Haeckel Hill
Thies Clima Ultrasonic Anemometer 2D Analysis

December 19, 2002 to April 30, 2003

Final Report

For
Yukon Energy Corporation
Whitehorse, Yukon

June 5, 2003

by
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Haeckel Hill Thies Clima Ultrasonic Anemometer 2D Analysis December 19, 2002 to April 30, 2003

The purpose of this report is to show how the Thies Clima Ultrasonic Anemometer 2D (Thies Clima 2D) performed under the icing conditions on Haeckel Hill in the Yukon from December 19, 2002 to April 30, 2003. In this report the Thies Clima 2D is compared to the NRG Ice-Free II anemometer (NRG) that was operating on the same site during the monitoring period.

Part 1 of this report describes and summarizes the data for the monitoring period. Part 2 summarizes the data monthly, parameter-by-parameter and is presented in tables and one-page graphs.

Part 1.

Site Description

Data are measured at Yukon Energy's Haeckel Hill Wind installations, just west of the City of Whitehorse at 1,433 metres above sea level. An electrically heated NRG anemometer and wind direction vane are mounted 30 metres above ground level on a monitoring tower located between the two wind turbines. A Thies Clima 2D anemometer, which measures wind direction as well as wind speed, is approximately 4 metres above ground level on a separate mounting attached to an equipment shed, located next to the tower. An ice detector and temperature gauge are installed directly below the Thies Clima 2D, on the same shed. The data are automatically stored on a Campbell Scientific data logger and remotely downloaded to a technician's computer in Yukon Energy's corporate office. All of the equipment is still in place and data are still being collected.

Wind Speed and Direction Summary

The tables and graphs in this section illustrate how the wind speed and wind direction data from the two anemometers compare to each other. Note that the NRG anemometer has an offset of 0.8 m/s which affects the low wind speed readings. Therefore, all readings less than 1 m/s are equated to 0 m/s. Figures 1 to 3 summarize the data monthly, while Figures 4 to 18 are hourly time-series graphs. Icing and temperature summary graphs have been included in this section to help determine when icing events may have affected the wind speed and direction data.

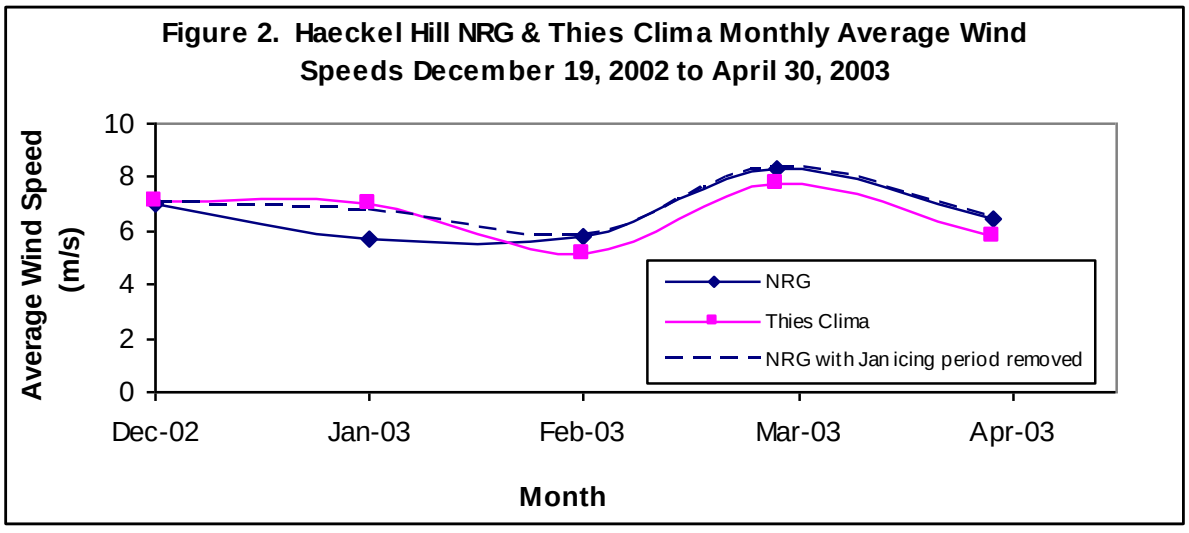
On average, the wind speed readings for the entire period are 6.76 m/s for the Thies Clima 2D and 6.70 m/s for the NRG. As shown in Figure 1, the wind speeds in January do not correlate as well as in the other months, probably because the NRG anemometer was affected by ice for an extended period of approximately seven days early in the month. If all wind speeds with standard deviations equal to zero (probable times when the anemometer was frozen in place) are removed from the NRG data, than the average wind speed for January increases from 5.68 m/s to 6.74 m/s, as reflected by the dashed line in Figure 2. If the period when icing affected the NRG is removed from the correlation analysis than the correlation coefficient for January strengthens from 0.41 to 0.91.

The low correlation values given in Figure 1 for the wind direction readings probably reflect the much greater variation in wind direction readings given by the Thies Clima 2D than the NRG wind vane. The correlation coefficients remain weak when the time step for the correlations is increased from a 10 minute average to an hourly average. However, the hourly graphs of the two wind directions plotted together visually show that over each month, the wind direction readings do correlate well. On average, the winds are from the south to south-southeast.

Figure 1. Monthly Averages

Month	Wind speeds			Wind Directions		
	Thies Clima 2D	NRG	r[1]	Thies Clima 2D	NRG	r
Dec 2002	7.10	7.02	0.80	161.64	176.60	0.37
Jan 2003	7.04	5.68	0.41*	166.89	170.26	0.26
Feb 2003	5.14	5.76	0.98	179.01	181.14	0.17
Mar 2003	7.75	8.35	0.98	217.19	187.71	0.55
Apr 2003	5.75	6.43	0.99	175.26	172.30	0.38
	Wind Speed Standard Deviations			**Wind Direction Standard Deviations**		
	Thies Clima 2D	NRG		Thies Clima 2D	NRG	
Dec 2002	1.03	0.52		21.10	3.35	
Jan 2003	0.96	0.44		16.84	5.40	
Feb 2003	0.68	0.57		28.71	8.53	
Mar 2003	0.91	0.74		35.14	27.43	
Apr 2003	0.84	0.67		26.57	13.81	

* r strengthens to 0.91 when icing data removed.



[1] The Pearson Correlation Coefficient, r, is a dimensionless index that ranges from -1.0 to +1.0, inclusive and reflects the extent of a linear relationship between two data sets. A value of -1 indicates a perfect negative association and a value of +1 indicates a perfect positive correlation. A value of 0 indicates that the two variables are statistically independent.

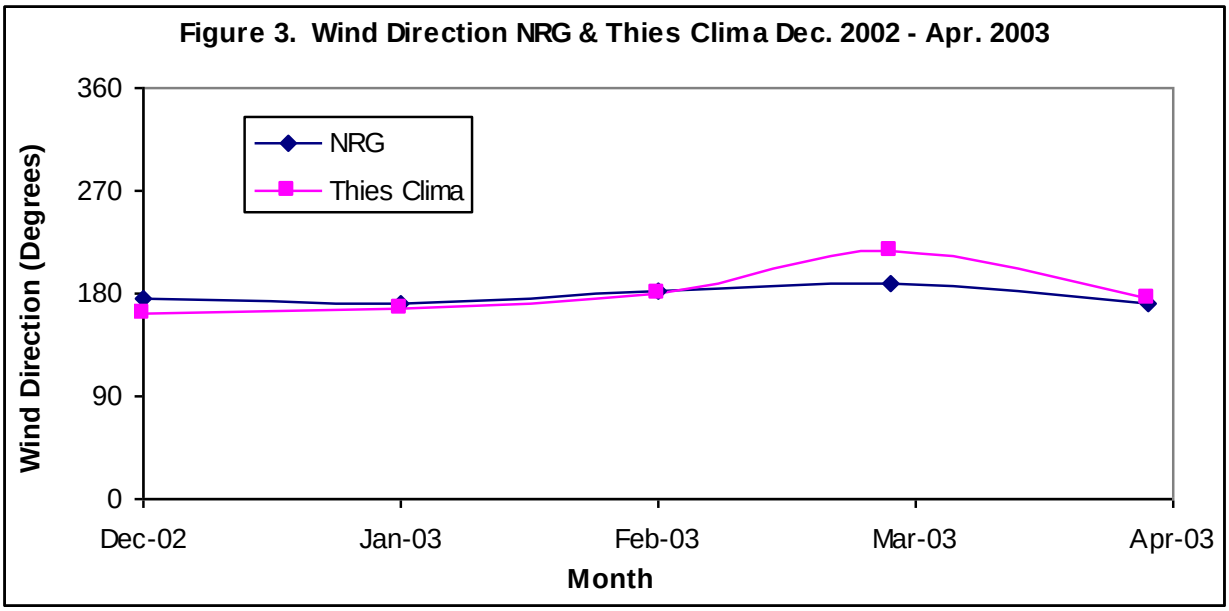


Figure 3. Wind Direction NRG & Thies Clima Dec. 2002 - Apr. 2003
Wind Direction (Degrees)
360
270
180
90
0
NRG
Thies Clima
Dec-02
Jan-03
Feb-03
Mar-03
Apr-03
Month

Figure 4. Haeckel Hill NRG & Thies Clima Average Hourly Wind Speed & Icing December 2002

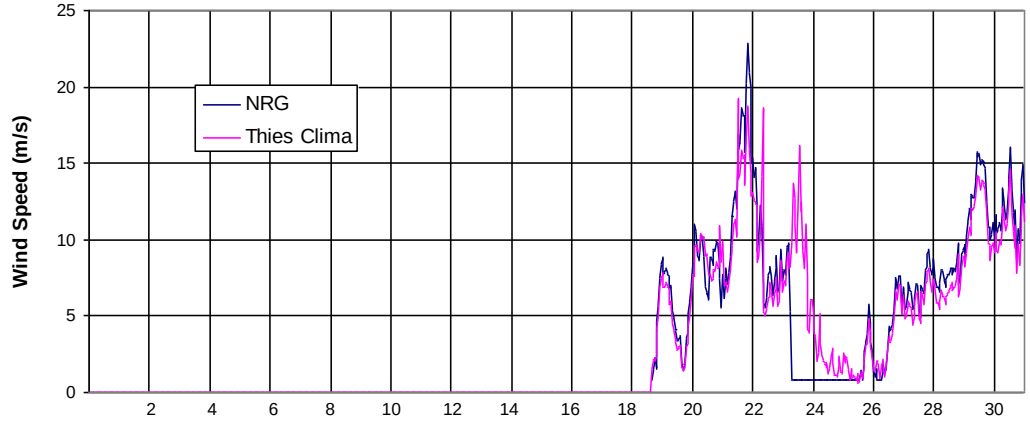


Figure 5. Haeckel Hill NRG & Thies Clima Average Hourly Wind Direction December 2002

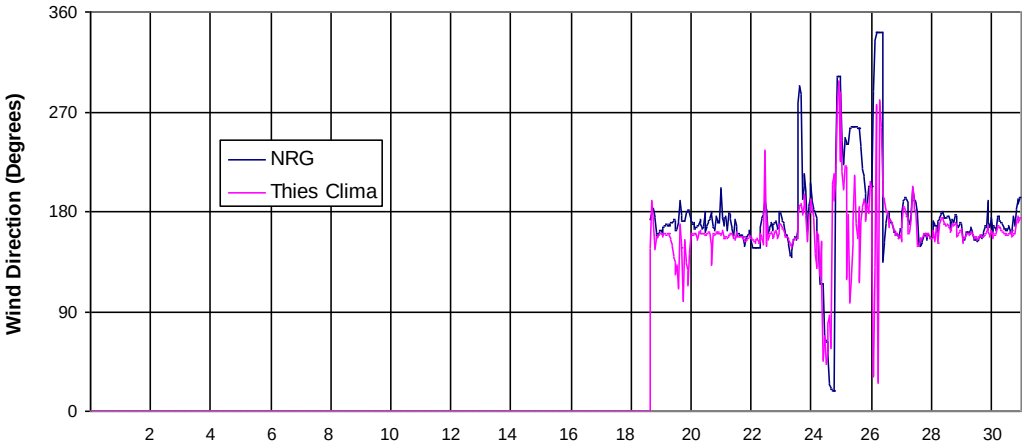


Figure 6. Haeckel Hill Average Hourly Temperature and Icing Severity December 2002

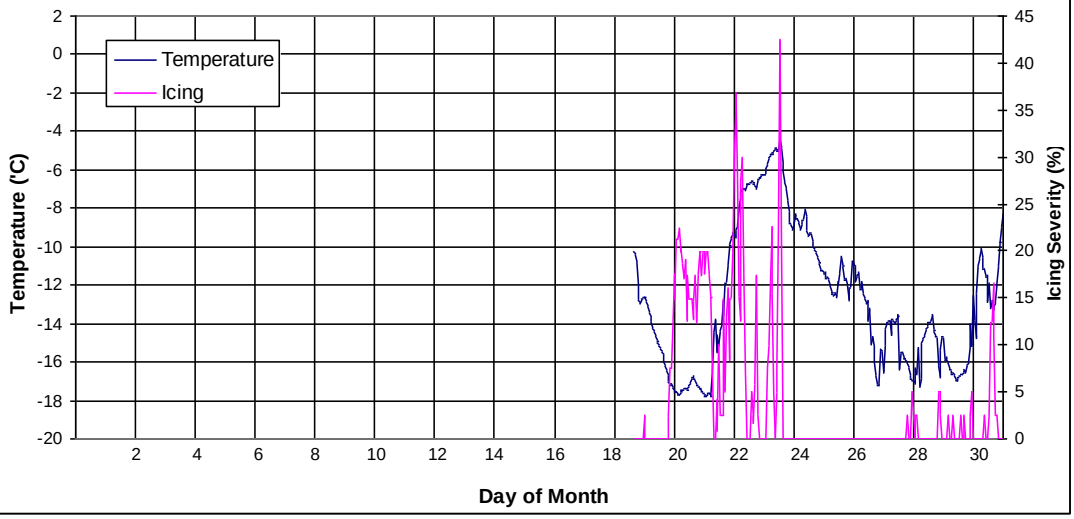


Figure 7. Haeckel Hill NRG & Thies Clima Average Hourly Wind Speed January 2003

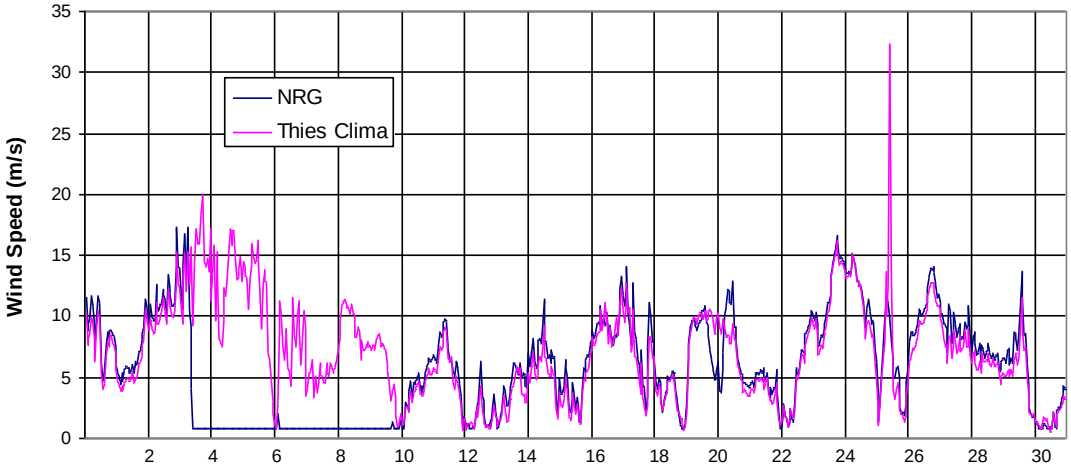


Figure 8. Haeckel Hill NRG & Thies Clima Average Hourly Wind Direction January 2003

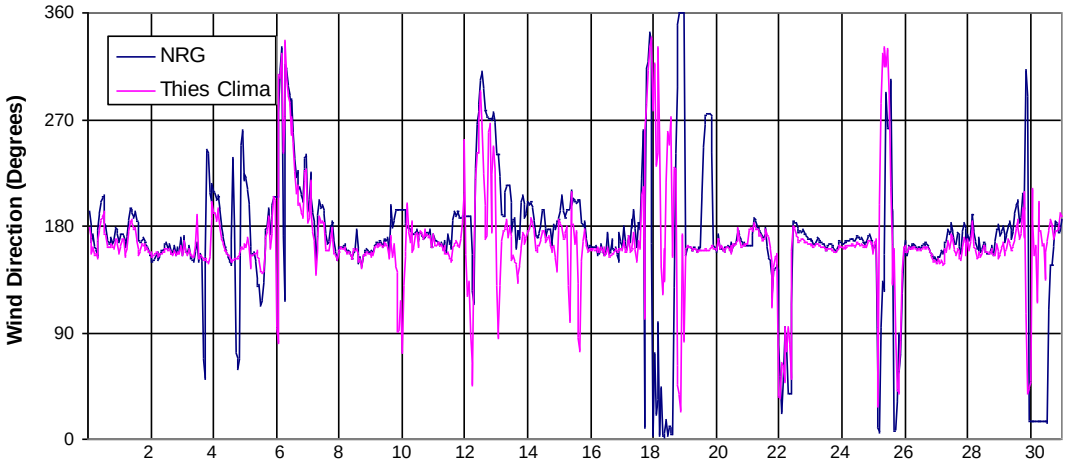


Figure 9. Haeckel Hill Average Hourly Temperature and Icing Severity January 2002

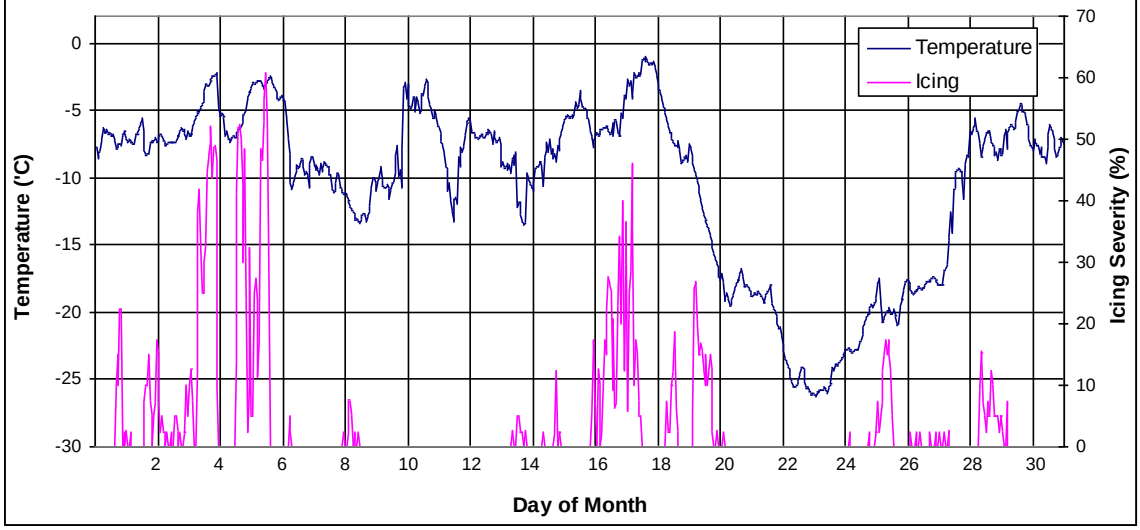


Figure 10. Haeckel Hill NRG & Thies Clima Average Hourly Wind Speed February 2003

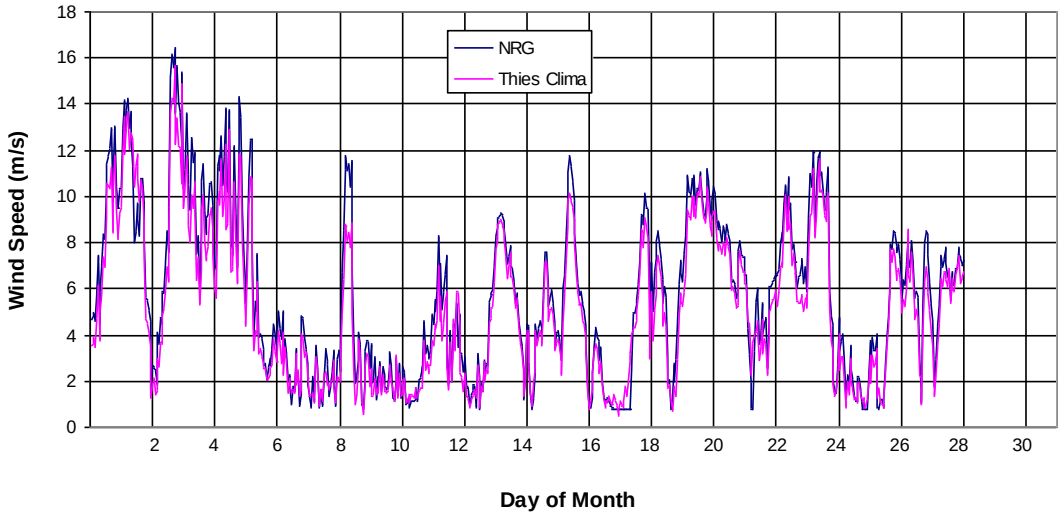


Figure 11. Haeckel Hill NRG & Thies Clima Average Hourly Wind Direction February 2003

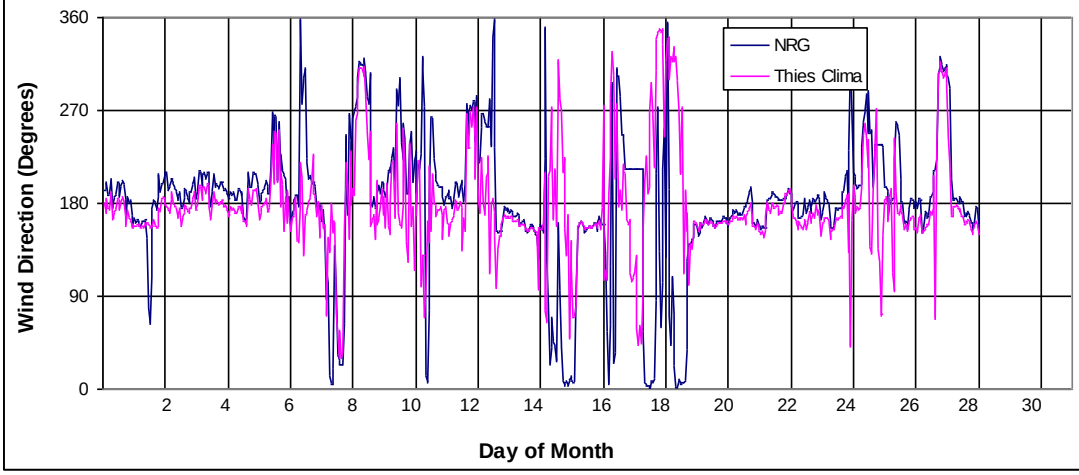


Figure 12. Haeckel Hill Average Hourly Temperature and Icing Severity February 2002

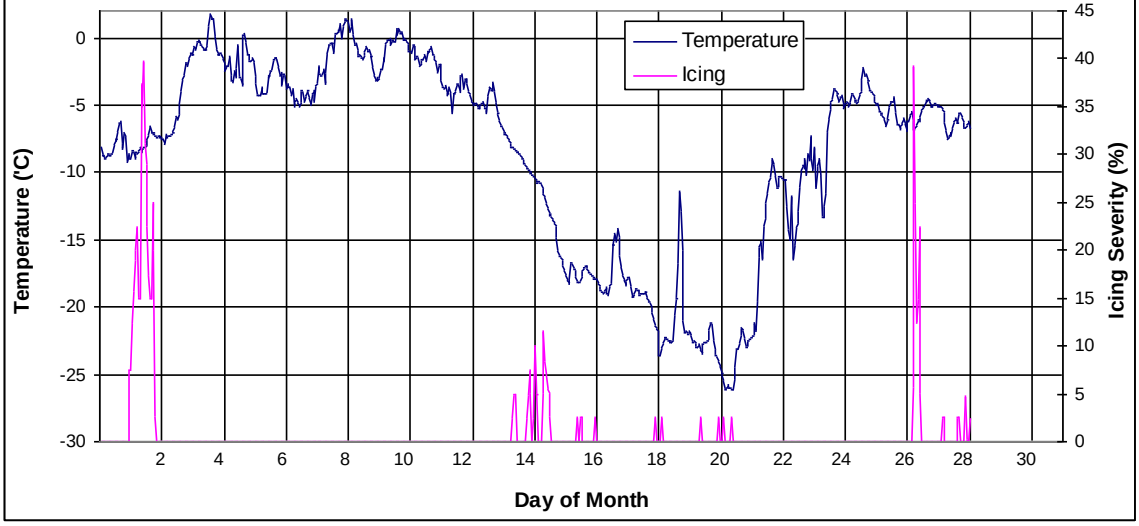


Figure 13. Haeckel Hill NRG & Thies Clima Average Hourly Wind Speed March 2003

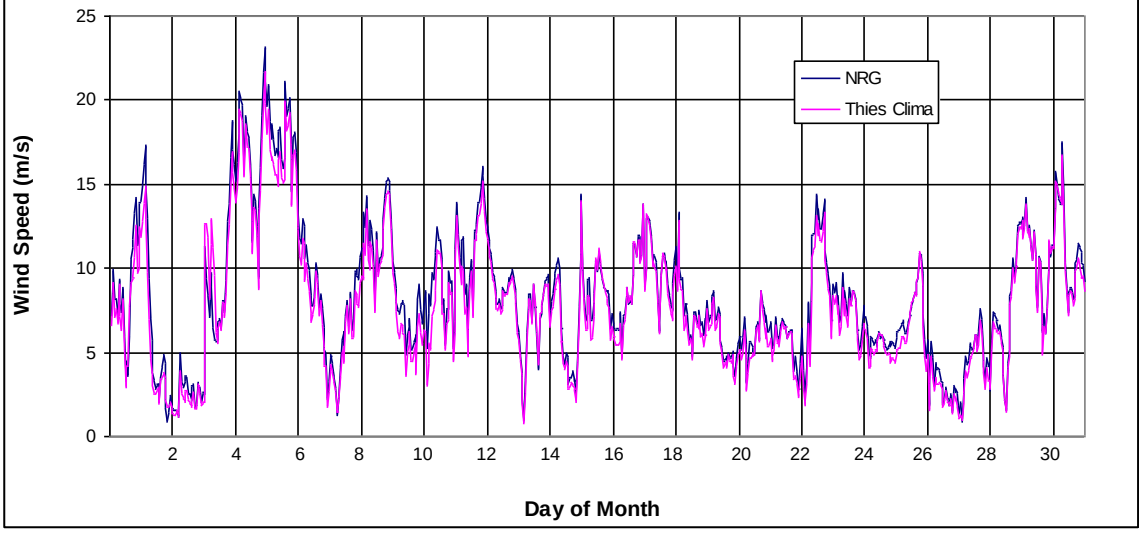


Figure 14. Haeckel Hill NRG & Thies Clima Average Hourly Wind Direction March 2003

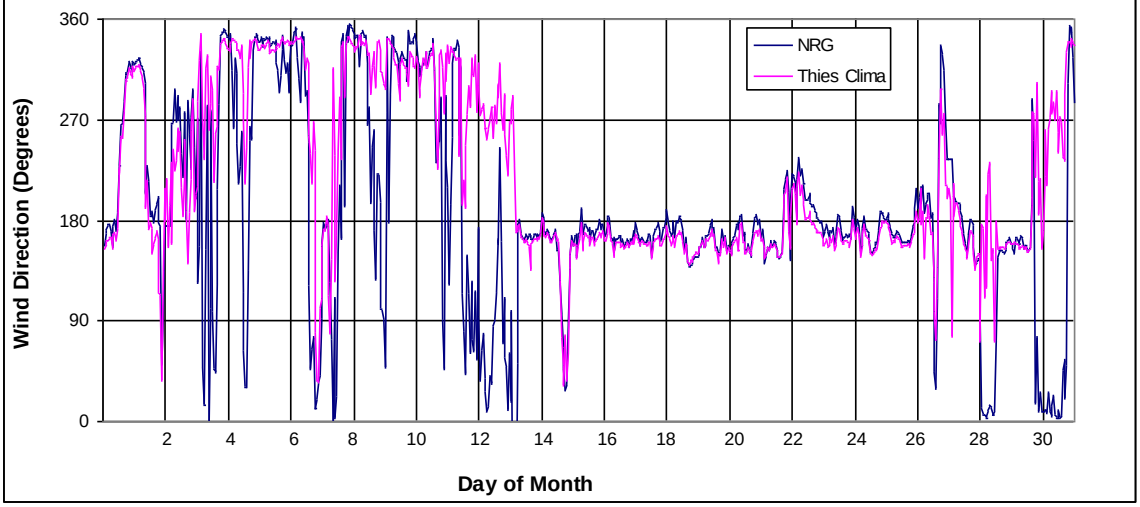


Figure 15. Haeckel Hill Average Hourly Temperature and Icing Severity March 2002

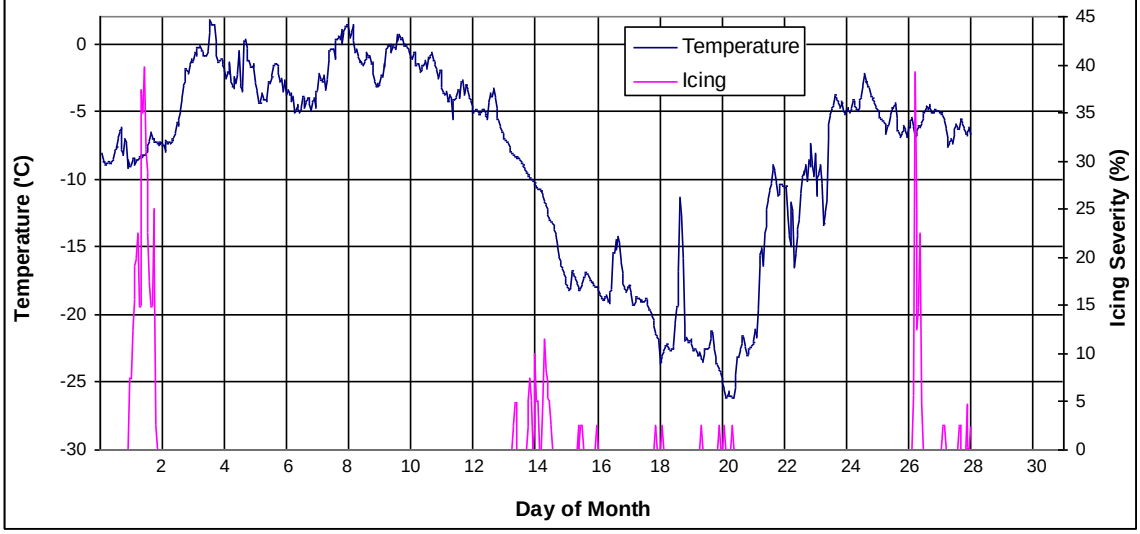


Figure 16. Haeckel Hill NRG & Thies Clima Average Hourly Wind Speed April 2003

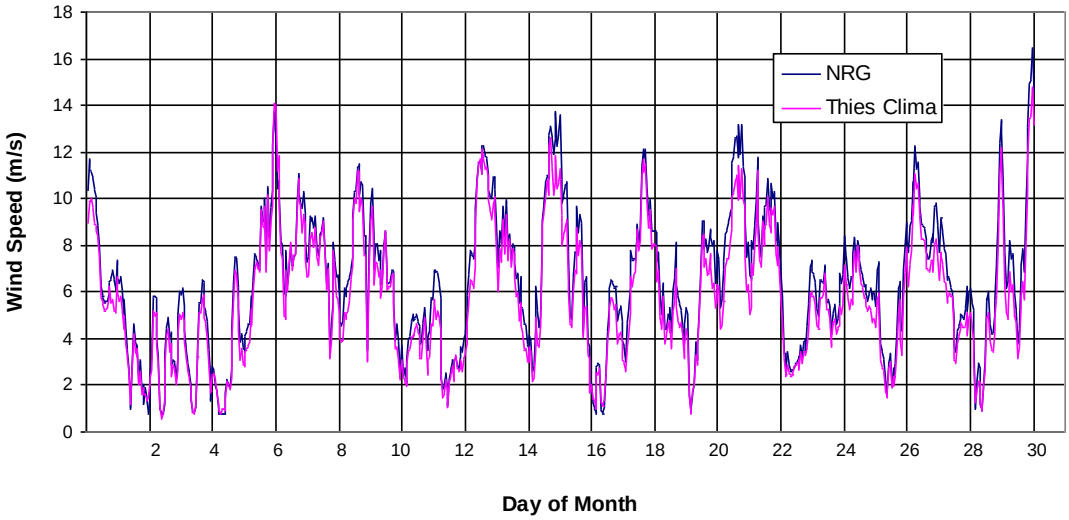


Figure 17. Haeckel Hill NRG & Thies Clima Average Hourly Wind Direction April 2003

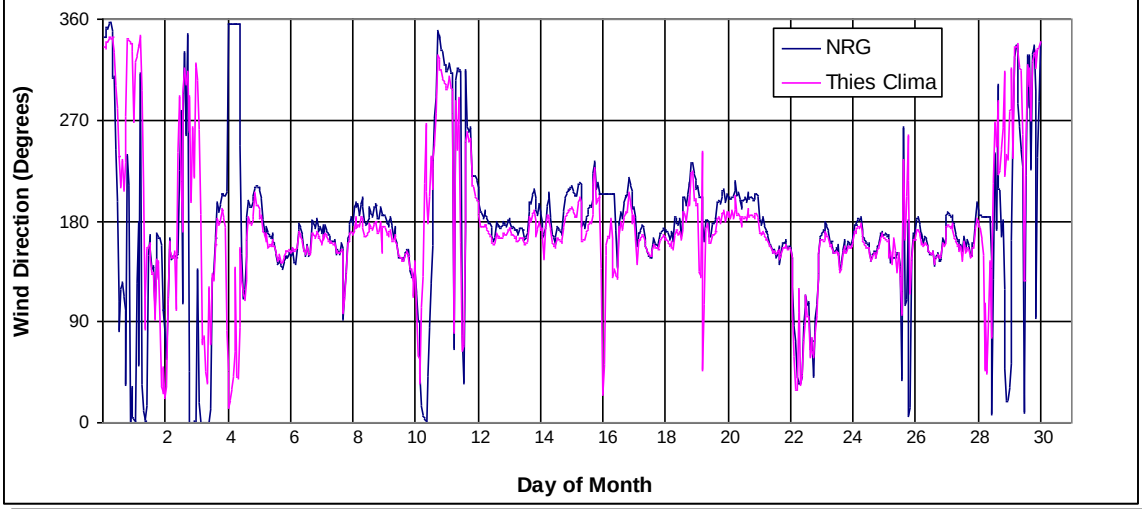
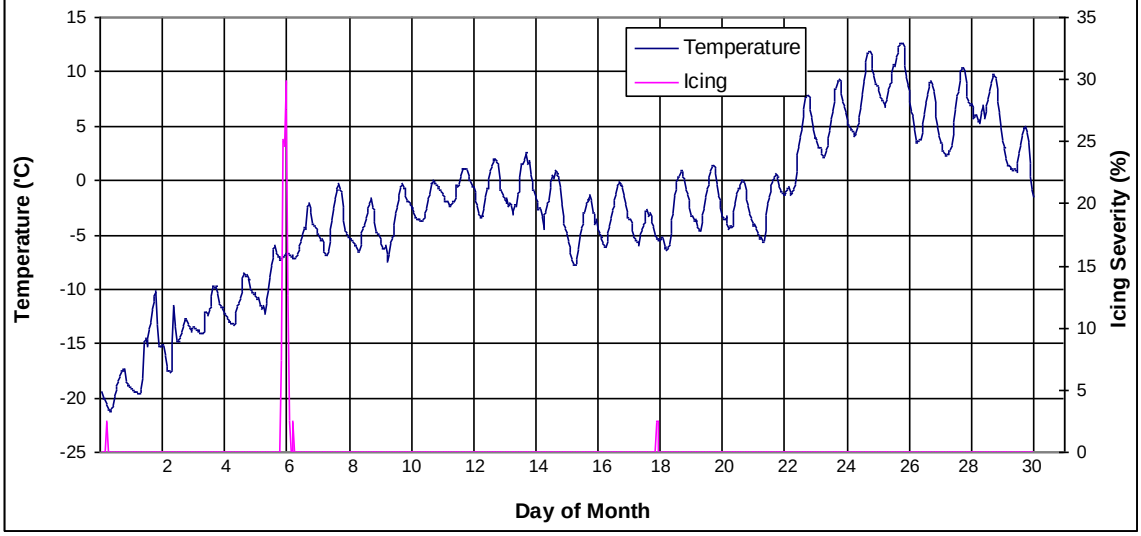


Figure 18. Haeckel Hill Average Hourly Temperature and Icing Severity April 2002



Icing

The December 2002 to April 2003 test of the Thies Clima 2D was encouraging because there was not the same distortion of the wind speed during periods of icing as in the test of the previous version of the instrument in the winter of 2001-2002. However, there was still an increase in the standard deviation of the wind speed and direction during heavy icing events, indicating that there was still some effect of the icing on the data collected. This is most obvious in the January data which is illustrated in Figures 19 and 20 below.

Figure 19. Haeckel Hill Ultransonic Anemometer Standard Deviation of the Wind Speed and Icing January 2003

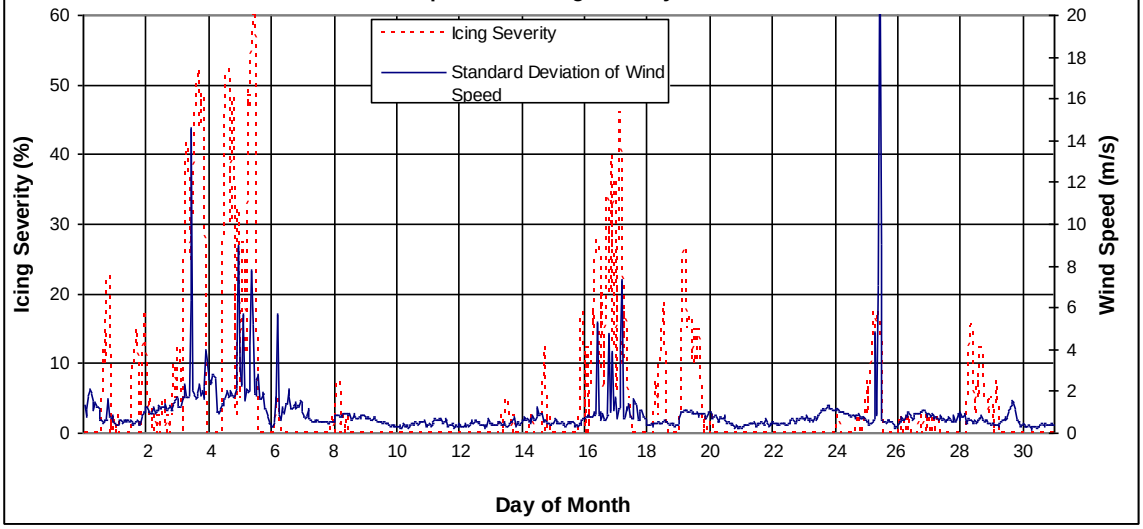
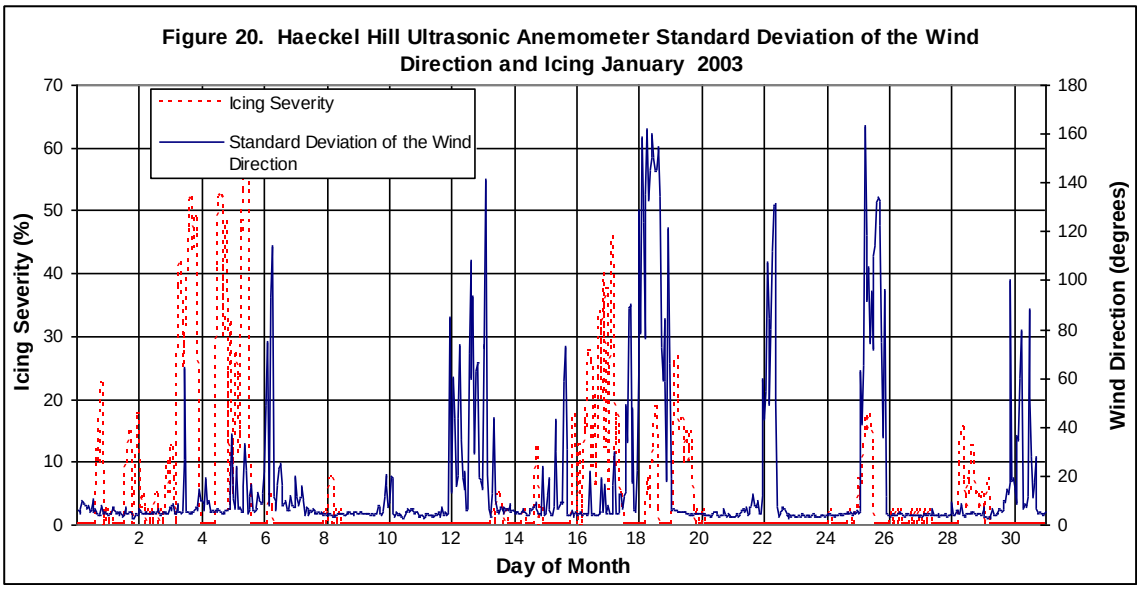


Figure 20. Haeckel Hill Ultrasonic Anemometer Standard Deviation of the Wind Direction and Icing January 2003



The NRG anemometer appeared to be affected by ice, even though it was heated. The December and January data both show extended periods of calm during and just after icing periods. The NRG wind vane also appears to have been affected by ice, but not for such extended periods as the NRG anemometer. Flat NRG wind direction lines on the graphs probably indicated periods when the wind vane was frozen in place.

Icing Summary

The icing detector records icing periods as the percentage of time in the 10 minute sampling period that it operates its de-icing heaters, which are initiated by it detecting ice. The icing detector shows that ice did, or did not occur during a 10 minute sampling period and the proportion of the 10 minute sampling period during which the de-icing heater was operating. This percentage is a measure of the severity of the icing event.

A compilation of the icing data from December 1, 2002 to April 30, 2003 appears below in Figure 21. Figure 22 plots the total numbers of hours of icing for each month from December 1, 2002 to April 30, 2003.

Figure 23 compares the 2001-2002 icing data to the 2002-2003 icing data. Note that there were more hours of icing this winter than last winter, while icing severity was approximately the same. Figures 24 to 28 are hourly time-series graphs comparing icing events for the two winters.

Figure 21. Haeckel Hill Monthly Icing Data Compilation December 1, 2002 to April 30, 2003

Month	# of Ice Free Days	# of Discrete Icing Events*	# of Hours of Icing in Month	Average Time of Icing Event (hrs)	Longest Icing Event (hrs)	Average Severity of Icing Events %	Most Severe Icing Event %
December	11	45	155.17	3.60	33.33	21.80	59.83
January	8	53	132.00	2.49	23.50	23.89	62.83
February	17	20	34.50	1.73	18.00	20.01	45.00
March	19	17	43.33	2.55	18.00	19.90	53.33
April	26	4	6.17	1.54	5.50	22.66	35.00
Period	81	139	371	2.38	33.33	21.65	62.83

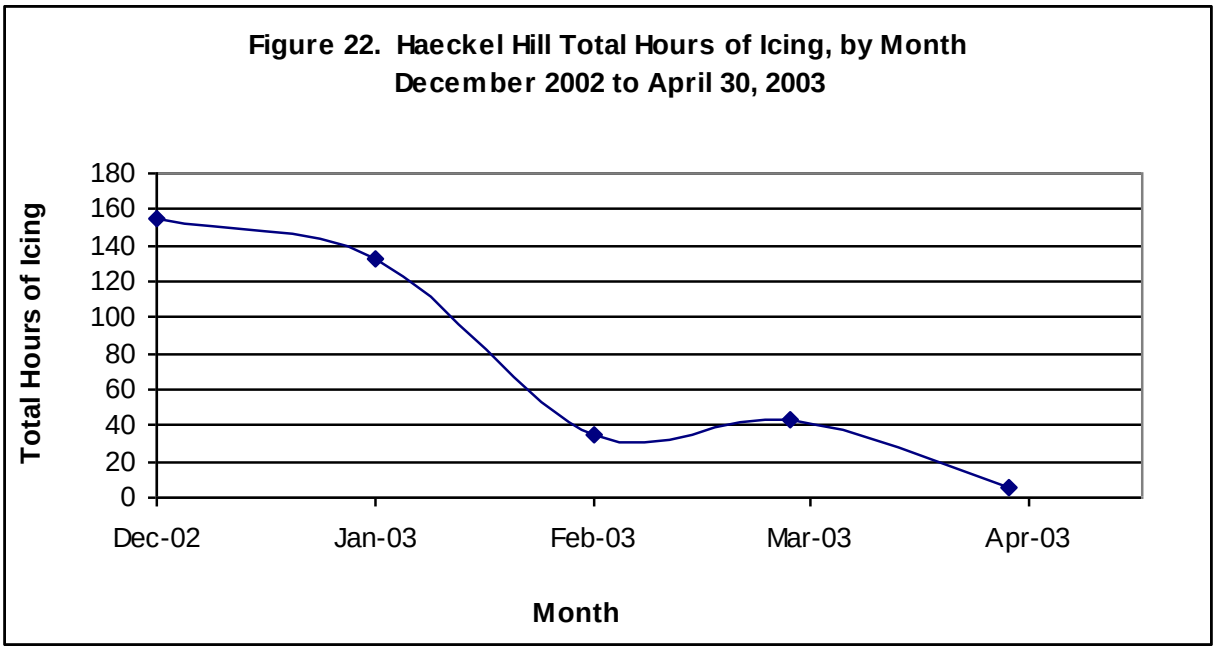
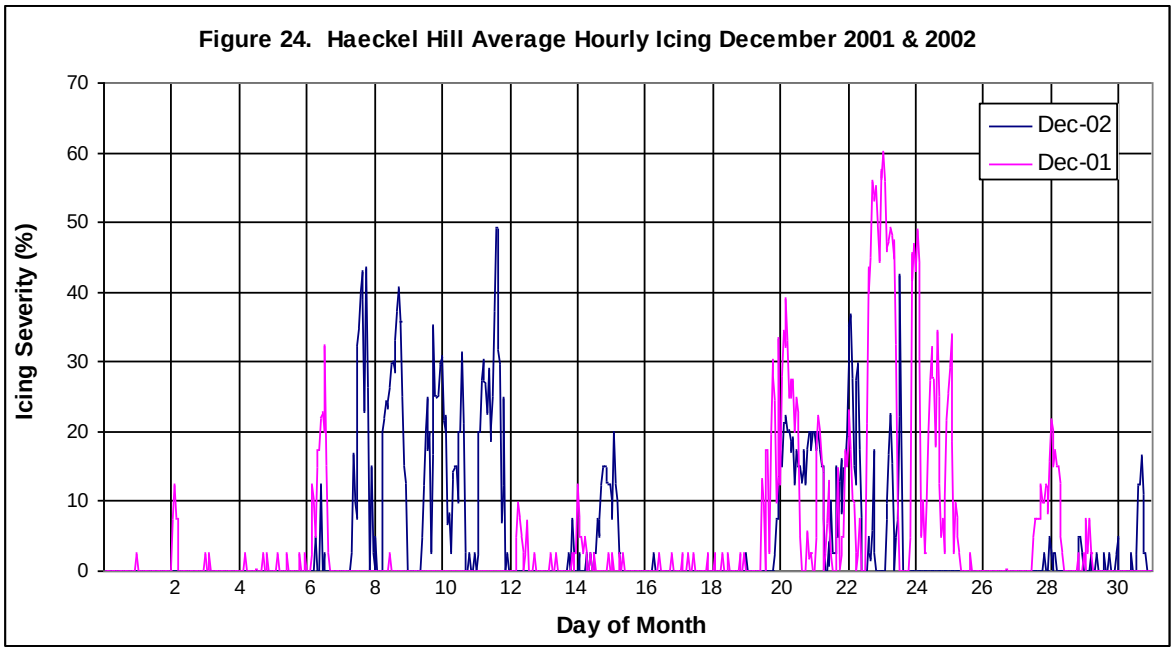
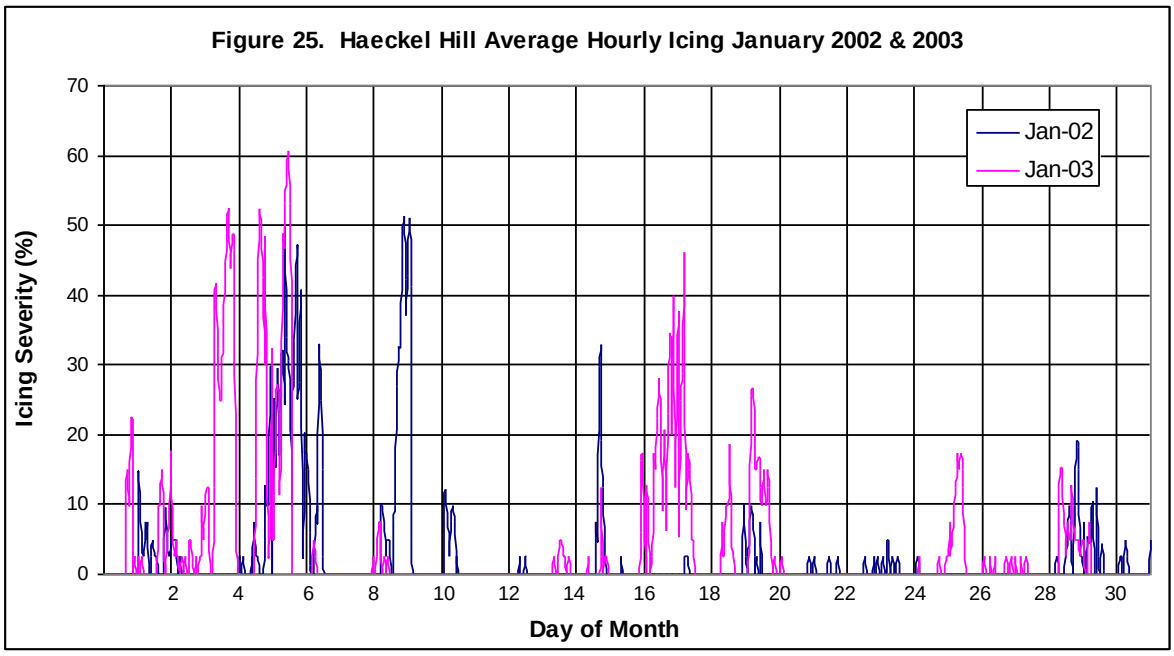


Figure 23. Haeckel Hill Icing Comparison Winter 2001-2002 to Winter 2002-2003				
Month	# of Hours of Icing in Month 2001-2002	# of Hours of Icing in Month 2002-2003	Average Severity of Icing Events (%) 2001-2002	Average Severity of Icing Events (%) 2002-2003
Dec	213.00	155.17	24.98	21.80
Jan	84.50	132.00	22.39	23.89
Feb	47.83	34.50	20.89	20.01
Mar	3.00	43.33	12.45	19.90
Apr	1.50	6.17	11.63	22.66
Total	349.83	371.17	18.47	21.65





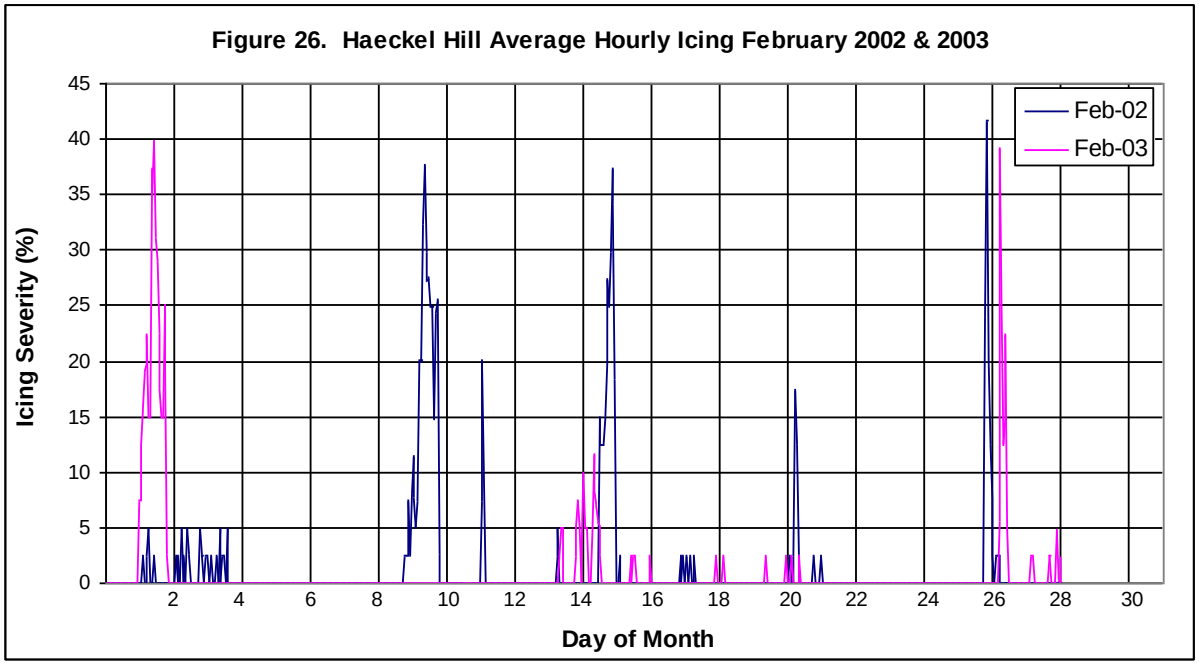


Figure 26. Haeckel Hill Average Hourly Icing February 2002 & 2003
Icing Severity (%)
Day of Month
Feb-02
Feb-03
0
5
10
15
20
25
30
35
40
45
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

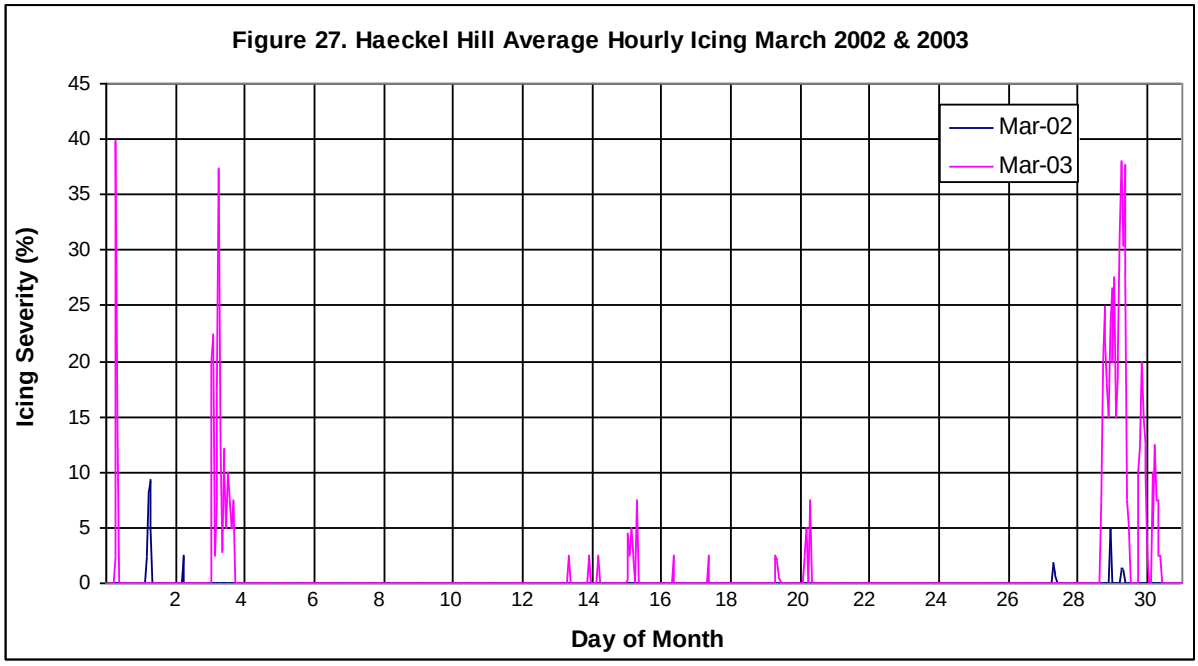


Figure 27. Haeckel Hill Average Hourly Icing March 2002 & 2003
Icing Severity (%)
Day of Month
Mar-02
Mar-03
0
5
10
15
20
25
30
35
40
45
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

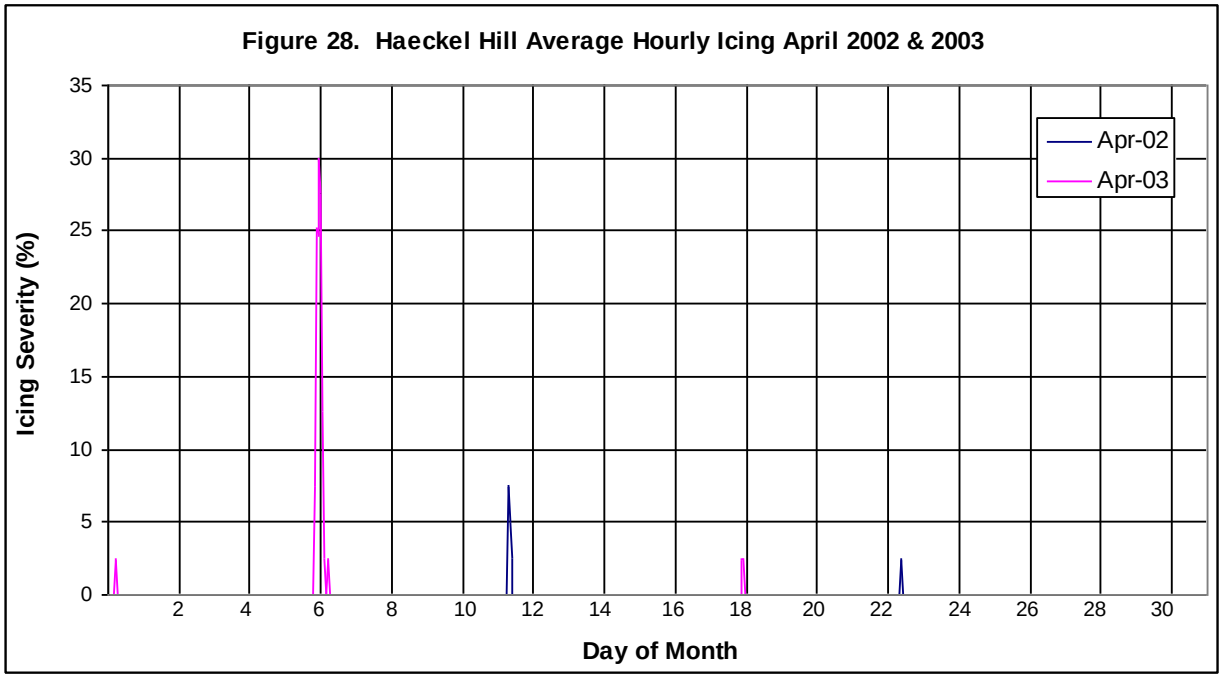


Figure 28. Haeckel Hill Average Hourly Icing April 2002 & 2003
Icing Severity (%)
35
30
25
20
15
10
5
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Day of Month
Apr-02
Apr-03

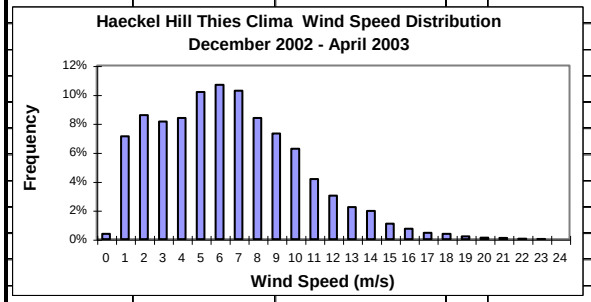
Haeckel Hill Thies Clima Ultrasonic Anemometer 2D Analysis
December 19, 2002 to April 30, 2003

Part 2.

Haeckel Hill -- Thies Clima -- 4 metre data

Period Summary: December 19, 2002 at 1510 to April 30, 2003 at 2400

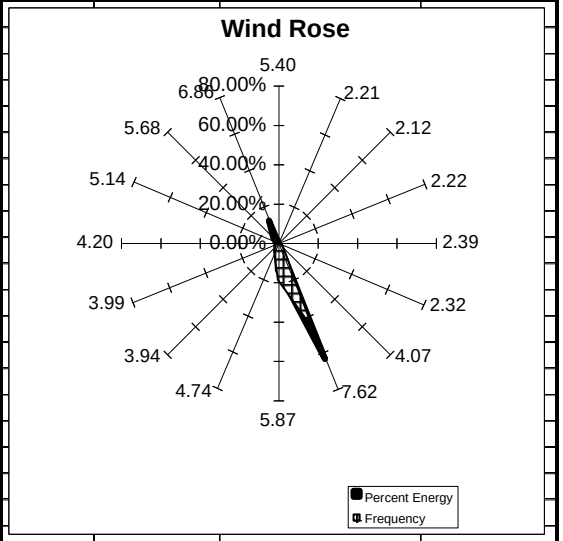
Wind Speed (m/s)		Std. Dev. W.S. (m/s)	Temp. (°C)		Maximum 10 Minute Average Wind Speed		Elevation (m.a.s.l.)=	1,433
Average	6.76	0.89		-10.89	48.76	m/s on January 26, 2003 at 0910; Direction 351.8 Deg.; Temp. -19.1°C		



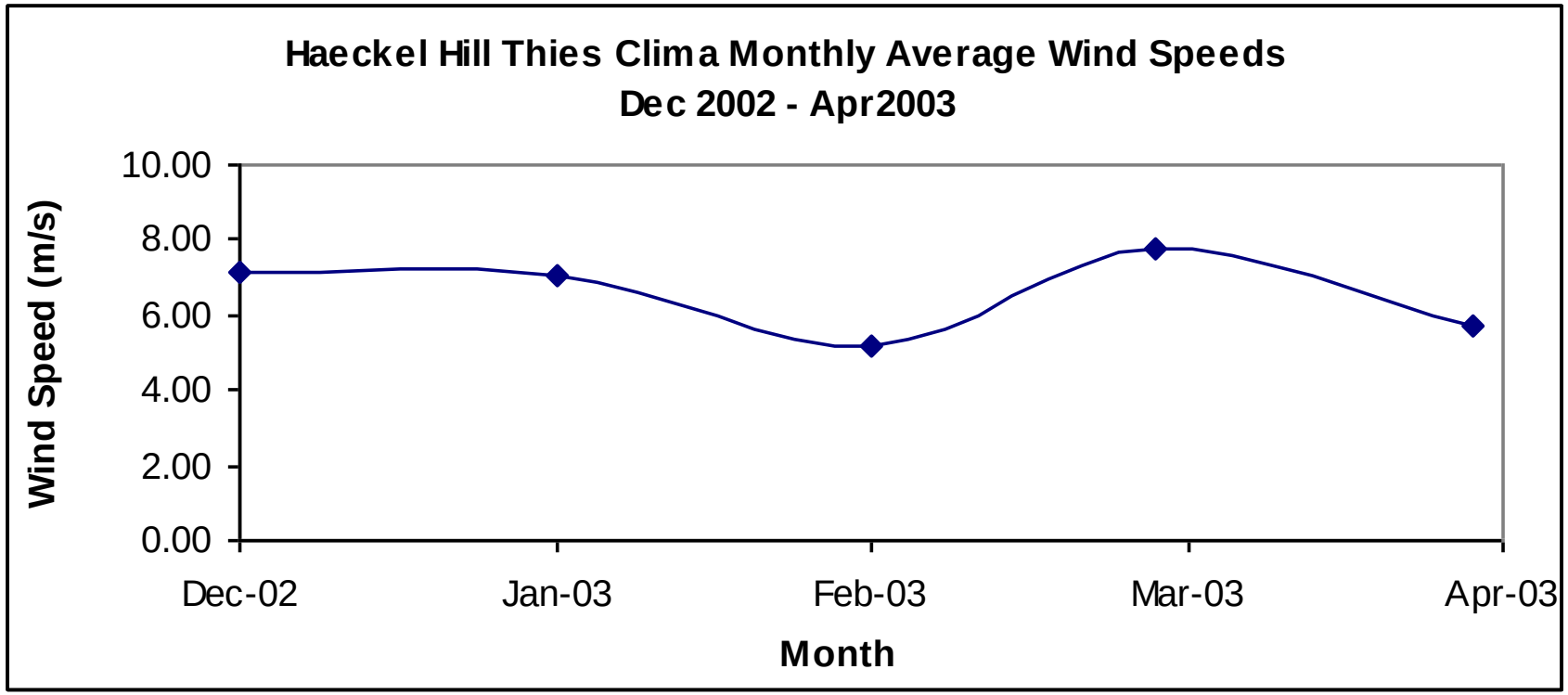
Wind Speed (m/s)	Frequency	Ave. Turbulence Intensity
0	0.36%	
1	7.11%	38.90%
2	8.58%	25.52%
3	8.13%	18.21%
4	8.37%	14.15%
5	10.18%	12.16%
6	10.66%	11.58%
7	10.26%	11.52%
8	8.38%	11.04%
9	7.31%	11.33%
10	6.25%	12.50%
11	4.16%	12.60%
12	3.00%	12.47%
13	2.23%	11.95%
14	1.95%	12.24%
15	1.07%	12.77%
16	0.72%	10.06%
17	0.44%	7.29%
18	0.38%	11.10%
19	0.20%	14.68%
20	0.11%	31.18%
21	0.09%	13.25%
22	0.03%	22.57%
23	0.01%	23.29%
24	0.00%	0.00%

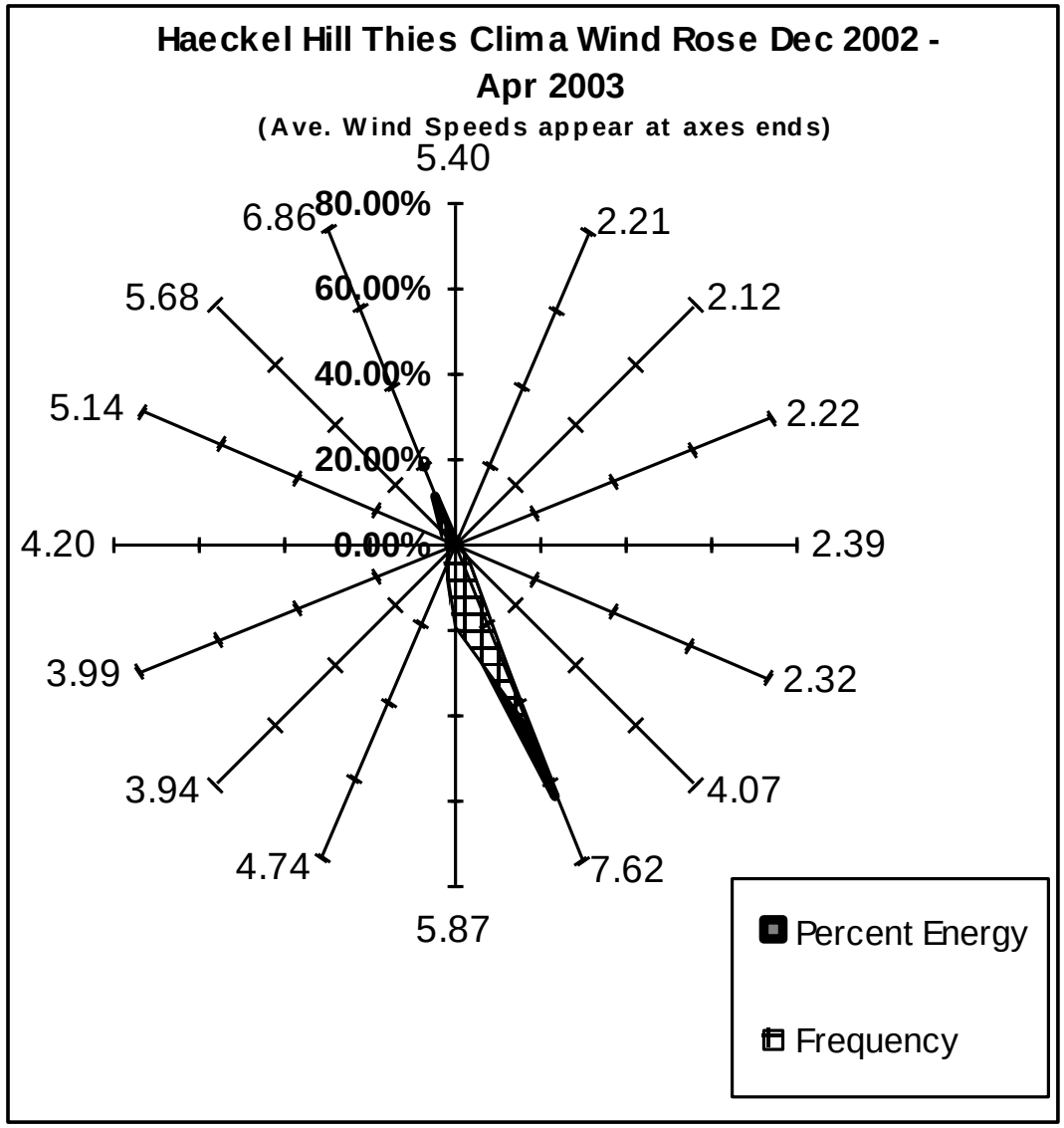
Hour of Day	Ave. Wind Speed (m/s)	Std. Dev. Of W.S. (m/s)
1	5.30	0.66
2	5.42	0.67
3	5.45	0.70
4	5.53	0.69
5	5.54	0.72
6	5.52	0.62
7	5.61	0.71
8	5.60	0.74
9	5.55	0.72
10	5.68	0.90
11	5.61	0.88
12	5.56	0.81
13	5.66	0.83
14	5.75	0.86
15	5.78	0.85
16	5.78	0.83
17	5.76	0.79
18	5.74	0.74
19	5.75	0.71
20	5.66	0.65
21	5.59	0.66
22	5.49	0.71
23	5.55	0.72
24	5.45	0.70

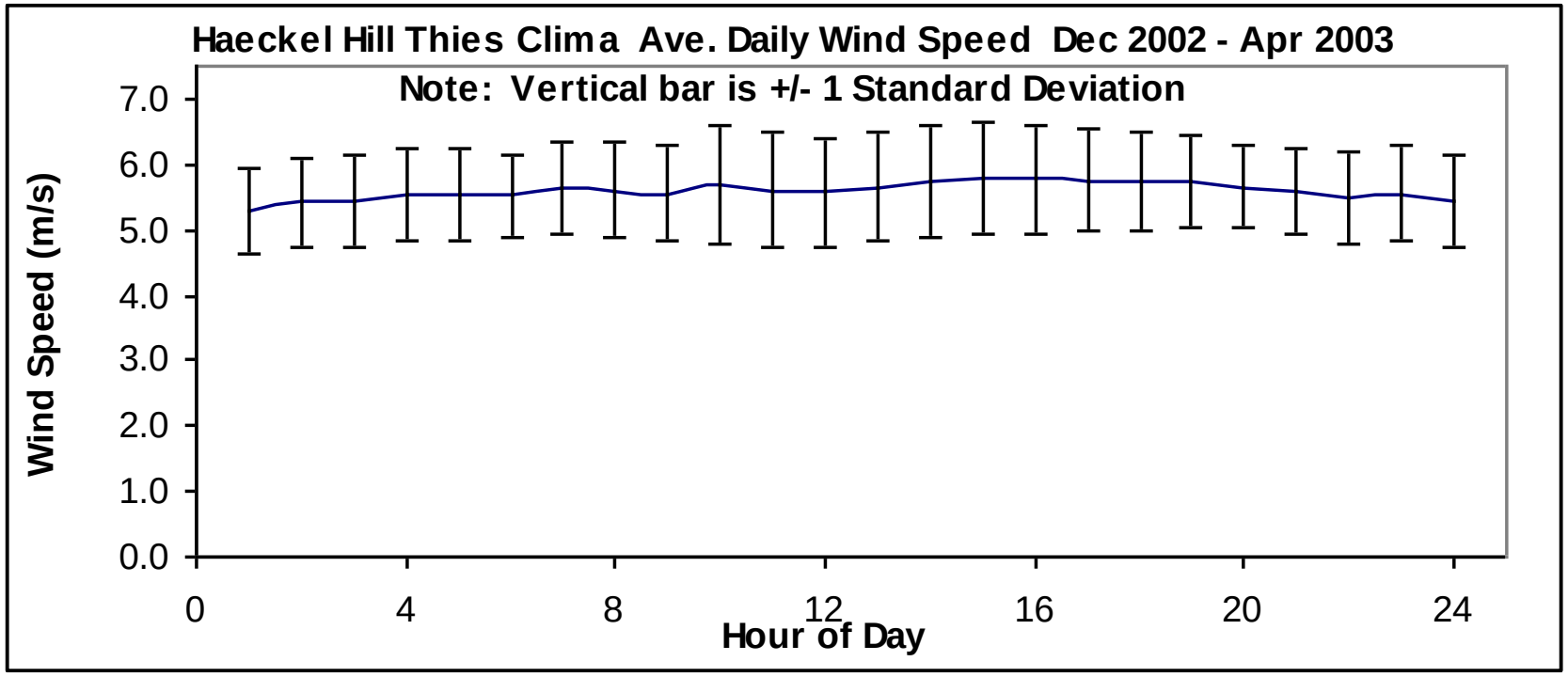
Potential Energy Production at 4 Metres		
	Energy Production (MWh)	Capacity Factor
Bonus 150	139.74	29.82%
Vestas 660	683.96	33.15%

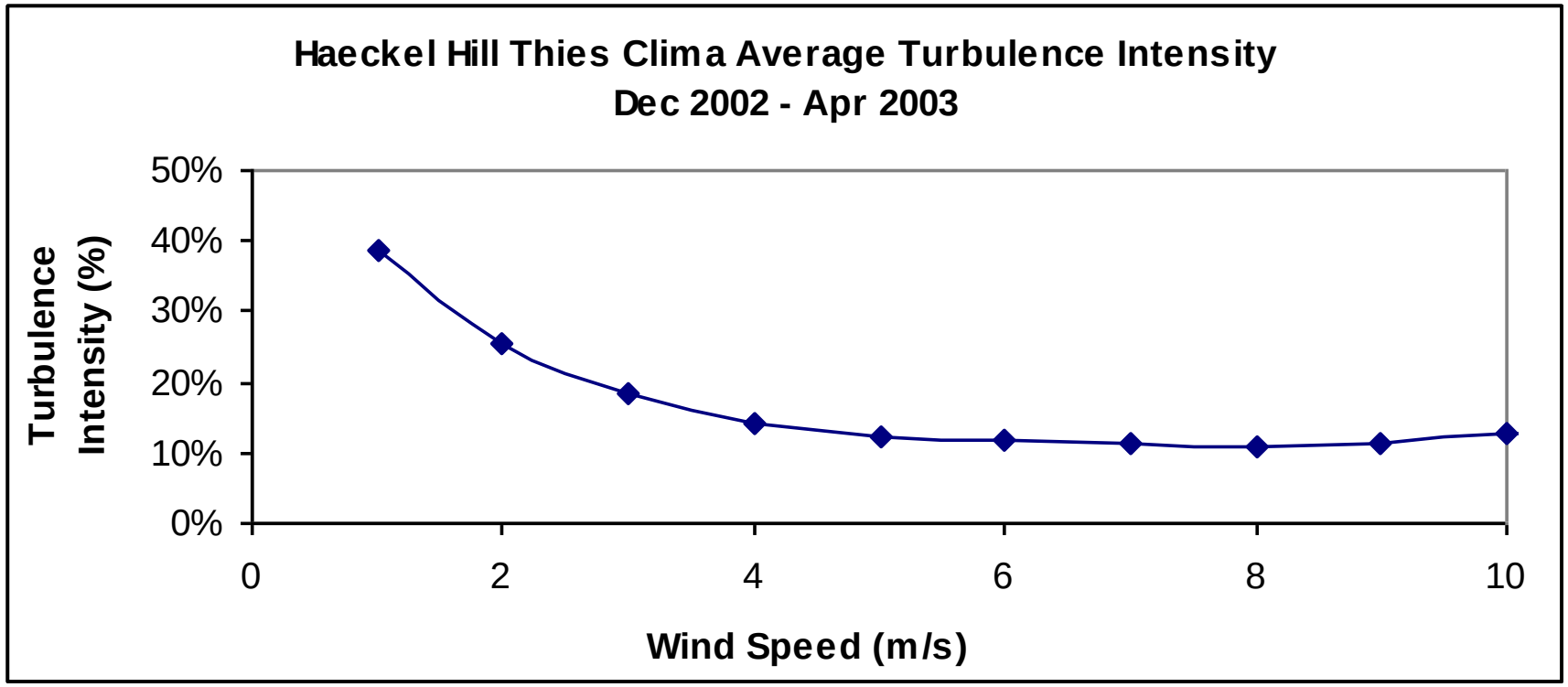


Direction	Ave Wind Speed (m/s)	Frequency of Occurrence	% Energy by Direction
N	5.40	0.21%	0.40%
NNE	2.21	1.93%	0.06%
NE	2.12	1.34%	0.04%
ENE	2.22	1.19%	0.05%
E	2.39	1.21%	0.05%
ESE	2.32	1.69%	0.07%
SE	4.07	4.04%	0.89%
SSE	7.62	47.26%	63.97%
S	5.87	19.07%	14.14%
SSW	4.74	5.04%	1.84%
SW	3.94	2.46%	0.54%
WSW	3.99	1.86%	0.50%
W	4.20	2.10%	0.80%
WNW	5.14	2.17%	1.39%
NW	5.68	2.98%	3.18%
NNW	6.86	5.44%	12.07%


Haeckel Hill Thies Clima Monthly Average Wind Speeds
Dec 2002 - Apr2003
Wind Speed (m/s)
10.00
8.00
6.00
4.00
2.00
0.00
Dec-02
Jan-03
Feb-03
Mar-03
Apr-03
Month


Haeckel Hill Thies Clima Wind Rose Dec 2002 - Apr 2003
(Ave. Wind Speeds appear at axes ends)
5.40
6.86
2.21
5.68
2.12
5.14
2.22
4.20
2.39
3.99
2.32
3.94
4.07
4.74
7.62
5.87
80.00%
60.00%
40.00%
20.00%
0.00%
Percent Energy
Frequency


Haeckel Hill Thies Clima Ave. Daily Wind Speed Dec 2002 - Apr 2003
Note: Vertical bar is +/- 1 Standard Deviation
Wind Speed (m/s)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
4
8
12
16
20
24
Hour of Day


Haeckel Hill Thies Clima Average Turbulence Intensity
Dec 2002 - Apr 2003
Turbulence Intensity (%)
50%
40%
30%
20%
10%
0%
0
2
4
6
8
10
Wind Speed (m/s)