Wind Energy Resource Assessment Report

Delivered to
City of Chignik Bay, Alaska

March 30, 2006

Prepared by

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Wind Energy Resource Assessment Report

City of Chignik Bay, Alaska *March 30, 2006*

Executive Summary

Purpose

This report describes the results of a wind energy resource assessment conducted for the City of Chignik, Alaska. The Alaska Department of Community and Economic Development funded the assessment. The Administration for Native Americans also supported the assessment in its early stages.

The assessment characterizes the quality of the local wind energy resource. It is a first step toward an evaluation of the engineering and economic potential for power generation from wind turbines in the community. The rationale for pursuing wind power generation arises primarily from the economic benefit of reducing local electric utility costs and associated risk. Uncertain future costs of diesel fuel consumption are replaced with certain debt maintenance costs from initial investment in wind generation equipment. Chignik relies entirely on diesel fuel for power, apart from a private local entity that self-generates from a small hydroelectric plant. Secondary economic benefits include greater local retention of ongoing utility costs in the form of employment for operation and maintenance.

Site Description

The City of Chignik wraps around Anchorage Bay, a natural harbor on the Gulf of Alaska, located 460 miles southwest of the city of Anchorage. The harbor faces northeast and backs up to mountains of the Alaska Peninsula National Wildlife Refuge. Several peaks over 2600 feet are within 3 miles of Chignik's new port facilities. The 8000-foot Mt. Veniaminof volcano lies 38 miles to the west-southwest. Proximity to the Gulf and these mountains tempers Chignik's climate, seldom allowing air temperatures outside a range of 15° to 70°F.

The met tower site was determined in August 2002 based on local knowledge of winds, proximity to Chignik's electrical grid, physical accessibility, and distance from taller landforms to the south and southeast. The site is approximately a third of the distance out from the base of a peninsula running 2½ miles north-northeast along the western shore of Anchorage Bay. Known as *Mud Bay Hill* for the shallow body of water it separates from Anchorage Bay, the peninsula is covered with thick, low vegetation. The site is approximately at the midpoint of the east-west width of the peninsula. Its elevation is 464 feet above mean sea level with coordinates of N56°18.54', W158°25.00' (WGS84). The peninsular ridge rises another 80 feet to its high point approximately nine tenths of a mile away as it extends to the northeast from the site. To the southwest the peninsula rises 20 feet over a distance of 500 yards before leveling and gradually falling about 100 feet to a saddle over the next 1200 yards. The site is above the local landfill and is known to attract brown bear.

Results

Conclusions

The wind resource at the *Mud Bay Hill* site has a class 6 wind power density on a scale to 7. It has a mean annual observed windspeed of 6.66 meters per second (m/s) (14.9 mph) and a mean annual wind power density of 574 Watts per square meter.

A class 6 wind resource signals a good economic development potential. Evaluations of the engineering and economic potential for wind power generation should be set in motion based on these results. Such evaluations, however, should not presume that *Mud Bay Hill* is a preferred site.

While a class 6 resource, the *Mud Bay Hill* site suffers from very high turbulence. The site has a 22 percent mean annual turbulence intensity when all windspeeds above 4 m/s are included. The observed level of turbulence is along the design edge of the International Electrotechnical Commission's (IEC) IEC 61400-1 standard for wind turbine safety and design. This *particular site* cannot be recommended for turbine development due to this turbulence.

Recommendations

The class 6 resource atop *Mud Bay Hill*, at just 464 feet above sea level, suggests nearby higher locations may have still higher power densities. Alternative sites where less turbulence can be expected should be evaluated. Foremost among these is *Chignik Head* atop Lumber Bay Ridge on the opposite side of Anchorage Bay from Mud Bay Ridge.

Turbulence at the *Mud Bay Hill* site discourages use of typical upwind, horizontal-axis wind turbines. Vertical-axis turbines less subject to fatigue from turbulence might be considered also as an alternative for use on *Mud Bay Hill*. These generators are an increasingly smaller category of installed wind capacity in the world but continue to be developed.

Investigations should be started regarding an alternative site atop *Chignik Head* on Lumber Bay Ridge. Parallel inquiries into these five issues should be begun:

- Contact Federal Aviation Administration regarding proximity to airport and aircraft flight paths
- Contact US Fish and Wildlife Service regarding proximity to flight paths of endangered Steller's and Spectacled Eiders
- Contact Far West Native Corporation regarding permission for general access and permission to develop limited physical access
- Examine possible physical approach routes to site and soil composition at site
- Examine possible physical approach routes for electric utility inter-tie

Introduction

This report describes the results of a wind energy resource assessment conducted for the City of Chignik, Alaska. The Alaska Department of Community and Economic Development funded the assessment. The Administration for Native Americans also supported the assessment in its early stages by funding purchase of the meteorological (met) tower and associated data acquisition equipment.

This assessment represents the step prior to an evaluation of the engineering and economic potential for wind power generation in the community. The rationale for pursuing wind power generation arises primarily from the economic benefit of reducing local electric utility costs and associated risk. Uncertain future costs of diesel fuel consumption are replaced with certain debt maintenance costs from initial investment in wind generation equipment. Chignik relies entirely on diesel fuel for power, apart from a private local entity that self-generates from a small hydroelectric plant. Secondary economic benefits include greater local retention of ongoing utility costs in the form of employment for operation and maintenance.

Site Description

The City of Chignik wraps around Anchorage Bay, a natural harbor on the Alaska Peninsula 460 miles southwest of the city of Anchorage. Facing northeast toward the Gulf of Alaska, Chignik backs up to steep slopes of the Alaska Peninsula National Wildlife Refuge. Several peaks over 2600 feet elevation and several topping 2200 feet are within 3 miles. Chignik is 38 miles east-northeast of the 8000-foot Mt. Veniaminof volcano. Figure 1 shows maps of the region and of the location of the met tower. Figure 14 and Figure 15 show additional maps with greater resolution.

The met tower site was determined in August 2002 based on local knowledge of winds, proximity to Chignik's electrical grid, physical accessibility, and distance from taller landforms to the south and southeast. The site is approximately a third of the distance out from the base of a peninsula running 2½ miles north-northeast along the western shore of Anchorage Bay. Known as *Mud Bay Hill* for the shallow body of water it separates from Anchorage Bay, the peninsula is covered with thick, low vegetation. The site is approximately at the midpoint of the east-west width of the peninsula. Its elevation is 464 feet above mean sea level with coordinates of N56°18.54', W158°25.00' (WGS84). The peninsular ridge rises another 80 feet to its high point approximately nine tenths of a mile away as it extends to the northeast from the site. To the southwest the peninsula rises 20 feet over a distance of 500 yards before leveling and gradually falling about 100 feet to a saddle over the next 1200 yards. The site is above the local landfill and is known to attract brown bear.

Proximity to the Gulf of Alaska and mountains tempers Chignik's climate. Air temperatures seldom range outside of 15°F to 70°F. These temperatures contribute to a better wind resource as they result in more dense air.

Due to friable rock below a shallow layer of loose organic matter at the site, setting of the four guy and one lifting anchor for the meteorological tower required excavation and placement of dead-men fashioned from salvaged steel plate. Excavated rock rubble buried these five anchors.

Figure 1 Chignik Maps Showing Region and Met Tower Location

Wind Data

Data Collection

Data collection began in mid-August of 2004 and continues as of the date of this report. The continued data collection may prove useful in further wind resource assessments in Chignik. Data used in this assessment include the period from August 15, 2004, through February 7, 2006. This period provides 539 complete days of un-interrupted data collection over 19 months during three years.

Data collection beyond the minimum 12-month period makes the resource assessment more robust. The assessment combines data by calendar months to create a composite year. A composite mitigates influences of exceptional weather that could misrepresent the long-term wind resource. Table 1 lists each of the 19 months during which some data were recorded. The rows of Table 1 are ordered by month number for comparison of specific month and year contributions to the composite year.

Table 1 Summary of Observed Data Records

Month	Year	Observation count	Percent of composite year	Percent of composite month	Hour count
1	2005	4464	5.7%	50%	744
1	2006	4464	5.7%	50%	744
2	2005	4032	5.2%	80%	672
2	2006	990	1.3%	20%	165
3	2005	4464	5.7%	100%	744
4	2005	4320	5.5%	100%	720
5	2005	4464	5.7%	100%	744
6	2005	4320	5.5%	100%	720
7	2005	4464	5.7%	100%	744
8	2004	2442	3.1%	35%	407
8	2005	4464	5.7%	65%	744
9	2004	4320	5.5%	50%	720
9	2005	4320	5.5%	50%	720
10	2004	4464	5.7%	50%	744
10	2005	4464	5.7%	50%	744
11	2004	4320	5.5%	50%	720
11	2005	4320	5.5%	50%	720
12	2004	4464	5.7%	50%	744
12	2005	4464	5.7%	50%	744

The months from April through July each included only one actual observed month. The composite month of February depends primarily on February 2005 as only 165 hours were collected in February 2006 before this resource assessment began final data processing. Unless stated otherwise, this report strictly describes results unbiased by the greater amount of data collected between the months of September through January when mean windspeeds are higher.

Data Sensors

An NRG Symphonie™ wind data acquisition system recorded data from five sensors. Table 2 lists the five sensors and their installation details. The sensor sampling interval was 2 seconds, and the recording interval was 10 minutes. Each record includes a mean, standard deviation, maximum, and minimum values for the 10-minute period.

Table 2 Sensor Installation Detail

Channel	Sensor Type	Height	Boom Orientation from Tower
1	#40 Anemometer	20 m.	324° True
2	#40 Anemometer	30 m.	(above tower)
7	#200P Wind Vane	30 m.	184° True
9	#110S Temperature	3 m.	339° True
10	LI-200SA Pyranometer	2 m.	84° True

An NRG 30-meter tall, 114-millimeter diameter guyed-tower held the five sensors and data logger. For better visibility to aircraft, Chignik project staff painted alternating 1-foot bands of red, white, and yellow on the upper-half of the galvanized-tube tower before raising it. For better visibility to airborne fowl, they also attached plastic surveyor's tape to the guys at regular intervals.

During regular site visits to verify operation and tower integrity, Chignik project staff exchanged data chips in the NRG Symphonie™ recorder. Independence Power and Energy received these data via email and reviewed them for veracity and potential problems. The pyranometer sensor did not record irradiance properly so its data were not considered.

Magnetic directional indices for the sensors were recorded by handheld compass. The site's February 2005 magnetic declination of 15°41' W corrected these to indices to true north bearing. The wind vane's north index was aligned *toward* the tower. The directional offset used in data analysis thus was +4°19'. The vane's known 8° deadband around the index thus tended to represent winds from 0° to 8° as being from 0°. This tendency had little impact on the assessment as less than two percent of observed mean directions were between 350° and 10° and winds from this bearing were characteristically unenergetic.

The upper anemometer was mounted on a short, vertical boom extending above the tower tube. This placement avoided lateral turbulence from wind-shadowing by the tower itself. The lower anemometer necessarily was installed on a side-boom. The tower shadow would have caused reduced windspeed observations for southeasterlies for the lower anemometer. Such lower values would yield higher wind shear exponents from that bearing. As results below indicate, the frequency of winds from a generally southeast direction exceeded 10 percent only in the months of February, March, and December. These winds were particularly energetic only in February when they contributed approximately 20 percent of the month's total wind energy. February did exhibit the highest wind shear exponent of 0.19. This wind-shadow effect otherwise had little impact on the assessment because the results fundamentally rely upon from the upper anemometer that is not shadowed.

Data Validation and Processing

Several validation procedures were used to identify and manage suspect data records that might misrepresent the wind resource. The procedures flagged suspect observations for selective treatment in subsequent data processing.

Sensor Operating Ranges

Observations were compared to known sensor operating ranges. No observations from either anemometer exceeded the 96 m/s (215 mph) upper limit of their operating range. Observations below the lower limit of 1 m/s (2.24 mph) were all non-negative. Likewise no observations from the vane or thermometer were outside their operating ranges. Much of the pyranometer's irradiance data were suspect and not processed for this assessment.

Ice Accumulation on Sensors

Proximity to the Gulf of Alaska created ample opportunity for ice accumulation on sensors. Icing of the #40 anemometers has been shown experimentally to reduce windspeed observations by up to 40 percent while cup rotation continues. Severe icing completely stops cup rotation and yields windspeed observations of zero.

The time for ice to accumulate and dissipate depends on temperature, windspeed, and water content of the air. These factors make it very difficult to identify windspeed data influenced by icing. Several sensor-icing data filters were considered to identify suspect windspeed observations. A key filter parameter was the observed standard deviation of the #200P wind vane mounted within several feet of the upper anemometer. With motion far less dynamic than the anemometer, it is more quick to accumulate and more slow to shed ice.

Data filtering results were compared graphically with trends in windspeeds recorded during temperatures well above freezing. Sensor threshold values were adjusted to flag clearly suspect data while avoiding flagging data that might be valid. Table 3 lists the threshold values chosen to flag observations as suspect due to sensor-icing. A temperature threshold above 32°F accounted for potential temperature gradient from location of thermometer near the tower base.

Table 3 Sensor-Icing Data Filter Criteria

Channel	Sensor Type	Height	Threshold Value
1	#40 Anemometer	20 m.	Standard deviation = 0
2	#40 Anemometer	30 m.	Standard deviation = 0
7	#200P Wind Vane	30 m.	Standard deviation = 0
9	#110S Temperature	3 m.	<= 35°F

The criteria of Table 3 flagged 459 of 78,024 observations, less than 0.6 percent, of the data as suspect. To account for gradual accumulation and dissipation of icing (although the latter may be sudden), additional data were flagged for the hour prior and the half-hour after suspect observations. This expanded filter brought the total to 1227 suspect observations, 1.58 percent of all observed data, or 205 total hours. Table 4 lists by year and month the numbers of suspect observations, their total hours, and percent of the month. Suspected icing was most frequent in December 2004 and February 2005, each with over 30 total hours of suspect observations.

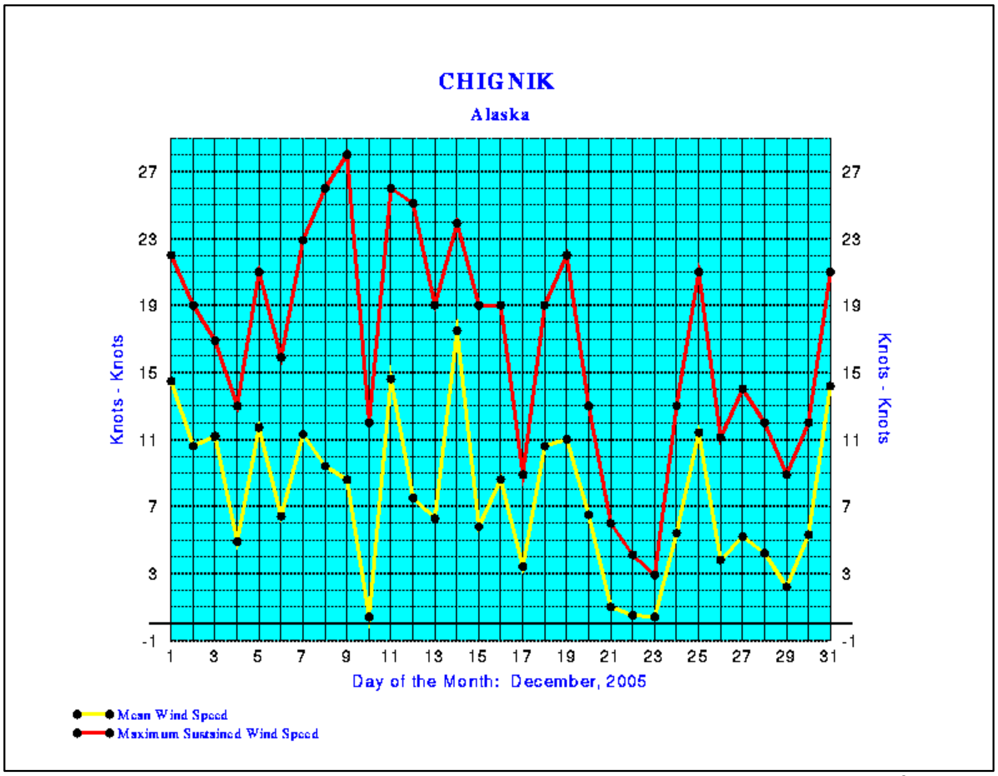
Table 4 Summary of Data Observations Suspected of Sensor-Icing

		Suspect Observations		
Year	Month	Count	Hour Total	Percent of month
2004	10	9	1.5	0.2%
2004	11	87	14.5	2.0%
2004	12	198	33.0	4.4%
2005	1	71	11.8	1.6%
2005	2	184	30.7	4.6%
2005	3	152	25.3	3.4%
2005	4	130	21.7	3.0%
2005	10	40	6.7	0.9%
2005	11	149	24.8	3.4%
2005	12	75	12.5	1.7%
2006	1	132	22.0	3.0%

Inclusion of icing-influenced observations underestimates a wind resource, but exclusion may underestimate or overestimate it. To avoid these problems, windspeed estimates were substituted for suspect observations. Various substitution approaches may be used when sensor-icing is suspected. The approach used here took advantage of data gathered beyond the accepted 12-month minimum data collection period. Actual, credible windspeed observations were substituted for suspect observations. Substitutes were selected at random, without replacement, from the same calendar month. Credible observations from December of 2004 and 2005, for example, were substituted for suspect observations in those same months. February, March, and April were the only months with suspect observations but without two full months from which to select random substitutes. Appendix A provides charts of the 19 months of observed data showing substituted estimates in a different shade. The suspect observations are not shown.

A singular instance of suspect data in December 2005 was not flagged by the data filter. From the night of the 20th to the afternoon of the 23rd, with observed temperatures above 35°F, the data showed three days of uncharacteristically absent wind. These observations were retained unchanged in the assessment, however, as a query of daily mean data from the National Climatic Data Center (NCDC) for the Chignik AWOS station data confirmed this unusual lull. Figure 2 shows the NCDC global summary of the day data plot for December 2005, with mean wind speeds below 0.5 m/s (1 knot) from the 21st through the 23rd.

Figure 2 Chignik AWOS Global Summary of Day, December 2005



Source: National Climatic Data Center Climate Visualization, CLIMVIS, Global Summary of the Day

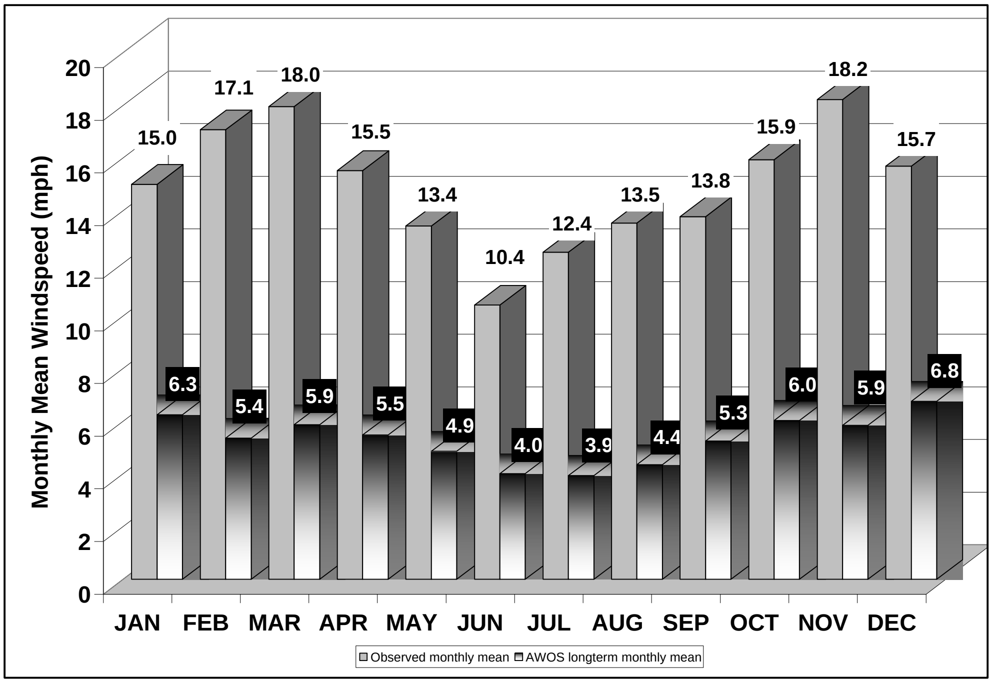
Comparison of Observed and Historical Data

A comparison of observed and historical windspeed data was possible using mean data observed at Chignik's AWOS weather station. Figure 3 shows monthly means for the observed and historical data in units of miles per hour. The AWOS station data were recorded at an elevation of only 30 feet above ground level and were influenced by the station's low elevation relative to nearby ridges and mountains. The comparison nevertheless was useful as a reference to the historical trend.

AWOS monthly mean windspeeds based on the period from February 1998 through September 2002 show the same general trend toward slower speeds in summer as the observed data. AWOS data show peaking monthly means in January and December. In contrast, the observed data show peaking windspeeds to be in March and November, with January being a relatively slow month.

The historical AWOS data compared well with the observed data, providing a general confirmation of the latter. The dramatic topographic relief of the Chignik area could easily explain far greater differences than those found between these two data sets.

Figure 3 Observed and AWOS Long-term Monthly Mean Windspeeds



Data Reduction

Raw data were validated, processed, and further results calculated and tallied using the SAS statistical software package. Results were exported into Microsoft Excel workbooks for creation of tabular and graphical summaries.

The 13,004 hours of observed data were reduced to a composite 12-month year by combining data by calendar month. This composite approach makes a more robust resource assessment than could be made from a minimum 12-month data collection period. .

Summary of Results

Wind Resource Characterization

- **Class 6 wind resource**

Wind Power Density and Speed

The wind resource at the *Mud Bay Hill* site is very strong. The observed mean annual windspeed is 6.66 m/s (14.9 mph). The mean annual windspeed adjusted for air at standard density.[1] is 6.75 m/s (15.1 mph). The mean annual wind power density is 574 Watts per square meter. At 30 meters above ground level this is in the middle range of the class 6 wind power density category, considered an excellent resource for economic development of wind energy. Appendix B shows power density ranges by wind power class and elevation of recording. Figure 4 shows the monthly distribution of mean wind power densities at standard air density. These values yield the mean annual power density of 574 Watts per square meter

The resource at this site is very turbulent, however, and so *this particular site* cannot be recommended for typical horizontal-axis wind turbines. High levels of turbulence can batter and shorten the operating life of turbine blades and components.

Figure 4 Observed Monthly Mean Wind Power Densities

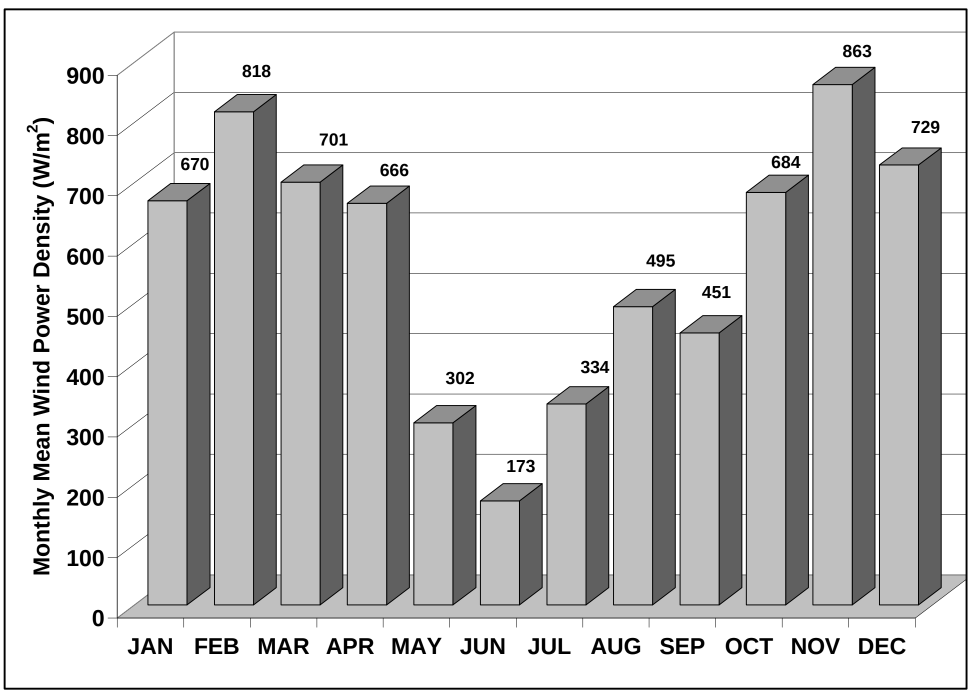


Figure 5 shows mean monthly windspeeds in m/s. The annual profile differs from the wind power density profile of Figure 4 because of the cubic exponent on windspeed term in the calculation of power density. The colder, more dense winter air also lifts the profiles of the

[1] Standard air density is 1.225 kg per cubic meter at 15°C, 1013.25 mbar and 50% relative humidity.

winter months. Figure 6 shows the distribution of annual percentage of time by windspeed bins in m/s. Fitted to the speed distribution data is a Weibull curve. Weibull parameters are used to describe a wind resource when modeling energy production from wind turbines.

Figure 5 Observed Monthly Mean Windspeeds

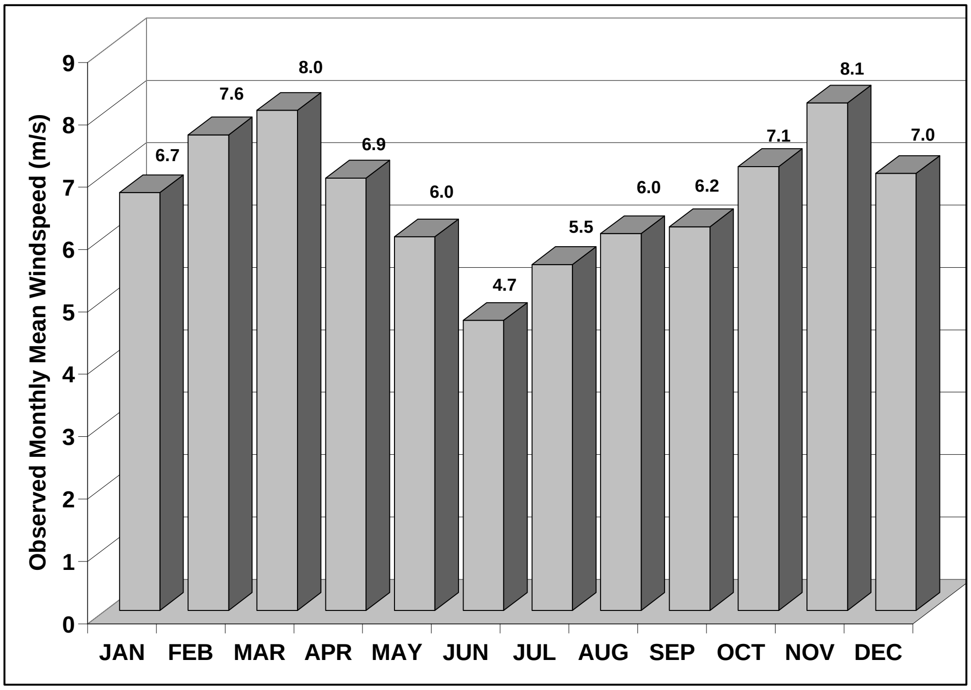
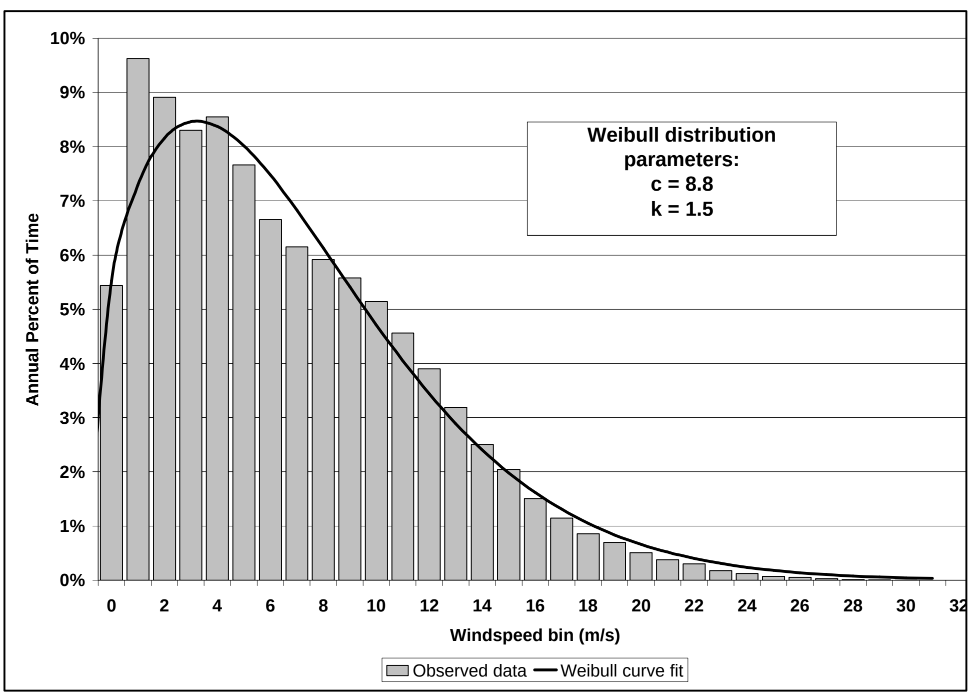


Figure 6 Observed Annual Windspeed Distribution



Westerly winds dominate the *Mud Bay Hill* site. Figure 7 provides a wind rose of annual energy percentages by 10° bins of true bearing. Upwards of 70-percent of the wind energy comes from between 245° and 275° bearings.

Figure 7 Observed Annual Wind Energy Percentages

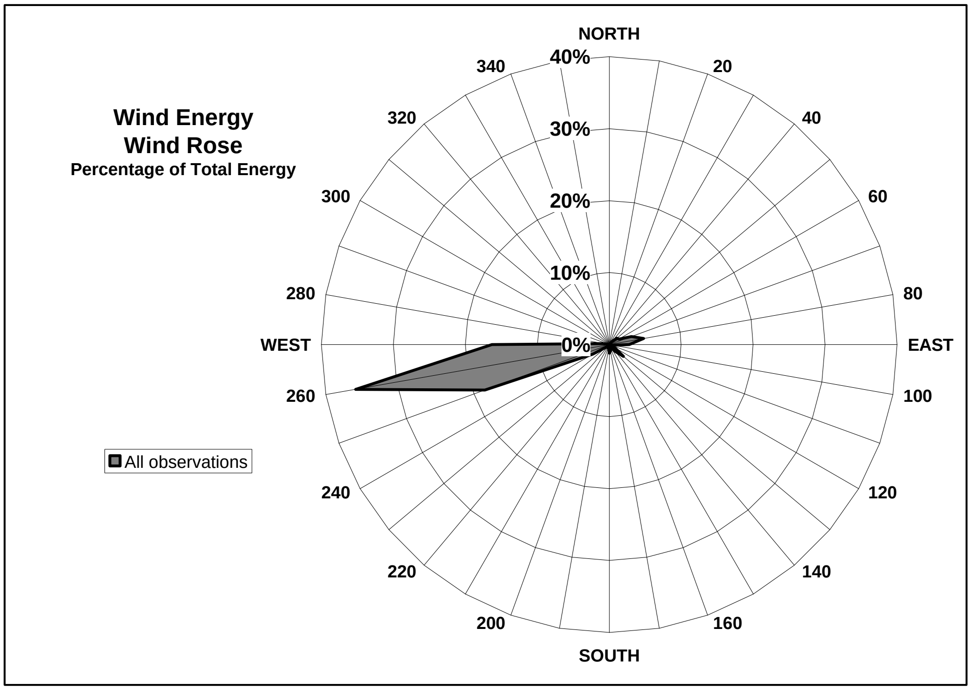


Figure 8 Observed Annual Wind Directional Percentages

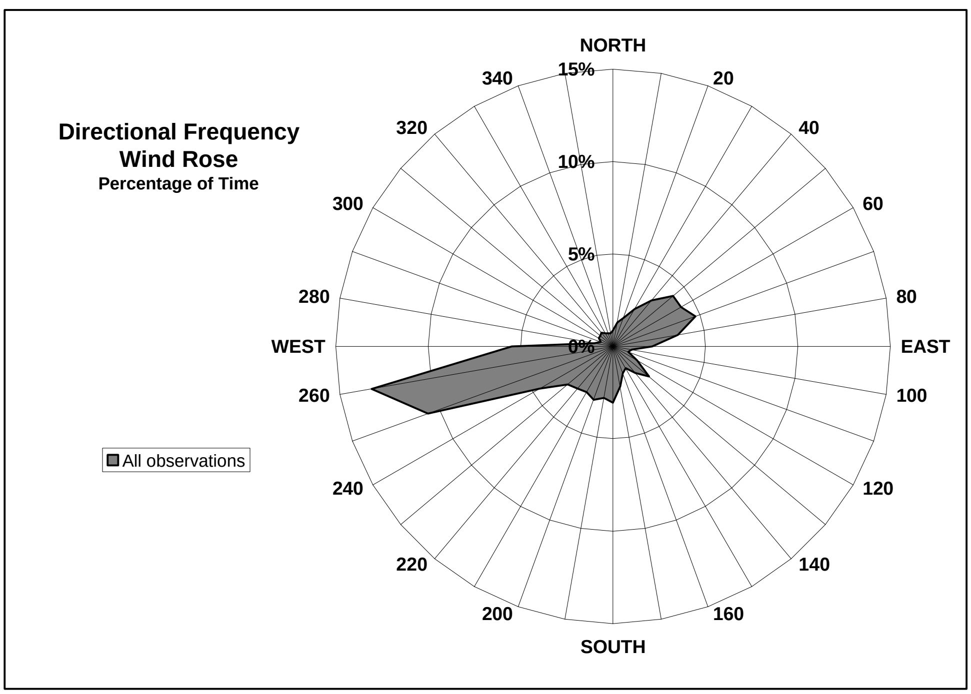


Figure 8 likewise provides annual time percentages by 10° bins. Westerly winds also dominate by direction, but northeasterly and southerly components are visible along with a distinct southeasterly spike. Appendix C and Appendix D provide energy and directional frequency wind roses respectively for individual months.

Turbulence Intensity

In addition to windspeed, wind turbulence is a critical characteristic of a wind resource. Turbulence can cycle turbine blades through repeated bendings, leading to fatigues and early component failures. Turbulence intensity is a simple characterization of the steadiness of windspeed over a time interval. Though imperfect as measure of potential turbine fatigue, turbulence intensity is used as a safety guide in planning turbine siting. As Equation 1 shows, it is defined as the ratio of the standard deviation of windspeed to the mean of windspeed for a given interval. The collected data included these terms for each recorded 10-minute time interval.

Equation 1
$$TI_i = \frac{s_i}{\bar{v}_i}$$

where TI_i = turbulence intensity over time interval *i*,

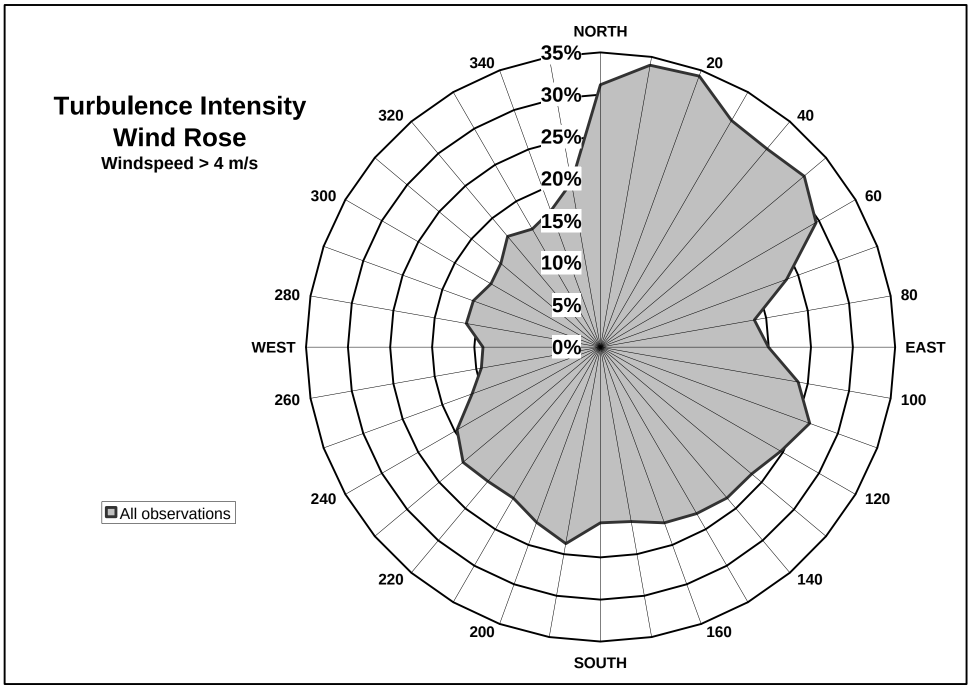
s_i = standard deviation from mean windspeed over time interval *i*,

$\bar{v}_i$ = mean windspeed over time interval *i*.

Turbulence intensity is most important at more energetic windspeeds when turbine blade bending and component stresses are greater. Turbulence intensity (*TI*) at slower windspeeds is of less concern since bending effect is less even though *TI* may be greater. A minimum mean windspeed of 4 m/s is considered when examining *TI*. Turbine safety design guidelines consider higher windspeeds, and some fatigue performance models use *TI* at 15 m/s as a basis.

The *Mud Bay Hill* site's mean annual *TI* for windspeeds over 4 m/s is 22 percent. This corresponds with values on the order of 20 percent expected for irregular terrain. Figure 9 shows a wind rose of the site's mean *TI* values binned every 10° according to true north bearing. The plot of Figure 9 is <u>biased</u>, that is, it is not for a composite year. The values plotted include all observations with windspeeds over 4 m/s. Observations from February through August are under-represented relative to other months, and so the data of Figure 9 would resolve to an mean annual *TI* above 22 percent. Figure 9 shows that the biased mean annual *TI* at the *Mud Bay Hill* site only briefly falls below 15 percent for windspeed in excess of 4 m/s.

Figure 9 Observed Annual Mean Turbulence Intensities for Windspeeds over 4 m/s (biased against summer months)



An unbiased *TI* wind rose with only windspeeds between 14 and 16 m/s is shown in Figure 10. This wind rose is for the month of November, the month with the highest power density. In November the *TI* regularly exceed 15 percent. Appendix E and Appendix F provide complete 12-month sets of unbiased *TI* plots for windspeeds in excess of 4 m/s and windspeeds between 14 and 16 m/s respectively. In both these sets lower *TI* can be seen in the mid-summer months that are under-represented in the biased plot of Figure 9.

The November wind rose of Figure 10 can be considered with respect to energy density and directional frequency for that month. Figure 11 and Figure 12 show wind roses by 10° bins of the percentages of mean total energy and of total time for the November. These two figures include all windspeeds, not simply observations over 4 or between 14 and 16 m/s. Figure 11 and Figure 12 show that November winds are predominantly from a 250° to 270° true bearing. The extreme *TI* values of Figure 10 tend not to be from that heading. The extreme *TI* values in the southeast quadrant do not have a corollary display in the wind energy rose of Figure 11, and only a small observed frequency in the directional frequency rose of Figure 12. Though perhaps reassuring, it must be remembered that the *TI* in the southeast quadrant are in excess of 14 m/s, and so are very energetic winds.

Figure 10 Observed November Mean Turbulence Intensities for Windspeeds between 14 and 16 m/s

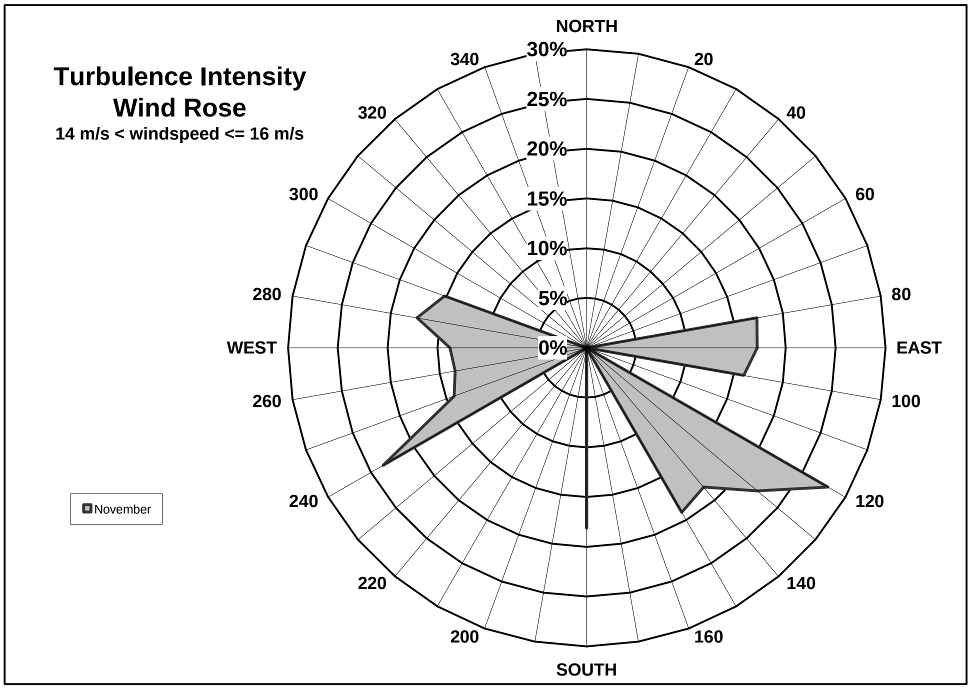


Figure 11 Observed November Wind Energy Percentages

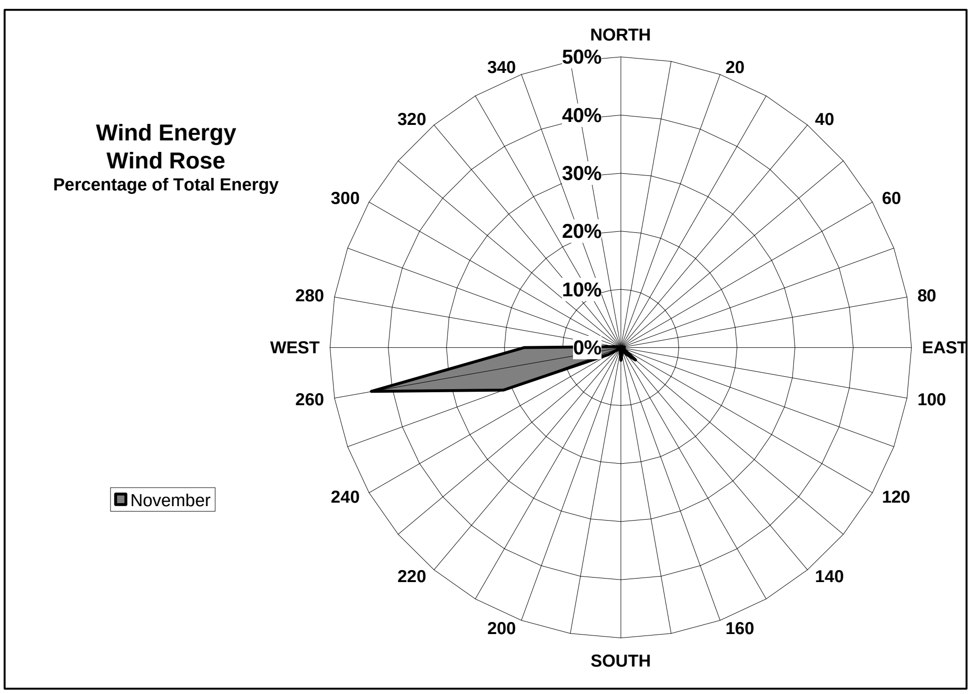
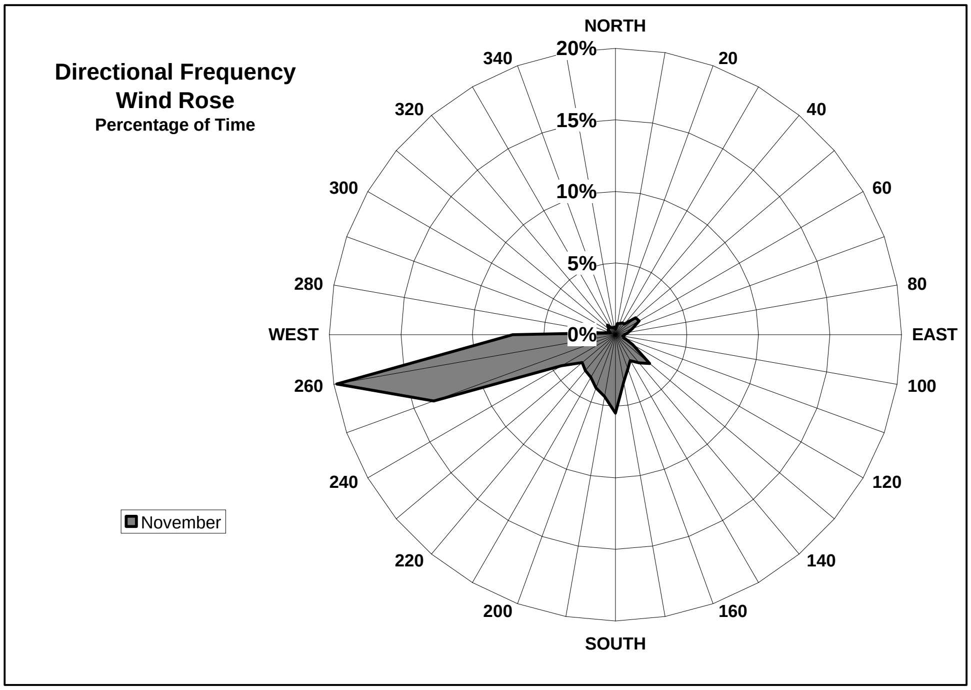


Figure 12 Observed November Wind Directional Percentages



The *TI* of the *Mud Bay Hill* site can be put in perspective relative to the International Electrotechnical Commission's (IEC) IEC 61400-1 standard for wind turbine safety and design. While continuing to be revised as the industry matures, standard IEC 61400-1 provides guidance on design *TI* values for turbine components. High and low mean design *TI* distribution curves have been developed over mean windspeeds from 4 to 24 m/s. In Appendix G, observed annual mean *TI* data by windspeed bins for *Mud Bay Hill* are plotted along side these high and low distribution curves. The *Mud Bay Hill* data are largely above one or both of these design curves, suggesting that turbine design limitations might be seriously challenged at that site.

Wind Shear

Wind shear is an indicator of the change in windspeed as elevation above ground changes. Higher wind shear values indicate greater value in increasing turbine height above ground to avoid surface effects such as vegetation that slow the wind. Wind shear measurement requires anemometers at two heights. The collected data included windspeeds at 20 and 30 meters above the ground.

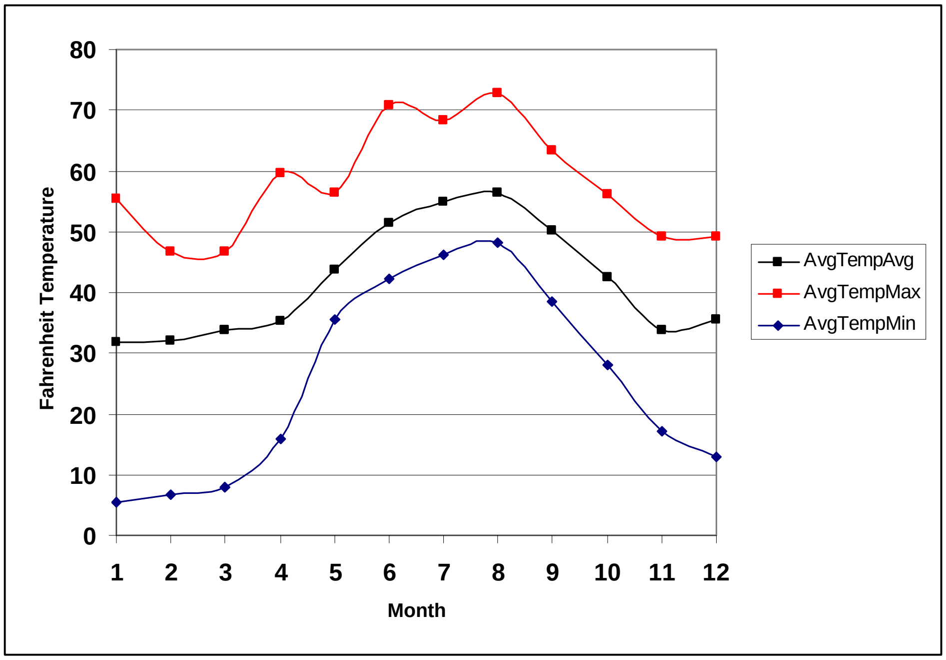
The observed mean monthly wind shears at the *Mud Bay Hill* site range from a low of 0.11 in November to a high of 0.19 in February. The lower value is in the range expected for winds crossing open water with few surface effects slowing it. The upper value is in the range expected for rough surfaces or very turbulent winds. The *Mud Bay Hill* mean annual wind shear value is 0.14, a value very close to the generally presumed exponent rule of $1/7^{th}$.

The mean annual wind shear value indicates that there is not a strong need to erect a taller turbine tower to capture more energetic winds.

Air Temperature

Air temperature influences wind power density. Colder air is more dense and so is more powerful than warmer air at the same windspeed. Although it cannot enjoy the subzero winds of Kotzebue, Chignik benefits from its generally chilly temperatures throughout the year.

Figure 13 Observed Mean, Maximum, and Minimum 10-minute Average Temperatures



Conclusions and Recommendations

Wind Resource Quality

The wind resource at the *Mud Bay Hill* site has a class 6 wind power density on a scale to 7. It has a mean annual observed windspeed of 6.66 meters per second (m/s) (14.9 mph) and a mean annual wind power density of 574 Watts per square meter.

A class 6 wind resource signals a good economic development potential. Evaluations of the engineering and economic potential for wind power generation should be set in motion based on these results. Such evaluations, however, should not presume that *Mud Bay Hill* is a preferred site.

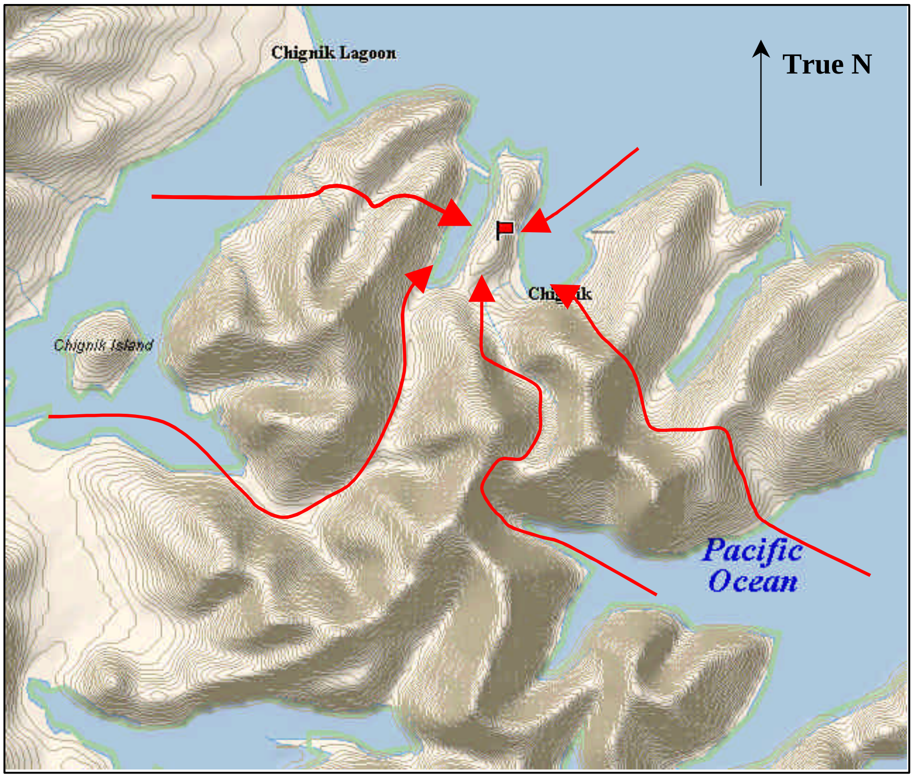
While a class 6 resource, the *Mud Bay Hill* site suffers from very high turbulence. The site has a 22 percent mean annual turbulence intensity when all windspeeds above 4 m/s are included. The observed level of turbulence is along the design edge of the International Electrotechnical Commission's (IEC) IEC 61400-1 standard for wind turbine safety and design. This *particular site* cannot be recommended for typical upwind, horizontal-axis wind turbines. Vertical-axis turbines less subject to fatigue from turbulence might be considered for use on *Mud Bay Hill*. These generators are an increasingly smaller category of installed wind capacity in the world but continue to be developed.

Consider Alternative Sites

The class 6 resource atop *Mud Bay Hill*, at just 464 feet above sea level, suggests nearby higher locations may have still higher power densities. The observed high power density and turbulence suggest consideration of alternative sites with less turbulence potential. The predominance of westerly winds suggests alternative sites with better westerly exposure. The turbulence observed from the less energetic northeast and southeast quadrants suggest exposure in those directions be considered as well. Foremost among alternative sites where less turbulence can be expected is *Chignik Head*, atop Lumber Bay Ridge on the opposite side of Anchorage Bay from Mud Bay Ridge.

The turbulence at the *Mud Bay Hill* site may be explained by reviewing the terrain in light of the observed data. Figure 14 shows the *Mud Bay Hill* site and several wind approach paths. The westerly approach traverses two substantially higher ridges within three miles of the site. Figure 15 shows a profile of a westerly approach and the heights of those two ridges and the *Mud Bay Hill* ridge. These high ridges are likely causes of turbulence. Approaches from the southwest to the southeast are circuitous and likely to have high turbulence. The *TI* roses of Appendix F, and to a lesser extent those of Appendix E, confirm this. Although it has far more fetch, the northeasterly approach also exhibits high turbulence. This perhaps results from the steep cliff faces of the eastern side of the *Mud Bay Hill* ridge to the northeast of the site

Figure 14 Wind Approaches to Mud Bay Hill Site



An attractive alternative site worth considering is the *Chignik Head* high point atop Lumber Bay Ridge that encloses Anchorage Bay from the eastern side. Over 600 feet higher than the *Mud Bay Hill* site, *Chignik Head* has over two more miles of fetch from the two ridges over which westerlies must pass. Figure 16 provides a view of *Chignik Head* and Lumber Bay Ridge looking west from offshore of Jack's Bay. The vertical relief of Figure 16 is exaggerated by a factor of two for emphasis. Figure 17 shows a profile of a westerly approach to *Chignik Head* and its height along with the heights of those two ridges and the *Mud Bay Hill* ridge. These heights are not exaggerated.

The *Chignik Head* site is anticipated to have less turbulence overall and a potentially higher mean annual power density. Turbulence from the northeast quadrant may pose a problem given the rather steep grade in that direction. Greater issues for wind development, however, are proximity to the airport, proximity to waterfowl flight paths, land ownership and general access, physical accessibility, and its distance from the existing electric utility infrastructure.

Figure 15 Westerly Approach Profile to Mud Bay Hill Site

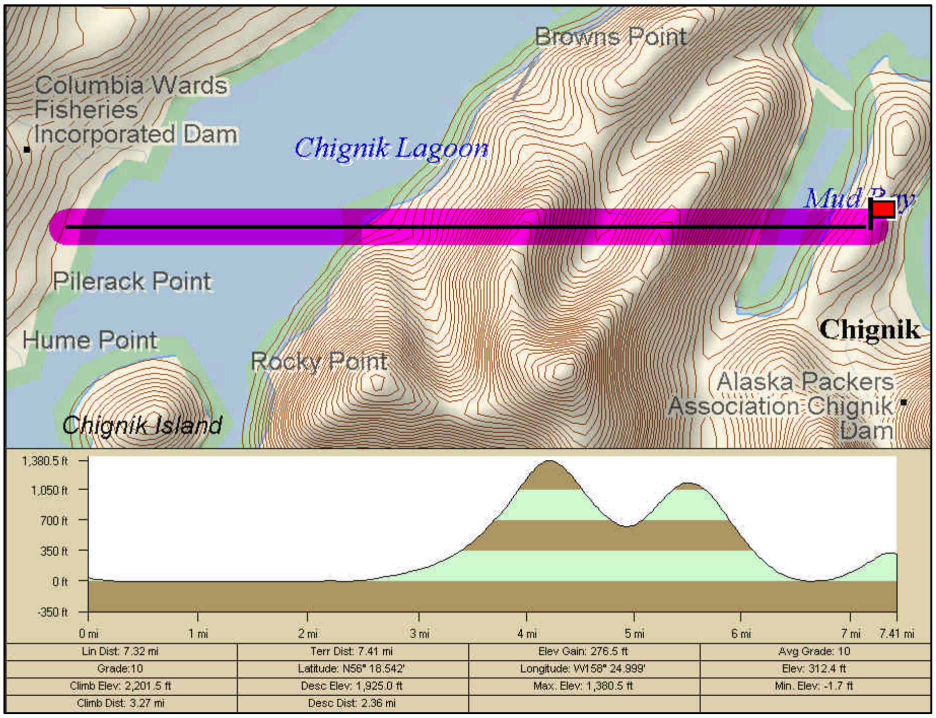


Figure 16 Potential Alternative Site of Chignik Head atop Lumber Bay Ridge, Looking West

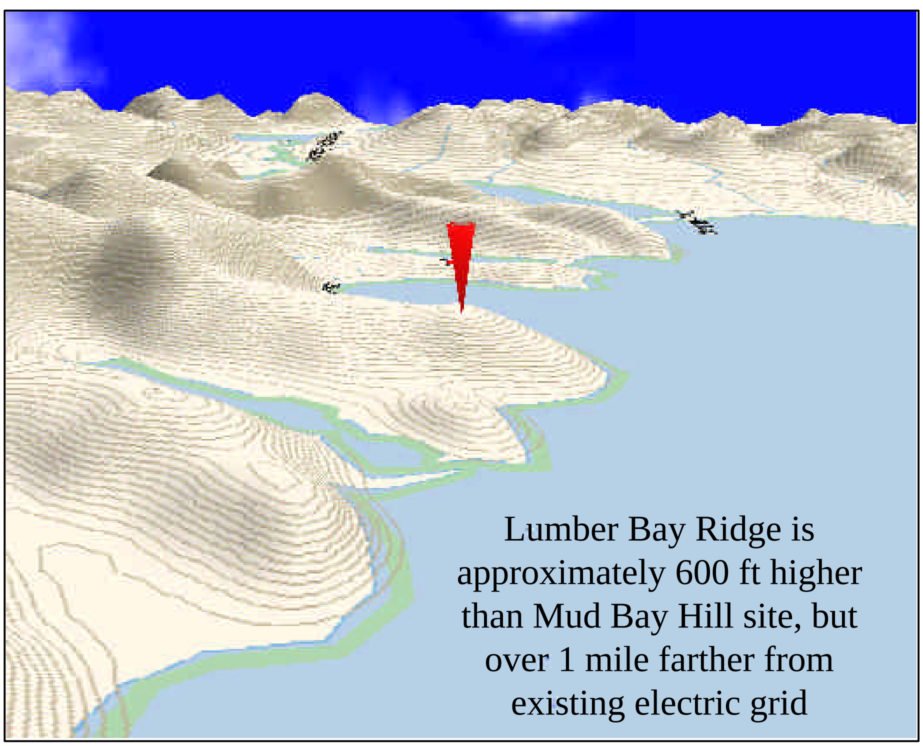
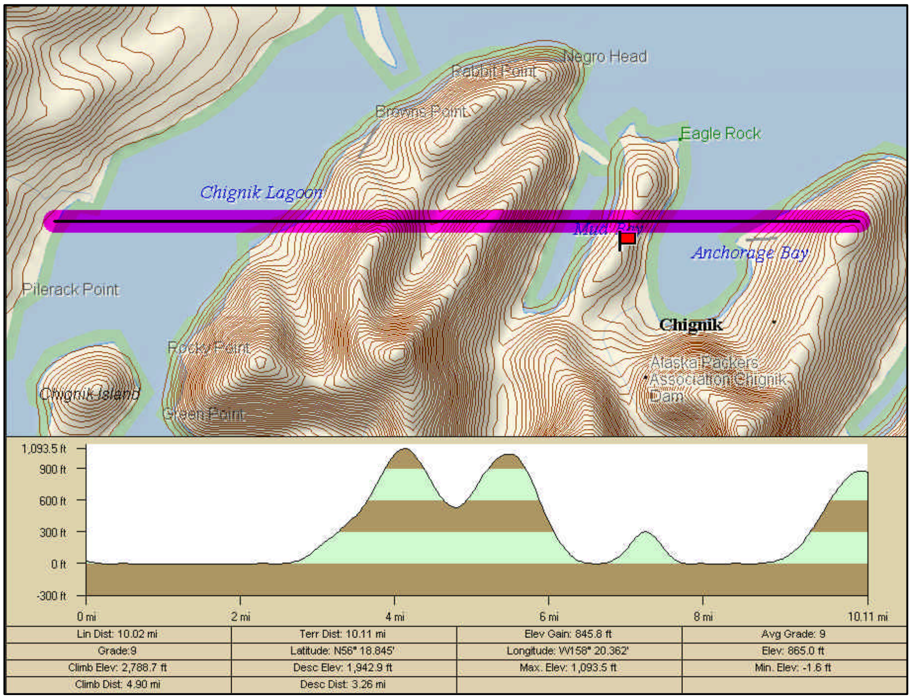


Figure 17 Westerly Approach Profile to Potential Lumber Bay Ridge Site



Several investigations should begin before proceeding with consideration of the *Chignik Head* alternative site. Issues besides turbulence and power density may be bigger hurdles to an wind resource development at that site. Parallel inquiries into these five issues should be begun:

- Contact Federal Aviation Administration regarding proximity to airport and aircraft flight paths
- Contact US Fish and Wildlife Service regarding proximity to flight paths of endangered Steller's and Spectacled Eiders
- Contact Far West Native Corporation regarding permission for general access and permission to develop limited physical access
- Examine possible physical approach routes to site and soil composition at site
- Examine possible physical approach routes for electric utility inter-tie

While outside the cone of approach, proximity to the airport should be addressed with the Federal Aviation Administration. Air traffic for this high-risk airport generally approaches and departs over the water to avoid ridge-induced turbulence. Nevertheless aircraft safety cannot be overemphasized.

While the elevation of *Chignik Head* may be well above the lower flight paths of the Steller's and Spectacled Eiders, it is essential to obtain USFWS approval for any activities that might in any way threaten these species. Mitigation procedures exist to reduce the threat and should be employed at the earliest possibility.

Land ownership and permission to access issues caused substantial delays in the investigation of the *Mud Bay Hill* site. Similar delays should be anticipated in order to be avoided or shortened. Development of limited physical accessibility should be discussed as easy access may be undesirable to the landowner.

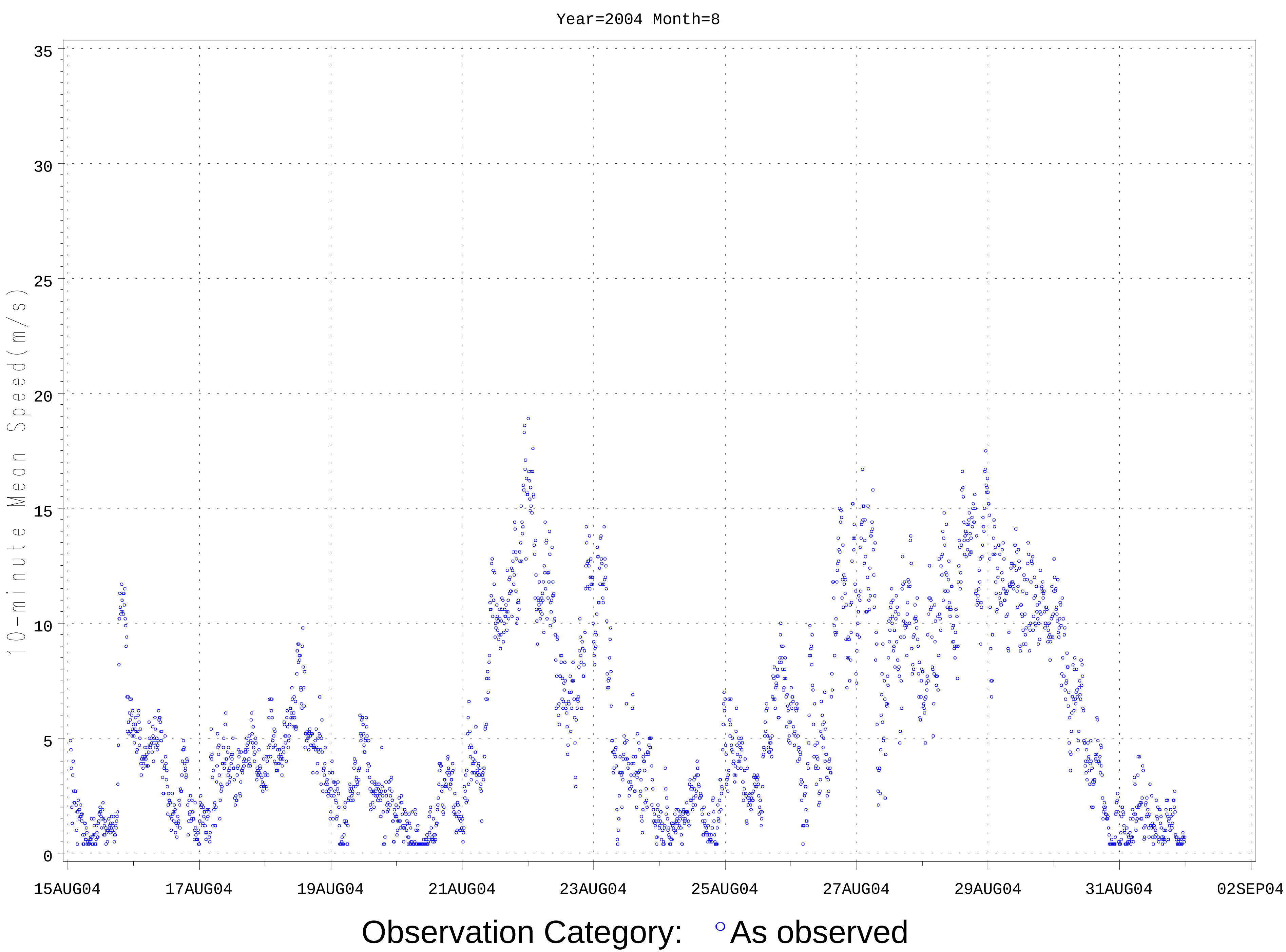
Accessibility currently is by foot alone. Physical approach to the site may be easiest by landing in Lumber Bay and ascending the east side of the ridge. An initial visit may establish whether or not a route is available to walk-up materials necessary to install a met tower. A preliminary assessment of soil conditions also will be useful to determine what tower-guy anchoring methods may be needed. Extensive excavations for setting dead-men anchors, as was the case at the *Mud Bay Hill* site, will be difficult if no machinery can be brought to the site.

An electric utility grid inter-tie would have to traverse an additional mile over difficult terrain compared to the *Mud Bay Hill* site. The issue of proximity to the existing electrical grid should not prevent an examination of the wind resource, but preliminary evaluations of possible routes should be considered when accessing the site.

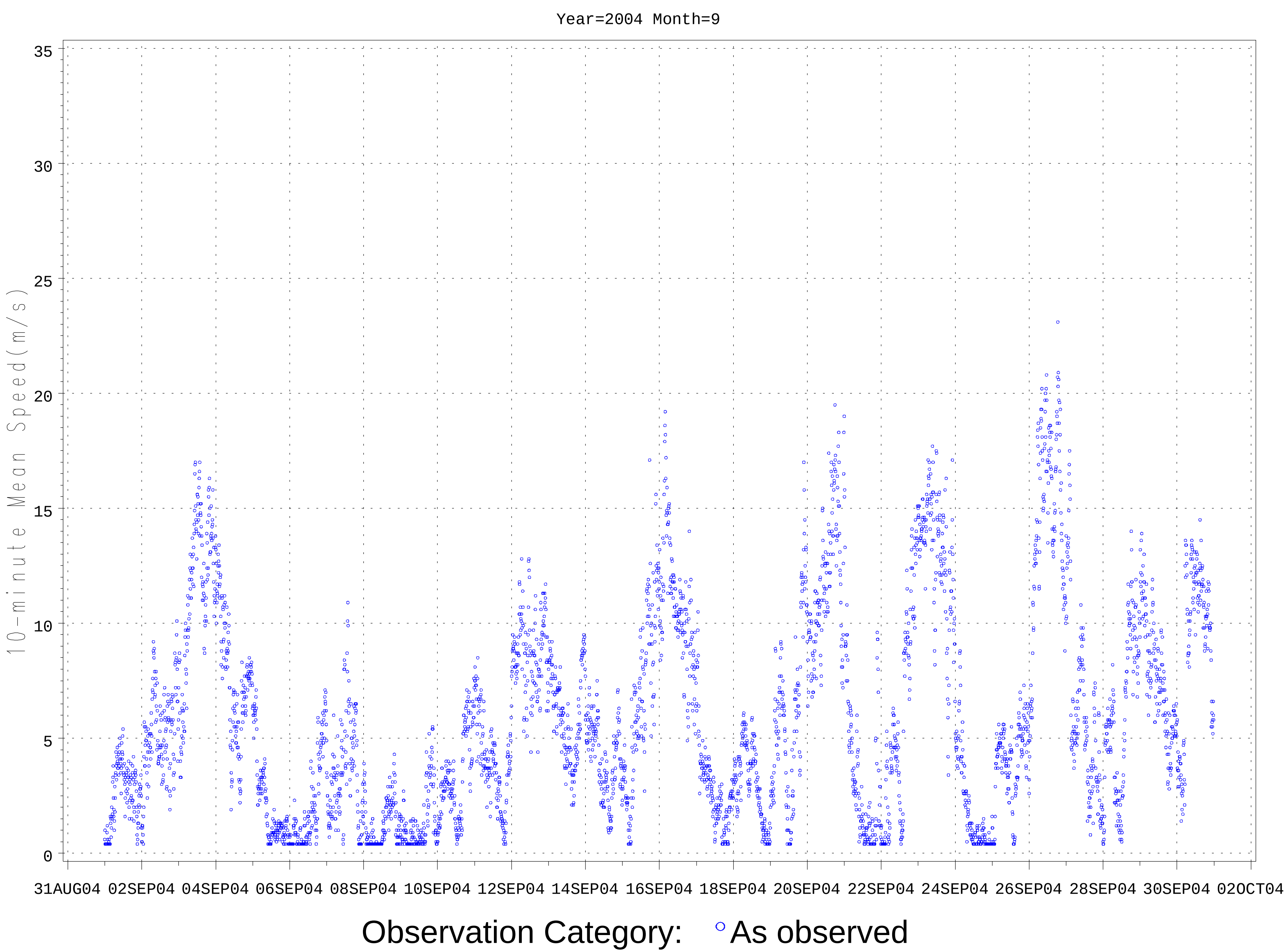
Appendices

Appendix A Observed and Filtered Windspeed Plots by Month

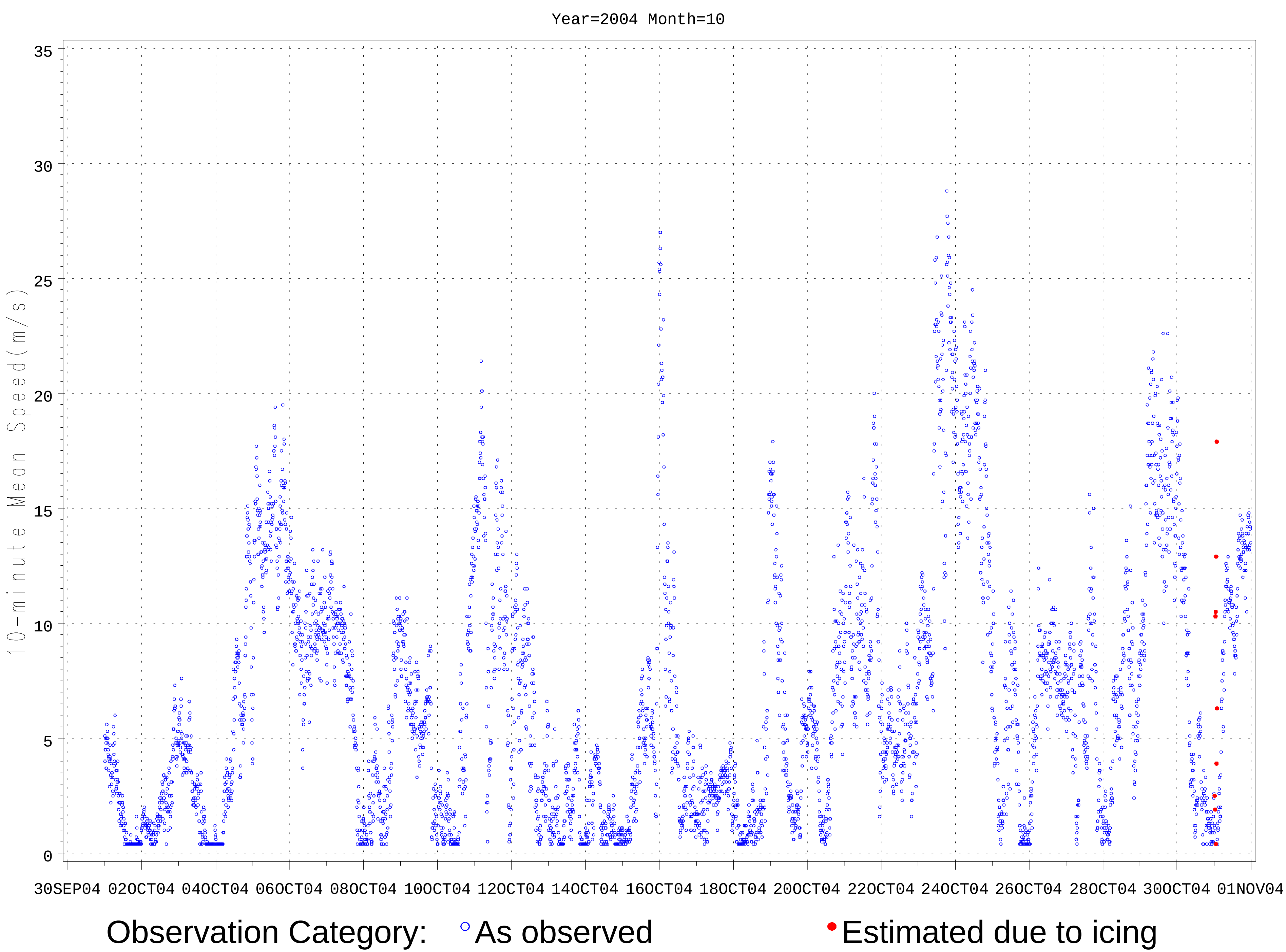
Plots of observed 10-minute mean windspeeds at upper anemometer with sensor-icing suspect observations replaced with by random selections from same calendar month. Replacement observations appear in different shade.

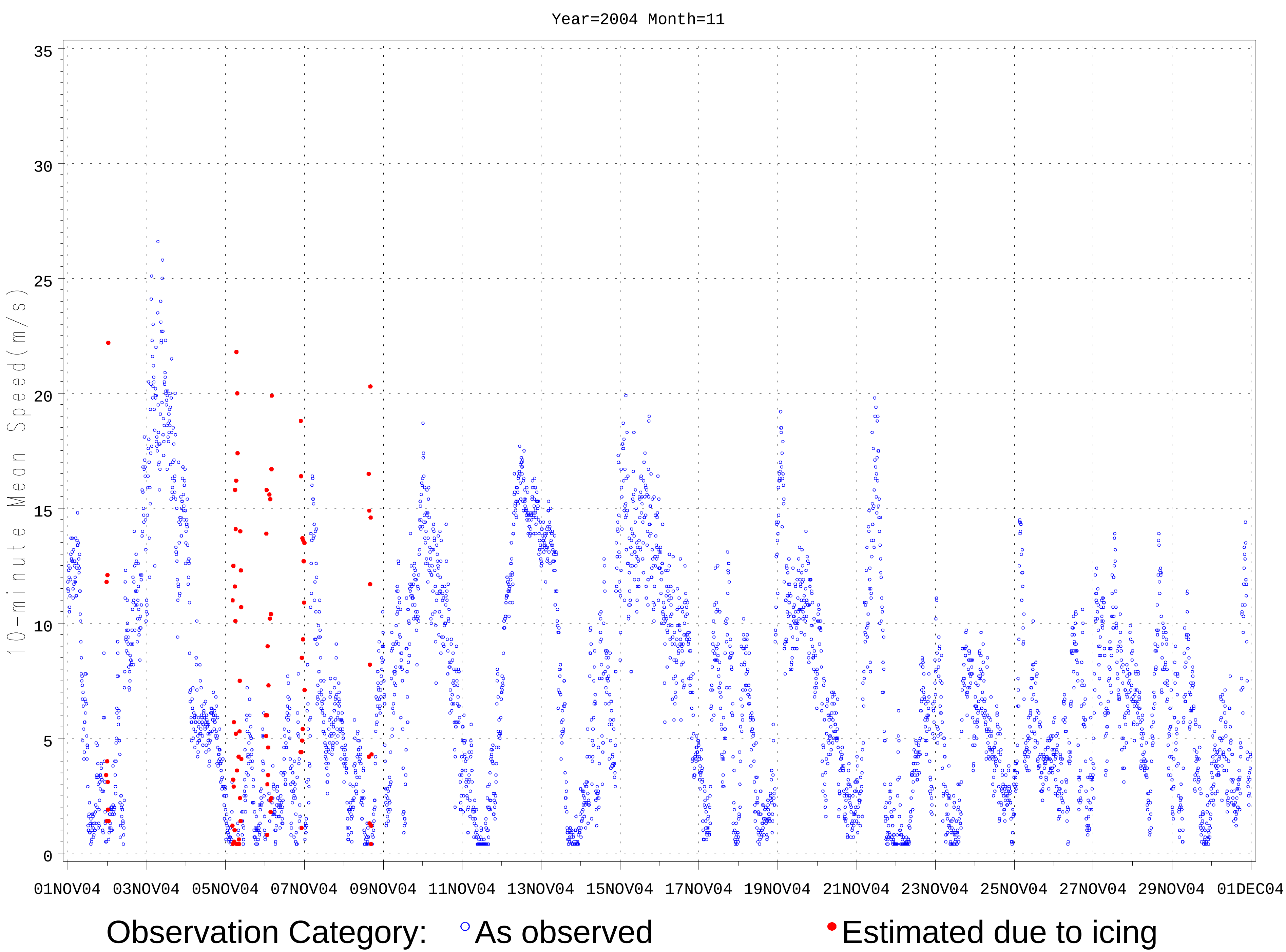


Year=2004 Month=8
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
15AUG04
17AUG04
19AUG04
21AUG04
23AUG04
25AUG04
27AUG04
29AUG04
31AUG04
02SEP04
Observation Category: As observed

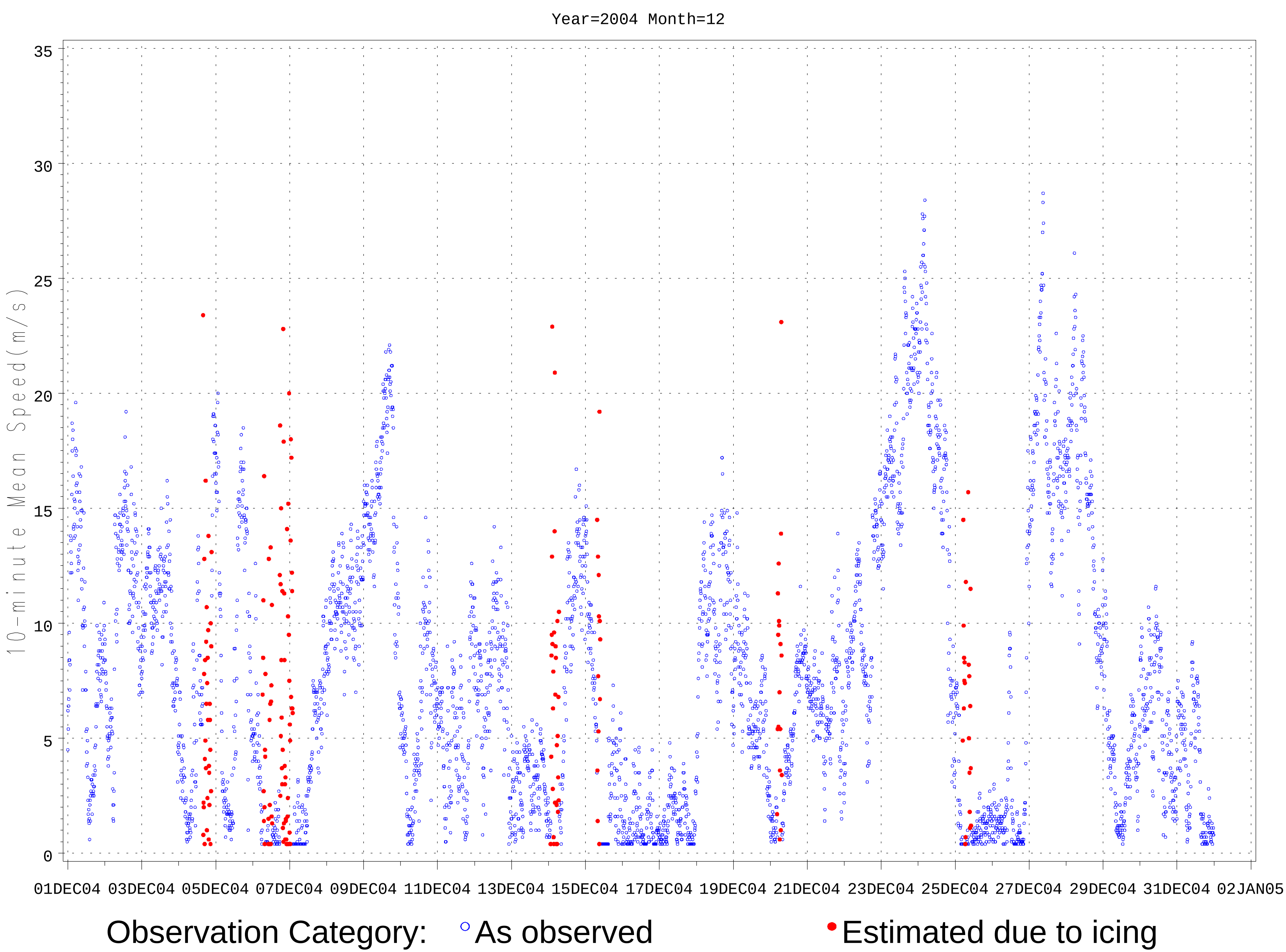


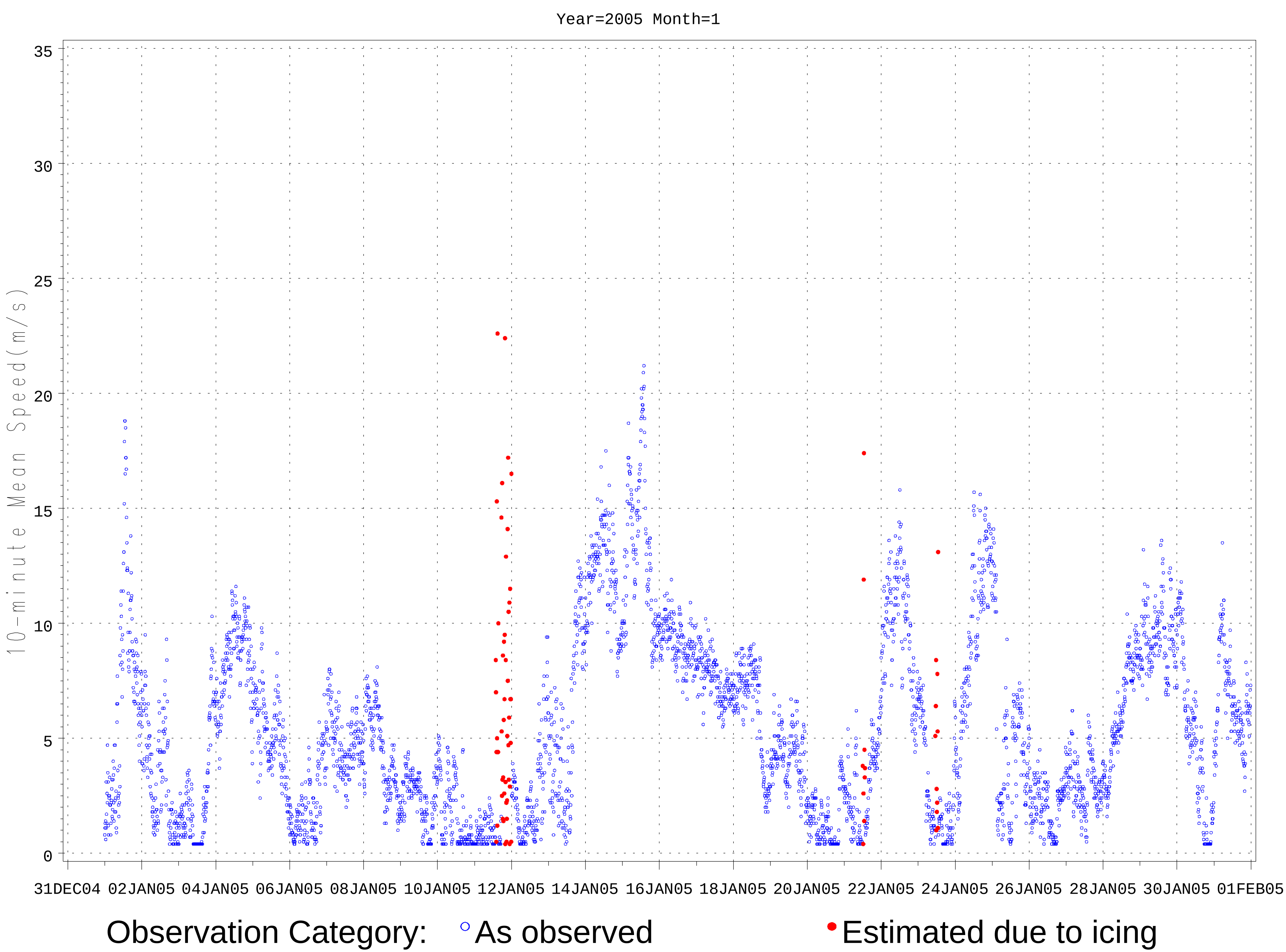
Year=2004 Month=9
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
31AUG04 02SEP04 04SEP04 06SEP04 08SEP04 10SEP04 12SEP04 14SEP04 16SEP04 18SEP04 20SEP04 22SEP04 24SEP04 26SEP04 28SEP04 30SEP04 02OCT04
Observation Category: As observed


Year=2004 Month=10
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
30SEP04 02OCT04 04OCT04 06OCT04 08OCT04 10OCT04 12OCT04 14OCT04 16OCT04 18OCT04 20OCT04 22OCT04 24OCT04 26OCT04 28OCT04 30OCT04 01NOV04
Observation Category: As observed Estimated due to icing

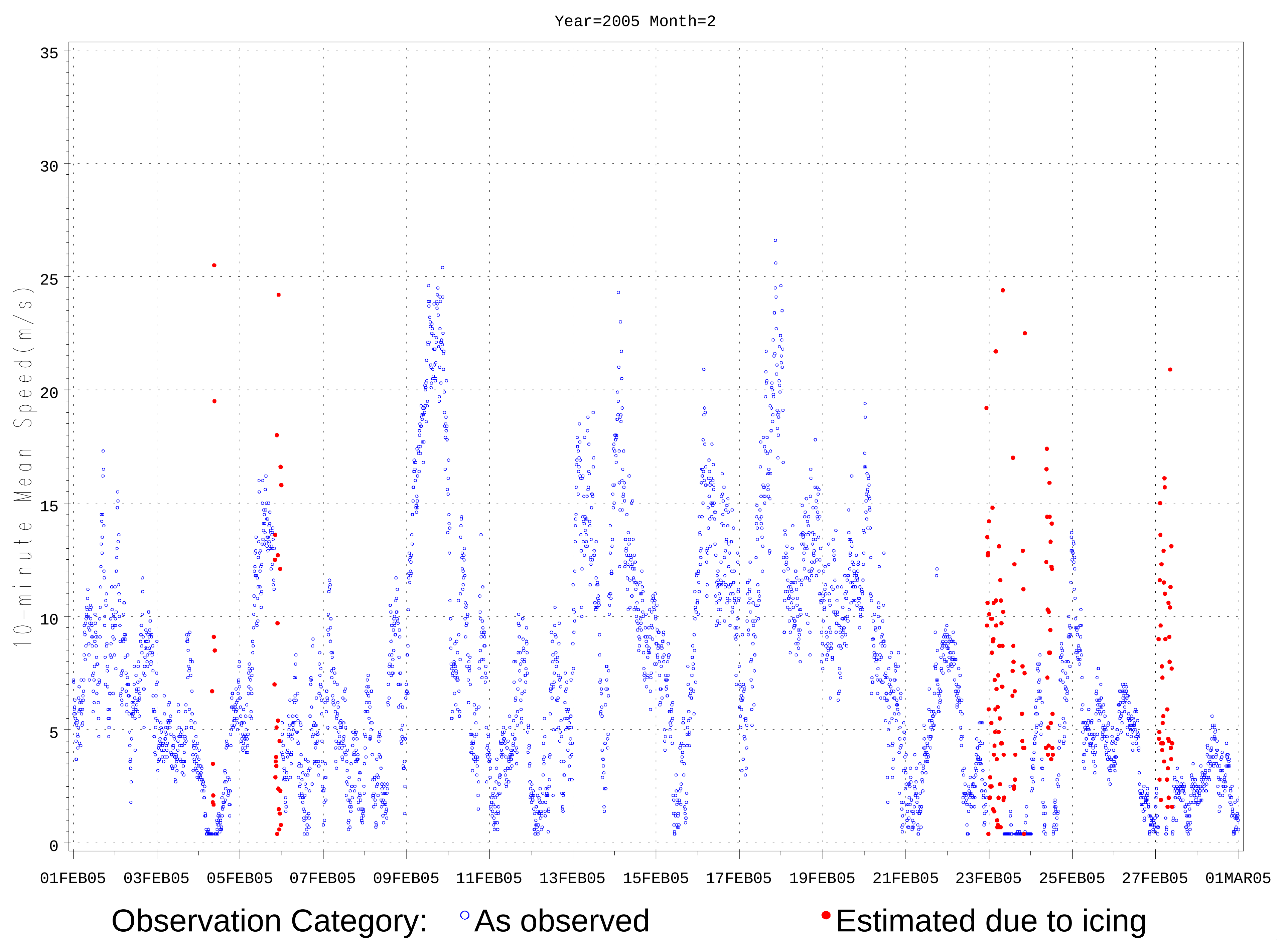


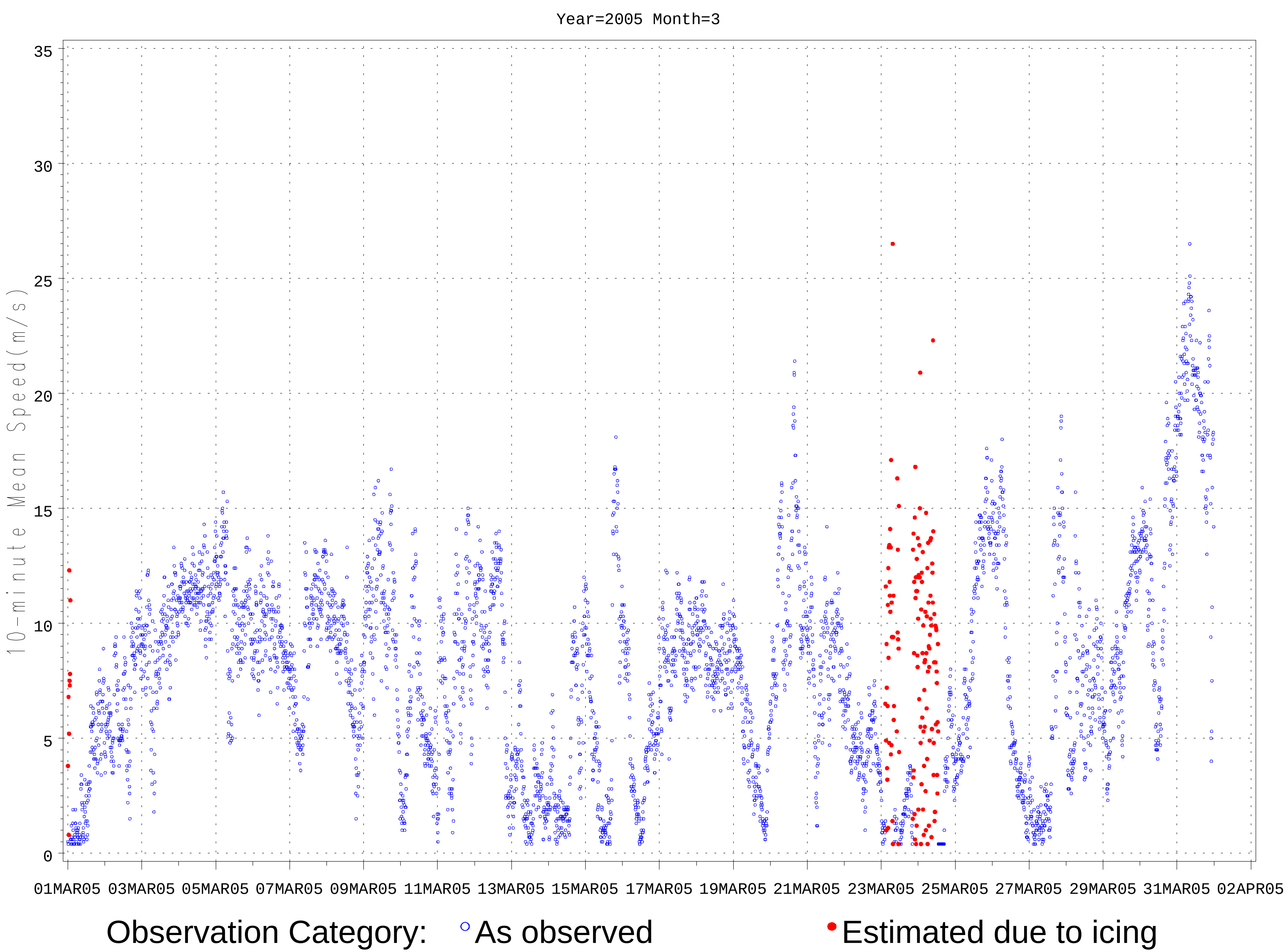
Year=2004 Month=11
10-minute Mean Speed(m/s)
35
30
25
20
15
10
5
0
01NOV04
03NOV04
05NOV04
07NOV04
09NOV04
11NOV04
13NOV04
15NOV04
17NOV04
19NOV04
21NOV04
23NOV04
25NOV04
27NOV04
29NOV04
01DEC04
Observation Category:
As observed
Estimated due to icing

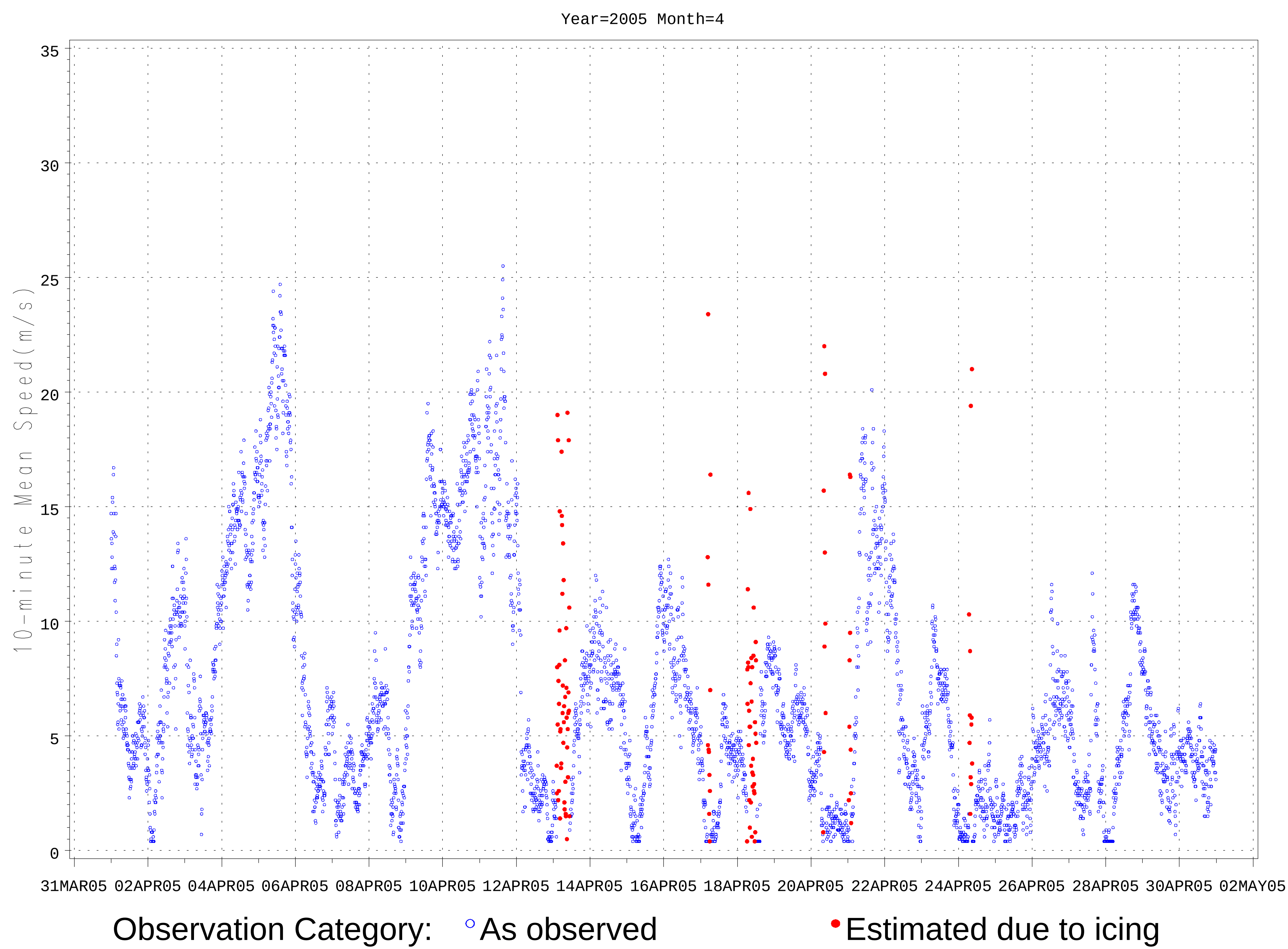

Year=2004 Month=12
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
01DEC04 03DEC04 05DEC04 07DEC04 09DEC04 11DEC04 13DEC04 15DEC04 17DEC04 19DEC04 21DEC04 23DEC04 25DEC04 27DEC04 29DEC04 31DEC04 02JAN05
Observation Category: As observed Estimated due to icing



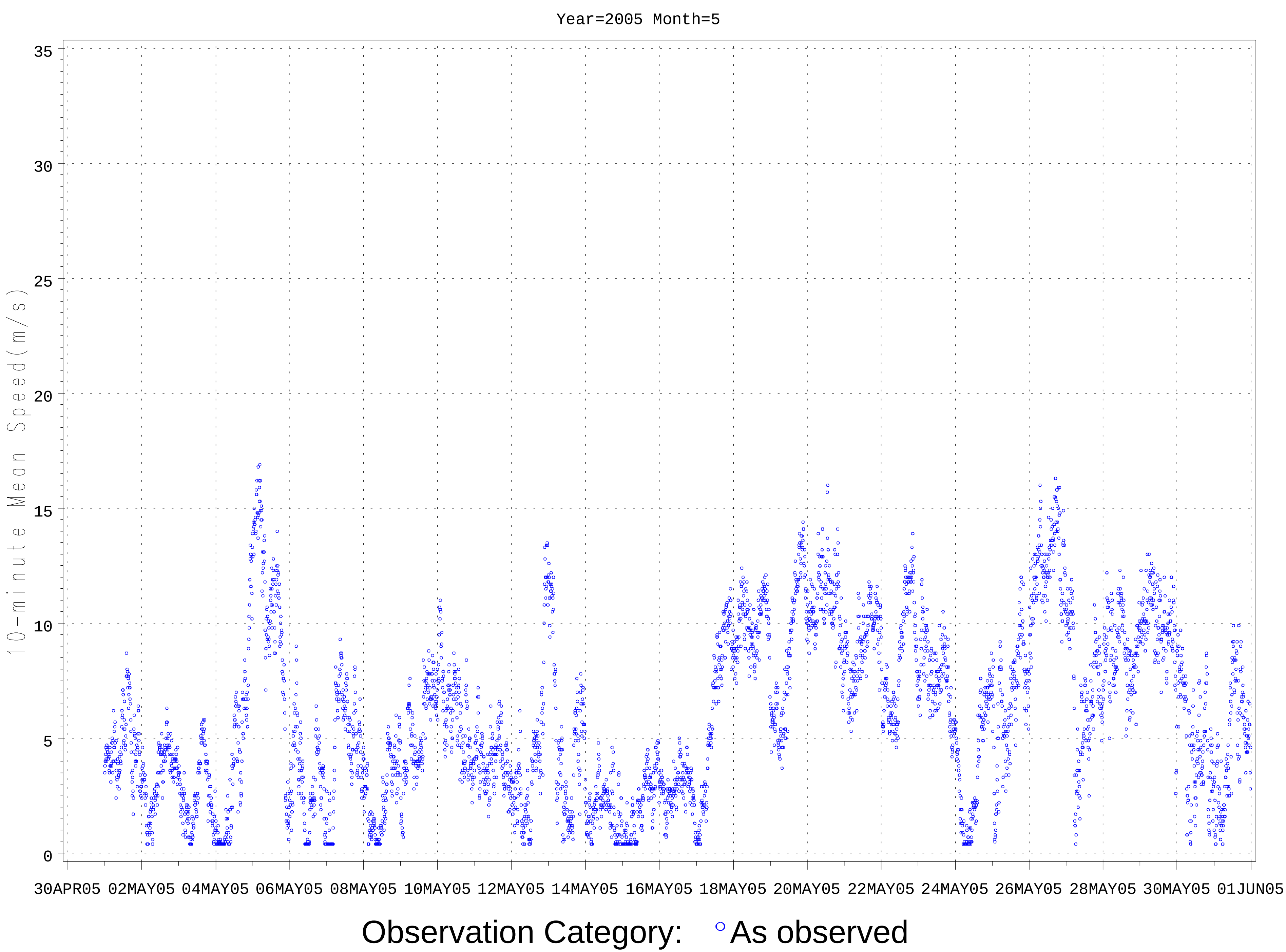
Year=2005 Month=1
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
31DEC04 02JAN05 04JAN05 06JAN05 08JAN05 10JAN05 12JAN05 14JAN05 16JAN05 18JAN05 20JAN05 22JAN05 24JAN05 26JAN05 28JAN05 30JAN05 01FEB05
Observation Category: As observed Estimated due to icing

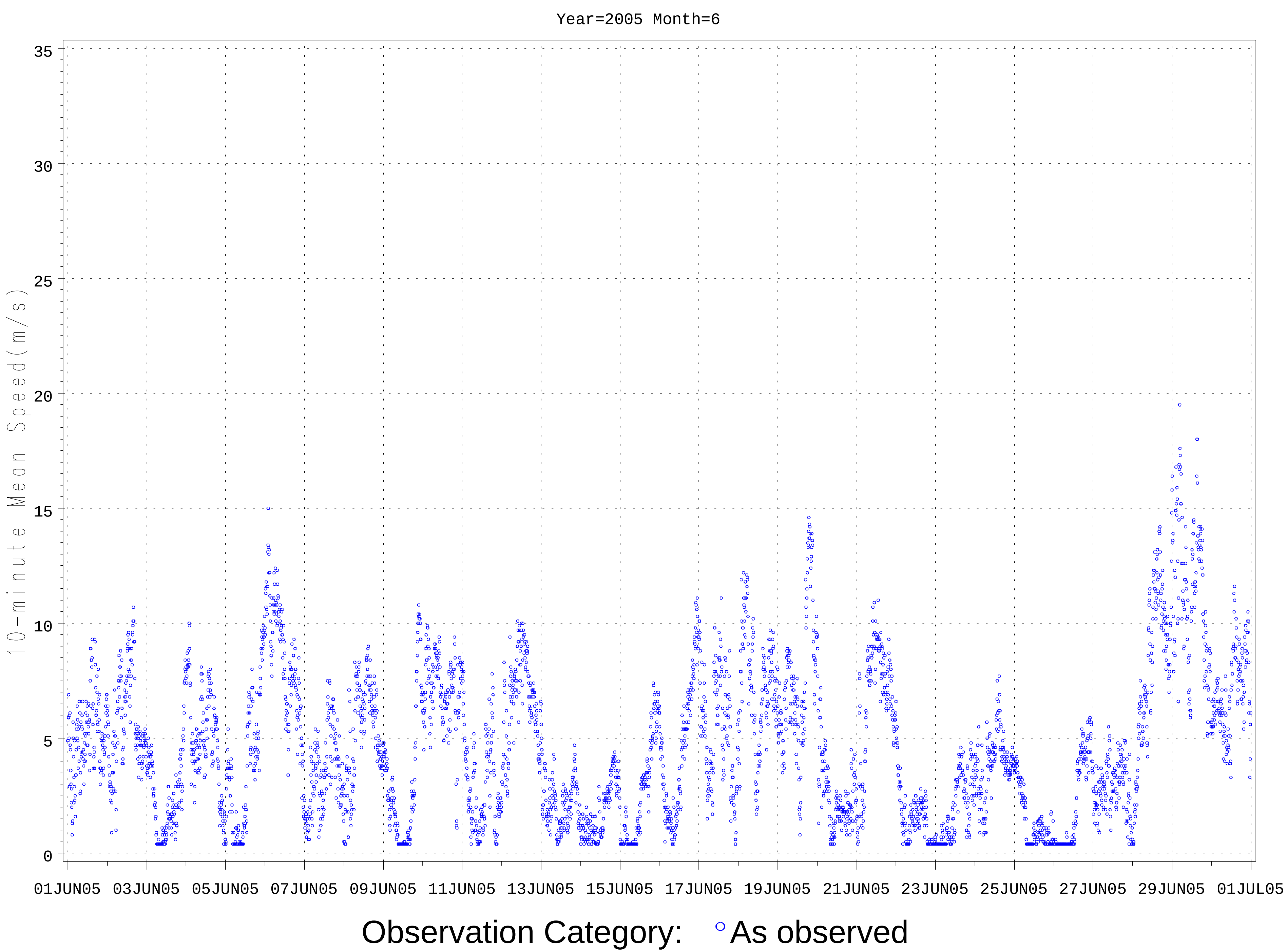

Year=2005 Month=2
10-minute Mean Speed(m/s)
35
30
25
20
15
10
5
0
01FEB05
03FEB05
05FEB05
07FEB05
09FEB05
11FEB05
13FEB05
15FEB05
17FEB05
19FEB05
21FEB05
23FEB05
25FEB05
27FEB05
01MAR05
Observation Category:
As observed
Estimated due to icing

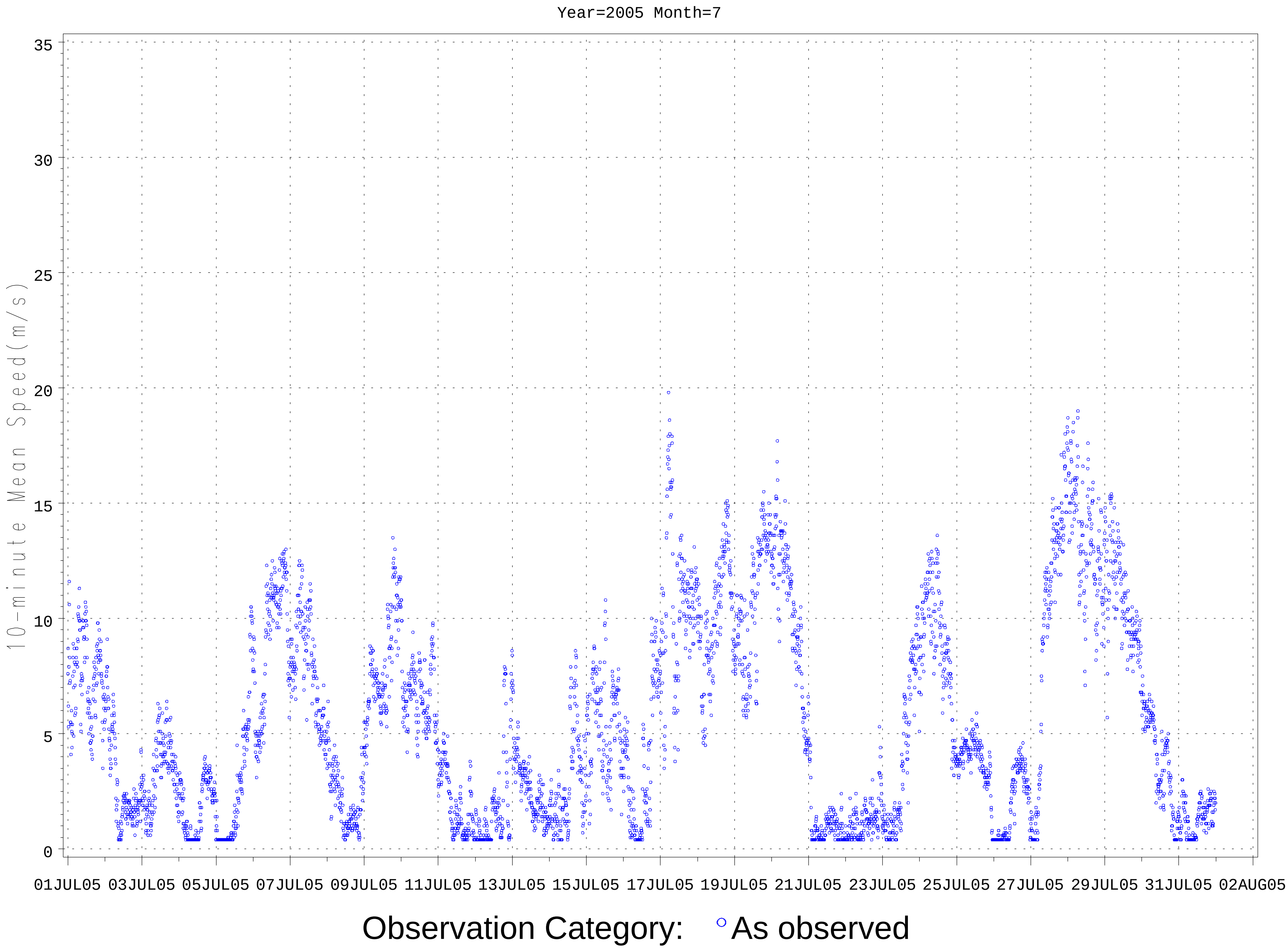

Year=2005 Month=3
35
30
25
20
15
10
5
0
10-minute Mean Speed(m/s)
01MAR05 03MAR05 05MAR05 07MAR05 09MAR05 11MAR05 13MAR05 15MAR05 17MAR05 19MAR05 21MAR05 23MAR05 25MAR05 27MAR05 29MAR05 31MAR05 02APR05
Observation Category: As observed Estimated due to icing



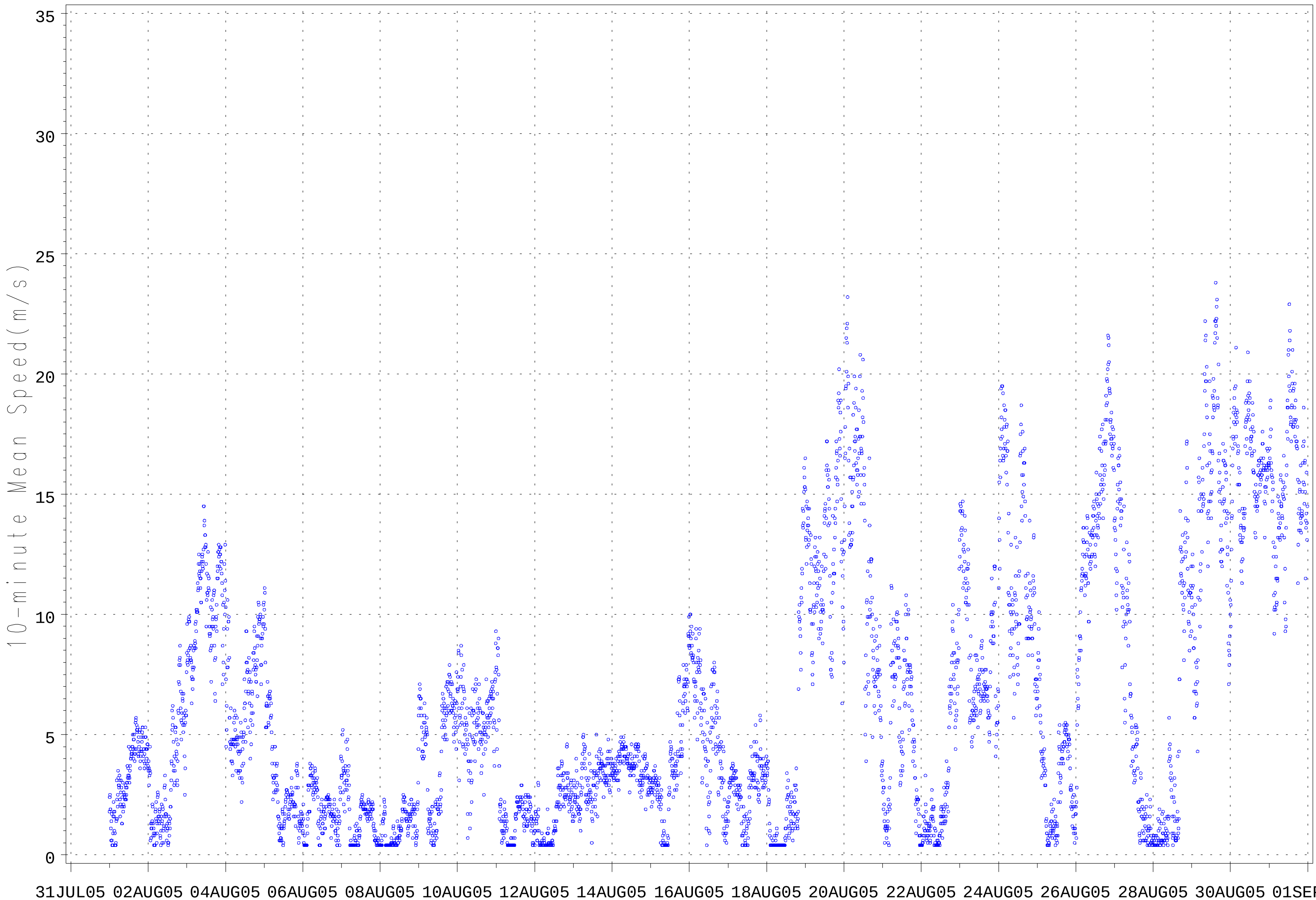
Year=2005 Month=4
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
31MAR05 02APR05 04APR05 06APR05 08APR05 10APR05 12APR05 14APR05 16APR05 18APR05 20APR05 22APR05 24APR05 26APR05 28APR05 30APR05 02MAY05
Observation Category: As observed Estimated due to icing


Year=2005 Month=5
10-minute Mean Speed(m/s)
35
30
25
20
15
10
5
0
30APR05 02MAY05 04MAY05 06MAY05 08MAY05 10MAY05 12MAY05 14MAY05 16MAY05 18MAY05 20MAY05 22MAY05 24MAY05 26MAY05 28MAY05 30MAY05 01JUN05
Observation Category: As observed

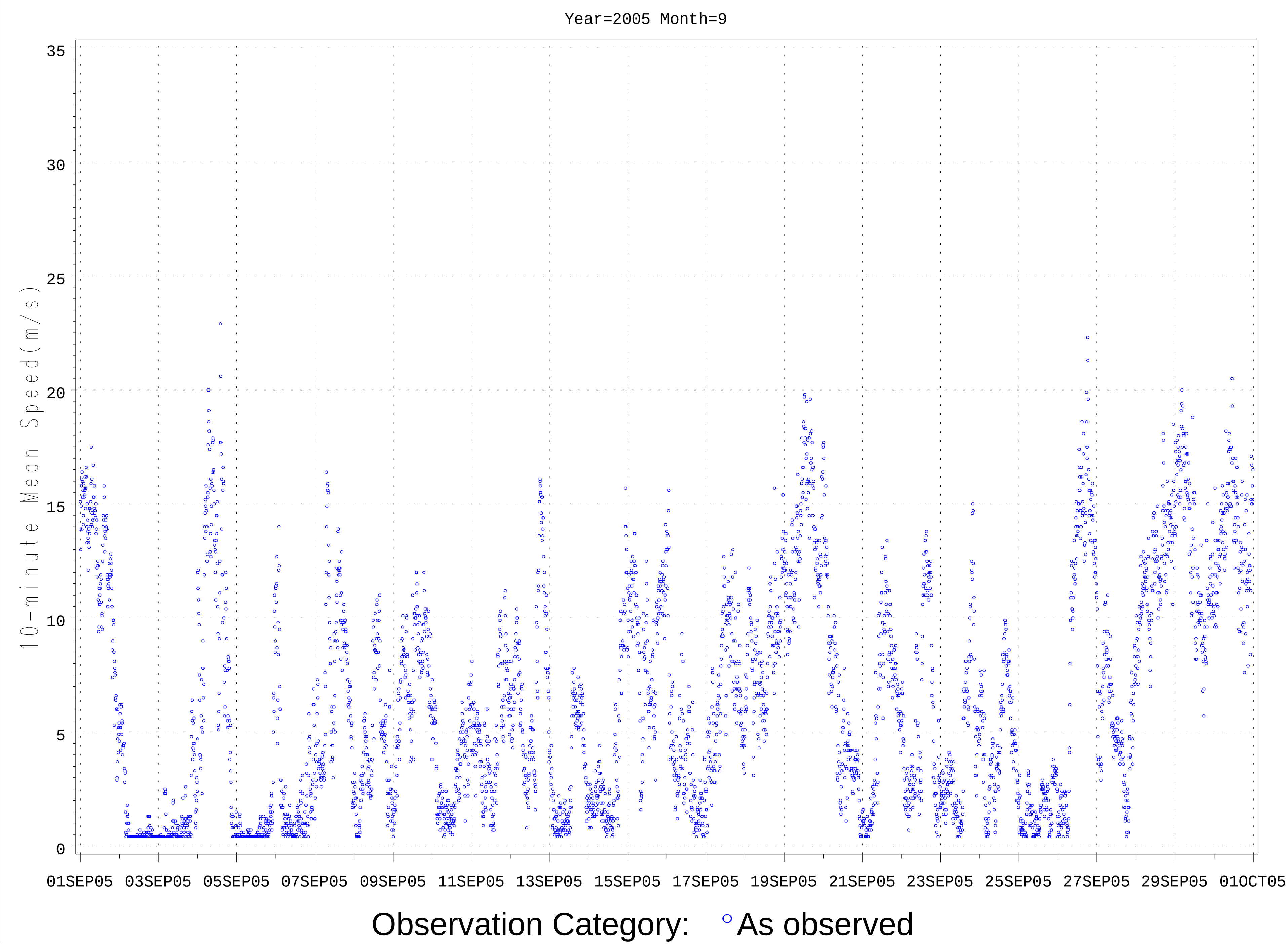

Year=2005 Month=6
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
01JUN05
03JUN05
05JUN05
07JUN05
09JUN05
11JUN05
13JUN05
15JUN05
17JUN05
19JUN05
21JUN05
23JUN05
25JUN05
27JUN05
29JUN05
01JUL05
Observation Category: As observed


Year=2005 Month=7
10-minute Mean Speed(m/s)
35
30
25
20
15
10
5
0
01JUL05
03JUL05
05JUL05
07JUL05
09JUL05
11JUL05
13JUL05
15JUL05
17JUL05
19JUL05
21JUL05
23JUL05
25JUL05
27JUL05
29JUL05
31JUL05
02AUG05
Observation Category:
As observed

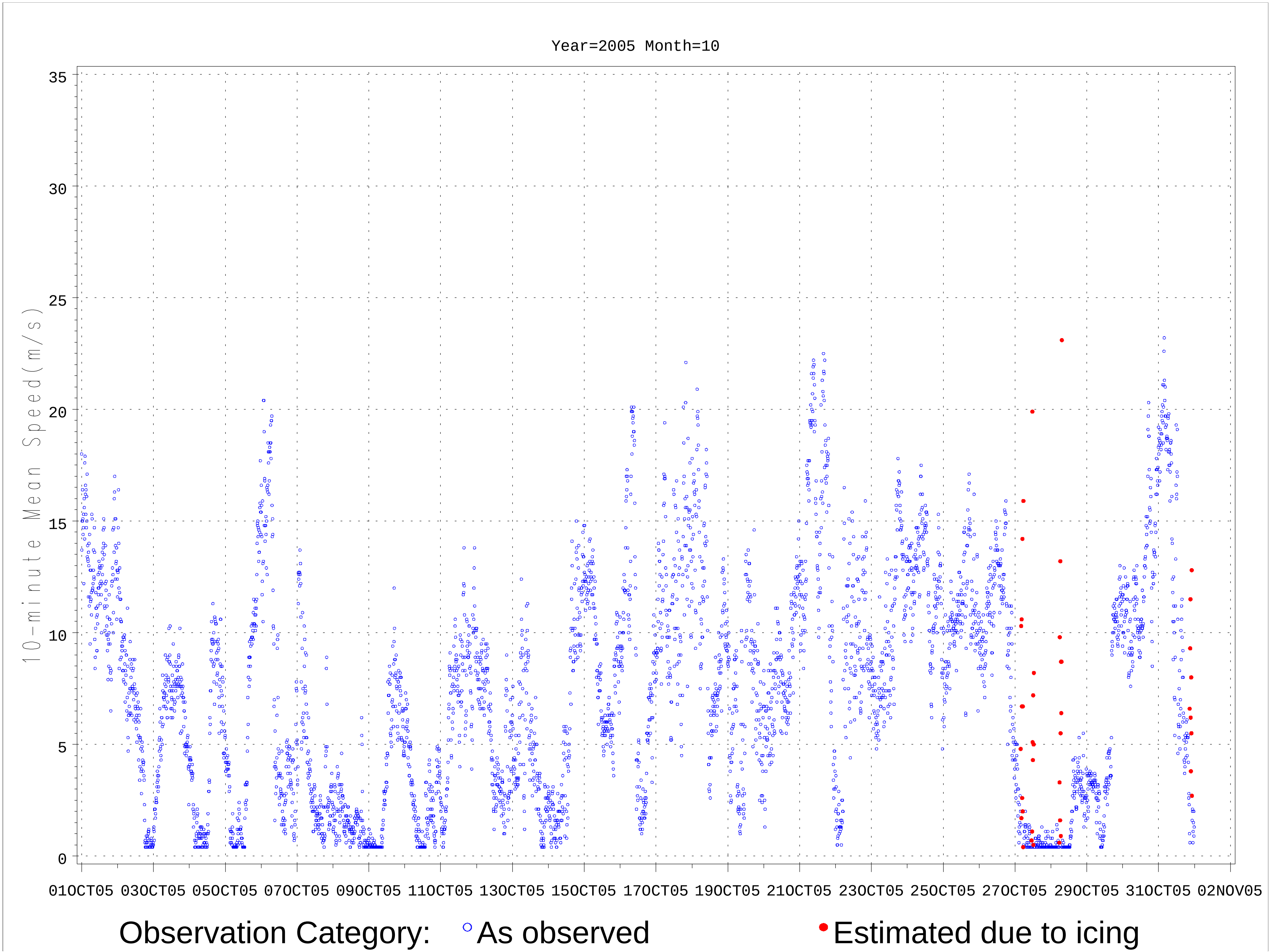
Year=2005 Month=8

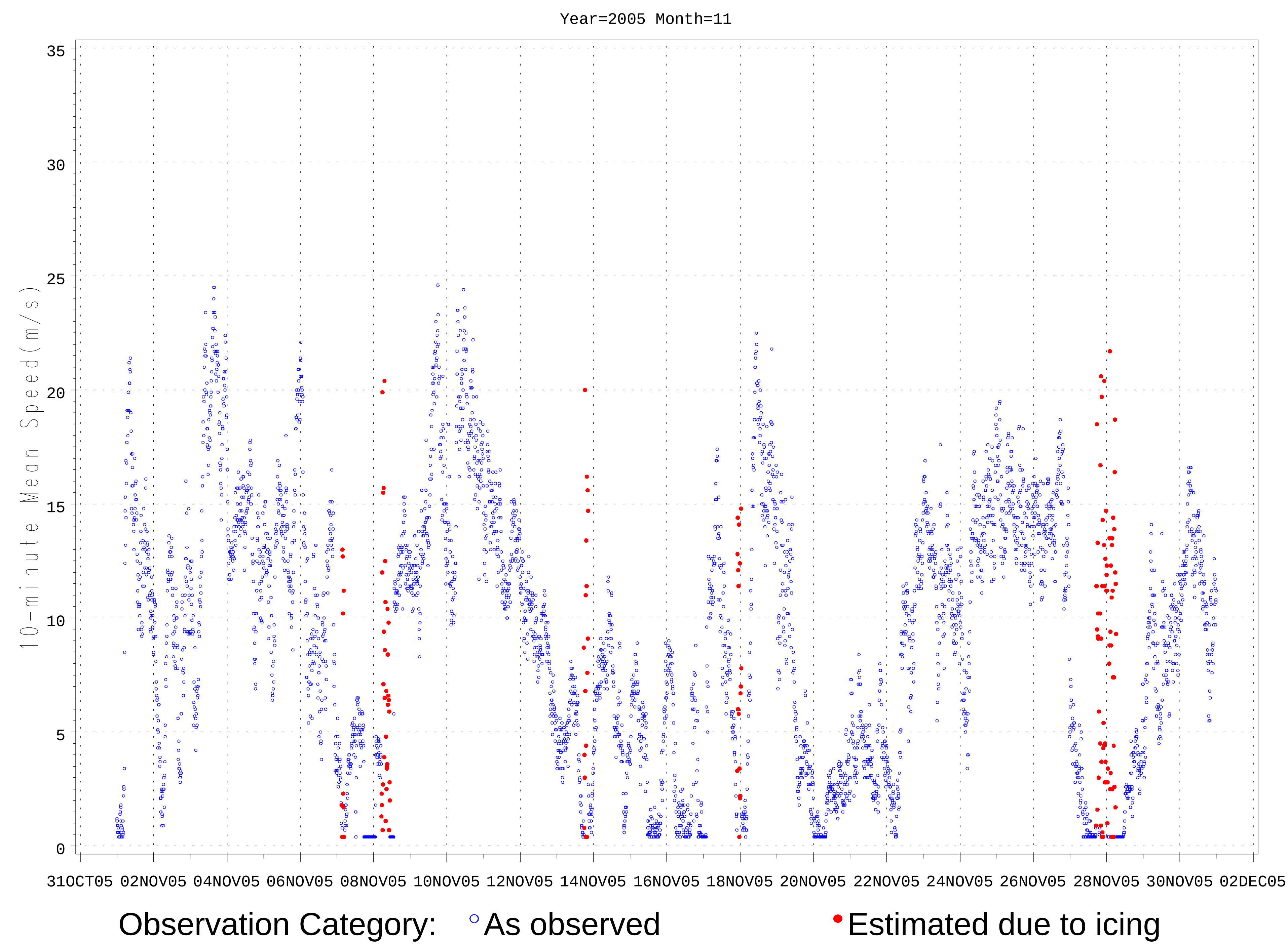


Observation Category: ○ As observed

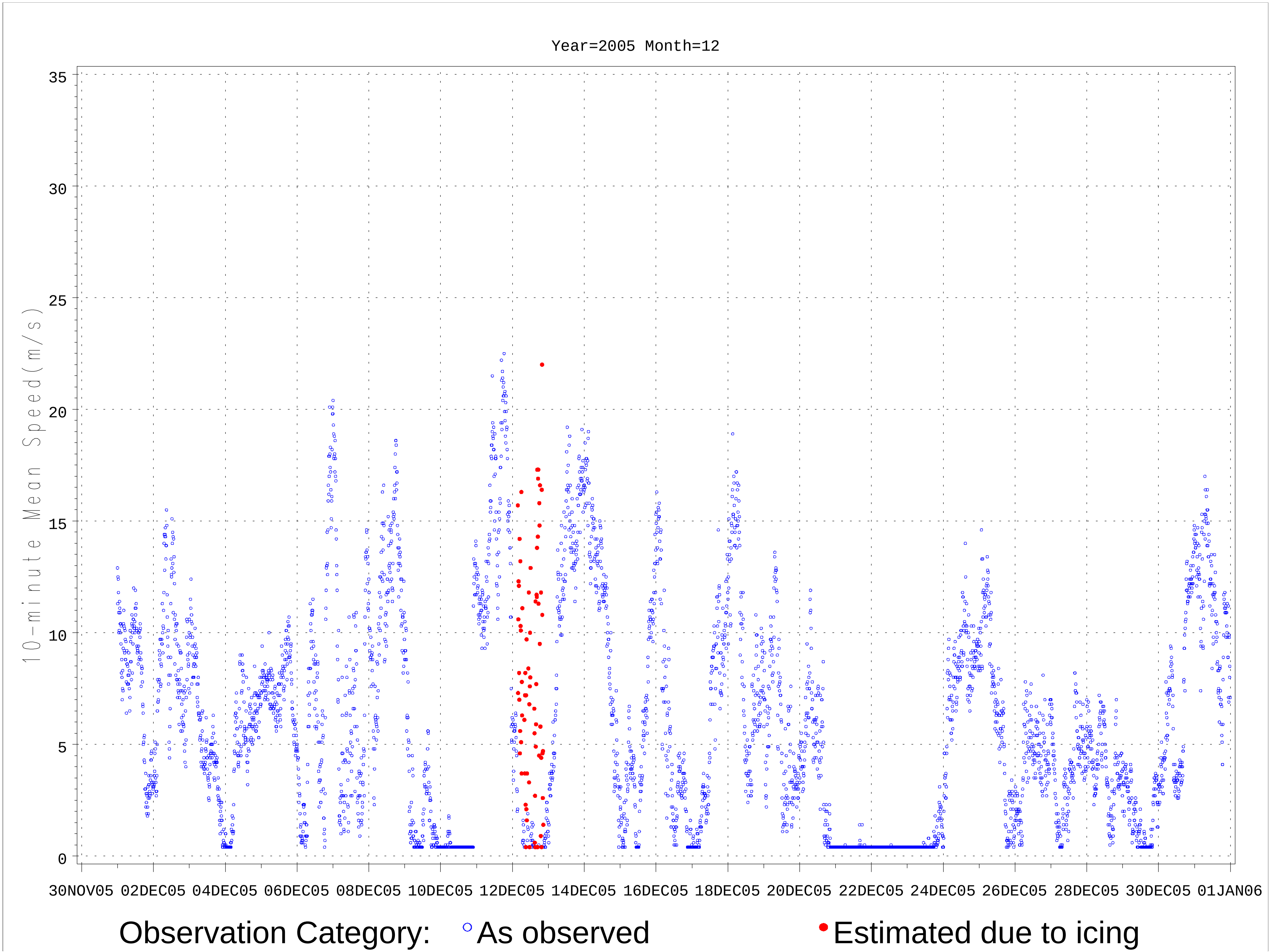


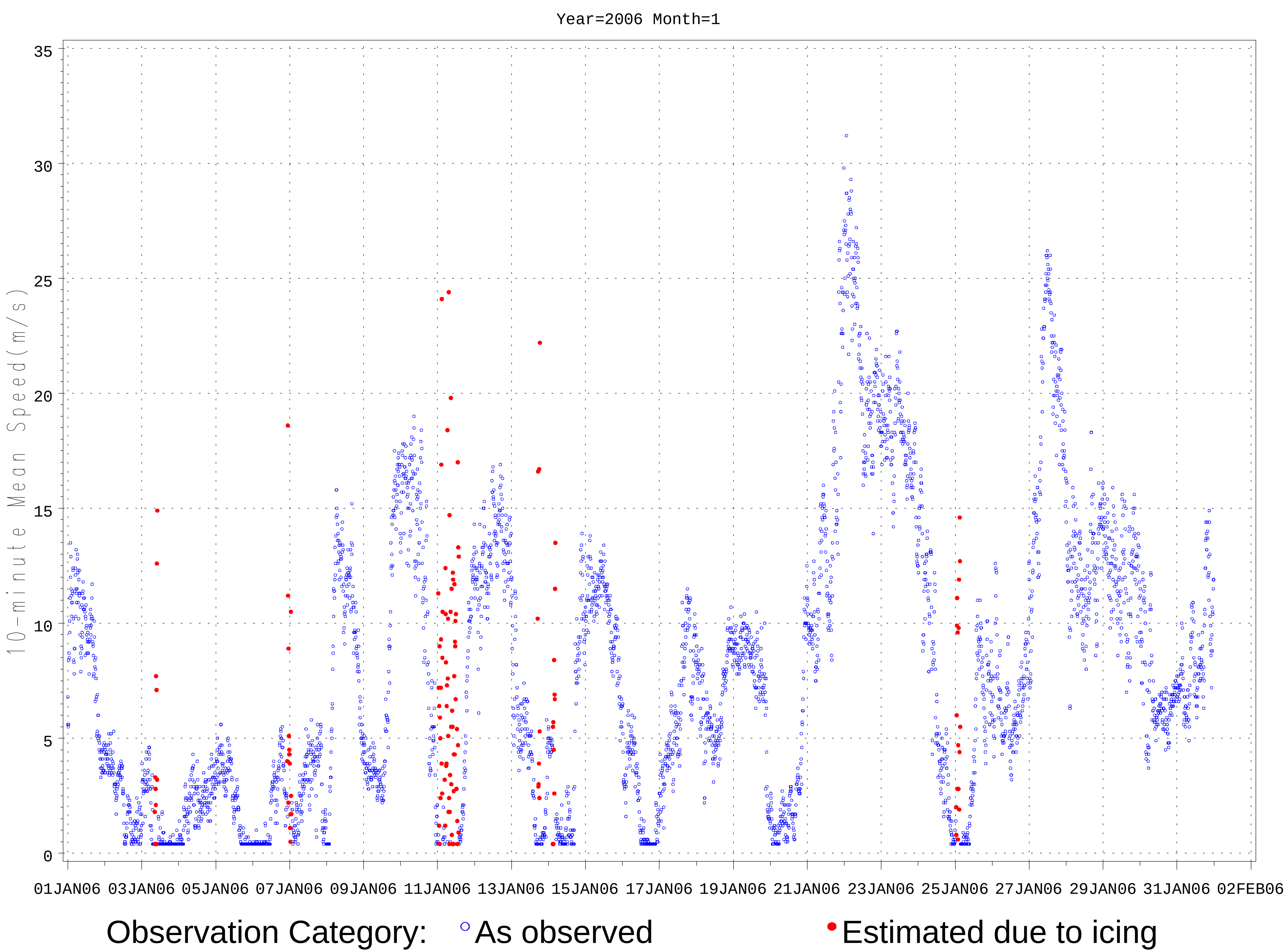
Year=2005 Month=9
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
01SEP05
03SEP05
05SEP05
07SEP05
09SEP05
11SEP05
13SEP05
15SEP05
17SEP05
19SEP05
21SEP05
23SEP05
25SEP05
27SEP05
29SEP05
01OCT05
Observation Category: As observed

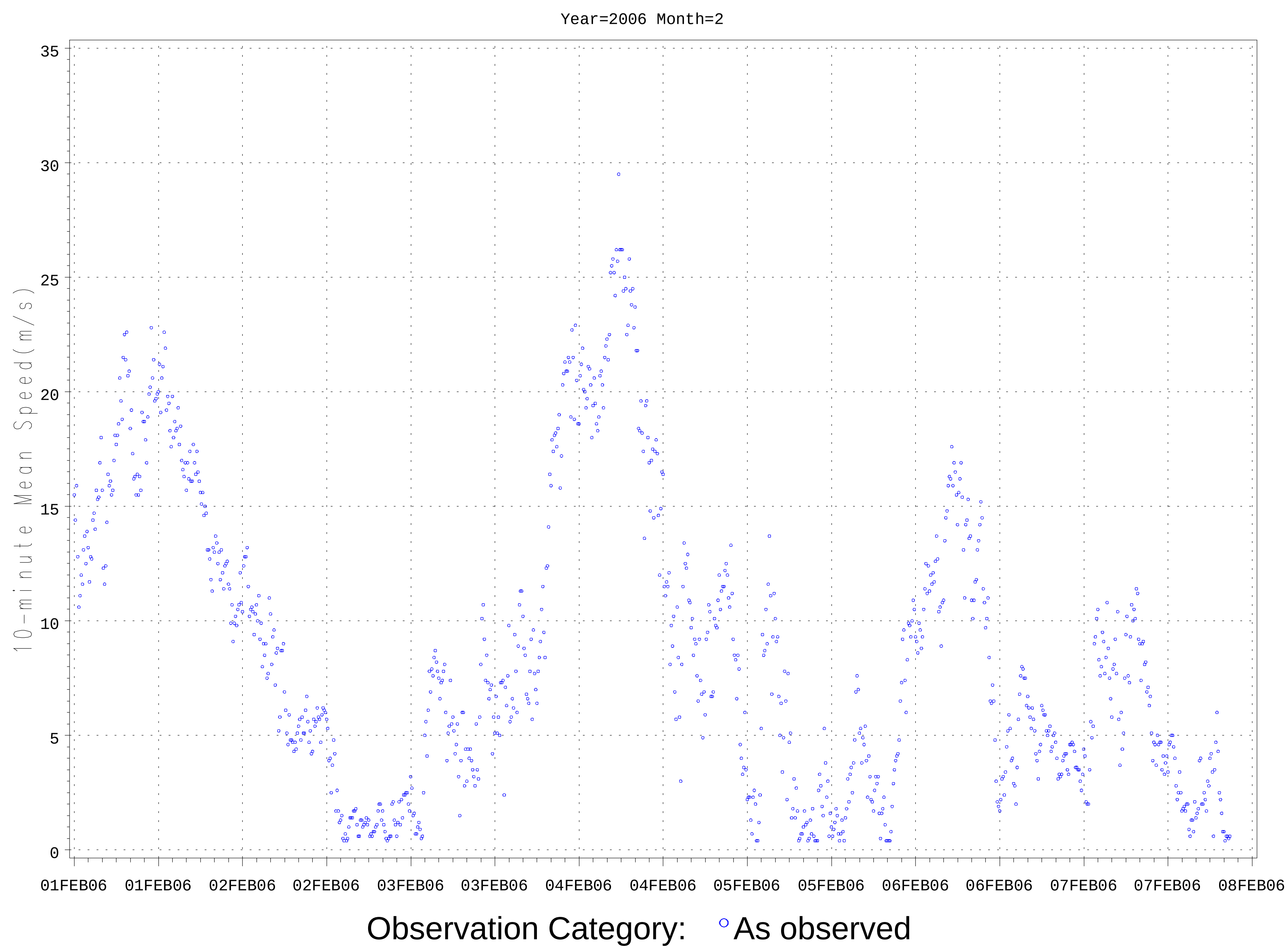

Year=2005 Month=10
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
01OCT05 03OCT05 05OCT05 07OCT05 09OCT05 11OCT05 13OCT05 15OCT05 17OCT05 19OCT05 21OCT05 23OCT05 25OCT05 27OCT05 29OCT05 31OCT05 02NOV05
Observation Category:
As observed
Estimated due to icing



Year=2005 Month=11
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
31OCT05 02NOV05 04NOV05 06NOV05 08NOV05 10NOV05 12NOV05 14NOV05 16NOV05 18NOV05 20NOV05 22NOV05 24NOV05 26NOV05 28NOV05 30NOV05 02DEC05
Observation Category: As observed Estimated due to icing


Year=2005 Month=12
10-minute Mean Speed(m/s)
35
30
25
20
15
10
5
0
30NOV05 02DEC05 04DEC05 06DEC05 08DEC05 10DEC05 12DEC05 14DEC05 16DEC05 18DEC05 20DEC05 22DEC05 24DEC05 26DEC05 28DEC05 30DEC05 01JAN06
Observation Category:
As observed
Estimated due to icing


Year=2006 Month=1
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
01JAN06 03JAN06 05JAN06 07JAN06 09JAN06 11JAN06 13JAN06 15JAN06 17JAN06 19JAN06 21JAN06 23JAN06 25JAN06 27JAN06 29JAN06 31JAN06 02FEB06
Observation Category: As observed Estimated due to icing


Year=2006 Month=2
10-minute Mean Speed(m/s)
0
5
10
15
20
25
30
35
01FEB06
01FEB06
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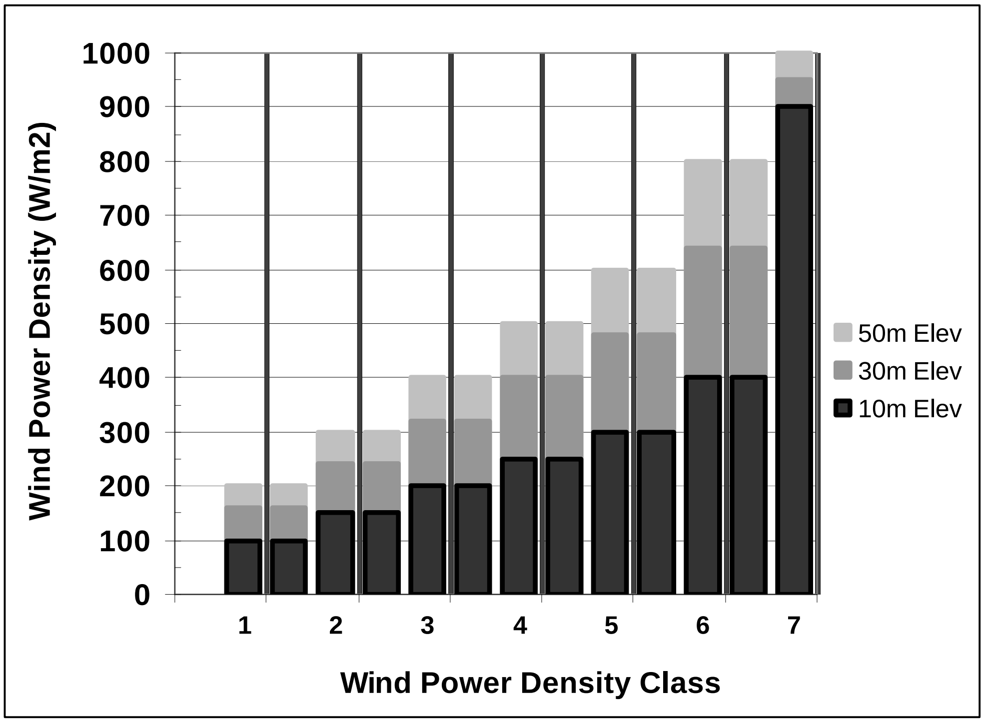
02FEB06
03FEB06
03FEB06
04FEB06
04FEB06
05FEB06
05FEB06
06FEB06
06FEB06
07FEB06
07FEB06
08FEB06
Observation Category:
As observed

Appendix B Wind Power Density Classes Reference

Wind power density ranges by wind power density class and elevation of recorded windspeed.

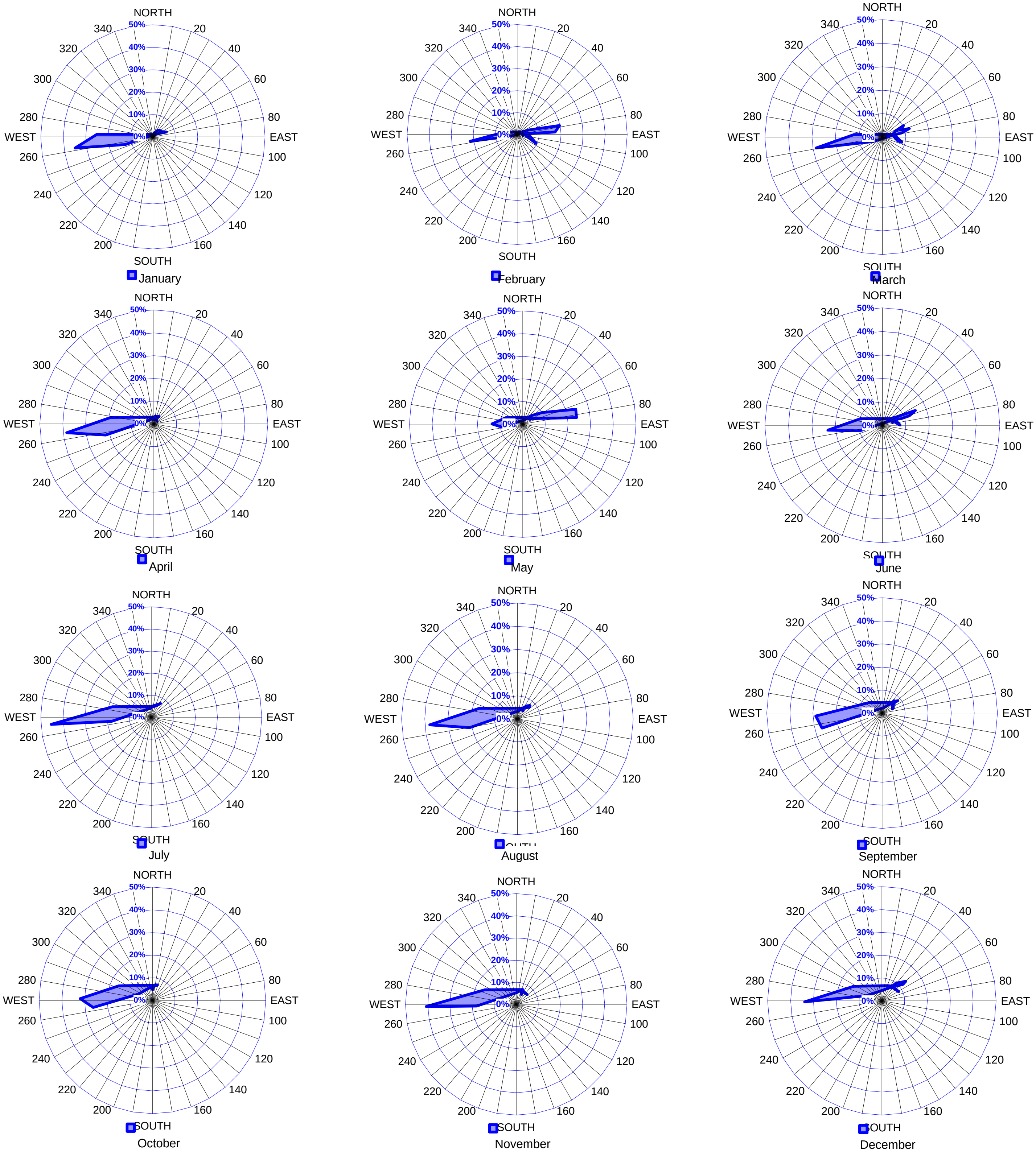
Classes of Wind Power Density at 10 m, 30 m, and 50 m Elevations						
	10 m (33 ft)		30 m (100 ft)		50 m (164 ft)	
Class	Density (W/m2)	Speed m/s (mph)	Density (W/m2)	Speed m/s (mph)	Density (W/m2)	Speed m/s (mph)
1	<100	<4.4 (9.8)	<160	<5.1 (11.5)	<200	<5.6 (12.5)
2	100 - 150	4.4 (9.8)/5.1 (11.5)	160 - 240	5.1 (11.5)/6 (13.3)	200 - 300	5.6 (12.5)/6.4 (14.3)
3	150 - 200	5.1 (11.5)/5.6 (12.5)	240 - 320	6 (13.3)/6.6 (14.7)	300 - 400	6.4 (14.3)/7.0 (15.7)
4	200 - 250	5.6 (12.5)/6.0 (13.4)	320 - 400	6.6 (14.7)/7 (15.7)	400 - 500	7.0 (15.7)/7.5 (16.8)
5	250 - 300	6.0 (13.4)/6.4 (14.3)	400 - 480	7 (15.7)/7.5 (16.7)	500 - 600	7.5 (16.8)/8.0 (17.9)
6	300 - 400	6.4 (14.3)/7.0 (15.7)	480 - 640	7.5 (16.7)/8.2 (18.3)	600 - 800	8.0 (17.9)/8.8 (19.7)
7	>400	>7.0 (15.7)	>640	>8.2 (18.3)	>800	>8.8 (19.7)



Appendix C Observed Wind Energy Roses by Month

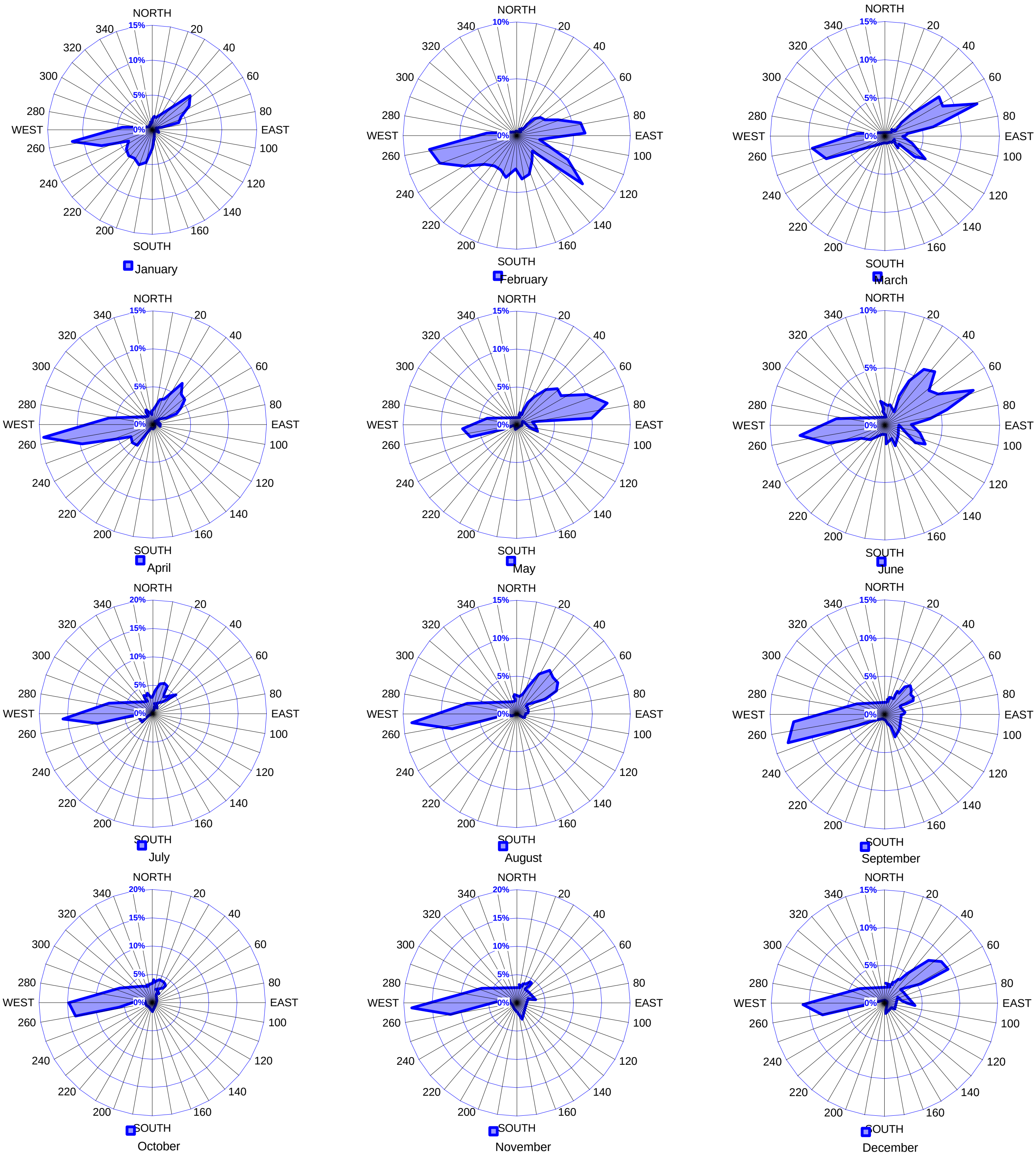
Wind Energy Wind Rose

Percent of Total Energy



Appendix D Observed Wind Directional Frequency Wind Roses by Month

Wind Directional Frequency
Wind Roses
Percent of Total Time



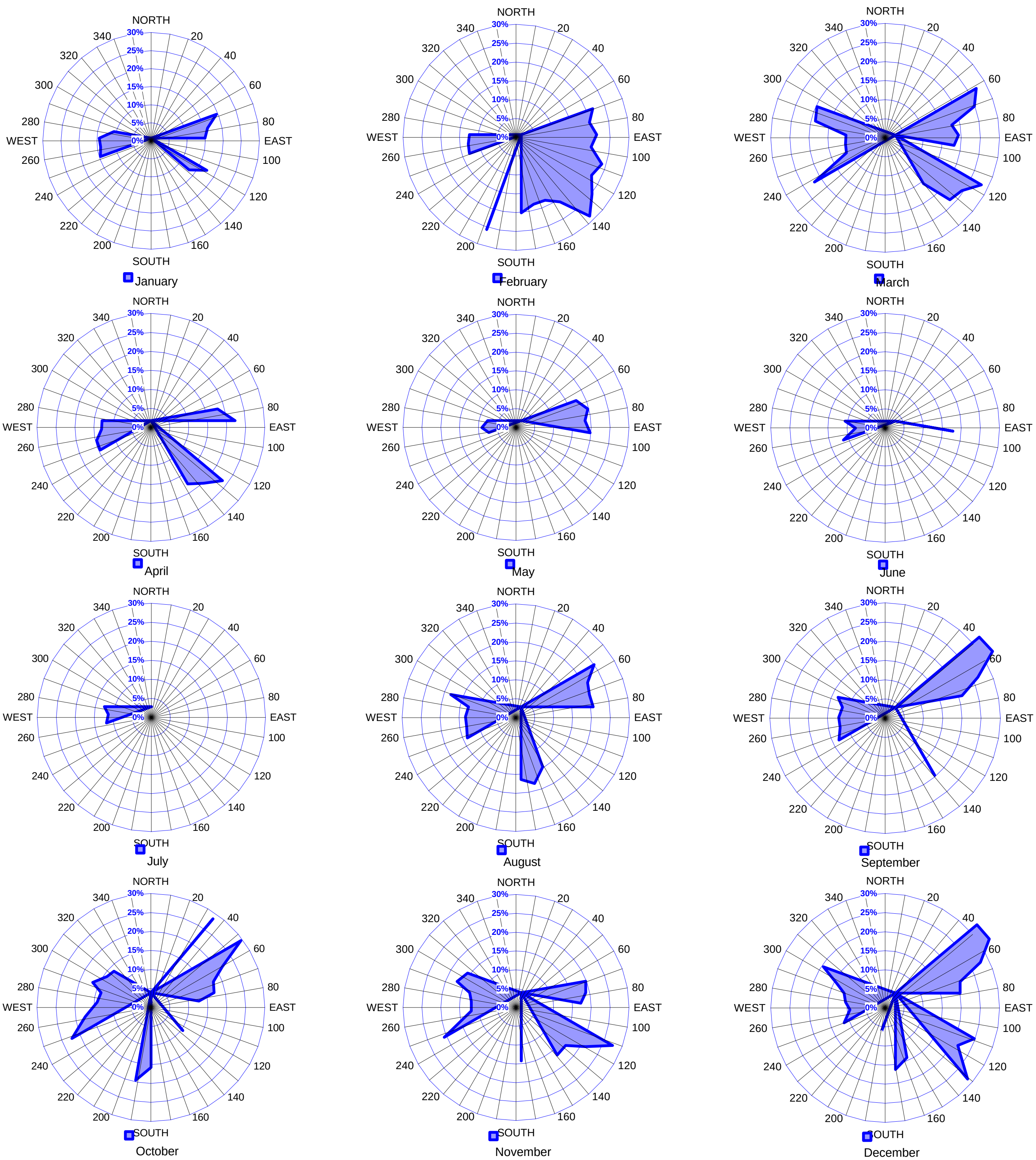
Appendix E Turbulence Intensity Wind Roses by Month for Windspeeds Greater Than 4 m/s

Turbulence Intensity Wind Rose
windspeeds > 4 m/s

Appendix F Turbulence Intensity Wind Roses by Month for Windspeeds Greater Than 14 and Less Than or Equal to 16 m/s

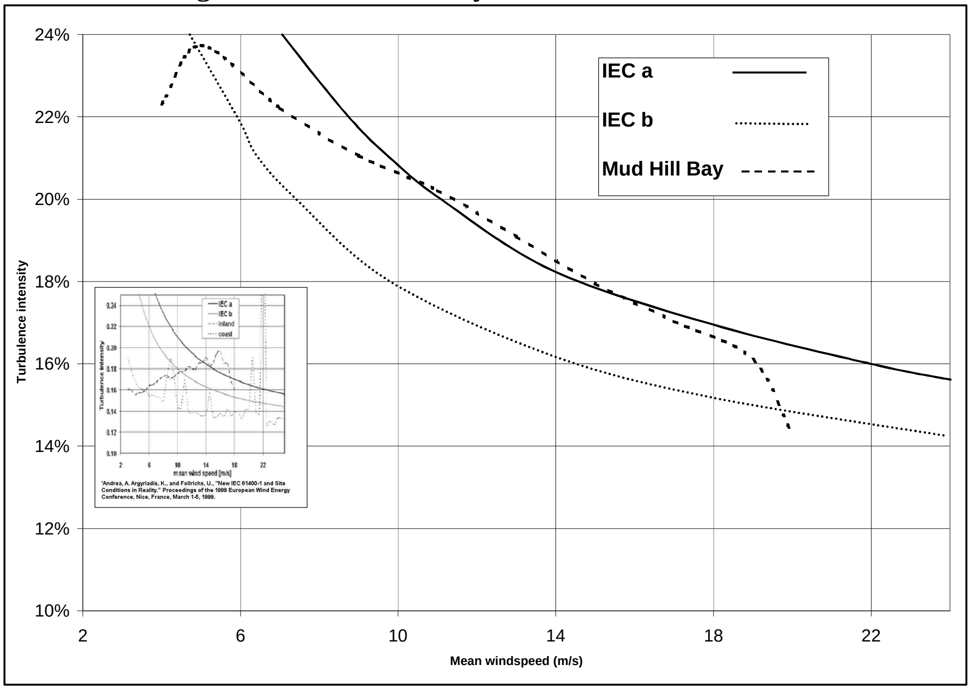
Turbulence Intensity Wind Rose

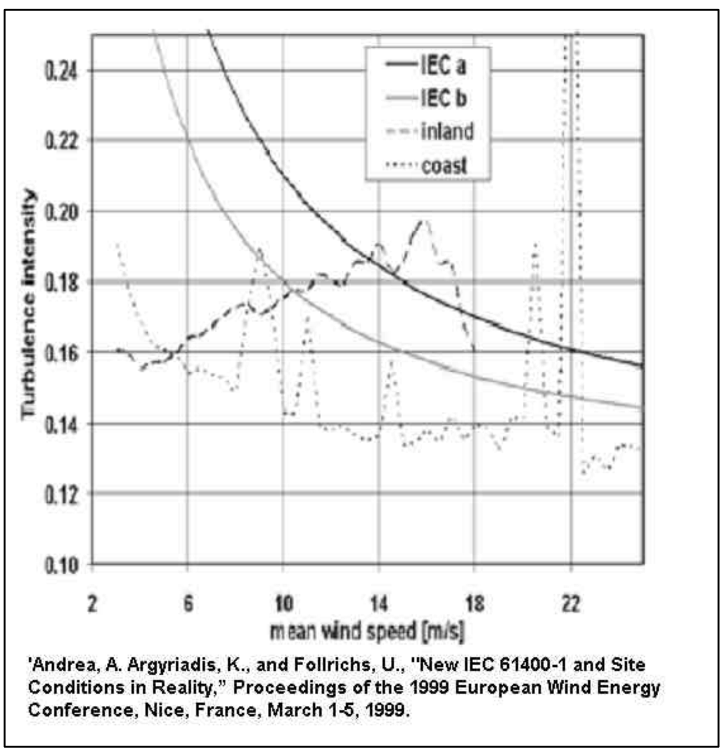
14 m/s <windspeeds <= 16 m/s



Appendix G Observed Mean Annual Turbulence Intensity

Observed mean annual turbulence intensity distribution for Mud Bay Hill compared with IEC 61400-1 design turbulence intensity curves.





Source: Andrea, A. Argyriadis, K., and Follrichs, U., "New IEC 61400-1 and Site Conditions in Reality," *Proceedings of the 1999 European Wind Energy Conference*, Nice, France, March 1-5, 1999, pp. 593-596.