Haeckel Hill
Thies Clima Ultrasonic Anemometer Analysis

January 1, 2001 to June 22, 2001

For
Yukon Energy Corporation
Whitehorse, Yukon

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by
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The purpose of this report is to show how the Thies Clima Ultrasonic Anemometer performed under the icing conditions on Haeckel Hill in the Yukon from January 1, 2001 to June 22, 2001. In this report the Thies Clima Ultrasonic Anemometer is compared to the NRG anemometer that was also operating on the same site during the monitoring period.

Site Description

Data were 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 were (and still are) mounted 30 metres above ground level on a monitoring tower located between the two wind turbines. A Thies Clima ultrasonic anemometer which measures wind direction as well as wind speed was placed 3 metres above ground level on a separate mounting attached to an equipment shed, located next to the tower. An ice detector and temperature gauge were (and still are) installed directly below where the Thies Clima anemometer was installed, on the same shed. The data were automatically stored on a Campbell Scientific data logger and remotely downloaded to a technician's computer in Yukon Energy's corporate office.

Wind Speed and Direction Summary

Figures 1 through 3 illustrate how the wind speed and wind direction data from the two anemometers compare to each other. Wind speeds from the two anemometers correlate well, but the Thies Clima wind speed readings are higher than the NRG wind speed readings until April when icing becomes much less of a factor. When data occurring during obvious icing periods are removed, the Thies Clima wind speed readings are lowered, but they still remain higher than the NRG wind speed readings until April.

Wind direction readings from both anemometers correlate well and are consistently (on average) from the south to south-southwest.

Figures 4 through 9 show how icing affects the Thies Clima wind speed readings. Note that the Thies Clima and NRG wind speed readings follow each other closely until an icing event, at which time the Thies Clima wind speed readings suddenly increase. When data occurring during obvious icing periods are removed the sudden increase in wind speed readings is reduced but not eliminated. The Thies Clima unit is referred to by the initials TC.

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Figure 1. Monthly Averages						
	Wind Speed (m/s)			Wind Direction (degrees)		
	NRG (Heated)	TC (Icing Data Included)	TC (Icing Data Removed)	NRG (Heated)	TC (Icing Data Included)	TC (Icing Data Removed)
January-01	9.05	18.39	12.76	178	174	178
February-01	6.32	9.19	7.03	206	189	192
March-01	7.94	10.03	8.05	192	185	188
April-01	6.99	6.68	6.22	197	187	188
May-01	6.75	6.12	6.12	181	174	174
June-01	5.29	4.28	4.28	178	175	175
	Wind Speed Standard Deviation (m/s)			Wind Direction Standard Deviation (deg.)		
January-01	0.84	1.48	1.39	43	38	39
February-01	0.64	0.99	0.84	94	84	85
March-01	0.79	1.07	1.02	77	66	66
April-01	0.72	1.02	0.94	59	54	54
May-01	0.83	1.08	1.08	75	61	61
June-01	0.71	0.86	0.86	101	81	81

Figure 2. Haeckel Hill Monthly Average Wind Speeds
January 1, 2001 to June 22, 2001

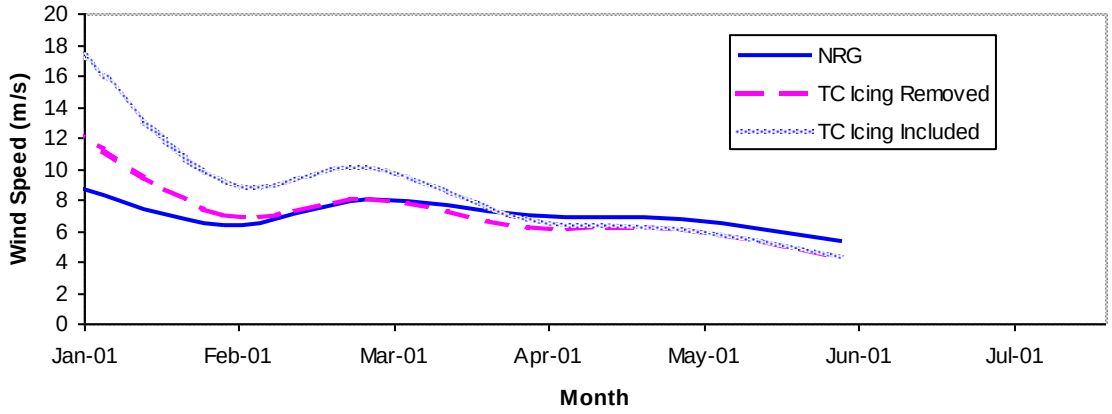
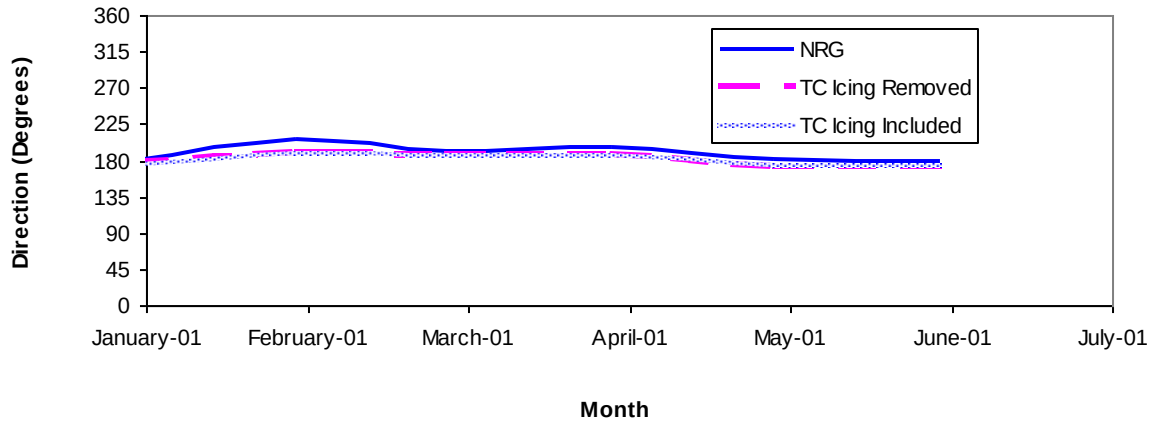


Figure 3. Haeckel Hill Monthly Average Wind Direction
January 1, 2001 to June 22, 2001



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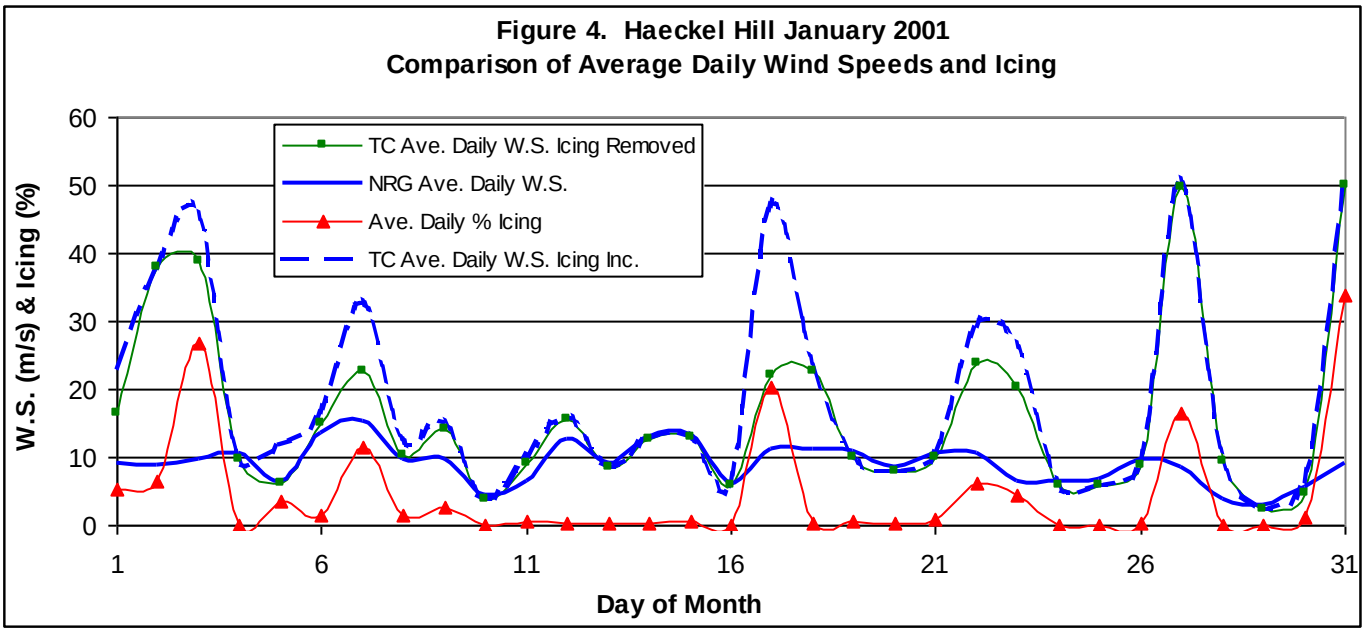

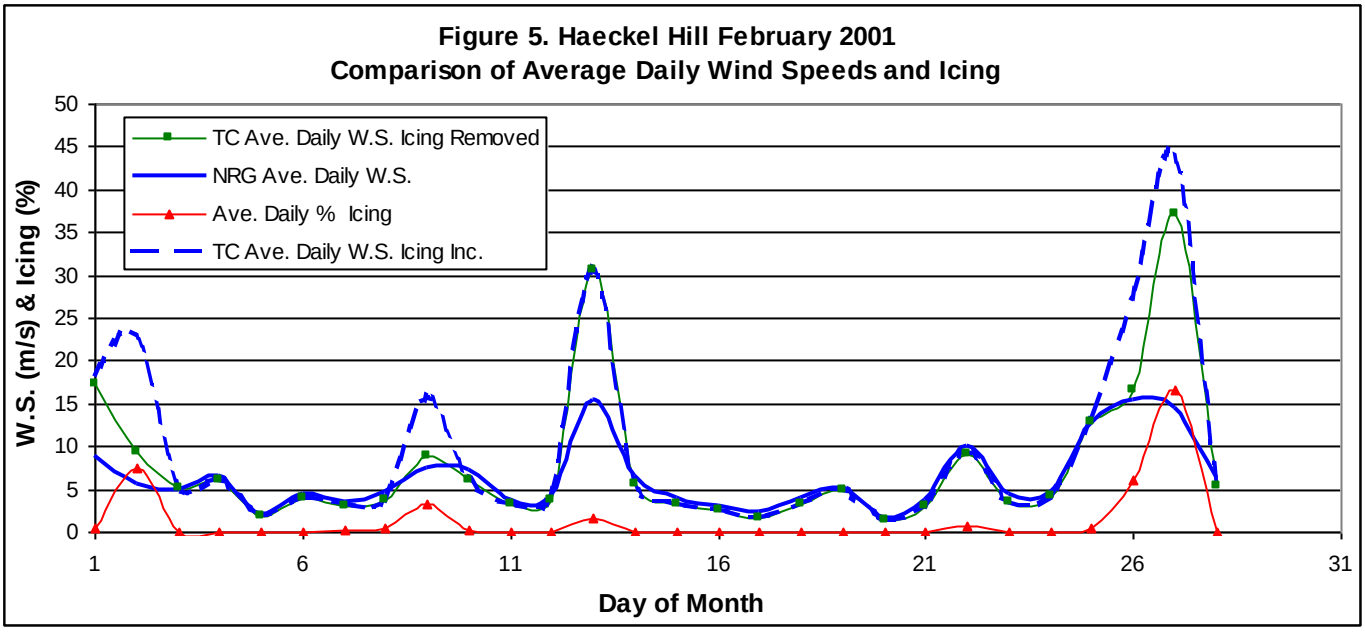

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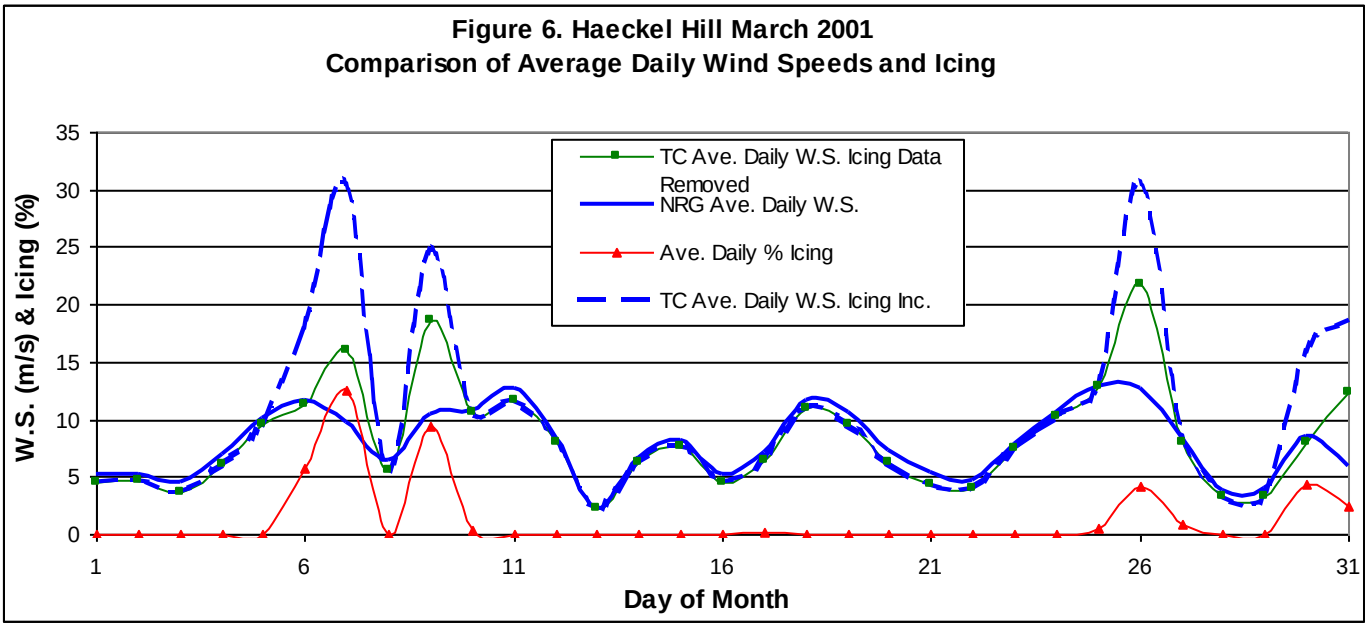

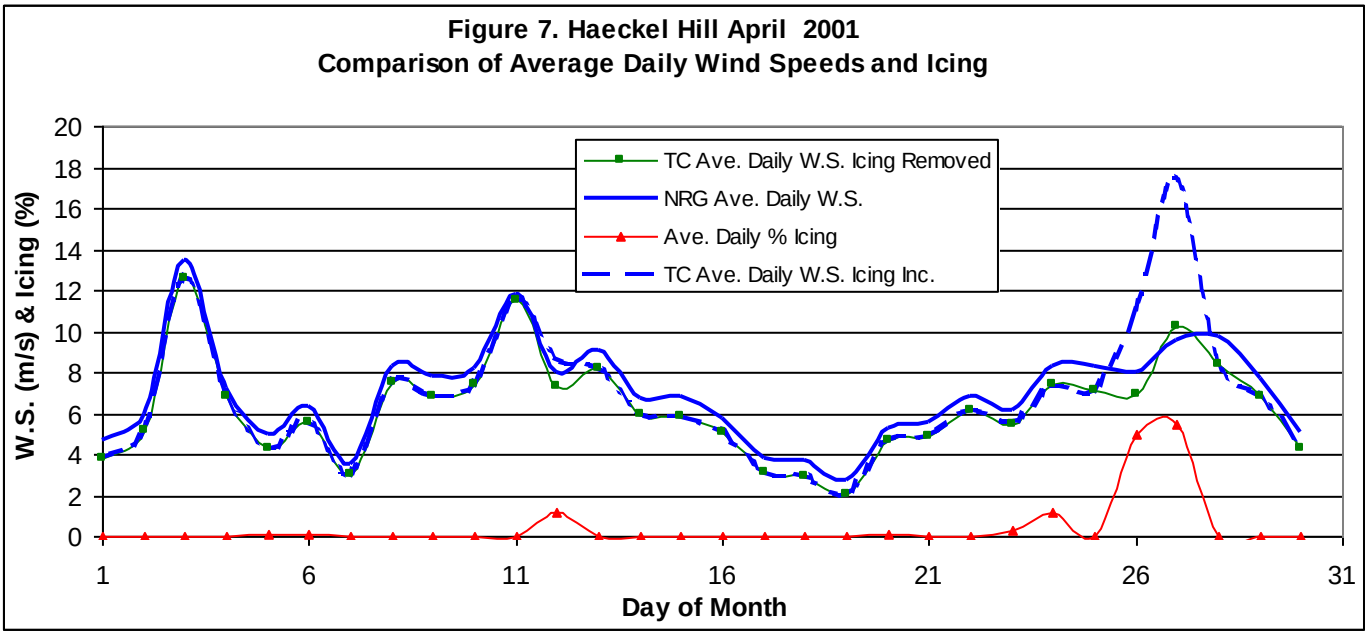

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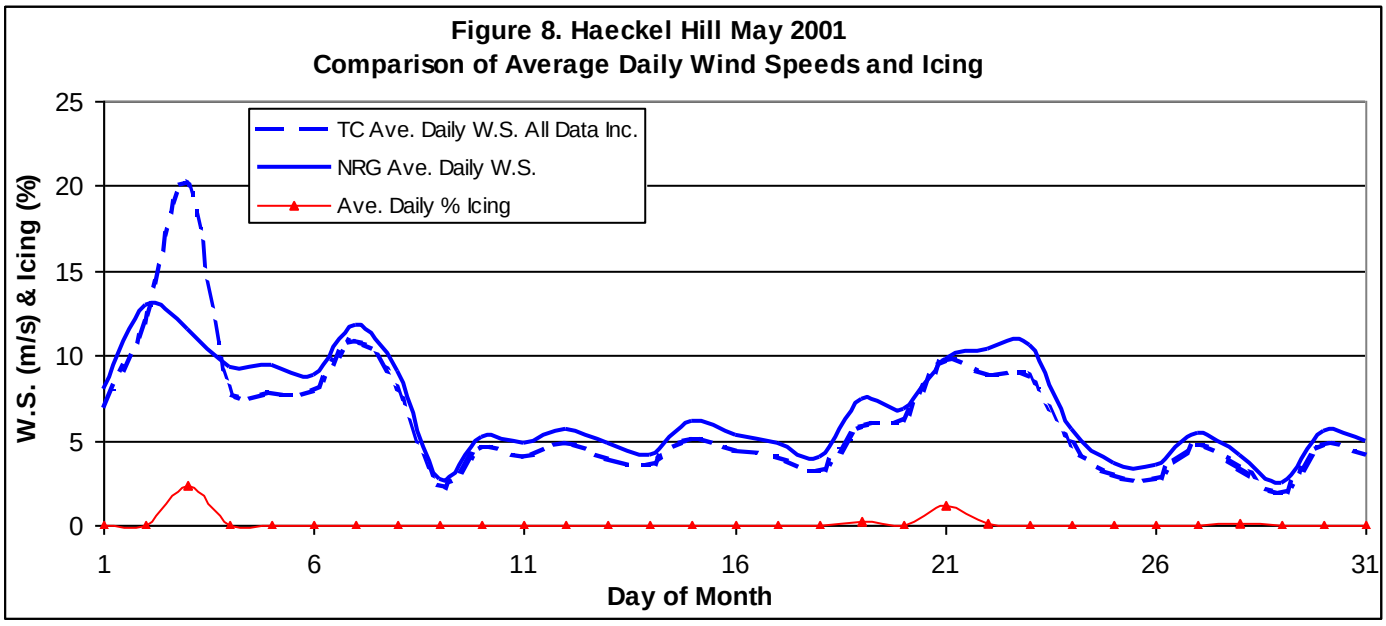
Figure 8. Haeckel Hill May 2001
Comparison of Average Daily Wind Speeds and Icing
TC Ave. Daily W.S. All Data Inc.
NRG Ave. Daily W.S.
Ave. Daily % Icing
W.S. (m/s) & Icing (%)
Day of Month
0
5
10
15
20
25
1
6
11
16
21
26
31

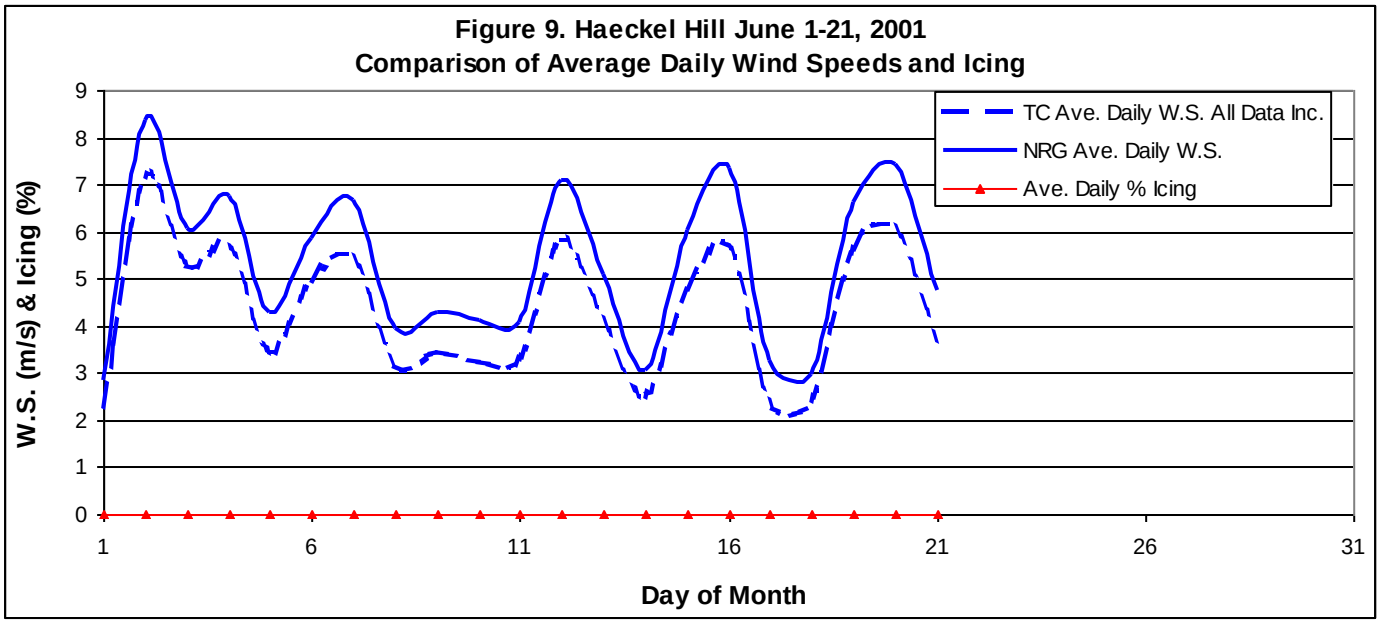
Figure 9. Haeckel Hill June 1-21, 2001
Comparison of Average Daily Wind Speeds and Icing
TC Ave. Daily W.S. All Data Inc.
NRG Ave. Daily W.S.
Ave. Daily % Icing
W.S. (m/s) & Icing (%)
Day of Month
0
1
2
3
4
5
6
7
8
9
1
6
11
16
21
26
31

Data Quality

The period being analyzed began in December 2000 and continued through to the end of November 2001. Although the new NRG tower was up and the instruments were reported as functioning as of December 6, 2000, an error code (6999) was all that was recorded until December 22, 2000. Maintenance was done on the NRG and Thies Clima instruments on December 15, 2000, but no link has been made between that maintenance and the erroneous data. Between December 22 and December 31, 2000 the data still showed anomalous values (wind speeds higher than 200 m/s from the NRG and higher than 50 m/s from the Thies Clima). Thus data analysis begins January 1, 2000 at 0010.

In the case of the Thies Clima December data, most of the unlikely values were removed when the data associated with icing occurrences were removed. Throughout the remaining months, the Thies Clima continued to register unlikely values, with the maximum wind speed for each month usually recorded as higher than 50 m/s. Most of these unlikely values were removed when the obvious icing data were removed. However some unusually high wind speed data remained which have skewed the Thies Clima monthly maximums and averages so that they appear to be higher than they probably were.

For the monitoring period, 4.1% of the Thies Clima wind speed data are greater than 24 m/s, compared to only 0.02% of the NRG data. This percentage decreases from December to June as shown in Figure 10.

Figure 10.

Month	**Percentage of Thies Clima Wind Speed Data Greater Than 24 m/s**
December	22.4%
January	11.5%
February	4.4%
March	1.9%
April	0.1%
May	0.8% *icing data not removed in this month
June	0% *there was no icing data to remove in this month

A possible explanation for there still being high wind speed values even after the icing data were removed *and* for the percentage of high wind speed values decreasing as the seasons changed from winter to summer, is that even when the icing detector was not registering ice, there may still have been some ice, or frost, on the Thies Clima transformer arms. Any ice on the transformer arms could have had the same effect as a mechanical deformation to the transformer arms. The Thies Clima manual, "Ultrasonic Anemometer 2D", states that, "Only a mechanical deformation of the transformer arms and the resulting changes in the length of the measurement paths lead to errors in the measured values", p9-10.

The Thies Clima anemometer was not taken down until September 21, 2001, but it stopped functioning properly on June 22, 2001 at 1110. After this time the wind speed and direction readings are all "0". Maintenance was done on the site on June 22, 2001, but no direct link has been made between that maintenance and the Thies Clima malfunctioning. Thus data analysis ends June 22, 2001 at 1110.

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Icing

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. From the icing detector record we can determine two things:

1. that ice did, or did not occur during a 10 minute sampling period and
2. the proportion of the 10 minute sampling period during which the de-icing heater was operating. This is a measure of the severity of the icing event.

A compilation of the icing data from January 2001 to April 2001 appears below in Figure 11. May and June did not have any significant icing.

Figure 11. Haeckel Hill Monthly Icing Data Compilation January 1, 2001 to June 22, 2001

Year	Month	# of Ice Free Days	# of Discrete Icing Events	# of Icing Hours in month	Average Time of Icing Event in Hours	Longest Icing Event (hrs)	Average Severity of Icing Events %	Most Severe Icing Event %
2001	January	6	52	134.33	3.12	27.83	16.97	66.50
	February	13	21	42.50	2.46	13.83	13.07	72.50
	March	21	15	36.67	2.78	12.00	17.14	59.83
	April	22	8	13.50	1.81	8.83	13.98	45.17
Totals		62	96	227.00	2.54	27.83	15.29	72.50

Wind Speed and Icing

As shown in the summary wind speed graphs (Figures 4 to 9), icing data correlates to the Thies Clima wind speed data. This correlation is also shown by the Pearson's Correlation Coefficient[1] (r) of 0.64 for the Thies Clima wind speed readings with the icing *occurrence* readings. Also, the Thies Clima wind speed readings correlate fairly well to the *value* of the icing readings (r=0.61). This means that 61% of the time, the Thies Clima wind speed readings increased and decreased with the severity of the icing events.

Wind Direction and Icing

The Pearson's Correlation Coefficient is very weak for the Thies Clima wind direction readings to the ice detector readings(r values are under –0.4), however when the wind direction readings are plotted against the icing data, a relationship is apparent. Figures 12 through 15 show that whenever an icing event of 3% severity or greater occurs, the wind direction data show wind coming from the southeast to southwest. This is true for both the NRG wind vane and the Thies Clima wind direction sensor readings. This is the predominant wind direction on Haeckel Hill and moist air comes from the Pacific or the open Southern lakes. This does not seem to indicate that the wind sensors default to one direction during icing events because there are still the expected fluctuations (at least for the NRG) for a vane that is not fixed in place. Figures 16 and 17 are included to show how the two anemometers' wind direction readings compare during months with little-to-no icing.

[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.

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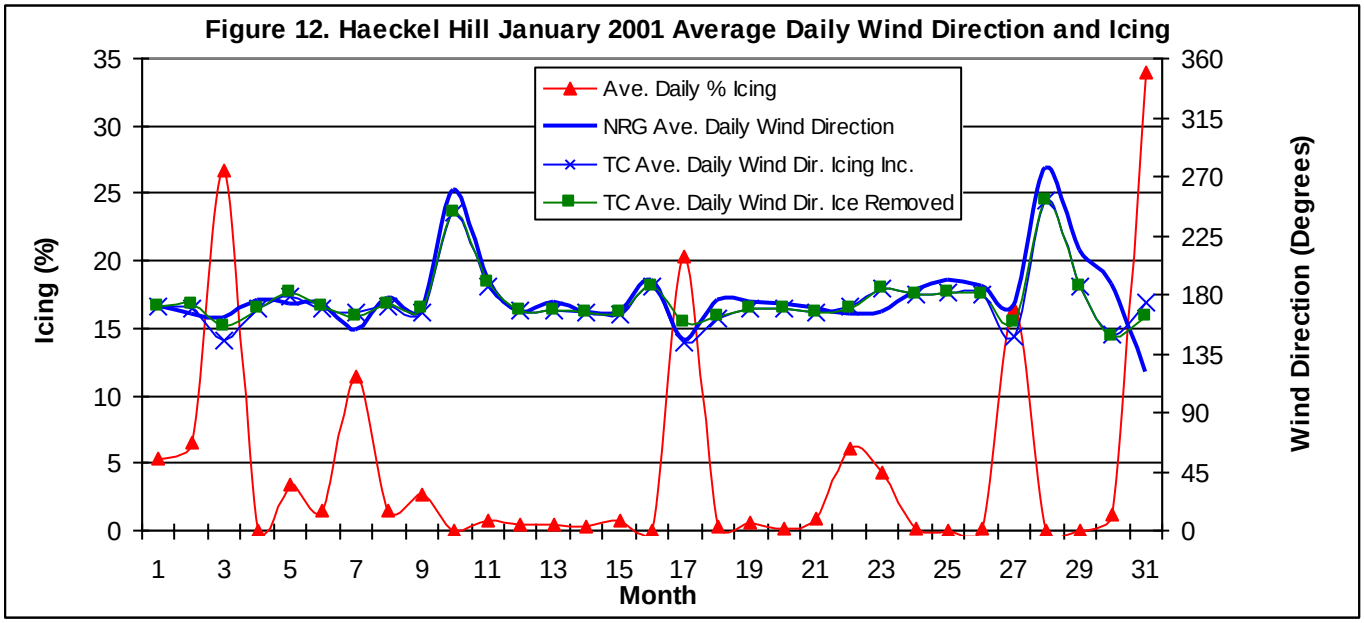

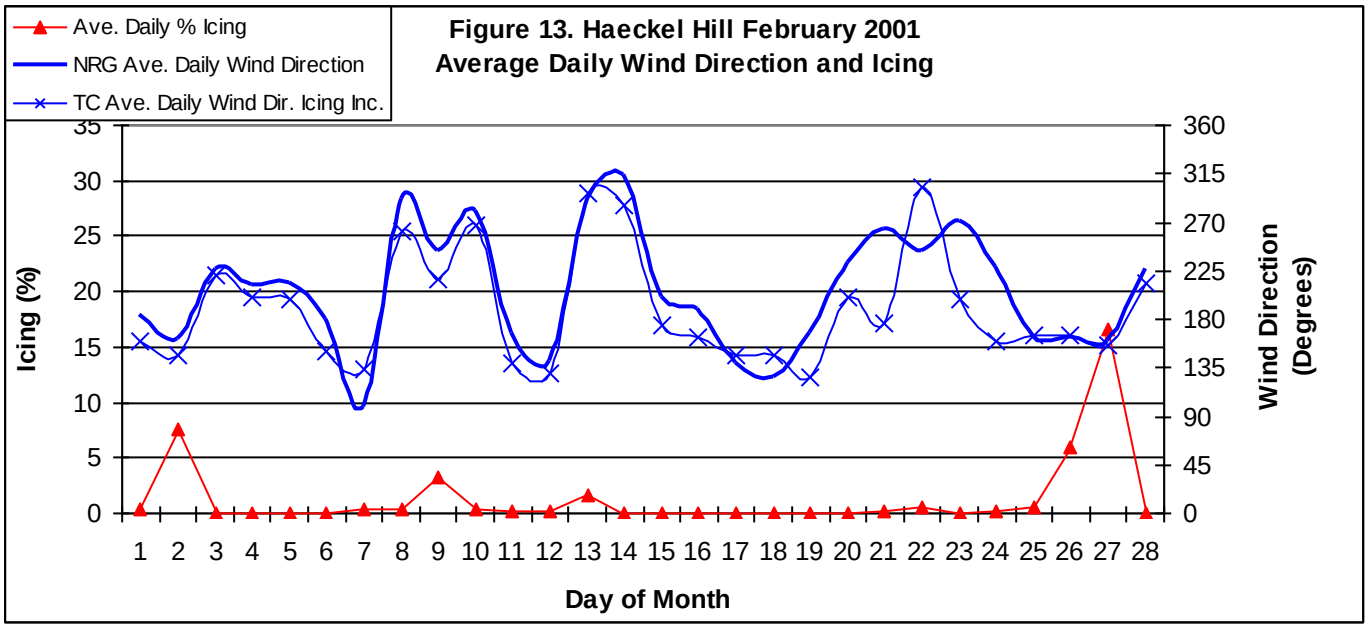

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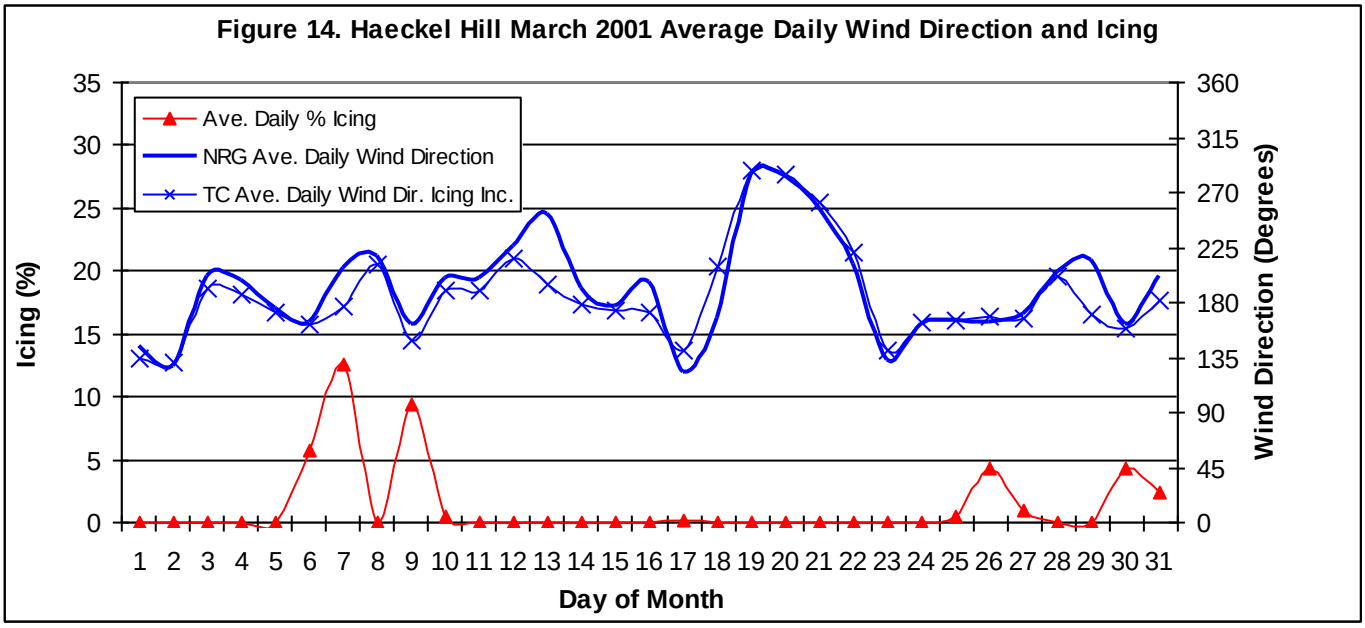

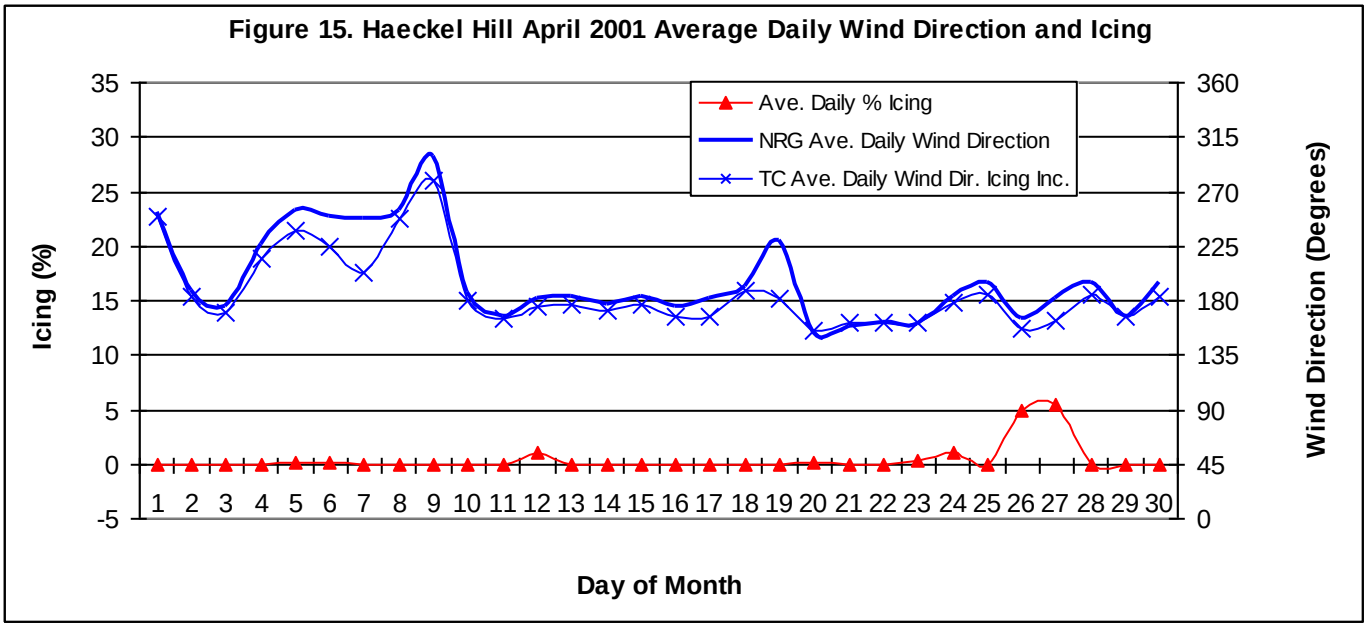

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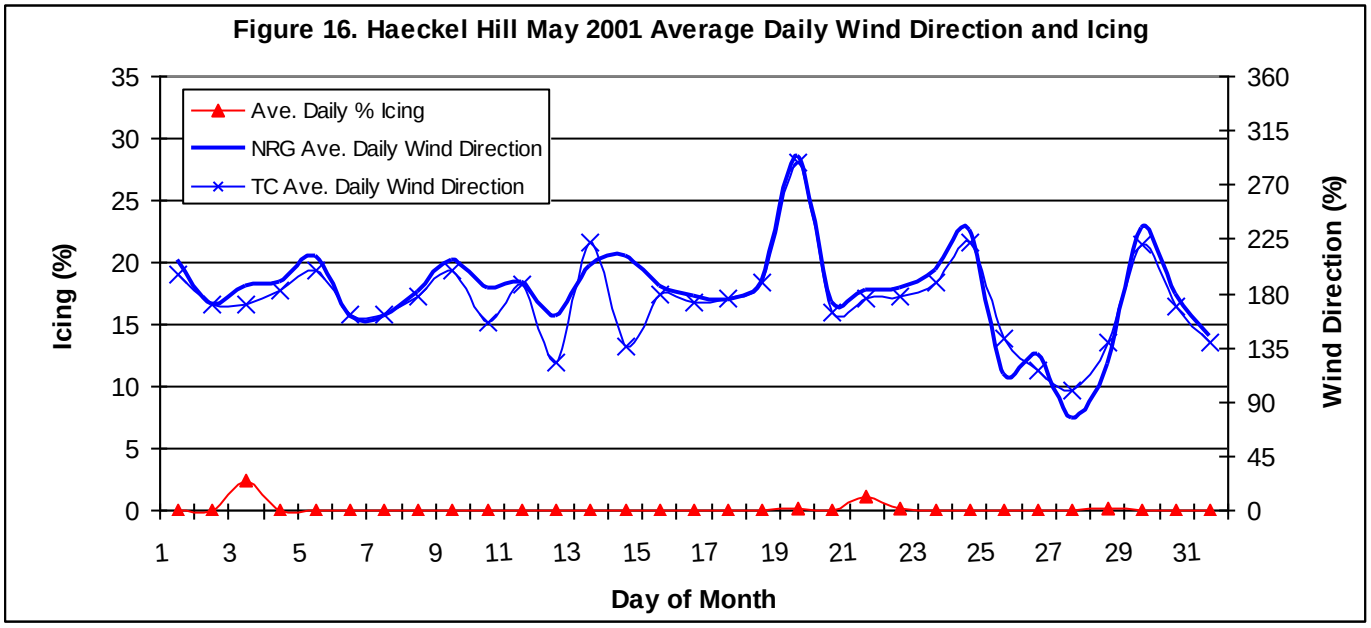

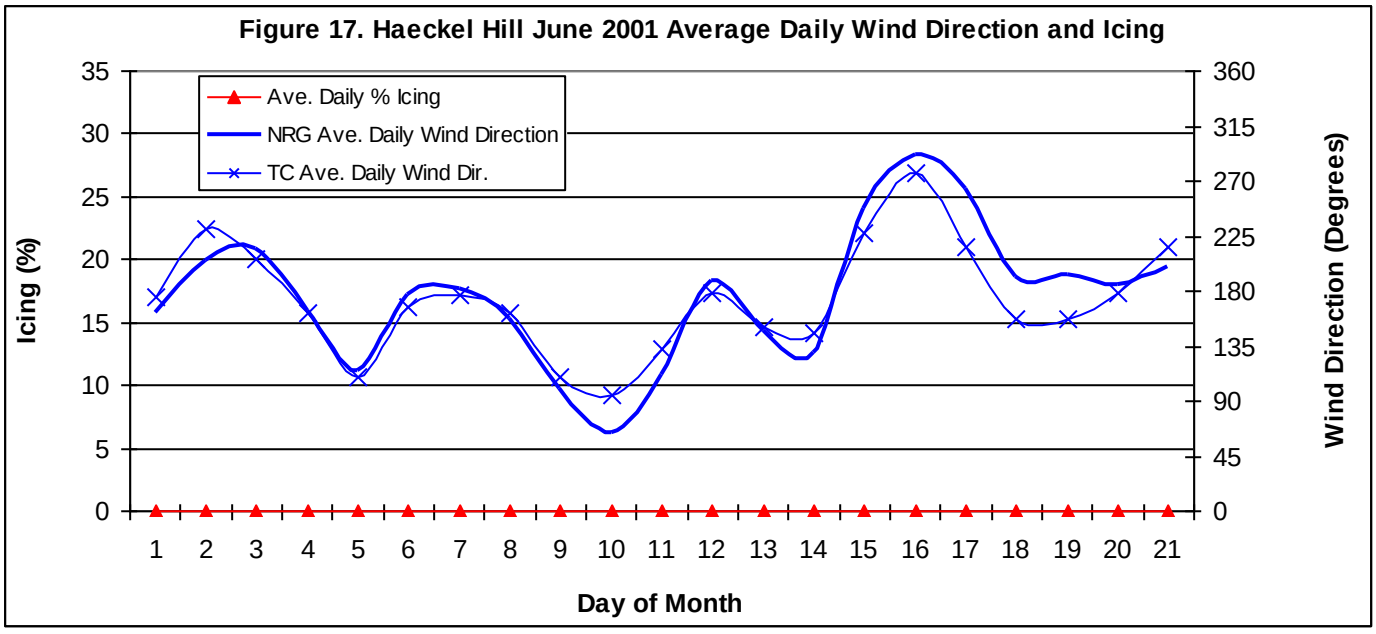

Figures 18 and 19 depict the hourly wind direction just before, during and after two different icing events in January and February, before which the Thies Clima wind speed readings were close to those of the NRG and during which they were much higher than

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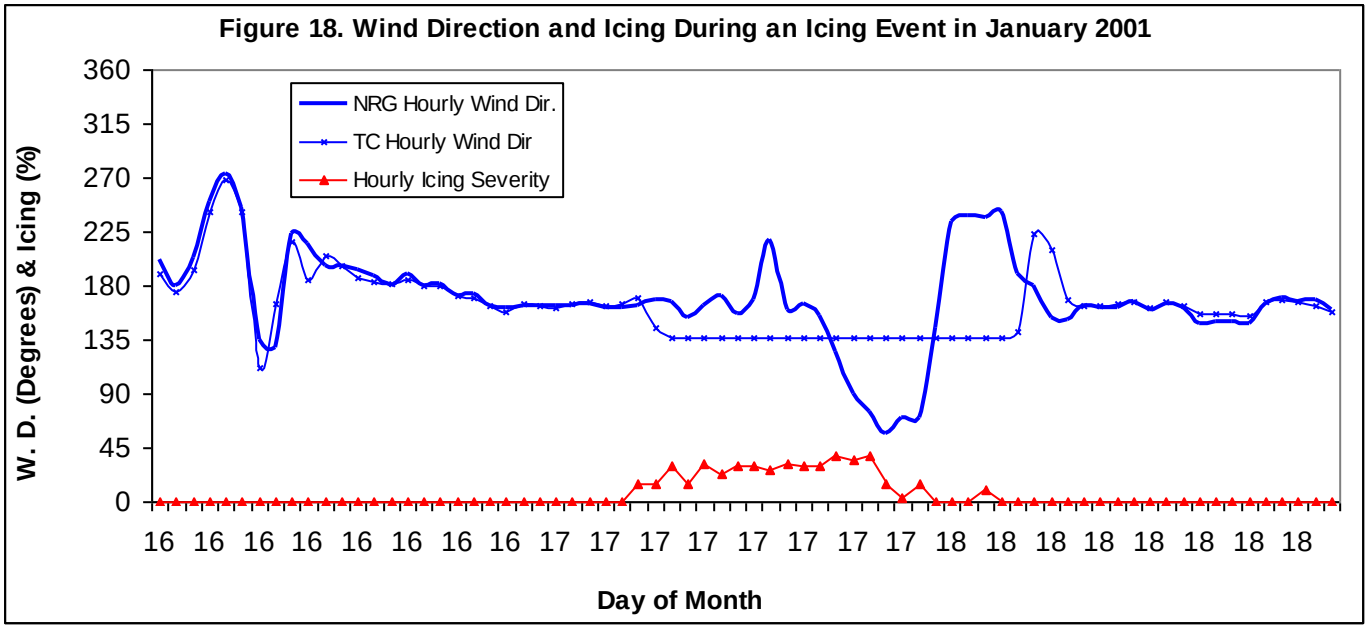
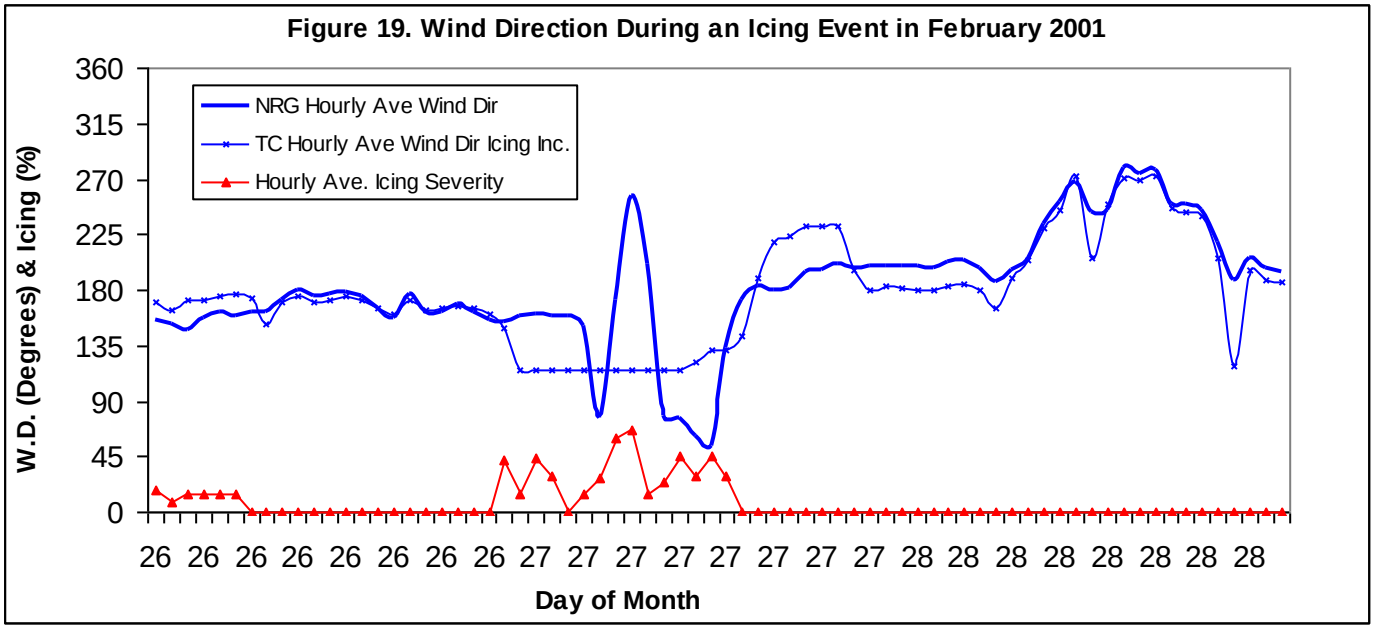
the NRG. These graphs show that there are instances when the Thies Clima direction sensor does appear to "freeze up" with ice as shown by the straight lines with no variations during the icing event.





Temperature and Icing

The Pearson's Correlation Coefficient is very weak for temperature data to icing data (r values are under 0.1). No relationship becomes apparent when the data are plotted together, other than what would be expected: when the temperature is above 0ºC, there is no icing. Monthly graphs of icing and temperature are included at the end of this report.

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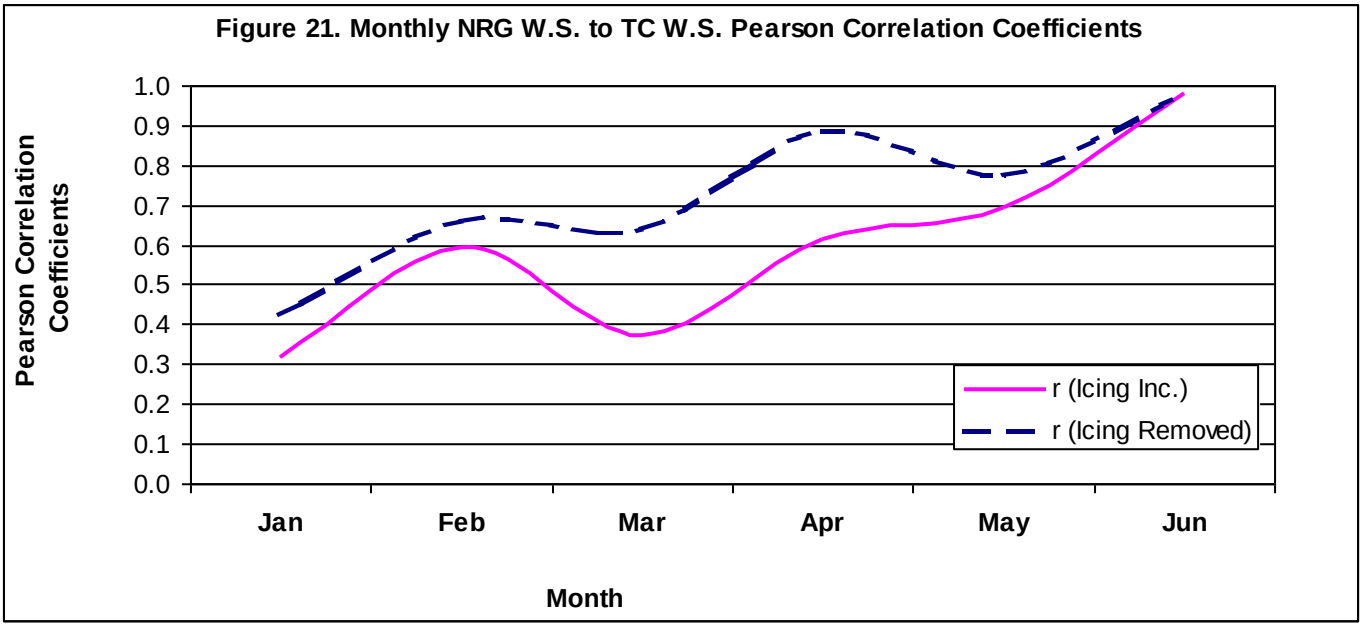
NRG Data to Thies Clima Data – Parameter by Parameter Comparison

Wind Speed

The Pearson Correlation Coefficient for the January to June 22 NRG to Thies Clima wind speed data is 0.48. When the data that occurs during icing periods are removed the correlation coefficient strengthens to 0.60. This means that the wind speed readings from the Thies Clima anemometer increased and decreased with the NRG anemometer wind speed readings 60% of the time. Monthly correlations of the wind speed readings are presented in tabular and graphical form in Figures 20 and 21.

Figure 20. Monthly Pearson Correlation of Thies Clima Wind Speed to NRG Wind Speed January 1, 2001 to June 22, 2001

	Icing data included	Icing data removed
January, 2001	0.31	0.42
February, 2001	0.59	0.66
March, 2001	0.37	0.64
April, 2001	0.61	0.89
May, 2001	0.69	0.77
June, 2001	0.98	0.98



Wind Direction

The Pearson Correlation Coefficient for the January to June 22 NRG wind direction data to the Thies Clima wind direction data is 0.67. When the data that occurs during icing periods are removed the correlation coefficient marginally strengthens to 0.70 for the

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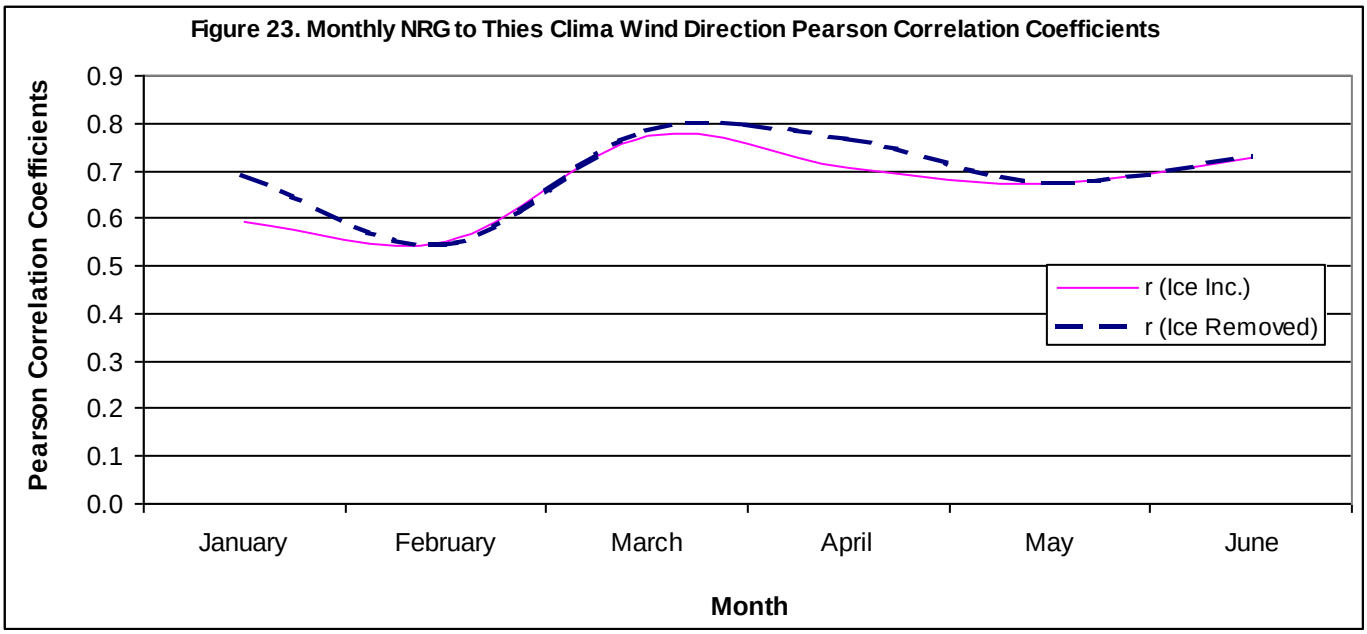
period. Figures 22 and 23 show the monthly correlation coefficients both in tabular and graphical form.

Figure 22. Monthly Pearson Correlation of Thies Clima Wind Direction to NRG Wind Direction January 1, 2001 to June 22, 2001		
	Icing data included	Icing data removed
January, 2001	0.59	0.69
February, 2001	0.55	0.54
March, 2001	0.77	0.78
April, 2001	0.71	0.76
May, 2001	0.67	0.67
June, 2001	0.73	0.73



Turbulence Intensity

The turbulence intensity for both anemometers is summarized in Figure 24. The NRG anemometer readings show less turbulence intensity than the Thies Clima anemometer readings for all wind speeds over 2 m/s. This is probably due to the NRG anemometer being at a greater height where ground roughness would have been less of a factor in creating turbulence.

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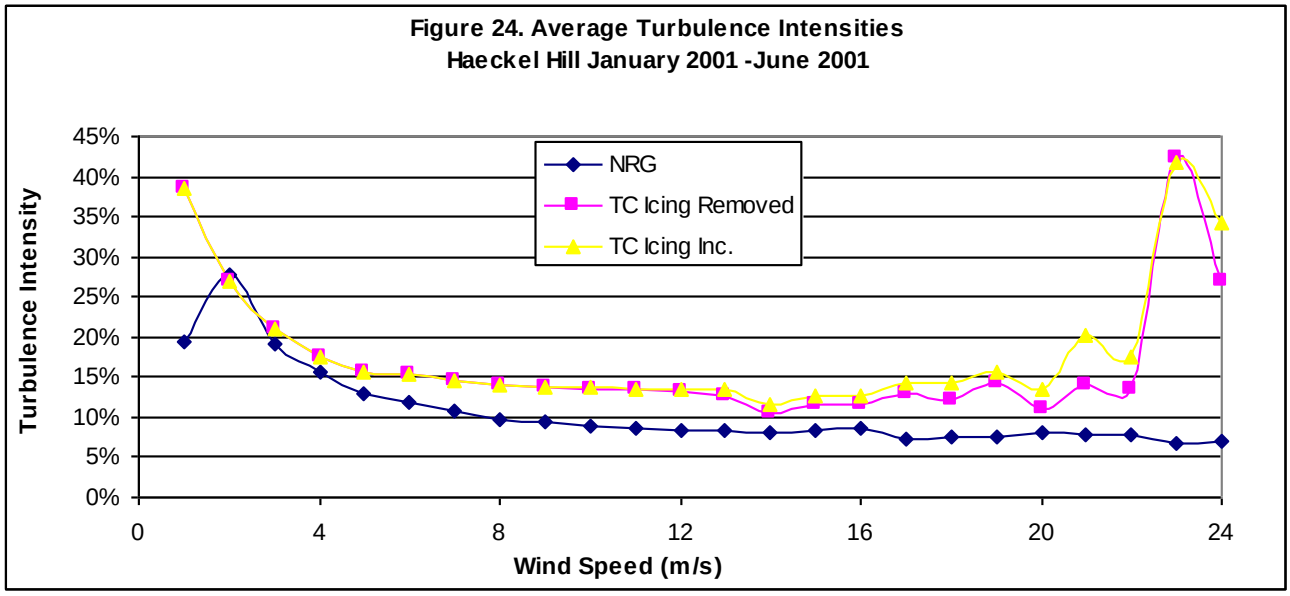
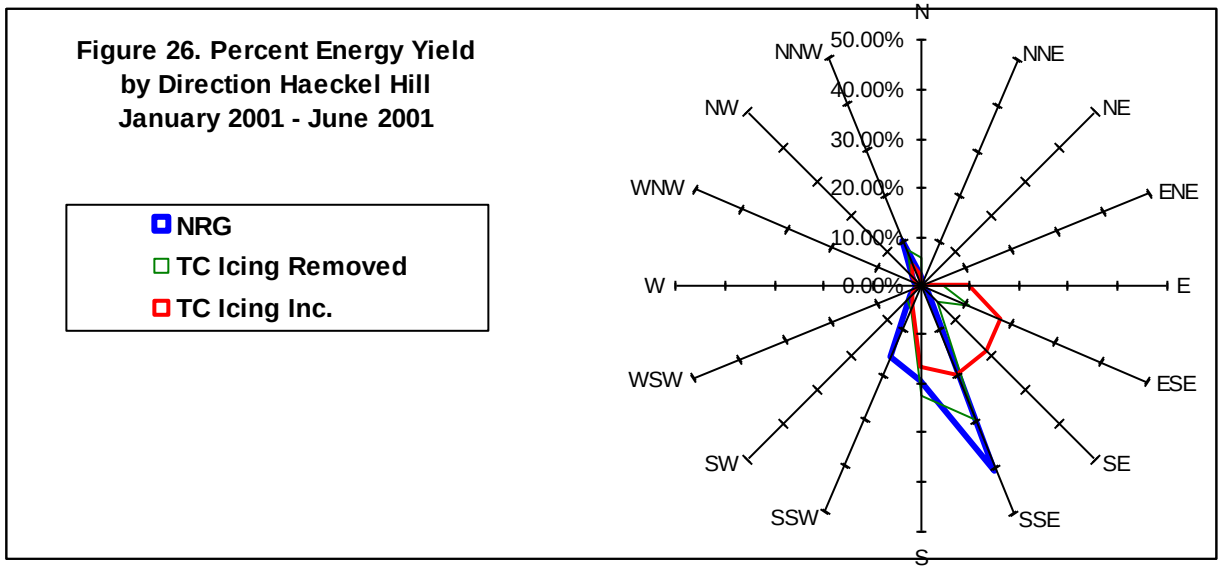


Energy Yield by Direction

Figures 25 and 26 show that the Thies Clima anemometer recorded the strongest winds as coming from a more easterly direction than the NRG anemometer. This difference could have been caused by the differing heights of the two anemometers.

Figure 25. Wind Direction With Greatest Energy Yield January 2001 – June 2001		
Anemometer	Wind Direction	Percent
NRG	SSE-SSW	76.12%
Thies Clima with Icing Data Removed	E-S	77.23%
Thies Clima with Icing Data Included	E-S	82.99%



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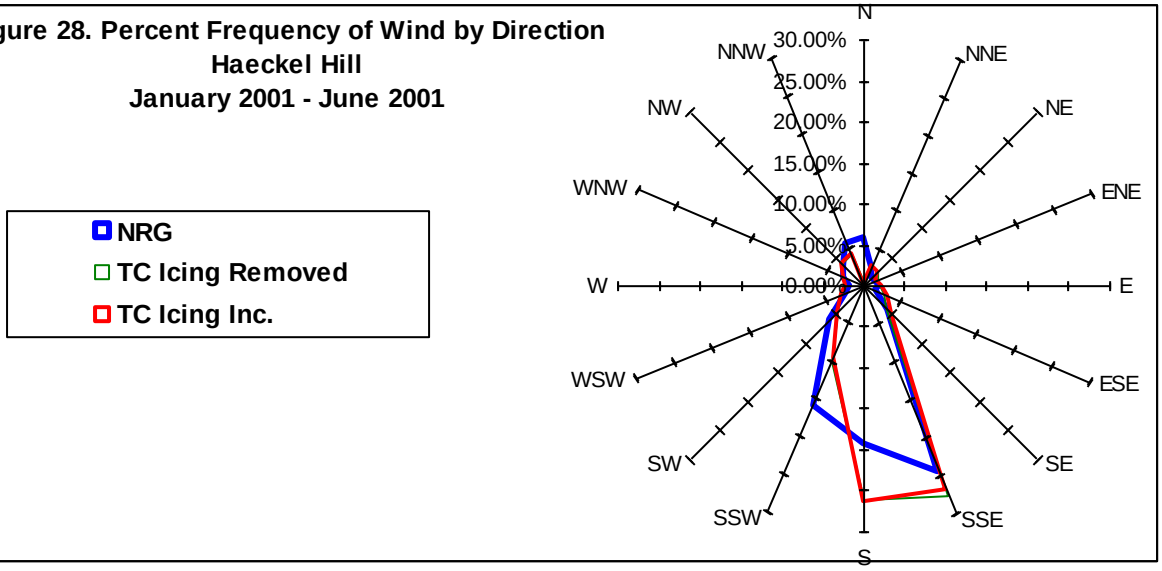
Wind Frequency by Direction

Figures 27 and 28 show that the Thies Clima wind direction readings tend to be slightly more focused in the south-southeast than the NRG wind direction readings. Note also that when the data associated with icing is removed from the Thies Clima readings, there is little affect on the frequency of occurrence of wind from any direction.

Figure 27. Wind Direction Frequency of Occurrence January 2001 – June 2001		
Anemometer	Wind Direction	Percent
NRG	SSE-SSW	59.53%
Thies Clima with Icing Data Removed	SSE-SSW	63.79%
Thies Clima with Icing Data Included	SSE-SSW	62.93%

Figure 28. Percent Frequency of Wind by Direction
Haeckel Hill
January 2001 - June 2001



Daily Variation in Wind Speeds

Figures 29 and 30 show how the Thies Clima average daily wind speed readings tend to be higher than the NRG wind speed readings, especially before icing data is removed. The greatest variation in wind speed readings also occurs for the Thies Clima data with the icing data included.

Figure 29. Daily Variation in Wind Speeds January 2001 – June 2001			
Anemometer	Peak Time	Slowest Time	~ Difference Between Peak & Slowest Times (m/s)
NRG	1700	2400	1.89
Thies Clima with Icing Data Removed	1900	2400	1.73
Thies Clima with Icing Data Included	0500	2400	2.31

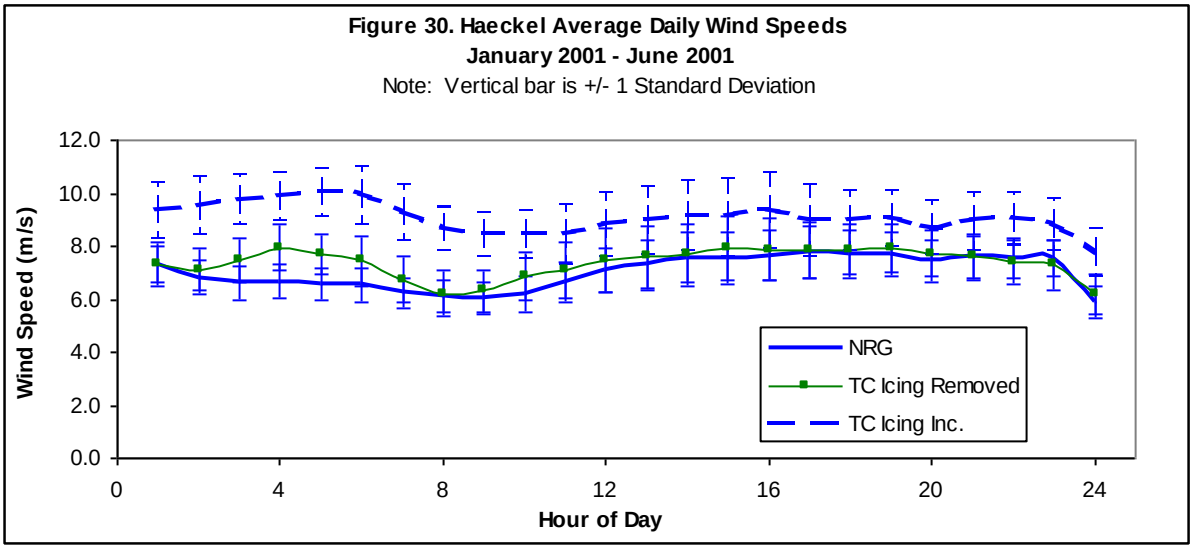
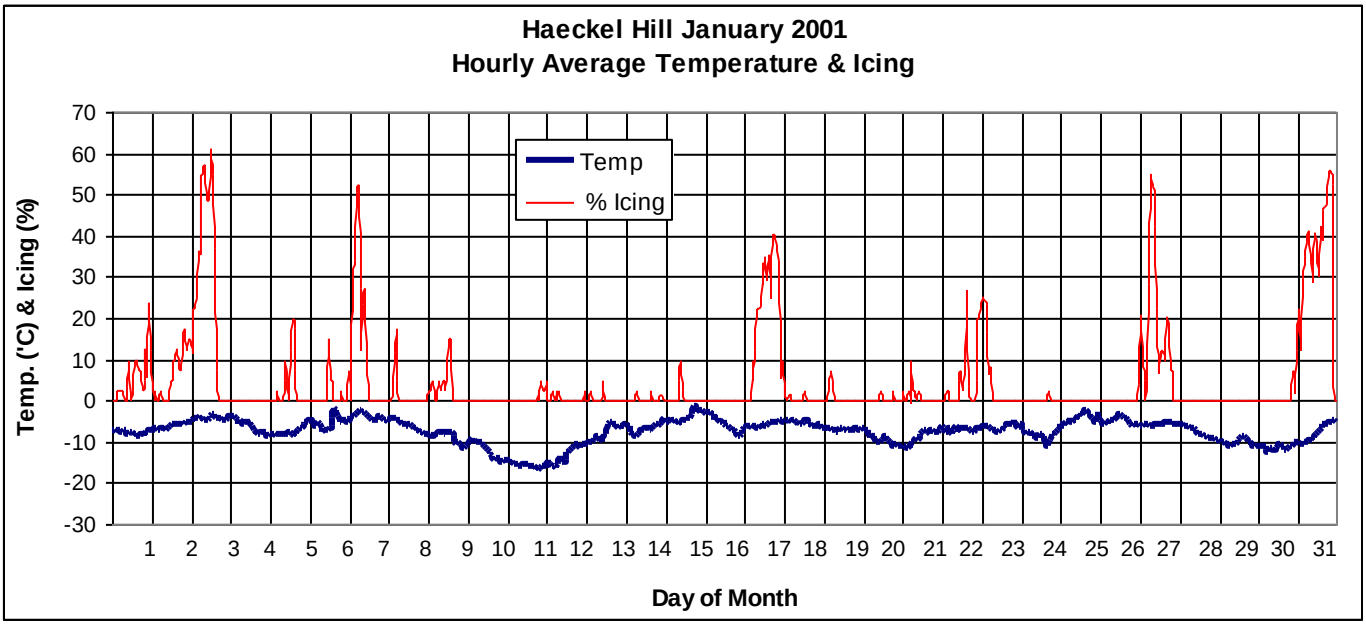
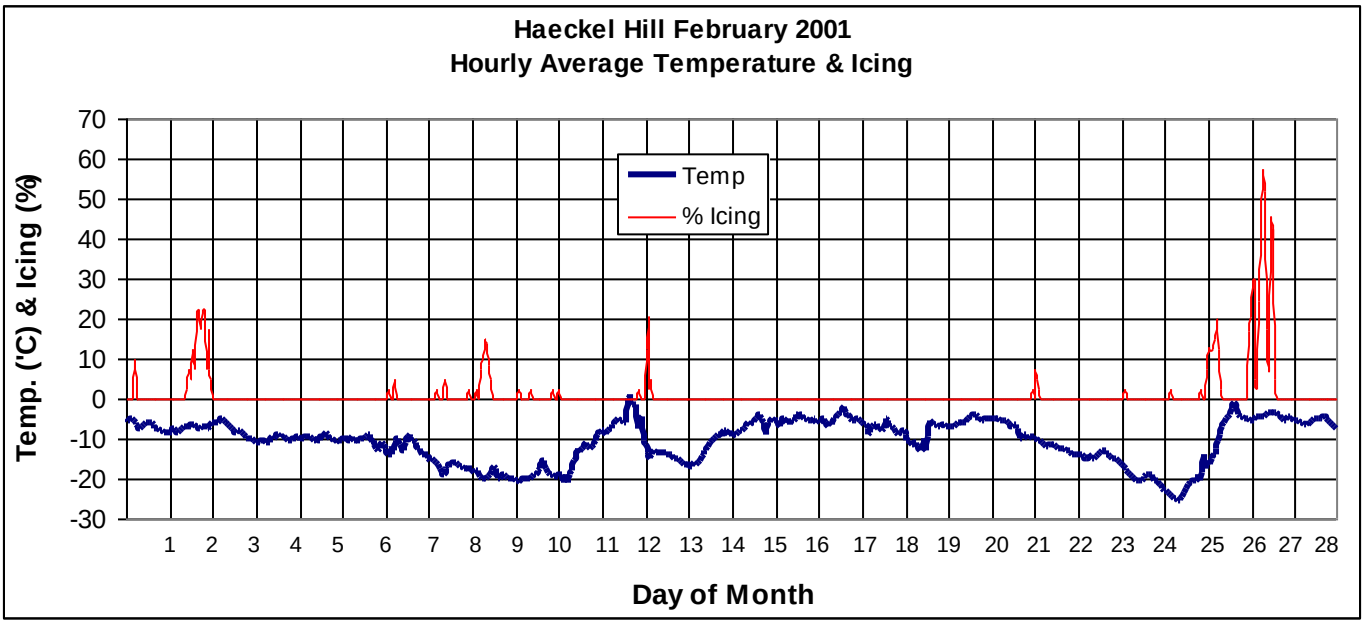


Figure 30. Haeckel Average Daily Wind Speeds
January 2001 - June 2001
Note: Vertical bar is +/- 1 Standard Deviation
Wind Speed (m/s)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
4
8
12
16
20
24
Hour of Day
NRG
TC Icing Removed
TC Icing Inc.

Haeckel Hill Icing and Temperature Monthly Graphs
January 2001 to June 2001





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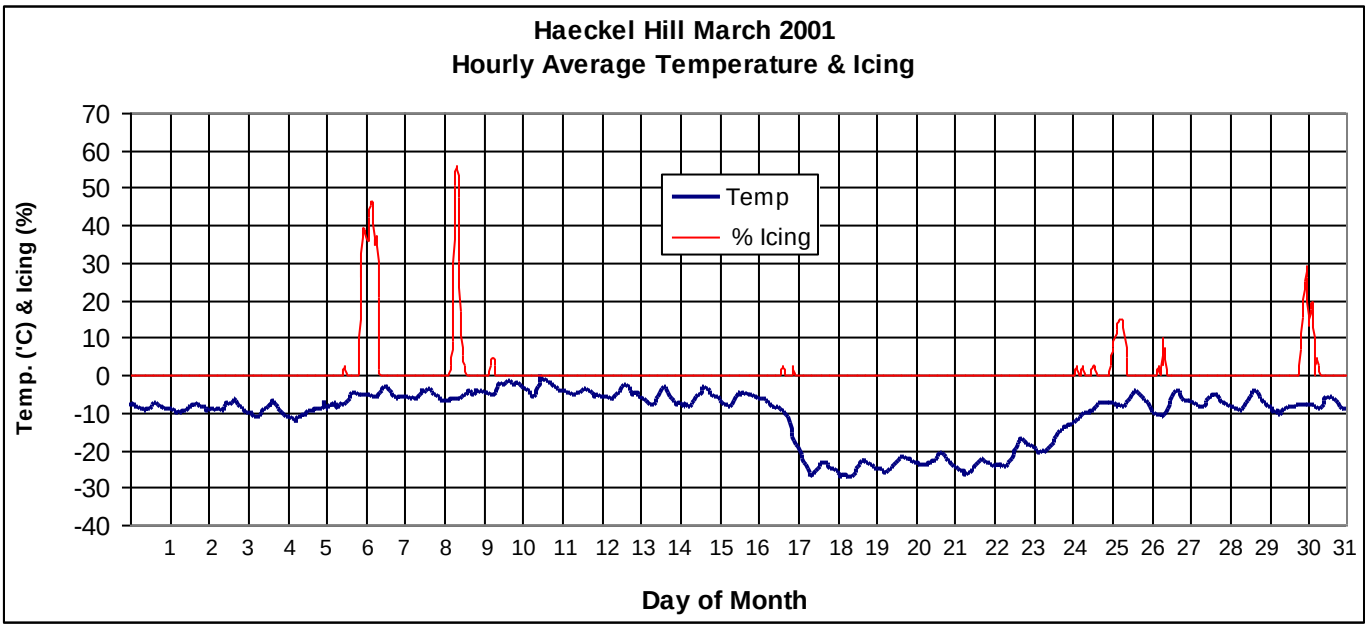

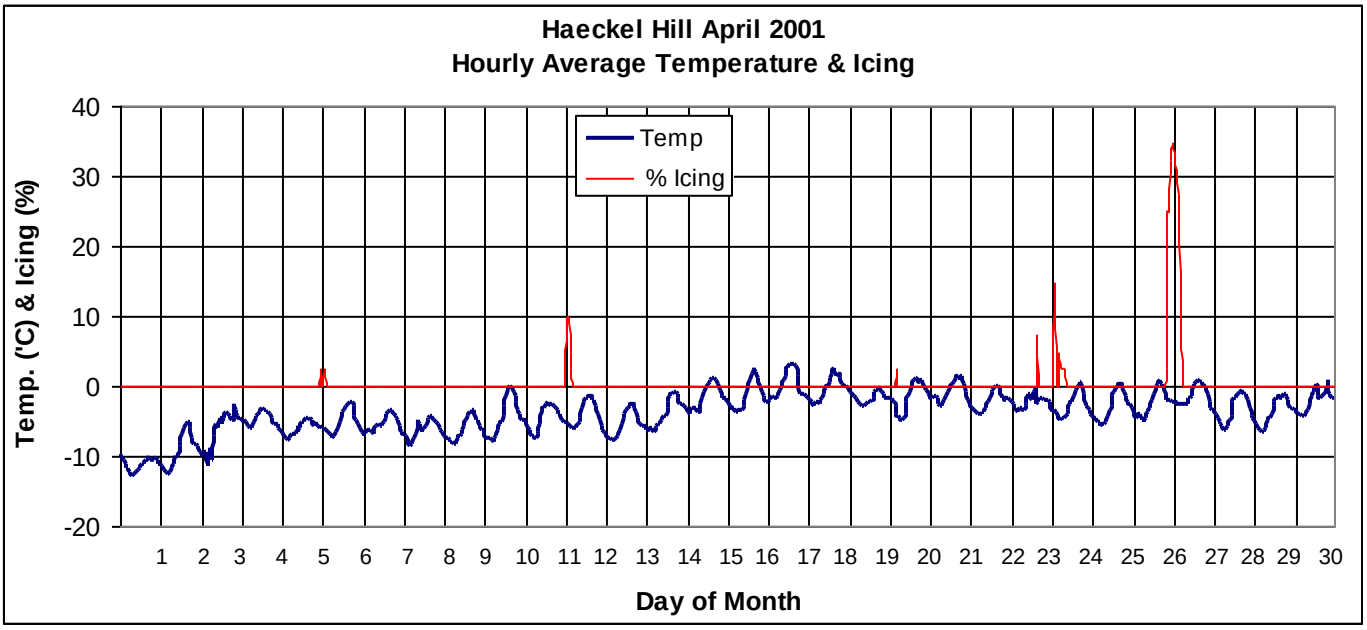

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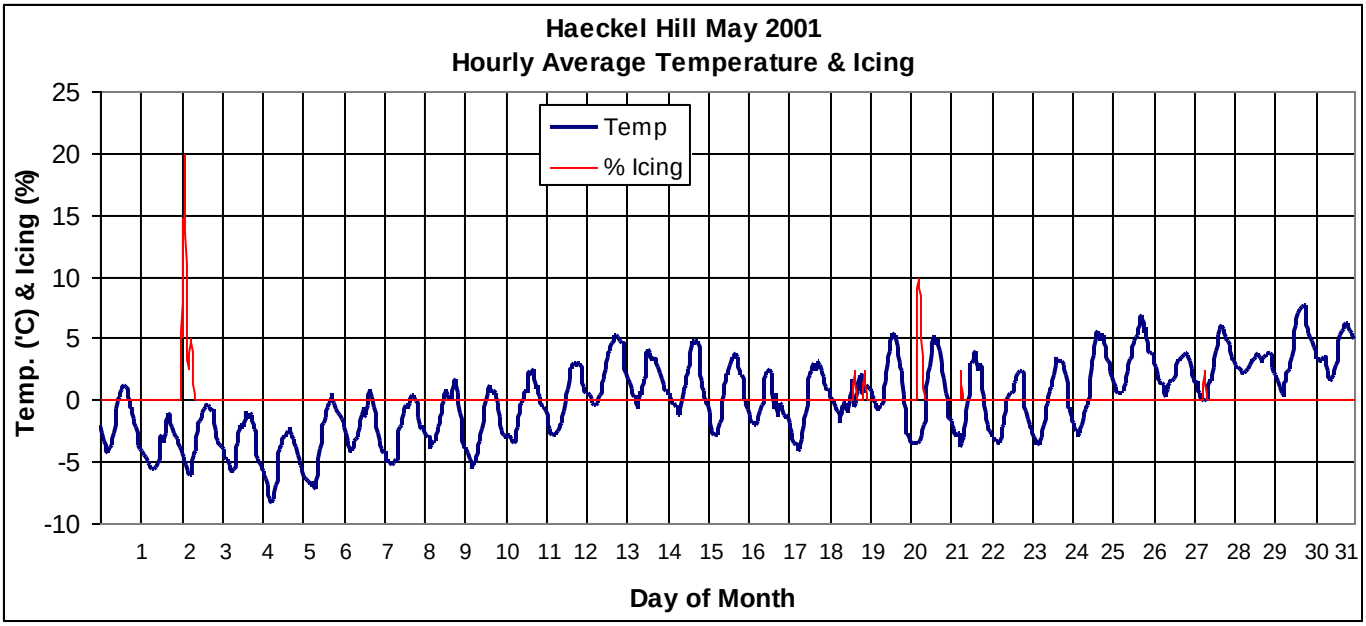

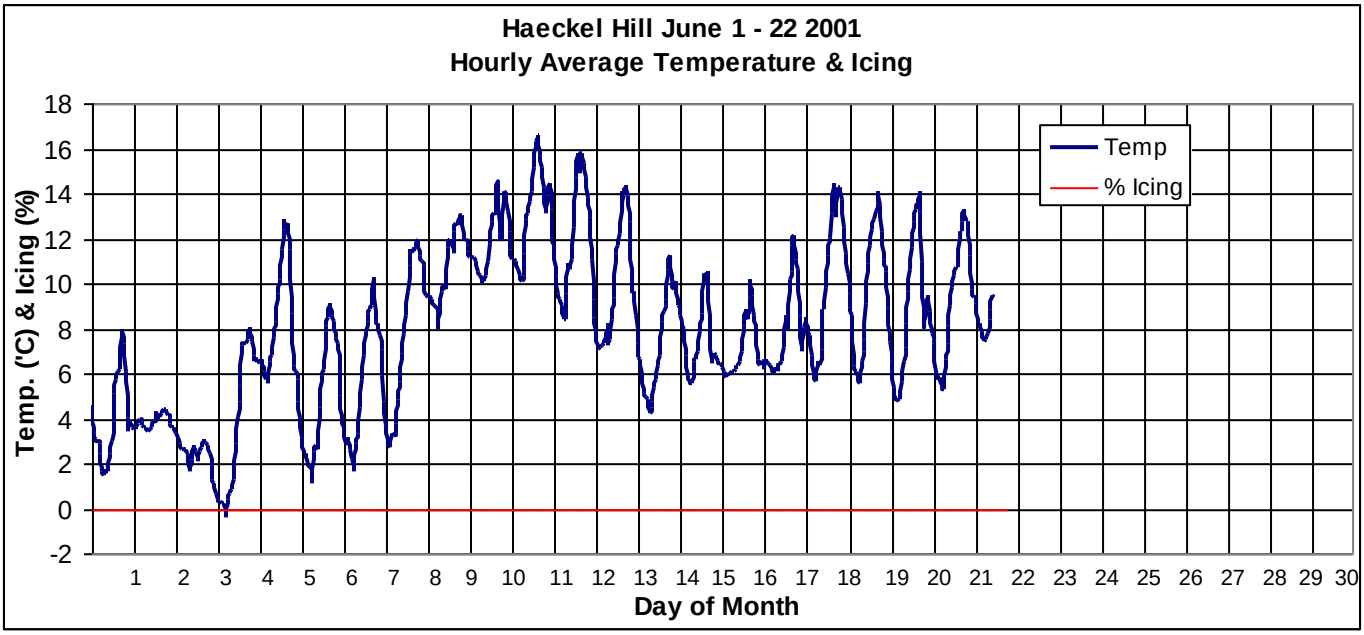

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