

Results of Wind Monitoring Effort for Tanana, Alaska

Introduction/Overview

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Project Overview/Summary of Results

As part of the WAPA Anemometer Loan Program an anemometer was installed near the village of Tanana, AK, to determine the area's wind energy potential. The monitoring period ran from 20 September 2001 to 13 October 2002. The annual average wind speed (at 20 meters [66']) measured at the site was 2.9 m/s (6.5 mph). Comparison with long term data from nearby sites indicates that the monitoring period data probably represents an above average year. This author's best estimates for the adjusted long term average wind speed and power density are 2.4 m/s (5.4 mph) and 23 watts/m², respectively.

Project Location

The monitoring site was located near the village of Tanana, AK at an elevation of 230 feet. (N 65.17°, W 152.08°).

Project Instrumentation

The instrumentation consisted of an NRG Wind Explorer system including cup anemometer, wind vane and data logger. The instruments were mounted at a height of 20 meters (66'). The data consists of 10-minute average wind speed, wind speed standard deviation and wind direction.

Results

Summary

Annual Average Wind Speed & Power Density: 2.9 m/s (6.5 mph) / 39 watts/m²

Month with best wind resource: January

Average wind speed and power density for best month: 3.6 m/s (8.1 mph) / 60 watts/m²

Month with worst wind resource: June

Average wind speed and power density for worst month: 2.6 m/s (5.8 mph) / 25 watts/m²

Adjusted Annual Average Wind Speed & Power Density 2.4 m/s (5.4 mph) / 22 watts/m²

Speed and Power by Month

Figure 1 shows the monthly average and annual average wind power density. The measured annual average power density is 39 watts/m². The power density is highest during the late winter and spring. The lowest months are in the summer and fall.

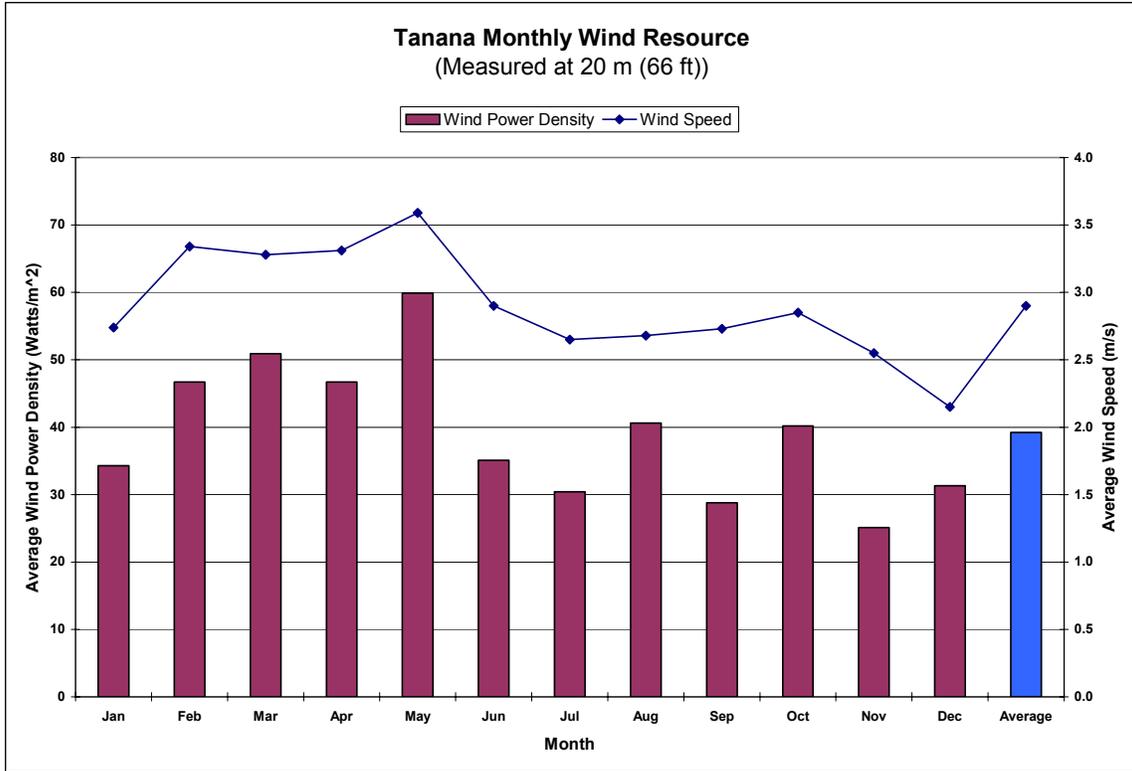


Figure 1: Monthly average and annual average wind power density and wind speed.

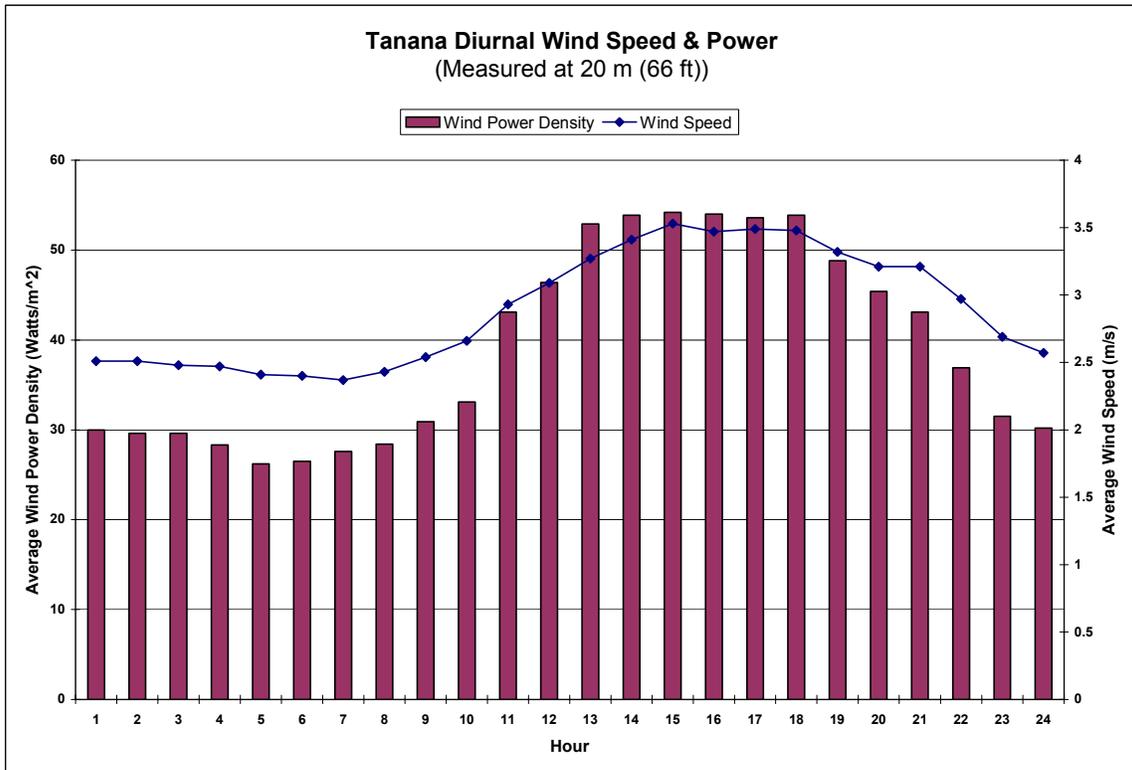


Figure 2: Average annual daily wind profile.

Speed and Power by Hour

Figure 2 shows the annual average diurnal (daily) profile for the site. In general the winds are highest in the afternoon and early evening. The winds are weakest in the early morning. (See Appendix B for monthly profiles)

Frequency and Speed by Direction

Figure 3 shows that on an annual basis the most energetic winds come from the northeast (NE) and southwest (SW). The NW winds prevail during the fall and winter. The SW winds prevail in the summer. Wind turbines placed in this area should have good northeast and southwest exposure.

The percentage of calms is very high, 18.8%. This value may be somewhat inflated due to intermittent freezing of the anemometer, which would lead to false zero wind speed readings.

The best fit Weibull parameters for the measured data are $k = 1.48$ and $c = 3.22$

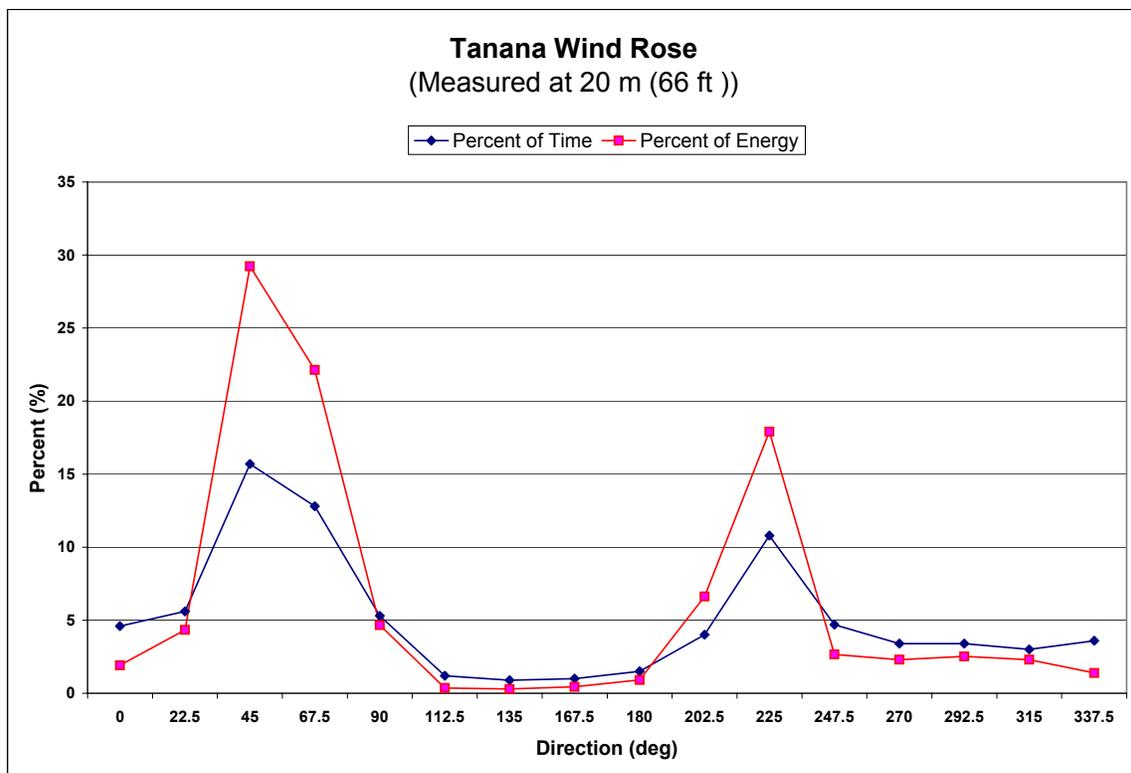


Figure 3: Frequency and Energy by direction

Frequency of Speed and Percent of Power by Speed

Figure 4 shows the annual frequency distribution of wind speed and power density. The line labeled PCTs shows the fraction of time that the wind falls within the specified bin. The line labeled PCTp shows the fraction of total annual energy contributed by winds of the indicated wind speed bin. On an annual basis, while most of the time the wind speed is between 0 m/s and 5 m/s, (84%), most of the wind energy is in winds with wind speeds from 3 to 8 m/s, (79%).

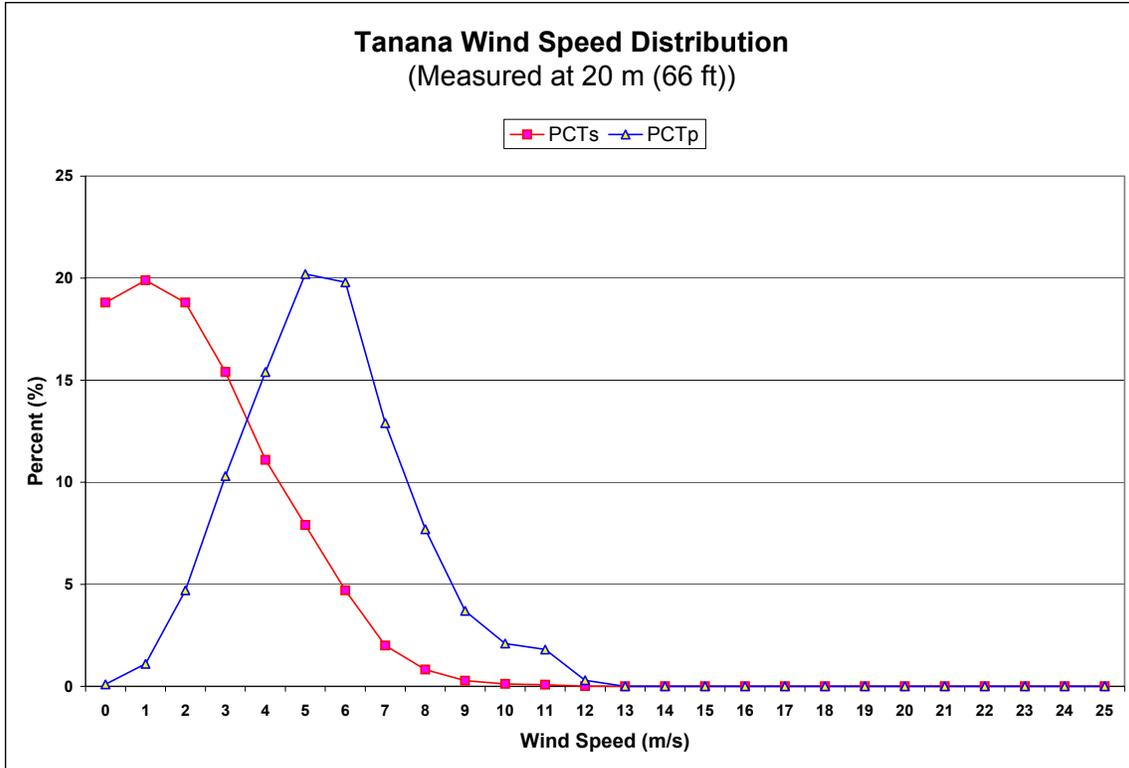


Figure 4: Annual wind and wind energy distribution.

Comparison of this data with long term average data

An important consideration is how well does the monitoring period data reflect the long-term (multi-year) average resource. In other words, does the monitoring period data reflect a good year, a bad year or an average year? To answer this question we examined long term data from two relatively nearby reference sites, Tanana/Calhoun and Minchumina. For each site the multi year average wind speed was compared to the wind speed during most of the monitoring period (September '01 – October '02 inclusive). The results are given in the table and graph below.

	Lat	Long	Monitoring Period	Long Term	Ratio
Tanana/Calhoun	65.1	152.05	2.58	2.91	0.89
Minchumina	63.53	153.16	1.98	1.32	1.5
Monitoring Site	65.1	152.05			1.20

Figure 5: Results of monitoring period data with long term data

The reference site data is somewhat ambiguous. The Tanana/Calhoun site was less windy than usual while the Minchumina site was much windier than usual. The low average wind speeds at the reference sites mean that small absolute variations in average annual speed result in large percentage changes. As a first cut, taking the average of the two reference sites, indicates that the monitoring period wind data is 20% greater than the long term average. The adjusted long term average wind speed and power density are then 2.4 m/s (5.4 mph) and 23 watts/m².

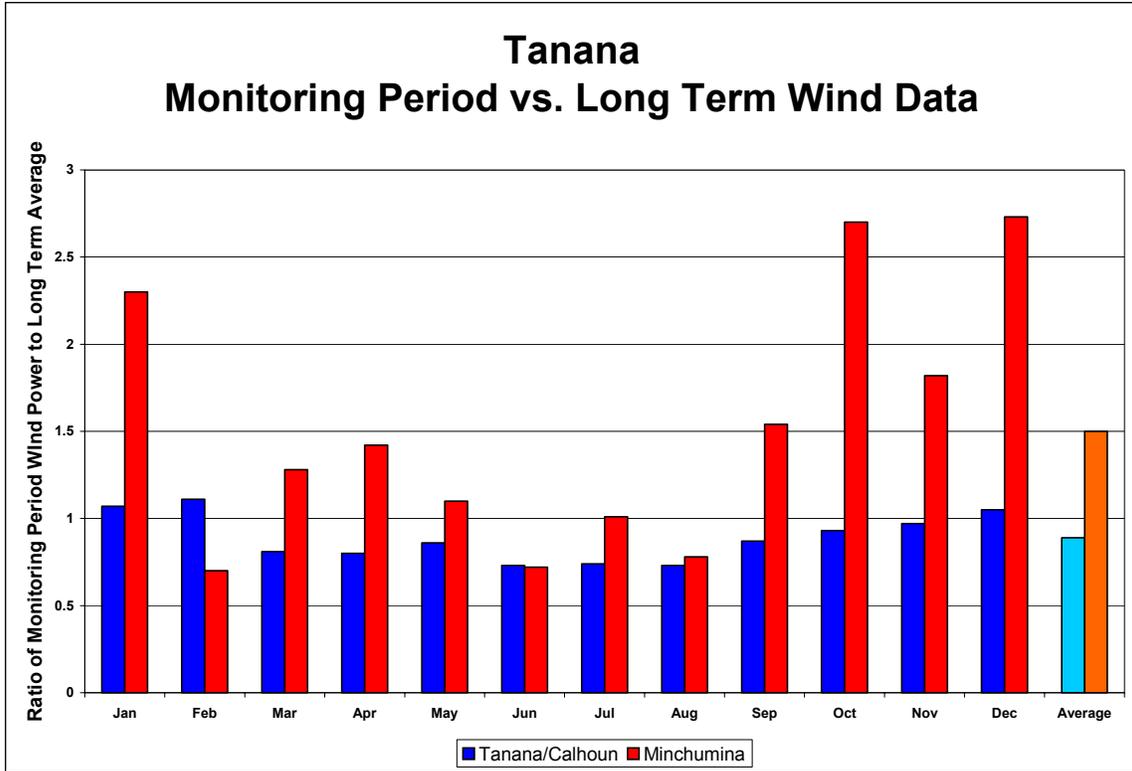


Figure 6: Long term versus monitoring period wind data for nearby sites

Appendix A: Wind Data in Tabular Form

Figure A1: Monthly average and annual average wind power density and wind speed.

Month	Wind Speed (m/s)	Wind Power (W/m ²)
Jan	2.7	34
Feb	3.3	47
Mar	3.3	51
Apr	3.3	47
May	3.6	60
Jun	2.9	35
Jul	2.7	30
Aug	2.7	41
Sep	2.7	29
Oct	2.9	40
Nov	2.6	25
Dec	2.2	31
Average	2.9	39

Figure A2: Average annual daily wind profile.

Hour	Wind Speed (m/s)	Wind Power (W/m ²)
1	2.5	30
2	2.5	30
3	2.5	30
4	2.5	28
5	2.4	26
6	2.4	27
7	2.4	28
8	2.4	28
9	2.5	31
10	2.7	33
11	2.9	43
12	3.1	46
13	3.3	53
14	3.4	54
15	3.5	54
16	3.5	54
17	3.5	54
18	3.5	54
19	3.3	49
20	3.2	45
21	3.2	43
22	3.0	37
23	2.7	32
24	2.6	30

Figure A3: Frequency and Energy by direction

	F%	%Pwr
Calm	18.8	
0	4.6	1.9
22.5	5.6	4.3
45	15.7	29.2
67.5	12.8	22.1
90	5.3	4.7
112.5	1.2	0.4
135	0.9	0.3
167.5	1.0	0.4
180	1.5	0.9
202.5	4.0	6.6
225	10.8	17.9
247.5	4.7	2.7
270	3.4	2.3
292.5	3.4	2.5
315	3.0	2.3
337.5	3.6	1.4

Figure A4: Annual wind and wind energy distribution.

Wind Speed (m/s)	PCTs	PCTp
0	18.8	0.1
1	19.9	1.1
2	18.8	4.7
3	15.4	10.3
4	11.1	15.4
5	7.9	20.2
6	4.7	19.8
7	2.0	12.9
8	0.8	7.7
9	0.3	3.7
10	0.1	2.1
11	0.1	1.8
12	0.0	0.3
13	0.0	0.0
14	0.0	0.0
15	0.0	0.0
16	0.0	0.0
17	0.0	0.0
18	0.0	0.0
19	0.0	0.0
20	0.0	0.0
21	0.0	0.0
22	0.0	0.0
23	0.0	0.0
24	0.0	0.0
25	0.0	0.0

Appendix B: Interpretation of the Wind Data Charts

Introduction

This appendix is a guide to interpreting the wind data charts included in the report. Included is background information and an explanation of the meaning of the data in each chart.

Power Density versus Wind Speed

Wind turbines convert the kinetic energy of moving air into useful mechanical or electrical energy. The power of a column of moving air is given by the equation below.

$$P = 0.5\rho Av^3 \quad \text{(Equation B - 1)}$$

Where

P	=	power in a column of air (watts)
ρ	=	density of air (kg/m^3) (Roughly $\sim 1 \text{ kg/m}^3$)
A	=	cross sectional area of the column of air (m^2)
v	=	velocity of the air (m/s)

Thus the power a wind turbine can extract from the wind is proportional to the cross sectional area of the rotor, the density of the air, and the cube of the wind velocity. At a given location the air density typically doesn't change by more than 10%. Therefore the big variable is the wind speed. Annual average wind turbine production is very sensitive to the annual average wind speed.

A wind turbine cannot extract all the energy from the air stream moving past it. A wind turbine's extraction efficiency typically varies with wind speed. In their range of maximum conversion efficiency most of today's wind turbines extract about 30% - 40 % of the wind's energy.

Power density is simply the power divided by the cross sectional area. Power density is given in units of watts per meter squared. (watts/m^2)

$$\text{Power Density} = 0.5\rho v^3 \quad \text{(Equation B - 2)}$$

The cubic dependence of wind power density upon velocity underscores the importance of accurately characterizing the wind at a given location. A small uncertainty in wind speed translates to a large uncertainty in wind turbine power production. For example a 5% uncertainty in wind speed leads to a 15% uncertainty in power output. The cubic relationship also makes it more difficult to predict the long term performance of a wind turbine. More information is needed than simply the average wind speed. For example, imagine a location where the wind speed is a constant five meters per second. The average power density of a column of air with a 1m^2 cross section is then $0.5 * 1.0 \text{ kg/m}^3 * 1.0 \text{ m}^2 * 5 \text{ (m/s)}^3 = 62.5 \text{ watts}$. Over a year the total energy of that column would be 547.5 kWh. Now imagine a location where half the time the wind speed is 3 m/s and the other half the time the wind speed is 7 m/s. The average wind speed is still 5 m/s but the average power density is now $0.5 * 1.0 * 1.0 * (3^3 + 7^3) / 2 = 92.5 \text{ watts}$. This leads to an annual energy of 810 kWh.

Power density is listed in many of the graphs below because power density gives a better indication of wind turbine production than does wind speed alone. As can be seen from the graph titled "Speed and Power by Month," power density correlates to wind speed, but doesn't follow wind speed exactly.

Wind Speeds/Wind Directions

These first plots simply show the wind speed and direction for the monitoring period. Good data is shown with a solid line. Bad data is shown with a dotted line.

Speed and Power by Month

This graph gives the average wind speed and average power density for each month. This shows how the wind resource is distributed throughout the year.

Observations by Month

This graph shows the number of observations for each month. The greater the number of observations, the greater the probability that the data is close to the long-term average resource.

Speed and Power by Hour

The top graph shows how the wind speeds and power densities are distributed by time of day over the whole year. The other 12 graphs show the same thing for each month. On top of each graph is an average wind speed and power density for the period in question.

Frequency and Speed by Direction

These graphs show how the winds are distributed by direction. The solid line shows the fraction of time that the wind comes from a particular direction. The dotted line shows the average wind speed of the winds coming from a particular direction. Above each graph the fraction of time that the wind is calm (below 1.0 m/s) is given. These graphs indicate the directions from which the strongest winds come. Special care should be taken to ensure the wind turbines have good exposure to winds from these directions.

Frequency of Speed and Percent of Power by Speed

These graphs show the distribution of wind speeds and power densities. The solid line indicates the fraction of time that the wind has a particular velocity. The solid line indicates the fraction of the total wind power contributed by winds at each wind speed.

Appendix C: Wind Data Graphs

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 Y:\5000\shared\Anemometer_Loan_Programs\Completed_Sites\Native American\Tanana - AK\Wind Data\Tanana 011206.csv
 Y:\5000\shared\Anemometer_Loan_Programs\Completed_Sites\Native American\Tanana - AK\Wind Data\Tanana 020227.csv

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Meteo data report, height: 20.0 m

Name of meteo object: Tanana

Data from: 09/20/2001 3:40 PM Data to: 10/13/2002 2:50 AM Observations: 55167 Observations per day: 144 Recovery rate: 99%

day	09/01	10/01	11/01	12/01	01/02	02/02	03/02	04/02	05/02	06/02	07/02	08/02	09/02	10/02
1		144	(142)	(143)	144	144	(143)	(140)	144	(133)	(141)	(126)	(143)	(132)
2		144	(122)	(127)	(135)	144	(120)	(142)	(140)	(142)	144	(122)	(126)	(131)
3		144	(139)	(135)	(125)	144	(143)	(139)	(142)	(141)	144	(103)	(123)	(140)
4		144	(135)	(100)	(134)	144	(113)	(141)	144	(138)	(140)	(110)	(143)	(133)
5		(137)	(133)	(133)	144	144	(143)	(141)	144	(143)	(133)	(139)	(143)	(134)
6		(139)	144	(143)	(143)	(143)	(141)	(143)	(142)	(135)	(142)	(141)	(127)	(132)
7		(137)	(142)	(139)	(143)	(140)	144	(143)	144	(142)	(136)	(134)	(131)	(142)
8		144	(135)	(129)	(138)	(140)	144	(141)	144	(138)	(141)	(141)	(143)	144
9		(140)	144	144	144	(141)	144	144	144	(143)	(137)	(140)	(133)	144
10		(139)	(139)	144	144	144	144	144	(138)	144	(130)	144	144	(137)
11		144	144	144	144	144	(143)	(143)	144	(136)	(138)	(135)	144	144
12		(143)	(138)	(140)	(130)	(142)	144	(135)	(126)	(135)	(131)	(140)	144	144
13		144	144	(104)	144	144	144	144	144	(136)	144	(140)	144	144
14		144	144	(112)	144	144	144	(141)	144	144	(140)	(138)	144	
15		(139)	(18)	(130)	(143)	(141)	144	(143)	(138)	(133)	(139)	(141)	(142)	
16		144	(0)	(124)	(143)	144	144	144	(142)	(136)	(105)	144	(143)	
17		(143)	(0)	(141)	144	(137)	(143)	144	(143)	(127)	(131)	144	(136)	
18		(137)	(0)	(135)	(131)	(122)	144	144	(134)	(140)	(131)	(143)	144	
19		144	(20)	(79)	(68)	(125)	(130)	(142)	(141)	(142)	144	(141)	144	
20	(45)	144	(143)	144	(125)	(130)	(137)	144	144	(142)	(134)	(140)	(138)	
21	(100)	144	144	144	(128)	(135)	(134)	144	144	144	(131)	(143)	(131)	
22	(139)	(139)	144	(141)	(143)	144	(138)	144	144	144	(136)	144	144	
23	144	(123)	144	(135)	144	144	144	(141)	(140)	(140)	(138)	(143)	(143)	
24	(138)	(125)	(136)	(74)	(142)	144	144	(141)	(138)	144	(138)	(129)	(137)	
25	(104)	(90)	(130)	(142)	(114)	144	(143)	(141)	(137)	(139)	144	(140)	(142)	
26	(110)	(127)	144	144	(95)	144	(141)	144	(143)	(128)	144	(124)	144	
27	(141)	144	144	(142)	(141)	144	144	(143)	144	(141)	(134)	(92)	144	
28	(141)	(141)	144	(135)	(126)	144	144	(143)	144	(131)	(137)	(121)	144	
29	(127)	(135)	144	144	(139)		(141)	(143)	144	(136)	(138)	(117)	144	
30	(143)	(135)	144	(141)	(128)		(138)	(135)	144	(142)	(131)	(135)	144	
31		144		144	(124)		(138)		(128)		(131)	(130)		
%	(89)	(96)	(82)	(91)	(93)	(98)	(97)	(99)	(98)	(96)	(95)	(92)	(97)	(96)

Project:
Tanana

Description:
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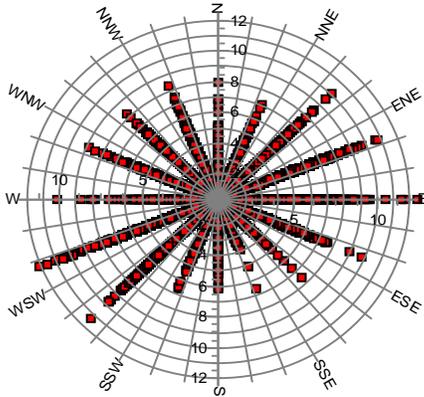
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Meteo data report, height: 20.0 m

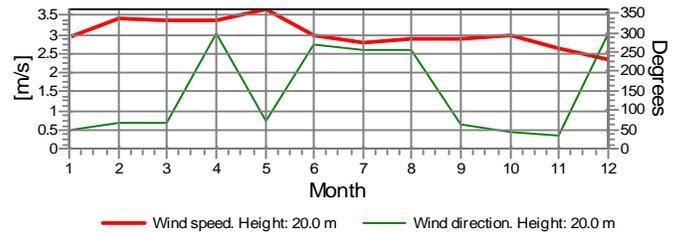
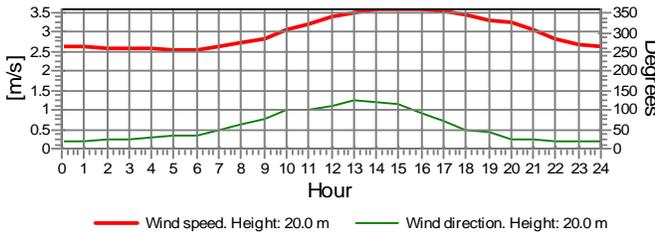
Name of meteo object: Tanana



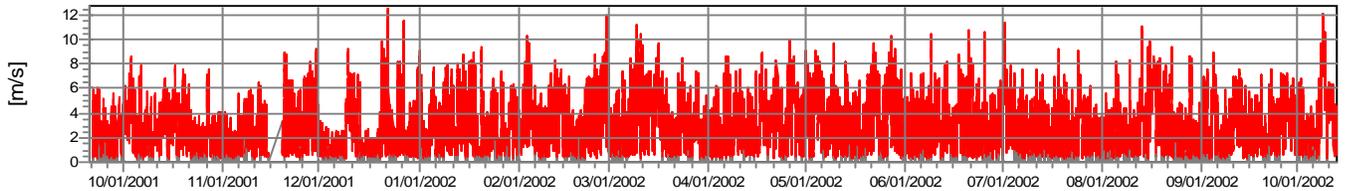
Monthly mean values of wind speed in m/s

Month	2001	2002	mean	mean of months
Jan	3.0	3.0	3.0	3.0
Feb	3.4	3.4	3.4	3.4
Mar	3.4	3.4	3.4	3.4
Apr	3.4	3.4	3.4	3.4
May	3.7	3.7	3.7	3.7
Jun	3.0	3.0	3.0	3.0
Jul	2.8	2.8	2.8	2.8
Aug	2.9	2.9	2.9	2.9
Sep	2.2	3.1	2.9	2.6
Oct	2.7	3.6	3.0	3.2
Nov	2.7	2.7	2.7	2.7
Dec	2.3	2.3	2.3	2.3
mean, all data	2.5	3.2	3.0	
mean of months	2.5	3.2		3.0

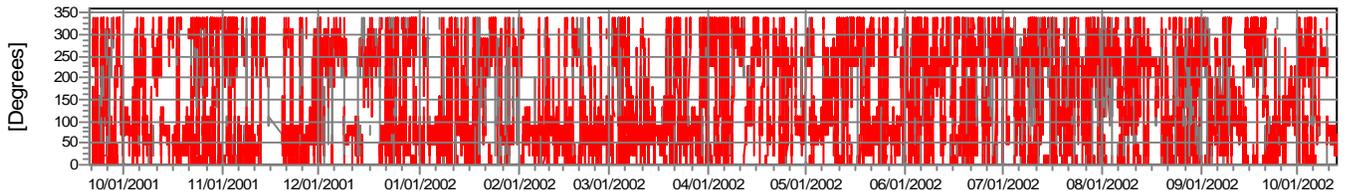
Wind speed [m/s]



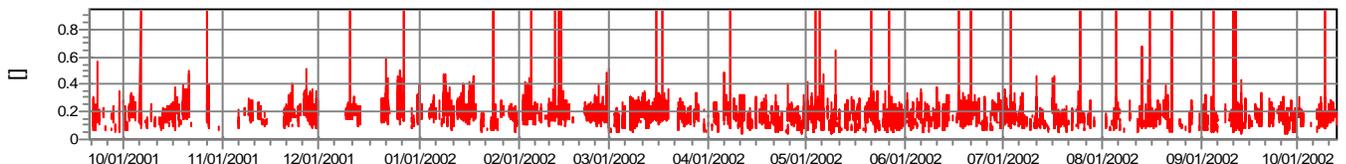
Wind speed



Wind direction



Turbulence intensity
V>4.0 m/s



Project:

Tanana

Description:

Data from file(s)
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Meteo data report, height: 20.0 m

Name of meteo object: Tanana

Frequency

Wind speed m/s	Sum	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW
0.00 - 0.49	1,946	123	109	241	95	90	175	98	120	342	201	128	224
0.50 - 1.49	11,644	802	752	1,496	675	702	754	326	440	2,097	1,472	806	1,322
1.50 - 2.49	10,584	774	872	1,958	973	760	446	173	240	1,826	904	617	1,041
2.50 - 3.49	9,642	524	879	2,431	1,472	721	246	138	222	1,442	451	416	700
3.50 - 4.49	7,360	165	306	2,350	1,476	500	74	56	121	1,292	214	240	566
4.50 - 5.49	5,066	45	83	1,850	1,187	277	24	44	48	940	133	114	321
5.50 - 6.49	3,509	20	15	1,280	909	205	13	5	21	739	79	75	148
6.50 - 7.49	1,766	15	10	674	417	46	6	2	6	463	18	41	68
7.50 - 8.49	694	6	1	236	164	15	3	0	8	206	18	10	27
8.50 - 9.49	284	1	0	91	65	4	1	0	0	107	11	2	2
9.50 - 10.49	106	0	0	25	15	2	0	0	0	57	5	2	0
10.50 - 11.49	56	0	0	10	10	1	0	0	0	34	1	0	0
11.50 - 12.49	20	0	0	2	4	0	0	0	0	14	0	0	0
12.50 - 13.49	1	0	0	1	0	0	0	0	0	0	0	0	0
Sum	52,678	2,475	3,027	12,645	7,462	3,323	1,742	842	1,226	9,559	3,507	2,451	4,419

Turbulence

Wind speed	Sum	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW
0.00 - 0.49	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.50 - 1.49	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.50 - 2.49	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.50 - 3.49	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3.50 - 4.49	0.181	0.177	0.132	0.216	0.176	0.114	0.206	0.201	0.174	0.142	0.213	0.190	0.199
4.50 - 5.49	0.180	0.187	0.148	0.212	0.172	0.109	0.185	0.173	0.189	0.143	0.216	0.181	0.193
5.50 - 6.49	0.181	0.217	0.182	0.207	0.174	0.111	0.204	0.201	0.174	0.151	0.222	0.225	0.205
6.50 - 7.49	0.171	0.219	0.167	0.197	0.159	0.098	0.168	0.220	0.173	0.140	0.203	0.190	0.201
7.50 - 8.49	0.167	0.204	0.213	0.194	0.155	0.093	0.149		0.176	0.141	0.182	0.211	0.193
8.50 - 9.49	0.158	0.181		0.191	0.149	0.098	0.176			0.139	0.115	0.203	0.231
9.50 - 10.49	0.149			0.182	0.135	0.115				0.139	0.128	0.195	
10.50 - 11.49	0.146			0.174	0.179	0.103				0.131	0.091		
11.50 - 12.49	0.126			0.144	0.143					0.119			
12.50 - 13.49	0.169			0.169									
Sum	0.178	0.191	0.145	0.208	0.171	0.110	0.193	0.185	0.180	0.144	0.209	0.196	0.198

Project:
Tanana

Description:
Data from file(s)
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Y:\5000\shared\Anemometer_Loan_Programs\Completed_Sites\Native American\Tanana - AK\Wind Data\Tanana 011119.csv
Y:\5000\shared\Anemometer_Loan_Programs\Completed_Sites\Native American\Tanana - AK\Wind Data\Tanana 011206.csv
Y:\5000\shared\Anemometer_Loan_Programs\Completed_Sites\Native American\Tanana - AK\Wind Data\Tanana 020227.csv

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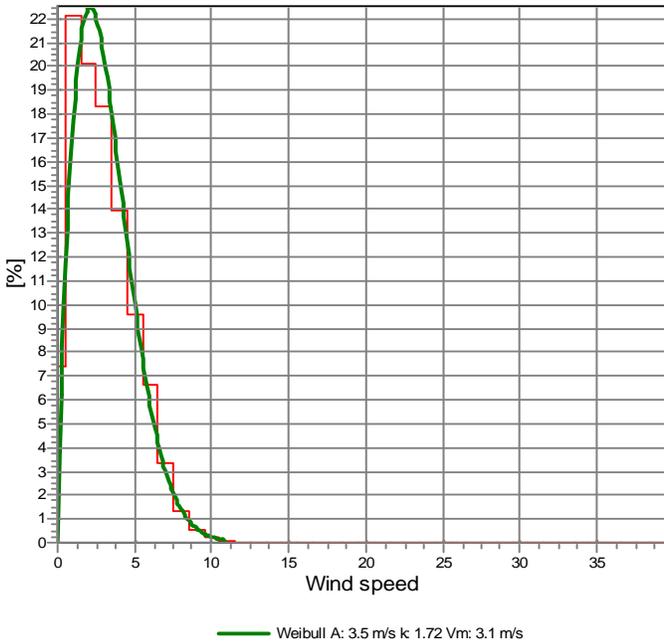
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US-GOLDEN, CO 80401
+1 303-384-7027

Calculated:
07/24/2006 9:48 AM/

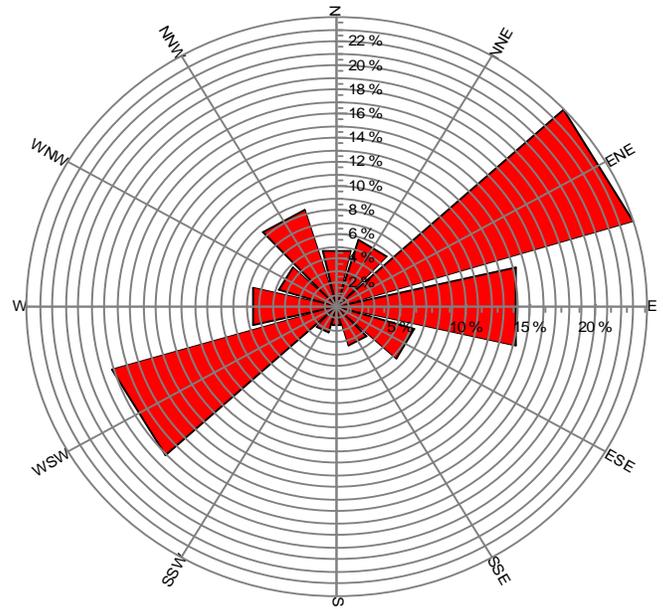
Meteo data report, height: 20.0 m

Name of meteo object: Tanana

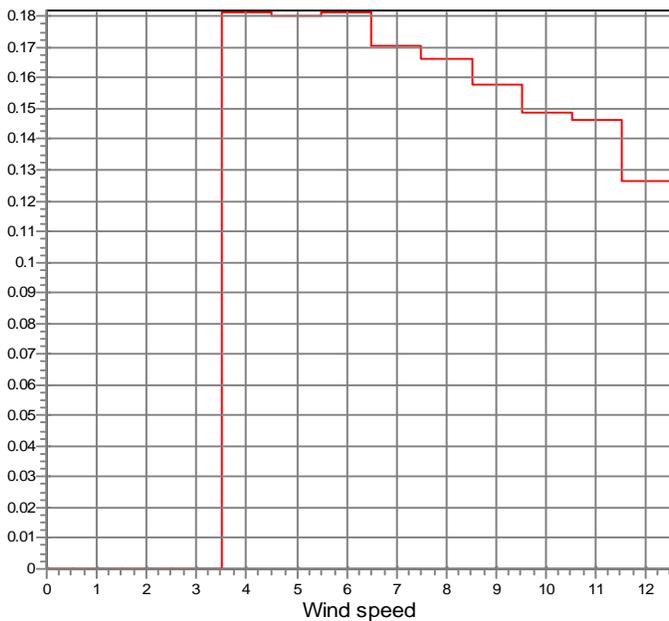
Frequency



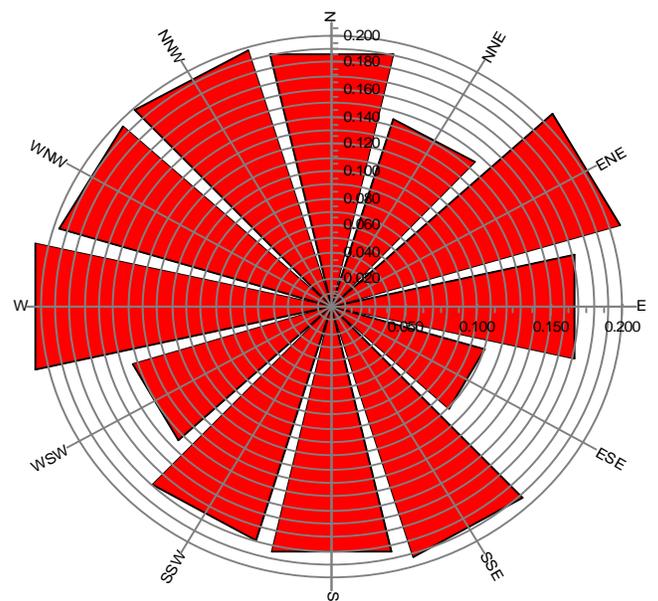
Frequency



Turbulence
V>4.0 m/s



Turbulence
V>4.0 m/s



Project: **Tanana**
 Description: Data from file(s)
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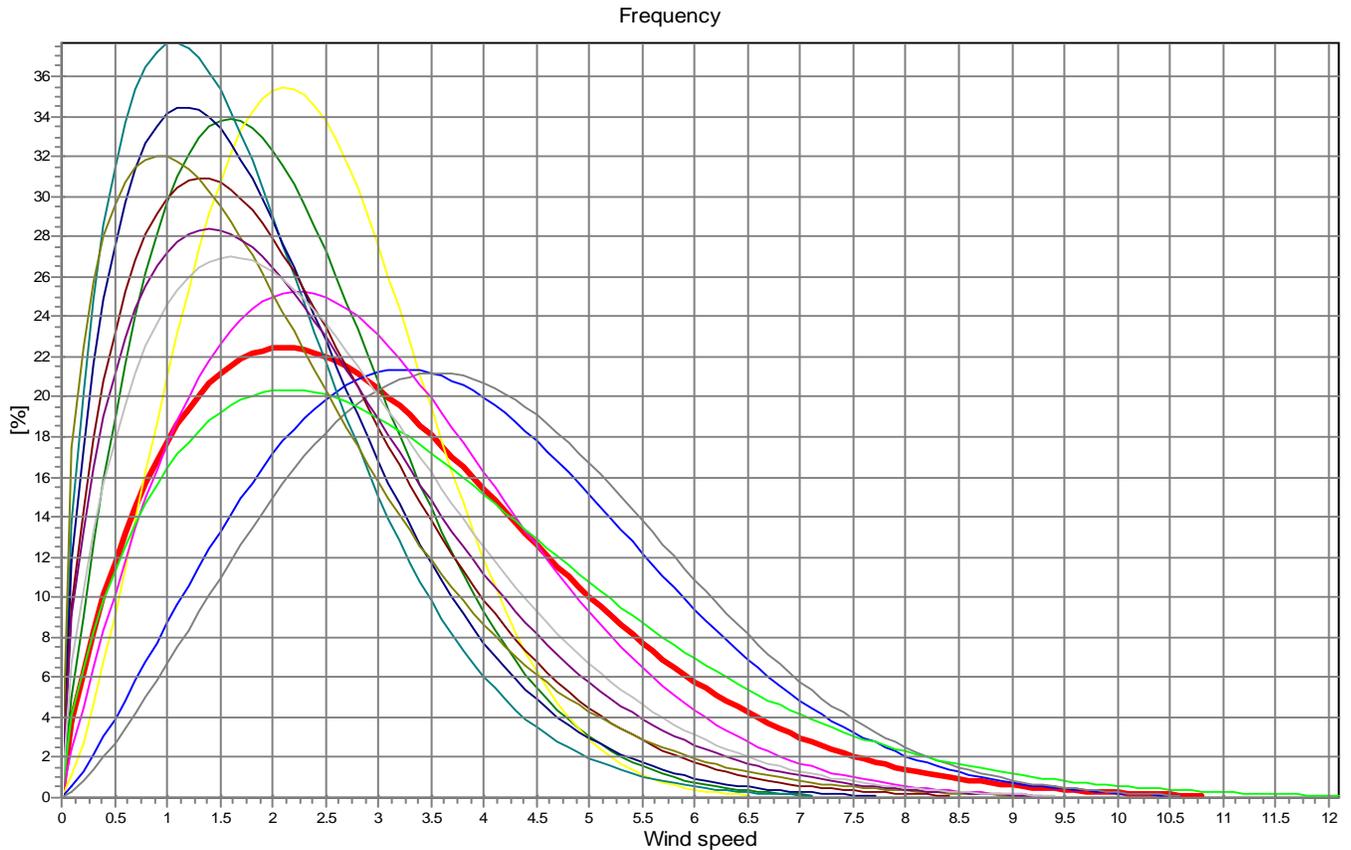
Meteo data report, height: 20.0 m

Name of meteo object: Tanana

Weibull Data

k-parameter correction: 0.0080/m

Sector	A- parameter [m/s]	Mean wind speed [m/s]	k- parameter	Frequency	Frequency [%]	Wind shear
0-N	2.42	2.15	1.856	4.70	4.7	0.00
1-NNE	2.69	2.39	2.327	5.75	5.7	0.00
2-ENE	4.28	3.79	2.192	24.00	24.0	0.00
3-E	4.52	4.01	2.336	14.17	14.2	0.00
4-ESE	3.30	2.93	1.910	6.31	6.3	0.00
5-SSE	2.01	1.80	1.579	3.31	3.3	0.00
6-S	2.20	1.97	1.583	1.60	1.6	0.00
7-SSW	2.46	2.21	1.595	2.33	2.3	0.00
8-WSW	3.79	3.39	1.650	18.15	18.1	0.00
9-W	2.29	2.09	1.393	6.66	6.7	0.00
10-WNW	2.66	2.39	1.569	4.65	4.7	0.00
11-NNW	2.85	2.55	1.642	8.39	8.4	0.00
mean	3.50	3.12	1.720	100.00	100.0	0.00



— Total A: 3.5 m/s k: 1.72 Vm: 3.1 m/s
 — N A: 2.4 m/s k: 1.86 Vm: 2.1 m/s
 — NNE A: 2.7 m/s k: 2.33 Vm: 2.4 m/s
 — ENE A: 4.3 m/s k: 2.19 Vm: 3.8 m/s
— E A: 4.5 m/s k: 2.34 Vm: 4.0 m/s
 — ESE A: 3.3 m/s k: 1.91 Vm: 2.9 m/s
 — SSE A: 2.0 m/s k: 1.58 Vm: 1.8 m/s
 — S A: 2.2 m/s k: 1.58 Vm: 2.0 m/s
— SSW A: 2.5 m/s k: 1.60 Vm: 2.2 m/s
 — WSW A: 3.8 m/s k: 1.65 Vm: 3.4 m/s
 — W A: 2.3 m/s k: 1.39 Vm: 2.1 m/s
 — WNW A: 2.7 m/s k: 1.57 Vm: 2.4 m/s
— NNW A: 2.9 m/s k: 1.64 Vm: 2.5 m/s