Article

Assessment of Wind Speed Statistics in Samaria Region and Potential Energy Production+

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Abstract: Statistical characteristics of the wind speed in Samaria region of Israel have been analyzed by processing 11 years of wind data provided by the Israeli Meteorological Service, recorded at 10 m height above the ground. The cumulative mean wind speed at measurement height was shown to be 4.53 m/s with standard deviation of 2.32 m/s. Prevailing wind direction is shown to be characterized by cumulative mean azimuth of 226° with standard deviation of 79.76°. The results were extrapolated to 70-meter height in order to estimate wind characteristics at hub height of a medium-scale wind turbine. Moreover, Weibull distribution parameters were calculated annually, monthly and seasonally, demonstrating a good match with histogram-based statistical representations. Shape parameter of the Weibull distribution was shown to reside within a narrow range of 1.93 to 2.15, allowing us to assume a Rayleigh distribution, thus simplifying wind turbines energy yield calculations. The novelty of the current paper is related to gathering wind statistics for a certain area (Samaria) we are not aware of any published statistics regarding wind velocity and direction in this area. The data may be interesting for potential regional wind energy development in which the obtained Weibull distribution can be used in calculations of expected power generation of particular turbines with known power dependence on velocity. We also point out that the fact that realistic wind velocity statistics is well described by an analytic formula (Weibull distribution) is not trivial, and in fact the fit may have been poor. The energetic and economic output is calculated for three different wind turbines.

Keywords: Wind statistics assessment; Weibull distribution; Rayleigh distribution.

1. Introduction

During the last decade, wind characteristics and wind power potential have been studied in many countries worldwide [1-47,61,63-65], demonstrating that despite the prolonging global economic crisis, the worldwide wind power ascent continues. The world's wind power capacity added 38.6 GW in 2009, growing by 32%/year and 38.1 GW in 2010 (24%/year growth), demonstrating 110% growth in three years, to extend total installations up to 197.0 GW. A huge part of this capacity was installed in China with 22.7% of the world wind energy yield (about third of the world year's additions) and USA with 20.4%, while Germany, Spain and India installing cumulative capacity of 30.9% together [48].

Wind energy became a significant player in the world's energy market. Global market worth of wind turbine installations in 2009 was around 63 billion US$. About half a million people are now employed, corresponding to GWEC estimates, by the wind industry around the world [49]. Main markets of the wind energy are situated in Asia, North America, and Europe, each of which adds more than 10 GW capacity a year.

Considering the Israeli energy market, the desire to add to the natural gas found, which is a nonrenewable local energy resource has also motivated the state to devote various efforts to the 'green' energy research and development, primarily in the area of solar energy. Recently, wind energy drew attention of energy initiatives as well. Yet the wind power amount produced in Israel is diminutive comparing to the continuously growing global market; however, the last steps undertaken by the state are destined to improve the situation.

Israel currently operates a single wind farm in Asanyia Hill in the Golan Heights, with total installed capacity of 6 MW (consisting of ten 600 kW turbines), satisfying the consumption of about 5 thousand families. The wind farm operates around 97% of the time and yields revenue of ~1 million US $ a year. Indeed, wind energy potential of Israel is restricted because of surplus of moderate- or poor-wind velocities' areas and is limited to the areas with sufficiently constant wind, some of which are being opposed by green groups on landscape conservation grounds. Nevertheless, the state continues efforts for bringing into operation of two more farms with a 50 MW capacity [50].

It is emphasized in the Israel Knesset document that an improved estimate, based on the wind turbines' technological development, gives a value much more than 500 MW of the Israeli potential wind energy capacity [51]. One of perspective areas for efficient wind technology development, considering its climatic characteristics, is the Samaria region.

It is well known that energy yield of a wind turbine mainly depends on wind energy characteristics and turbine power curve [52, 53]. In this paper, statistical characteristics of the wind speed behavior in Ariel (located in Samaria) are derived and investigated, relying on data collected be meteorological station located in Ariel University campus.

2. Materials and Methods

Eleven years of meteorological data (2001-2011), acquired by Ariel Meteorological Station and supplied by the Israeli Meteorological Service were processed. Measurement samples were taken at 10-meter height above the ground and were available at 10 minutes intervals. The city of Ariel is located at 32° 6′ 21.6″ N, 35° 11′ 16.43″ E, in the center of Israel (Fig. 1). Ariel Meteorological Station is located inside Ariel University campus at eastern part of the city (Fig. 2), residing at 700 m above sea level.

Figure 1. The city of Ariel

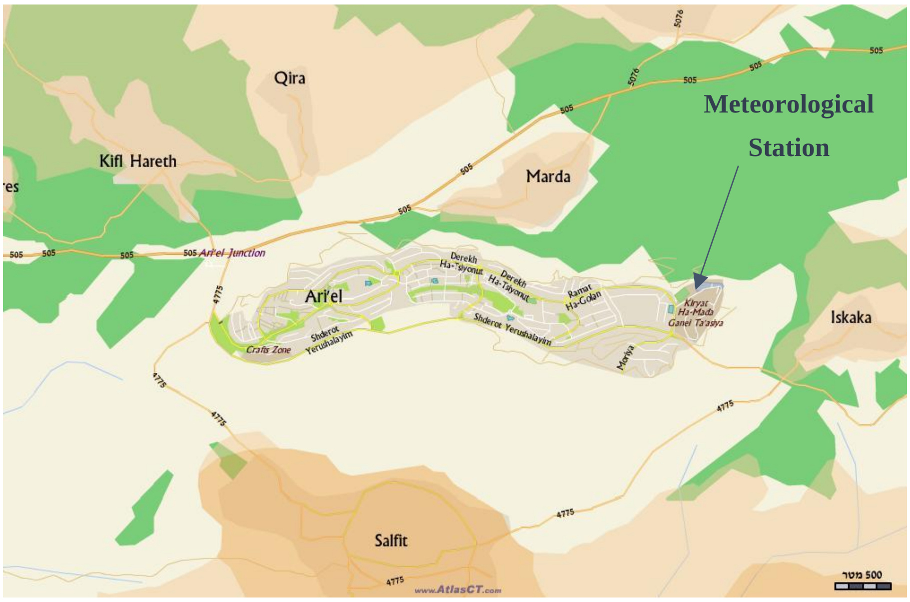

Figure 2. Meteorological station location

The wind speed data was provided by meteorological station as raw matrix of wind speed ad azimuth versus time at 10 m height, sampled at 10 minutes. In reality, the sample time is much higher than stated and the available data sample is actually an average of tens to thousands of faster samples. An example of monthly wind speed raw data in Ariel represented by 10 minutes samples is shown in Fig. 3.

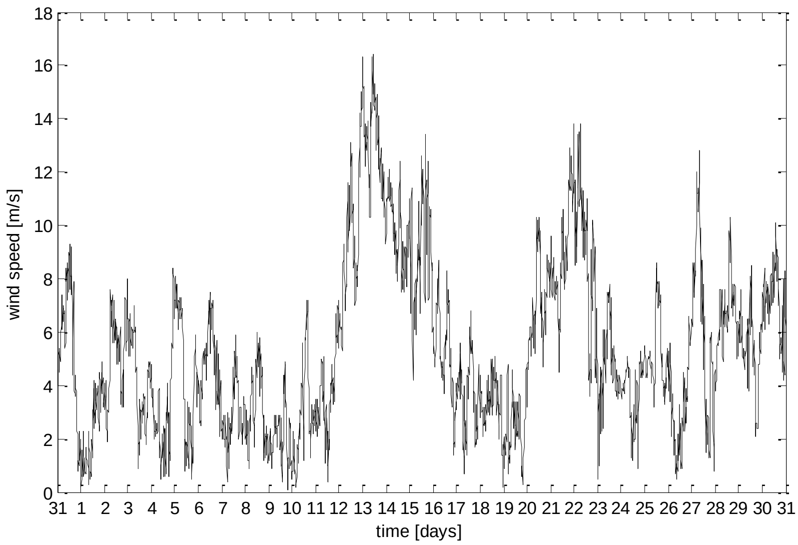

Figure 3. Typical monthly wind speed raw data.

The raw vector is used to extract mean and standard deviation parameters and then can be either transformed into a histogram (discrete probability distribution function – PDF) or fitted to a known PDF, typically of Weibull type, as shown in Fig. 4. When creating a histogram, the bins are typically chosen to be 1 m·s^{-1} wide to match the resolution of the manufacturer provided turbine power curve data, resulting in the following discrete PDF,

$$f_{HST}(v) = f(v_i), \quad v_i - 0.5 \leq v < v_i + 0.5 \tag{1}$$

where $f(v_i)$ is the magnitude of the histogram bin, centered at v_i.

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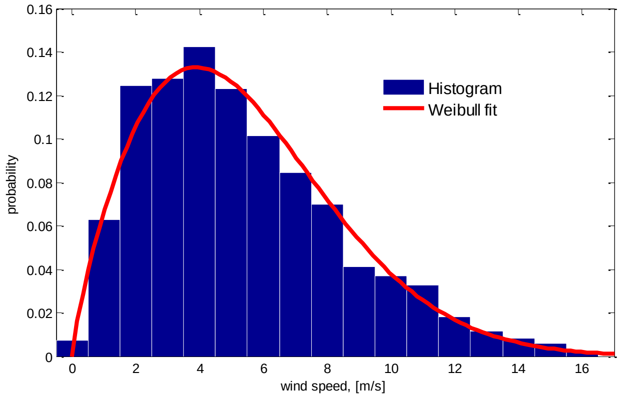

Figure 4. Histogram and Weibull PDF fit of wind speed raw data of Fig. 3.

Weibull PDF is defined by two parameters: shape or Weibull modulus (k, dimensionless), and scale (c, m/s for wind speed). The general form of the Weibull PDF is given by:

$$f_{WBL}(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-(v/c)^k} \quad (2)$$

for positive wind speeds (v > 0) with parameters c and k = related to the site wind speed mean μ_v and standard deviation σ_v as [54]:

$$\mu_v = c\Gamma\left(1+\frac{1}{k}\right) \quad (3)$$

and

$$\sigma_v = c\sqrt{\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)} \quad (4)$$

respectively, where:

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt \quad (5)$$

is the complete Gamma function. In case the wind raw data of a site is unavailable, but the mean and standard deviation of the wind speed are given, Weibull PDF is usually assumed, and its parameters are extracted from (4) and (5). In general, several ways to extract Weibull parameters from raw data exist [55]; MATLAB function *wblfit* was used in this work.

A particular (and very common) case of Weibull PDF is the case where k = 2. It is called Rayleigh PDF and is given by

$$f_{RLH}(v) = \frac{2v}{c^2} e^{-(v/c)^2} \quad (6)$$

for positive wind speeds (v > 0) with scale parameter c related to the site mean wind speed as

$$\mu_v = \frac{\sqrt{\pi}}{2} c \quad (7)$$

making (6) to be dependent on average wind speed as [56]:

$$f_{RLH}(v) = \frac{\pi v}{2\mu_v^2} e^{-(\sqrt{\pi} v / 2\mu_v)^2} \quad (8)$$

It is worth noting that wind energy resource is typically classified according to average wind speed at 10 m height as shown in Table I [56].

Table 1. Wind power classification.

Wind Power Class	Average Wind Speed (m/s) at 10 m Height
1	0 – 4.4
2	4.4 – 5.1
3	5.1 – 5.6
4	5.6 – 6.0
5	6.0 – 6.4
6	6.4 – 7.0
7	7.0 – 9.5

Since power in the wind increases with height [57, 58], the turbine hub of medium and large-scale wind turbines is usually located a 50 – 150 m height. Therefore, statistical wind parameters must be either measured at hub height or extrapolated from measurements available at smaller heights. In case single height measurements only are available, power law is usually employed to estimate wind speed v_1 at height H_1 as

$$\left(\frac{v_1}{v_0}\right) = \left(\frac{H_1}{H_0}\right)^{\alpha} \quad (9)$$

where v_0 is the wind speed measurement available at height H_0 and α is the surface roughness dependent friction coefficient [59, 60]. Friction coefficient dependence on terrain characteristics is typically determined from Table II [56].

Table 2. Friction coefficient dependence in terrain type.

Terrain Characteristics	α
Smooth hard ground, calm water	0.10
Tall grass on level ground	0.15
High crops, hedges and shrubs	0.20
Wooded countryside , many trees	0.25
Small town with trees and shrubs	0.30
Large city with tall building	0.40

According to the above, a software simulator was created receiving meteorological data (excel format) as an input and calculating the following output. Using the wind speed raw data, mean and standard deviation (STD) vales were calculated, followed by Weibull parameters extraction, and plotting respective histograms along with resulting Weibull PDFs. The process was repeated after extrapolating the samples to 70-meter height using friction coefficient of 0.3 according to Table II. All the results were calculated monthly, annually, and seasonally. As to wind directions, annual Rose diagrams were created for both 10 and 70 m heights.

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3. Results

Tables 3 and 4 summarize yearly and cumulative mean and STD of wind speed and azimuth at 10 and 70 m heights, respectively. It may be concluded that the wind belongs to class 2, according to Table I.

Table 3. Yearly and cumulative wind speed statistics at 10 m height.

Year	Parameter	Speed	Azimuth
2001	Mean	4.28	209.41
	STD	2.21	81.13
2002	Mean	4.89	227.31
	STD	2.51	83.03
2003	Mean	4.81	224.15
	STD	2.57	78.48
2004	Mean	4.57	228.17
	STD	2.49	80.32
2005	Mean	4.64	227.63
	STD	2.33	77.45
2006	Mean	4.35	231.65
	STD	2.20	83.15
2007	Mean	4.50	228.73
	STD	2.21	79.28
2008	Mean	4.50	221.94
	STD	2.25	77.23
2009	Mean	4.54	231.31
	STD	2.38	75.39
2010	Mean	4.41	225.30
	STD	2.27	79.84
2011	Mean	4.26	230.11
	STD	2.08	79.28
2001-2011	Mean	4.53	226.00
	STD	2.32	79.76

Table 4. Yearly and cumulative wind speed statistics at 70 m height.

Year	Parameter	Speed	Azimuth
2001	Mean:	7.72	209.41
	STD:	3.94	81.13
2002	Mean:	8.78	227.31
	STD:	4.50	83.03
2003	Mean:	8.68	224.15
	STD:	4.57	78.48
2004	Mean:	8.24	228.17
	STD:	4.43	80.32
2005	Mean:	8.37	227.63
	STD:	4.15	77.45

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2006	Mean:	7.82	231.65
	STD:	3.94	83.15
2007	Mean:	8.07	228.73
	STD:	3.97	79.28
2008	Mean:	8.07	221.94
	STD:	4.04	77.23
2009	Mean:	8.15	231.31
	STD:	4.28	75.39
2010	Mean:	7.91	225.30
	STD:	4.08	79.84
2011	Mean:	7.64	230.11
	STD:	3.74	79.28
2001-2011	Mean:	8.13	226.00
	STD:	4.17	79.76

Tables 5 and 6 summarize monthly, yearly, and cumulative Weibull parameters of wind speed at 10 and 70 m heights, respectively. It may be concluded that winds in Ariel may be accurately assumed as Rayleigh since the cumulative *k* is very close to 2.

Table 5. Monthly, yearly, and cumulative Weibull parameters at 10 m height.

Month	Parameter	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jan	c	4.18	6.40	5.97	6.21	6.19	5.45	6.11	6.65	6.08	6.03	5.40
	k	1.60	2.11	2.33	1.93	2.06	1.83	1.86	2.31	1.81	2.35	2.06
Feb	c	5.60	6.39	7.46	5.92	6.02	5.95	5.58	6.03	6.42	6.10	5.82
	k	1.76	2.03	2.39	1.70	1.89	1.80	2.03	2.33	2.12	2.07	1.99
Mar	c	4.69	6.20	6.47	5.23	5.16	5.45	5.77	5.51	5.64	5.50	4.98
	k	1.71	1.98	1.83	1.81	2.02	1.95	2.17	2.18	2.06	2.05	1.89
Apr	c	4.55	5.80	5.49	5.39	5.77	5.55	5.77	5.15	4.97	4.24	5.13
	k	1.52	2.28	1.92	1.93	1.77	2.12	2.31	2.18	1.80	1.93	2.10
May	c	5.12	4.69	5.72	5.41	5.04	4.23	4.73	4.39	4.75	4.58	4.69
	k	1.65	2.20	2.08	2.02	2.14	2.17	2.15	2.07	1.91	2.12	2.39
Jun	c	4.76	5.2	4.55	4.90	4.87	4.78	5.06	4.63	4.51	5.06	5.03
	k	2.14	2.71	2.40	2.77	2.39	2.92	2.70	2.25	2.38	2.24	2.84
Jul	c	4.87	5.06	4.77	4.73	4.99	5.02	5.06	4.56	5.32	4.85	4.45
	k	2.72	2.77	2.21	2.71	2.80	3.00	2.70	2.81	2.91	2.82	2.64
Aug	c	4.75	5.12	4.12	4.86	4.81	4.36	4.67	4.58	4.50	4.08	4.67
	k	2.87	2.74	1.94	2.47	2.63	2.72	2.85	2.78	2.68	2.70	3.01
Sep	c	4.63	4.75	4.58	4.11	4.68	4.32	4.65	4.46	4.74	4.21	4.09
	k	2.46	2.44	1.73	2.12	2.26	2.38	2.76	2.01	2.49	2.33	2.44
Oct	c	4.15	3.90	4.31	3.38	4.58	4.27	4.12	3.88	4.27	4.13	4.08
	k	2.20	2.14	1.74	1.67	1.78	2.36	2.26	2.32	2.15	2.16	2.23
Nov	c	5.22	6.59	4.63	5.71	4.96	4.44	4.49	4.62	4.84	4.50	4.14
	k	2.05	1.88	1.72	1.70	1.88	2.09	1.81	2.17	1.88	1.91	2.02
Dec	c	4.87	6.09	6.66	5.44	5.11	4.97	4.77	6.34	5.59	6.47	5.24
	k	1.98	1.84	2.03	1.60	1.66	1.77	1.88	2.03	1.92	2.02	2.16
Yearly	c	4.85	5.54	5.45	5.18	5.26	4.93	5.09	5.09	5.14	4.98	4.81

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	k	2.03	2.05	1.96	1.93	2.10	2.08	2.14	2.10	2.00	2.03	2.15
2001-2011	c	5.12										
	k	2.05										

Table 6. Monthly, yearly, and cumulative Weibull parameters at 70 m height.

Month	Parameter	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jan	c	6.48	8.13	8.96	8.54	8.58	10.32	9.25	11.93	10.90	10.81	9.68
	k	1.78	2.05	1.93	2.06	1.74	2.57	2.16	2.32	1.81	2.35	2.06
Feb	c	9.56	10.44	10.21	10.29	10.81	9.26	8.57	11.04	11.52	10.94	10.43
	k	1.91	2.13	1.92	2.17	2.36	2.06	2.41	2.44	2.12	2.07	1.99
Mar	c	7.68	11.08	10.14	10.58	10.23	9.74	8.77	9.74	10.11	9.87	8.94
	k	1.88	2.59	2.09	2.23	2.23	1.93	2.33	2.13	2.06	2.05	1.89
Apr	c	7.73	9.68	10.66	9.76	11.49	9.92	8.20	9.30	8.91	7.60	9.21
	k	1.87	2.23	2.19	2.17	2.27	1.94	1.93	2.22	1.80	1.93	2.10
May	c	11.09	9.54	9.09	8.55	9.82	8.88	10.12	7.99	8.51	8.21	8.40
	k	1.81	1.95	2.10	1.77	2.08	2.17	2.32	2.13	1.91	2.12	2.39
Jun	c	8.59	9.86	8.04	8.69	8.36	7.39	10.97	8.27	8.08	9.08	9.02
	k	1.95	2.13	1.94	2.17	1.98	2.06	2.67	2.24	2.38	2.24	2.84
Jul	c	8.86	10.23	8.67	8.80	10.70	8.72	10.81	8.20	9.54	8.70	7.99
	k	2.90	2.26	2.14	1.89	2.04	1.98	3.01	2.82	2.91	2.82	2.64
Aug	c	7.67	9.47	10.10	8.21	11.88	9.61	8.88	8.22	8.07	7.32	8.37
	k	2.97	2.38	2.21	1.96	2.05	1.97	2.72	2.79	2.68	2.70	3.01
Sep	c	9.42	9.85	8.51	8.34	8.42	10.51	8.14	7.82	8.49	7.54	7.33
	k	2.61	1.89	2.03	2.02	2.31	2.03	2.42	2.09	2.49	2.33	2.44
Oct	c	7.21	9.84	9.40	8.97	9.16	8.02	9.34	7.22	7.66	7.40	7.32
	k	2.09	2.07	2.05	2.21	2.43	2.22	2.49	2.20	2.15	2.16	2.23
Nov	c	8.18	10.44	10.36	9.60	8.39	8.54	10.05	8.38	8.67	8.06	7.42
	k	1.98	2.19	2.20	2.50	2.21	2.38	2.53	2.27	1.88	1.91	2.02
Dec	c	9.90	9.69	10.19	8.93	8.11	7.96	7.99	11.12	10.03	11.60	9.40
	k	2.09	2.29	2.35	2.36	1.80	1.94	2.77	1.96	1.92	2.02	2.16
Yearly	c	8.70	9.92	9.78	9.29	9.44	8.83	9.12	9.12	9.21	8.93	8.63
	k	2.03	2.05	1.96	1. 93	2.10	2.08	2.14	2.10	2.00	2.03	2.15
2001-2011	c	9.17										
	k	2.05										

In order to validate the applicability of Weibull PDF to wind statistics in Ariel, Figs. 5 – 15 present yearly wind speed raw data histograms and Weibull PDFs at both 10 and 70 m heights. Good matching is evident at all figures.

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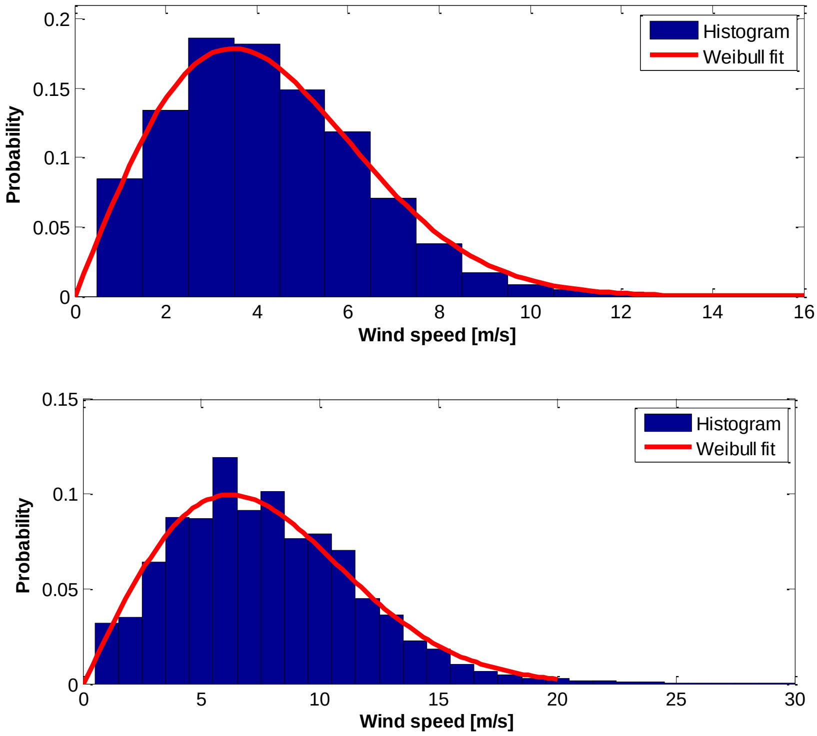

Figure 5. 2001 wind speed raw data Histogram and Weibull PDF. Top – 10 m height, Bottom – 70 m height.

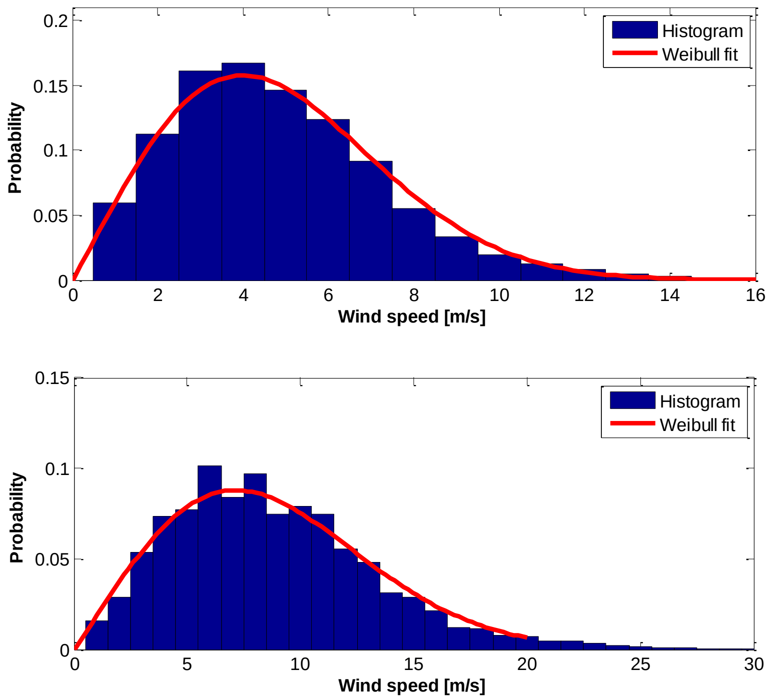

Figure 6. 2002 wind speed raw data Histogram and Weibull PDF. Top – 10 m height, Bottom – 70 m height.

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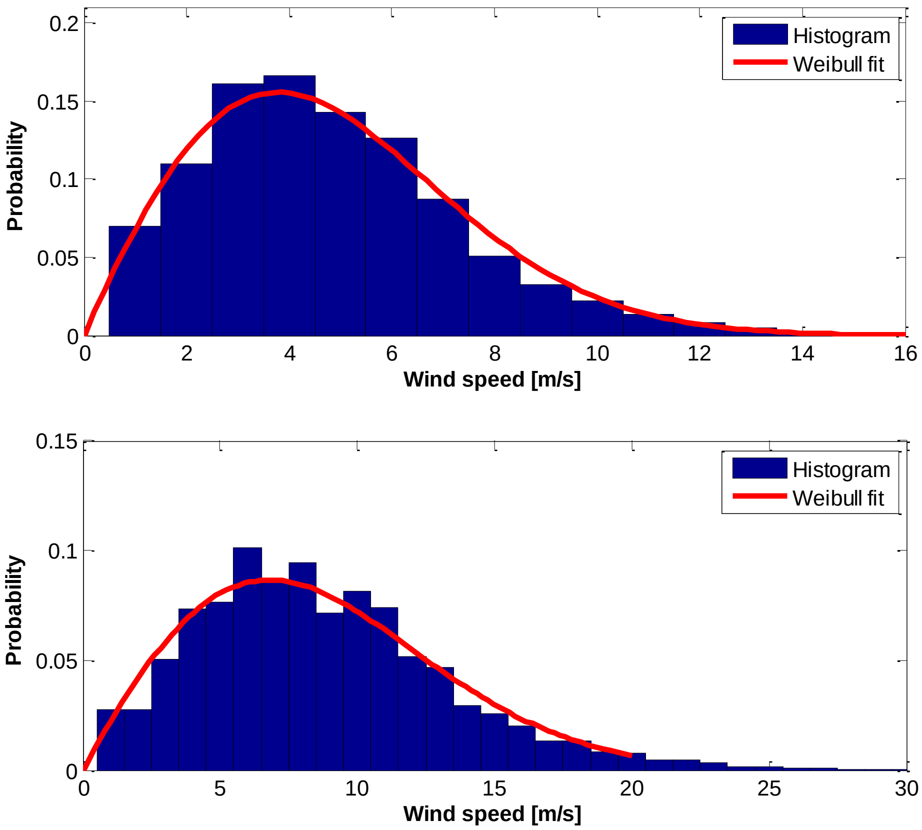

Figure 7. 2003 wind speed raw data Histogram and Weibull PDF. Top – 10 m height, Bottom – 70 m height

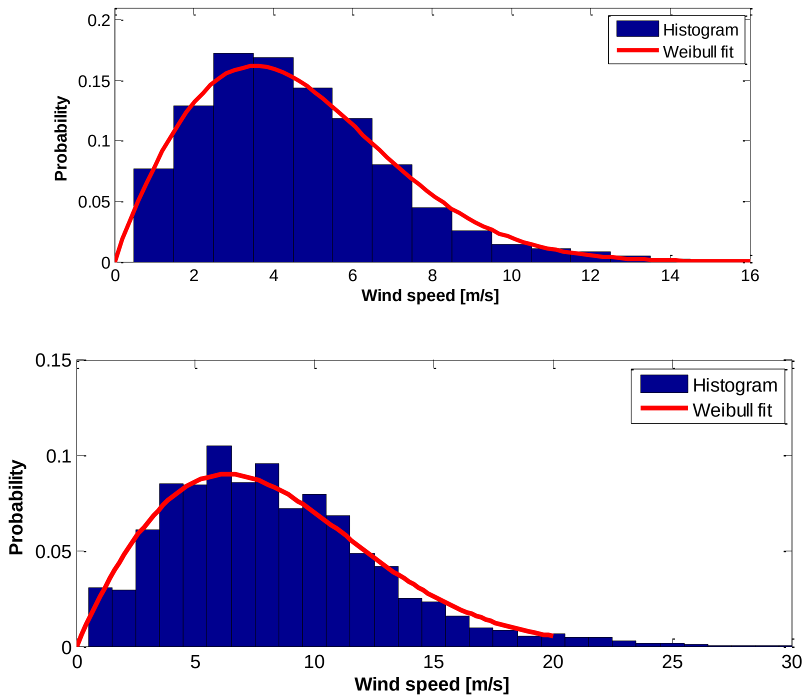

Figure 8. 2004 wind speed raw data Histogram and Weibull PDF. Top – 10 m height, Bottom – 70 m height.

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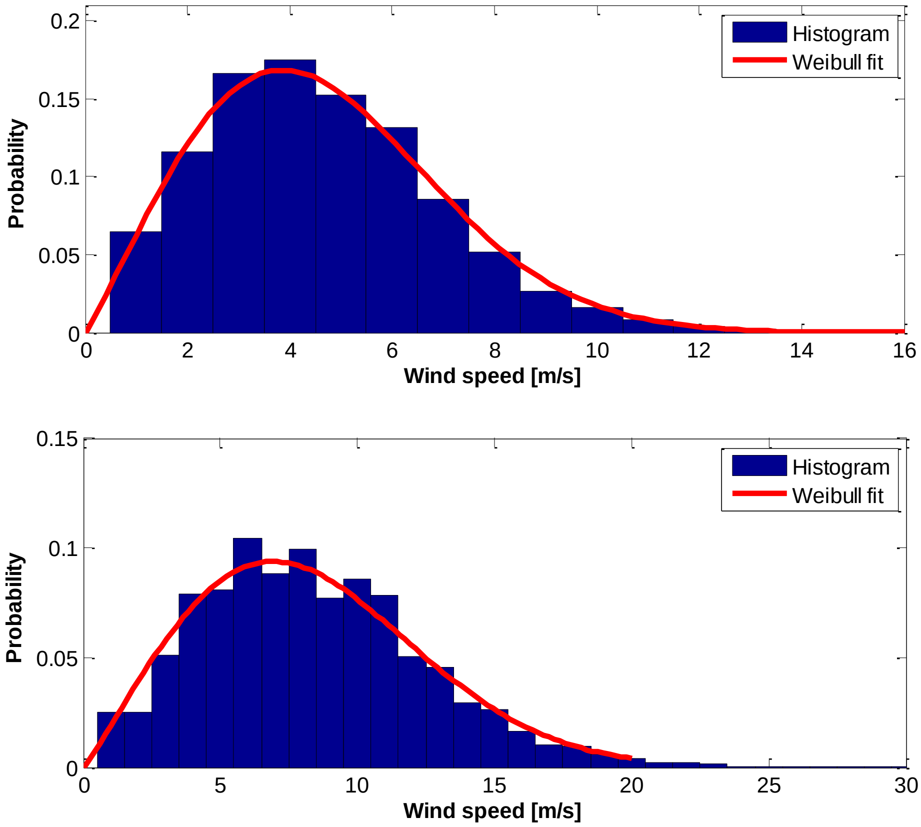


Figure 9. 2005 wind speed raw data Histogram and Weibull PDF. Top – 10 m height, Bottom – 70 m height.

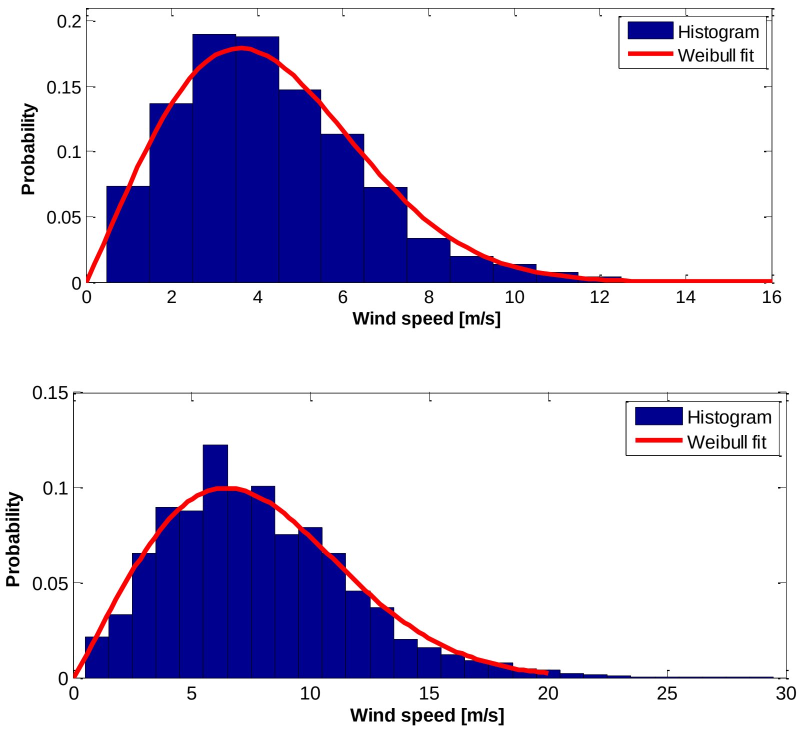
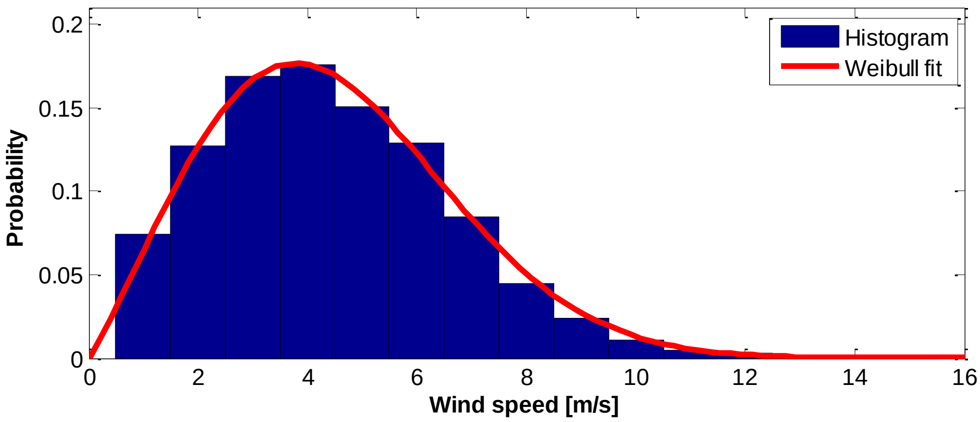


Figure 10. 2006 wind speed data Histogram and Weibull PDF. Top – 10 m height, Bottom – 70 m height.



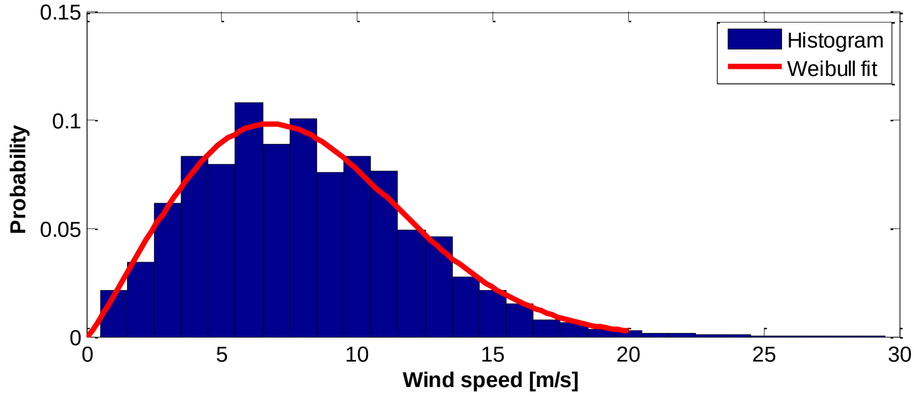
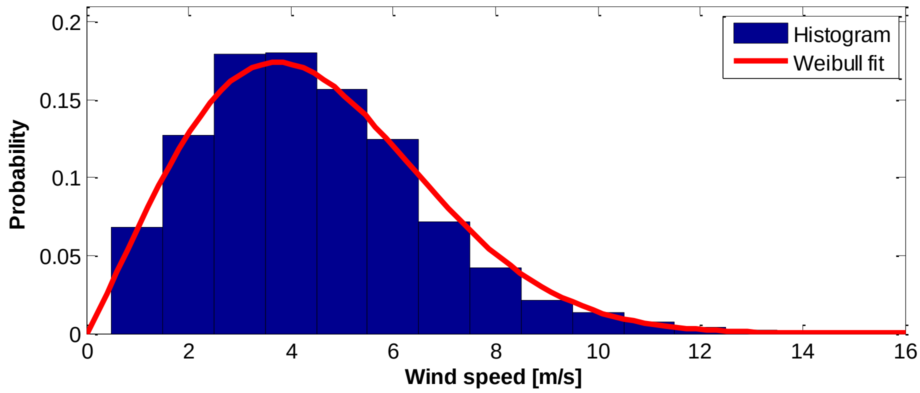


Figure 11. 2007 wind speed data Histogram and Weibull PDF. Top – 10 m height, Bottom – 70 m height



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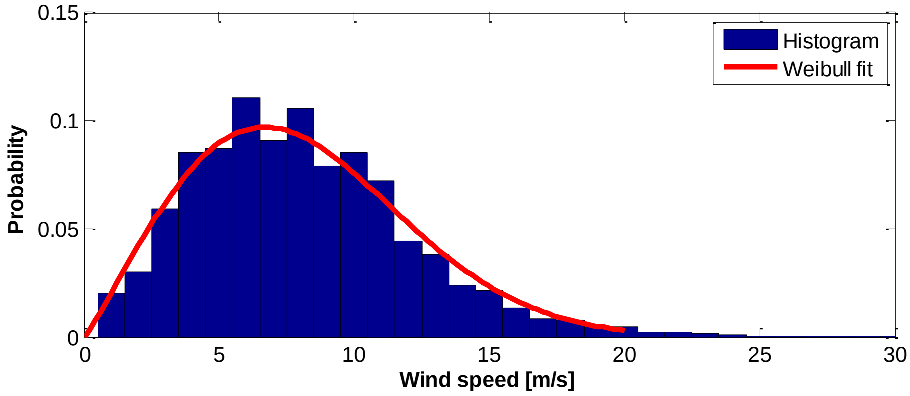

Figure 12. 2008 wind speed data Histogram and Weilbull PDF. Top – 10 m height, Bottom – 70 m height.

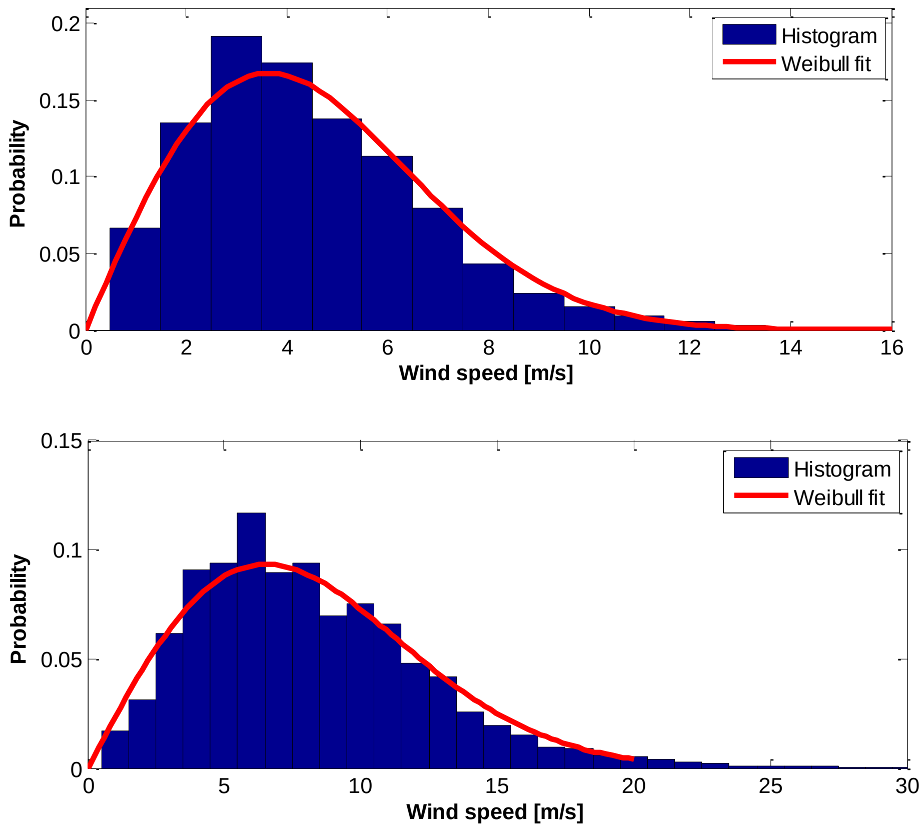

Figure 13. 2009 wind speed data Histogram and Weilbull PDF. Top – 10 m height, Bottom – 70 m height.

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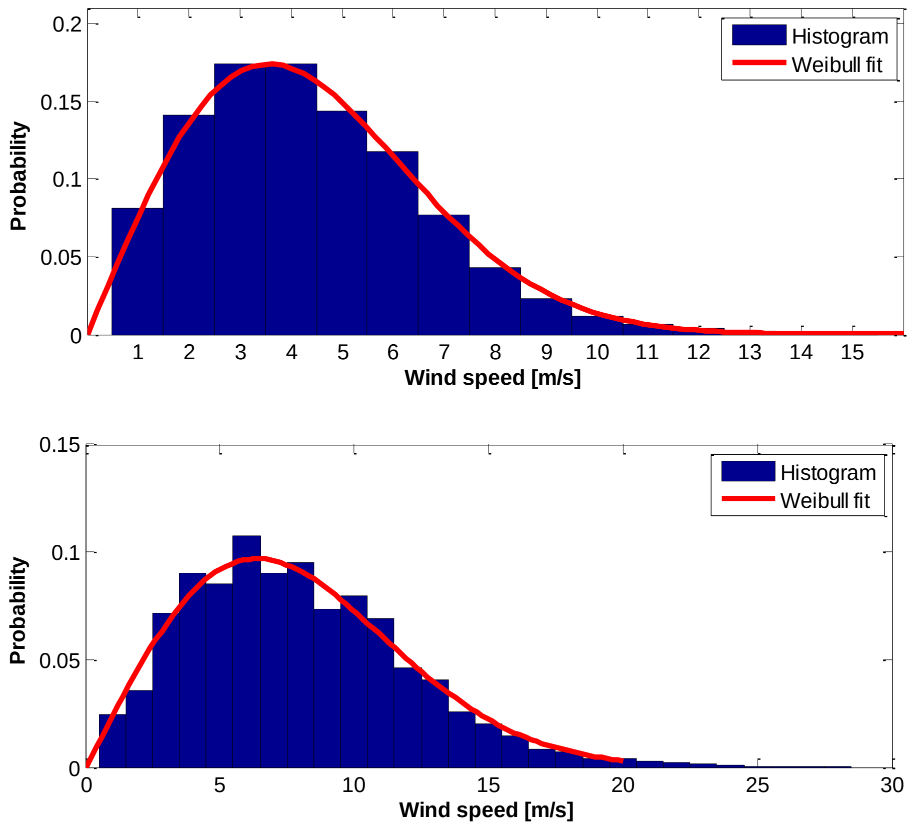

Figure 14. 2010 wind speed raw data Histogram and Weibull PDF. Top – 10 m height, Bottom – 70 m height.

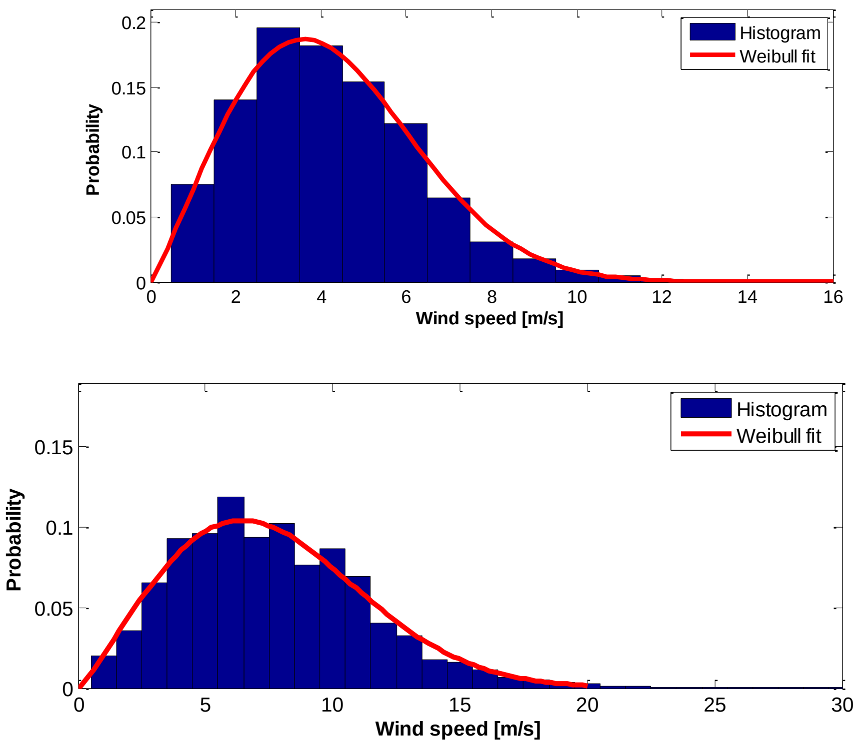

Figure 15. 2011 wind speed raw data Histogram and Weibull PDF. Top – 10 m height, Bottom – 70 m height

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All yearly Weibull PDFs are plotted together in Fig. 16 for 10 and 70 m heights, respectively. It may be concluded that wind regime is relatively stable and hence predictable. This is supported by Fig. 17, presenting statistical as well as Weibull parameters variations throughout the years at 10 m height.

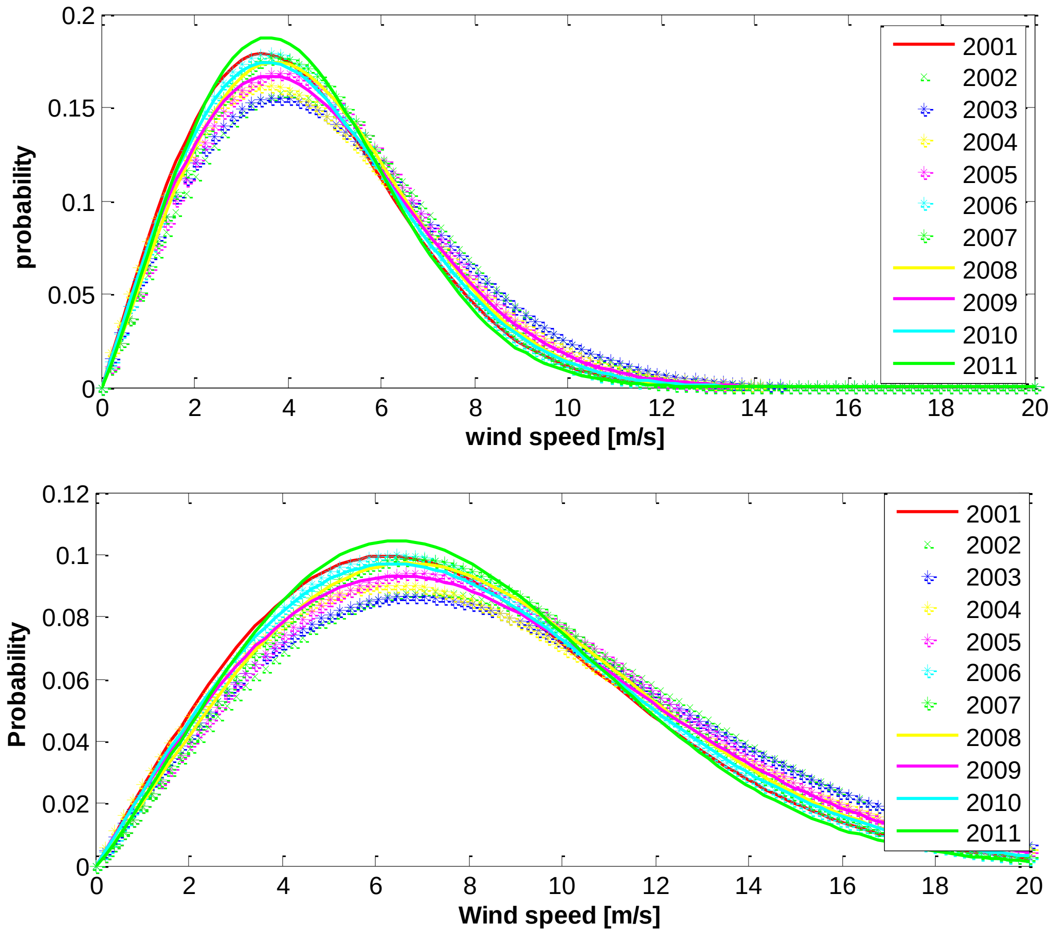
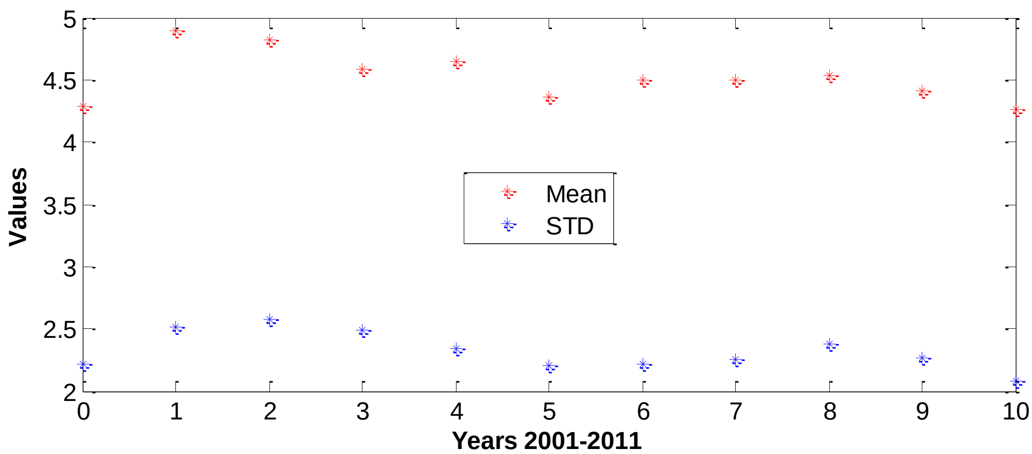


Figure 16. 2001-2011 Weibull PDFs. Top – 10 m height, Bottom – 70 m height.



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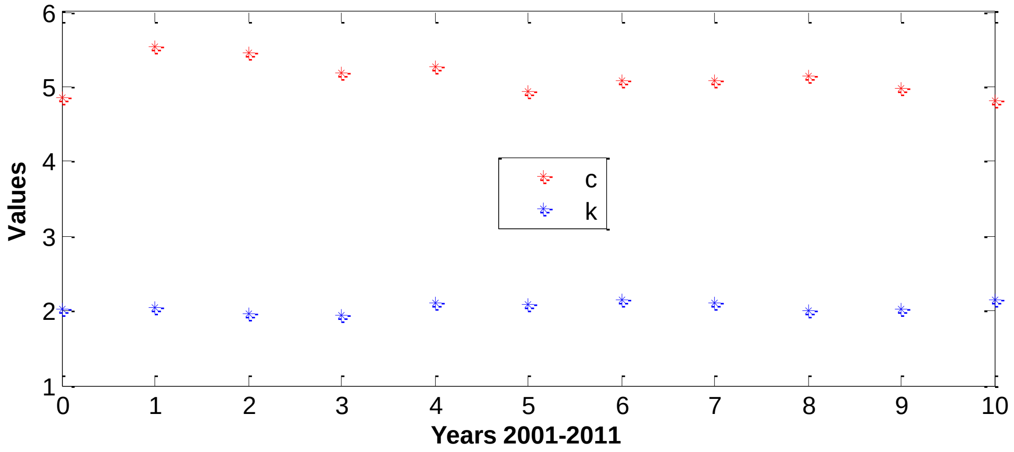

Figure 17. 2001-2011 parameter variations at 10 m. Top – statistical, Bottom – Weibull.

Weibull parameters were estimated seasonally as well. Winter season in Israel generally takes place from November to January, autumn season - from August to October, spring season - from February and April and summer season from May to July. The results are summarized in Tables VII and VIII for 10 and 70 m heights, respectively. Cumulative seasonal PDF plots are given in Figs. 18 - 21, respectively.

Table 7. Seasonal variation of Weibull parameters at 10 m height.

	Parameter	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
winter	*c*	4.53	5.25	5.48	5.03	4.67	4.99	5.08	5.86	5.51	5.68	4.94
Nov-Jan	*k*	1.85	2.12	2.13	2.29	1.88	2.21	2.35	2.04	1.83	1.99	2.02
Spring	*c*	4.63	5.80	5.77	5.69	6.05	5.38	4.75	5.58	5.66	5.26	5.30
Feb-Apr	*k*	1.84	2.29	2.06	2.18	2.26	1.96	2.20	2.23	1.95	1.93	1.97
Summer	*c*	5.33	5.58	4.80	4.84	5.37	4.65	5.94	4.55	4.87	4.83	4.72
May-Jul	*k*	2.00	2.10	2.05	1.92	1.99	2.03	2.62	2.35	2.24	2.34	2.58
Autumn	*c*	4.53	5.43	5.21	4.75	5.48	5.23	4.90	4.33	4.50	4.14	4.29
Aug-Oct	*k*	2.39	2.08	2.08	2.05	2.05	1.99	2.51	2.30	2.41	2.36	2.50

Table 8. Seasonal variation of Weibull parameters at 70 m height.

	Parameter	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
winter	c	8.12	9.42	9.82	9.03	8.37	8.95	9.11	10.51	9.88	10.18	8.85
Nov-Jan	k	1.85	2.12	2.13	2.29	1.88	2.21	2.35	2.04	1.83	1.99	2.02
Spring	c	8.31	10.41	10.34	10.21	10.84	9.64	8.52	10.01	10.14	9.44	9.50
Feb-Apr	k	1.84	2.29	2.06	2.18	2.26	1.96	2.20	2.23	1.95	1.93	1.97
Summer	c	9.55	10.01	8.60	8.68	9.62	8.34	10.64	8.16	8.73	8.67	8.47
May-Jul	k	2.00	2.10	2.05	1.92	1.99	2.03	2.62	2.35	2.24	2.34	2.58
Autumn	c	8.12	9.73	9.34	8.51	9.83	9.38	8.79	7.76	8.07	7.42	7.68
Aug-Oct	k	2.39	2.08	2.08	2.05	2.05	1.99	2.51	2.30	2.41	2.36	2.50

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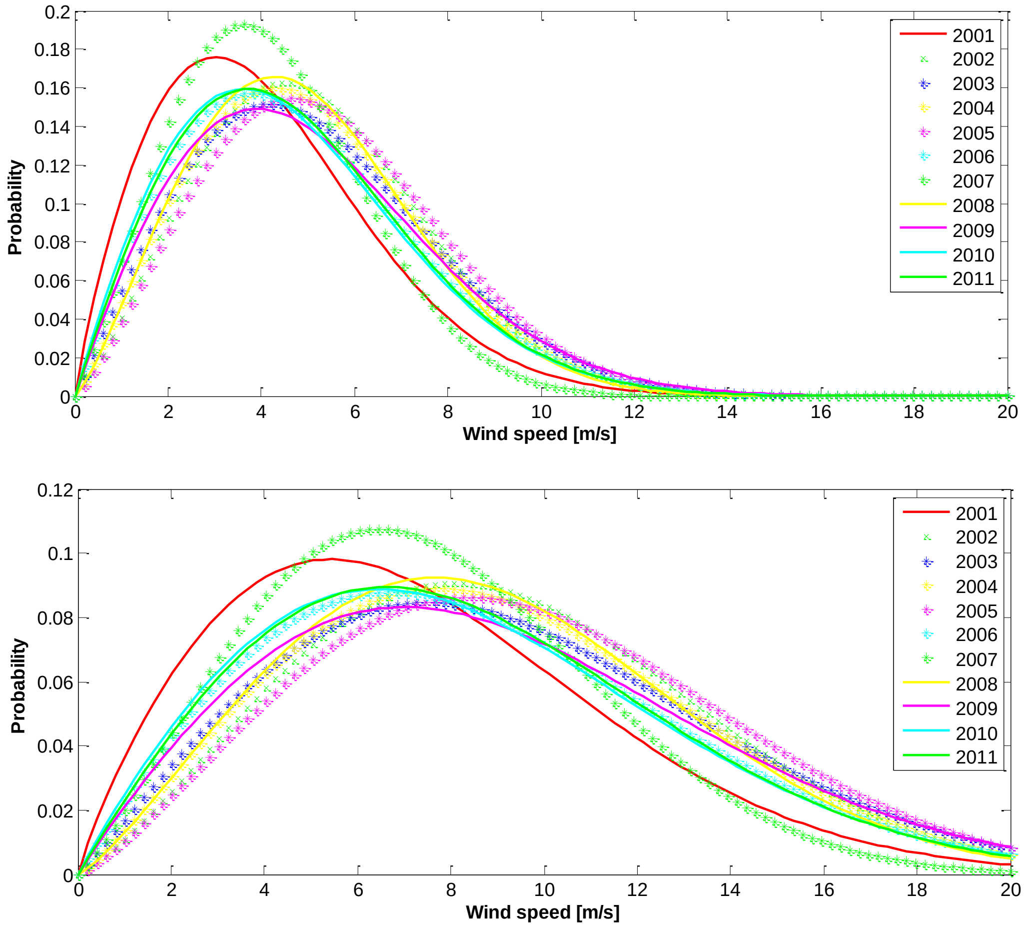
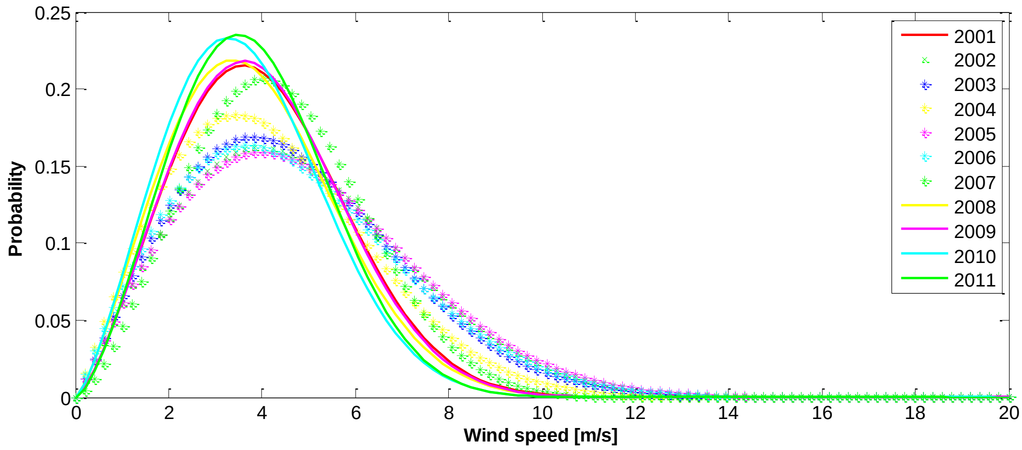


Figure 18. 2001-2011 spring Weibull PDFs. Top – 10 m height, Bottom – 70 m height.



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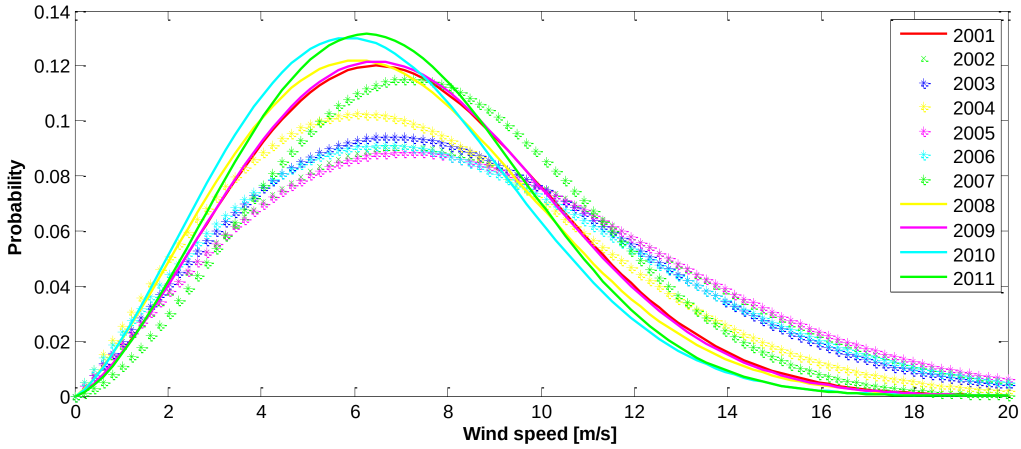


Figure 19. 2001-2011 autumn Weibull PDFs. Top – 10 m height, Bottom – 70 m height.

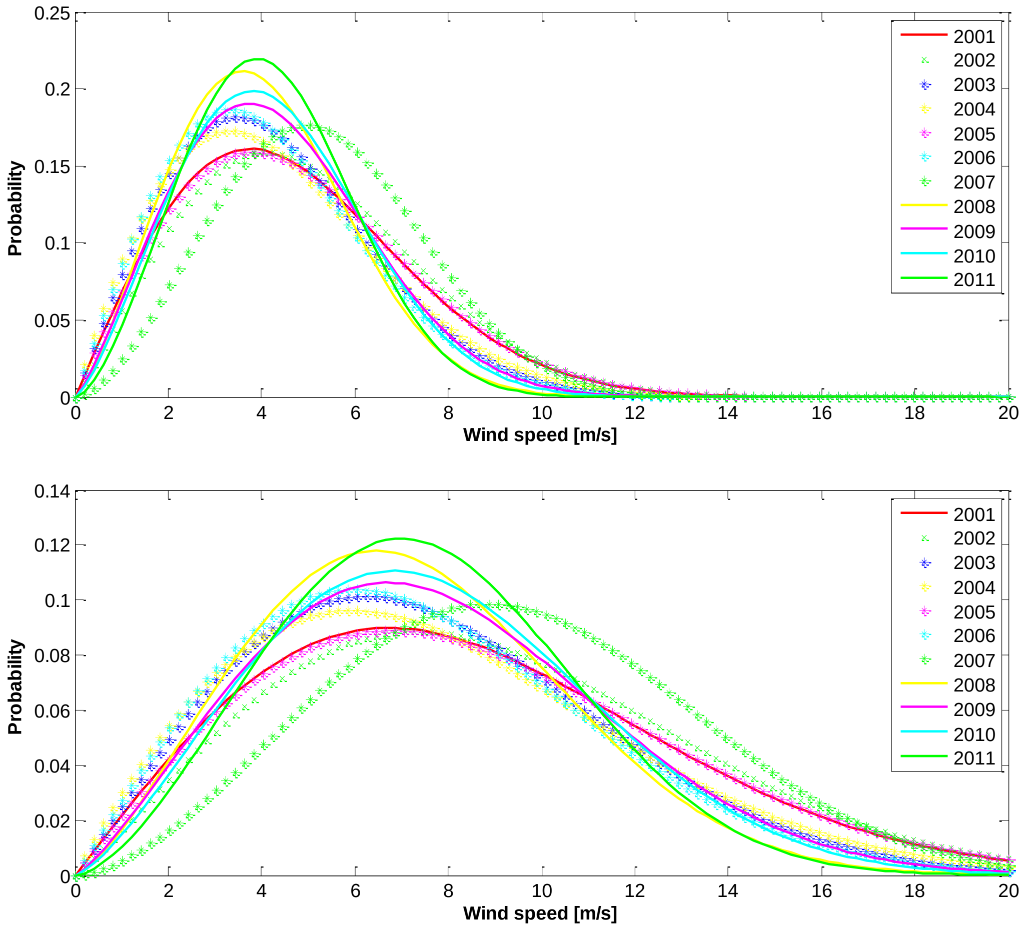
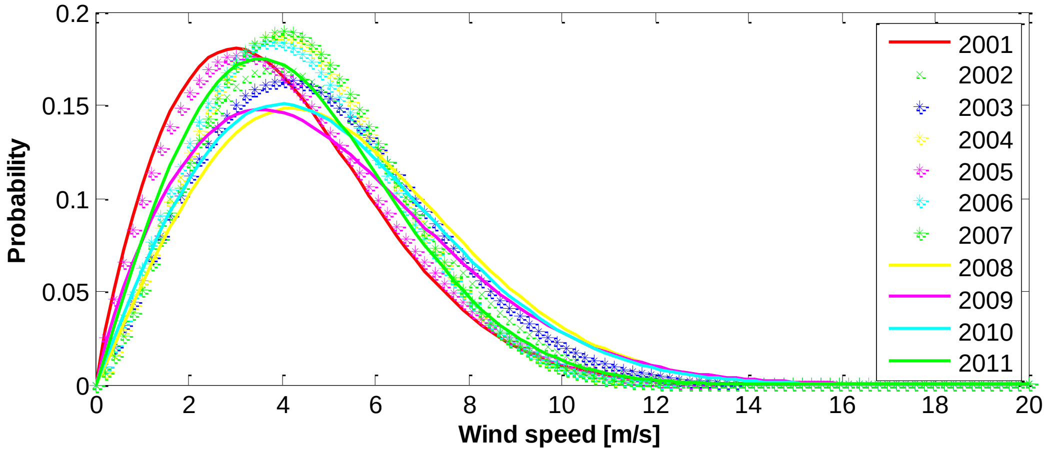


Figure 20. 2001-2011 summer Weibull PDFs. Top – 10 m height, Bottom – 70 m height.



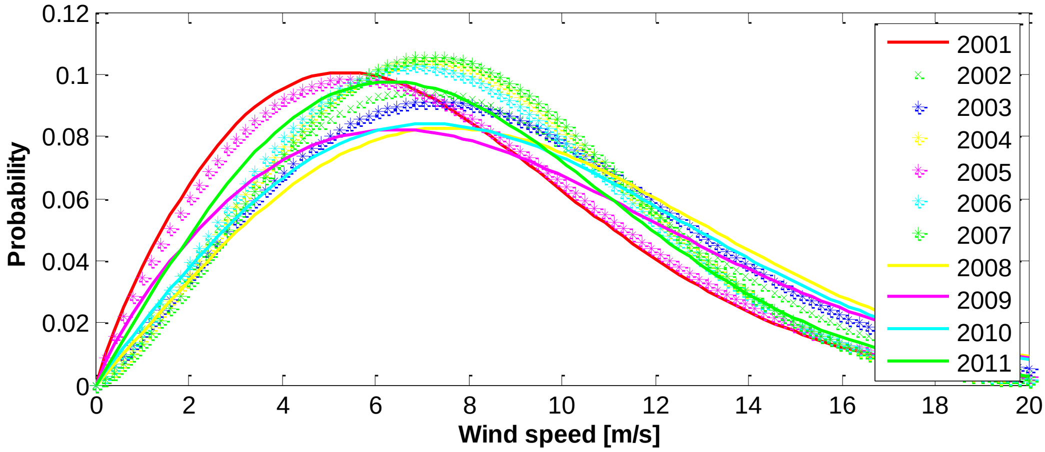
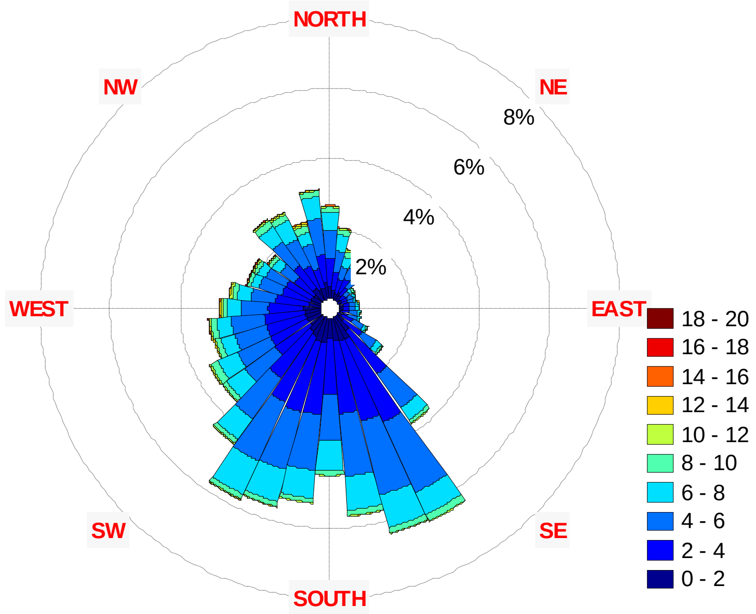


Figure 21. 2001-2011 winter Weibull PDFs. Top – 10 m height, Bottom – 70 m height.

Another important aspect of wind analysis is prevailing wind direction (azimuth). Eleven years wind direction polar histograms (Rose diagrams) are shown as rose diagram in Figs. 22 – 32 for both 10 and 70 m heights. Cumulative wind rose diagrams are shown in Fig. 33. It may be concluded that the prevailing wind direction remains relatively stable throughout the years.



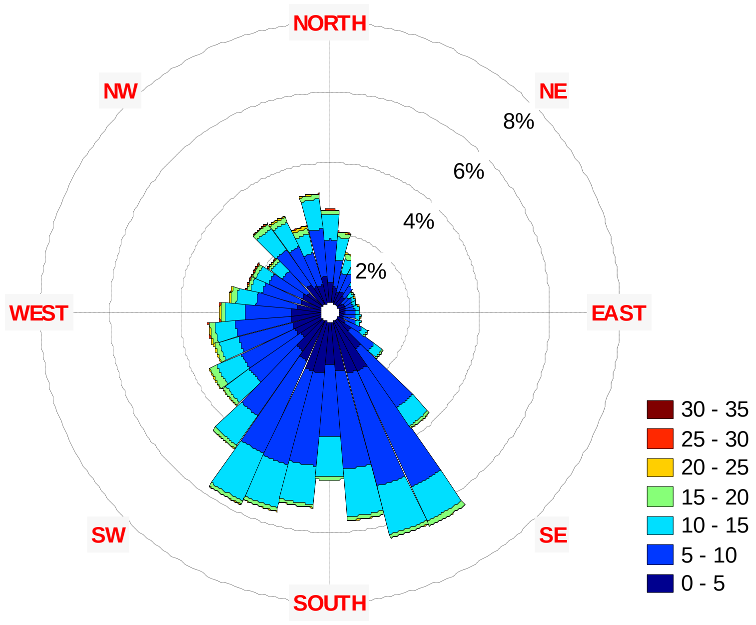
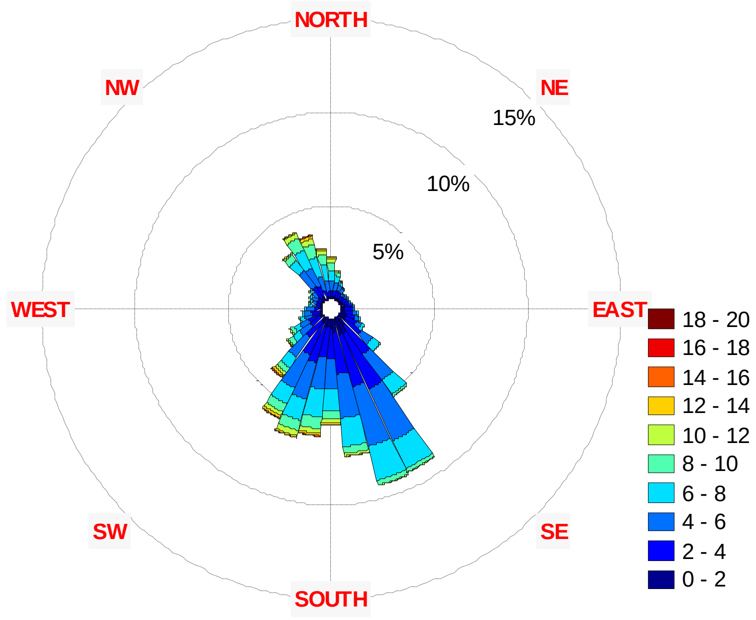


Figure 22. 2001 wind rose diagrams. Top – 10 m height, Bottom – 70 m height



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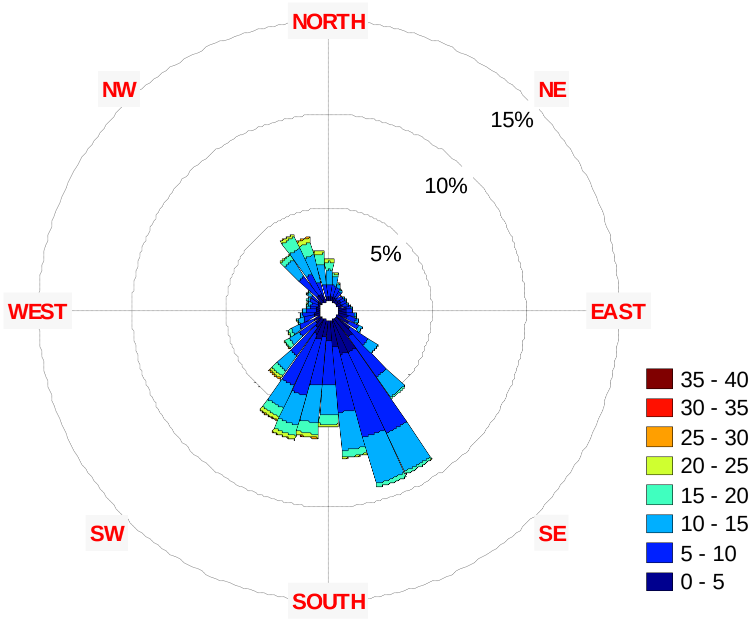
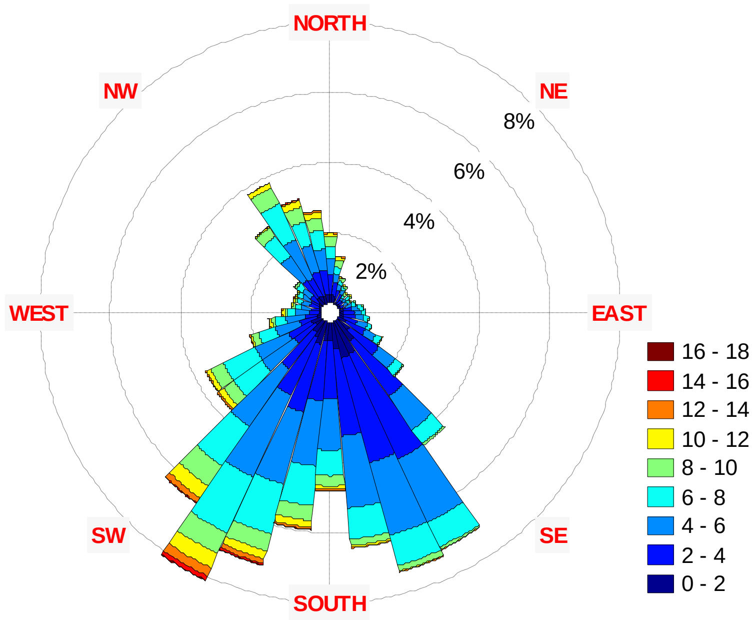


Figure 23. 2002 wind rose diagrams. Top – 10 m height, Bottom – 70 m height.



doi:10.20944/preprints202301.0584.v1

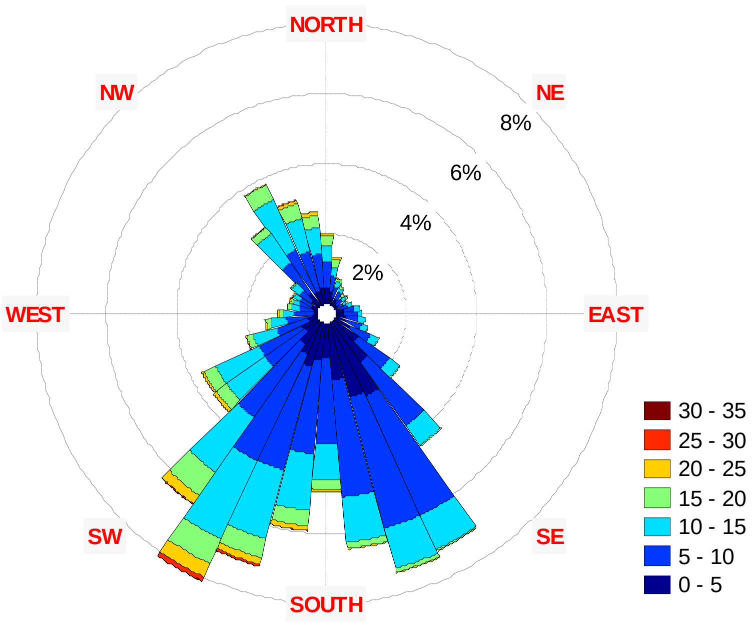
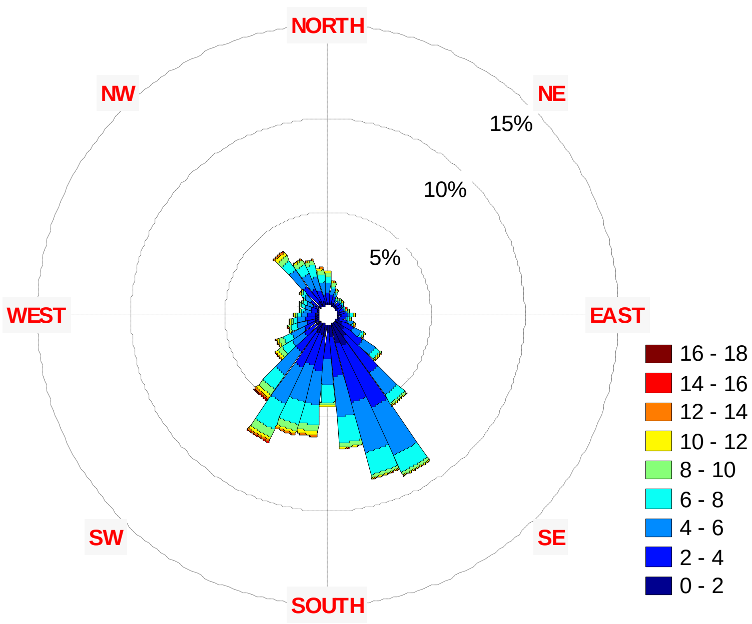


Figure 24. 2003 wind rose diagrams. Top – 10 m height, Bottom – 70 m height



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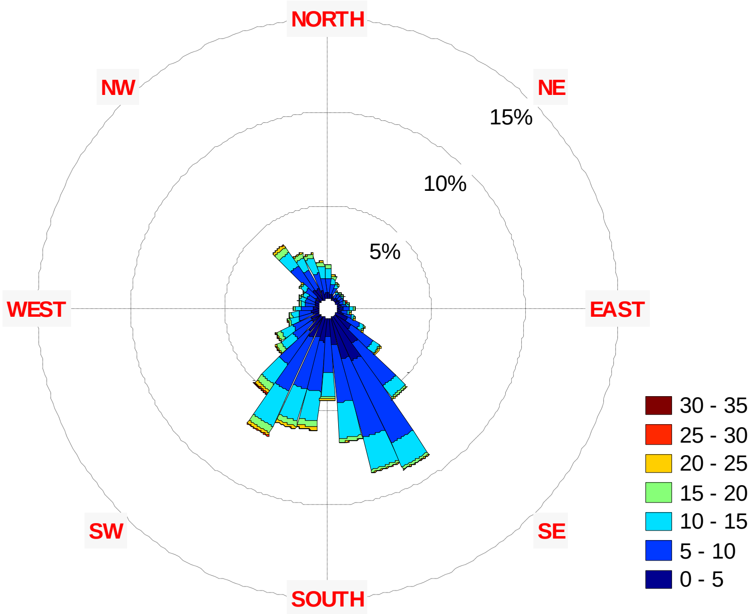
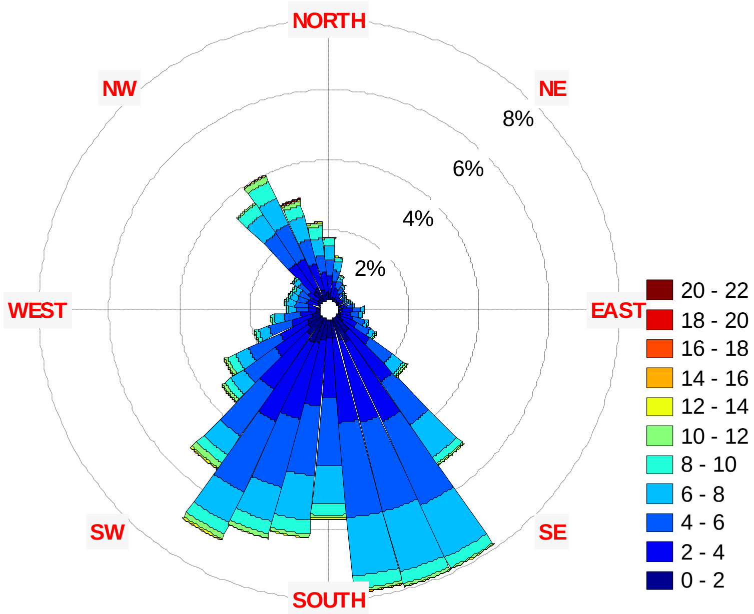


Fig. 25: 2004 wind rose diagrams. Top – 10 m height, Bottom – 70 m height



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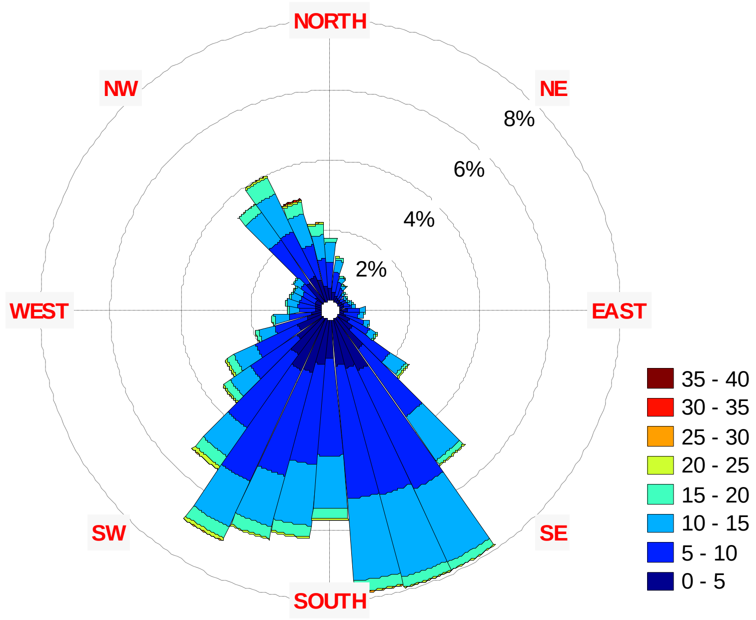
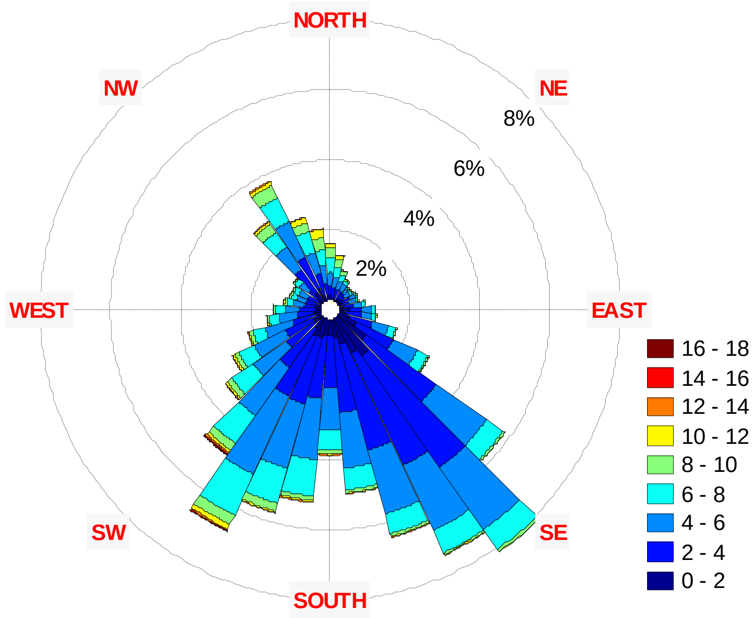


Figure 26. 2005 wind rose diagrams. Top – 10 m height, Bottom – 70 m height



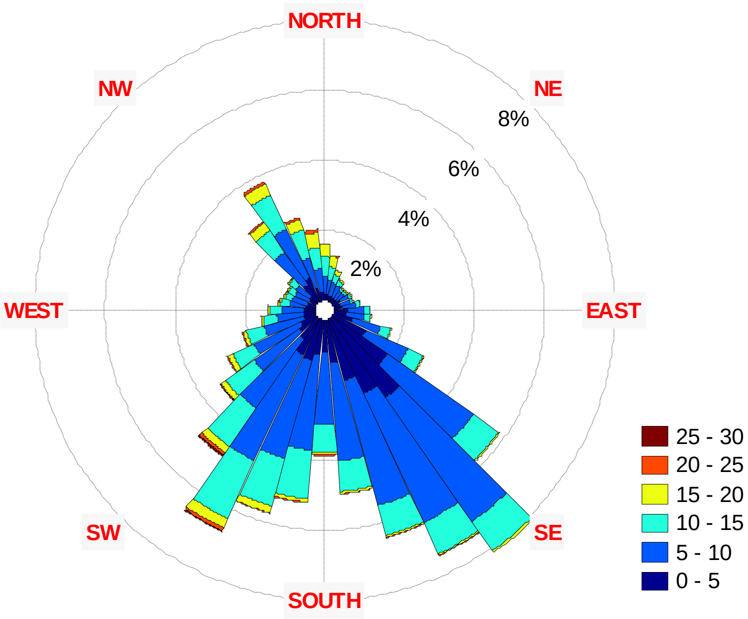
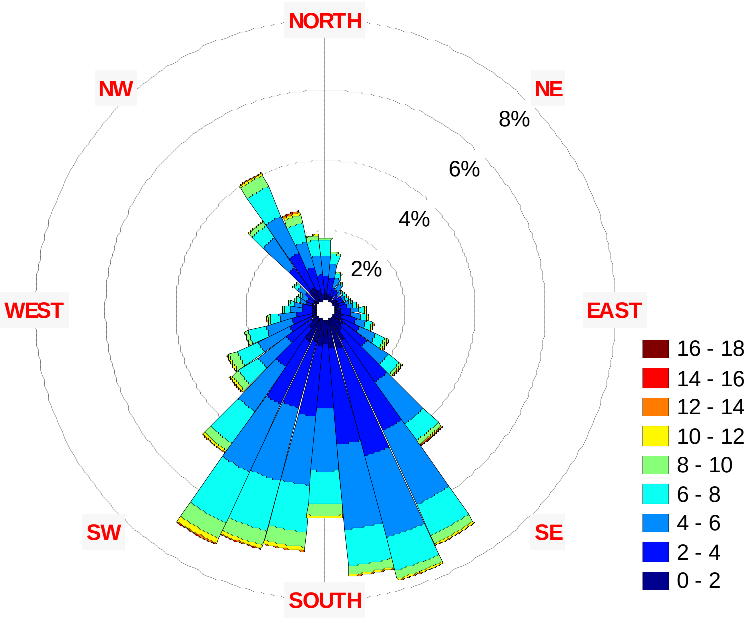


Figure 27. 2006 wind rose diagrams. Top – 10 m height, Bottom – 70 m height.



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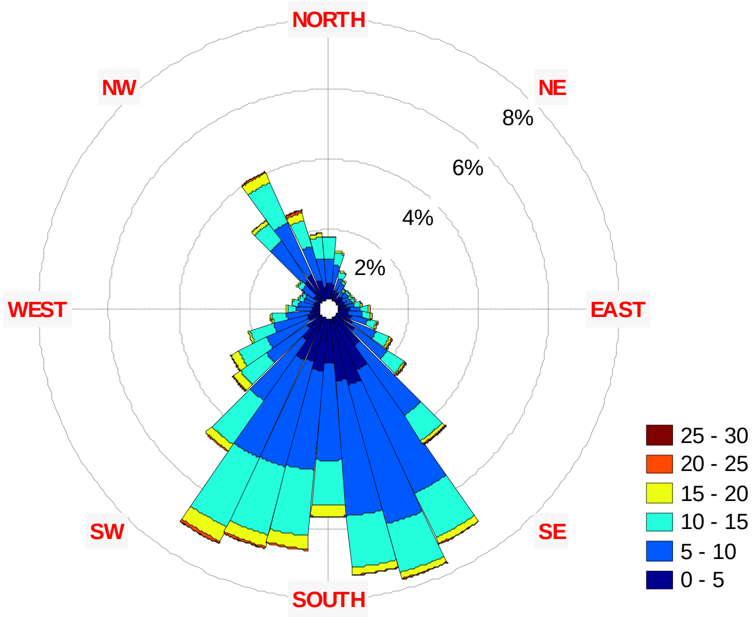
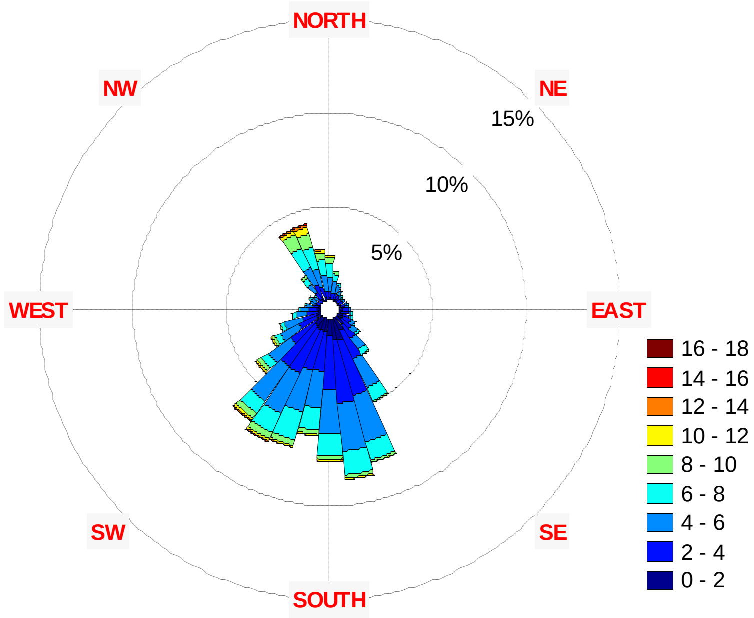


Figure 28. 2007 wind rose diagrams. Top – 10 m height, Bottom – 70 m height.



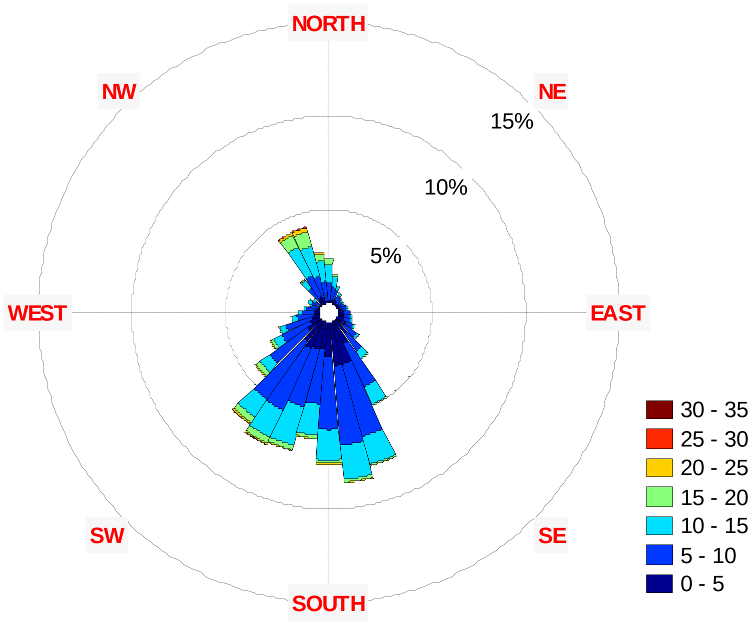
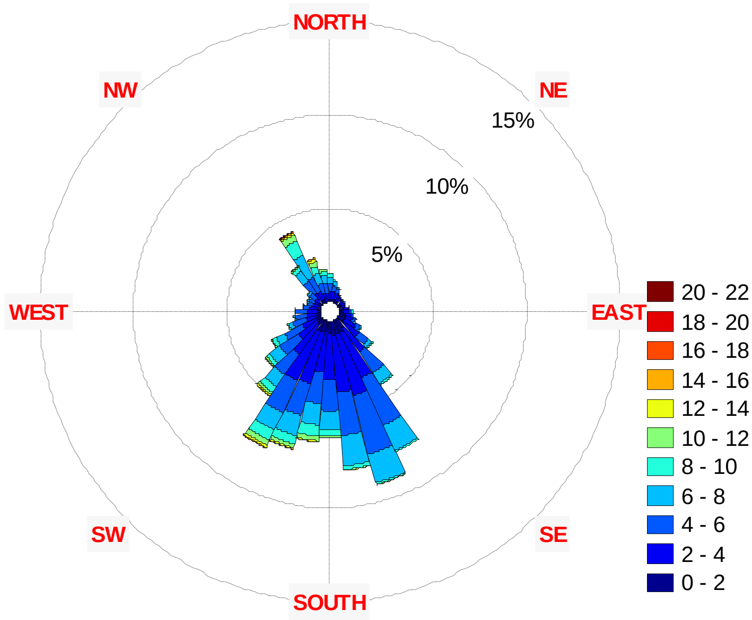


Figure 29. 2008 wind rose diagrams. Top – 10 m height, Bottom – 70 m height.



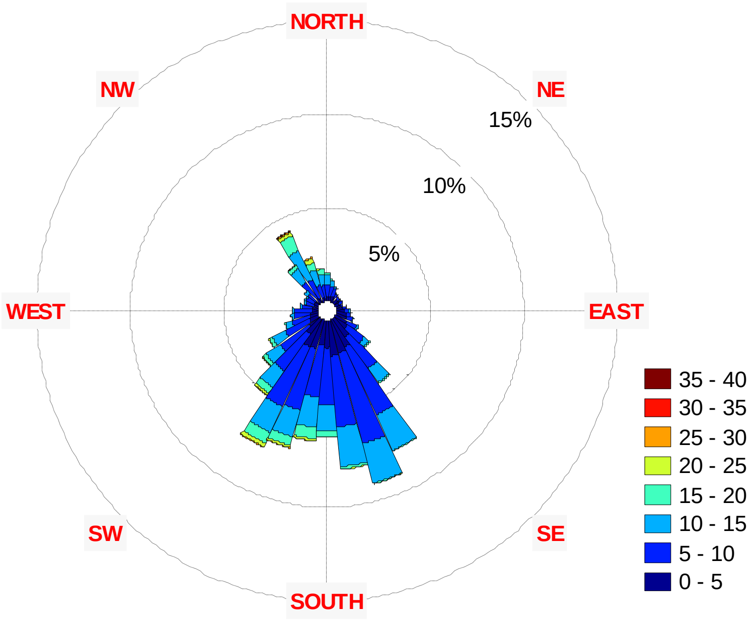
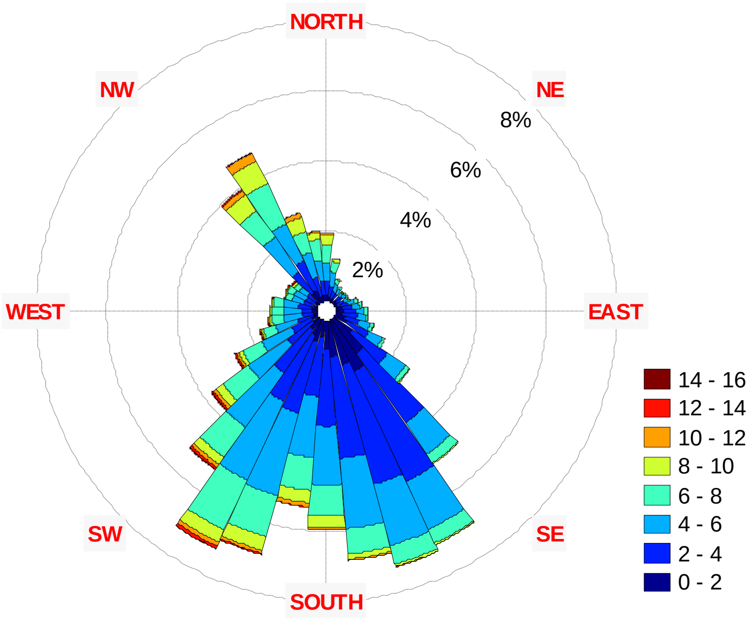


Figure 30. 2009 wind rose diagrams. Top – 10 m height, Bottom – 70 m height.



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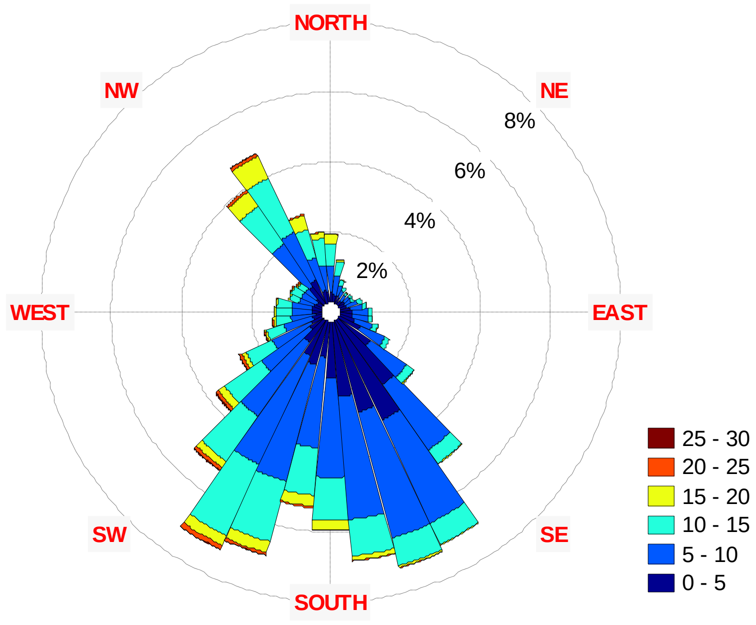
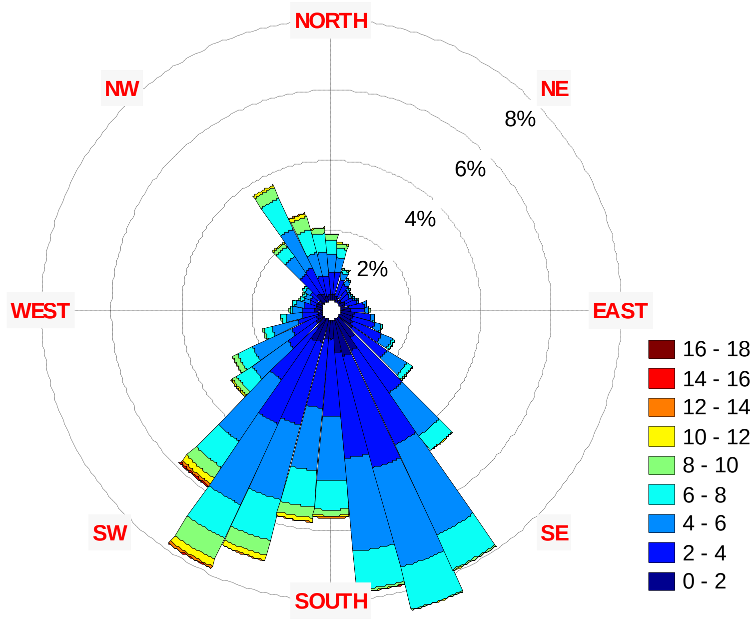


Figure 31. 2010 wind rose diagrams. Top – 10 m height, Bottom – 70 m height.



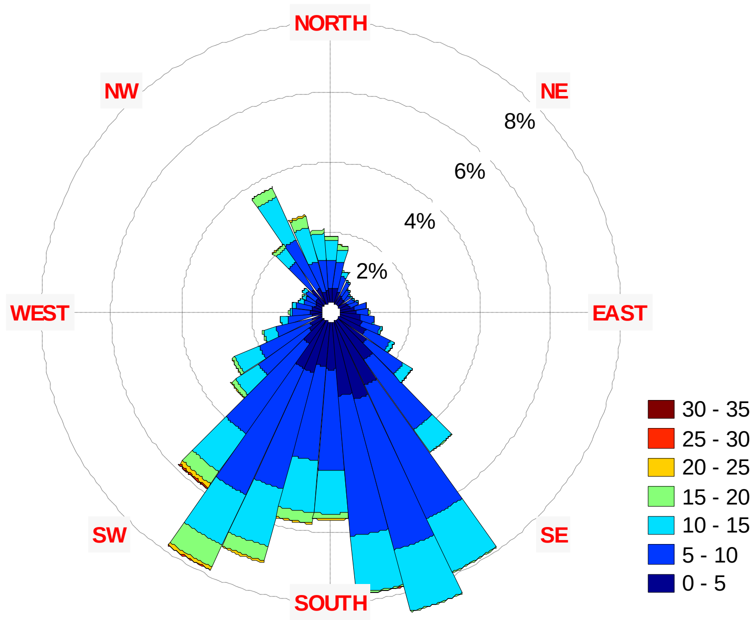
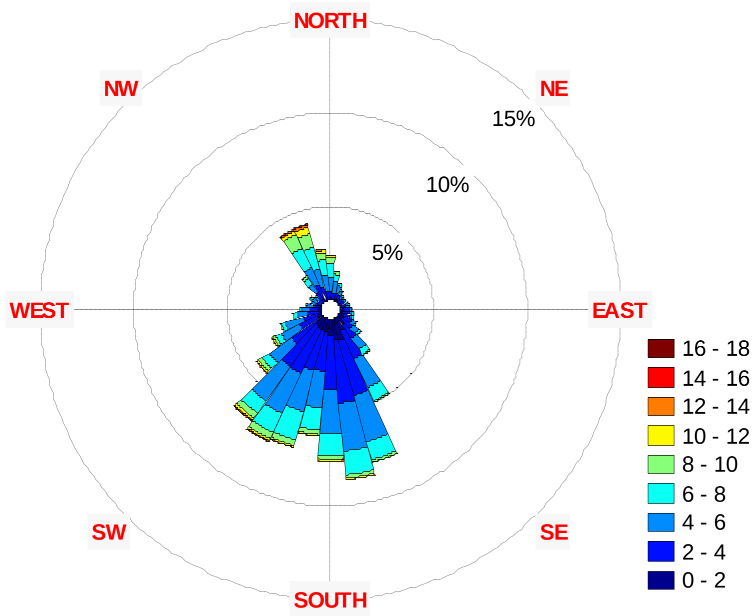


Figure 32. 2011 wind rose diagrams. Top – 10 m height, Bottom – 70 m height.



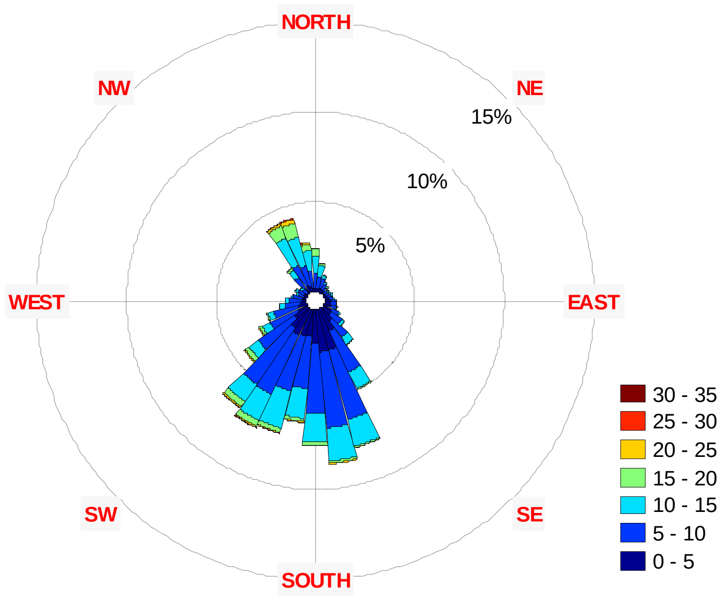


Figure 33. 2001-2011 wind rose diagrams. Top – 10 m height, Bottom – 70 m height.

4. Wind power generation

The power curves of available turbines are described in [66,67], from which three examples are analyzed in this paper and are depicted in Figure 34.

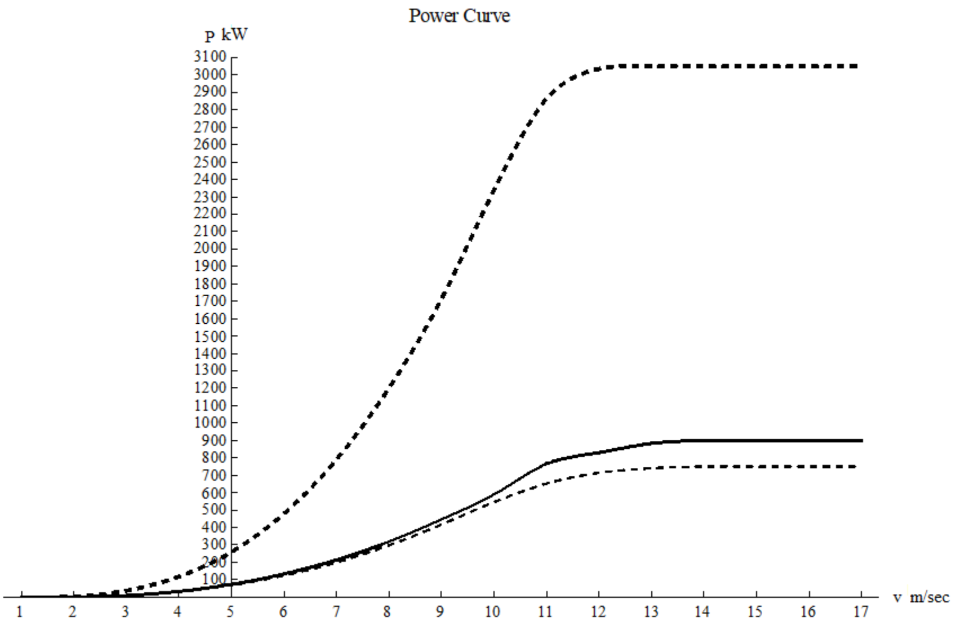


Figure 34. Power curves of wind turbines [66]. The dashed thick curve is the power curve of Enercon's model E101/3000 turbine, the thick line is the power curve of AWE's model 54–900 turbine, and the dashed curve is the power curve of EWT's model Direct wind 52/750 turbine.

Among the turbines analyzed, the largest is Enercon's model E101/3000 turbine with a radius of 50.5 m. Hence, we will assume from now on that the hub of the turbine is 70 m. Table 9 will summarize the area and radii of the turbines under study:

Table 9. Wind turbine geometric parameters.

Turbine	Enercon's E101/3000	AWE's 54–900	EWT's Directwind 52/750
Area (m^2)	8012	2290	2083
Radius (m)	50.5	27	25.75

For this height, we obtain a speed average of 8.8 m/s. The average of the power and the standard deviation obtained for each turbine are depicted in Table 10, we have used the Weibull distribution to calculate the average power and the power standard deviation.

Table 10. Wind turbine power & economic yield.

Turbine	Enercon's E101/3000	AWE's 54–900	EWT's Directwind 52/750
Average Power (kW)	1380.97	379.06	333.25
Power Standard Deviation (kW)	1160.94	326.58	275.32
Annual Revenue (Million SH)	6.46	1.77	1.56
Annual Revenue (Million $)	1.84	0.50	0.44

Table 10 contains the annual economic value of the turbine based on the current price of energy for household consumers in Israel, which is 0.5342 SH for kW hour on January 1, 2023 (before tax), the exchange rate for the same date is 3.5190 SH for one US $. In Israel the price is determined by governmental authorities who strike a balance between the interest of other producers, the cost of transmission and distribution, and the public interest in clean energy.

5. Conclusions

In this work, statistical characteristics, and Weibull parameters of the wind speed in Samaria region have been extracted from 11 years of wind data provided by the Israeli Meteorological Service, acquired at 10 m height above the ground. The cumulative mean wind speed at measurement height was found to be 4.53 m/s with standard deviation of 2.32 m/s. Prevailing wind direction is shown to be characterized by cumulative mean azimuth of 226^o with standard deviation of 79.76^o. Weibull distribution parameters were calculated yearly, monthly, and seasonally, demonstrating good match with histogram-based statistical representations. Shape parameter of Weibull distribution was shown to reside within narrow range around 2, allowing to assume Rayleigh statistics. The results were extrapolated to 70-meter height in order to estimate wind characteristics at hub height of a medium-scale wind turbine. It was shown that both statistical parameters and wind direction distribution remain relatively constant throughout the years, indicating good prediction potential. The novelty of the current paper is related to gathering wind statistics for a certain area (Samaria), we are not aware of any published statistics regarding wind velocity and direction in this area. The data may be interesting for potential regional wind energy development in which the obtained Weibull distribution can be used in calculations of expected power generation of particular turbines with known power dependence on velocity. We also point out that the fact that realistic wind velocity statistics is well described by an analytic formula (Weibull distribution) is not trivial, and in fact the fit may have been poor.

Author Conceptualization, A.Y. and A.K.; methodology, A.K.; software, Y.R.; validation, S.K..; formal analysis, M.B.; investigation, M.B.; resources, A.K.; data curation, A.Y.; writing—original draft preparation, Y.R.; writing—review and editing, A.Y.; visualization, Y.R.; supervision, A.Y. and A.K.; project administration, A.Y. and A.K. All authors have read and agreed to the published version of the manuscript

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Conflicts of Interest: The authors declare no conflict of interest.

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