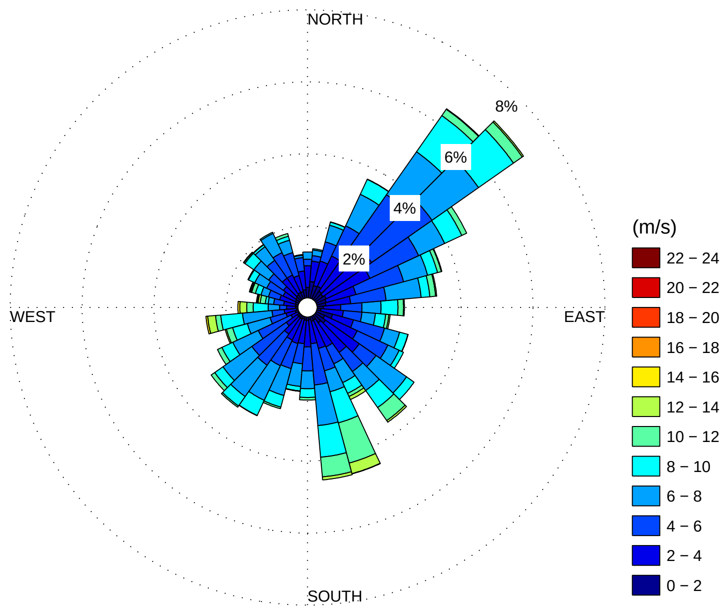


Figure 1.401: Annual wind rose of WSO, 2013

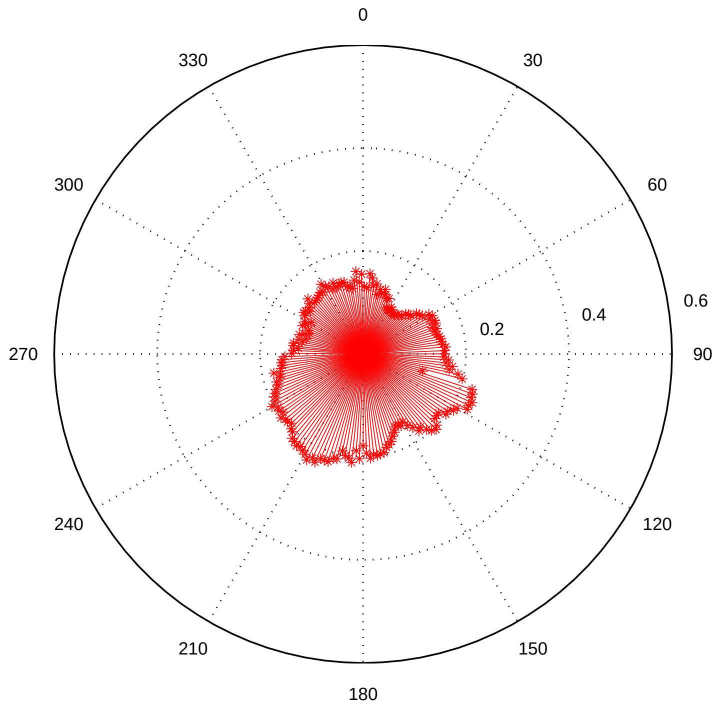


Figure 1.402: Turbulence intensity of WSO, 2013

Table 1.33: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2013

Month	Min	Mean	Max
January	0.03	8.21	23.04
February	0.00	5.15	21.01
March	0.00	5.99	20.79
April	0.01	5.11	18.37
August	0.74	5.99	12.29
September	0.00	4.51	20.29
October	0.05	6.50	28.14
November	2.48	9.38	18.11

Table 1.34: Monthly wind speed [ms-1] parameters of 10 min. averaged data, 2013

Month	Data Availability(%)	Min	Mean	Max	K	C
January	3.27	0.94	8.23	16.85	2.54	9.24
February	31.87	0.48	5.14	10.98	2.33	5.77
March	99.24	0.23	5.99	14.02	2.42	6.76
April	71.85	0.24	5.11	12.71	2.20	5.77
August	1.57	3.21	5.98	8.66	3.79	6.66
September	77.31	0.33	4.51	13.56	2.10	5.10
October	98.25	0.37	6.50	21.32	2.59	7.32
November	0.42	8.66	9.38	10.08	25.44	9.57

1.10.2.1 2013 Monthly Statistics

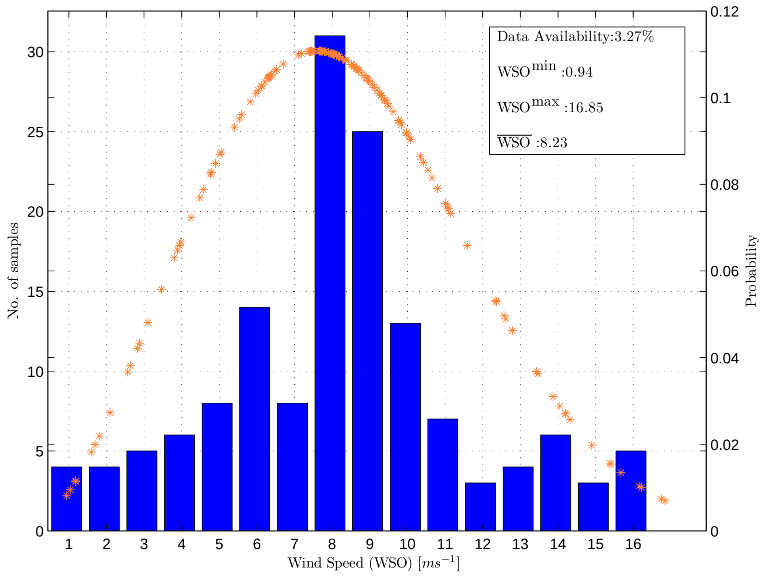


Figure 1.403: January 2013 probability distribution function

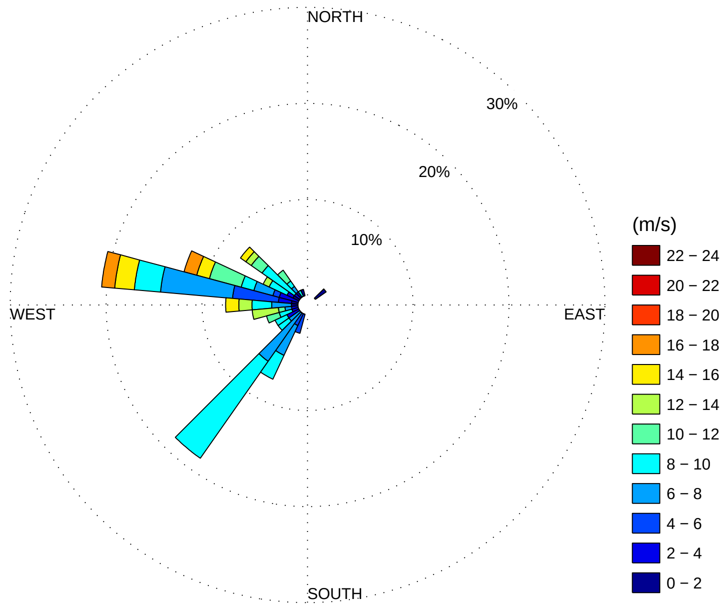


Figure 1.404: January 2013 wind rose

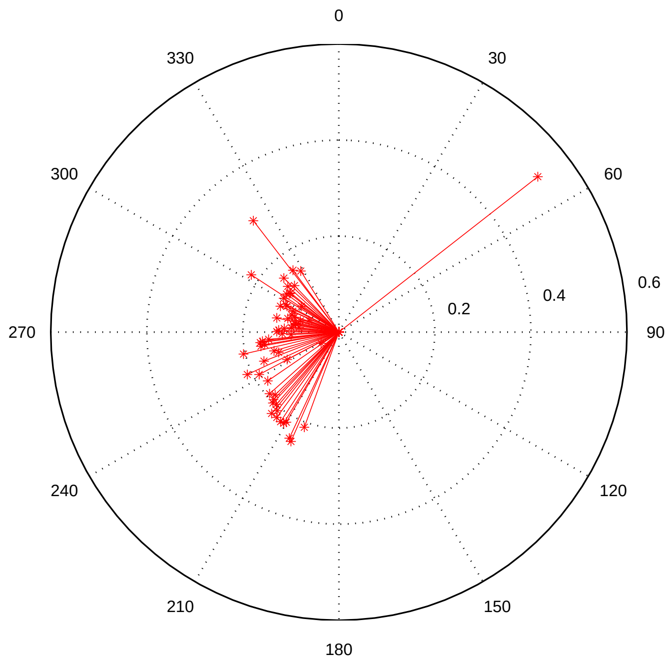


Figure 1.405: January 2013 turbulence intensity

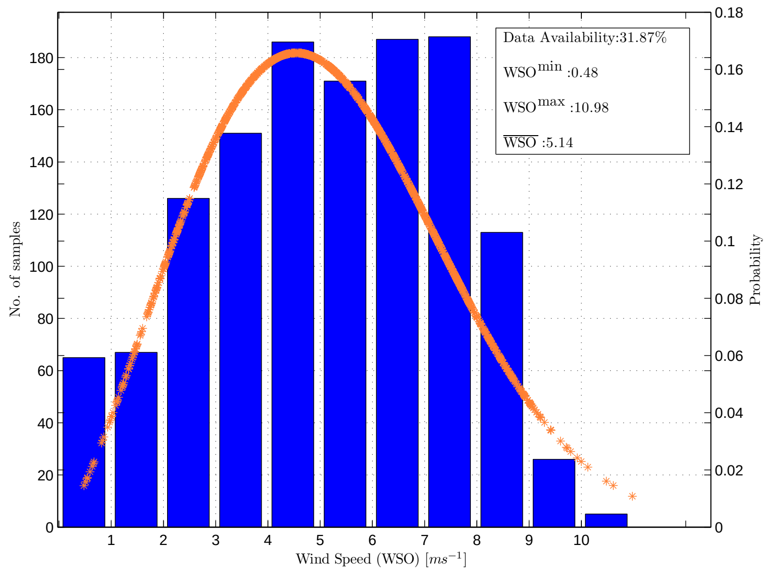


Figure 1.406: February 2013 probability distribution function

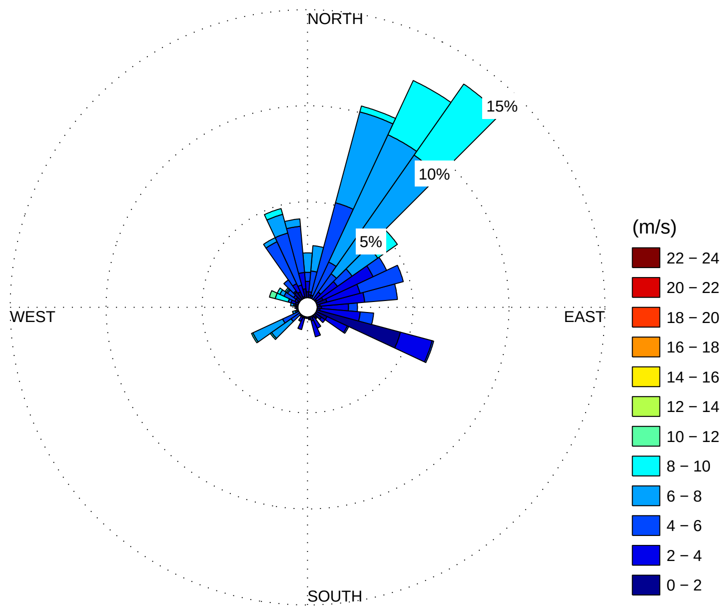


Figure 1.407: February 2013 wind rose

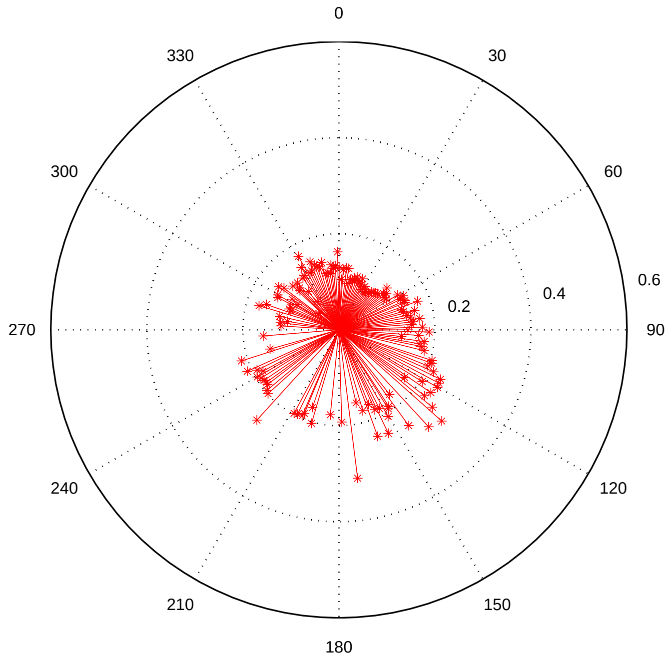


Figure 1.408: February 2013 turbulence intensity

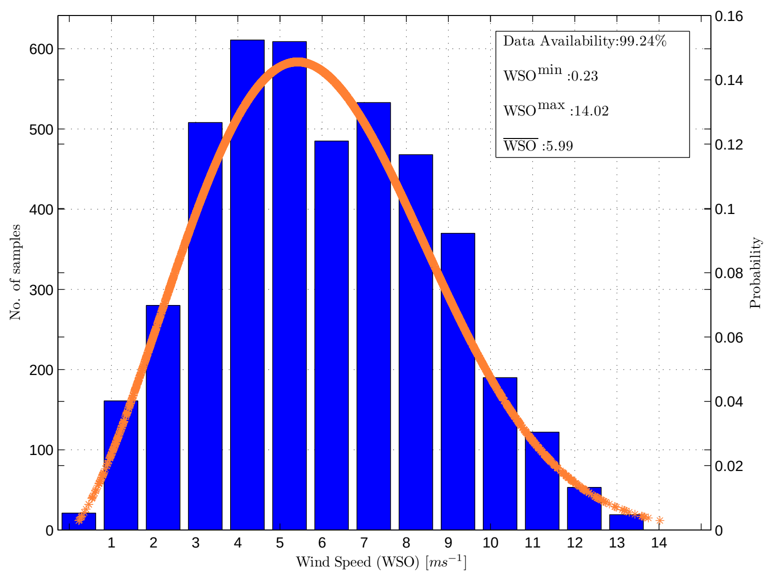


Figure 1.409: March 2013 probability distribution function

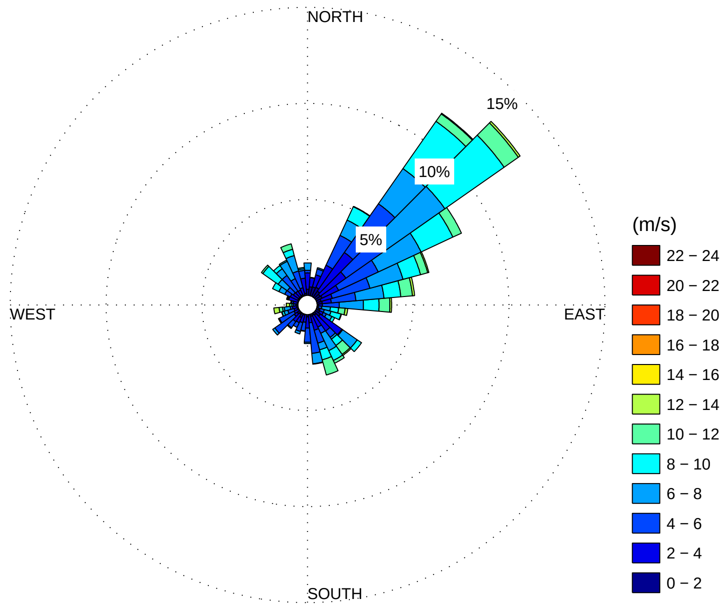


Figure 1.410: March 2013 wind rose

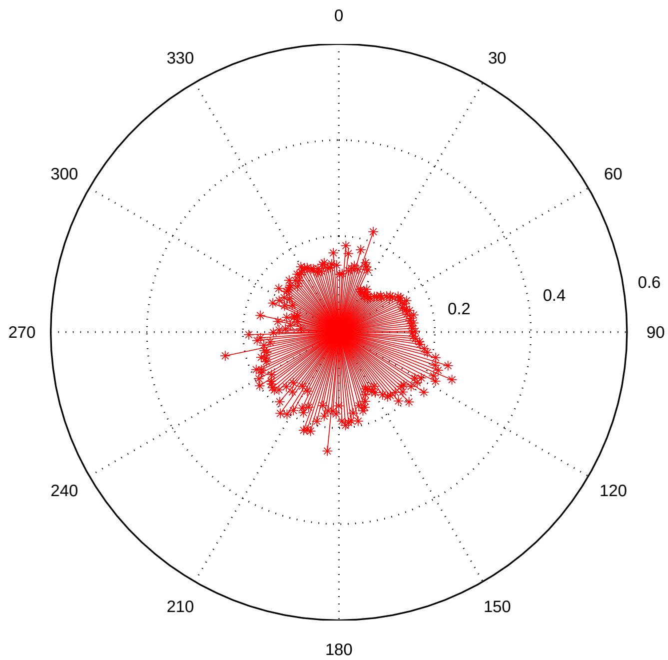


Figure 1.411: March 2013 turbulence intensity

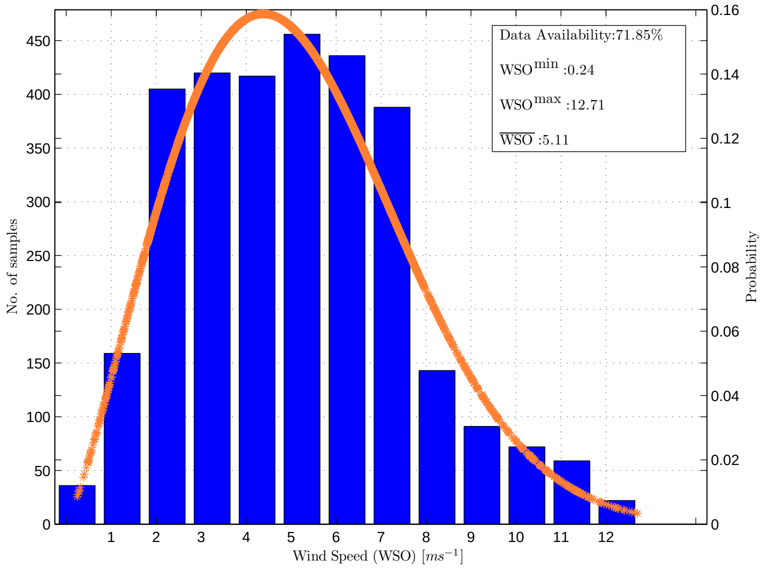


Figure 1.412: April 2013 probability distribution function

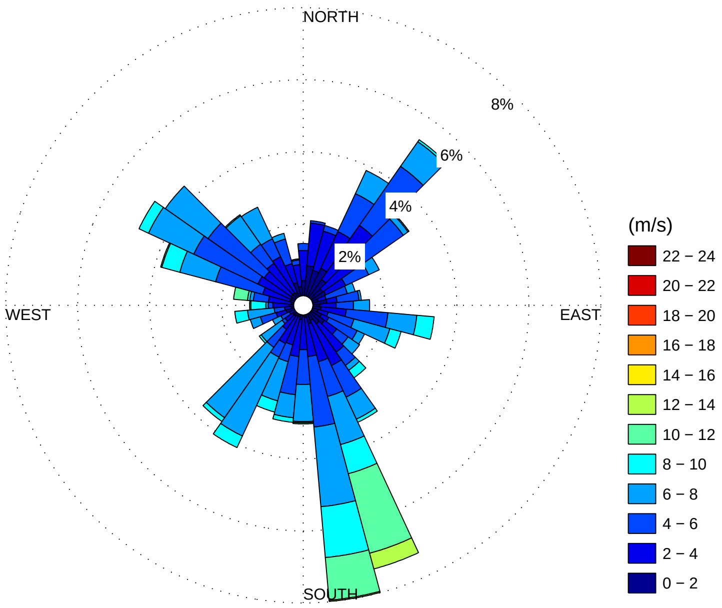


Figure 1.413: April 2013 wind rose

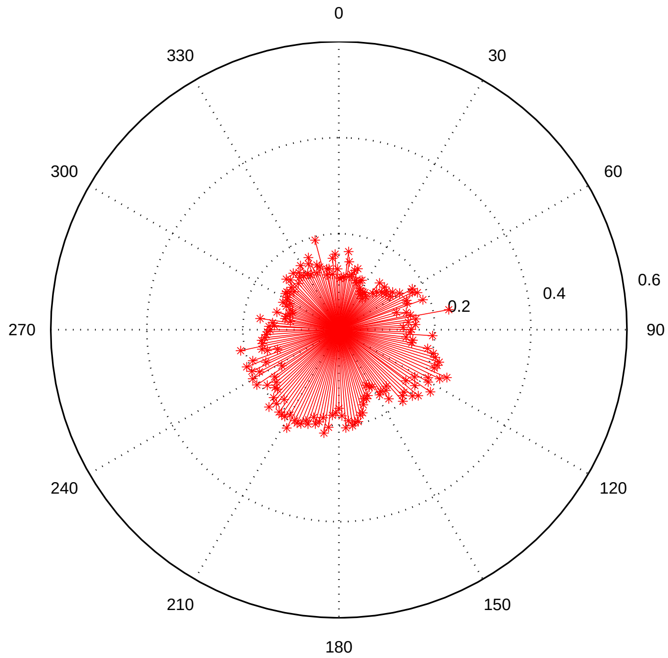


Figure 1.414: April 2013 turbulence intensity

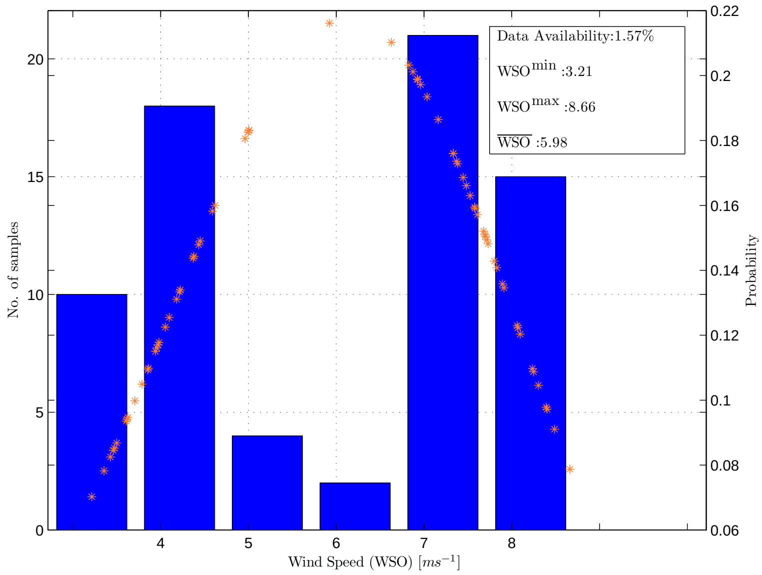


Figure 1.415: August 2013 probability distribution function

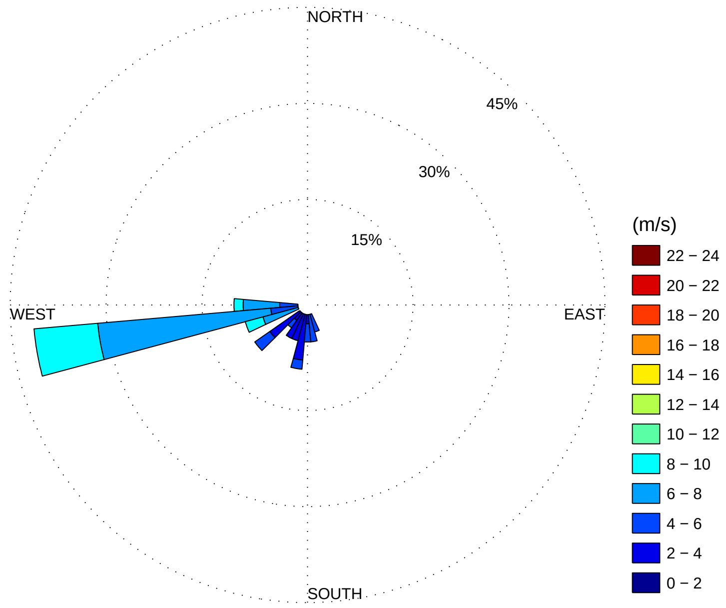


Figure 1.416: August 2013 wind rose

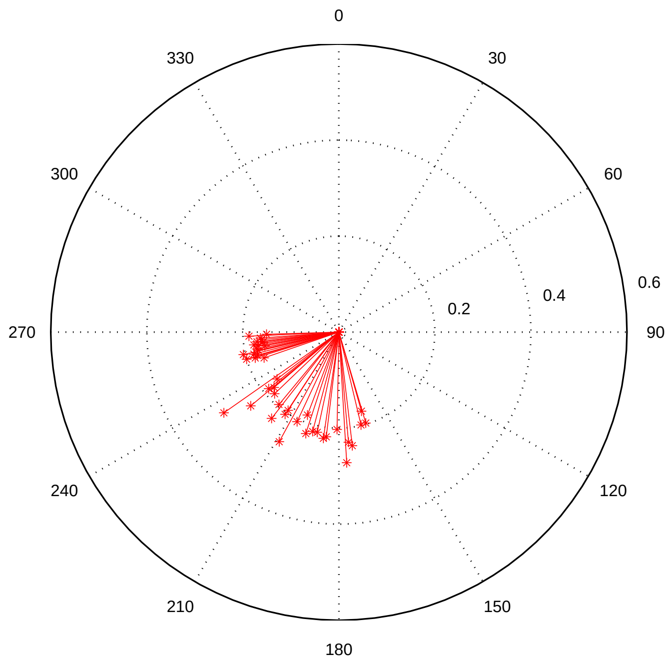


Figure 1.417: August 2013 turbulence intensity

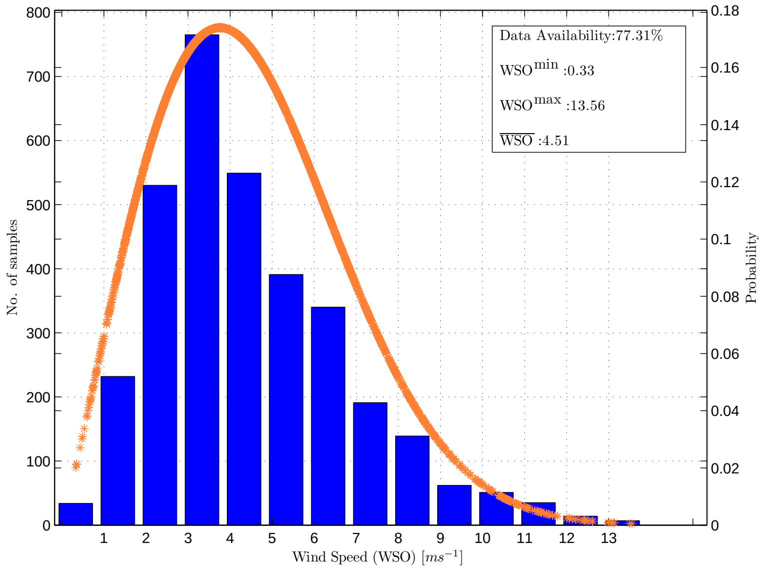


Figure 1.418: September 2013 probability distribution function

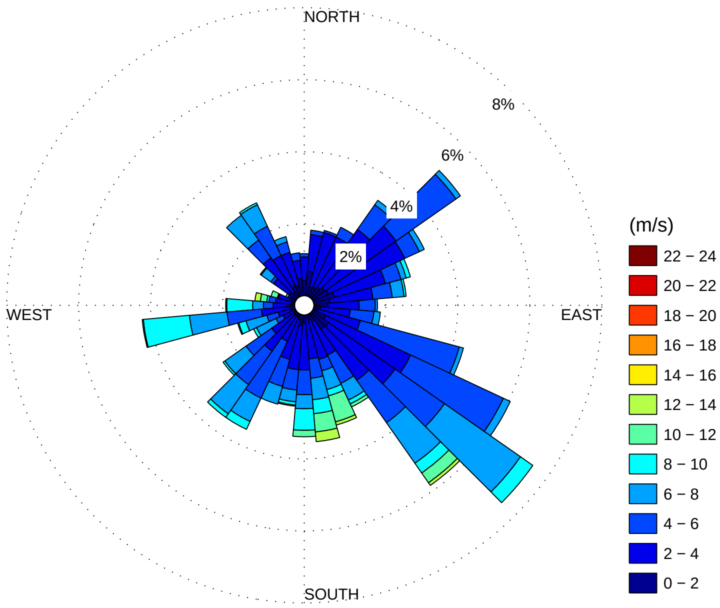


Figure 1.419: September 2013 wind rose

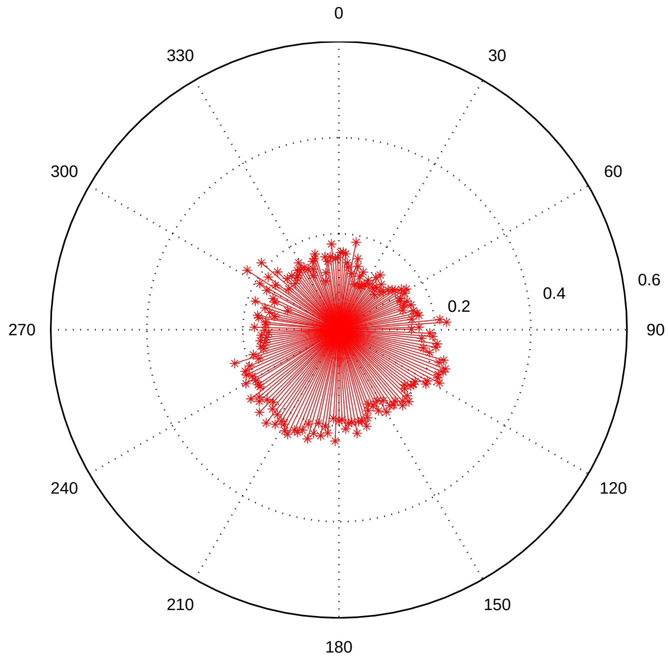


Figure 1.420: September 2013 turbulence intensity

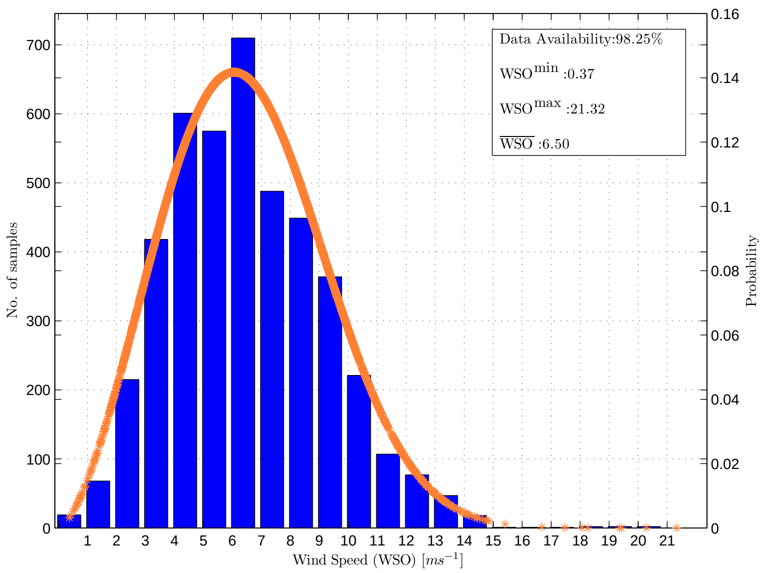


Figure 1.421: October 2013 probability distribution function

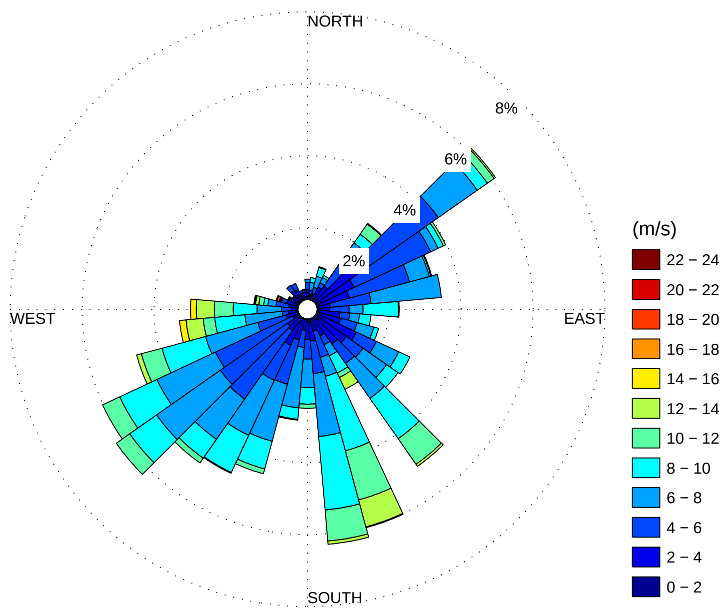


Figure 1.422: October 2013 wind rose

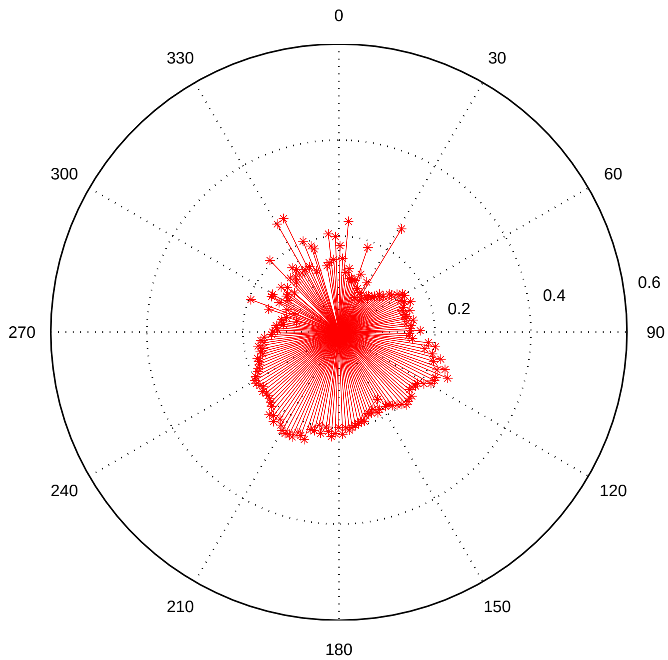


Figure 1.423: October 2013 turbulence intensity

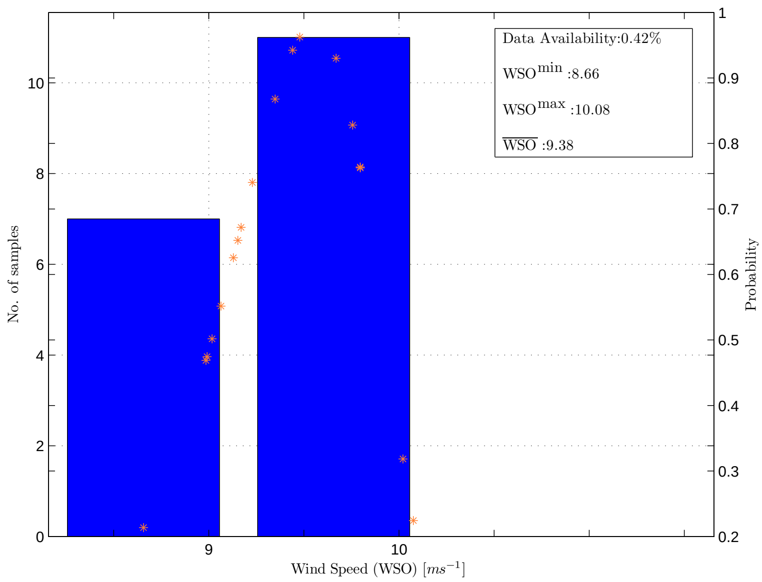


Figure 1.424: November 2013 probability distribution function

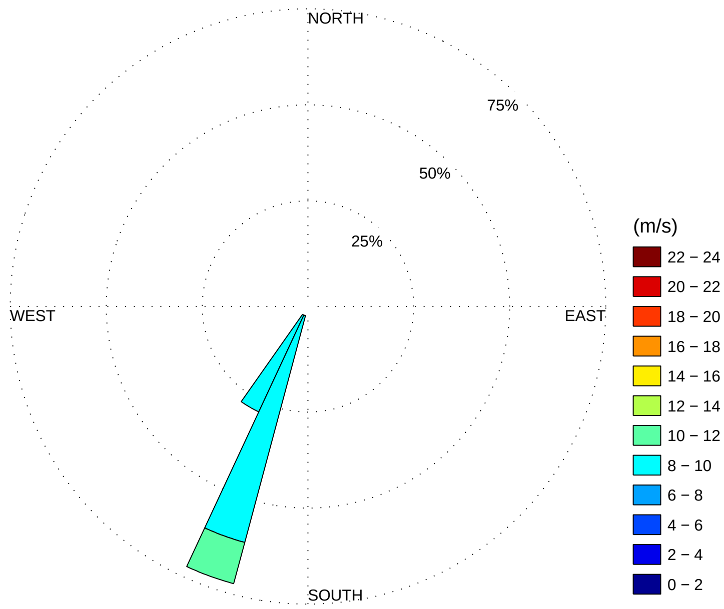


Figure 1.425: November 2013 wind rose

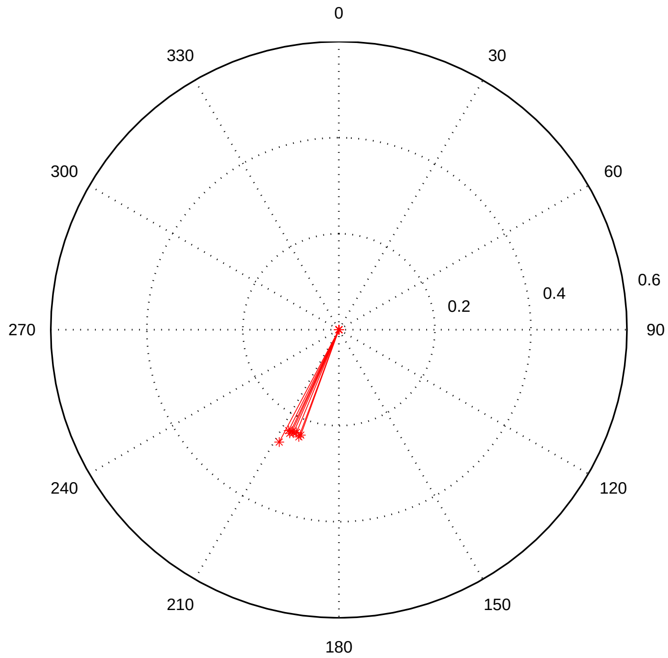


Figure 1.426: November 2013 turbulence intensity

1.11 WSM Statistics

1.11.1 2012 Annual Statistics

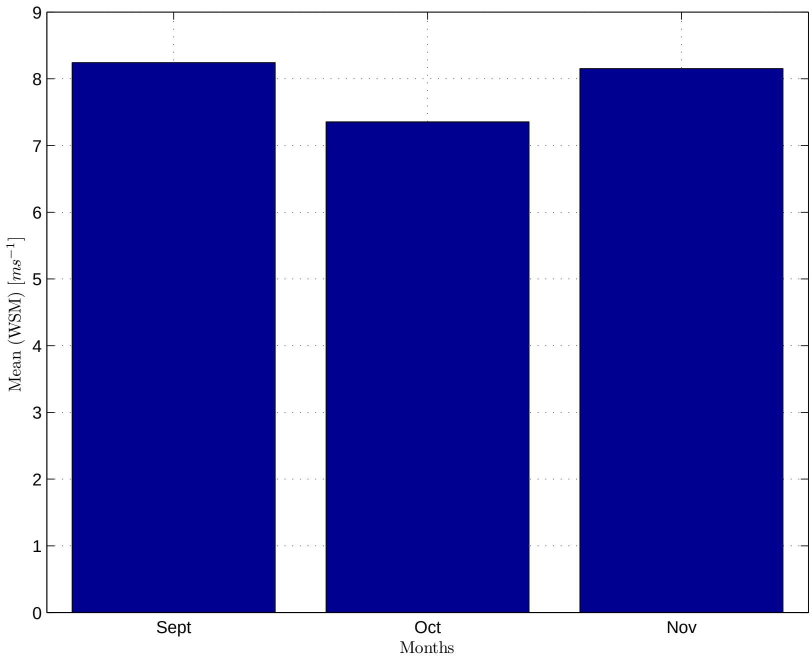


Figure 1.427: Annual wind speed distribution of WSM, 2012

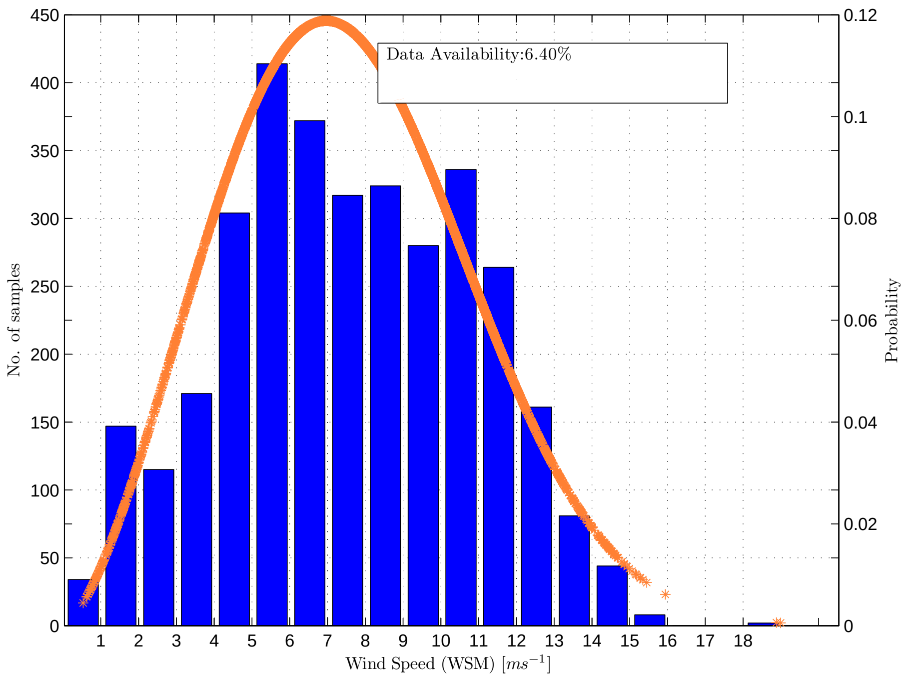


Figure 1.428: Annual wind speed distribution of WSM, 2012

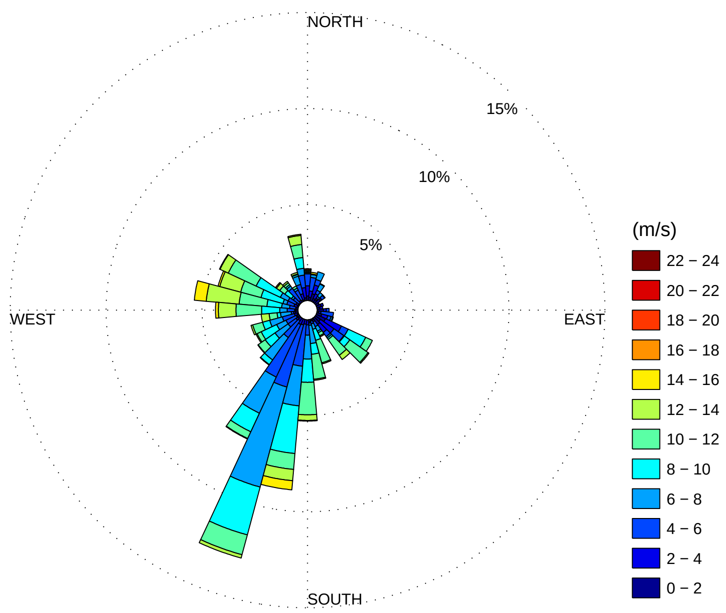


Figure 1.429: Annual wind rose of WSM, 2012

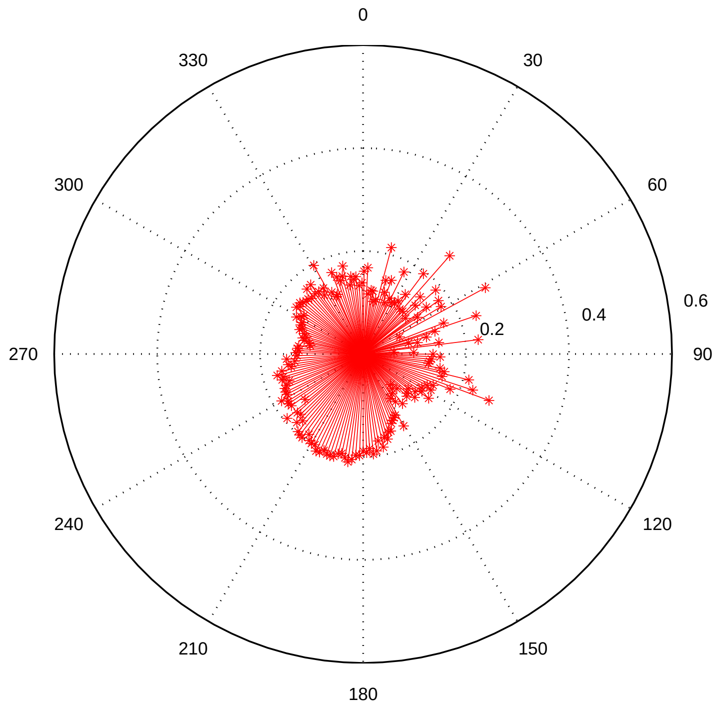


Figure 1.430: Turbulence intensity of WSM, 2012

Table 1.35: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2012

Month	Min	Mean	Max
September	1.16	8.24	20.43
October	0.02	7.35	26.25
November	0.93	8.15	19.47

Table 1.36: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2012

Month	Data Availability(%)	Min	Mean	Max	K	C
September	9.19	3.70	8.24	15.94	3.18	9.20
October	55.62	0.53	7.36	18.99	2.27	8.29
November	11.44	2.71	8.15	12.89	3.92	9.03

1.11.1.1 2012 Monthly Statistics

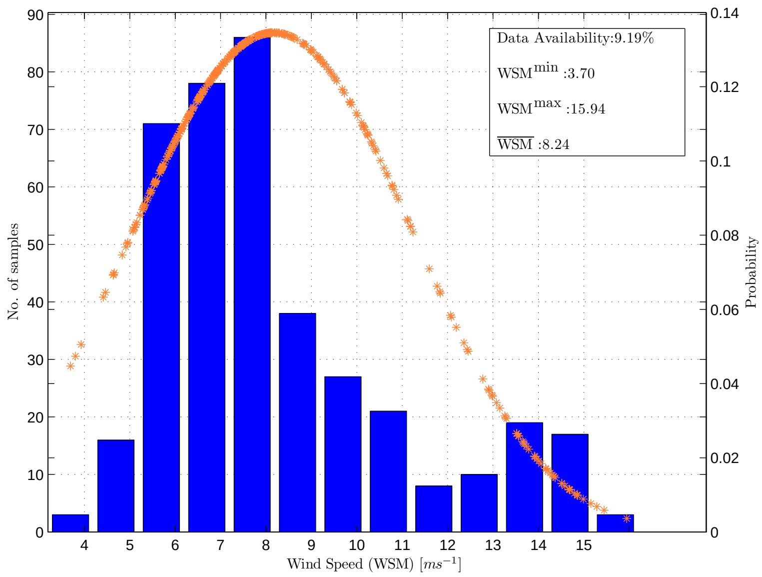


Figure 1.431: September 2012 probability distribution function

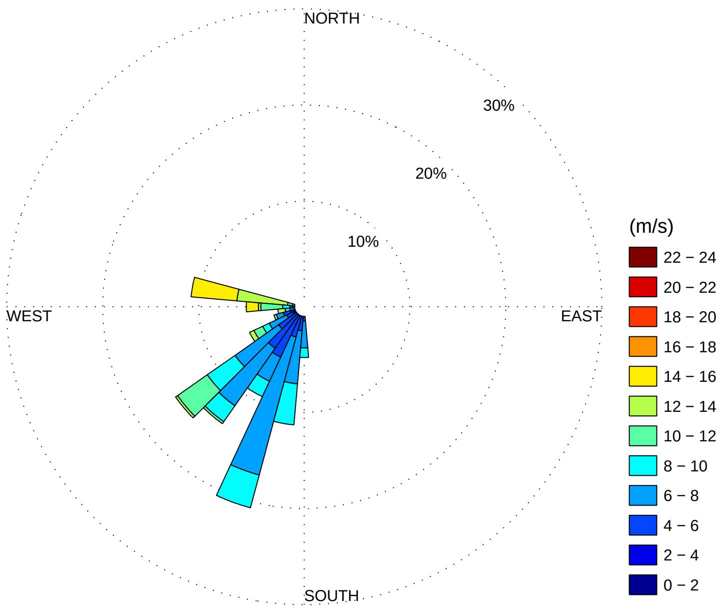


Figure 1.432: September 2012 Wind Rose

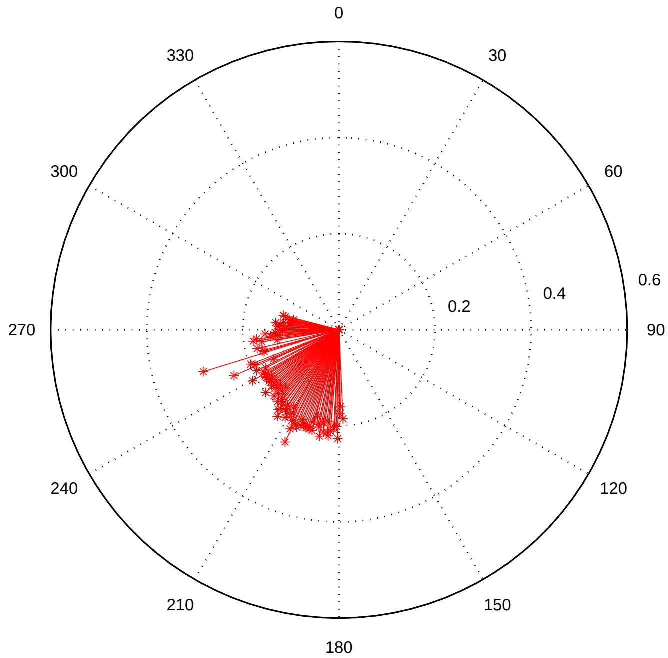


Figure 1.433: September 2012 turbulence intensity

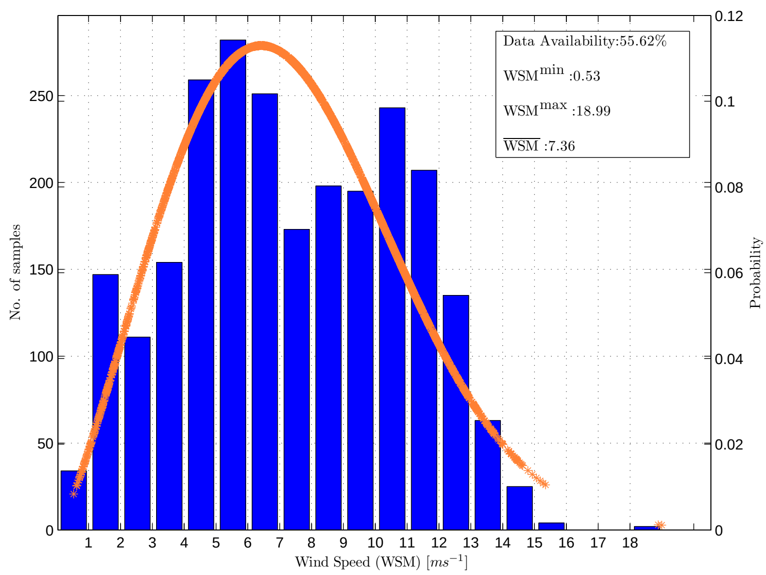


Figure 1.434: October 2012 probability distribution function

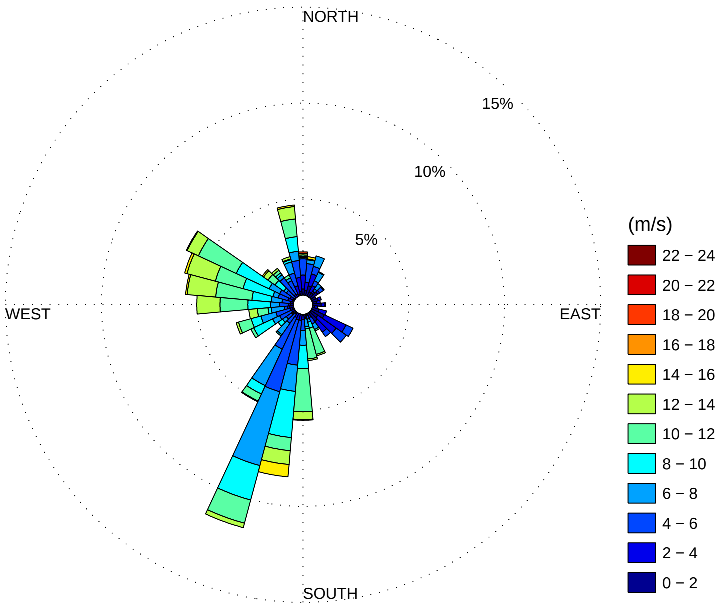


Figure 1.435: October 2012 Wind Rose

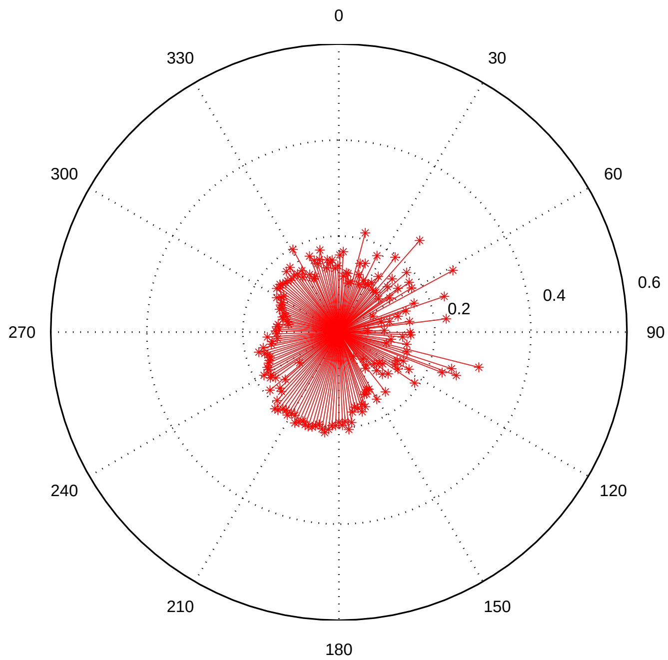


Figure 1.436: October 2012 turbulence intensity

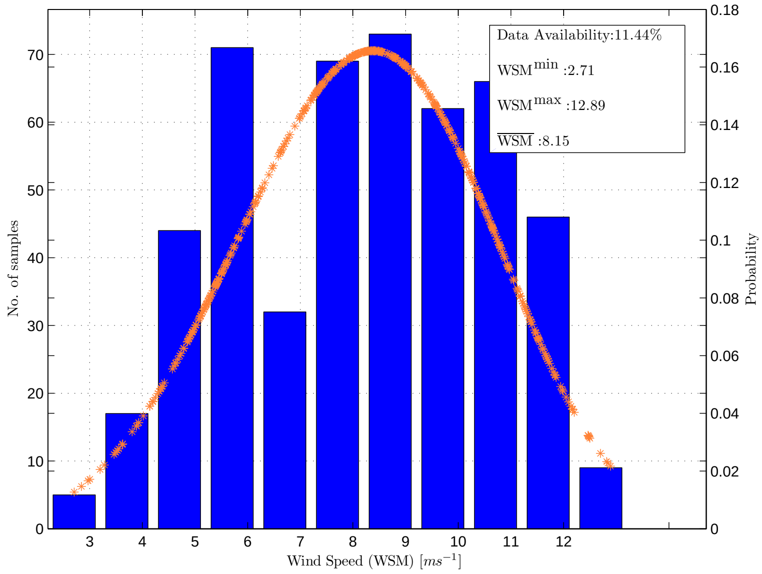


Figure 1.437: November 2012 probability distribution function

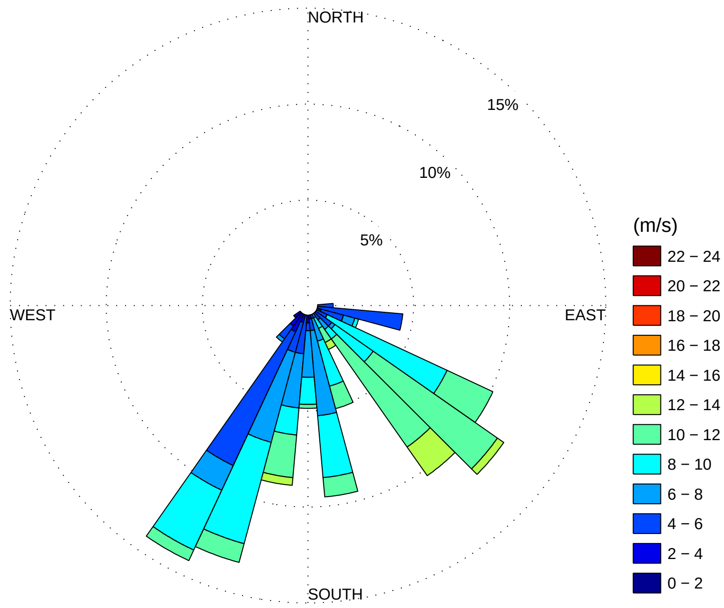


Figure 1.438: November 2012 Wind Rose

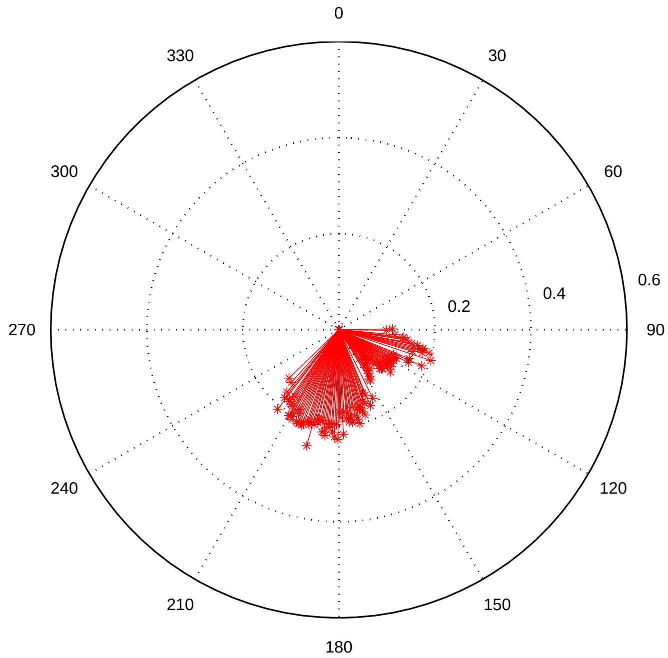


Figure 1.439: November 2012 turbulence intensity

1.11.2 2013 Annual Statistics

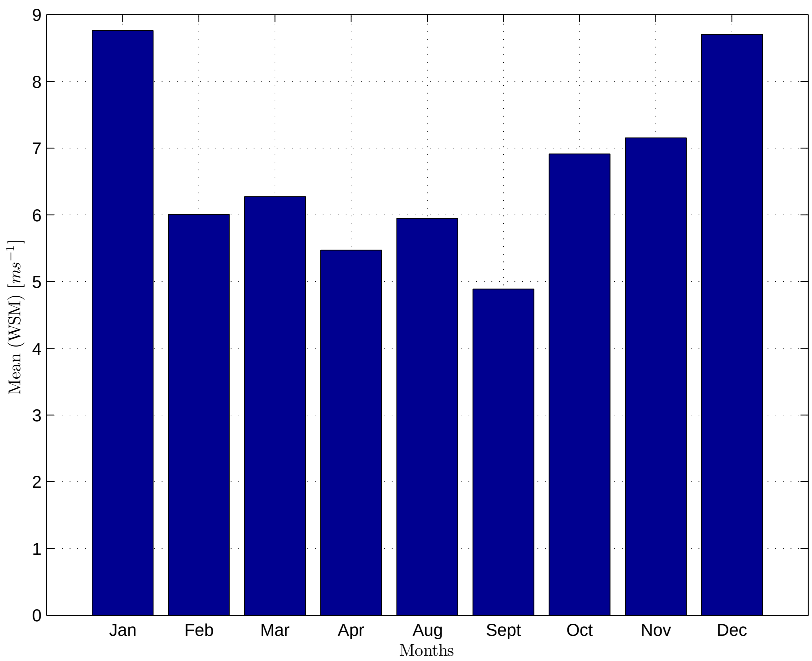


Figure 1.440: Annual wind speed distribution of WSM, 2013

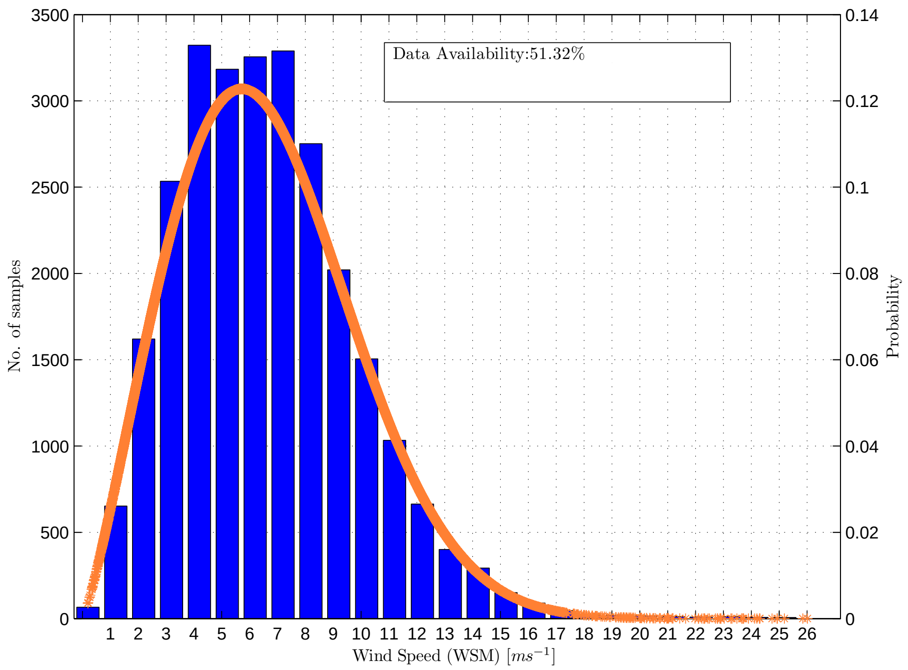


Figure 1.441: Annual wind speed distribution of WSM, 2013

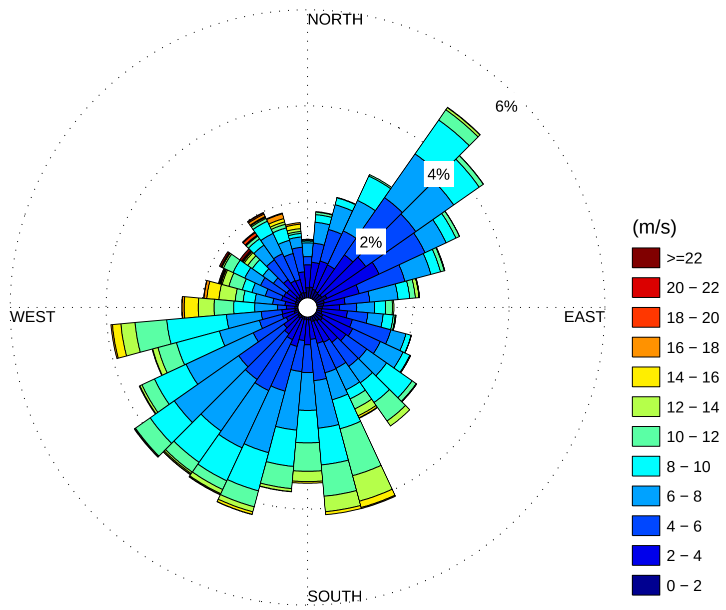


Figure 1.442: Annual wind rose of WSM, 2013

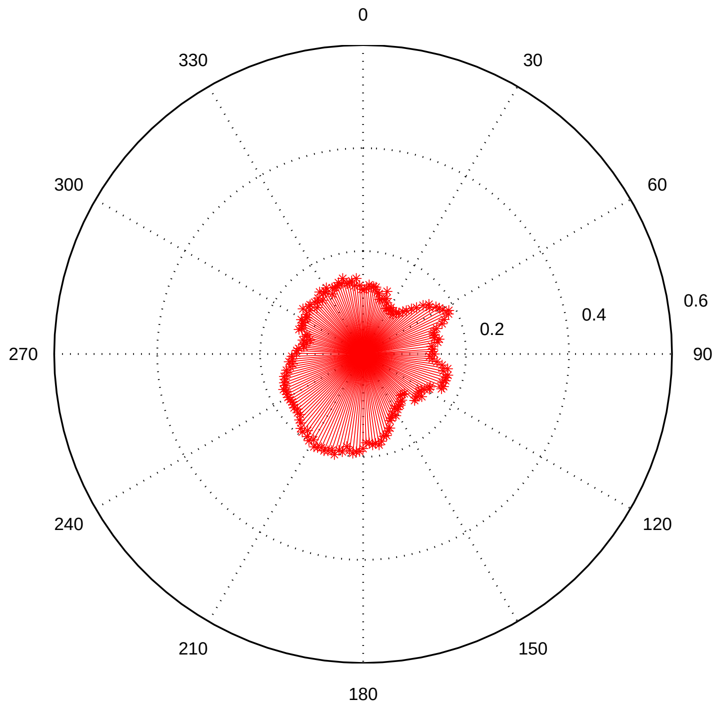


Figure 1.443: Turbulence intensity of WSM, 2013

Table 1.37: Monthly wind speed [ms^{-1}] parameters of 1 sec. raw data, 2013

Month	Min	Mean	Max
January	0.12	8.74	23.88
February	0.05	6.01	32.14
March	0.03	6.27	20.31
April	0.01	5.47	19.27
August	0.92	5.95	13.17
September	0.04	4.89	21.40
October	0.03	6.91	28.16
November	0.01	7.15	22.62
December	0.06	8.70	36.88

Table 1.38: Monthly wind speed [ms^{-1}] parameters of 10 min. averaged data, 2013

Month	Data Availability(%)	Min	Mean	Max	K	C
January	4.19	1.11	8.76	17.30	2.91	9.78
February	50.42	0.52	6.01	22.87	2.09	6.78
March	99.24	0.34	6.27	15.12	2.46	7.07
April	71.85	0.20	5.47	14.24	2.18	6.18
August	8.67	3.13	5.95	9.45	3.53	6.64
September	83.31	0.39	4.89	14.48	2.11	5.54
October	99.73	0.36	6.91	22.23	2.55	7.79
November	100.00	0.35	7.15	16.85	2.45	8.07
December	100.00	0.66	8.70	26.01	2.61	9.79

1.11.2.1 2013 Monthly Statistics

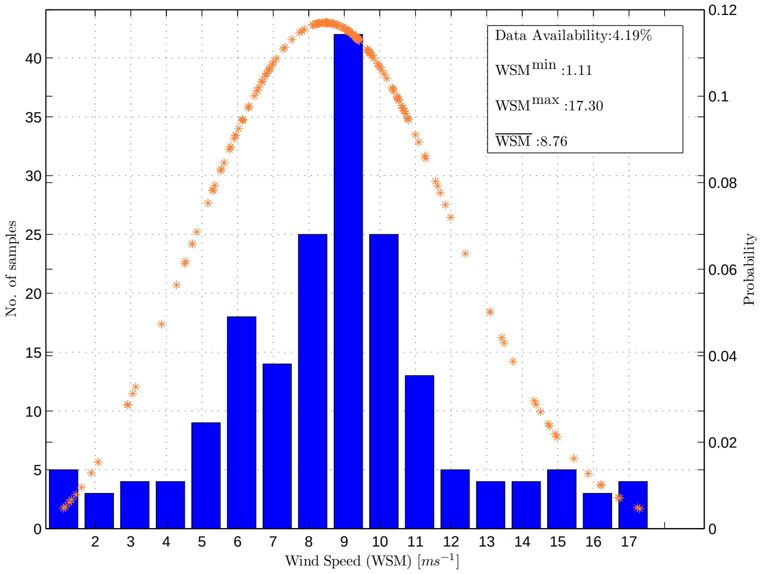


Figure 1.444: January 2013 probability distribution function

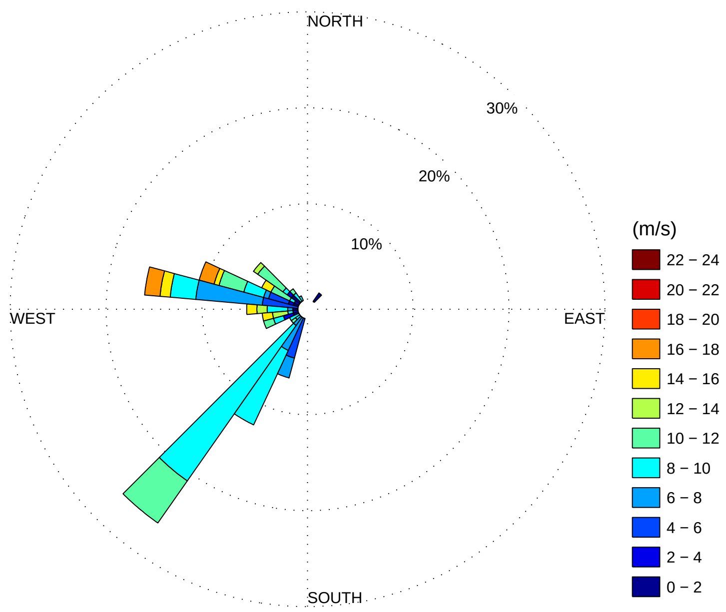


Figure 1.445: January 2013 Wind Rose

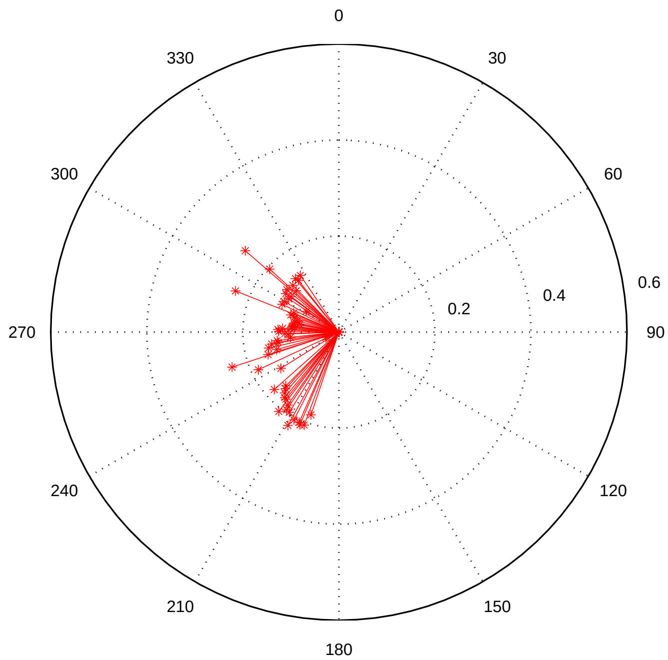


Figure 1.446: January 2013 turbulence intensity

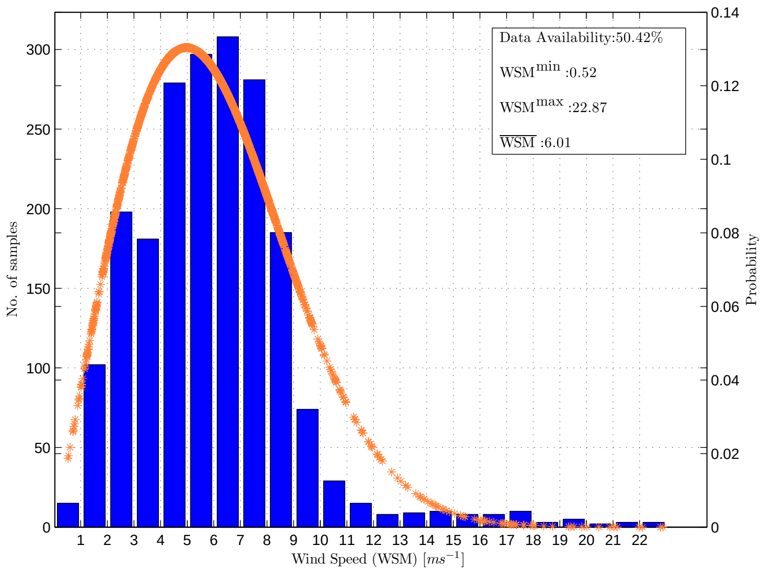


Figure 1.447: February 2013 probability distribution function

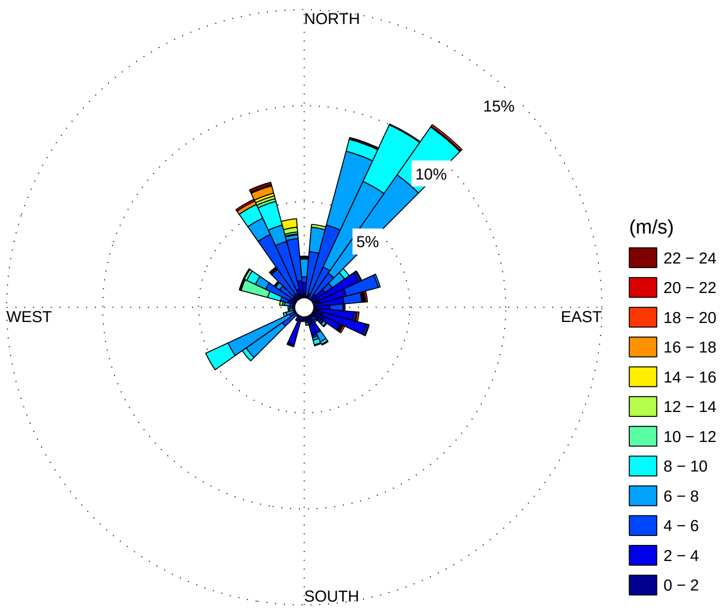


Figure 1.448: February 2013 Wind Rose

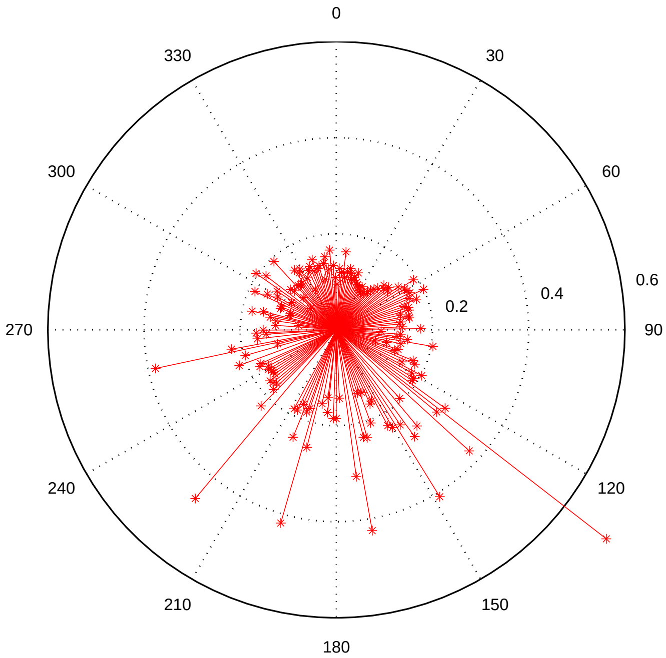


Figure 1.449: February 2013 turbulence intensity

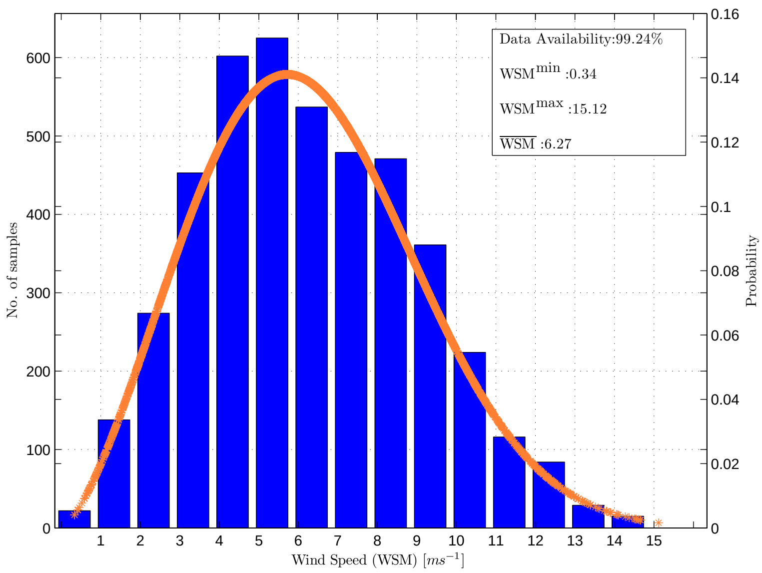


Figure 1.450: March 2013 probability distribution function

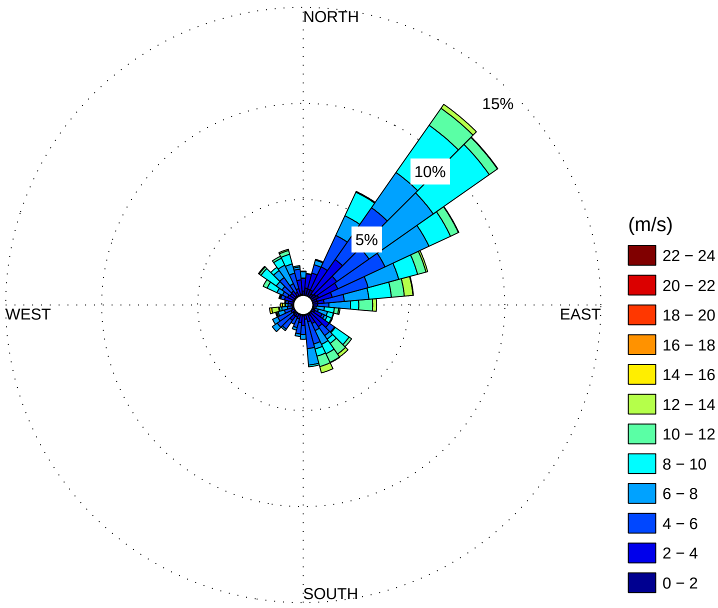


Figure 1.451: March 2013 Wind Rose

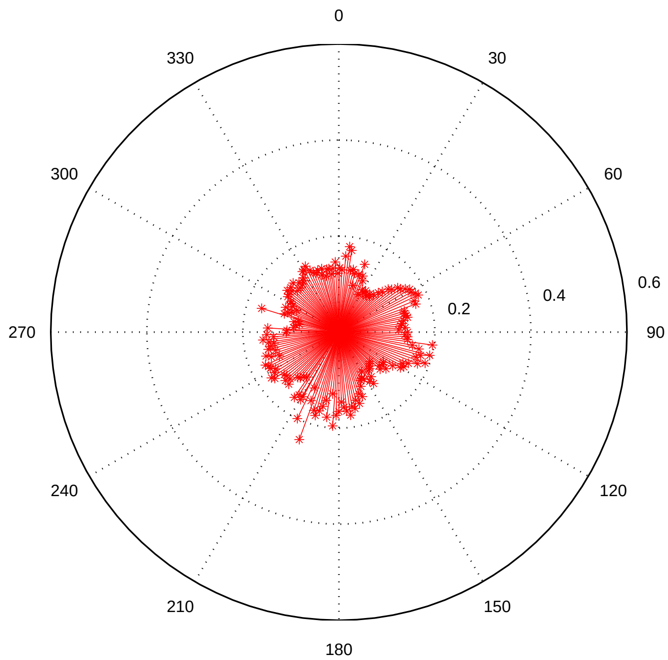


Figure 1.452: March 2013 turbulence intensity

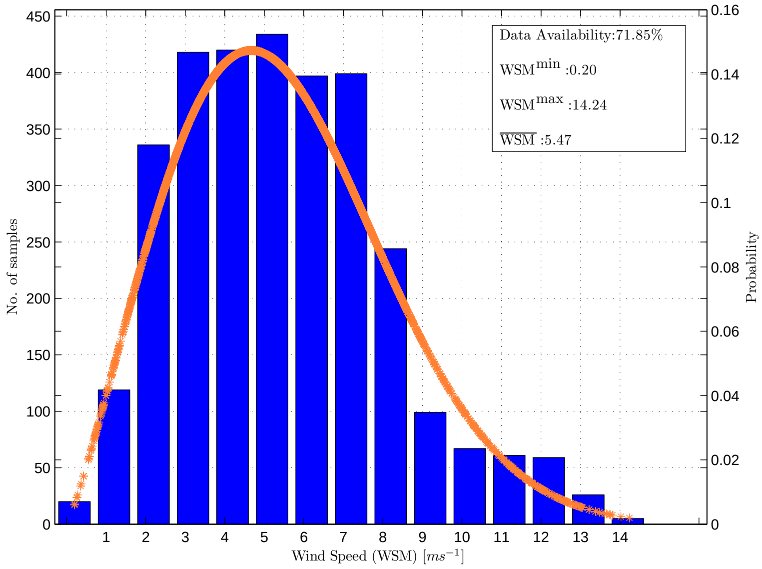


Figure 1.453: April 2013 probability distribution function

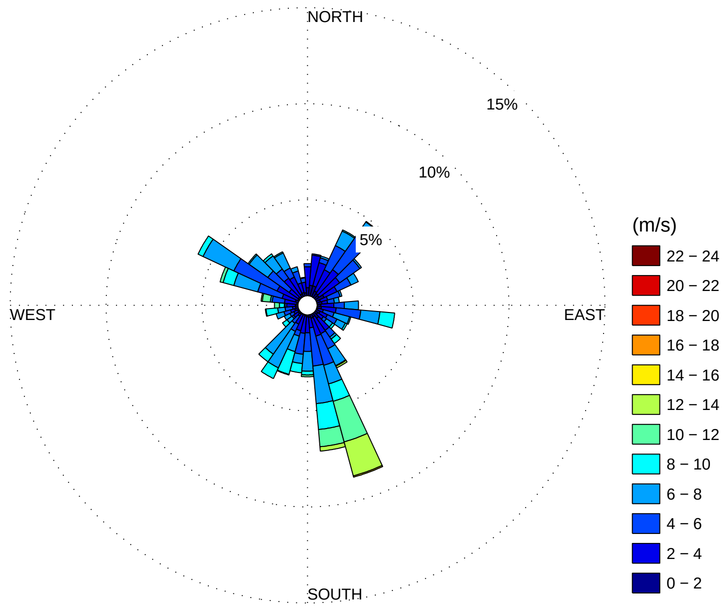


Figure 1.454: April 2013 Wind Rose

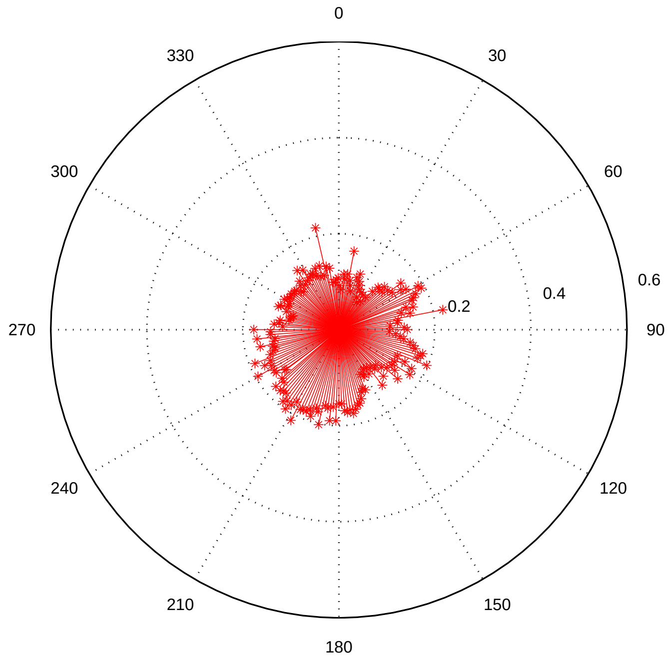


Figure 1.455: April 2013 turbulence intensity

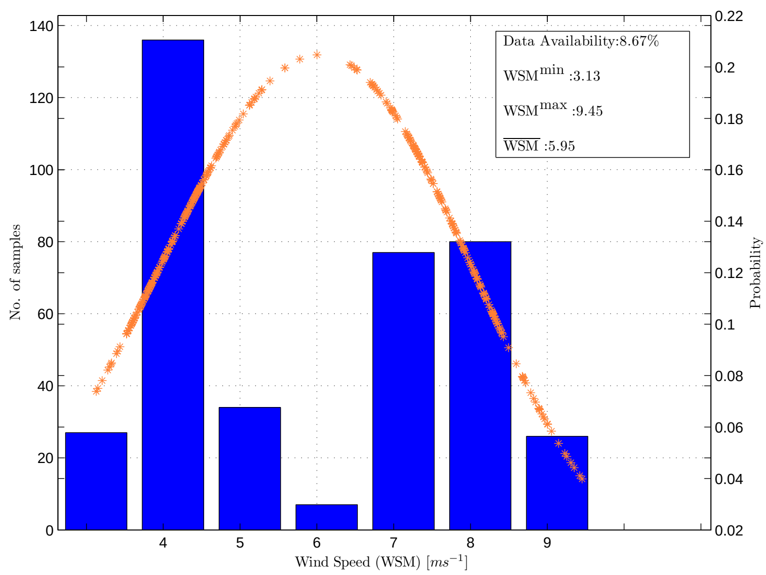


Figure 1.456: August 2013 probability distribution function

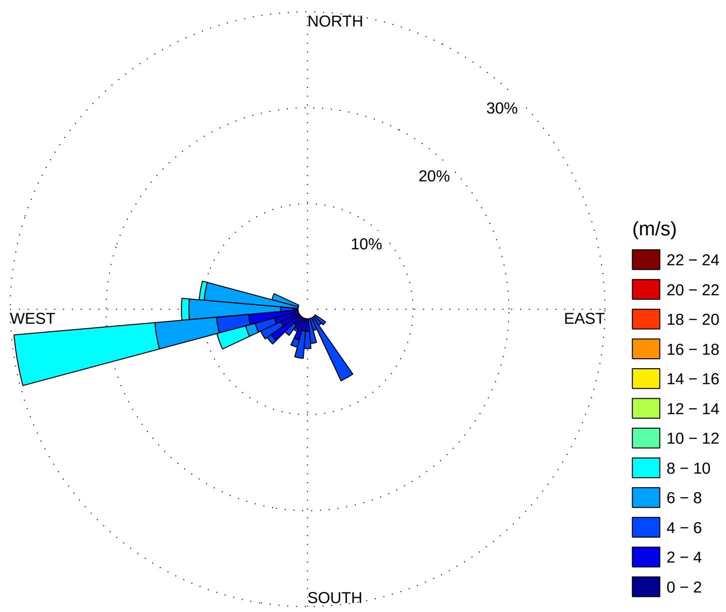


Figure 1.457: August 2013 Wind Rose

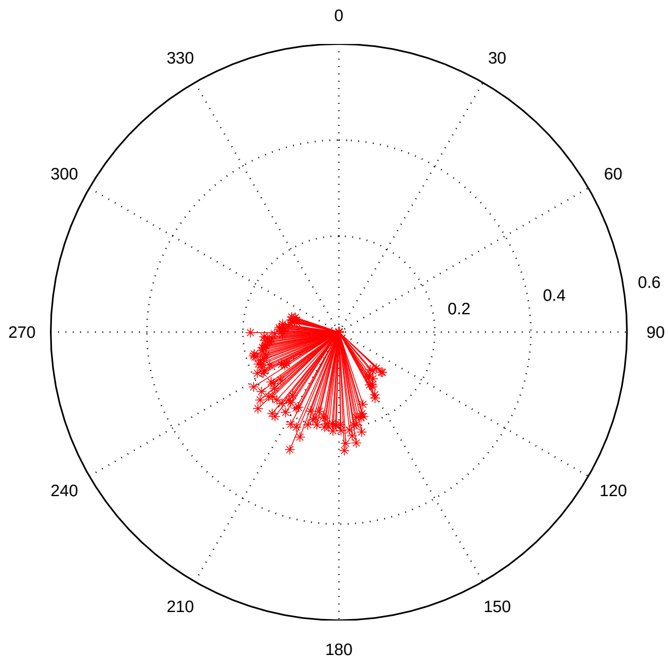


Figure 1.458: August 2013 turbulence intensity

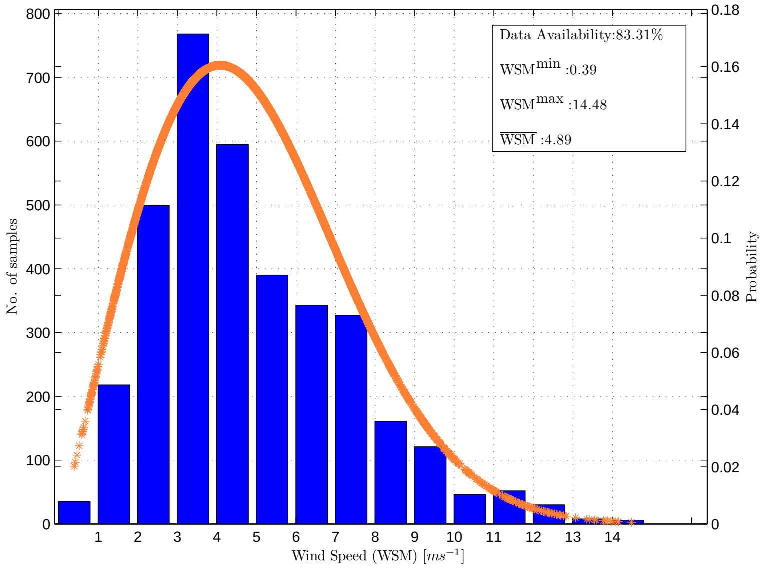


Figure 1.459: September 2013 probability distribution function

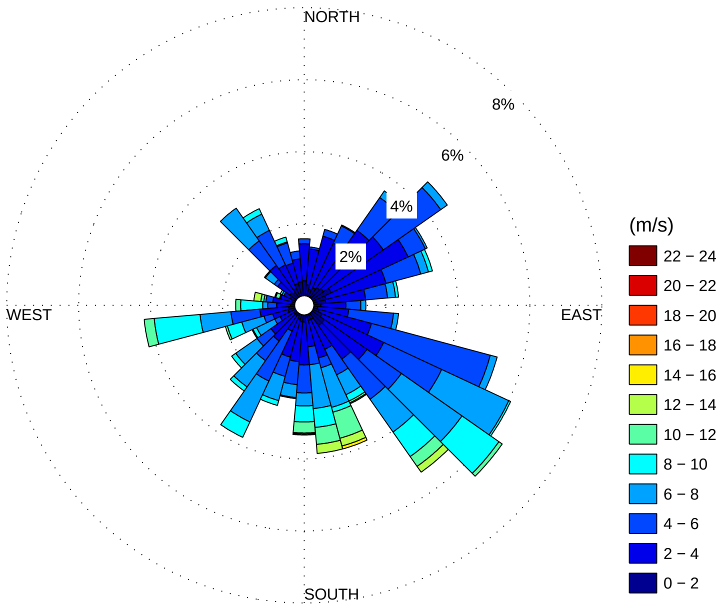


Figure 1.460: September 2013 Wind Rose

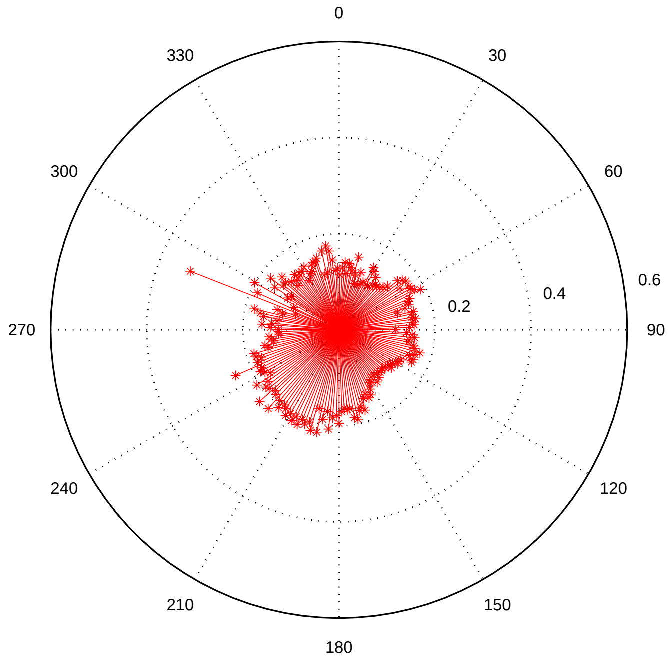


Figure 1.461: September 2013 turbulence intensity

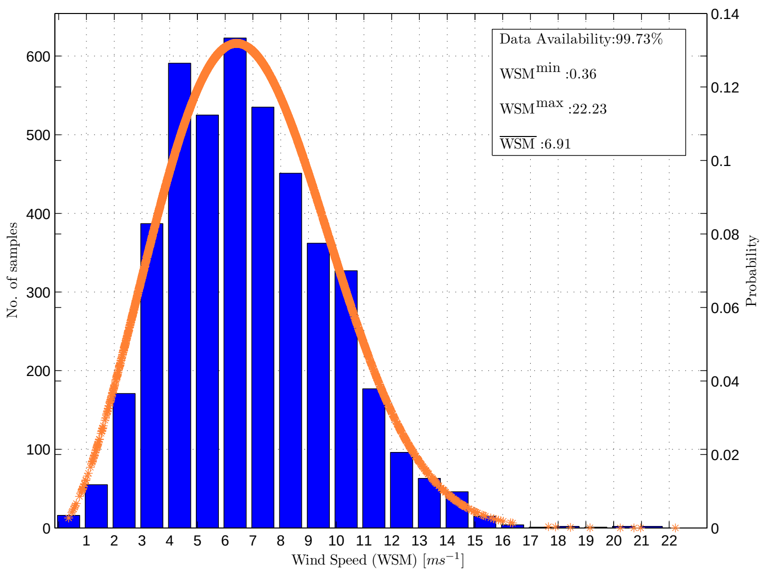


Figure 1.462: October 2013 probability distribution function

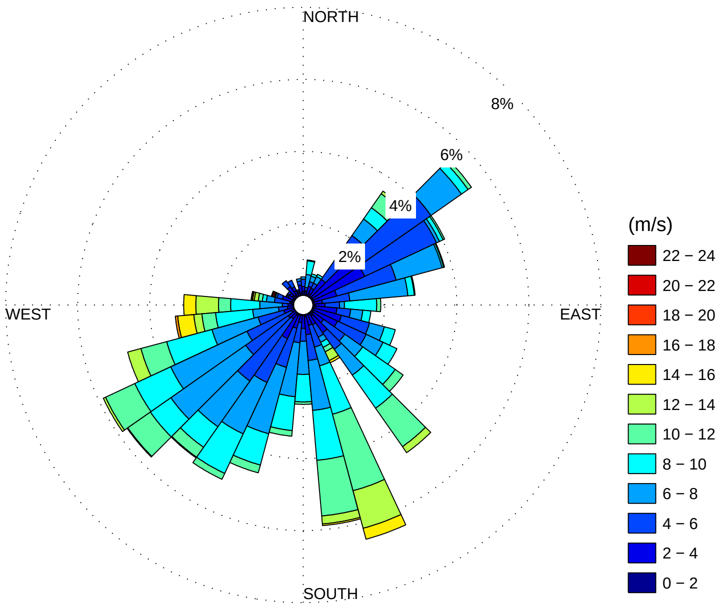


Figure 1.463: October 2013 Wind Rose

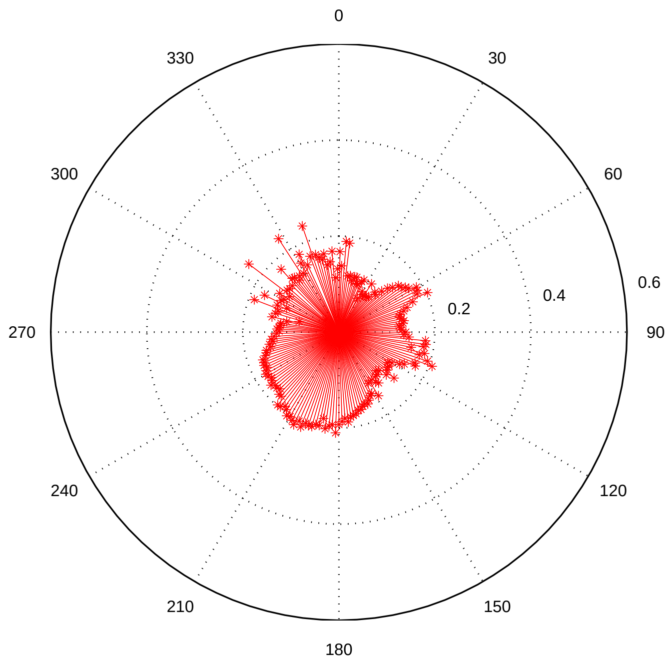


Figure 1.464: October 2013 turbulence intensity

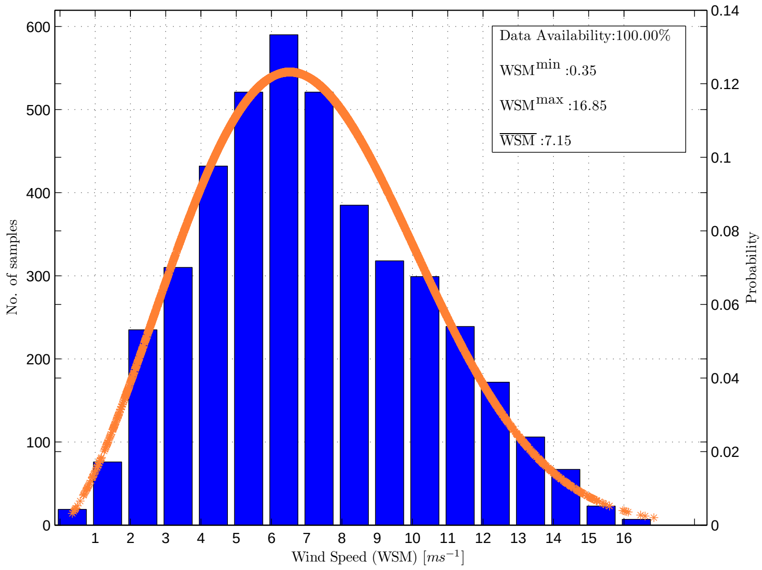


Figure 1.465: November 2013 probability distribution function

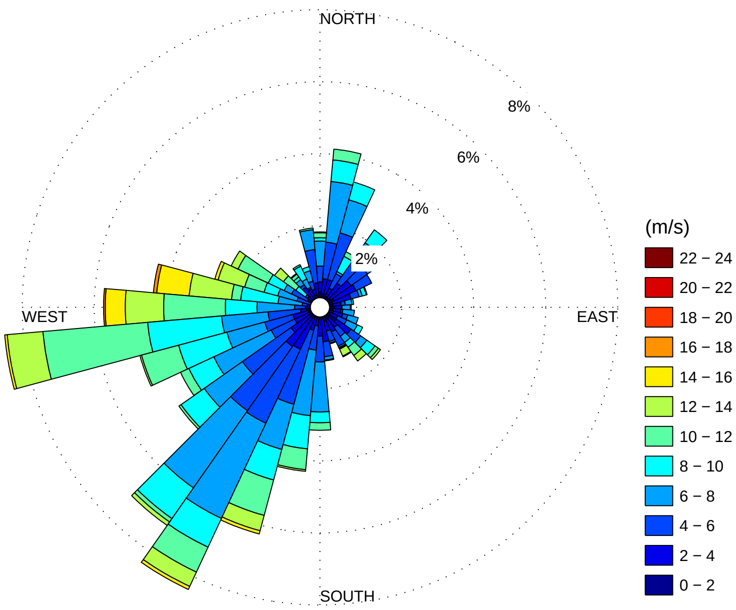


Figure 1.466: November 2013 Wind Rose

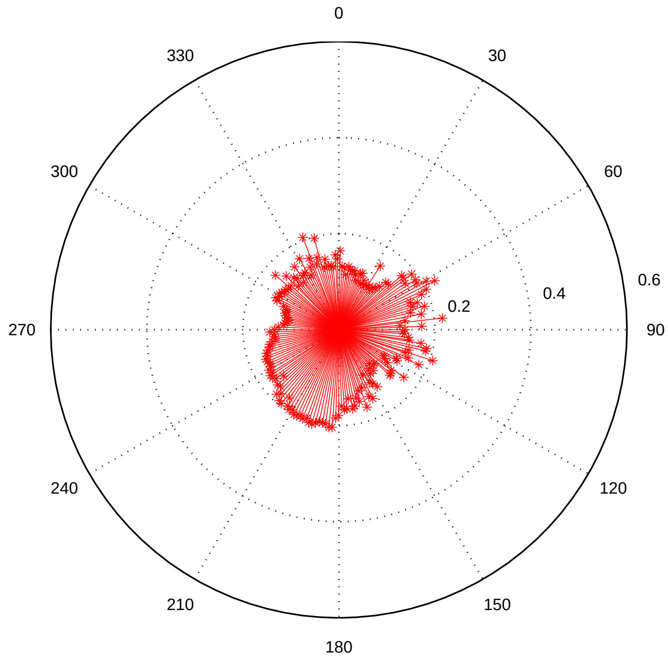


Figure 1.467: November 2013 turbulence intensity

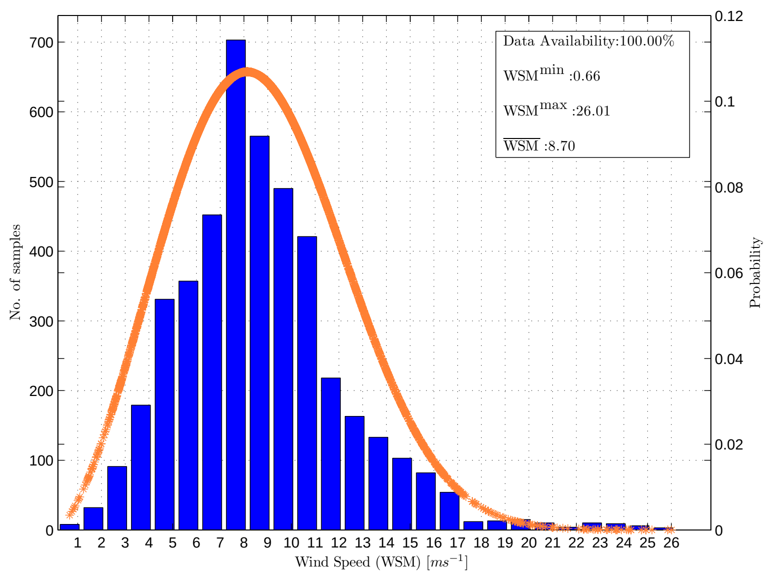


Figure 1.468: December 2013 probability distribution function

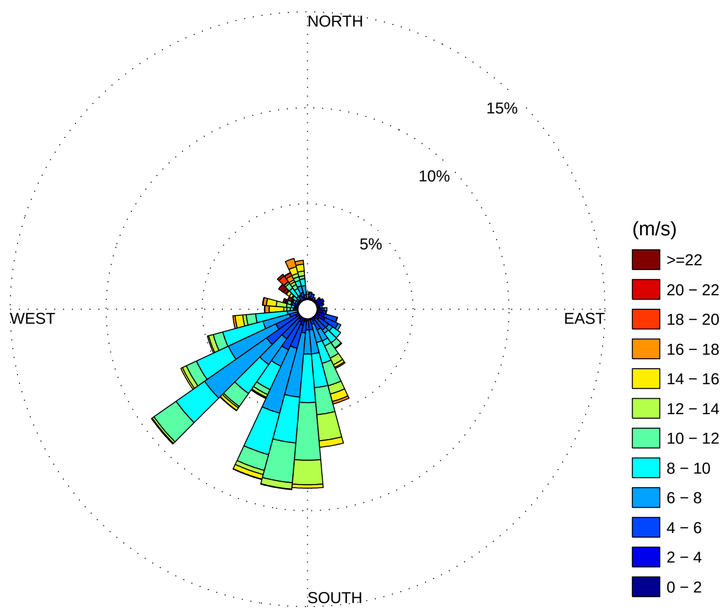


Figure 1.469: December 2013 Wind Rose

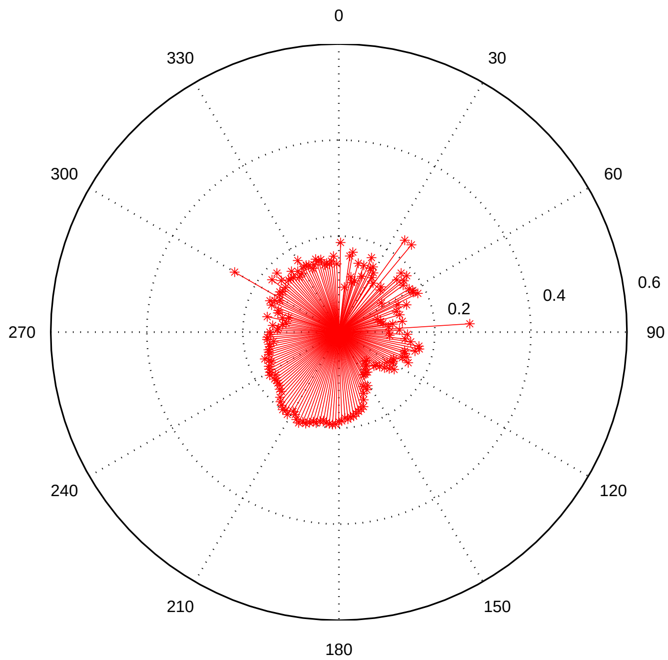


Figure 1.470: December 2013 turbulence intensity

Chapter 2

Comparison of WST with WSO & WSM

WST is a mechanical cup anemometer and hence frictional effects, particularly at lower wind speeds would contribute to inaccuracy in wind speed readings. This inaccuracy is corrected with the help of WSO anemometer data. WSO is a sonic anemometer which is at almost the same height as the WST anemometer. This sonic anemometer is a newly installed and does not have any moving parts, and is assumed to be accurate. WST anemometer stopped working during November 2012 when one of its cup was broken. Both WSO and WST anemometers were under parallel operation during end of October 2012. Therefore the concurrent data availability of both the anemometers is very limited. Both these anemometers experience mast wake of meteorological mast-1.

2.1 Comparison of WST with WSO

The raw WSO files have 10 Hz precision and contains different file lengths. They are processed to have 1 file/day with 1 Hz precision, so that they can be compared to raw WST files with 1 Hz precision. Number of lines/rows in the processed WSO files vary. In an ideal case there should be 86399 lines/rows recorded. However due to lag in writing/saving raw WSO data files and other disturbances in the measurement computer, the number of lines differs. In this differed no. of lines/rows scenario, lines/rows that is a minimum of the two is considered.

For example, as shown in Table B.3, WSO processed file dated October 4 contains 84452 columns compared to 86399 columns in corresponding WST file. In this case 84452 samples are considered in both WSO and WST files. Table B.3 shows the files that are considered for the analysis. The rest of the files in the month are not available for WSO files and so the corresponding

WST are not considered.

Number of lines recorded for different anemometer files for the same day have slight differences. The hardware card that interfaces WST anemometer with the measurement computer samples the data at 5000 Hz before they are averaged to 1 Hz by a LabView program. LabView program then writes the 1 Hz data into LabView measurement files (.lvm) onto the system hard disk, this writing is synchronized to the operating system clock. There could be a lag or lead in the above tasks that could possibly cause slight variations in the number of rows recorded. Gill sonic anemometers are equipped with an internal clock that samples data at 10 Hz. They are stored on the measurement computer initially with a WindView program. They are then processed with a LabView program to make them loadable in Matlab environment. WSO and WST presented in the table B.3 are concatenated in increasing order of their date and are averaged to 10 minute resolution.Figure 2.1 shows the 10 minute averaged WSO and WST data.

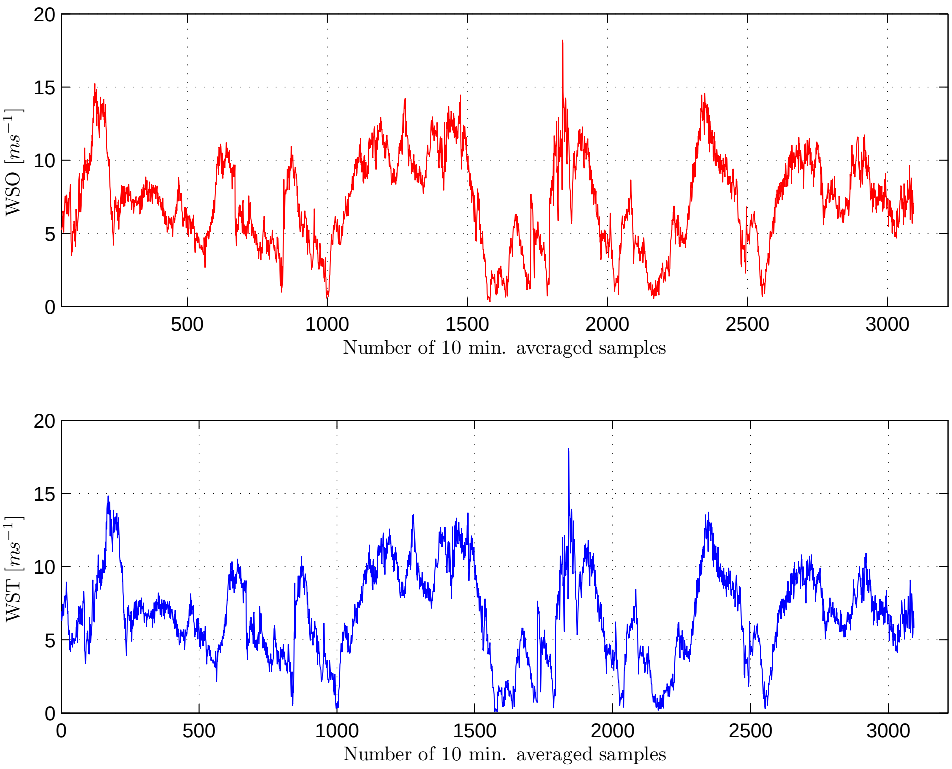


Figure 2.1: Comparison of WSO and WST 10 min. averaged data

Figure 2.3 shows the ratio of wind speeds of WSO and WST over different directions. It can be observed that in the sector spanning from 0°-180°, has a significant scatter since a part of this sector is under the wake of met. mast-1. This sector could also experience wake of nearby Chalmers wind turbine. Sector from 180°-360° is relatively undisturbed compared to the previous sector and as a result the wind ratio samples ranges between 0.45 and 5 while the mean is 1.11.

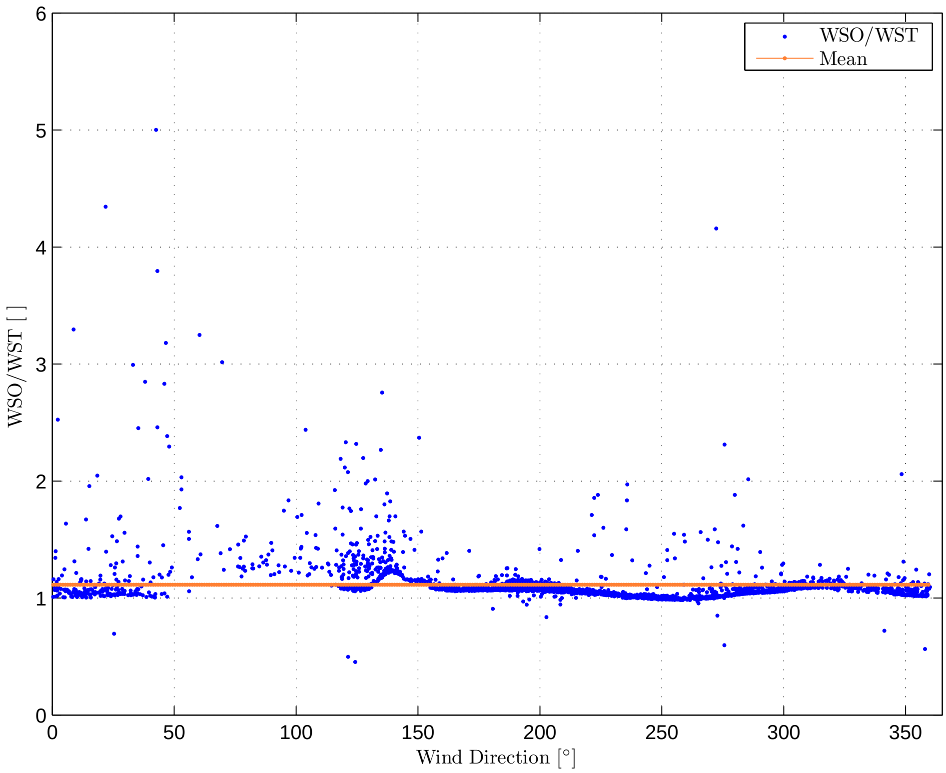


Figure 2.2: Ratio of wind speeds of WSO and WST for different directions

2.1.1 Correction Factor of WST for Friction

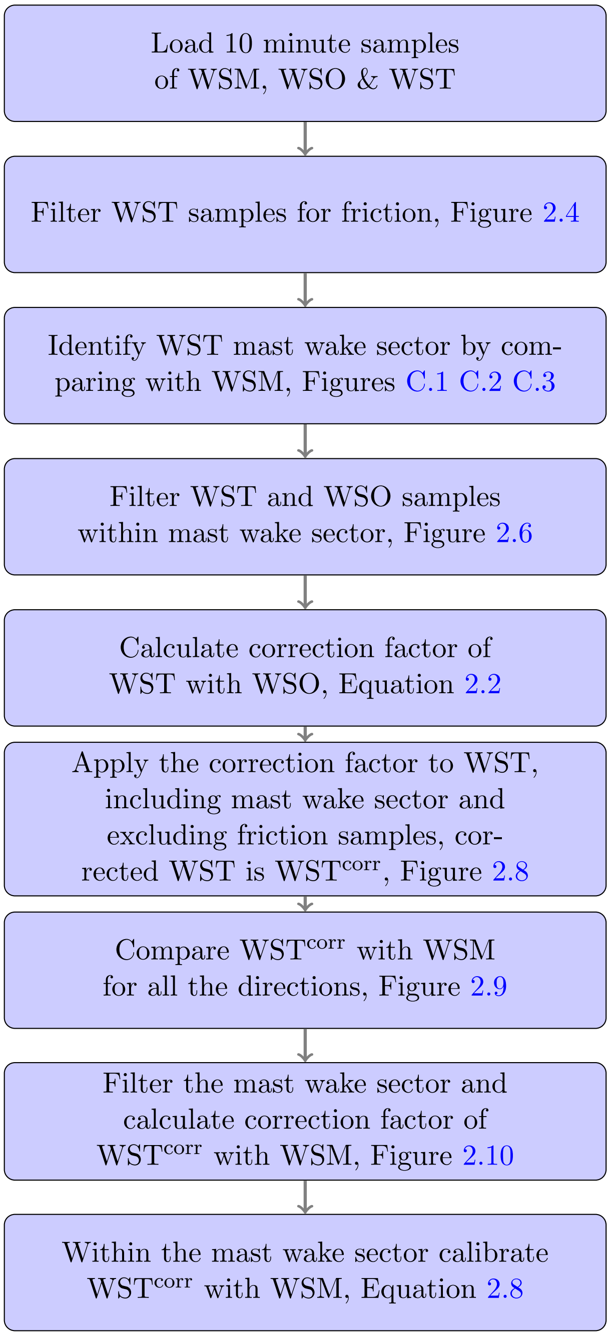


Figure 2.3: Flow chart to calculate WST correction factor for friction and wake

Mechanical cup anemometer (WST) during lower speeds could experience friction from the rotating parts and thereby could record inaccurate wind speeds. Therefore an assumption is made that WST could experience friction during wind speeds lower than $2\mathrm{ms}^{-1}$. This assumption can be partly motivated from the Table C.1. To filter the scatter, an assumption that WSO records accurate data is also made. This assumption can be motivated from the fact that WSO does not have moving parts and also that it is a newly installed anemometer. Samples of WSO that are greater than 2 ms^{-1} are considered. This filter is also applied to WST samples. Table C.1 shows the scatter points ratio higher than 1.3 speed ratio and their corresponding anemometer speed readings in sector 180°-360°. For the scatter ratio less than 1.4, WST records values lower than 2 ms^{-1}. As scatter ratio decreases, an increasing trend for the WST reading is observed. This suggests that a higher scatter is observed when WST records values lower than 2 ms^{-1}. Wind speed ratio of WSO and WST is filtered for friction in WST as shown Figure 2.4. Filtered friction samples are 191, while the considered samples for further analysis are 2902.

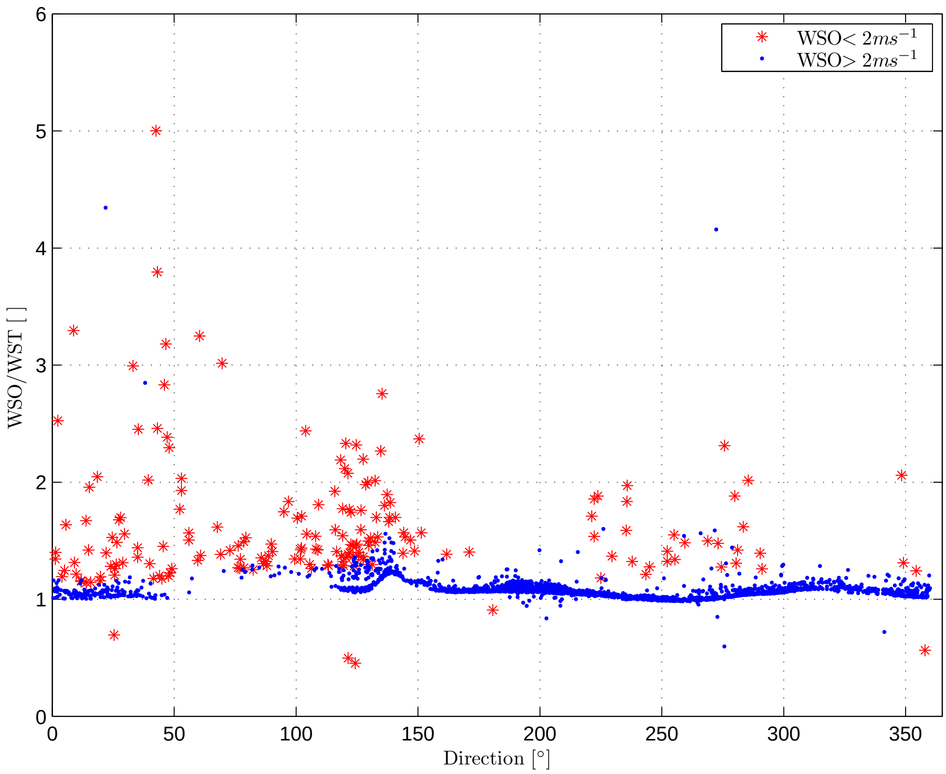


Figure 2.4: Friction and non friction samples of WSO and WST wind speed ratios for different directions

Figure 2.5 shows the wind speed ratio of WSO and WST after friction samples are filtered. The wind speed ratio varies between 0.59 and 4.34 while the mean of wind speed ratio is 1.08.

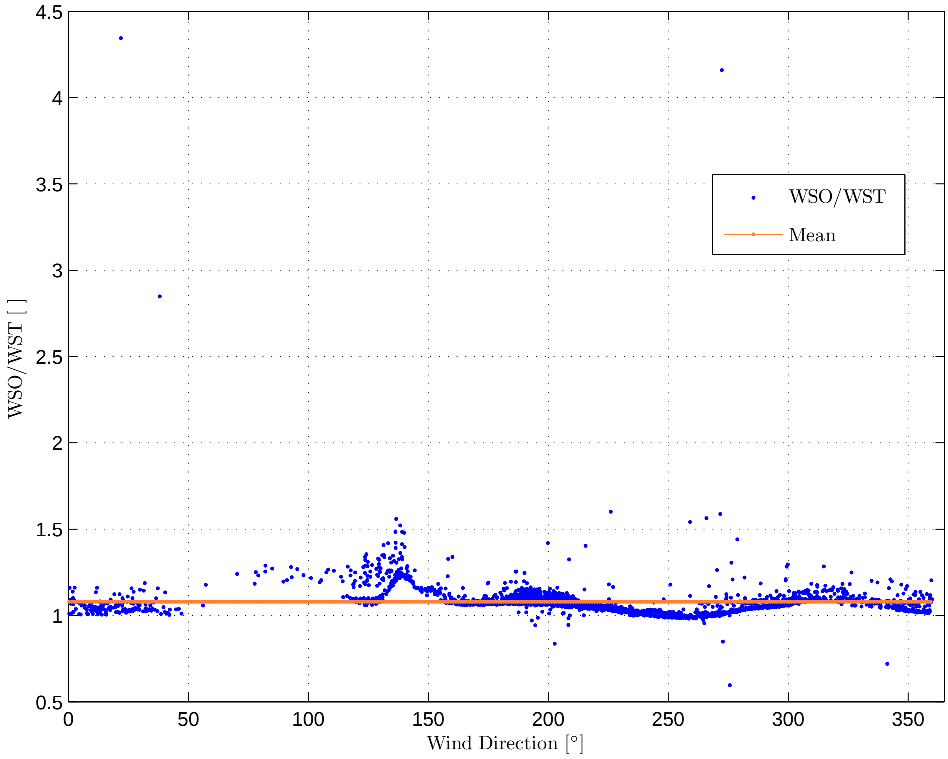


Figure 2.5: Wind speed ratio of WSO and WST after filtering friction samples

The possible mast wake sector of WST and WSO should also be identified and samples within this sector should be discarded in-order to calibrate WST with WSO. This is because the samples within mast wake sector experience as mentioned before. Anemometers in the mast wake record low wind speeds as shown in the Figures C.3 C.4. Neglecting them in the calibration would contribute to a more accurate WST correction factor. The angle of mast wake of the anemometers is identified practically in Section C.1 and theoretically in Section G. Figure 2.6 shows the wind speed ratio of WSO and WST excluding possible mast wake sector of 110°-148°.

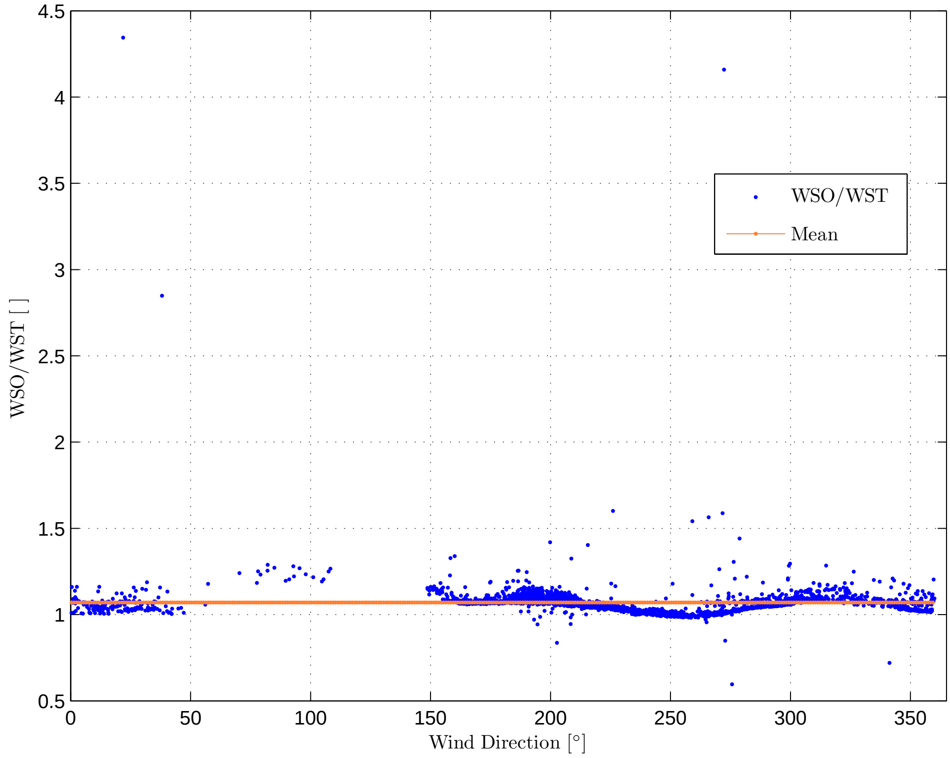


Figure 2.6: Wind speed ratio of WSO and WST for different directions excluding mast wake sector and friction samples

A linear curve fitting function is applied to the binned data after mast wake filtration as shown in the Figure 2.7.The curve fitting yielded a mathematical relation between WST and WSO as:

$$\mathrm{WST} = 0.96 \times \mathrm{WSO} - 0.1, \forall\, 0^\circ \leq \theta \leq 110^\circ, 148^\circ \leq \theta \leq 360^\circ \tag{2.1}$$

Changing the subject of the Equation 2.1

$$\mathrm{WST}^{\mathrm{corr}} = 1.03 \times \mathrm{WST} + 0.14, \forall\, 0^\circ \leq \theta \leq 110^\circ, 148^\circ \leq \theta \leq 360^\circ \tag{2.2}$$

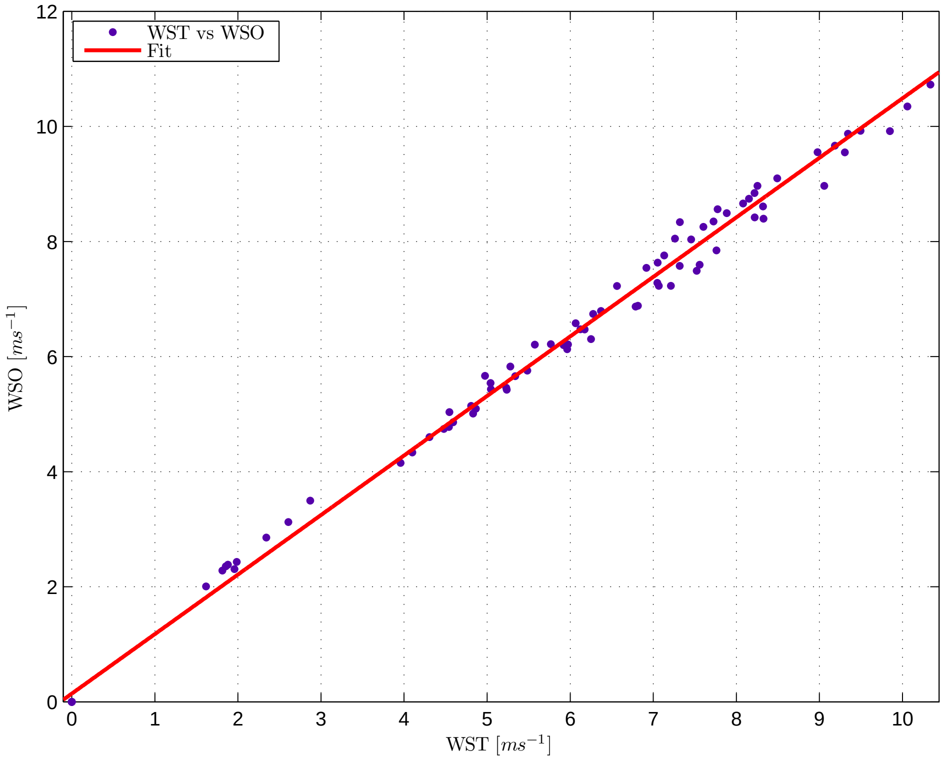


Figure 2.7: Curve fitting of filtered data

Correction factor of WST is applied to WST samples excluding friction samples. Figure 2.8 shows the wind speed ratio of WSO and WST^{corr} for different directions. The scatter is considerably reduced after correction, compared to the Figure 2.5 before correction. Wind speed ratio ranges between 0.57 and 3.66 while the mean of wind speed ratio is 1.02.

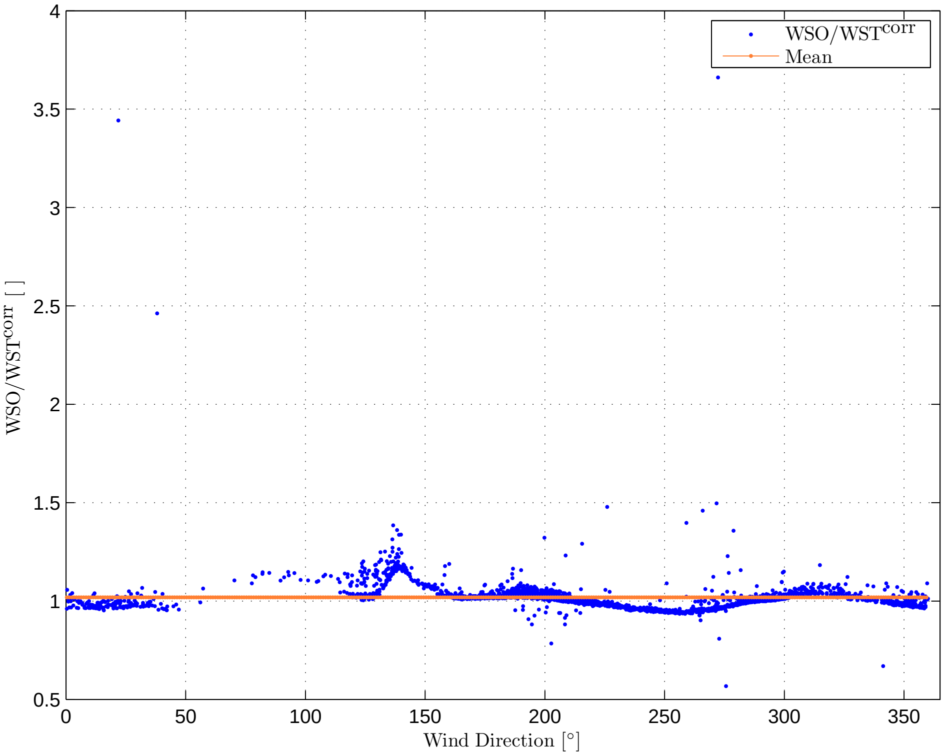


Figure 2.8: Ratio of wind speed of WSO and WST^{corr}

The following are the observations that are worth pointing about the correction factor of WST

- It is assumed that WST and WSO anemometer booms are oriented in the same angle with respect to mast-1. In practice, as it appears from Figure 1.4, they differ slightly. If say, WST is orientated at 318° then WSO is oriented less than 318° with respect to mast-1. This difference could lead to slightly different mast wake sectors for WST and WSO.

- When correcting WST for friction, the correction is derived such that WST should record the same wind speed as WSO, considering their same height. The wake of WSO on WST is neglected here for simplicity in calculation and also due to the lack of concurrent data for WSO and WST anemometers.

- WST is close to mast-1 and has a larger/wider mast wake sector compared to that of mast wake sector of WSO. WST mast wake sector samples are discarded in calculating WST correction and the same filter is applied to WSO data. This means that even though WSO has a slightly different mast wake, this filter could compensate for this difference.

- When correcting WST for mast wake, the correction is derived in a way such that the wind speed ratio of WSM and WST would be the same in all directions. This is based on the *Wind profile power law* which mentions that the wind speed changes with height. As heights of WSO and WST are different they cannot be equated directly but can be corrected to have the same wind speed ratio for all wind directions.

2.2 Comparison of WST with WSM

Mast wake sector of WST is slightly wider compared to that of the mast wake sector of WSO. This is due to WST being closer to mast compared to that of WSO. This scenario can be understood from the Figure C.5. WST within the mast wake sector is corrected with respect to WSM. Before WST is corrected with WSM, it is calibrated with WSO excluding the mast wake sector.

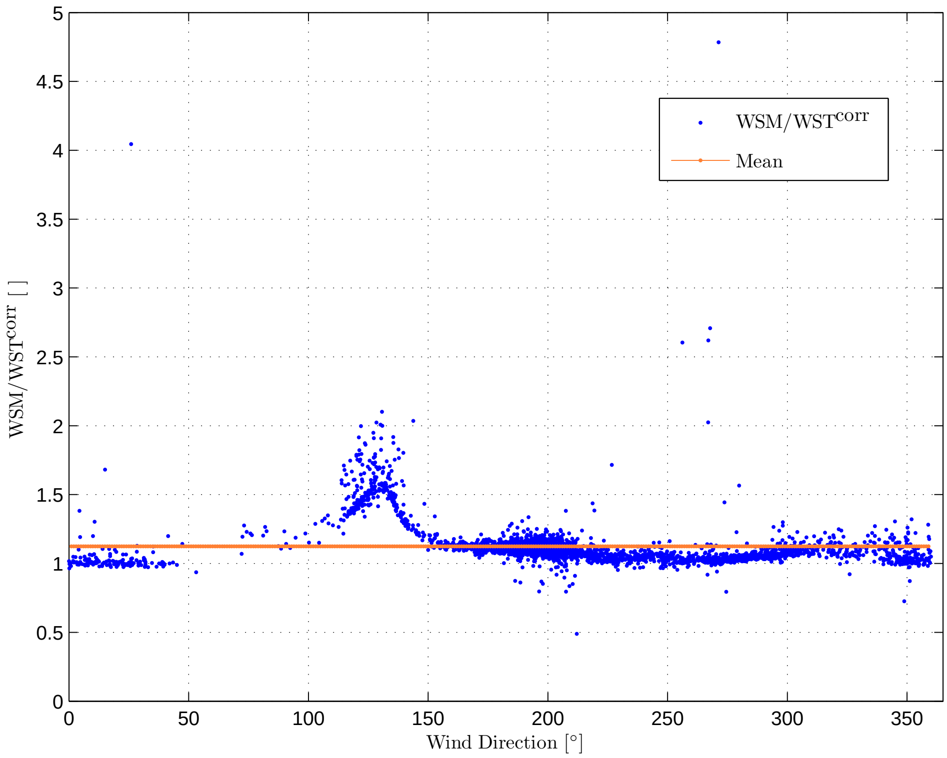


Figure 2.9: Comparison of WSM and WST^{corr} for all directions

The mast wake sector of WST needs to be corrected with WSM. WSM is the top anemometer located at around 28.5 meters without any known obstacles around it. Hence data from WSM is compared to that of WST, to calculate the correction factor for WST within mast wake. This correction is required to know the accurate annual power production from the WST anemometer height. Figure 2.9 shows the wind speed ratio of WSM and WST^{corr} over different directions.

Mast wake sector should be discarded as WST^{corr} within this sector still need to be corrected. Figure 2.10 shows the wind speed ratio of WSM and WST^{corr} excluding the mast wake sector. Number of samples after filtering those corresponding to the mast wake are 3008 and the mean of the wind speed ratio is 1.07 while the samples ranging between 0.5 and 4.78.

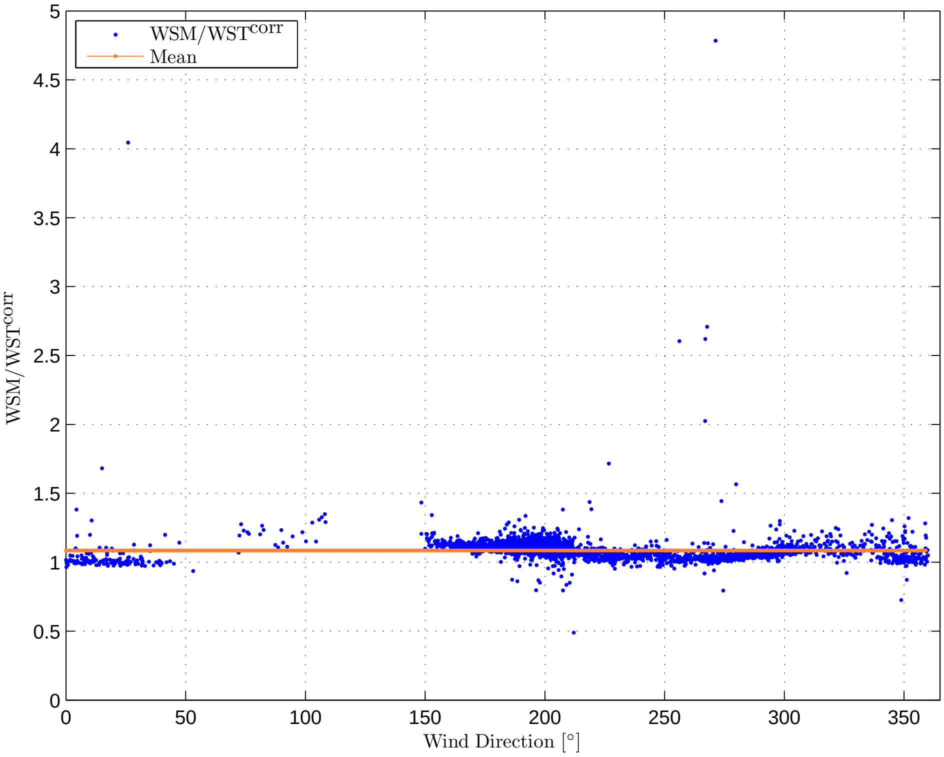


Figure 2.10: Wind speed ratio of WSM and WST^{corr} for different directions excluding mast wake sector

2.2.1 Correction Factor of WST for Mast Wake

WST in the mast wake should not be corrected with WSM anemometer readings. This is because the anemometers are at different heights and hence there bound to be a wind speed difference. However, the wind speed ratio of WSM and WST in the mast wake and no mast wake regions should be equal. This assumption forms the basis for correcting WST in the mast wake sector. The wind speed ratio of WSM and WST in other than the mast wake region should be equal to the wind speed ratio of WSM and WST in the mast wake region. Wind speed ratio of WSM and WST outside mast wake region is 1.09. The following mathematical procedure furnishes the calculation of correction factor of WST in the mast wake, so that within the mast wake region the wind speed ratio of WSM and WST is changed from 1.5 to ratio close to 1.09.

$$\frac{\mathrm{WSM}}{\mathrm{WST^{corr}}} = 1.09,\ \text{Excluding mast wake and friction samples} \tag{2.3}$$

$$\frac{\mathrm{WSM_{wake}}}{\mathrm{WST^{corr}_{wake}}} = 1.5,\ \text{Excluding friction samples} \tag{2.4}$$

$$\text{let,}\ \frac{\overline{\mathrm{WSM}}}{\mathrm{k} \times \overline{\mathrm{WST^{corr}_{wake}}}} = 1.09 \tag{2.5}$$

where, k is correction factor of $\mathrm{WST^{corr}}$ within mast wake sector, solving for k

$$\mathrm{k} = \frac{\overline{\mathrm{WSM}}}{1.09 \times \overline{\mathrm{WST^{corr}_{wake}}}} \tag{2.6}$$

Mast wake sector of WST (110°-148°) is further divided into smaller sectors and correction factor (k) is obtained in these smaller sectors. Figure 2.11 shows the wind speed ratio of WSM and WST after WST is corrected within the mast wake. Four sector are considered within the mast wake sector and correction factor is obtained as following

$$\frac{\overline{\mathrm{WSM}}}{\overline{\mathrm{WST^{corr}}}} = 1.45,\ 1.58,\ 1.54,\ 1.29 \tag{2.7}$$

$$\mathrm{k_1} = 1.28,\ \mathrm{k_2} = 1.39,\ \mathrm{k_3} = 1.36,\ \mathrm{k_4} = 1.16 \tag{2.8}$$

$$\frac{\overline{\mathrm{WSM}}}{\overline{\mathrm{WST^{corr}_{wake}}}} = 1.13,\ 1.14,\ 1.14,\ 1.12 \tag{2.9}$$

$$\frac{\overline{\mathrm{WSM}}}{\overline{\mathrm{WST^{corr}_{wake}}}} = 1.13 \tag{2.10}$$

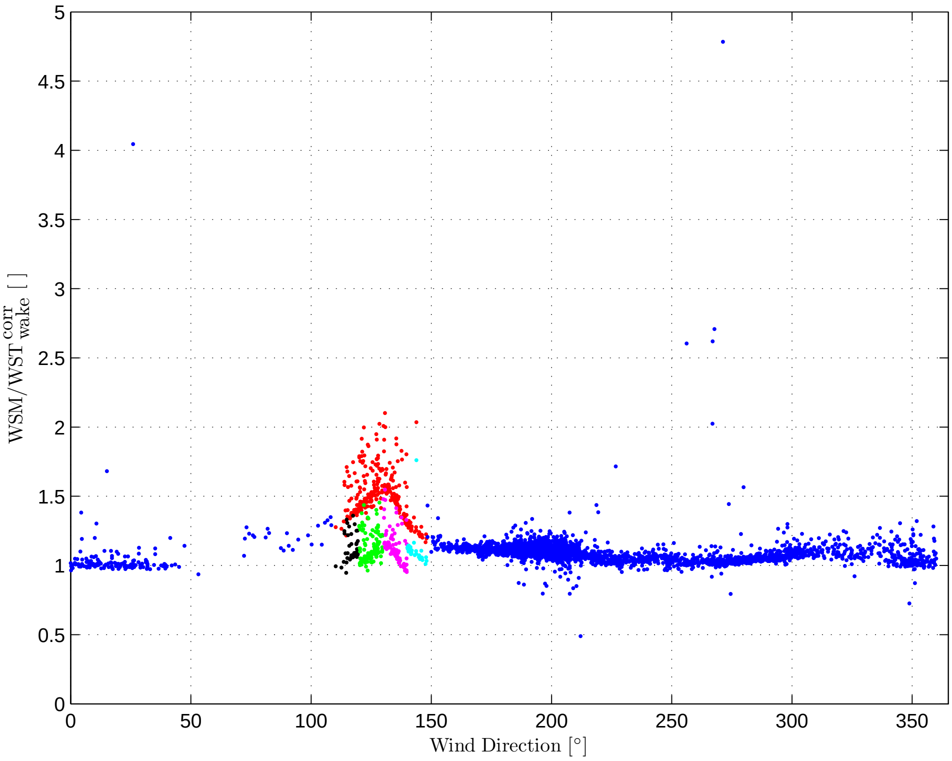


Figure 2.11: Wind speed ratio of WSM and WST$^{corr}_{wake}$ for different directions

Chapter 3

Comparison of WSO with WSM

In this chapter data of WSO anemometer is compared with WSM anemometer data to identify the mast wake sector. A correction factor for WSO anemometer within the mast wake sector is then calculated. The mast wake correction of WSO anemometer is calculated in the same way as in the case of WST anemometer. The theoretical mast wake sector of WSO anemometer is approximately between 130°-138°. Data chosen for this analysis is presented in the Table B.1 B.2.

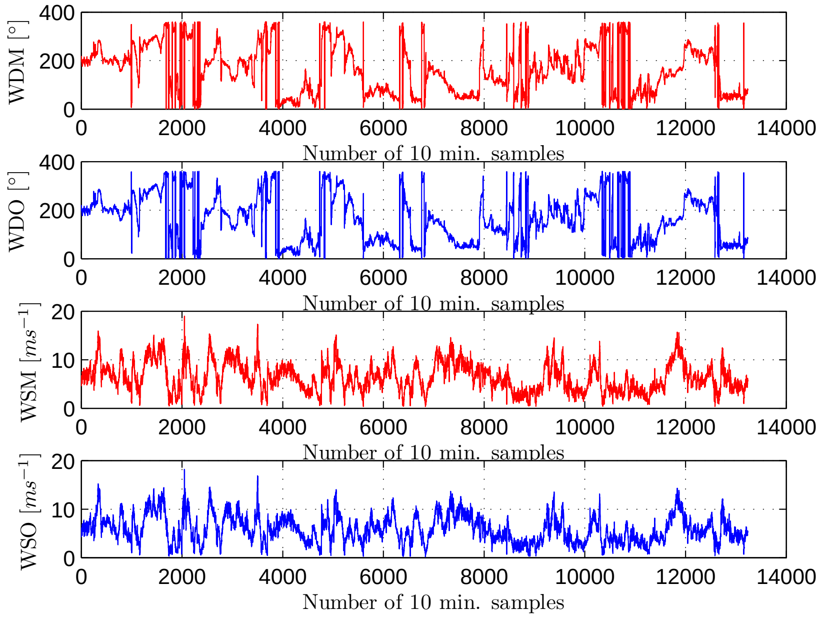


Figure 3.1: Comparison of WSM and WSO 10 min. averaged data

Figure 3.1 shows the 10 minute averaged time series plot for wind speed and wind direction from WSM and WSO anemometers for different directions. Total number of samples considered for this analysis are 13236.

3.1 Correction Factor of WSO for Mast Wake

Figure 3.2 shows the ratio of wind speed of WSM and WSO for different directions. The mean of the wind speed ratio is 1.0974. Wind speed ratio ranges between 0.35 and 3.32.

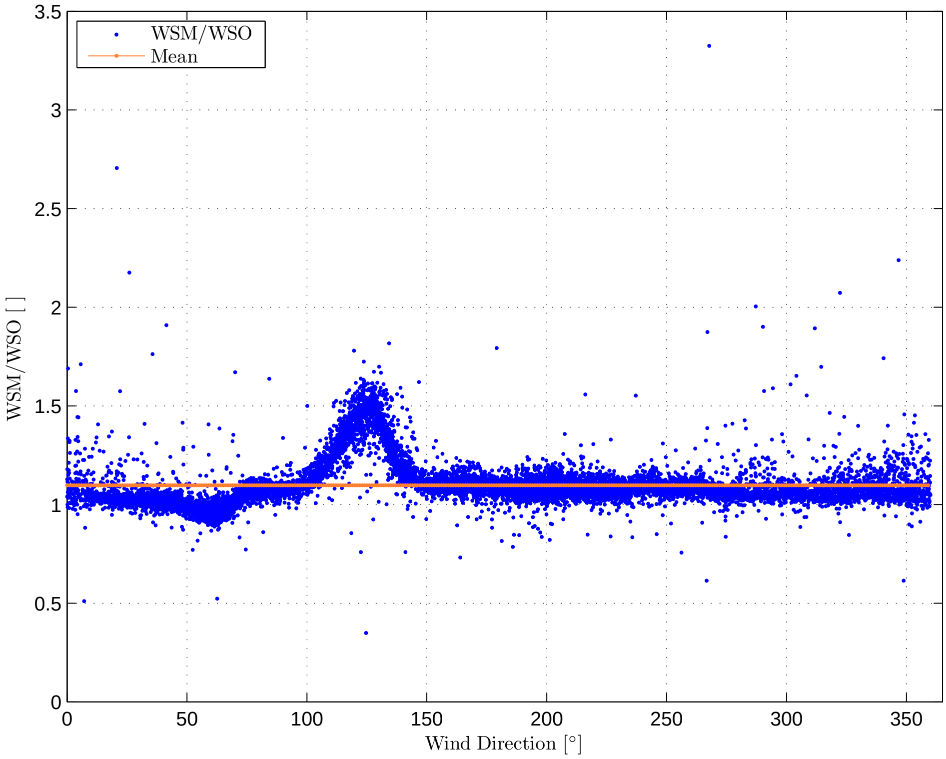


Figure 3.2: Ratio of wind speeds over different directions

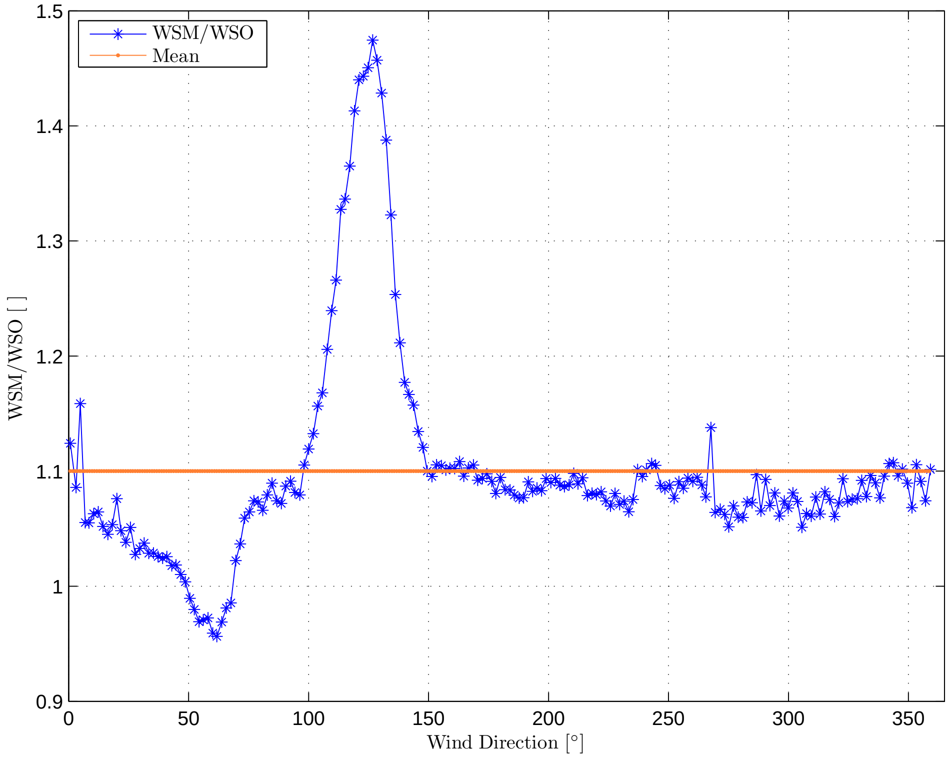


Figure 3.3: Binned plot of wind speed ratio over different directions

Figure 3.3 shows the binned plot of WSM and WSO wind speed ratio. The mast wake sector spans approximately from 100°-150°. The mean wind speed ratio within mast wake sector is 1.28 compared to wind speed ratio of 1.06 outside mast wake sector. The mast wake correction factor for WSO anemometer is calculated as in the case of WST anemometer mast wake corrections as follows

$$\frac{\text{WSM}}{\text{WSO}} = 1.06, \text{ Excluding mast wake samples} \tag{3.1}$$

$$\frac{\text{WSM}_{\text{wake}}}{\text{WSO}_{\text{wake}}} = 1.28 \tag{3.2}$$

$$\text{let, } \frac{\overline{\text{WSM}_{\text{wake}}}}{\text{k} \times \overline{\text{WSO}_{\text{wake}}}} = 1.06 \tag{3.3}$$

where, k is correction factor of WSO within mast wake sector, solving for k

$$\text{k} = \frac{\overline{\text{WSM}_{\text{wake}}}}{1.06 \times \overline{\text{WSO}_{\text{wake}}}} \tag{3.4}$$

Mast wake sector of WSO (100°-150°) is further divided into smaller sectors and correction factor (k) is obtained in these smaller sectors. Figure 3.4 shows the wind speed ratio of WSM and WSO after WSO is corrected within the mast wake sector. Five sectors are considered within the mast wake sector and the correction factor is obtained as

$$\frac{\overline{\mathrm{WSM}}}{\overline{\mathrm{WSO_{wake}}}} = 1.17,\ 1.34,\ 1.45,\ 1.3,\ 1.15 \tag{3.5}$$

$$\mathrm{k_1} = 1.1,\ \mathrm{k_2} = 1.25,\ \mathrm{k_3} = 1.37,\ \mathrm{k_4} = 1.19,\ \mathrm{k_5} = 1.07 \tag{3.6}$$

$$\frac{\overline{\mathrm{WSM}}}{\overline{\mathrm{WSO_{wake}}}} = 1.07,\ 1.06,\ 1.05,\ 1.08,\ 1.07 \tag{3.7}$$

$$\frac{\overline{\mathrm{WSM}}}{\overline{\mathrm{WSO_{wake}}}} = 1.06 \tag{3.8}$$

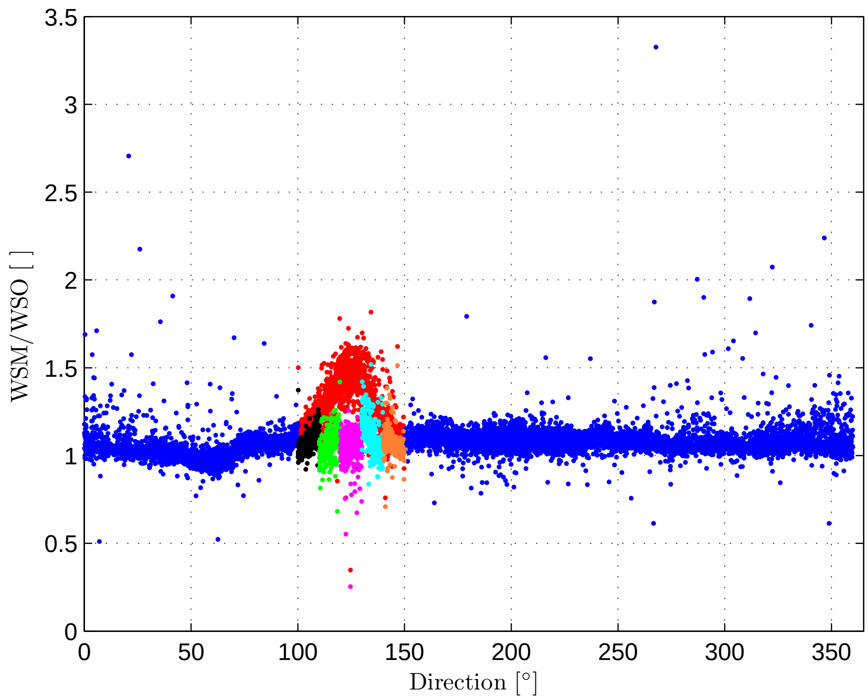


Figure 3.4: Wind speed ratio of WSM and $\mathrm{WSO_{wake}}$ over different directions

Chapter 4

Comparison of WSX with WSM

In this chapter wind data from Vaisala wind sensor is compared with Gill wind master anemometer to identify the mast wake sector of Vaisala wind sensor (WXT510/WXT520). This weather sensor is installed at a height of about 10 meters. Due to its low height, this weather sensor could probably experience higher turbulence due to the surrounding obstacles/structures compared to the other anemometers. Correction factor of WSX within the mast wake sector is calculated.

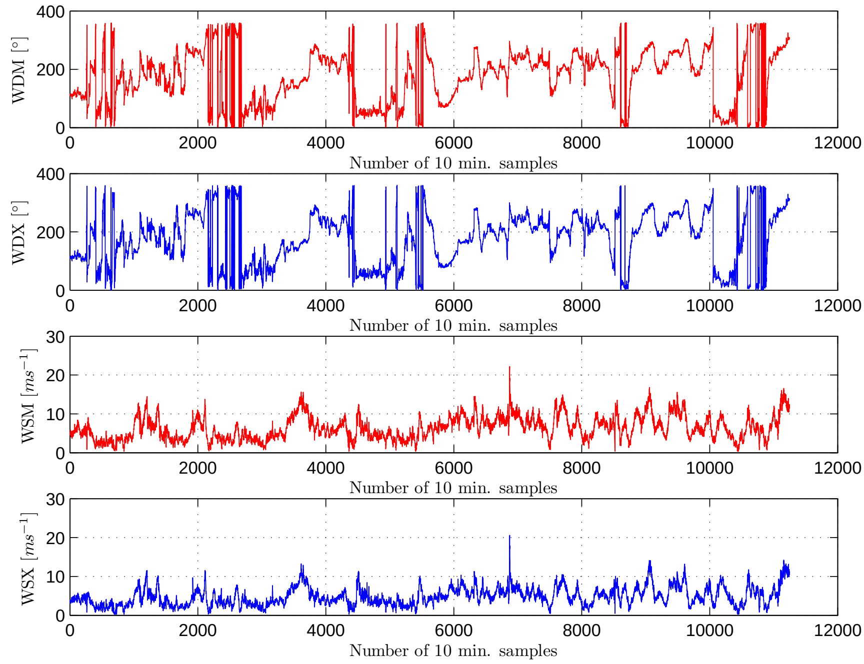


Figure 4.1: Comparison of WSM and WSX 10 min. averaged data

Figure 4.1 shows the time series plot of 10 min averaged data of wind direction and wind speed from WSM anemometer and the WSX sensor. The time series spans from 2013-09-08 to 2013-11-28 with a total of 81 days. Number of samples are therefore 1164 (81×144) without any data loss.

4.1 Correction Factor of WSX for Mast Wake

Figure 4.2 shows the wind speed ratio of WSM anemometer and WSX sensor. The mean wind speed ratio is 1.35. Wind speed ratio ranges between 0.26 and 3.39. Wind speed ratio is highly disturbed due to the low height of WSX Vaisala weather sensor as mentioned in the previous section. Sector from 270° - 50° seems to be relatively undisturbed compared to other sectors. This is because the sector 270° - 50° toward the north contains a water body towards Öckero which is largely obstacle free. WSX weather sensor is oriented at approximately 240° with respect to Met. mast-2. The wake of Met. mast-2 approximately spans from 60° - 76° theoretically. In practice, this wake sector could increase because of the approximations in calculations.

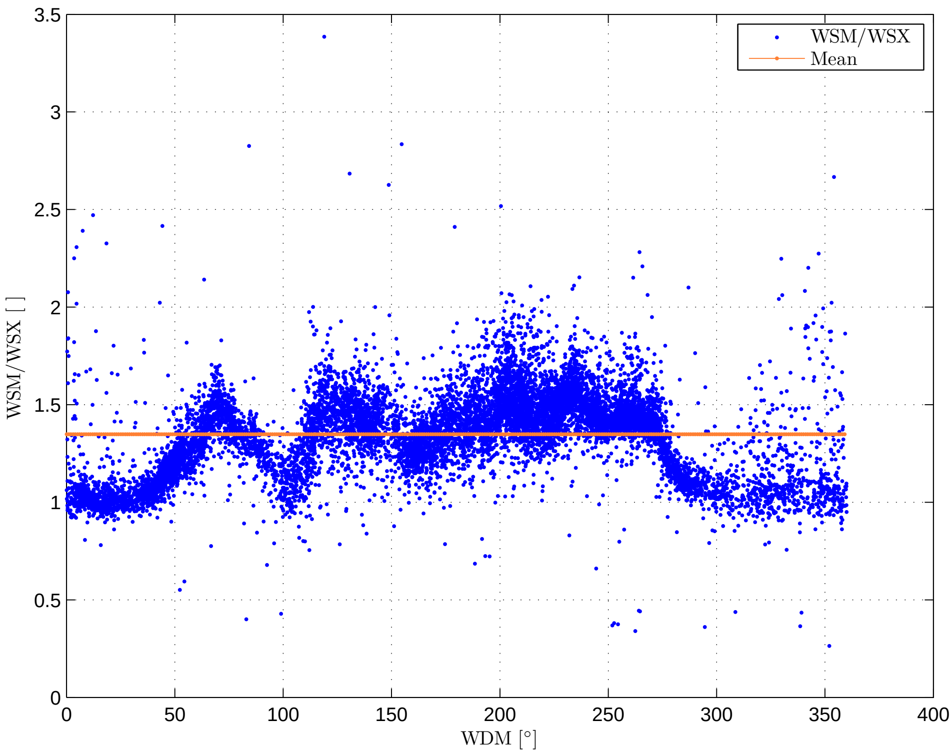


Figure 4.2: Ratio of wind speeds over different directions

Mast wake sector identified from the the Figure 4.3 shows the wake spanning from 50° - 100°. After the wake ceases, the WSX weather sensor starts experiencing the turbulence caused by the surrounding buildings which spans until 270°. Figure 4.3 shows the binned wind speed ratio of WSM and WSX.

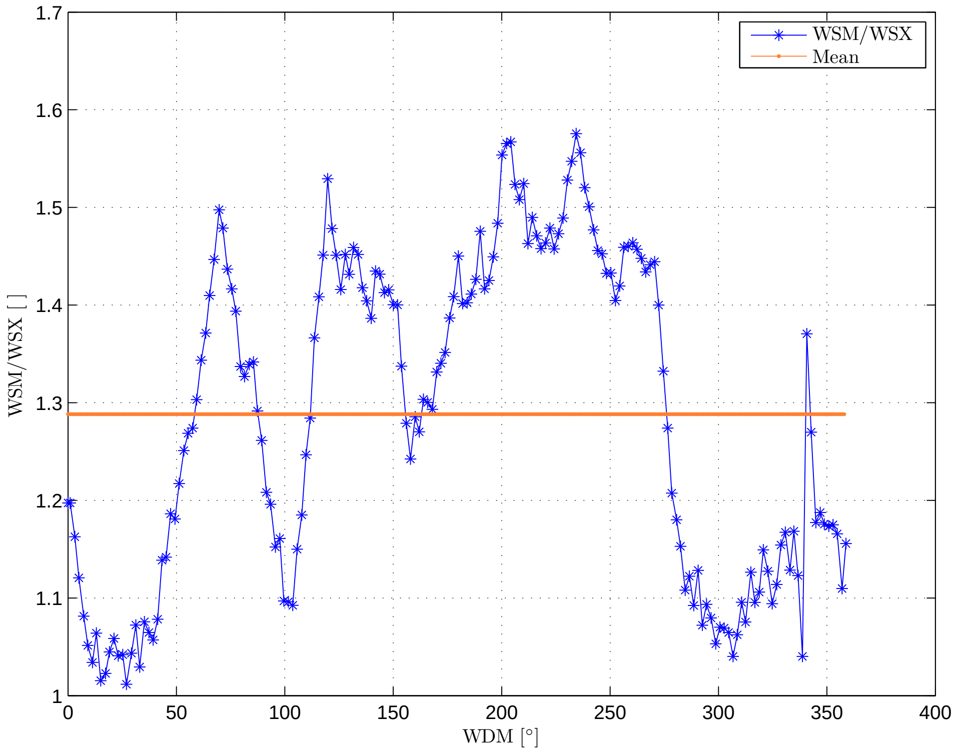


Figure 4.3: Binned plot of wind speed ratio over different directions

Mast wake correction is obtained for WSX sensor as in the case of WSO anemometer. WSX sensor does not have any moving parts unlike WST anemometer, so filtering friction samples is not required. Samples in mast wake sector are filtered to obtain the mean wind speed ratio of WSM and WSX readings as shown in the Figure 4.4. Number of samples after filtering wake are 11305 and wind speed ratio ranges between 0.51 and 3.32.

The binned curve shown in Figure 4.4 gives a better approximation of the nature of wind speed ratio. The mean wind speed ratio of binned plot after filtering mast wake is 1.28 compared to the wind speed ratio of binned plot including wake of 1.35.

$$\frac{\text{WSM}}{\text{WSX}} = 1.28, \text{ Excluding mast wake samples} \tag{4.1}$$

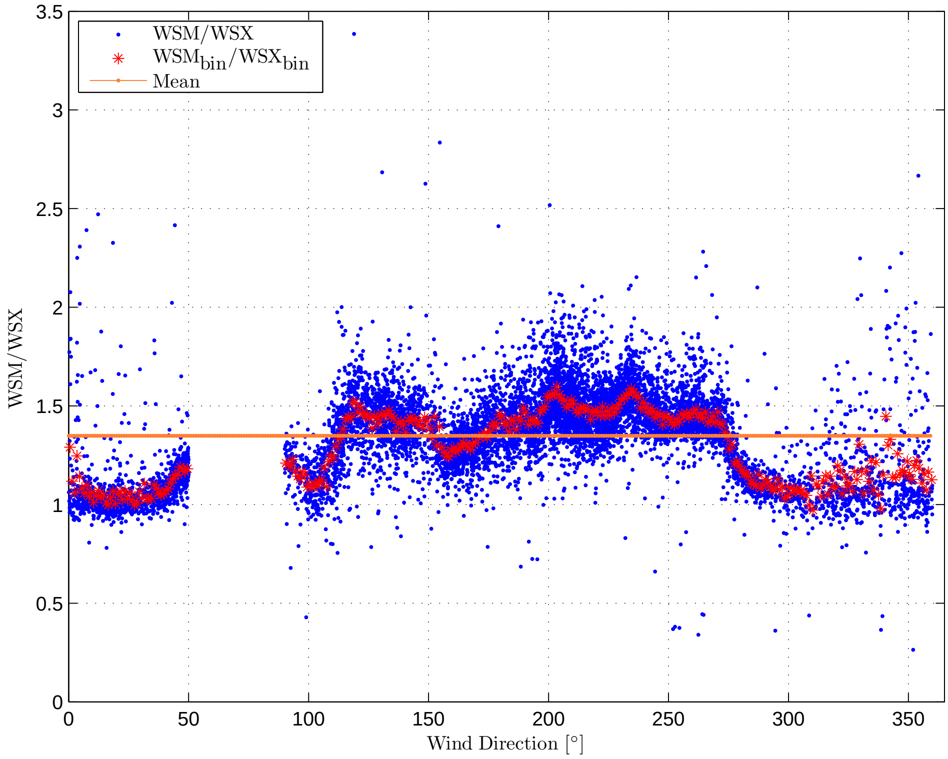


Figure 4.4: Binned plot of wind speed ratio over different directions

From Figure 4.4 it can be seen that WXT510 experiences disturbance from other sectors in addition to the mast wake. This translates to the mean wind speed ratio of WSM and WSX within the mast wake sector more or less equal to mean wind speed ratio out of mast wake. This could yield a correction factor equal to 1 which is not practical. Therefore sectors around WXT510 which are relativity undisturbed are considered in calculating the correction factor. In the Figure 4.4, sectors 280°-40° are considered as less disturbed. Wind speed ratio in this undisturbed sector is

$$\frac{\mathrm{WSM}}{\mathrm{WSX}} = 1.1, \text{ Excluding mast wake samples, turbulent sectors} \tag{4.2}$$

$$\frac{\mathrm{WSM_{wake}}}{\mathrm{WSX_{wake}}} = 1.35 \tag{4.3}$$

$$\text{let, } \frac{\overline{\mathrm{WSM_{wake}}}}{\mathrm{k} \times \overline{\mathrm{WSX_{wake}}}} = 1.1 \tag{4.4}$$

where, k is correction factor of WSX within mast wake sector, solving for k

$$k = \frac{\overline{\mathrm{WSM}_{\mathrm{wake}}}}{1.1 \times \overline{\mathrm{WSX}_{\mathrm{wake}}}} \tag{4.5}$$

Mast wake sector of WSX (50°-90°) is further divided into smaller sectors and correction factor (k) is obtained in these smaller sectors. Figure 3.4 shows the wind speed ratio of WSM and WSX after WSX is corrected within the mast wake. Five sectors are considered within the mast wake sector and correction factor is obtained as

$$\frac{\overline{\mathrm{WSM}}}{\overline{\mathrm{WSX}_{\mathrm{wake}}}} = 1.25,\ 1.4,\ 1.42,\ 1.31 \tag{4.6}$$

$$k_1 = 1.14,\ k_2 = 1.28,\ k_3 = 1.29,\ k_4 = 1.19 \tag{4.7}$$

$$\frac{\overline{\mathrm{WSM}}}{\overline{\mathrm{WSO}_{\mathrm{wake}}}} = 1.01,\ 1.09,\ 1.09,\ 1.10 \tag{4.8}$$

$$\frac{\overline{\mathrm{WSM}}}{\overline{\mathrm{WSO}^{\mathrm{corr}}_{\mathrm{wake}}}} = 1.09 \tag{4.9}$$

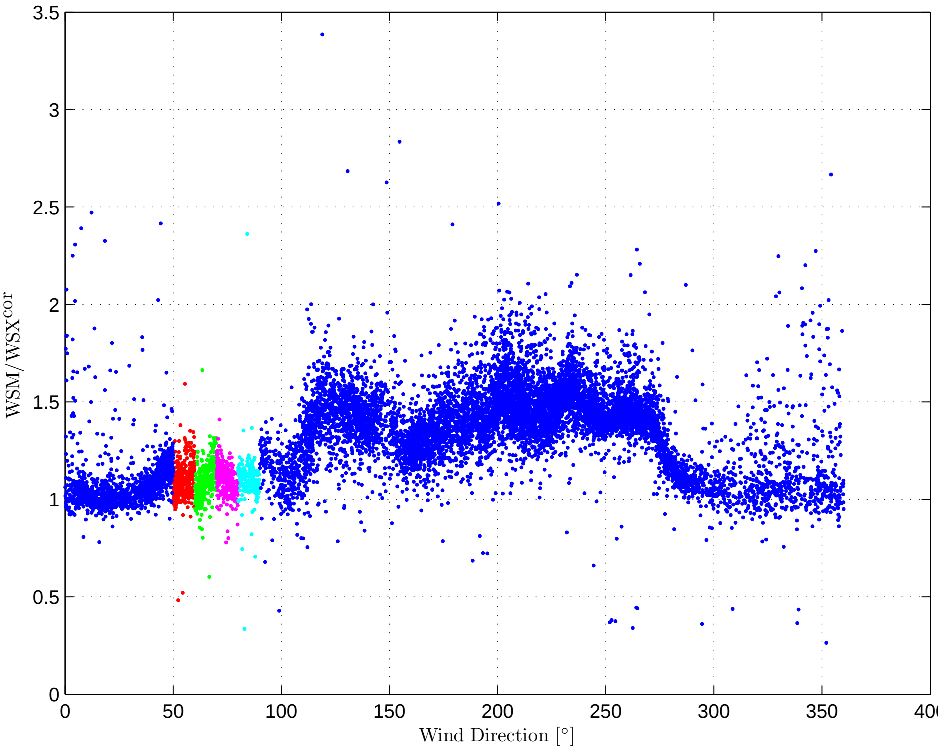


Figure 4.5: Wind speed ratio of WSM and corrected WSX over different directions

Chapter 5

Suggestions for New Measurement Logging System

The following are few of the specifications for a new measurement logging system at Hönö, which would produce the kind of statistics that are included in this report.

- There should be single clock synchronization for different types of anemometer files. This would ensure 1 sample per second for 1 Hz files and exactly 10 samples per second for 10 Hz files and 20 samples per second for 20 Hz files. In the present system, the 10 Hz, 20 Hz sampled data files contain different number of samples than the stipulated amount of samples. This means either the last 1 second averaging interval could have more samples or all the extra samples should be disregarded.
- All the files should have the same start time and end time. This would be helpful in comparing the data for different anemometers. In case when an anemometer undergoes maintenance or recovers from an error, the data file should be ended by 23:59:59 and a new day should always start with a new file.

  When the above implementation fails, it could be useful to have time stamp in data files (either as 1st column or end column) that does not start at 00:00:00 and ends at 23:59:59. This would ensure that the data is not lost and the data in pieces can be comparable. But this would mean that the data file will have one extra column (time stamp column) compared to the regular files.
- Time stamp including seconds information (HH:MM:SS) for the cre-

ation of raw data file should be included within its file name. This would save the computation time in processing the data files. Without the time stamp on the file name, it consumes a lot of computation to know the date and time of creation of raw file.

- The file names should have a similar format for all the anemometers. This could reduce a lot of computing time when comparing file name strings to get similar month or similar year data files.

  Example:
  Anemometername_height_samplingrate_YYYY-MM-DD_HHMMSS.lvm

- The precision of data with the data files could be decreased compared to the existing data files precision; this would save memory and also the computation time.

- There should be few conditions to avoid writing erroneous values in the data files, for any reason the program tries to write them.

  Examples of conditions could be: Negative wind directions, wind directions greater than 360°, negative wind speeds, very high wind speeds, and also invalid cases for meteorological data.

- The program should also calculate 10 min averages (one month files) of the wind data for different anemometers. Also the processing of meteorological data should also be done simultaneously. A suitable folder structure should be sorted out initially, to ensure uniformity in data organization.

Appendix A

Hönö Map

The map of Hönö and its surrounding locations in the Göteborg archipelago is shown in the Figure A.1. Marker B in Figure A.1 represents the Chalmers test station. Chalmers wind turbine station is located adjacent to Hönö ferry station and is about 15 km Northwest of Göteborg. The place where the Chalmers wind turbine station is located is called "Pinan" and is known for being windy. East of the site is sea water towards Hisingen, the largest island of the Göteborg archipelago. To the west and south is the Hönö island. Towards North is Öckerö island.

The approximate geographic details of Meteorological mast-1 are

Latitude 57° 41′ 59.15″ N
Longitude 11° 39′ 41.78″ E

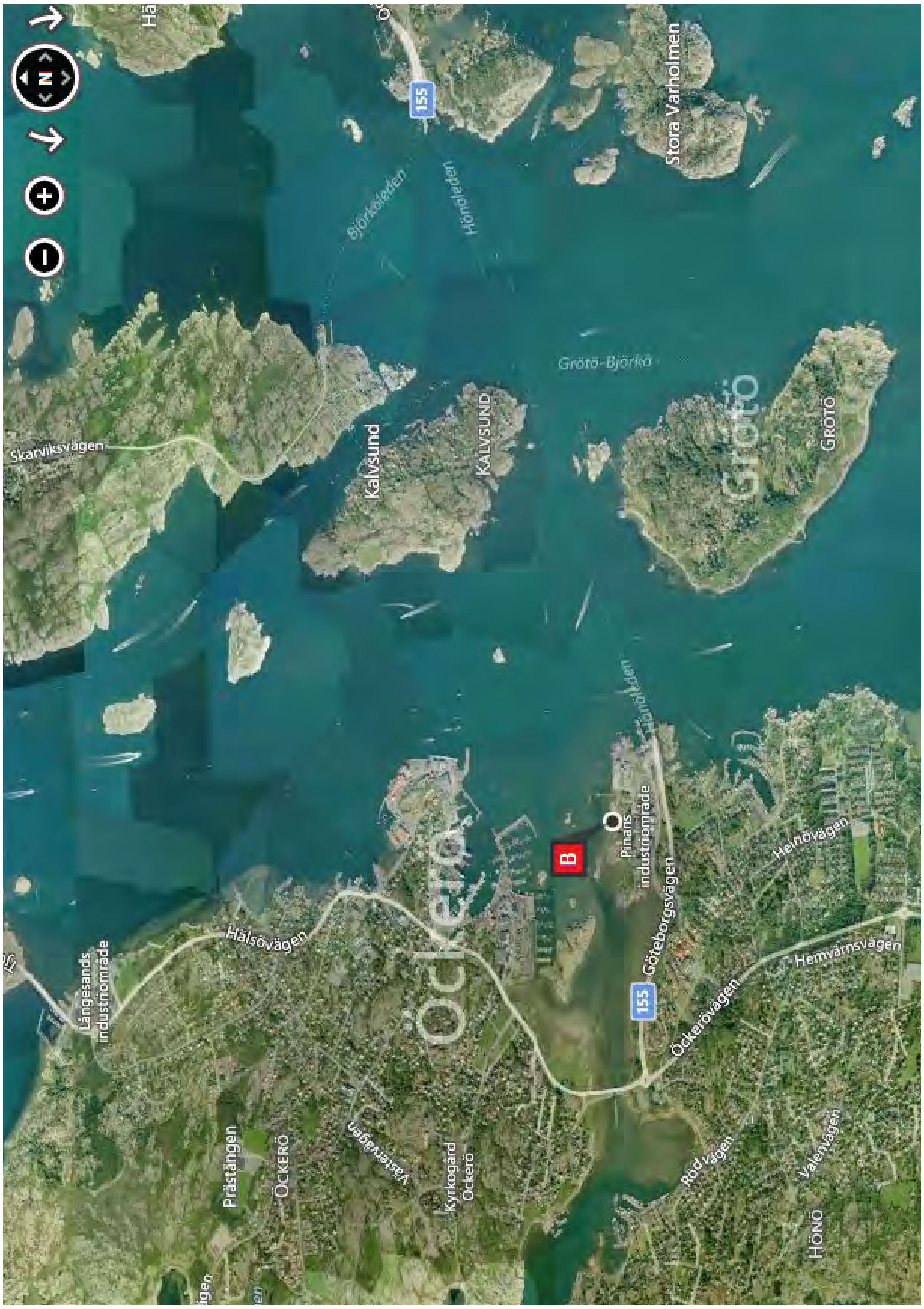


Figure A.1: Map of chalmers wind turbine station site at Hönö and its surroundings (Source: Bing Maps)

Appendix B

Data Chosen for Mast Wake Analysis

Table B.1: File names and no. of samples considered for analysing WSO mast wake in Chapter 3

WSM File names (.txt)	No. of lines	WSO File names (.txt)	No. of lines
2012-09-28_Gill30min_[WindMaster28m]	97704	2012-09-28_Gill30min_[WindObserver20m]	97596
2012-09-29_Gill30min_[WindMaster28m]	86488	2012-09-29_Gill30min_[WindObserver20m]	86392
2012-09-30_Gill30min_[WindMaster28m]	86496	2012-09-30_Gill30min_[WindObserver20m]	86400
2012-10-01_Gill30min_[WindMaster28m]	86492	2012-10-01_Gill30min_[WindObserver20m]	86400
2012-10-02_Gill30min_[WindMaster28m]	86493	2012-10-02_Gill30min_[WindObserver20m]	86400
2012-10-03_Gill30min_[WindMaster28m]	86496	2012-10-03_Gill30min_[WindObserver20m]	86400
2012-10-04_Gill30min_[WindMaster28m]	84452	2012-10-04_Gill30min_[WindObserver20m]	85329
2012-10-05_Gill30min_[WindMaster28m]	86496	2012-10-05_Gill30min_[WindObserver20m]	86400
2012-10-06_Gill30min_[WindMaster28m]	86496	2012-10-06_Gill30min_[WindObserver20m]	86400
2012-10-07_Gill30min_[WindMaster28m]	86496	2012-10-07_Gill30min_[WindObserver20m]	86400
2012-10-08_Gill30min_[WindMaster28m]	86496	2012-10-08_Gill30min_[WindObserver20m]	86400
2012-10-09_Gill30min_[WindMaster28m]	86490	2012-10-09_Gill30min_[WindObserver20m]	86397
2012-10-10_Gill30min_[WindMaster28m]	86496	2012-10-10_Gill30min_[WindObserver20m]	86400
2012-10-11_Gill30min_[WindMaster28m]	18020	2012-10-11_Gill30min_[WindObserver20m]	18000
2012-10-24_Gill30minB_ [WindMaster28m]	9640	2012-10-24_Gill30minB_ [WindObserver20m]	9632
2012-10-25_Gill30minB_ [WindMaster28m]	86489	2012-10-25_Gill30minB_ [WindObserver20m]	86400
2012-10-26_Gill30minB_ [WindMaster28m]	86496	2012-10-26_Gill30minB_ [WindObserver20m]	86400
2012-10-27_Gill30minB_ [WindMaster28m]	86496	2012-10-27_Gill30minB_ [WindObserver20m]	86400
2012-10-28_Gill30minB_ [WindMaster28m]	86496	2012-10-28_Gill30minB_ [WindObserver20m]	86400
2012-10-29_Gill30minB_ [WindMaster28m]	86466	2012-10-29_Gill30minB_ [WindObserver20m]	86400
2012-10-30_Gill30minB_ [WindMaster28m]	86496	2012-10-30_Gill30minB_ [WindObserver20m]	86400
2012-10-31_Gill30minB_ [WindMaster28m]	86492	2012-10-31_Gill30minB_ [WindObserver20m]	86400
2012-11-01_Gill30minB_ [WindMaster28m]	86485	2012-11-01_Gill30minB_ [WindObserver20m]	86400
2012-11-02_Gill30minB_ [WindMaster28m]	86486	2012-11-02_Gill30minB_ [WindObserver20m]	86400
2012-11-03_Gill30minB_ [WindMaster28m]	86494	2012-11-03_Gill30minB_ [WindObserver20m]	86400
2012-11-04_Gill30minB_ [WindMaster28m]	37234	2012-11-04_Gill30minB_ [WindObserver20m]	37192
WindMaster28m_13-01-30	12313	WindObserver20m_13-01-30	12305
WindMaster28m_13-01-31	75287	WindObserver20m_13-01-31	75231
WindMaster28m_13-02-02	47816	WindObserver20m_13-02-02	47796
WindMaster28m_13-02-03	21251	WindObserver20m_13-02-03	21232
WindMaster28m_13-02-05	52710	WindObserver20m_13-02-05	52656
WindMaster28m_13-02-06	86476	WindObserver20m_13-02-06	86399
WindMaster28m_13-02-07	86467	WindObserver20m_13-02-07	86394
WindMaster28m_13-02-08	86468	WindObserver20m_13-02-08	86397
WindMaster28m_13-02-09	86461	WindObserver20m_13-02-09	86390
WindMaster28m_13-02-10	86476	WindObserver20m_13-02-10	86399
WindMaster28m_13-02-11	49535	WindObserver20m_13-02-11	49493
WindMaster28m_13-02-12	46045	WindObserver20m_13-02-12	46112
WindMaster28m_13-02-13	43695	WindObserver20m_13-02-13	43659
WindMaster28m_13-02-16	19208	WindObserver20m_13-02-16	19168
WindMaster28m_13-02-28	27023	WindObserver20m_13-02-28	26998
WindMaster28m_13-03-01	86476	WindObserver20m_13-03-01	86395
WindMaster28m_13-03-02	86474	WindObserver20m_13-03-02	86394
WindMaster28m_13-03-03	86480	WindObserver20m_13-03-03	86398

Table B.2: File names and no. of samples considered for analysing WSO mast wake in Chapter 3

WSM File names (.txt)	No. of lines	WSO File names (.txt)	No. of lines
WindMaster28m_13-03-04	86477	WindObserver20m_13-03-04	86399
WindMaster28m_13-03-05	86471	WindObserver20m_13-03-05	86400
WindMaster28m_13-03-06	86479	WindObserver20m_13-03-06	86400
WindMaster28m_13-03-07	86485	WindObserver20m_13-03-07	86399
WindMaster28m_13-03-08	86484	WindObserver20m_13-03-08	86399
WindMaster28m_13-03-09	86470	WindObserver20m_13-03-09	86398
WindMaster28m_13-03-10	86451	WindObserver20m_13-03-10	86394
WindMaster28m_13-03-11	86453	WindObserver20m_13-03-11	86394
WindMaster28m_13-03-12	86469	WindObserver20m_13-03-12	86398
WindMaster28m_13-03-13	86467	WindObserver20m_13-03-13	86400
WindMaster28m_13-03-14	86461	WindObserver20m_13-03-14	86396
WindMaster28m_13-03-15	86473	WindObserver20m_13-03-15	86400
WindMaster28m_13-03-16	86467	WindObserver20m_13-03-16	86400
WindMaster28m_13-03-17	86467	WindObserver20m_13-03-17	86399
WindMaster28m_13-03-18	86466	WindObserver20m_13-03-18	86397
WindMaster28m_13-03-19	66611	WindObserver20m_13-03-19	66580
WindMaster28m_13-03-20	86450	WindObserver20m_13-03-20	86394
WindMaster28m_13-03-21	86462	WindObserver20m_13-03-21	86399
WindMaster28m_13-03-22	60863	WindObserver20m_13-03-22	60854
WindMaster28m_13-08-27	16612	WindObserver20m_13-08-27	16577
WindMaster28m_13-08-29	25135	WindObserver20m_13-08-29	25107
WindMaster28m_13-09-02	3528	WindObserver20m_13-09-02	3524
WindMaster28m_13-09-06	34416	WindObserver20m_13-09-06	34380
WindMaster28m_13-09-07	86496	WindObserver20m_13-09-07	86400
WindMaster28m_13-09-08	86496	WindObserver20m_13-09-08	86400
WindMaster28m_13-09-09	86496	WindObserver20m_13-09-09	86400
WindMaster28m_13-09-10	86494	WindObserver20m_13-09-10	86400
WindMaster28m_13-09-11	86496	WindObserver20m_13-09-11	86400
WindMaster28m_13-09-12	86500	WindObserver20m_13-09-12	86404
WindMaster28m_13-09-13	86491	WindObserver20m_13-09-13	86394
WindMaster28m_13-09-14	86496	WindObserver20m_13-09-14	86400
WindMaster28m_13-09-15	86494	WindObserver20m_13-09-15	86400
WindMaster28m_13-09-16	86487	WindObserver20m_13-09-16	86400
WindMaster28m_13-09-17	86495	WindObserver20m_13-09-17	86400
WindMaster28m_13-09-18	86494	WindObserver20m_13-09-18	86400
WindMaster28m_13-09-19	86502	WindObserver20m_13-09-19	86406
WindMaster28m_13-09-20	86496	WindObserver20m_13-09-20	86400
WindMaster28m_13-09-21	86496	WindObserver20m_13-09-21	86400
WindMaster28m_13-09-22	86492	WindObserver20m_13-09-22	86400
WindMaster28m_13-09-23	86496	WindObserver20m_13-09-23	86400
WindMaster28m_13-09-24	25568	WindObserver20m_13-09-24	25539
WindMaster28m_13-09-25	39520	WindObserver20m_13-09-25	39480
WindMaster28m_13-09-26	86496	WindObserver20m_13-09-26	86400
WindMaster28m_13-09-27	86490	WindObserver20m_13-09-27	86400
WindMaster28m_13-09-28	86495	WindObserver20m_13-09-28	86400
WindMaster28m_13-09-29	86494	WindObserver20m_13-09-29	86400
WindMaster28m_13-09-30	86495	WindObserver20m_13-09-30	86400
WindMaster28m_13-10-01	86496	WindObserver20m_13-10-01	86400
WindMaster28m_13-10-02	86503	WindObserver20m_13-10-02	86407
WindMaster28m_13-10-03	86496	WindObserver20m_13-10-03	86400
WindMaster28m_13-10-04	86489	WindObserver20m_13-10-04	86400
WindMaster28m_13-10-05	86493	WindObserver20m_13-10-05	86400
WindMaster28m_13-10-06	86496	WindObserver20m_13-10-06	86400
WindMaster28m_13-10-07	86496	WindObserver20m_13-10-07	86400
WindMaster28m_13-10-08	86492	WindObserver20m_13-10-08	86400
WindMaster28m_13-10-09	86502	WindObserver20m_13-10-09	86406
WindMaster28m_13-10-10	86496	WindObserver20m_13-10-10	86400
WindMaster28m_13-10-11	86496	WindObserver20m_13-10-11	86400
WindMaster28m_13-10-12	86495	WindObserver20m_13-10-12	86400
WindMaster28m_13-10-13	86496	WindObserver20m_13-10-13	86400
WindMaster28m_13-10-14	28957	WindObserver20m_13-10-14	28921

Table B.3: File names and no. of columns of WSO and WST considered for correction factor of WST in Chapter 2

WSO File names (.txt)	No.of lines	WST File names (.lvm)	No.of lines	No. of lines Selected
2012-09-29_Gill30min_[WindObserver20m]	86488	H4_1Hz_12-09-29_0000	86399	86399
2012-09-30_Gill30min_[WindObserver20m]	86496	H4_1Hz_12-09-30_0000	86400	86400
2012-10-01_Gill30min_[WindObserver20m]	86492	H4_1Hz_12-10-01_0000	86400	86400
2012-10-02_Gill30min_[WindObserver20m]	86493	H4_1Hz_12-10-02_0000	86401	86401
2012-10-03_Gill30min_[WindObserver20m]	86496	H4_1Hz_12-10-03_0000	86399	86399
2012-10-04_Gill30min_[WindObserver20m]	84452	H4_1Hz_12-10-04_0000	86400	84452
2012-10-05_Gill30min_[WindObserver20m]	86496	H4_1Hz_12-10-05_0000	86400	86400
2012-10-06_Gill30min_[WindObserver20m]	86496	H4_1Hz_12-10-06_0000	86399	86399
2012-10-07_Gill30min_[WindObserver20m]	86496	H4_1Hz_12-10-07_0000	86400	86400
2012-10-08_Gill30min_[WindObserver20m]	86496	H4_1Hz_12-10-08_0000	86399	86399
2012-10-09_Gill30min_[WindObserver20m]	86490	H4_1Hz_12-10-09_0000	86399	86399
2012-10-10_Gill30min_[WindObserver20m]	86496	H4_1Hz_12-10-10_0000	86400	86400
2012-10-25_Gill30minB_ [WindObserver20m]	86489	H4_1Hz_12-10-25_0000	86399	86399
2012-10-26_Gill30minB_ [WindObserver20m]	86496	H4_1Hz_12-10-26_0000	86400	86400
2012-10-27_Gill30minB_ [WindObserver20m]	86496	H4_1Hz_12-10-27_0000	86400	86400
2012-10-28_Gill30minB_ [WindObserver20m]	86496	H4_1Hz_12-10-28_0000	86399	86399
2012-10-29_Gill30minB_ [WindObserver20m]	86466	H4_1Hz_12-10-29_0000	86399	86399
2012-10-30_Gill30minB_ [WindObserver20m]	86496	H4_1Hz_12-10-30_0000	86399	86399
2012-10-31_Gill30minB_ [WindObserver20m]	86492	H4_1Hz_12-10-31_0000	86399	86399
2012-11-01_Gill30minB_ [WindObserver20m]	86485	H4_1Hz_12-11-01_0000	86399	86399
2012-11-02_Gill30minB_ [WindObserver20m]	86486	H4_1Hz_12-11-02_0000	86399	86399
2012-11-03_Gill30minB_ [WindObserver20m]	86494	H4_1Hz_12-11-03_0000	86399	86399

Appendix C

Results & Observations

Table C.1: Wind speed scattered ratio of WSO and WST and their corresponding wind speeds in sector 180°-360°, to analyse the effect of friction on WST readings

Wind speed ratio	WSO	WST
3.79	0.33	0.09
2.99	0.45	0.15
2.52	0.6	0.24
2.46	0.85	0.35
2.31	0.68	0.3
2.06	0.74	0.36
2.01	0.71	0.35
1.97	0.69	0.35
1.88	0.84	0.45
1.86	0.86	0.46
1.83	0.76	0.41
1.71	0.89	0.52
1.64	0.7	0.43
1.62	0.91	0.56
1.59	0.86	0.54
1.55	0.8	0.52
1.54	1.09	0.71
1.5	1.28	0.85
1.48	0.93	0.62
1.48	0.97	0.65
1.42	1.41	0.99
1.41	1.08	0.76
1.4	1.15	0.82
1.39	1.61	1.16
1.37	1.59	1.16
1.34	1.58	1.17
1.34	1.46	1.09
1.32	1.53	1.15
1.32	1.55	1.17
1.31	1.38	1.05
1.31	1.53	1.17
1.31	1.69	1.3

Table C.2: Wind statistics summary of all years and months from 2008-2010, empty cells indicate unavailability of data

Year	Month	WSM		WSO		WST		WSX	
		DAV	Mean	DAV	Mean	DAV	Mean	DAV	Mean
2008	Jan								
	Feb								
	Mar								
	Apr								
	May								
	Jun								
	Jul								
	Aug								
	Sept							4.79	4.51
	Oct							99.4	6.09
	Nov					59.98	7.87	100	6.1
	Dec					99.55	4.65	96.53	4.5
2009	Jan					99.98	5.44	100	5.12
	Feb					100	3.84	100	3.86
	Mar					99.15	5.23	99.96	4.96
	Apr					94.93	3.99	58.82	3.73
	May								
	Jun					95.19	5.45	95.16	4.93
	Jul					100	5.72	100	4.53
	Aug					100	5.88	100	4.72
	Sept					99.88	7.02	99.98	5.62
	Oct					99.96	6.39	99.98	5.64
	Nov					100	7.26	100	6.04
	Dec					70.39	5.48	70.39	5.24
2010	Jan					78.38	4.82	78.43	4.72
	Feb					100	4.45	100	4.41
	Mar					56.32	4.2	99.66	4.24
	Apr							99.98	5.03
	May							100	4.64
	Jun							100	4.33
	Jul					53.14	5.28	98.23	4.32
	Aug					100	5.68	99.98	4.75
	Sept					100	6.24	100	5.37
	Oct					100	5.88	100	5.01
	Nov					89.12	7.4	89.12	6.5
	Dec					91.17	4.94	91.2	4.7

Table C.3: Wind statistics summary of all years and months from 2010-2013, empty cells indicate unavailability of data

Year	Month	WSM		WSO		WST		WSX	
		DAV	Mean	DAV	Mean	DAV	Mean	DAV	Mean
2011	Jan					100	4.88	100	4.5
	Feb					100	6.06	100	5.55
	Mar					100	5.56	100	4.7
	Apr					100	4.71	100	4.15
	May					100	5.9	100	4.72
	Jun					100	5.4	100	4.41
	Jul					99.84	4.97	99.84	4.43
	Aug					100	4.98	100	4.19
	Sept					95.44	6.59	96.23	5.21
	Oct					100	7.16	100	5.88
	Nov					100	5.37	100	4.5
	Dec					99.96	8.29	99.89	6.69
2012	Jan					99.1	6.09	100	5.44
	Feb					100	5.63	100	4.86
	Mar					100	5.64	100	5.06
	Apr					100	5.09	100	4.63
	May					100	5.28	100	4.48
	Jun					100	5.36	100	4.59
	Jul					100	5.1	100	4.11
	Aug					100	4.59	99.96	3.84
	Sept	9.19	8.24	9.17	7.68	99.75	7.79	99.72	6.21
	Oct	55.62	7.36	55.65	6.88	100	5.85	100	5.01
	Nov	11.44	8.15	11.44	7.51			99.56	5.92
	Dec							49.26	5.48
2013	Jan	4.19	8.76	3.27	8.23				
	Feb	50.42	6.01	31.87	5.14				
	Mar	99.24	6.27	99.24	5.99				
	Apr	71.85	5.47	71.85	5.11				
	May								
	Jun								
	Jul								
	Aug	8.67	5.95	1.57	5.98			2.26	4.86
	Sept	83.31	4.89	77.31	4.51			76.44	3.73
	Oct	99.73	6.91	98.25	6.5			95.14	5.14
	Nov	100	7.15	0.42	9.38			100	5.53
	Dec	100	8.7					100	6.6

C.1 Mast Wake Identification

C.1.1 WST Mast Wake Identification

From the following figures WST mast wake sector can be identified.

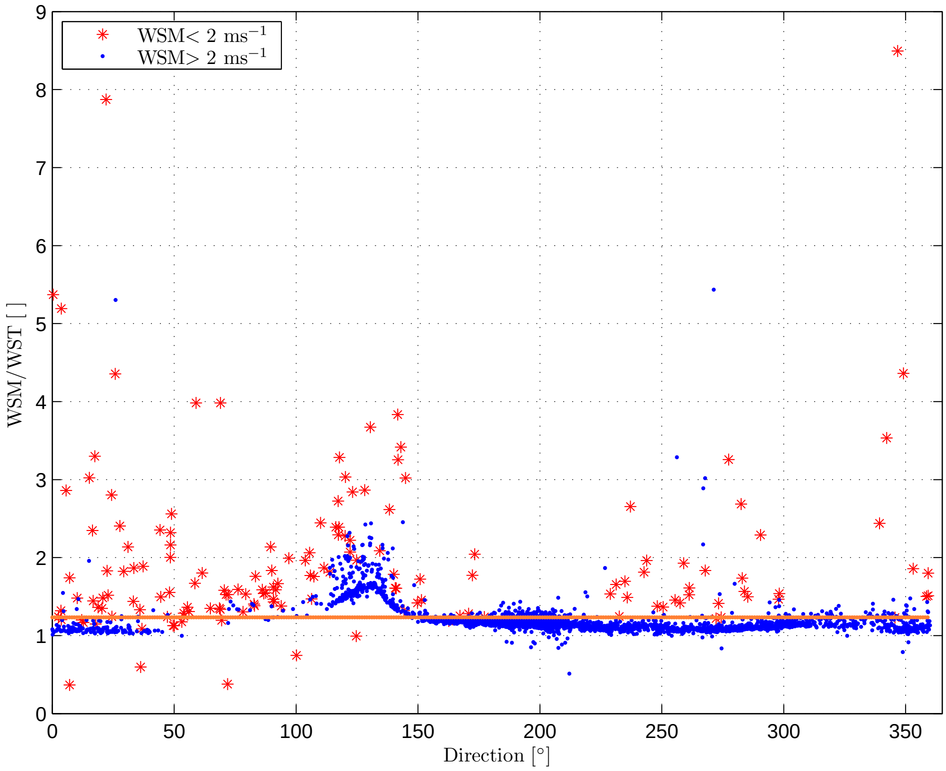


Figure C.1: Wind speed ratio of WSM and WST to analyse the mast wake sector of WST

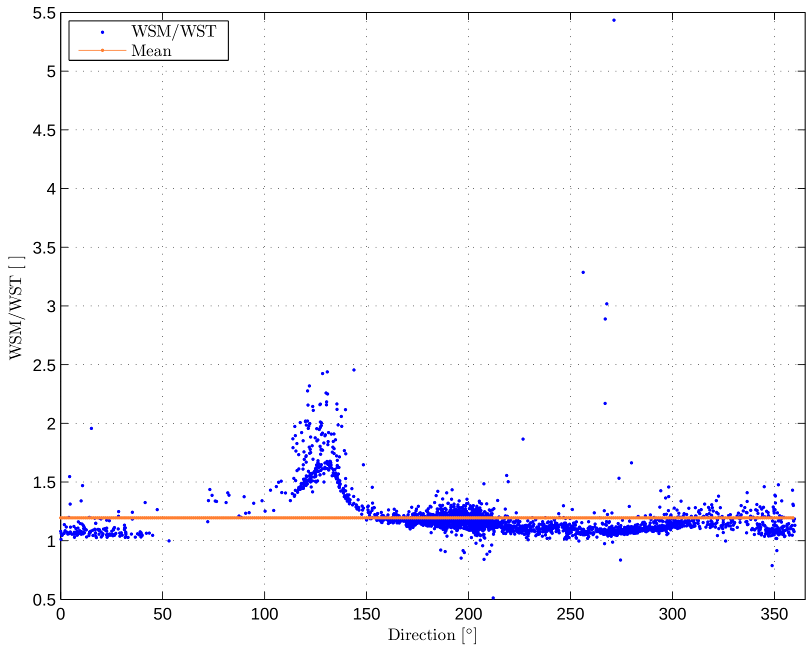


Figure C.2: Wind speed ratio of WSM and WST to analyse the mast wake sector of WST after filtering WST mast wake sector

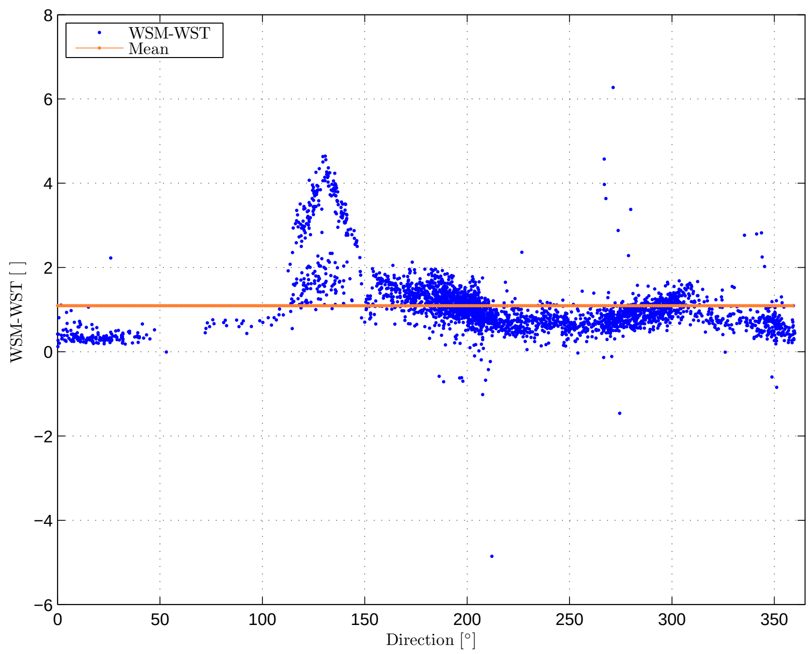


Figure C.3: Wind speed difference of WSM and WST to analyse the mast wake sector of WST after filtering WST mast wake sector

It can be seen from that, the wake sector of WST anemometer lies approximately from 110°-148°.

C.1.2 WSO Mast Wake Identification

Figure C.4 shows the wind speed difference of WSM and WSO. It can be seen, the mast wake sector of WSO anemometer lies approximately from 100°-150°.

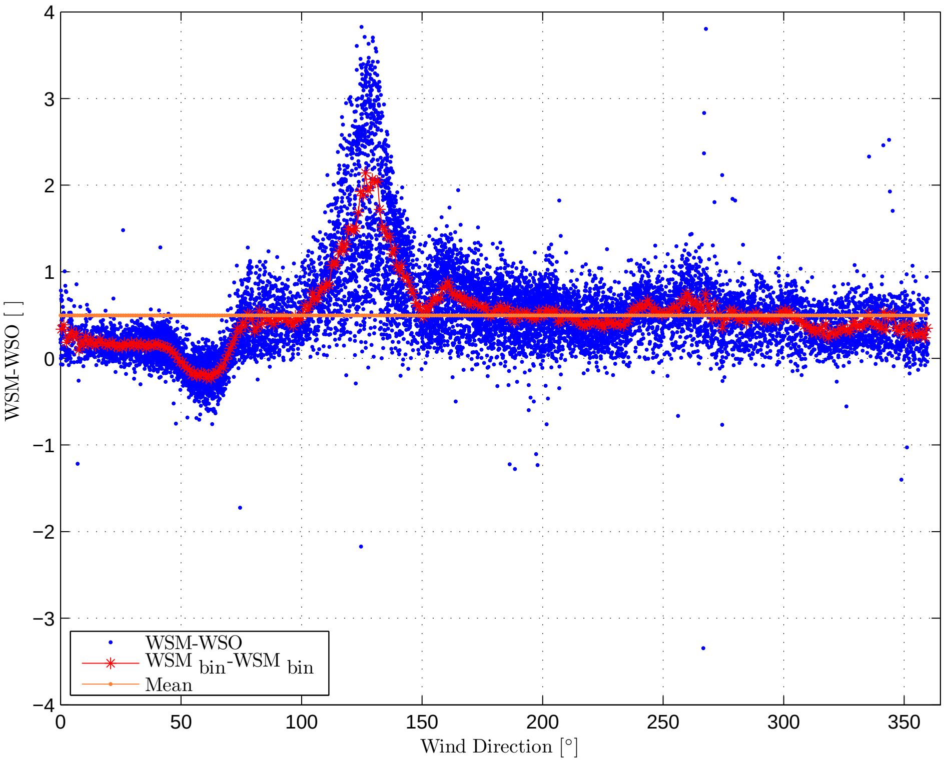


Figure C.4: Wind speed difference of WSM and WSO to analyse the mast wake sector of WSO

WST is closer to mast compared to WSO, therefore WST has higher mast wake compared to WSO which can also be understood from the schematic shown in the Figure C.5

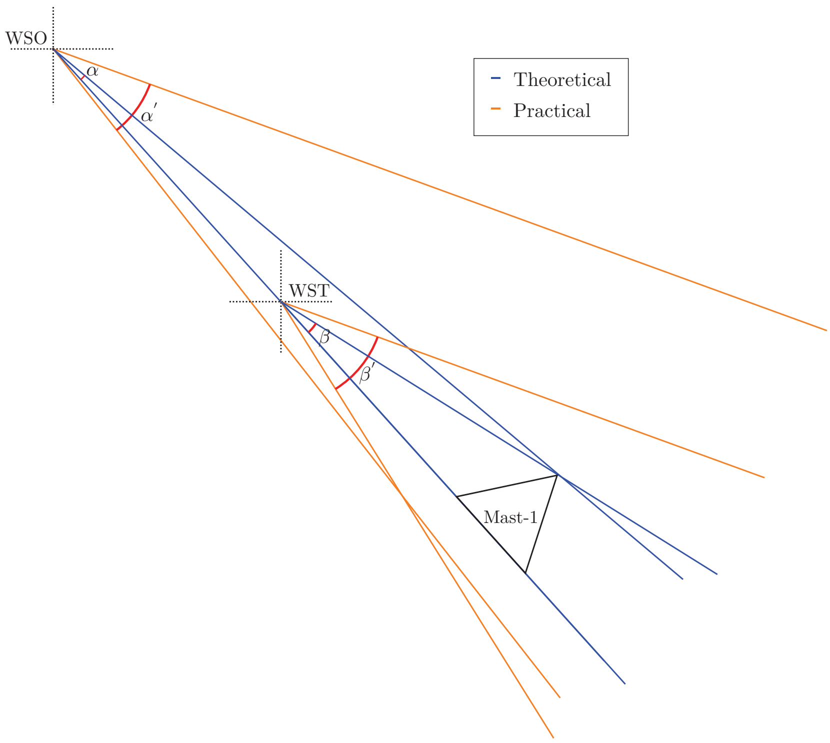


Figure C.5: Approximate schematic drawing of WSO and WST anemometers on mast-1 to represent theoretical and practical mast wake sector [Drawing to scale]

C.2 WSO wake on WST

Figure C.6 show wind speed difference between WSO and WST. In ideal case the difference should be zero, however due to the disturbances in various sectors the wind speed difference is not constant. Wind speed difference between 300°-320° has a higher peak. This means in this WSO anemometer records higher values than WST anemometer. The orientation of WST and WSO anemometers are appropriately 318° with respect to lattice mast-1 as shown in the Figure 1.3. In the range of 300°-320° wind initially hits the WSO anemometer before the WST cup anemometer.

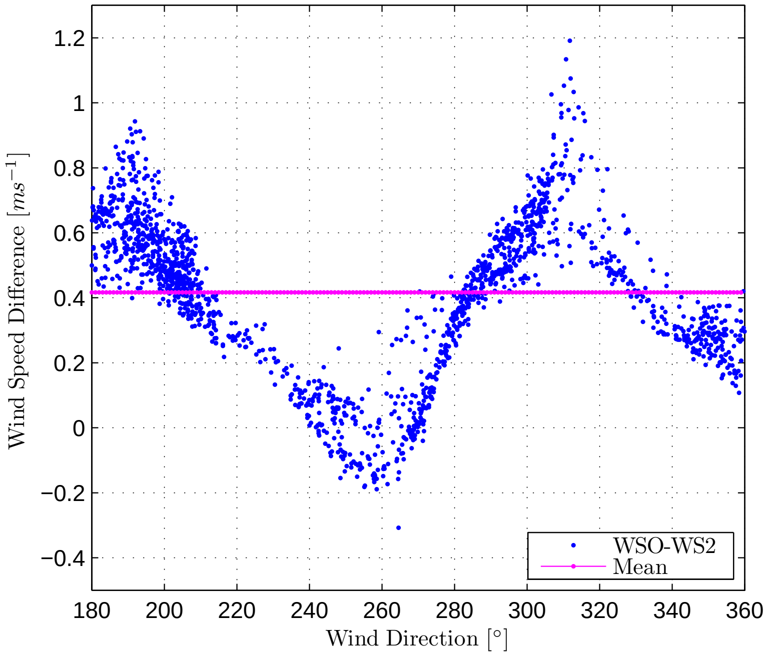


Figure C.6: Wind speed difference of WSO and WST over different directions before WST correction

Appendix D

Hönö Data Guide

D.1 Hönö Data Folder

This folder *Hönö_Data* consists of raw data from different anemometers. Each anemometer has a unique folder. In addition to the anemometer folders, there are two miscellaneous folders *Gill* and *Others*.

D.1.1 Gill Folder

Gill folder contains two folders, *Raw* and *Intermediate_Stages*. *Raw* folder contains the raw data from Gill anemometers. This initial set of data from Gill anemometers is in different lengths and of different variations in file-names. The precision of raw WSO files is 10 Hz while the precision of raw WSM files is 20 Hz. These files are treated in different stages based on their raw file-names which are given in *Intermediate_Stages* folder. The final set of processed data files are located in folders *WSMp*, *WSOp* for WSM and WSO anemometer data respectively. The intermediate stages of data file are explained in detailed in the report. The files in folders *WSMp*, *WSOp* contains one second averaged data from the higher resolution files. Subscript p refers to processed.

D.1.2 Others Folder

Others folder contains data which was used in calculations concerning correction factors of the anemometers. *WS2_WSO_Comp* folder contains data used in calculating friction calibration factor and mast wake correction for WST and WSO anemometers by comparing with WSM data. The data is concurrent data from WSM, WSO and WST anemometers and having a resolution of 1 Hz. *WSM_WXT510_Comp* contains concurrent 1 Hz data files from WSM and WSX anemometers which were used in calculations concerning mast wake correction of WSX.

D.1.3 Anemometer Folders

The anemometer folders contains two folders *Raw* and *Processed*. These folders are further divided into two different sub folders based on their years. The resolution of the files in *Raw* and *Rawp* folders is 1 Hz with wind direction as column-1 and wind speed as column-2. The *Processed* subfolders in all the anemometer folders contains data classified with respect to their years. These yearly anemometer data sub folders contains two folders *Day_files* and *Month_files*. The resolution of these files are 10 min averages with wind direction as column-1 and wind speed as column-2. The shorter processed (less than day/month span) files do not obey time series principle. The data treatment and data flow for different anemometers is shown in the Figure D.1

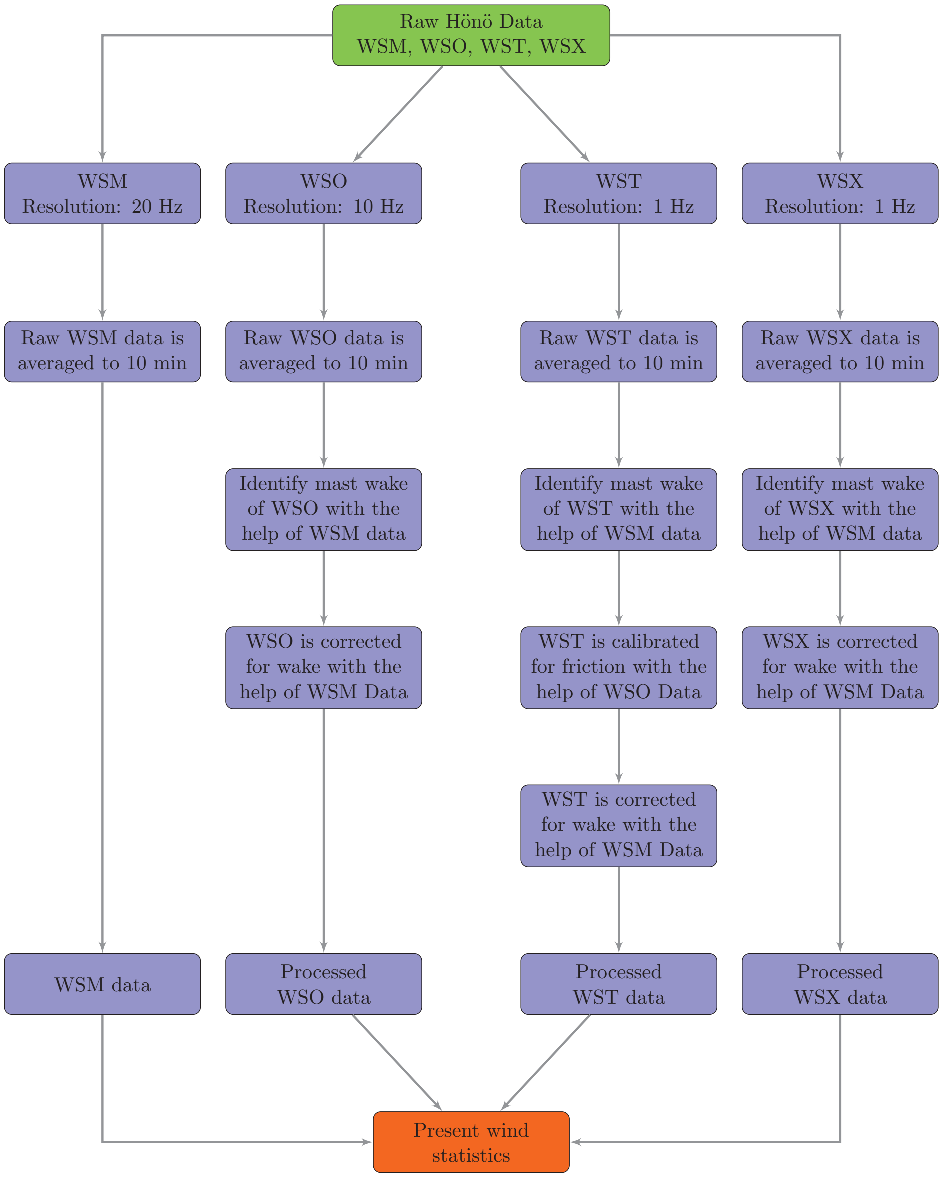


Figure D.1: Data treatment and data flow for different anemometers

Appendix E

Mathematical Formulations

E.1 Mean of Wind Direction

Wind direction cannot not be averaged right away since it sometimes jumps back and forth between 359° and 1° (north) the average would then be around south but in reality it is 0° or 360°. The following mathematical formulation is used to compute mean of angles

- Let θ_1, θ_2 are the angles
- Convert angles into radians

$$\omega_1 = \theta_1 \times \frac{\pi}{180}; \omega_2 = \theta_2 \times \frac{\pi}{180} \tag{E.1}$$

- Convert the angles into exponential form

$$\omega_1 = e^{w_1} + ie^{jw_1}; \omega_2 = e^{w_2} + ie^{jw_2} \tag{E.2}$$

- Find the mean

$$\omega_m = \frac{\omega_1 + \omega_2}{2} \tag{E.3}$$

- Convert the angle back to degrees

$$\theta_m = \omega_m \times \frac{180}{\pi} \tag{E.4}$$

- Locate the quadrant of resultant mean angle

$$\theta_m = \theta_m + 360 \,\forall\, \theta_m < 0 \tag{E.5}$$

E.2 Meteorological Conversions

E.2.1 Precipitation

Precipitation is recorded by the Vaisala weather sensor (WXT510) in mm/h is converted into minute averages by the following mathematical formulation

- Convert precipitation in mm/h to mm/sec

$$p_1 = \frac{p}{60 \times 60} \tag{E.6}$$

- Sum precipitation in mm/sec for a minute

$$P = \int_0^{60} p_1(t)\ dt \tag{E.7}$$

Where t in seconds, P is precipitation in mm/min, p_1 is precipitation in mm/sec.

Appendix F

Processing of Gill Anemometer Files

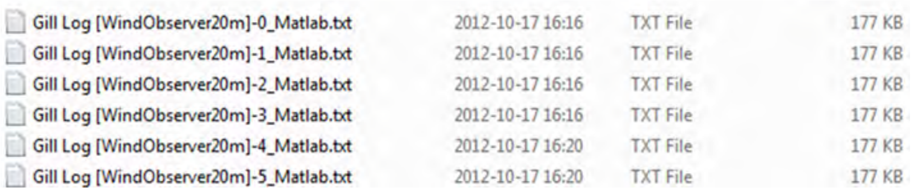
WSO and WSM files are processed to have 1 Hz sample rate. The files that are generated by the LabView program initially have 10 minutes data and later changed to 30 have minutes data to reduce the number of files. The sampling rate of the files for WSO and WSM are 10 Hz and 20 Hz respectively. The Matlab programs in this chapter will modify these files to have 1 Hz sampling rate so that they can be compared to WST files with H4_1Hz file series having a sample rate of 1 Hz.

F.1 Data Representation & Layout

Gill anemometers are interfaced to the measurement computers by WindView program. WindView program generates ASCII files which contain a mix of numbers and letters on each row. These files cannot be loaded into Matlab environment. To overcome this problem, a LabView program has been developed that interprets the WindView files and writes the result to new ASCII files which are more easily loadable into Matlab environment. The conversion program also calculates some statistical data of each file. The statistics is written in the beginning of each output file. Gill WindObserver writes the following data into the text file

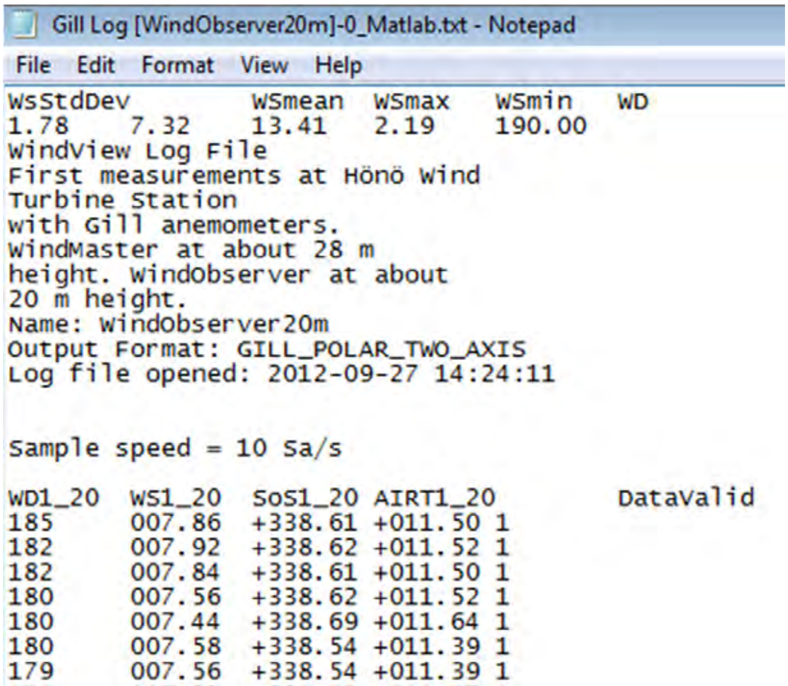
WD1_20	Wind Direction, Mast 1, 20 m height [degrees]
WS1_20	Wind Speed, Mast 1, 20m height (Horizontal wind speed) [m/s]
SoS1_20	Speed of Sound, Mast 1, 20m height [m/s]
AIRT_20	AIR Temperature, Mast 1, 20m height [degrees Celsius]

Filenames in the file directory is shown in Figure F.1. The layout of data in the text documents are as shown in Figure F.2. In each file there is short statistics written at the beginning.



Gill Log [WindObserver20m]-0_Matlab.txt	2012-10-17 16:16	TXT File	177 KB
Gill Log [WindObserver20m]-1_Matlab.txt	2012-10-17 16:16	TXT File	177 KB
Gill Log [WindObserver20m]-2_Matlab.txt	2012-10-17 16:16	TXT File	177 KB
Gill Log [WindObserver20m]-3_Matlab.txt	2012-10-17 16:16	TXT File	177 KB
Gill Log [WindObserver20m]-4_Matlab.txt	2012-10-17 16:20	TXT File	177 KB
Gill Log [WindObserver20m]-5_Matlab.txt	2012-10-17 16:20	TXT File	177 KB

Figure F.1: Filenames of data to be analysed



```
Gill Log [WindObserver20m]-0_Matlab.txt - Notepad
File  Edit  Format  View  Help
WsStdDev        WSmean  WSmax   WSmin   WD
1.78    7.32    13.41   2.19    190.00
WindView Log File
First measurements at Hönö Wind
Turbine Station
with Gill anemometers.
WindMaster at about 28 m
height. WindObserver at about
20 m height.
Name: WindObserver20m
Output Format: GILL_POLAR_TWO_AXIS
Log file opened: 2012-09-27 14:24:11


Sample speed = 10 Sa/s

WD1_20  WS1_20  SoS1_20 AIRT1_20        DataValid
185     007.86  +338.61 +011.50 1
182     007.92  +338.62 +011.52 1
182     007.84  +338.61 +011.50 1
180     007.56  +338.62 +011.52 1
180     007.44  +338.69 +011.64 1
180     007.58  +338.54 +011.39 1
179     007.56  +338.54 +011.39 1
```

Figure F.2: Layout of the file

F.2 Stage-1

In this stage, files in the previous section are loaded in Matlab environment to process and synthesize them to simple version. Matlab program shown in Section I.5 process these text files to text files as shown in the figure F.3. The filenames are modified such that there is file start time stamp and date on them. The start time and date are taken from the contents of the files prior to stage-1. This will simplify to organize/process the files files further as it is difficult to open the file to know the date and time stamp. The filename apart from the date and time stamp remains the same as pre stage-1 filename.

Figure F.3: Filenames after stage-1

Statistics at the beginning of the files, header of columns is removed. This will make it easy to count number of rows/lines to know the span of readings present in the file. The internal layout is shown in the Figure F.4

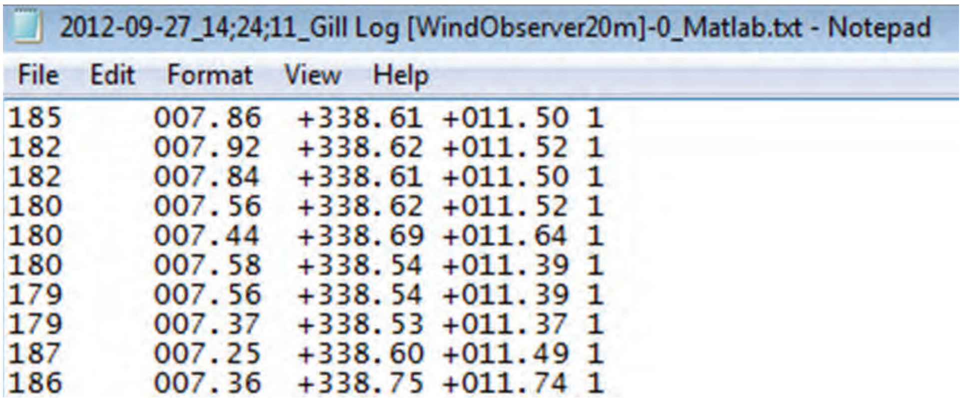


Figure F.4: Internal layout of files after stage-1

F.3 Stage-2

In this stage files from the previous stage are further reduced to have one sec average data, meaning each row represents one second value. Files after stage-2 contains only selected columns, wind direction and wind speed. Matlab program used during stage-2 is given in the Section I.6. The filenames remain unchanged. Initially the program is tested for October 1 - October 10. Explorer view of files after stage-2 are shown in the Figure F.5, internal layout of files within folder after stage-2 is shown in the Figure F.6

Figure F.5: Explorer view of files after stage-2

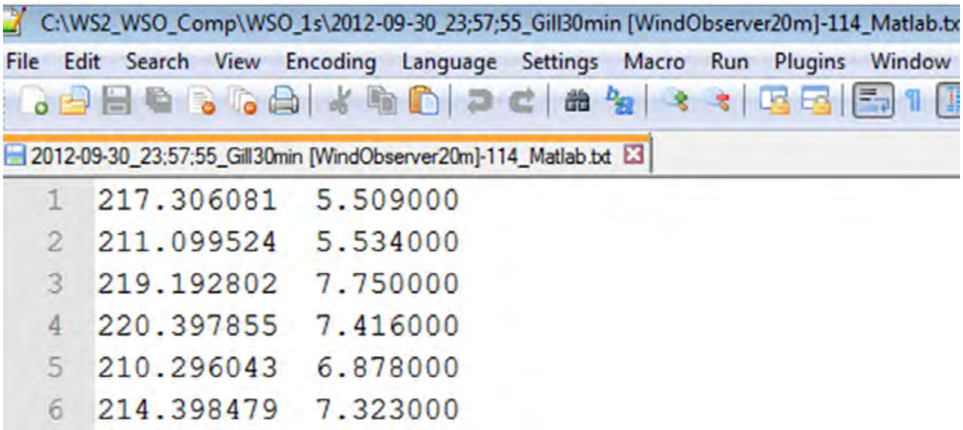


Figure F.6: Internal layout of files after stage-2

F.4 Stage-3

In this section the files are grouped according to the day, each text file per day containing one second average values of wind direction and wind speed. The programming logic is heavy because the files structure is not in order until now. The day start from a previous day file and have around 48 files in a particular day. File layout and explorer view of files after stage-3 are shown in the Figure F.7, Figure F.8 respectively. Program used for this stage is given in Section I.7.

Figure F.7: Explorer view of files after stage-3

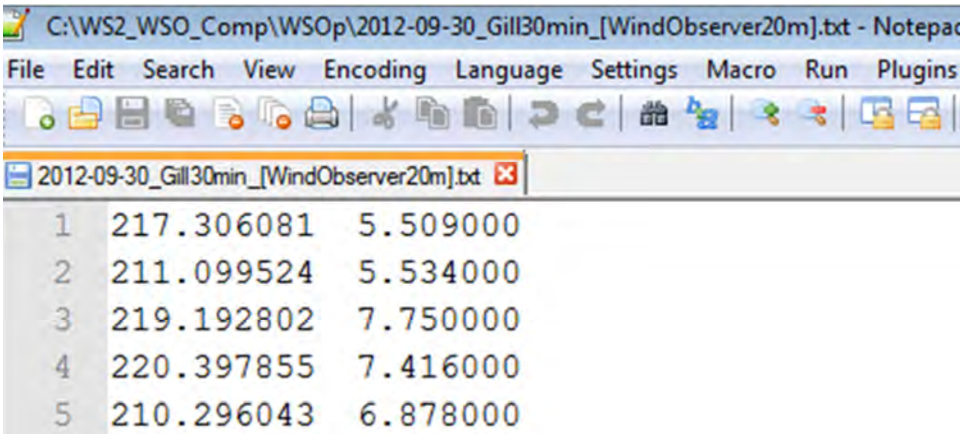


Figure F.8: Internal layout of files after stage-3

Appendix G

Theoretical WST Mast Wake Identification

Figure G.1 represents the approximate schematic drawing of WST and met. mast-1. β or sector AOB represents the mast wake of Met. mast-1 on WST. Mast-1 in reality is close to a triangle with all the sides measuring equal, however vertices of the mast-1 are not pointed instead they have a curvature. The approximation that the mast-1 is an equilateral triangle is thus motivated. Hence $\triangle$ ABC is an equilateral triangle with all sides measuring 0.4 m and all angles θ_1, θ_2, θ_3 measuring 60°.

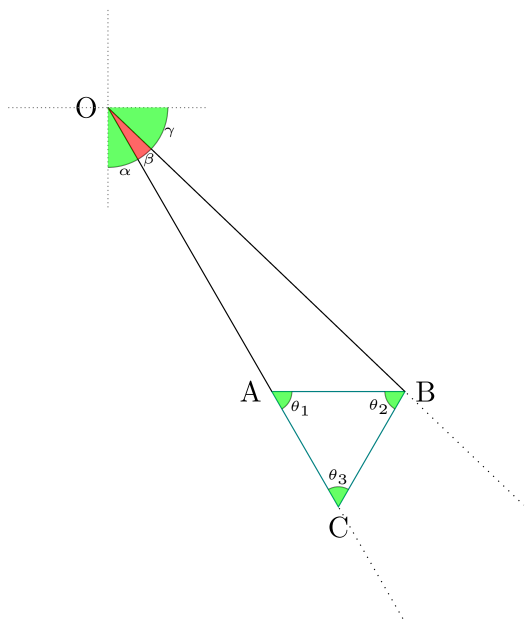


Figure G.1: Geometry of WST and Met. mast-1

O represents the centre of WST anemometer. The possible mast wake on WST will be within south east direction. The following are the dimensions of the drawings in Figure G.1 .

$$\theta_1 = \theta_2 = \theta_3 = 60^\circ \tag{G.1}$$

Since WST boom is oriented at 318° with respect to mast-1, which means boom OAC is at 138° with respect to point O and thereby

$$\alpha = 42^\circ \tag{G.2}$$

$$\text{AB} = \text{BC} = \text{CA} = 0.4 \text{ meters} \tag{G.3}$$

$$< \text{OAC} =< \text{OAB}+ < \text{CAB} = 180^\circ \tag{G.4}$$

$$< \text{OAC} =< \text{OAB}+ < 60^\circ = 180^\circ \tag{G.5}$$

$$< \text{OAB} = 120^\circ \tag{G.6}$$

As OAB triangle is obtuse angled triangle, and length of OA is 1 meter and length of AB is 0.4 meter and the rest of the triangle parameters are calculated

$$< \text{AOB} = \beta = 16.1^\circ \tag{G.7}$$

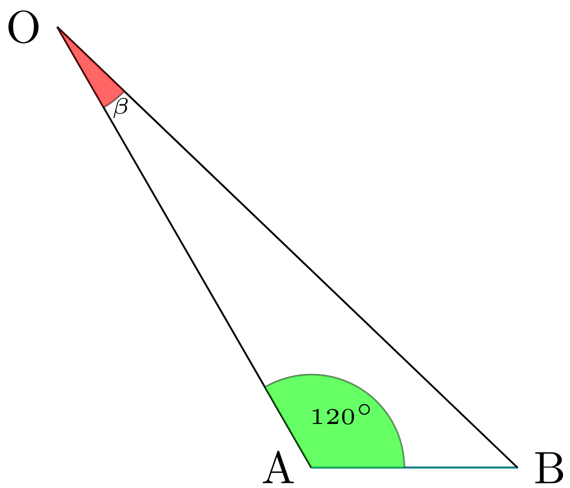


Figure G.2: Geometry of WST and Met. mast-1

Appendix H

Wind Rose

A wind rose is a graphical representation of wind availability and distribution in different directions over a particular location. Wind rose uses a polar coordinate system to represent the direction. The length of rose petals/spokes represents the availability of particular wind speed class over the measured horizon. The concept of wind rose is basically derived from the compass roses. Wind rose is widely used in aviation, meteorology and power sectors. The concept of wind rose can be extended to plot wind regimes like frequency rose, velocity rose, energy rose. There are a lot of software available to plot wind rose. However, three of the freeware are evaluated in this project which are as follows:

- WRPLOT View™7.0.0 by Lakes Environmental [5].
- Hydrognomon 4.1.0.26 by National Technical University of Athens [6].
- Wind Resource Assessment by The MathWorks, Inc. [7].

H.1 WRPLOT

WRPLOT is a freeware developed by Lakes Environmental software that can analyse wind data and can plot wind rose, wind speed distribution. WRPLOT accepts variety of input data formats, most of them are difficult to generate by Matlab. There is an option in WRPLOT where an excel file can be converted to formats that WRPLOT accepts. It has a simple user interface can export wind rose in a structured way. There is also an option to increase the wind direction bins from 8 - 36 to have a more precise view of wind availability over different directions. The working of WRPLOT can be explained in the following steps

1. Matlab program given in Section I.8 generates a excel file that contains one hour average value of wind speed and direction. The input to this

program is raw H4_1Hz_XXX.lvm file series that contains 33 columns and 86400 rows. The program is tested for entire 2011 year data. Figure H.1 shows the window of WRPLOT software.

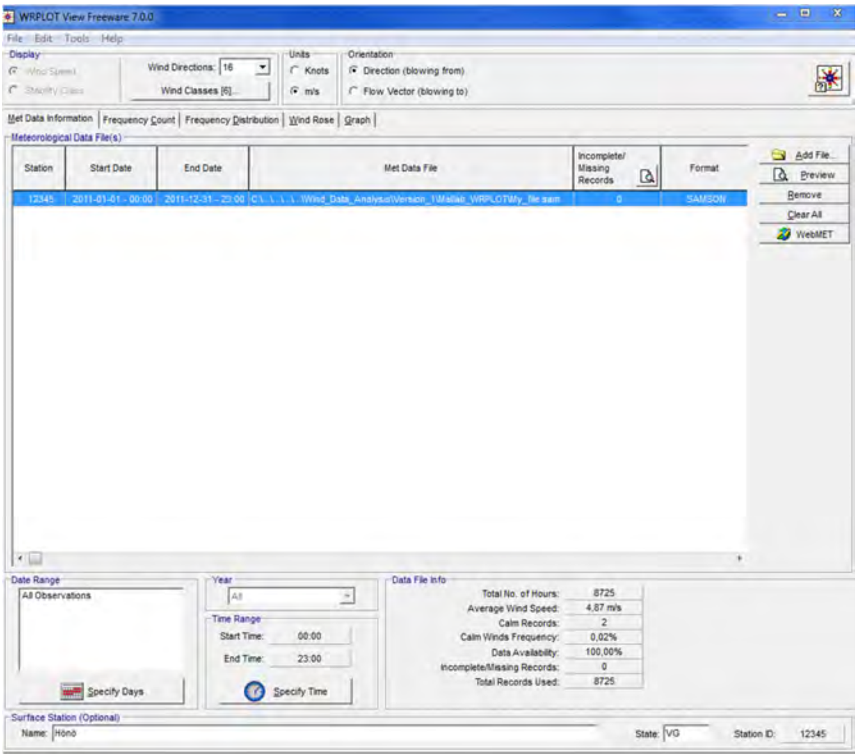
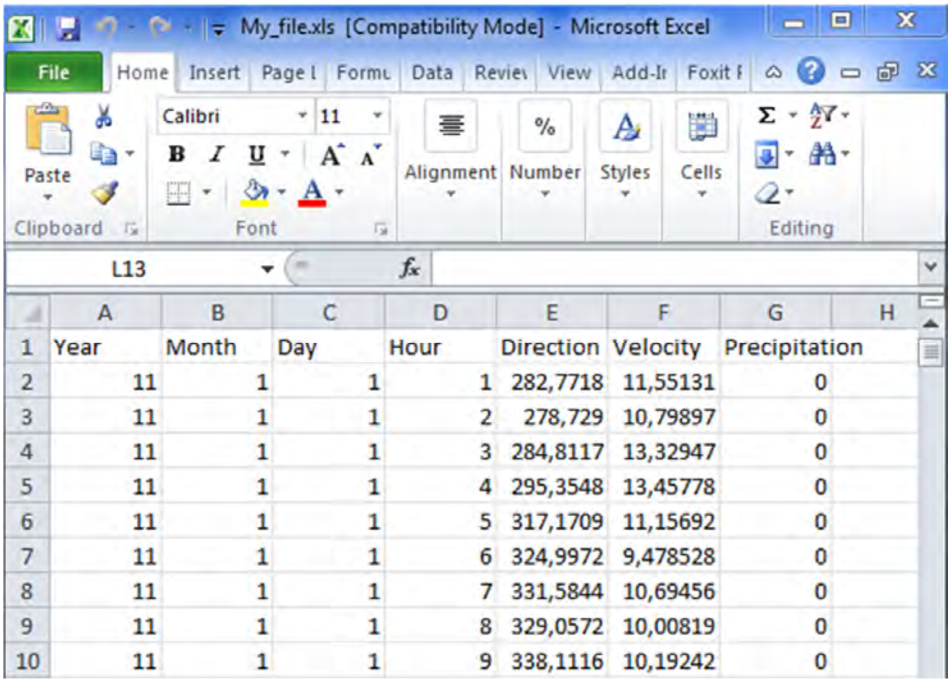


Figure H.1: Screenshot of WRPLOT window

2. The excel file shown in the Figure H.2 is then imported into WRPLOT and is converted into one of the format that WRPLOT can directly handle. The excel file is converted to SAMSON format which has an extension *filename.sam*.



	A	B	C	D	E	F	G	H
1	Year	Month	Day	Hour	Direction	Velocity	Precipitation	
2	11	1	1	1	282,7718	11,55131	0	
3	11	1	1	2	278,729	10,79897	0	
4	11	1	1	3	284,8117	13,32947	0	
5	11	1	1	4	295,3548	13,45778	0	
6	11	1	1	5	317,1709	11,15692	0	
7	11	1	1	6	324,9972	9,478528	0	
8	11	1	1	7	331,5844	10,69456	0	
9	11	1	1	8	329,0572	10,00819	0	
10	11	1	1	9	338,1116	10,19242	0	

Figure H.2: Screen shot of excel file created

3. Once the excel file is created WRPLOT can be used to convert into SAMSON format. This can be done by clicking

   Tools → Import from Excel → Import Surface Data from (Excel File):

   Open the excel file and load into the WRPLOT. The excel file will be loaded with the same layout as in Microsoft excel spreadsheet. Now select the number of rows for analysis, as the first row is the header row it should be discarded.

4. In the *Data Fields* tab write the columns name for the corresponding year, month etc. as in loaded excel file. Then check the *Unit in Excel file* menu to enter the right unit system of measurement.

5. Beside the *Data Fields* tab there is another tab *Station Information* where the station information should be entered. This is a mandatory field, by specifying latitude and longitude of the measurement site the wind rose can be exported to Google earth to plot on the geographic location. The geographic coordinated of met mast-1 is approx 57° 41′ 59.15″ N & 11° 39′ 41.78″ E

6. After the details of station are entered click on *Import* to import it to SAMSON file and save it. SAMSON file can be viewed with any

default Microsoft word editors.

7. Once the SAMSON file is created move to the WRPLOT main window and click on *Add File* and then select the created SAMSON file. The *Data File Info* tab provides the overview of loaded data, when entire data is imported properly without any errors or missing data, the data availability would be 100% and *Incomplete/Missing Records* would be 0%.

8. When the SAMSON file is loaded we can navigate to different menus *Frequency Count*, *Frequency Distribution*, *Wind Rose*, *Graph* to directly see them. *Units* tab in the main window should be matched to the unit system of measurement. To export the wind rose into Google maps, Google earth freeware should be installed in the computer. And the wind rose on the geographical site can be plotted according to

   Wind Rose → Export, A window *Export To Google Earth* pops up where the location can be verified/changed and also the style of the plot can be customized, and then click *Export*.

H.2 Hydrognomon

Hydrognomon is freeware developed by National Technical University of Athens primarily designed to analyse and process hydrological data in the form of time series. It has a simple user interface and accepts the data in the format *filename.hts*. These .hts files are created using Matlab program given in the Section I.9.

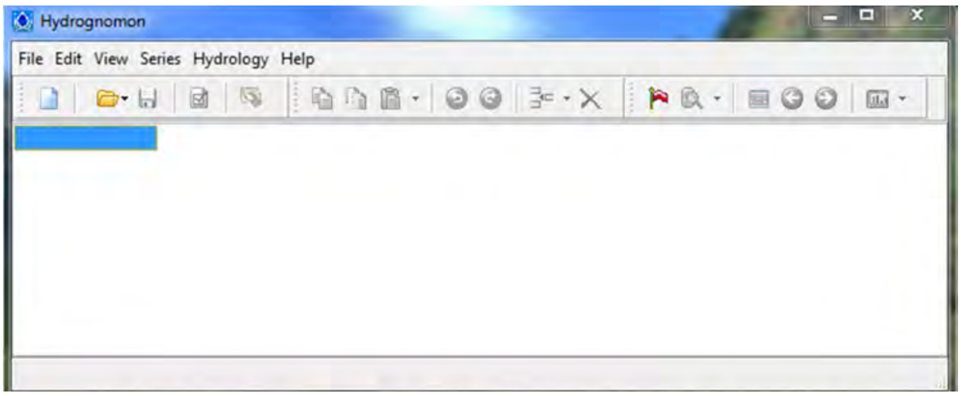


Figure H.3: Screenshot of Hydrognomon window

1. The Matlab program generates two files Input_1.hts with time series, wind direction & Input_2.hts with time series, wind speed. Time

series in both the files should be identical before they can be imported into Hydrognomon. The input to the Matlab program is raw H4_1Hz_XXX.lvm file series that contains 33 columns and 86400 rows. The program is tested for entire January 2011 month data.

2. These input files can be directly opened or can be dragged into Hydrognomon window.

3. Once the input files are loaded into Hydrognomon window, follow: View → Rose diagram... A window pops up named *Time series selections for processes* which has two menus namely *Available time series:* and *Time series selections:* as shown in the Figure. Drag the direction and speed series to time series selections of degrees and speed respectively and click OK.

4. There are a lot of customizations available on the *Rose diagram* window.

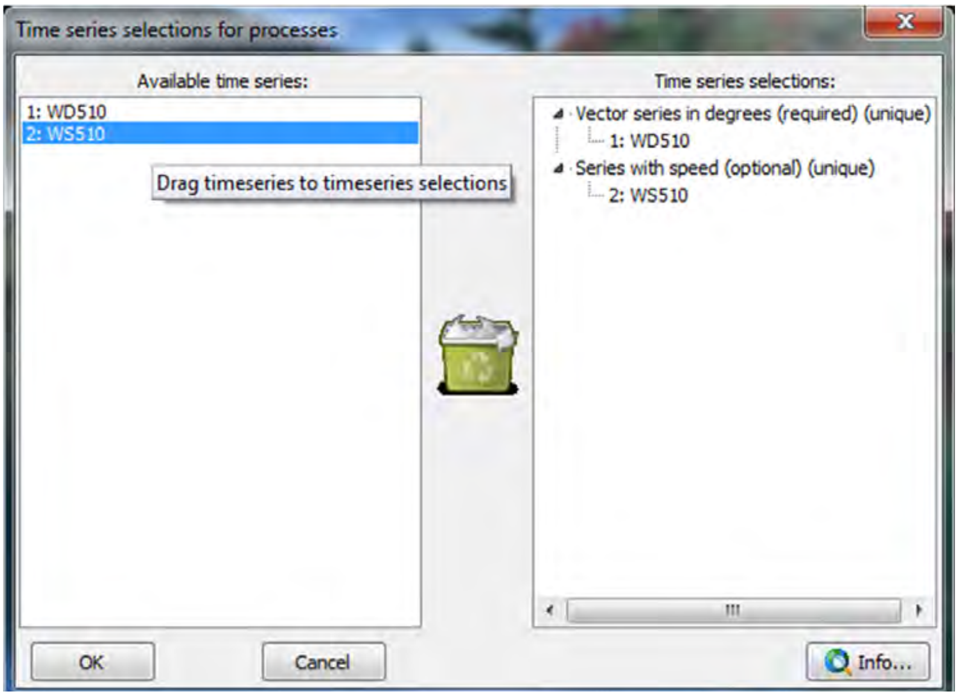


Figure H.4: Screen-shot of Hydrognomon window

H.3 MathWorks

wind_ rose is a Matlab function file given in Mathworks file exchange [7]. There is also a supplement webinar video to know the working of this file and also wind resource assessment in general which can be viewed in reference [8].

The input to this file is array of wind direction and wind speed. Wind direction (θ) should be converted to mathematical angles (θ_1) before they are processed by the following equation

$$\theta_1 = (90 - \theta, 360) \tag{H.1}$$

Appendix I

Matlab Programs

I.1 Turbulence Intensity

```
% Input to TI_calc function are input array and length of the
    input array and o/p is TI_calc array
function[TI_calc]=TI_calc(ip1,nLines)
lim=round(nLines/600); % No of 10 minutes averages that can be
    calculated input array in one second resolution
for j=0:1:lim-1
    if j<lim-1 % j=1 to 143
        mv1=(ip1(j*600+1:600*(j+1)));
        TI_calc(1,j+1)=std(mv1)/mean(mv1);  %#ok<AGROW>
    else   % j=144  or j=lim
        mv1=(ip1(j*600+1:end));
        TI_calc(1,j+1)=std(mv1)/mean(mv1);  %#ok<AGROW>
    end
end
```

I.2 Weibull Probability Distribution Function and Wind Speed Distribution

```
%Plot Weibull distribution and Wind Speed Distribution
wbl_param=wblfit(ip1); % wblfit calculates scale and shape factor
    for input array (ip1), i.e wind speed array
C1=wbl_param(1); K1=wbl_param(2); % Scale and shape factor
val2=wblpdf(ip1,C1,K1); % Calulates probability for each bins of
    ip1
[nelements,centers]=hist(ip1,min(ip1):1:max(ip1)); % nelements are
     length of bars & centers are x axis values of bar plot
fig_PDF=figure;
bar(centers,nelements,'b'); grid on; % Plot wind speed
    distribution
xlim([min(ip1)-0.5 max(centers)+2]); ylim([0 max(nelements)+max(
    nelements)/20])
```

```
xlabel('Wind Speed [ms^{−1}]');
ylabel('No. of samples');
set(gca,'XTick',ceil(min(ip1)):floor(max(ip1)))
hAxes = gca; hAxes_pos = get(hAxes,'Position');
hAxes2 = axes('Position',hAxes_pos);
plot(ip1,val2,'Marker','*','LineStyle','none',...
    'Color',[1 0.5 0.2]); % Plot probability distribution function
        on the same graph as wind speed distribution
set(hAxes2,'YAxisLocation','right','Color','none','XTickLabel',[])
    ;
centers_xlim = get(hAxes,'XLim'); % store x−axis limits of first
    axes
set(hAxes2,'XLim',centers_xlim) % specify x−axis limits of second
    axes
ylabel('Probability');
saveas(fig_PDF,'Prob_dis_func','emf'); % Save the fig in emf file
    format
```

I.2.1 Wind Direction Average

```
lim1=round(nLines1/600);
    for j=0:1:lim1−1
        if j<lim1−1 % for j=1−142
            angles=(ia(j*600+1:600*(j+1)));
            ar=angles*pi/180;
            ae=mean(exp(1i*ar));
            mean_angle=(angle(ae)*180/pi);
            if mean_angle < 0
                mean_angle=360+mean_angle;
            end
            ia_avg(1,j+1)=mean_angle;  %#ok<AGROW>
        else
            angles=ia(j*600+1:end); % mv1=(ip1(j*600+1:end));
            ar=angles*pi/180;
            ae=mean(exp(1i*ar));
            mean_angle=(angle(ae)*180/pi);
            if mean_angle < 0
                mean_angle=360+mean_angle;
            end
            ia_avg(1,j+1)=mean_angle;  %#ok<AGROW>
        end
    end
```

I.2.2 Wind Speed Average

```
lim=round(nLines/600);
for j=0:1:lim−1
        if j<lim−1% j=1−142 or j=1−lim
            mv1=(ip1(j*600+1:600*(j+1)));
            call_avg(1,j+1)=sum(mv1)/length(mv1);  %#ok<AGROW>
        else   % j=143      or j=lim
```

```
            mv1=(ip1(j*600+1:end));
            call_avg(1,j+1)=sum(mv1)/length(mv1); %#ok<AGROW>
        end
end
```

I.3 Process WXT510 Files

```
% Place the program in a folder containing WXT510 1 second files
% Apply correction factor and process all WXT510 files
% This program generates 1. 2. 3. 4.
% Ensure the following matlab programs in the working directory
    before
% running the  program
% binkv3 % To simultaneous bin two vectors (order of vectors
    should be DIRECTION, WIND SPEED, NO.OF BINS)
% call_avg % To average one second wind speed values to 10 min
    avgs
% dir_avg % To average one second wind dir values to 10 min avgs
% TI_calc % To calculate turbulence intensity of 10 min. wind
    speeds
% wind_rose % To plot wind rose

tic;  clc; clear all; close all;
yay1=2011; % Year array (MANUALLY ENTER YEARS, either one year at
    a time)

%% STAGE-1 (Process & apply correction)
yay=num2str(yay1);
ya=yay(3:4);
allfilenames=dir(fullfile('*lvm'));        % Get files with lvm
    extn. in the directory
filenames={allfilenames.name}';            % Get file names

% Generalize the format of filenames Ex:WXT510_1s_mv_11-01-01
    _0000.lvm
e1='^WXT(\d+)\_';    % WXT510
e2='(\d+)s\_';       % 1s
e3='mv\_';           % mv
e4='(\d+)\-';        % year
e5='(\d+)\-';        % month
e6='(\d+)\_';        % date
e7='(\d+).lvm$';     % time
ex='\-';
eya='\_';

mkdir(strcat(yay,'_WXT510_files')); % Make a directory in current
    working directory for storing proc. files
mkdir(strcat(yay,'_WXT510_figures')); % Make a directory in
    current working directory for storing proc. figs
files_path=strcat(pwd,'\',yay,'_WXT510_files\');
figures_path=strcat(pwd,'\',yay,'_WXT510_figures\');
fig_export_format='emf'; % Figure export format
```

```
% Correction factor
lim_r1=50; lim_r2=60; lim_r3=70; lim_r4=80; lim_r5=90; % Limits of
     sectors in degrees
cf_r1=1.1418; cf_r2=1.2875; cf_r3=1.2977; cf_r4=1.1961; %
    Correction factor of sectors

% Other useful variables
Month_WD_av=[]; Month_WS_av=[];
WS_1sec=[]; WS_cor_1sec=[]; WD_1sec=[];
Monthly_WS_1sec_matrix=[];Monthly_WS_10min_matrix=[]; Month_TI_av
    =[];

expr=strcat(e1,e2,e3,ya,ex,e4,e6,e7);        % Concatenate the
    strings to form generalized ip_filename
filedata=regexp(filenames,expr,'tokens');    % Find tokens that
    matches the expression (expr)
index=~cellfun('isempty',filedata);          % Find index of
    matches
filedata=[filedata{index}];
filedata = vertcat(filedata{:});             % Format token data
year = filenames(index);                     % Group all the
    similar year files in 'year'
ma1=filedata(1:size(filedata,1),3);          % Know the months in
    the year cell
ma2=unique(ma1);                             % Delete the duplicate
     entries
ma=str2num(cell2mat(ma2));                   %#ok<ST2NM> %
    Available months in the selected year

for mi=1:length(ma)
    x2=ma2{mi(1)};                               % Select the first
         month in the year
    expr2=strcat(e1,e2,e3,ya,ex,x2,ex,e6,e7);   % Concatenate the
        strings to form generalized ip_filename with the selected
        month
    fdm=regexp(year,expr2,'tokens');             % Find tokens that
         matches the expression (expr2) with selected month
    idm=~cellfun('isempty',fdm);                 % Find index of
        matches
    fdm=[fdm{idm}];
    fdm=vertcat(fdm{:});
    da1=fdm(1:(size(fdm,1)),3);
    da2=unique(da1);                             % Delete the
        duplicate entries
    da=str2num(cell2mat(da2));                   %#ok<ST2NM> %
        Available days in the selected month

    for di=1:length(da)
        x5=da2(di);                              % Select the first
             date in the month
        expr3=strcat(e1,e2,e3,ya,ex,x2,ex,x5,eya,e7); %
            Concatenate the strings to form generalized
            ip_filename with the selected month and date
```

```
fd3=regexp(year,expr3,'tokens');        % Find tokens that
     matches the expression (expr3) with selected month
    and date
id3=~cellfun('isempty',fd3);
fd3=[fd3{id3}];
fd3=vertcat(fd3{:});
filez=year(id3);                        % ip_filename to
    read the data

if length(filez)>1                      % When a day
    contains MORE than one LVM file
    WD=[]; WS=[];
    for u=1:length(filez)
        ip_filename=filez{u};

        % Overwrite comma with point
        filex=memmapfile(ip_filename,'writable',true);
        comma=uint8(',');
        point=uint8('.');
        filex.Data(transpose(filex.Data==comma))=point;

        fid=fopen(ip_filename,'r');
        matdata=textscan(fid, '%f %f %f %f %f %f %f');
        matdata=cell2mat(matdata);
        fclose(fid);

        %Load the selected columns
        WSu=matdata(:,2);           % Wind Speed WS [m/s]
        WDu=matdata(:,1);         % Wind Direction Vaisala
             WXT510 [degrees]

        WS=vertcat(WS,WSu); %#ok<AGROW>
        WD=vertcat(WD,WDu); %#ok<AGROW>
    end
else                                    % When a day
    contains ONLY one LVM file
    ip_filename=filez{:};

    % Load the i/p file data into matdata
    filex=memmapfile(ip_filename,'writable',true);
    comma=uint8(',');
    point=uint8('.');
    filex.Data(transpose(filex.Data==comma))=point;

    fid=fopen(ip_filename,'r');               % Open the
        file in read mode
    matdata=textscan(fid,'%f %f %f %f %f %f %f') ; % Load
        the data from i/p files containing 7 columns
    matdata=cell2mat(matdata);                % Convert
        cell to array
    fclose(fid);

    % Load the selected columns
    WS=matdata(:,2);         % Wind Speed WS [m/s]
```

```
    WD=matdata(:,1);         % Wind Direction Vaisala
        WXT510 [degrees]
end

% Skip NaN values
tk1=isnan(mean(WD(:)));    % When WD contains NaN
tk2=isnan(mean(WS(:)));     % When WS contains NaN

if tk1==1 % WD
    Ind_nan1=find(isnan(WD));
    WD(Ind_nan1)=[]; %#ok<SAGROW>
    WS(Ind_nan1)=[]; %#ok<SAGROW>
end
if tk2==1 % WS
    Ind_nan2=find(isnan(WS));
    WD(Ind_nan2)=[]; %#ok<SAGROW>
    WS(Ind_nan2)=[]; %#ok<SAGROW>
end

% Check for negative wind direction values and apply the
    correction (Magnus Logic)
tk3=find(WD<0);
if ~isempty(tk3)      % Enter loop if WD records atleast
    one negative value
    WD(tk3)=mod(WD(tk3),360); %#ok<SAGROW>
end

% Check for negative wind speeds values and delete them
Ind_neg=find(WS<=0);
if ~isempty(Ind_neg)
    WD(Ind_neg)=[]; %#ok<SAGROW>
    WS(Ind_neg)=[]; %#ok<SAGROW>
end

nLines=length(WS);
if ~isempty(WD) % Enter the loop if WD is not a empty
    array
    WS_cor=WS;
    % Apply correction factor 2 (Mast wake)
    ind_r1=find(WD > lim_r1 & WD <= lim_r2); % Region 1
    WS_cor(ind_r1)=cf_r1*WS(ind_r1);

    ind_r2=find(WD > lim_r2 & WD <= lim_r3); % Region 2
    WS_cor(ind_r2)=cf_r2*WS(ind_r2);

    ind_r3=find(WD > lim_r3 & WD <= lim_r4); % Region 3
    WS_cor(ind_r3)=cf_r3*WS(ind_r3);

    ind_r4=find(WD > lim_r4 & WD <= lim_r5); % Region 4
    WS_cor(ind_r4)=cf_r4*WS(ind_r4);

    % Make 10 min avg
    WS_av=call_avg(WS_cor,nLines);
    WD_av=dir_avg(WD,nLines);
```

```
        TI_av=TI_calc(WS_cor,nLines);

        op_filename=strcat(yay,ip_filename(16:21),'_',
            ip_filename(1:7),'10minavg','.txt'); % Create o/p
            filename
        op_filepath_1=strcat(files_path,op_filename);

        %  Save the file (10 min average day files)
        dlmwrite(op_filepath_1,[WD_av' WS_av'],'delimiter','\t
            ');

        % Create 10 min average array of all days in a month
        Month_WD_av=[Month_WD_av WD_av]; %#ok<AGROW>    %
            Concatenate all 10 min avgs of WD into a month
            variable
        Month_WS_av=[Month_WS_av WS_av]; %#ok<AGROW>    %
            Concatenate all 10 min avgs of WS into a month
            variable
        Month_TI_av=[Month_TI_av TI_av]; %#ok<AGROW>    %
            Concatenate all 10 min avgs of TI into a month
            variable

        % Create 1 sec raw array of all days in a month
        WS_cor_1sec=[WS_cor_1sec WS_cor']; %#ok<AGROW>  %
            Concatenate all 1 sec corrected WS values into a
            month variable to calculate 1 sec min, max values
            of wind speed
    end
end

xx=[min(WS_cor_1sec) max(WS_cor_1sec) mean(WS_cor_1sec)]; %
    min, max, mean of corr 1 sec values
Monthly_WS_1sec_matrix=[Monthly_WS_1sec_matrix; xx]; %#ok<
    AGROW>

yy=[min(Month_WS_av) max(Month_WS_av) mean(Month_WS_av)]; %
    min, max, mean of corr 1o min values
Monthly_WS_10min_matrix=[Monthly_WS_10min_matrix; yy]; %#ok<
    AGROW>

% Write 10 min average array of all days in a month in a text
    file
op_filename_2=strcat(yay,ip_filename(16:18),'_',ip_filename
    (1:7),'10minavg','.txt');
op_filepath_2=strcat(files_path,op_filename_2);

% Save the file (10 min average day files)
dlmwrite(op_filepath_2,[Month_WD_av' Month_WS_av'],'delimiter'
    ,'\t');

Monthly_WD{mi}=Month_WD_av; %#ok<SAGROW> % Save 10 min WD avg
    array into a yearly cell
Monthly_WS{mi}=Month_WS_av; %#ok<SAGROW> % Save corr 10 min WS
     avg array into a yearly cell
```

```
    Monthly_TI{mi}=Month_TI_av; %#ok<SAGROW> % Save 10 min TI avg
        array into a yearly cell
    Month_WD_av=[]; Month_WS_av=[];Month_TI_av=[];
    WS_cor_1sec=[];
end
save(strcat(yay,'_','WXT510'),'Monthly_WD','Monthly_WS','
    Monthly_TI'...
    ,'ma','Monthly_WS_1sec_matrix','Monthly_WS_10min_matrix');
% Save the above parameters to plot graphs in stage-2

%% STAGE-2 (Plot graphs)
clearvars -except yay1 files_path figures_path fig_export_format

yay=num2str(yay1);
year=yay(3:4);
numbins=180; % Used in binning the data
load(strcat(yay,'_WXT510.mat'));
Month_list={'January','February','March','April','May','June'...
    ,'July','August','September','October','November','December'};
mlm={'Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sept','Oct',
    'Nov','Dec'};
Monthly_C=[]; Monthly_K=[]; Rec_data_avail=[]; Mean_mon_WS=[];
    Months_rec_WS=[];
csk=0.6; % Scale factor in the compass plot

% Know which months are recorded
mal=(ma(~cellfun('isempty',Monthly_WS))); Rec_Month=Month_list(mal
    );
mlm=mlm(mal);

% Remove empty month cells
Monthly_WS=Monthly_WS(~cellfun('isempty',Monthly_WS));
Monthly_WD=Monthly_WD(~cellfun('isempty',Monthly_WD));
Monthly_TI=Monthly_TI(~cellfun('isempty',Monthly_TI));

% Assign 1 sec values
WS1min=Monthly_WS_1sec_matrix(:,1); WS1max=Monthly_WS_1sec_matrix
    (:,2);
WS1mn=Monthly_WS_1sec_matrix(:,3);

% Monthly Stats
for k =1:length(Rec_Month)
    WD=Monthly_WD{k}; WS=Monthly_WS{k}; % Convert cell to array

    % Calculate data avaiability
    days=eomday(str2num(strcat('20',year)),mal(k)); %#ok<ST2NM>
        Calculate no. of days in the month (mal(k))
    tot10mins=days*144;         % Total 10 mins in a month
    rec10mins=length(WD);       % Recorded 10 mins in a month
    data_avail=(rec10mins/tot10mins)*100; % Data availablity
    Rec_data_avail=[Rec_data_avail data_avail]; %#ok<AGROW>

    % Writes emf month emf figure with speed distribution and
        probability distribution
```

```
op_figurename_1=strcat('20',year,'_WXT510','_',Rec_Month{k},'
    _Probability_distribution_function');
op_figurepath_1=strcat(figures_path,op_figurename_1);

%Plot Weibull distribution and Wind Speed Distribution
wbl_param=wblfit(WS); % wblfit calculates scale and shape
    factor for input array (WS), i.e wind speed array
C1=wbl_param(1); K1=wbl_param(2); % Scale and shape factor
val2=wblpdf(WS,C1,K1); % Calulates probability for each bins
    of WS
[nelements,centers]=hist(WS,min(WS):1:max(WS)); % nelements
    are length of bars & centers are x axis values of bar plot
fig_PDF=figure;
bar(centers,nelements,'b'); grid on; % Plot wind speed
    distribution
xlim([min(WS)-0.5 max(centers)+2]); ylim([0 max(nelements)+max
    (nelements)/20])
xlabel('Wind Speed [ms^{-1}]');
ylabel('No. of samples');
set(gca,'XTick',ceil(min(WS)):floor(max(WS)))
hAxes = gca; hAxes_pos = get(hAxes,'Position');
hAxes2 = axes('Position',hAxes_pos);
plot(WS,val2,'Marker','*','LineStyle','none',...
    'Color',[1 0.5 0.2]); % Plot probability distribution
        function on the same graph as wind speed distribution
set(hAxes2,'YAxisLocation','right','Color','none','XTickLabel'
    ,[]);
centers_xlim = get(hAxes,'XLim'); % store x-axis limits of
    first axes
set(hAxes2,'XLim',centers_xlim) % specify x-axis limits of
    second axes
ylabel('Probability');
saveas(fig_PDF,op_figurepath_1,fig_export_format); % Save the
    fig in emf file format
set(fig_PDF,'Visible','off');
Monthly_C=[Monthly_C C1];   Monthly_K=[Monthly_K K1]; %#ok<
    AGROW>

% Plot wind rose
WD1=mod(90-WD,360);     % Convert met angles to math angles
wrf=figure; wind_rose(WD1,WS,'di',[0:2:24],'lablegend','(m/s)'
    );
% 24 m/s is given to scale all the wind roses, legend is given
     in
% steps of 2
set(wrf,'InvertHardCopy','off');
op_figurename_2=strcat(yay,'_WXT510','_',Rec_Month{k},'
    _Wind_rose');
op_figurepath_2=strcat(figures_path,op_figurename_2);
saveas(wrf,op_figurepath_2,fig_export_format);
set(wrf,'Visible','off');

% Plot Turbulence Intensity rose
TI=Monthly_TI{k};
```

```
    [WDbin,TIbin]=binkv3(WD,TI,numbins);
    WDrbin = WDbin * pi/180;
    [x,y]=pol2cart(WDrbin,TIbin);
    tipf=figure;
    h = compass(csk); hold on
    tipf1=compass(x,y,'*-r');
    set(h, 'Visible', 'off');
    for i =1:length(tipf1) %the last line on the axes
        xData = get(tipf1(i),'XData');
        yData = get(tipf1(i),'YData');
        set(tipf1(i),'XData',xData(1:2),'YData',yData(1:2))
    end %for
    az = 90; % azimuth i.e. rotate around z-axis horizontally by
        90 degrees
    el = -90; % elevation negative, effectively looking beneath
        plot
    view(az, el);
    op_figurename_3=strcat(yay,'_WXT510','_',Rec_Month{k},'
        _Turbulence_intensity');
    op_figurepath_3=strcat(figures_path,op_figurename_3);
    saveas(tipf,op_figurepath_3,fig_export_format)
    set(tipf,'Visible','off');

    Mean_mon_WS=[Mean_mon_WS mean(WS)]; %#ok<AGROW>
end
Months_rec_WS=[Months_rec_WS; mal'];
Monthly_param=horzcat(Rec_data_avail',Monthly_WS_10min_matrix,
    Monthly_C',Monthly_K'); %10 min WS matrix with shape & scale
    fators

% Yearly Stats
% Wind Rose
WD=cell2mat(Monthly_WD);
WS=cell2mat(Monthly_WS);
TIYC=cell2mat(Monthly_TI);

% Availability for the year
totdays=yeardays(str2num(strcat('20',year))); %#ok<ST2NM>
tot10mins=144*totdays;
rec10mins=length(WS);
year_avail=(rec10mins./tot10mins)*100;
dav=strcat('Data Availability: ',sprintf('%.2f',year_avail),'\%');

% Wind rose for year                          ### YEAR FIG-1 ###
WDn=mod(90-WD,360); % Convert met angles to math angles
pfR=figure;
set(pfR,'InvertHardCopy','off');
wind_rose(WDn,WS,'di',[0:2:24],'lablegend','(m/s)'); %,'lablegend
    ','Wind Speed (m/s)');
op_figurename_4=strcat(strcat(yay,'_WXT510_Wind_rose'));
op_figurepath_4=strcat(figures_path,op_figurename_4);
saveas(pfR,op_figurepath_4,fig_export_format);
set(pfR,'Visible','off');
```

```
% Plot Histogram of monthly means in a year    ### YEAR FIG-2 ###
Monthly_mean=Monthly_param(:,4);
fH=figure;
axes1 = axes('Parent',fH,...
    'XTickLabel',mlm,...
    'XTick',1:length(mlm)); box(axes1,'on');
hold(axes1,'all');
bar(Monthly_mean); grid on;
xlabel('{Months}','interpreter','latex');
op_figurename_5=strcat(yay,'
    _WXT510_Monthly_mean_wind_speed_histogram');
op_figurepath_5=strcat(figures_path,op_figurename_5);
saveas(fH,op_figurepath_5,fig_export_format);
set(fH,'Visible','off');

%Plot Weibull distribution and Wind Speed Distribution ### YEAR
    FIG-3 ###
wbl_param=wblfit(WS); % wblfit calculates scale and shape factor
    for input array (WS), i.e wind speed array
C1=wbl_param(1); K1=wbl_param(2); % Scale and shape factor
val2=wblpdf(WS,C1,K1); % Calulates probability for each bins of WS
[nelements,centers]=hist(WS,min(WS):1:max(WS)); % nelements are
    length of bars & centers are x axis values of bar plot
fig_PDF=figure;
bar(centers,nelements,'b'); grid on; % Plot wind speed
    distribution
xlim([min(WS)-0.5 max(centers)+2]); ylim([0 max(nelements)+max(
    nelements)/20])
xlabel('Wind Speed [ms^{-1}]');
ylabel('No. of samples');
set(gca,'XTick',ceil(min(WS)):floor(max(WS)))
hAxes = gca; hAxes_pos = get(hAxes,'Position');
hAxes2 = axes('Position',hAxes_pos);
plot(WS,val2,'Marker','*','LineStyle','none',...
    'Color',[1 0.5 0.2]); % Plot probability distribution function
         on the same graph as wind speed distribution
set(hAxes2,'YAxisLocation','right','Color','none','XTickLabel',[])
    ;
centers_xlim = get(hAxes,'XLim'); % store x-axis limits of first
    axes
set(hAxes2,'XLim',centers_xlim) % specify x-axis limits of second
    axes
ylabel('Probability');
op_figurename_6=strcat(yay,'
    _WXT510_Probability_distribution_function');
op_figurepath_6=strcat(figures_path,op_figurename_6);
saveas(fig_PDF,op_figurepath_6,fig_export_format); % Save the fig
    in emf file format
set(fig_PDF,'Visible','off');

% Turbulence intensity rose                        ### YEAR FIG-4
     ###
[WDyrbin,TIyrbin]=binkv3(WD,TIYC,numbins);
WDrC = WDyrbin * pi/180;
```

```
[xx,yy]=pol2cart(WDrC,TIyrbin);
trf=figure;
h=compass(csk); hold on
trf1=compass(xx,yy,'*-r'); % Turbulence rose figure
set(h, 'Visible', 'off');
for i =1:length(trf1) %the last line on the axes
    xData = get(trf1(i),'XData');
    yData = get(trf1(i),'YData');
    set(trf1(i),'XData',xData(1:2),'YData',yData(1:2))
end %for
az = 90; % azimuth i.e. rotate around z-axis horizontally by 90
    degrees
el = -90; % elevation negative, effectively looking beneath plot
view(az, el);
op_figurename_7=strcat(yay,'_WXT510','_Turbulence_intensity');
op_figurepath_7=strcat(figures_path,op_figurename_7);
saveas(trf,op_figurepath_7,fig_export_format)
close all
toc
```

I.4 Process WST Files

```
% Place the program in a folder containing WS2 1 second files
% Apply correction factor and process all WS2 files
% Ensure the following matlab programs in the working directory
    before running the  program
% binkv3 % To simultaneous bin two vectors (order of vectors
    should be WIND DIRECTION, WIND SPEED, NO.OF BINS)
% call_avg % To average one second wind speed values to 10 min
    avgs
% dir_avg % To average one second wind dir values to 10 min avgs
% TI_calc % To calculate turbulence intensity of 10 min. wind
    speeds
% wind_rose % To plot wind rose

tic;  clc; clear all; close all;
yay1=2011; % Year array (MANUALLY ENTER YEARS, one at a time)
yay=num2str(yay1);
ya=yay(3:4);
allfilenames=dir(fullfile('*lvm'));        % Get files with LVM
    extn. in the directory
filenames={allfilenames.name}';            % Get file names WST
    series

% Generalize the format of filenames
e1='^H(\d+)\_'; % H4
e2='(\d+)Hz\_'; % 1Hz
e3='(\d+)\-';   % year
e4='(\d+)\-';   % month
e5='(\d+)\_';   % date
e6='(\d+).lvm$';% time
ex='\-';
```

```
eya='\_';

mkdir(strcat(yay,'_WS2_files')); % Make a directory in current
    working directory for storing proc. files
mkdir(strcat(yay,'_WS2_figures')); % Make a directory in current
    working directory for storing proc. figs
files_path=strcat(pwd,'\',yay,'_WS2_files\');
figures_path=strcat(pwd,'\',yay,'_WS2_figures\');
fig_export_format='emf'; % Figure export format

% Correction factor
lim_r1=110; lim_r2=120; lim_r3=130; lim_r4=140; lim_r5=148; %
    Limits of sectors in degrees
cf_r1=1.2848; cf_r2=1.3910; cf_r3=1.3572; cf_r4=1.1562;     %
    Correction factor of sectors

% Other useful parameters
Month_WD510_av=[]; Month_WST_av=[];
WST_1sec=[]; WST_cor_1sec=[]; WD510_1sec=[];
Monthly_WST_1sec_matrix=[];Monthly_WST_10min_matrix=[];
    Month_TI_av=[];

%% Formulation
expr=strcat(e1,e2,ya,ex,e4,e5,e6);          % Concatenate the
    strings to form generalized ip_filename
filedata=regexp(filenames,expr,'tokens');   % Find tokens that
    matches the expression (expr)
index=~cellfun('isempty',filedata);         % Find index of
    matches
filedata = [filedata{index}];
filedata = vertcat(filedata{:});            % Format token data
year = filenames(index);                    % Group all the
    similar year files in 'year'
ma1=filedata(1:size(filedata,1),3);         % Know the months in
    the year cell
ma2=unique(ma1);                            % Delete the duplicate
     entries
ma=str2num(cell2mat(ma2));                  %#ok<ST2NM> % Months
    in the selected year

for mi=1:length(ma)
    x2=ma2{mi(1)};                          % Select the first
        month in the year
    expr2=strcat(e1,e2,ya,ex,x2,ex,e5,e6);  % Concatenate the
        strings to form generalized ip_filename with the selected
        month
    fdm=regexp(year,expr2,'tokens');        % Find tokens that
        matches the expression (expr2) with selected month
    idm=~cellfun('isempty',fdm);            % Find index of
        matches
    fdm=[fdm{idm}];
    fdm=vertcat(fdm{:});
    da1=fdm(1:(size(fdm,1)),3);
```

```
da2=unique(da1);                             % Delete the duplicate
     entries
da=str2num(cell2mat(da2));                   %#ok<ST2NM> %
    Available days in the selected month

for di=1:length(da)
    x5=da2(di);                              % Select the first
        date in the month
    expr3=strcat(e1,e2,ya,ex,x2,ex,x5,eya,e6); % Concatenate
        the strings to form generalized ip_filename with the
        selected month and date
    fd3=regexp(year,expr3,'tokens');     % Find tokens that
        matches the expression (expr3) with selected month and
         date
    id3=~cellfun('isempty',fd3);
    fd3=[fd3{id3}];
    fd3=vertcat(fd3{:});
    filez=year(id3);                         % ip_filename to read
        the data

    if length(filez)>1                       % When a day contains
        more than one LVM file
        WD510=[]; WST=[];
        for u=1:length(filez)
            ip_filename=filez{u};

            fid=fopen(ip_filename,'r');
            matdata=textscan(fid, '%f %f %f %f %f %f %f %f %f
                %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %
                f %f %f %f %f %f %f %f %f') ;
            matdata=cell2mat(matdata);
            fclose(fid);

            %Load the selected columns
            WSTu=matdata(:,19);                % Wind Speed WST [m/
                s]
            WD510u=matdata(:,27);              % Wind Direction
                Vaisala WXT510 [degrees]

            WST=vertcat(WST,WSTu); %#ok<AGROW>
            WD510=vertcat(WD510,WD510u); %#ok<AGROW>
        end
    else                  % When a day contains ONLY one LVM file
        ip_filename=filez{:};

        % Load the file data into matdata
        fid=fopen(ip_filename,'r');
        matdata=textscan(fid,'%f %f %f %f %f %f %f %f %f %f %f
             %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %
            f %f %f %f %f %f') ;
        matdata=cell2mat(matdata);
        fclose(fid);

        % Load the selected columns
```

```
    WST=matdata(:,19);             % Wind Speed WST [m/s]
    WD510=matdata(:,27);           % Wind Direction Vaisala
        WXT510 [degrees]
end

% Skip NaN values
tk1=isnan(mean(WD510(:)));    % When WD510 contains NaN
tk2=isnan(mean(WST(:)));      % When WST contains NaN

if tk1==1 % WD510
    Ind_nan1=find(isnan(WD510));
    WD510(Ind_nan1)=[]; %#ok<SAGROW>
    WST(Ind_nan1)=[];
end
if tk2==1 % WST
    Ind_nan2=find(isnan(WST));
    WD510(Ind_nan2)=[]; %#ok<SAGROW>
    WST(Ind_nan2)=[]; %#ok<SAGROW>
end %%%%%%%%%%%%%%%%%%%%%%%%%%%

% Check for negative wind direction values and apply the
    correction (Magnus Logic)
tk3=find(WD510<0);
if ~isempty(tk3)       % Neglect
    WD510(tk3)=mod(WD510(tk3),360); %#ok<SAGROW>
end

% Check for negative wind speeds values
Ind_neg=find(WST<0);
if ~isempty(Ind_neg)
    WD510(Ind_neg)=[];
    WST(Ind_neg)=[];
end

nLines=length(WST);
if ~isempty(WD510)==1 % Enter the loop if WD510 is not a
    empty array

    % Apply correction factor 1 (from WSO)
    WST_cor=1.035.*WST+0.1426;

    % Apply correction factor 2 (Mast wake)
    ind_r1=find(WD510 > lim_r1 & WD510 <= lim_r2); %
        Region 1
    WST_cor(ind_r1)=cf_r1*WST_cor(ind_r1);

    ind_r2=find(WD510 > lim_r2 & WD510 <= lim_r3); %
        Region 2
    WST_cor(ind_r2)=cf_r2*WST_cor(ind_r2);

    ind_r3=find(WD510 > lim_r3 & WD510 <= lim_r4); %
        Region 3
    WST_cor(ind_r3)=cf_r3*WST_cor(ind_r3);
```

```
        ind_r4=find(WD510 > lim_r4 & WD510 <= lim_r5); %
            Region 4
        WST_cor(ind_r4)=cf_r4*WST(ind_r4);

        % Make 10 min avg
        WST_av=call_avg(WST_cor,nLines);
        WD510_av=dir_avg(WD510,nLines);
        TI_av=TI_calc(WST_cor,nLines);

        op_filename=strcat(yay,ip_filename(1:20),'_','10minav'
            ,'.txt'); % o/p ip_filename
        op_filepath_1=strcat(files_path,op_filename); %
            concatenate file path and ip_filename

        % Save the file (10 min average day files)
        dlmwrite(op_filepath_1,[WD510_av' WST_av'],'delimiter'
            ,'\t');

        % Create 10 min average array of all days in a month
        Month_WD510_av=[Month_WD510_av WD510_av]; %#ok<AGROW>
            % Concatenate all 10 min avgs of WD into a month
            variable
        Month_WST_av=[Month_WST_av WST_av]; %#ok<AGROW>
            % Concatenate all 10 min avgs of WS into a month
            variable
        Month_TI_av=[Month_TI_av TI_av]; %#ok<AGROW>
            % Concatenate all 10 min avgs of TI into a month
            variable

        % Create 1 sec raw array of all days in a month
        WST_cor_1sec=[WST_cor_1sec WST_cor']; %#ok<AGROW>  %
            Concatenate all 1 sec corrected WS values into a
            month variable to calulate 1 sec min, max values
            of wind speed
    end
end
if ~(isempty(Month_WD510_av) && isempty(Month_WST_av))==1 %
    Enter the loop if WD510 is not a empty array
    xx=[min(WST_cor_1sec) max(WST_cor_1sec) mean(WST_cor_1sec)
        ]; % min, max, mean of corr 1 sec values
    Monthly_WST_1sec_matrix=[Monthly_WST_1sec_matrix; xx]; %#
        ok<AGROW>

    yy=[min(Month_WST_av) max(Month_WST_av) mean(Month_WST_av)
        ]; % min, max, mean of corr 10 min values
    Monthly_WST_10min_matrix=[Monthly_WST_10min_matrix; yy]; %
        #ok<AGROW>

    % Write 10 min average array of all days in a month in a
        text file
    op_filename_2=strcat(ip_filename(1:7),'20',ip_filename
        (8:9),'-',ip_filename(11:12),'_','10minavg','.txt');
    op_filepath_2=strcat(files_path,op_filename_2);
```

```
        % Save the file (10 min average day files)
        dlmwrite(op_filepath_2,[Month_WD510_av' Month_WST_av'],'
            delimiter','\t');

        Monthly_WD510{mi}=Month_WD510_av; %#ok<SAGROW> % Save 10
            min WD avg array into a yearly cell
        Monthly_WST{mi}=Month_WST_av; %#ok<SAGROW>     % Save corr
             10 min WS avg array into a yearly cell
        Monthly_TI{mi}=Month_TI_av; %#ok<SAGROW>       % Save 10
            min TI avg array into a yearly cell
        Month_WD510_av=[]; Month_WST_av=[];Month_TI_av=[];
        WST_cor_1sec=[];
    end
end
save(strcat(yay,'_','WS2'),'Monthly_WD510','Monthly_WST','
    Monthly_TI'...
    ,'ma','Monthly_WST_1sec_matrix','Monthly_WST_10min_matrix');
% Save the above parameters to plot graphs in stage-2

%% STAGE-2 (Plot graphs)
clearvars -except yay1 files_path figures_path fig_export_format

yay=num2str(yay1);
year=yay(3:4);
numbins=180; % Used in binning the data 360 means 1 value for 1
    degree bin, 180 is one value for 2 degree bin
load(strcat(yay,'_WS2.mat'));
Month_list={'January','February','March','April','May','June'...
    ,'July','August','September','October','November','December'};
mlm={'Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sept','Oct',
    'Nov','Dec'};
Monthly_C=[]; Monthly_K=[]; Rec_data_avail=[];
csk=0.6; % Compass scale factor in the plot to plot turbulence
    intensity rose

% Know which months are recorded
mal=(ma(~cellfun('isempty',Monthly_WST))); Rec_Month=Month_list(
    mal);
mlm=mlm(mal);

% Remove empty month cells
Monthly_WS=Monthly_WST(~cellfun('isempty',Monthly_WST));
Monthly_WD=Monthly_WD510(~cellfun('isempty',Monthly_WD510));
Monthly_TI=Monthly_TI(~cellfun('isempty',Monthly_TI));

% Assign 1 sec values
WS1min=Monthly_WST_1sec_matrix(:,1); WS1max=
    Monthly_WST_1sec_matrix(:,2);
WS1mn=Monthly_WST_1sec_matrix(:,3);

% Monthly Stats
for k =1:length(Rec_Month)
    WD=Monthly_WD{k}; WS=Monthly_WS{k}; % Convert cell to array
```

```
% Calculate data avaiability
days=eomday(str2num(strcat('20',year)),mal(k)); %#ok<ST2NM>
    Calculate no. of days in the month (mal(k))
tot10mins=days*144;         % Total 10 mins in a month
rec10mins=length(WD);       % Recorded 10 mins in a month
data_avail=(rec10mins/tot10mins)*100; % Data availablity
Rec_data_avail=[Rec_data_avail data_avail]; %#ok<AGROW>

% Writes emf month emf figure with speed distribution and
    probability distribution
op_figurename_1=strcat('20',year,'_WS2','_',Rec_Month{k},'
    _Probability_distribution_function');
op_figurepath_1=strcat(figures_path,op_figurename_1);

%Plot Weibull distribution and Wind Speed Distribution
wbl_param=wblfit(WS); % wblfit calculates scale and shape
    factor for input array (WS), i.e wind speed array
C1=wbl_param(1); K1=wbl_param(2); % Scale and shape factor
val2=wblpdf(WS,C1,K1); % Calulates probability for each bins
    of WS
[nelements,centers]=hist(WS,min(WS):1:max(WS)); % nelements
    are length of bars & centers are x axis values of bar plot
fig_PDF=figure;
bar(centers,nelements,'b'); grid on; % Plot wind speed
    distribution
xlim([min(WS)-0.5 max(centers)+2]); ylim([0 max(nelements)+max
    (nelements)/20])
xlabel('Wind Speed [ms^{-1}]');
ylabel('No. of samples');
set(gca,'XTick',ceil(min(WS)):floor(max(WS)))
hAxes = gca; hAxes_pos = get(hAxes,'Position');
hAxes2 = axes('Position',hAxes_pos);
plot(WS,val2,'Marker','*','LineStyle','none',...
    'Color',[1 0.5 0.2]); % Plot probability distribution
        function on the same graph as wind speed distribution
set(hAxes2,'YAxisLocation','right','Color','none','XTickLabel'
    ,[]);
centers_xlim = get(hAxes,'XLim'); % store x-axis limits of
    first axes
set(hAxes2,'XLim',centers_xlim) % specify x-axis limits of
    second axes
ylabel('Probability');
saveas(fig_PDF,op_figurepath_1,fig_export_format); % Save the
    fig in emf file format
set(fig_PDF,'Visible','off');
Monthly_C=[Monthly_C C1];   Monthly_K=[Monthly_K K1]; %#ok<
    AGROW>

% Plot wind rose
WD1=mod(90-WD,360);      % Convert met angles to math angles
wrf=figure; wind_rose(WD1,WS,'di',[0:2:24],'lablegend','(m/s)'
    );
% 24 m/s is given to scale all the wind roses, legend is given
     in
```

```
    % steps of 2
    set(wrf,'InvertHardCopy','off');
    op_figurename_2=strcat(yay,'_WS2','_',Rec_Month{k},'_Wind_rose
        ');
    op_figurepath_2=strcat(figures_path,op_figurename_2);
    saveas(wrf,op_figurepath_2,fig_export_format);
    set(wrf,'Visible','off');

    % Plot Turbulence Intensity rose
    TI=Monthly_TI{k};
    [WDbin,TIbin]=binkv3(WD,TI,numbins);
    WDrbin = WDbin * pi/180;
    [x,y]=pol2cart(WDrbin,TIbin);
    tipf=figure;
    h = compass(csk); hold on
    tipf1=compass(x,y,'*-r');
    set(h, 'Visible', 'off');
    for i =1:length(tipf1) %the last line on the axes
        xData = get(tipf1(i),'XData');
        yData = get(tipf1(i),'YData');
        set(tipf1(i),'XData',xData(1:2),'YData',yData(1:2))
    end %for
    az = 90; % azimuth i.e. rotate around z-axis horizontally by
        90 degrees
    el = -90; % elevation negative, effectively looking beneath
        plot
    view(az, el);
    op_figurename_3=strcat(yay,'_WS2','_',Rec_Month{k},'
        _Turbulence_intensity');
    op_figurepath_3=strcat(figures_path,op_figurename_3);
    saveas(tipf,op_figurepath_3,fig_export_format)
    set(tipf,'Visible','off');
end
Monthly_param=horzcat(Rec_data_avail',Monthly_WST_10min_matrix,
    Monthly_C',Monthly_K'); %10 min WS matrix with shape & scale
    fators

% Yearly Stats
% Wind Rose
WD=cell2mat(Monthly_WD);
WS=cell2mat(Monthly_WS);
TIYC=cell2mat(Monthly_TI);

% Availability for the year
totdays=yeardays(str2num(strcat('20',year))); %#ok<ST2NM>
tot10mins=144*totdays;
rec10mins=length(WS);
year_avail=(rec10mins./tot10mins)*100;
dav=strcat('Data Availability: ',sprintf('%.2f',year_avail),'\%');

% Wind rose for year                         ### YEAR FIG-1 ###
WDn=mod(90-WD,360); % Convert met angles to math angles
pfR=figure;
set(pfR,'InvertHardCopy','off');
```

```
wind_rose(WDn,WS,'di',[0:2:24],'lablegend','(m/s)'); %,'lablegend
    ','Wind Speed (m/s)');
op_figurename_4=strcat(strcat(yay,'_WS2_Wind_rose'));
op_figurepath_4=strcat(figures_path,op_figurename_4);
saveas(pfR,op_figurepath_4,fig_export_format);
set(pfR,'Visible','off');

% Plot Histogram of monthly means in a year    ### YEAR FIG-2 ###
Monthly_mean=Monthly_param(:,4);
fH=figure;
axes1 = axes('Parent',fH,...
    'XTickLabel',mlm,...
    'XTick',1:length(mlm)); box(axes1,'on');
hold(axes1,'all');
bar(Monthly_mean); grid on;
xlabel('{Months}','interpreter','latex');
op_figurename_5=strcat(yay,'_WS2_Monthly_mean_wind_speed_histogram
    ');
op_figurepath_5=strcat(figures_path,op_figurename_5);
saveas(fH,op_figurepath_5,fig_export_format);
set(fH,'Visible','off');

%Plot Weibull distribution and Wind Speed Distribution ### YEAR
    FIG-3 ###
wbl_param=wblfit(WS); % wblfit calculates scale and shape factor
    for input array (WS), i.e wind speed array
C1=wbl_param(1); K1=wbl_param(2); % Scale and shape factor
val2=wblpdf(WS,C1,K1); % Calulates probability for each bins of WS
[nelements,centers]=hist(WS,min(WS):1:max(WS)); % nelements are
    length of bars & centers are x axis values of bar plot
fig_PDF=figure;
bar(centers,nelements,'b'); grid on; % Plot wind speed
    distribution
xlim([min(WS)-0.5 max(centers)+2]); ylim([0 max(nelements)+max(
    nelements)/20])
xlabel('Wind Speed [ms^{-1}]');
ylabel('No. of samples');
set(gca,'XTick',ceil(min(WS)):floor(max(WS)))
hAxes = gca; hAxes_pos = get(hAxes,'Position');
hAxes2 = axes('Position',hAxes_pos);
plot(WS,val2,'Marker','*','LineStyle','none',...
    'Color',[1 0.5 0.2]); % Plot probability distribution function
        on the same graph as wind speed distribution
set(hAxes2,'YAxisLocation','right','Color','none','XTickLabel',[])
    ;
centers_xlim = get(hAxes,'XLim'); % store x-axis limits of first
    axes
set(hAxes2,'XLim',centers_xlim) % specify x-axis limits of second
    axes
ylabel('Probability');
op_figurename_6=strcat(yay,'_WS2_Probability_distribution_function
    ');
op_figurepath_6=strcat(figures_path,op_figurename_6);
```

```
saveas(fig_PDF,op_figurepath_6,fig_export_format); % Save the fig
    in emf file format
set(fig_PDF,'Visible','off');

% Turbulence intensity rose                          ### YEAR FIG-4
     ###
[WDyrbin,TIyrbin]=binkv3(WD,TIYC,numbins);
WDrC = WDyrbin * pi/180;
[xx,yy]=pol2cart(WDrC,TIyrbin);
trf=figure;
h=compass(csk); hold on
trf1=compass(xx,yy,'*-r'); % Turbulence rose figure
set(h, 'Visible', 'off');
for i =1:length(trf1) %the last line on the axes
    xData = get(trf1(i),'XData');
    yData = get(trf1(i),'YData');
    set(trf1(i),'XData',xData(1:2),'YData',yData(1:2))
end %for
az = 90; % azimuth i.e. rotate around z-axis horizontally by 90
    degrees
el = -90; % elevation negative, effectively looking beneath plot
view(az, el);
op_figurename_7=strcat(yay,'_WS2','_Turbulence_intensity');
op_figurepath_7=strcat(figures_path,op_figurename_7);
saveas(trf,op_figurepath_7,fig_export_format)
close all
toc
```

I.5 Stage-1

```
clc; clear all; close all;
root='C:\Users\madapati\Documents\My Box Files\Wind_Data_Analysis\
    Version_2\Task_4a';
path1='C:\H n _D a t a\Gill\Raw\WindObserver20m\';
path2='C:\H n _D a t a\Gill\Intermediate_Stages\
    WindObserver20m_Stage1\';
cd(path1);
dirData=dir(fullfile(cd, '*txt'));      %# Get text files in the
    directory
filenames = {dirData.name}';            %# Get file names

% I/P File Types
% 2012-09-27_14;24;11_Gill Log [WindObserver20m]-0_Matlab.txt
% 2012-09-28_14;57;47_Gill30min [WindObserver20m]-0_Matlab.txt
% 2012-10-24_23;19;51_Gill30minB [WindObserver20m]-603_Matlab.txt
% 2013-01-23_10;09;39_Gill30minD [Anemometer 2]-0_Matlab.txt

for fn=1:length(filenames)
    filename=filenames(fn);
    filename=filename{:};
    fName=strcat(path1,filename);
    fid1 = fopen(fName, 'r');
```

```
    % Detect no.of lines
    nLines = 0;
    while (fgets(fid1) ~= -1),
        nLines = nLines+1;
    end
    fclose(fid1);

    opfName=filename;
    cond1=strcmp(filename(1:8),'Gill Log') | strcmp(filename(1:11)
        ,'Gill30min [');
    cond2=strcmp(filename(1:10),'Gill30minB') | strcmp(filename
        (1:10),'Gill30minD');

    if cond1==1
        % Collect strings to print file name
        datetime = readline(fName,12);     % Reads line 12:
        date=datetime(18:27); hr= datetime(29:30); min=datetime
            (32:33); sec=datetime(35:36);
        us='_'; ds=';';
        datevec=strcat(date,us,hr,ds,min,ds,sec);
        opfName=strcat(path2,datevec,us,filename);
        saveascii(readline(fName,18:nLines,1),opfName); % Save the
             new file
    end

    if cond2==1
        % Collect strings to print file name
        datetime = readline(fName,6);     % Reads line 6:
        date=datetime(18:27); hr= datetime(29:30); min=datetime
            (32:33); sec=datetime(35:36);
        us='_'; ds=';';
        datevec=strcat(date,us,hr,ds,min,ds,sec);
        opfName=strcat(path2,datevec,us,filename);
        saveascii(readline(fName,12:nLines,1),opfName); % Save the
             new file
    end
end
cd(root)
toc
```

I.6 Stage-2

```
% Create 1Hz/s files from 10Hz/s files from Gill wind obesrver
% I/P file ex: 2012-09-30_23;57;55_Gill30min [WindObserver20m]-114
    _Matlab.txt
% O/P file ex: 2012-10-01_00;27;55_Gill30min [WindObserver20m]-115
    _Matlab.txt
% O/P file contains only two columns wd and ws and 86399 rows,
    date and timesstamp on the filename
tic
```

```
root='C:\Users\madapati\Documents\My Box Files\Wind_Data_Analysis\
    Version_2\Task_4b\';
path2='C:\WS2_WSO_Comp\WSO\'; % Contains selected day files (
    October 1-10)
path3='C:\WS2_WSO_Comp\WSO_1s\';

cd(path2);
dirData=dir(fullfile(cd, '*txt'));       %# Get text files in the
    directory
filenames = {dirData.name}';             %# Get file names

for fn=1:length(filenames)
    filename=filenames(fn);
    filename=filename{:};
    fName=strcat(path2,filename);
    fid1 = fopen(fName, 'r');
    matdata=load(fName);
    nLines = 0; % Detect no. of lines
    while (fgets(fid1) ~= -1),
        nLines = nLines+1;
    end
    fclose(fid1);
    wd=matdata(:,1);
    ws=matdata(:,2);
    dv=matdata(:,5);
    cd(root);
    if any(dv==0) || any(dv==1) % Condition to know if the data is
         valid
        wd_sec=dir_avg2(wd,nLines)'; % Direction
        ws_sec=call_avg2(ws,nLines)'; % Speed
    else
        errordlg('One of the data sample is invalid','Invalid Data
            ');
        return
    end

    opf=strcat(path3,filename);
    fid1= fopen(opf,'w'); % Open the o/p file
    fprintf(fid1,'%f  %f\n',[wd_sec ws_sec]');
    fprintf(fid1,'\n');
    fclose(fid1);

end
toc
```

I.7 Stage-3

I.7.1 Stage-3a

```
clc; clear all; close all;
root='C:\Users\madapati\Documents\My Box Files\Wind_Data_Analysis\
    Version_2\Task_4c\';
```

```
path2='C:\WS2_WSO_Comp\WSO_1s\'; % Location of i/p files
path3='C:\WS2_WSO_Comp\WSOp\';   % Location of o/p files
cd(path2);
dirData=dir(fullfile(cd, '*txt'));       %# Get text files in the
    directory
filenames = {dirData.name}';             %# Get file names
buff_ws=[]; buff_wd=[];

typ1='2012-09-28_14;57;47_Gill30min [WindObserver20m]-0_Matlab.txt
    '; % From 1-10 OCT
typ2='2012-10-24_23;49;51_Gill30minB [WindObserver20m]-604
    _Matlab.txt'; % From 25-31 OCT

for fn=481:length(filenames)
    % for fn=47:49
    filename=filenames(fn);
    filename=filename{:};

    cond1=strcmp(typ1(21:30),filename(21:30));
    cond2=strcmp(typ2(21:30),filename(21:30));

    if cond1==1
        fName=strcat(path2,filename);
        fid1 = fopen(fName, 'r');
        matdata=load(fName);  % Load the i/p file in matdata
        nLines = 0; % Detect no. of lines
        while (fgets(fid1) ~= -1),
            nLines = nLines+1;
        end
        fclose(fid1);
        wd=matdata(:,1); % Wind direction is first column
        ws=matdata(:,2); % Wind speed is second column
        opfName=strcat(filename(1:10),'_',filename(21:29),'_',
            filename(31:47),'.txt'); % Create a string of o/p
            filename from i/p file name
        opf=strcat(path3,opfName); % Concatenate strings o/p file
            path and o/p filename

        if str2num(filename(12:13))==0 && str2num(filename(15))<=2
             %#ok<ST2NM> Check if the file is first file in a day
            val= isempty(buff_ws) && isempty(buff_wd);
            if  val ==0
                wd=vertcat(buff_wd,wd);
                ws=vertcat(buff_ws,ws);
            end

            fid1= fopen(opf,'w'); % Open the o/p file
            fprintf(fid1,'%f  %f\n',[wd ws]');
            fclose(fid1);
            buff_ws=[]; buff_wd=[] ;

        elseif str2num(filename(12:13)) == 23 && str2num(filename
            (15:16))+str2num(filename(18:19)) > 100 %#ok<ST2NM> %
            Last file in the day
```

```
            date1=strcat(filename(12:13),',',filename(15:16),',',
                filename(18:19)); % Date on the file name
            endtime='23,59,59';
            date=strcat(filename(1:4),',',filename(6:7),',',
                filename(9:10));
            date2=strcat(date,',',endtime);
            date1=strcat(date,',',date1);
            dn1=datenum(str2num(date1));  %#ok<ST2NM>
            dn2=datenum(str2num(date2));  %#ok<ST2NM>
            secdiff=etime(datevec(dn2),datevec(dn1));
            last_ws=ws(1:secdiff); last_wd=wd(1:secdiff);
            del_ind =1:secdiff; % Indices to be removed
            ws(del_ind) = [] ; % remove
            wd(del_ind)=[];
            buff_ws=ws;
            buff_wd=wd;

            fid1= fopen(opf,'a'); % Open the o/p file
            fprintf(fid1,'%f  %f\n',[last_wd last_ws]');
            fclose(fid1);

        else
            fid1= fopen(opf,'a'); % Open the o/p file
            fprintf(fid1,'%f  %f\n',[wd ws]');
            fclose(fid1);
        end
    end
end
toc
```

I.7.2 Stage-3b

```
% Creates one sec file per DAY with wind direction (wd) and wind
    speed (ws) from unsorted gill 1sec files with wind direction (
    wd) and wind speed (ws)
% approx single output file should contain 86399 rows and 2
    columns
% I/P file ex: 2012-09-30_23;57;55_Gill30min [WindObserver20m]-114
    _Matlab.txt
% O/P file ex: 2012-10-01_Gill30min_[WindObserver20m].txt
tic
clc; clear all; close all;
root='C:\Users\madapati\Documents\My Box Files\Wind_Data_Analysis\
    Version_2\Task_4c\';
path2='C:\WS2_WSO_Comp\WSO_1s\'; % Location of i/p files
path3='C:\WS2_WSO_Comp\WSOp\';   % Location of o/p files
cd(path2);
dirData=dir(fullfile(cd, '*txt'));      %# Get text files in the
    directory
filenames = {dirData.name}';            %# Get file names
buff_ws=[]; buff_wd=[];
```

```
typ1='2012-09-28_14;57;47_Gill30min [WindObserver20m]-0_Matlab.txt
    '; % From 1-10 OCT
typ2='2012-10-24_23;49;51_Gill30minB [WindObserver20m]-604
    _Matlab.txt'; % From 25-31 OCT

for fn=481:length(filenames)
    filename=filenames(fn);
    filename=filename{:};

    cond1=strcmp(typ1(21:30),filename(21:30));
    cond2=strcmp(typ2(21:30),filename(21:30));

    if cond2==1
        fName=strcat(path2,filename);
        fid1 = fopen(fName, 'r');
        matdata=load(fName);  % Load the i/p file in matdata
        nLines = 0; % Detect no. of lines
        while (fgets(fid1) ~= -1),
            nLines = nLines+1;
        end
        fclose(fid1);
        wd=matdata(:,1); % Wind direction is first column
        ws=matdata(:,2); % Wind speed is second column
        opfName=strcat(filename(1:10),'_',filename(21:30),'_',
            filename(31:48),'.txt'); % Create a string of o/p
            filename from i/p file name
        opf=strcat(path3,opfName); % Concatenate strings o/p file
            path and o/p filename

        if str2num(filename(12:13))==0 && str2num(filename(15))<=2
             %#ok<ST2NM> Check if the file is first file in a day
            val= isempty(buff_ws) && isempty(buff_wd);
            if  val ==0
                wd=vertcat(buff_wd,wd);
                ws=vertcat(buff_ws,ws);
            end

            fid1= fopen(opf,'w'); % Open the o/p file
            fprintf(fid1,'%f  %f\n',[wd ws]');
            fclose(fid1);
            buff_ws=[]; buff_wd=[] ;

        elseif str2num(filename(12:13)) == 23 && str2num(filename
            (15:16))+str2num(filename(18:19)) >= 100 %#ok<ST2NM> %
             Last file in the day
            date1=strcat(filename(12:13),',',filename(15:16),',',
                filename(18:19)); % Date on the file name
            endtime='23,59,59';
            date=strcat(filename(1:4),',',filename(6:7),',',
                filename(9:10));
            date2=strcat(date,',',endtime);
            date1=strcat(date,',',date1);
            dn1=datenum(str2num(date1));  %#ok<ST2NM>
            dn2=datenum(str2num(date2));  %#ok<ST2NM>
```

```
            secdiff=etime(datevec(dn2),datevec(dn1));
            last_ws=ws(1:secdiff); last_wd=wd(1:secdiff);
            del_ind =1:secdiff; % Indices to be removed
            ws(del_ind) = [] ; % remove
            wd(del_ind)=[];
            buff_ws=ws;
            buff_wd=wd;

            fid1= fopen(opf,'a'); % Open the o/p file
            fprintf(fid1,'%f  %f\n',[last_wd last_ws]');
            fclose(fid1);

        else
            fid1= fopen(opf,'a'); % Open the o/p file
            fprintf(fid1,'%f  %f\n',[wd ws]');
            fclose(fid1);
        end
    end

end
toc
```

I.8 WRPLOT

```
tic
clc; clear all; close all;
root='C:\Users\madapati\Documents\My Box Files\Wind_Data_Analysis\
    Version_1\Task_WRPLOT\';
ya=[11]; % Year array (Enter the years present in the folder
    2011-11)
path='C:\Raw_1s\';                  % Path for i/p files
cd(path);                           % Change directory to i/p
    files path
dirData1 = dir(path);               % Loads all the file names in
    a cell format
dirData=dir(fullfile(cd, '*lvm')); % Get lvm files in the
    directory
filenames = {dirData.name}';        % Get file names
z='0';                              % Useful during string
    comparison
e1='^H(\d+)\_';        % H4
e2='(\d+)Hz\_';        % 1Hz
e3='(\d+)\-';          % year
e4='(\d+)\-';          % month
e5='(\d+)\_';          % date
e6='(\d+).lvm$';       % time
ex='\-';
ex1='\_';

% Standard File Format
% expr= '^H(\d+)\_(\d+)Hz\_(\d+)\-(\d+)\-(\d+)\_(\d+).lvm$'
% H4_1Hz_10-07-15_1320.lvm
```

```
for yi=1:length(ya)
    x1=ya(yi); % year
    x1=num2str(x1);
    expr1=strcat(e1,e2,x1,ex,e4,e5,e6);
    filedata = regexp(filenames,expr1,'tokens'); % Find tokens
    index = ~cellfun('isempty',filedata);        % Find index of
        matches
    filedata = [filedata{index}];
    filedata = vertcat(filedata{:});             % Format token
        data
    year = filenames(index);                     % Group all the
        similar year files in 'year'
    ma=filedata(1:(size(filedata,1)),3);         % Know the months
         in the year cell
    ma=unique(ma);                               % Months in the
        selected year

    for mi=1:length(ma)
        x2=ma{mi(1,1)};                              % Selected
            month
        x2=num2str(x2);                              % Conver to
            string
        expr2=strcat(e1,e2,x1,ex,x2,ex,e5,e6);       % Make a
            standard expression
        fdm = regexp(year,expr2,'tokens');           % Find tokens
            matching above expr
        idm = ~cellfun('isempty',fdm);
        fdm = [fdm{idm}];
        fdm = vertcat(fdm{:});                   %# Format token data
        da = fdm(1:(size(fdm,1)),3);             %# Group all the
            similar year,month files in 'dates'

        for di=1:length(da)
            x5=da(di);
            expr3=strcat(e1,e2,x1,ex,x2,ex,x5,ex1,e6);
            fd3 = regexp(year,expr3,'tokens');  %# Find tokens
            id3 = ~cellfun('isempty',fd3);     %# Find index of
                matches
            fd3 = [fd3{id3}];                  %# Remove non-
                matches
            fd3 = vertcat(fd3{:});             %# Format token
                data
            file=year(id3);
            filename=file{:};
            filepath=strcat(path,filename);

            % Load File and concatenate
            fName=filepath;
            fid1 = fopen(fName, 'r');
            if fid1<0
                matdata=load(filepath);
            else
```

```
    matdata   = textscan(fid1, '%f %f %f %f %f %f %f %
        f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f
         %f %f %f %f %f %f %f %f %f %f') ;
    matdata   = cell2mat(matdata);
end
fclose(fid1);

% Choose the selected columns
WSNA=matdata(:,18);            % (mean) [m/s]
WS2=matdata(:,19);             % (mean) [m/s]
WD510=matdata(:,27);           % Wind Direction Vaisala
    WXT510 [degrees]
WS510=matdata(:,28);           % Wind Speed Vaisala
    WXT510 [m/s]

% Skip NaN values from the selected columns
WSNA=WSNA(isfinite(WSNA(:, 1)), :);
WS2=WS2(isfinite(WS2(:, 1)), :);
WD510=WD510(isfinite(WD510(:, 1)), :);
WS510=WS510(isfinite(WS510(:, 1)), :);

dd1=filename(8:9);            % Detect the YEAR from
    each file name, Ex-H4_1Hz_10-07-17_0000.lvm
dd2=filename(11:12);          % Detect the MONTH from
    each file name
dd2=str2num(dd2);
dd2=num2str(dd2);
dd3=filename(14:15);          % Detect the DAY from each
     file name
dd3=str2num(dd3);
dd3=num2str(dd3);
ddx1=strcat(32,dd1);
ddx2=strcat(32,32,dd2);
ddx3=strcat(32,32,dd3);
ddz=strcat(ddx1,ddx2,ddx3);

% Calculate One hour average of all channels
cd(root)                       % To call the func "
    dir_avg_total"
WSNA=(call_avg(WSNA,size(WSNA,1)))'; % Func format
    call_avg(ip1,nLines)
WS2=(call_avg(WS2,size(WS2,1)))';
WD510=(dir_avg(WD510,size(WD510,1)))';
WS510=(call_avg(WS510,size(WS510,1)))';
hr=1:1:size(WSNA,1);
pr=zeros(1,size(WSNA,1));
dd1m=repmat(str2num(dd1),1,size(WSNA,1));
dd2m=repmat(str2num(dd2),1,size(WSNA,1));
dd3m=repmat(str2num(dd3),1,size(WSNA,1));

matr=[dd1m;dd2m;dd3m;hr;WD510';WS510';pr]';
%            matrix=[year month day hour direction
    velocity Precipitation];
if mi==1 && di==1
```

```
                matrix=matr;
            else
                matrix=vertcat(matrix,matr);
            end
        end
        % % Create a excel file
        col_header={'Year','Month','Day','Hour','Direction','
            Velocity','Precipitation'}; %Row cell array (for
            column labels)
        matrixc=num2cell(matrix);
        output_matrix=[col_header; matrixc]; %Join cell arrays
        xlswrite('My_file.xls',output_matrix); %Write data and
            both headers

    end
end
toc
```

I.9 Hydrognomon

```
tic
clc; clear all; close all;
root='C:\Users\madapati\Documents\My Box Files\Wind_Data_Analysis\
    Version_1\Matlab_Hydrognomon\';
ya=[11]; % Year Array                    % GIVE THE YEARS OF DATA
    PRESENT (I/P)
path='C:\Raw_1s\';
cd(path);
dirData1 = dir(path);
dirData=dir(fullfile(cd, '*lvm'));       %# Get lvm files in the
    directory
filenames = {dirData.name}';             %# Get file names
z='0';                                   %# Useful during string
    comparison
e1='^H(\d+)\_'; % H4
e2='(\d+)Hz\_'; % 1Hz
e3='(\d+)\-';       % year
e4='(\d+)\-';        % month
e5='(\d+)\_';        % date
e6='(\d+).lvm$';     % time
ex='\-';
ex1='\_';
% Standard File Format   expr= '^H(\d+)\_(\d+)Hz\_(\d+)\-(\d+)\-(\
    d+)\_(\d+).lvm$'; % H4_1Hz_10-07-15_1320.lvm

% Know the years in folder
for yi=1:length(ya)
    x1=ya(yi); % year
    x1=num2str(x1);
    expr1=strcat(e1,e2,x1,ex,e4,e5,e6);
    filedata = regexp(filenames,expr1,'tokens');     %# Find tokens
```

```
index = ~cellfun('isempty',filedata);           %# Find index
    of matches
filedata = [filedata{index}];
filedata = vertcat(filedata{:});                %# Format
    token data
year = filenames(index);                        %# Group all
    the similar year files in 'year'
ma=filedata(1:(size(filedata,1)),3);            %# Know the
    months in the year cell
ma=unique(ma);                                  %# Months in
    the selected year

for mi=1:1%length(ma)
    x2=ma{mi(1,1)}; % selected month
    x2=num2str(x2);
    expr2=strcat(e1,e2,x1,ex,x2,ex,e5,e6);
    fdm = regexp(year,expr2,'tokens');     %# Find tokens
    idm = ~cellfun('isempty',fdm);
    fdm = [fdm{idm}];
    fdm = vertcat(fdm{:});                 %# Format token data
    da = fdm(1:(size(fdm,1)),3);           %# Group all the
        similar year,month files in 'dates'
    WSNA_total=[]; WS2_total=[]; WD510_total=[]; WS510_total
        =[]; WD510_total_o=[];

    for di=1:length(da)
        x5=da(di);
        expr3=strcat(e1,e2,x1,ex,x2,ex,x5,ex1,e6);
        fd3 = regexp(year,expr3,'tokens');  %# Find tokens
        id3 = ~cellfun('isempty',fd3);      %# Find index of
            matches
        fd3 = [fd3{id3}];                   %# Remove non-
            matches
        fd3 = vertcat(fd3{:});              %# Format token
            data
        file=year(id3);
        filename=file{:};
        filepath=strcat(path,filename);

        % Load File and concatenate
        fName=filepath;
        fid1 = fopen(fName, 'r');
        if fid1<0
            matdata=load(filepath);
        else
            matdata   = textscan(fid1, '%f %f %f %f %f %f %f %
                f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f
                 %f %f %f %f %f %f %f %f %f %f') ;
            matdata   = cell2mat(matdata);
        end
        fclose(fid1);

        % Choose the selected columns
        WSNA=matdata(:,18);             % (mean) [m/s]
```

```
WS2=matdata(:,19);           % (mean) [m/s]
WD510=matdata(:,27);         % Wind Direction Vaisala
    WXT510 [degrees]
WS510=matdata(:,28);         % Wind Speed Vaisala
    WXT510 [m/s]

% Skip NaN values from the selected columns
WSNA=WSNA(isfinite(WSNA(:, 1)), :);
WS2=WS2(isfinite(WS2(:, 1)), :);
WD510=WD510(isfinite(WD510(:, 1)), :);
WS510=WS510(isfinite(WS510(:, 1)), :);

% Calculate 10 min average of all channels
cd(root)                     % To call the func "
    dir_avg_total"
WSNA=(call_avg(WSNA,size(WSNA,1)))'; % Func format
    call_avg(ip1,nLines)
WS2=(call_avg(WS2,size(WS2,1)))';
WD510=(dir_avg(WD510,size(WD510,1)))';
WS510=(call_avg(WS510,size(WS510,1)))';

% Create hts file
dd1=filename(8:9);          % Detect the YEAR from
    each file name, Ex-H4_1Hz_10-07-17_0000.lvm
dd2=filename(11:12);        % Detect the MONTH from
    each file name
dd3=filename(14:15);        % Detect the DAY from each
     file name
dd6='-';
ddz='_';
hu=':';
D1=strcat('20',dd1,dd6,dd2,dd6,dd3);      % Create a
    time column with above year,month,date

ts=0:1:143;
dr=datestr(ts./(24*6),'HH:MM');
dr=strcat(D1,32,dr);
Tim=strcat('Timezone=CET',32,'(UTC+0100)');

if di==1
    fid1= fopen('Input_1.hts','w'); % Open the o/p
        file
    fprintf(fid1,'%s\n%s\n%s\n%s\n%s\n%s\n%s','Version
        =2','Unit=m/s','Count=149','Title=WD510',Tim,'
        Variable=Wind speed','Precision=9'); % Print
        the header in the output file
    fprintf(fid1,'\n\n');
    fclose(fid1);
    for p=1:length(WD510)
        fid1 = fopen('Input_1.hts','a');
        fprintf(fid1,'%s%s%d%s',dr(p,:),',',WD510(p,1)
            ,',');
        fprintf(fid1,'\n');
        fclose(fid1);
```

```
                end
            else
                for p=1:length(WD510)
                    fid1 = fopen('Input_1.hts','a');
                    fprintf(fid1,'%s%s%d%s',dr(p,:),',',WD510(p,1)
                        ,',');
                    fprintf(fid1,'\n');
                    fclose(fid1);
                end

                if di==1
                    fid2 = fopen('Input_2.hts','w'); % Open the o/
                        p file
                    fprintf(fid2,'%s\n%s\n%s\n%s\n%s\n%s\n%s','
                        Version=2','Unit=m/s','Count=149','Title=
                        WS510',Tim,'Variable=Wind speed','
                        Precision=9'); % Print the header in the
                        output file
                    fprintf(fid2,'\n\n');
                    fclose(fid2);
                    for p=1:length(WD510)
                        fid = fopen('Input_2.hts','a');
                        fprintf(fid2,'%s%s%d%s',dr(p,:),',',WS510(
                            p,1),',');
                        fprintf(fid2,'\n');
                        fclose(fid2);
                    end
                else
                    for p=1:length(WD510)
                        fid2 = fopen('Input_2.hts','a');
                        fprintf(fid2,'%s%s%d%s',dr(p,:),',',WS510(
                            p,1),',');
                        fprintf(fid2,'\n');
                        fclose(fid2);
                    end

                end
            end
        end
    end
end
toc
```

I.10 WST & WSO comparison

```
tic
clc; clear all; close all;
root='C:\Users\madapati\Documents\My Box Files\Wind_Data_Analysis\
    Version_2\Task_4e\';
path1='C:\WS2_WSO_Comp\WS2\';
path2='C:\WS2_WSO_Comp\WSOp\';
cd(path1);
```

```
dirData1=dir(fullfile(cd, '*lvm'));       %# Get text files in the
    directory
filenames1 = {dirData1.name}';            %# Get file names WS2/H4
    series
cd(path2);
dirData2=dir(fullfile(cd, '*txt'));       %# Get text files in the
    directory
filenames2 = {dirData2.name}';            %# Get file names WSO/Gil
     series
wso=[]; ws2=[]; wd=[];
wso_10=[]; ws2_10=[]; wd_10=[];
wso_1=[]; ws2_1=[]; wd_1=[];
Lines=[];

if length(filenames1) == length(filenames2) % Enters the loop when
     both folders have same no.of text files
    for fn=1:length(filenames1)
        filename1=filenames1(fn);       filename1=filename1{:};
        filename2=filenames2(fn);       filename2=filename2{:};
        fName1=strcat(path1,filename1); fName2=strcat(path2,
            filename2);

        % Detect no.of lines in the i/p txt file
        fid1=fopen(fName1,'r');
        matdata1=load(fName1);
        nLines1 = 0;
        while (fgets(fid1) ~= -1),
            nLines1 = nLines1+1;
        end
        fclose(fid1);

        fid2=fopen(fName2,'r');
        matdata2=load(fName2);
        nLines2 =0;
        while (fgets(fid1) ~= -1),
            nLines2 = nLines2+1;
        end
        fclose(fid2);

        nLines=[nLines1 nLines2];
        Lines=[Lines nLines]; %#ok<AGROW>

        % Load the data from the i/p txt file
        wd_wso=matdata2(:,1);   % Wind direction from wind observer
        ws_wso=matdata2(:,2);   % Wind speed from wind observer
        ws_ws2=matdata1(:,19); % Wind speed from wind anemometer
            WS2

        wd=[wd wd_wso(1:86397)']; %#ok<AGROW>
        wso=[wso ws_wso(1:86397)']; %#ok<AGROW>
        ws2=[ws2 ws_ws2(1:86397)']; %#ok<AGROW>

        cd(root)
```

```
        % 10 min average
        wd_wso_av_10=dir_avg(wd_wso,nLines2);
        ws_wso_av_10=call_avg(ws_wso,nLines2);
        ws_ws2_av_10=call_avg(ws_ws2,nLines1);

        wd_10=[wd_10 wd_wso_av_10]; %#ok<AGROW>
        wso_10=[wso_10 ws_wso_av_10]; %#ok<AGROW>
        ws2_10=[ws2_10 ws_ws2_av_10]; %#ok<AGROW>

        % 1 min average
        wd_wso_av_1=dir_avg_1min(wd_wso,nLines2);
        ws_wso_av_1=call_avg_1min(ws_wso,nLines2);
        ws_ws2_av_1=call_avg_1min(ws_ws2,nLines1);

        wd_1=[wd_1 wd_wso_av_1]; %#ok<AGROW>
        wso_1=[wso_1 ws_wso_av_1]; %#ok<AGROW>
        ws2_1=[ws2_1 ws_ws2_av_1]; %#ok<AGROW>
    end
end
frac_10=(wso_10./ws2_10); % 10 min average
frac_1=(wso_1./ws2_1);    % 1 min average
frac=wso./ws2;            % 1 sec ratio
toc
```

I.10.1 WST Friction Calibration Factor

```
clc; clear all; close all;
load('avg_10.mat'); % Loads wd_10, ws2_10, wso_10 values
frac_10=(wso_10./ws2_10);
% wd_10a=wd_10(find(wd_10<180)); frac_10a=frac_10(wd_10<180);
    ws2_10a=ws2_10(wd_10<180); wso_10a=wso_10(wd_10<180);
wd_10b=wd_10(find(wd_10>180)); frac_10b=frac_10(wd_10>180);
    ws2_10b=ws2_10(wd_10>180); wso_10b=wso_10(wd_10>180);

% Analysis of 180-360
figure; plot(wd_10b,frac_10b,'.k'); ylim([0.8 2.6]);
hold on; plot(wd_10b,1,'.-r');
xlabel('{Wind Direction [$^{\circ}$]}','interpreter','latex');
ylabel('{ $ \frac{WSO}{WS2} $ }','interpreter','latex');
legend('WSO/WS2','Ideal');
cftool(wso_10b,ws2_10b);

lim_b=1;
ind_b1=find(wso_10b>lim_b);
fil_frac_10b=frac_10b(ind_b1); wd_10b1=wd_10b(ind_b1); ws2_10b1=
    ws2_10b(ind_b1); wso_10b1=wso_10b(ind_b1);
figure; plot(wd_10b1,wso_10b1./ws2_10b1,'.k'); ylim([0.8 2.6]);
    hold on; plot(wd_10b1,mean(wso_10b1./ws2_10b1),'.-r')
xlabel('{Wind Direction [$^{\circ}$]}','interpreter','latex');
ylabel('{WSO/WS2}','interpreter','latex');

lim_b2x=2;
ind_b2x=find(wso_10b<lim_b2x);
```

```
fil_frac_10b2x=frac_10b(ind_b2x); wd_10b2x=wd_10b(ind_b2x);
    ws2_10b2x=ws2_10b(ind_b2x); wso_10b2x=wso_10b(ind_b2x);
% figure; plot(wd_10b2x,wso_10b2x./ws2_10b2x,'.m'); ylim([0.8 2.6
    ]); hold on; plot(wd_10b2,mean(wso_10b2./ws2_10b2),'.-r')
M_leftout=[wso_10b2x' ws2_10b2x'];

lim_b2=2;
ind_b2=find(wso_10b>lim_b2);
fil_frac_10b2=frac_10b(ind_b2); wd_10b2=wd_10b(ind_b2); ws2_10b2=
    ws2_10b(ind_b2); wso_10b2=wso_10b(ind_b2);
% figure; plot(wd_10b2,wso_10b2./ws2_10b2,'.k'); ylim([0.8 2.6]);
    hold on; plot(wd_10b2,mean(wso_10b2./ws2_10b2),'.-r')

figure % Combined points
plot(wd_10b2x,wso_10b2x./ws2_10b2x,'*r'); ylim([0.8 2.6]);
hold on;
plot(wd_10b2,wso_10b2./ws2_10b2,'.k'); ylim([0.8 2.6]);
hold on
plot(wd_10b2,mean(wso_10b2./ws2_10b2),'.-m')
grid on;
legend('Filtered samples','Considered samples','Mean of considered
     samples')
xlabel('{Wind Direction [$^{\circ}$]}','interpreter','latex');
ylabel('{WSO/WS2}','interpreter','latex');
```

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