OCS Study
MMS 2005-069

Study Final Report

for the

Beaufort Sea Meteorological Monitoring and Data Synthesis Project

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1 INTRODUCTION

This report presents the results of the 2001- 2005 Nearshore Beaufort Sea Coast Meteorological Monitoring Project commissioned by the U.S. Department of the Interior Minerals Management Service (MMS). This work was performed by HCG, Inc., d.b.a., Hoefler Consulting Group (HCG) under MMS Contract No. 1435-01-00-CT-31067.

1.1 Background

MMS predicts that in the near future oil and gas development will expand in the nearshore region of the Beaufort Sea. In the Outer Continental Shelf (OCS) areas of the Bering Sea and of the continental U.S., MMS maintains networks of offshore buoys to collect long-term surface wind data, but such a system is absent in the Beaufort Sea. Data sets collected prior to this study were not suitable for use in MMS models because the data sets were too limited (e.g. 3 month offshore exploration projects) or the distance from the area of interest was too great (e.g. Barrow or Barter Island).

Research by Dr. Thomas Kozo in the 1980's demonstrated that Arctic regional circulation models based upon upper air pressure fields are inaccurate predictors of surface winds within 20-30 km of the Beaufort Sea Coast. The two major effects predicted to explain the differences are 1) the existence of an Arctic sea breeze effect [Kozo, 1982] and 2) orographic effects caused by the Brooks Range on Alaska's eastern Beaufort Coast [Kozo and Robe, 1986]. Kozo suggests that the sea breeze effect influences an area centered along the coastline that is approximately 40 km in width, while orographic effects of the Brooks Range influence an area extending at least 50 km offshore from Camden Bay to Mackenzie Bay.

The Arctic sea breeze effect described by Kozo [1982] occurs during the summer, when ice-free conditions occur and daylight is almost constant in the Arctic. The long days lead to a land-sea thermal imbalance, with the land always being warmer. This causes the upper air surface to slope seaward, causing offshore pressure to rise and inducing a shoreward wind (east to north-east in the Beaufort). In contrast to the well-known sea breeze effect of the lower and mid-latitudes, this wind is consistently shoreward. Since the sun does not set for long periods while the ocean is ice-free, there is never a reversal of temperature gradients resulting in a lack of seaward breezes that are commonplace at coastal areas at lower latitudes.

The effects of the Brooks Range are somewhat more complex than the Arctic sea breeze effect. Due to the stable atmospheric boundary layer typical in the Arctic, air flow around the Brooks Range almost always presents less of an obstacle than air flow over it. This leads to changes in wind speed and direction relative to that predicted in models. The exact nature of the diverted flow will depend on the incoming direction of the large-scale wind.

Model results presented by Kozo and Robe [1986] predict that for the dominant wind direction (northeast), winds should be supergeostrophic in the area west of 142°W, peaking at 162% of geostrophic speed in eastern Camden Bay and declining to 151% north of Mikkelsen Bay and 140% north of Prudhoe Bay. Winds in Camden Bay were diverted from NE to ENE, while little diversion occurred at the other sites. Wind speed was predicted to increase moving eastward from Prudhoe Bay to Camden Bay when winds came from the east, northeast, west, and northwest. Of the five wind conditions modeled by Kozo and Robe (E, NE, N, NW, and W), only north winds were predicted to be stronger at Prudhoe Bay than at Camden Bay, while in all other cases the reverse was true.

1.2 Objectives and History

The originally stated goals of this study were to collect historical meteorological data from the Beaufort Sea region, subject to immediate development, and to collect new meteorological data from the deployment of new meteorological stations.

The study was intended to provide a comprehensive time-series of wind data for MMS modelers and researchers for use in their ongoing modeling of the nearshore Beaufort Sea. Meteorological data were collected at both offshore and nearshore locations to provide data for MMS models, such as the Oil Spill Risk Analysis (OSRA), Coastal Zone Oil Spill (COZOIL), oil weathering, and nearshore circulation models.

The historical meteorological data sets were identified, collected, and delivered to MMS as an electronic database in November 2005.

This database represents the most comprehensive collection of weather observations ever assembled for the Beaufort Sea coast, containing all valid hourly data collected by any station operating along the U.S. or Canadian coastline from 1985 to October 2005. This collection of over 1.2 million station-hours of data should prove to be a valuable resource for MMS and the public in modeling the meteorology of this region.

For this study, HCG operated a total of five nearshore meteorological monitoring stations spanning about 100 kilometers along the Beaufort Sea coast from western Simpson Lagoon to Mikkelsen Bay. Four of the five meteorological stations were located at BP facilities: the Badami storage pad, Endicott's Satellite Drilling Island (SDI), the top of the Northstar living quarters (PLQ) on Seal Island, and Milne Point F-Pad. These four stations began collecting data January 1, 2001. Another station on the east end of Cottle Island was added to the study beginning August 21, 2002.

Data collection began at four of the stations on January 1, 2001. The monitoring stations are still operating at the time of this writing, and will likely continue to collect data until September 2006. These stations all collected a variety of parameters, including wind speed and direction, wind sigma (a measure of turbulence), temperature, relative humidity, solar radiation, and barometric pressure.

Over the life of this project HCG prepared 18 Quarterly Data Reports for MMS, which summarize the stations operating history, equipment and collected data in detail. The primary concern of this report is to focus on the most pertinent data and results. As this was foundationally a study to aid in modeling wind fields to predict oil spill movements, the main emphasis is on the wind speed and direction data. Variables of secondary interest; temperature, wind sigma, barometric pressure, solar radiation and relative humidity, are included but given less thorough treatment.

2 ABSTRACT

This report summarizes meteorological data collected from January 2001 to June 2005 from five nearshore meteorological monitoring stations spanning a 100 km stretch of the Beaufort Sea coast centered on Prudhoe Bay.

The data are generally similar between most of the sites, although statistically significant differences are shown to exist between different sites and between seasons. The station at Badami is the most distinctive due to a weakened sea breeze effect and orographic effects of the Brooks Range, which appear to influence the eastern edge of the study area.

The data support the sea breeze and orographic effects theorized by Dr. Thomas Kozo in the 1980's, while providing more detail in the area around Prudhoe Bay. The data indicate that the sea breeze effect is stronger in May and June than in August.

Northstar is not a good location for a meteorological monitoring station due to several obstructions on the island. However, the Milne Point and Cottle Island stations are representative of the area, especially the Cottle Island station.

It was discovered over the course of this project that 3-cup anemometers will pack with snow and under-report wind speed in mid-winter at some Arctic coastal sites. It was proven through simultaneous operation that propeller-style wind sensors are a far more reliable means of collecting wind data in this region. Therefore, the use of propeller-style wind instruments is recommended in all future studies where icing might be an issue.

3 METHODS

3.1 Elements of the Study

This study included four key elements:

(1) Collection of new meteorological data
(2) Collection of historical wind data
(3) Development of meteorological databases for the collected data
(4) Analysis of the collected data.

These four tasks were conducted as follows.

3.1.1 Collection of Meteorological Data

A primary element of this study was the collection of new meteorological data from the nearshore Beaufort Sea region of Alaska. The study included a total of five meteorological monitoring stations. Four new meteorological stations were established for this study at Badami, Endicott, Northstar, and Milne Point in January 2001. To address concerns about wind interferences at Northstar, a fifth meteorological station was installed on Cottle Island in August 2002. The observed parameters for this study were wind speed, wind direction, air temperature, barometric pressure, relative humidity, and solar radiation. All parameters were monitored continuously. Data collection will likely continue through September 2006.

The meteorological monitoring sites were selected to measure nearshore Beaufort Sea winds in the vicinity of proposed offshore oil and gas development. Four of the stations were located at BP Exploration (Alaska) Inc. oil and gas exploration and production facilities. All five sites were situated in flat areas near sea level. The Badami and Milne Point stations are "nearshore stations" located on the mainland. The Endicott, Northstar, and Cottle island stations are "offshore stations", located on islands. A map of the five meteorological sites is presented in Figure 3-2. Photographs of the five site locations are presented in Figure 3-3 through Figure 3-7.

3.1.2 Collection of Historical Meteorological Data

Historical Beaufort Sea wind speed and direction data from all available sources were compiled into a single database with consistent formats. Historical wind data collected near the Beaufort Sea coast between 1985 through 2005 were obtained from public and private sources. The historical data gathering effort included a literature search of the known studies in the Beaufort Sea, Alaska region. A total of 32 sets of historical wind data were collected for this region. Two additional private-domain wind data sets were identified, but could not be readily obtained in an electronic format.

Many of the historical data sets consisted of only a few months of data. Only wind data, which was collected approximately every hour, was used in the historical database. Data sets were limited to an area stretching from Barrow to Herschel Island (just beyond the Alaska-Canada border). An updated historical database was presented to MMS on April 2005. This historical database was entitled the "Nearshore Beaufort Sea Historical Wind Database". A listing and a map of the historical wind data sets included in this database is included in Appendix A.

3.1.3 Development of Meteorological Databases

A system of data management was developed to support the collection of the new and historical meteorological data. The historical wind data was compiled into a “Nearshore Beaufort Sea Historical Wind Database”, as previously described. The newly collected data was compiled into the primary “Beaufort Sea Meteorological Monitoring and Data Synthesis Project Database”. Each of these databases was developed in a Microsoft Access format.

Throughout the study period, newly collected meteorological data from the five stations are downloaded every working day to an Anchorage-based server. The data are then reviewed and posted to a web-enabled database that is available for public access. Public access to this database is available on the Beaufort Sea Meteorological Monitoring and Data Synthesis Project website at http://www.resdat.com/mms/.

3.2 Station Locations

This study includes five meteorological monitoring stations located along the Beaufort Sea coast of Alaska. Four of the meteorological stations are situated at oil and gas exploration and production facilities owned by BP Exploration (Alaska) Inc. (BPXA), and one station is located on land owned by the state of Alaska. The host facilities are the Badami Development Project, Endicott Production Facility, F-Pad in the Milne Point Unit, and Northstar Production Facility. The fifth station is located on Cottle Island, which is owned by the state of Alaska. These meteorological stations span across 100 kilometers of the Beaufort Sea coastline. Maps of the study area and the station locations are shown in Figure 3-1 and Figure 3-2, respectively. Table 3-1 provides the coordinates for each station.

Table 3-1 Meteorological Monitoring Station Coordinates

Site	Latitude	Longitude
Badami	70° 08.171’N	147° 00.522’W
Endicott	70° 19.370’N	147° 51.895’W
Northstar	70° 29.428’N	148° 41.901’W
Cottle Island	70° 29.920’N	149° 05.571’W
Milne Point	70° 30.402’N	149° 39.725’W

The meteorological monitoring sites were selected to measure the nearshore winds along the Beaufort Sea coast in the vicinity of proposed offshore oil and gas development. The sites were located in a manner consistent with the Environmental Protection Agency (EPA) Prevention of Significant Deterioration (PSD) criteria for surface meteorological data collection. Data collection at the Badami, Endicott, Milne Point, and Northstar stations began on January 1, 2001 and at Cottle Island on August 21, 2002.

All five sites are situated in flat areas near sea level. The Badami and Milne Point stations are located on the mainland, Endicott and Northstar stations are located on man-made islands, and the Cottle Island station is located on a natural island. Photographs of each meteorological station are provided in Figure 3-3 through Figure 3-7.

Figure 3-1 Project Location Map

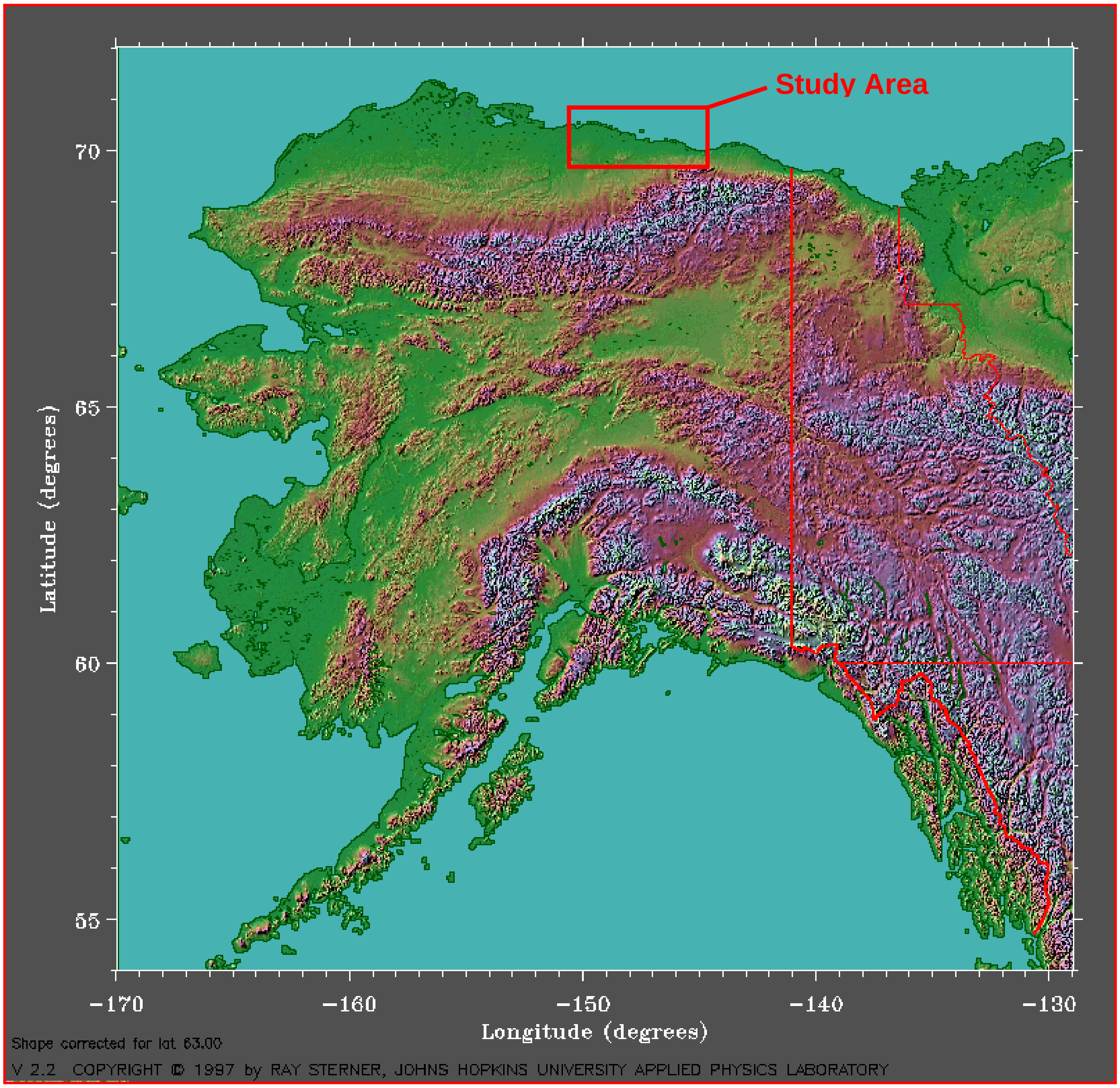


Figure 3-2 Meteorological Monitoring Station Map

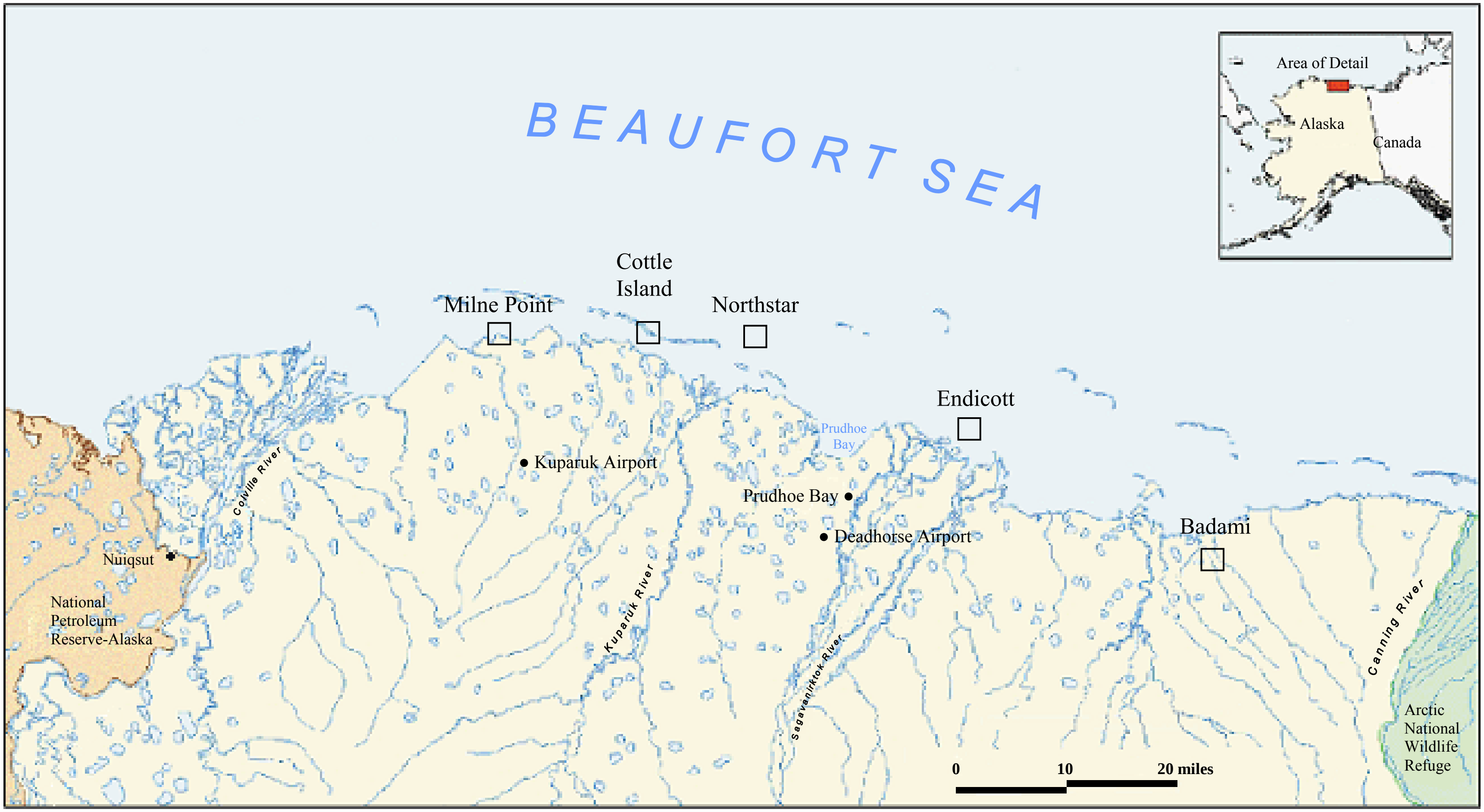


Figure 3-3 Badami MMS Meteorological Monitoring Tower

Figure 3-4 Cottle Island MMS Meteorological Monitoring Tower

Figure 3-5 Endicott MMS Meteorological Monitoring Tower

Figure 3-6 Milne Point MMS Meteorological Monitoring Tower

Figure 3-7 Northstar MMS Meteorological Monitoring Tower

The Endicott, Northstar, and Cottle Island stations are located on islands and considered "offshore" stations. The Endicott monitoring station is located on Endicott's Satellite Drilling Island (SDI), which is connected to shore by a causeway. SDI is located about three kilometers offshore from the mouth of the Saganavirktok River. The Northstar monitoring station is located at the Northstar Production Facility on Seal Island, a two hectare (five acre) gravel island 10 kilometers from the coast. The Cottle Island monitoring station is located on an undeveloped island five kilometers from the coast.

The Badami and Milne Point stations are located on the mainland, and are considered "onshore" stations. To the south of the Badami and Milne Point stations is tundra, with numerous lakes scattered throughout the region. Vegetation in the area consists of mosses, lichens, grasses, and low-growing Arctic tundra bushes. Milne Point is located on the coast, a few meters from the ocean. Badami is somewhat inland, separated from the Beaufort Sea by two kilometers of flat, treeless tundra.

3.3 Instrumentation

This section briefly describes the meteorological sensors used in this monitoring program. All five sites use identical instrumentation. All instruments meet or exceed the stringent EPA PSD requirements for range accuracies, thresholds, response times, resolutions, damping ratios, and other performance measures. The meteorological monitoring program collects hourly data for the following parameters at each monitoring location:

- Wind speed (meters/second [m/s]);
- Wind direction (degrees [°]);
- Wind direction standard deviation (wind sigmą [σ_θ]);
- Air temperature, motor-aspirated shield (degrees Celsius [°C]);
- Air temperature, motor-aspirated shield, backup (degrees Celsius [°C]);
- Barometric pressure (millibar [mbar]);
- Solar radiation (watts/m^2 [W/m^2]); and
- Relative humidity, motor-aspirated shield (percent [%]).

Each site also records the minimum and maximum instantaneous temperature and the maximum instantaneous wind speed during the previous hour. All parameters are collected as hourly averages, except barometric pressure which is recorded at the start of each hour. All measured parameters (except barometric pressure and solar radiation) were audited and calibrated semi-annually.

The mean hourly temperature, minimum instantaneous temperature, and maximum instantaneous temperature will be very similar most of the time. The mean hourly temperature is defined as the average temperature recorded for every second of the specified one-hour interval. The minimum instantaneous temperature is defined as the lowest temperature recorded in the one-second measurements throughout the specified one-hour interval. The maximum instantaneous temperature is defined as the highest temperature recorded in the one-second measurements throughout the specified one-hour interval.

Wind speed, wind direction, and wind sigma are measured at a height of approximately 10 m at Badami, Cottle Island and Endicott, and at approximately 14 m and 23 m at Milne Point and

Northstar, respectively. Temperature and relative humidity are measured at a height of 2 meters at Badami, Cottle Island, and Endicott, and at 11 m and 19 m at Milne Point and Northstar, respectively.

Barometric pressure is measured at a height of 1 to 2 m at Badami, Cottle Island, Endicott, and Milne Point, at 19 m at Northstar. Solar radiation is measured at a height of approximately 5 m at Badami, Cottle Island, and Endicott, and at 11 m and 21 m at Milne Point and Northstar, respectively.

A listing of each parameter and sampling method used during the monitoring program is provided in Table 3-2.

Table 3-2 Primary MMS Meteorological Monitoring Equipment

Parameter	Manufacturer/ Model	Operating Range	Method
Wind Speed	Climatronics F460	0.2 to 60 m/s	Three-cup anemometer assembly
Wind Direction	Climatronics F460	0^o to 360^o	Vane, potentiometer voltage output is proportional to wind direction
Wind Sigma	Campbell Scientific CR10X-XT	---	DAS calculated, 15-minute root mean square values averaged to 1-hour values
Temperature	Climatronics 100093-2	-50°C to +50°C	Platinum 4-wire probe and thermistor in a motor-aspirated shield
Barometric Pressure	Campbell Scientific 105	600 to 1,060 mb	Silicon capacitive pressure sensor
Relative Humidity	Campbell Scientific HMP-45C	-40°C to +60°C (0% - 100% RH)	Capacitive polymer H chip in a motor-aspirated shield
Solar Radiation	Campbell Scientific LI200X	400 to 1,100 nanometers	Silicon photovoltaic detector mounted in cosine-corrected head
Datalogger	Campbell Scientific CR10X-XT	-55°C to +85°C	1.0-second scans, processed to hourly averages recorded on the hour

3.3.1 Wind Speed and Direction

Wind speed and direction are measured continuously using Climatronics F460 Wind Sensors and RM Young Model 05305-AQ Wind Monitors. The Climatronics sensor uses a three-cup anemometer to measure wind speed. The cup rotation produces a signal frequency that is proportional to wind speed and is recorded by the datalogger. RM Young sensors are deployed at Cottle Island and Endicott and measure wind speed using a propeller anemometer. The propeller rotation produces a signal frequency which is proportional to wind speed. These signal frequencies are recorded by the datalogger.

Both Climatronics and RM Young wind direction sensors consists of a wind vane with a 360-degree potentiometer for a signal transducer. The wind speed sensor and wind direction sensor are separate instruments on the Climatronics assembly. The standard deviation of the wind direction (wind sigma [σ_θ]) is computed by the Campbell CR10X-XT datalogger using the EPA-preferred Yamartino (1984) method.

3.3.1.1 Adjusting Wind Speed Height

Wind speed is measured at a height of 10 meters at Badami, Cottle Island and Endicott, but the Milne Point and Northstar towers were raised to avoid interfering obstacles (this was more successful at Milne Point than Northstar). The sensor heights are 14 and 23 meters at Milne Point and Northstar, respectively.

Theoretically, wind speed is equal to zero at the ground, then increases logarithmically with height. The rate of increase depends upon the surface roughness (z_0). If the surface roughness is known, and if the wind speed M_1 at height z_1 is known, then wind speed M_2 at height z_2 can be estimated using the formula:

$$M_2 = M_1 \cdot \left(\frac{\ln(z_2 / z_0)}{\ln(z_1 / z_0)} \right)$$

Heights are in meters and speeds in m/s. At Milne Point we assume a surface roughness of 0.005 meters, which is defined by the Davenport-Wieringa roughness length classification as "smooth", representing surfaces such as beaches pack ice, morass, and snow covered fields. The formula then tells us that the wind speeds observed at Milne Point should be multiplied by 0.958 to estimate the wind speed at 10 meters.

Adjusting the height at Northstar is more problematic, since the general area around the station has a surface roughness length between 0.0002 ("sea") and 0.005 ("smooth"), but the area around it is >2, or "chaotic", representing city centers or irregular forests with scattered clearings. This is further complicated by what should be considered to be "ground height". For example, in a forest the tree tops are considered "ground height", but Northstar has many structures taller than the wind sensor, leaving the ground height ambiguous.

Assuming that the surface of the island is effectively ground height and the surface roughness is 0.005, it is estimated that the wind speed should be multiplied by 0.929 to approximate the wind speed at 10 meters. However, if a surface roughness of 2 is applied, then the multiplier falls to 0.659.

All data in the historical database, on the website, in the appendices, and in the wind roses represents the raw unadjusted data. The summary tables in Section 4.1 have been adjusted by 0.958 for Milne Point for 0.929 at Northstar, the most conservative estimate.

3.3.2 Temperature

The stations measure temperature at different heights. The stations at Endicott, Badami and Cottle Island rest on the ground, whereas the Milne Point and Northstar stations are mounted atop raised structures. The Endicott and Cottle Island temperature probes are located at a height of 2.0 m above ground level; the Badami temperature probes are located at 2.6 m. At Milne Point and Northstar, the probes are mounted at 11 m and 19 m above ground level, respectively. Two separate temperature probes are located at each site: a Climatronics Temperature Sensor Model 100093-2 and a Campbell Model HMP-45C instrument, which is a slightly modified version of the Vaisala HMP45 dual temperature/relative humidity probe. The Campbell Model HMP-45C instrument has a similar temperature measurement range as the Climatronics probe, but is not certified for accuracy below -40°C. Data from the Campbell probe are being used to back up and verify data from the primary Climatronics probe.

3.3.3 Barometric Pressure

Pressure is measured using a Campbell CS105 (Vaisala PTB-101B) Barometric Pressure Sensor housed inside the Campbell datalogger enclosure. The barometric pressure sensor takes an hourly instantaneous reading. No user-serviceable parts are present on the sensor.

Barometric pressure varies significantly from site to site, but some of this variation is due to the height of the sensor. The Badami, Endicott, Milne Point, and Cottle Island stations have their sensors mounted at approximately 2 meters, while the Northstar station measures barometric pressure at 21 meters. The exact height above sea level at the base of each tower is unknown, but estimates of the total elevation of the sensors and the corresponding estimated adjustment to sea-level are shown in Table 3-3. The pressure was corrected using the formula:

$$\Delta P = \frac{\rho \cdot g \cdot \Delta z}{100}$$

ΔP is the change in pressure, ρ is density (1.225 kg/m^3), g is the force of gravity (9.8m/s^2), and Δz is the change in height in meters. Presssure units of Pascals are converted to millibar by dividing by a factor of 100. All data in the historical database, on the website, in the appendices and in the wind roses represents the raw, unadjusted data. The adjustments shown in Table 3-3 have been added to the summary tables in Section 4.5 where noted.

Table 3-3 Adjustment to Sea-Level Pressure

Monitoring Station	Elevation (m)	Adjustment (mbar)
Badami	17	+2.0
Cottle Is	5	+0.6
Endicott	5	+0.6
Milne Pt	7	+0.8
Northstar	24	+2.9

3.3.4 Solar Radiation

A Campbell LI200X Silicon Pyranometer, manufactured by Li-Cor, measures solar radiation at each of the sites. The pyranometer measures sun plus sky wavelengths between 400 and 1,100 nanometers (daylight spectrum). The instrument has an absolute error in natural daylight of plus or minus 5 percent. Occasional artificial light sources (facility lighting, flaring) have caused false readings at some sites. Suspect solar radiation readings are especially noted at Northstar due to the nearby facility flare.

3.3.5 Relative Humidity

Relative humidity is measured at the same heights as the temperature probes using a Campbell Model HMP-45C, which is essentially a Vaisala HMP-45A dual temperature/relative humidity probe. The probe uses a capacitive polymer H chip for the relative humidity measurement and operates in a -40°C to +60°C temperature range.

3.3.6 Data Acquisition and Telemetry

A Campbell Scientific Model CR10X-XT, 12-channel datalogger located at the base of each tower, monitors all instruments. At all sites except Northstar, the enclosure/datalogger is situated at ground level. At Northstar, the enclosure is located at the base of the tower on the roof of the PLQ. The datalogger collects a continuous stream of data from the instruments and then stores hourly averages, peaks, and/or instantaneous readings in the datalogger storage module. The data are then downloaded from the storage modules to the HCG office in Anchorage via cellular connection on a daily basis.

3.4 Station Operating History

The network of five meteorological monitoring stations generally performed well during the four and one-half years of the study (January 2001 - June 2005). However, the study was not without some periods of lost data due to equipment failures, equipment damage, station audits, and other factors. Frozen anemometers, broken or corroded wind vanes and broken relative humidity sensors were the most common equipment problems. The Northstar station, in particular, had significant periods of missing data due to wind direction sensor damage and repeated relative humidity sensor failures.

Meteorological data collected during this study were validated using guidelines set forth in EPA's *On-site Meteorological Program Guidance for Regulatory Modeling Applications* (EPA, 1995) and screened based on EPA's suggested screening criteria (EPA, 2000). The data validation criteria are also outlined in the *Minerals Management Service Meteorological Monitoring Plan (*Hoefler, 2001). The EPA data validation screening criteria were not effective in identifying an error in wind direction measurements at Northstar. As a result, additional wind direction validation procedures were developed and implemented in December 2002 to notify HCG of any errors in wind direction data collection. A Certified Consulting Meteorologist (CCM) from HCG performed a final review of the collected data for accuracy.

Data flagged under the EPA or HCG criteria were carefully examined, but were generally not removed unless the values were outside the normal range of variation, the values become almost constant for an unidentified reason, maintenance activity has occurred at the site, instruments have been damaged, or if the flags continue uninterrupted for an extended period without explanation. The Quarterly Data Reports cover these procedures in greater detail, and provide discussion of all significant occurrences of lost or questionable data.

Data recovery from the stations was quite good, especially considering the remoteness of the sites and the hostile conditions. Data recovery is expressed as a percentage equal to the number of valid hourly measurements divided by the total number of hours. Data recovery for each parameter at all sites was above 90%, with the exception of Northstar's wind direction and wind sigma measurements. This performance complies with EPA's rigorous PSD air quality modeling data capture requirements. Data capture for each major meteorological parameter at each station is summarized in Table 3-4.

Table 3-4 Data Capture Summary

Monitoring Station	Wind Speed	Wind Direction	Wind Sigma	Temperature	Barometric Pressure
Badami	99.8%	99.0%	99.0%	99.8%	99.9%
Cottle Island	99.6%	93.4%	93.4%	99.9%	99.9%
Endicott	94.1%	91.4%	91.4%	93.2%	99.3%
Milne Point	99.4%	98.1%	98.1%	99.9%	100.0%
Northstar	97.0%	81.9%	81.9%	99.6%	99.6%

4 RESULTS

This section of the report presents summary tables and general discussion of descriptive statistics for wind speed, wind direction, wind sigma, temperature, barometric pressure, solar radiation and relative humidity for the study period January 2001 to June 2005.

Because Cottle Island station began acquiring data in August of 2002, it has a smaller data set than the other stations. Throughout this section, the confidence interval given for the mean is the 95 percent confidence interval.

Supplementary information is contained within the Appendices. Yearly data graphs, composite monthly wind roses, and descriptive statistics with histograms are provided in Appendices B, C and D, respectively.

4.1 Wind Speed

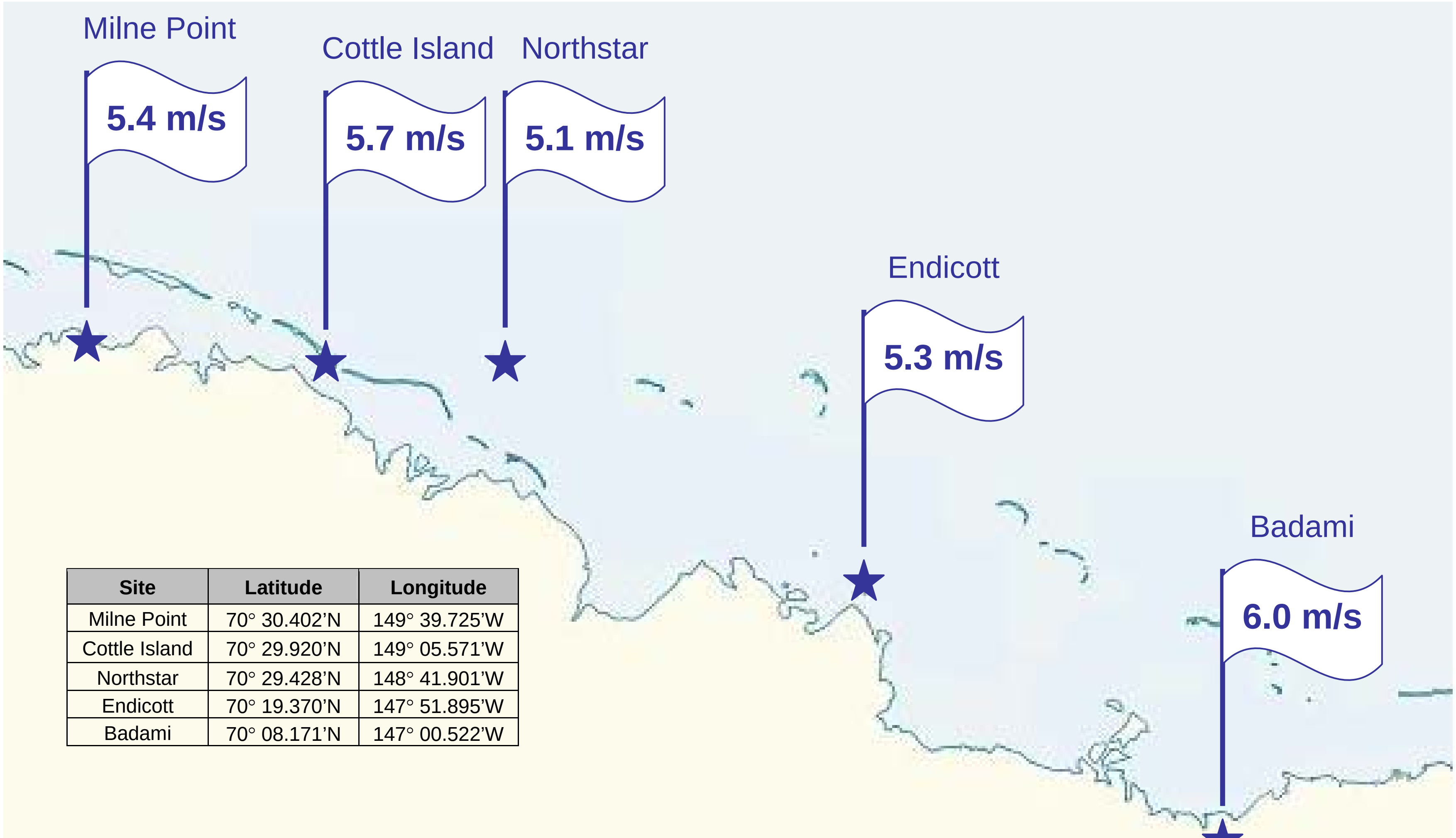
Wind speed data at Milne Point and Northstar have been adjusted in Table 4-1, Table 4-2, and Figure 4-1 through Figure 4-3 to account for the monitoring height of the anemometer, as described in Section 3.3.1.1. Graphs of annual wind speeds can be found in Appendix B. Figure 4-1 provides a map of the spatial distributions of average wind speeds and Figure 4-2 provides a map of the highest recorded instantaneous wind speeds at each site.

Badami had the highest average wind speed and the highest hourly wind speed was recorded at Northstar. It should be noted that Cottle Island wind speeds were measured only from August 21, 2002 and maximum instantaneous wind speeds were not recorded at Cottle Island until January 2003.

Table 4-1 Wind Speed Summary (m/s)

Monitoring Station	Hourly Mean Wind Speed		Instantaneous Wind Speed	
	Mean	Max	Mean	Max
Badami	6.0	27.9	8.0	35.5
Cottle Island	5.7	25.0	7.6	26.7
Endicott	5.3	23.7	7.2	30.6
Milne Point	5.4	24.9	7.2	33.8
Northstar	5.1	24.9	7.5	36.2

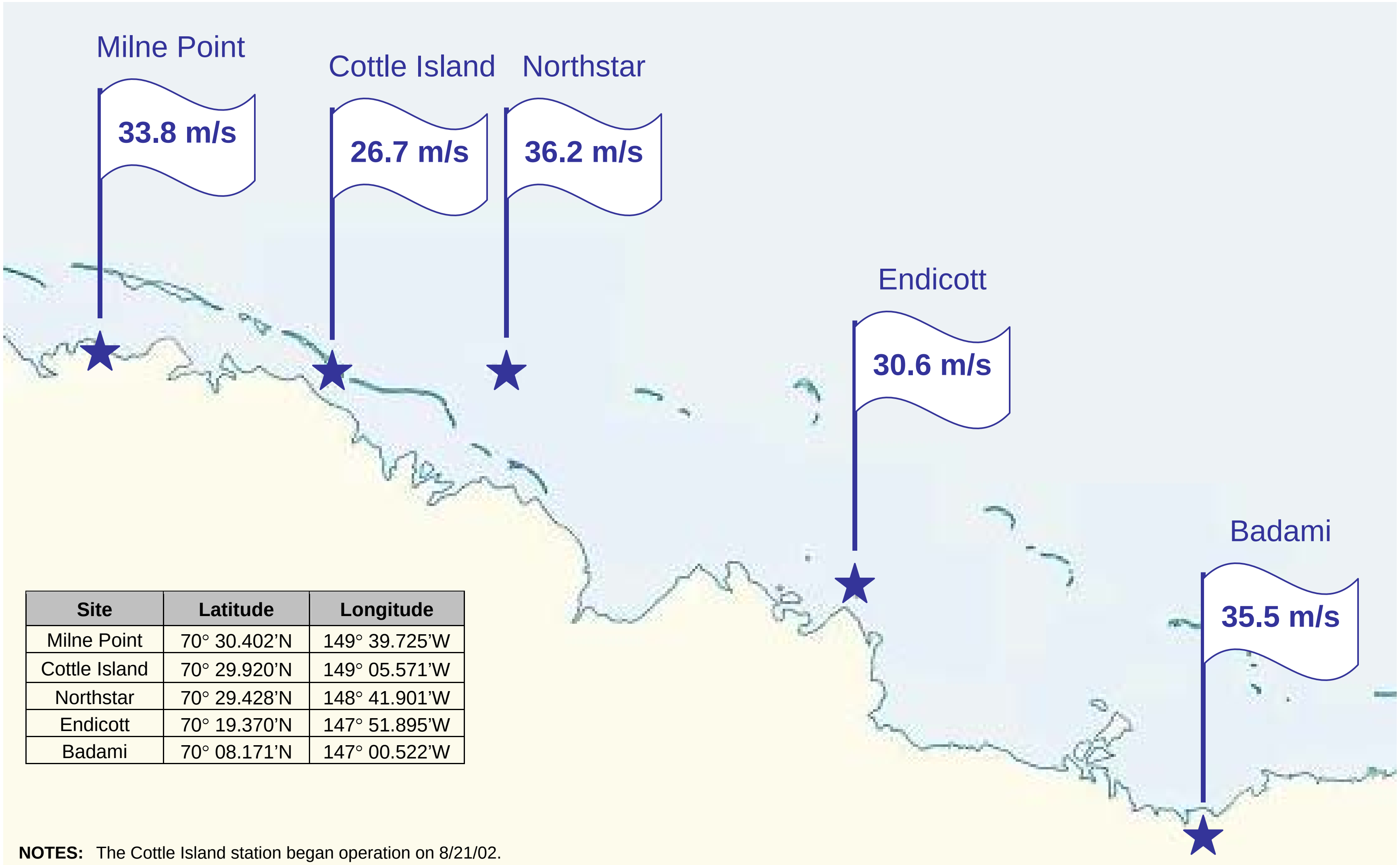
Figure 4-1 Spatial Distribution of Average Hourly Wind Speed



Site	Latitude	Longitude
Milne Point	70° 30.402'N	149° 39.725'W
Cottle Island	70° 29.920'N	149° 05.571'W
Northstar	70° 29.428'N	148° 41.901'W
Endicott	70° 19.370'N	147° 51.895'W
Badami	70° 08.171'N	147° 00.522'W

NOTES: The Cottle Island station began operation on 8/21/02.
Wind Speed is measured at a height of 10 meters at Badami, Cottle Island, and Endicott, and at 14 meters and 23 meters at Milne Point and Northstar, respectively.
Wind speeds at Northstar and Milne Point have been adjusted to approximate the local wind speed at 10 meters.

Figure 4-2 Spatial Distribution of Maximum Hourly Wind Speed



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Badami	70° 08.171'N	147° 00.522'W

NOTES: The Cottle Island station began operation on 8/21/02.
Wind Speed is measured at a height of 10 meters at Badami, Cottle Island, and Endicott, and at 14 meters and 23 meters at Milne Point and Northstar, respectively. Wind speeds at Northstar and Milne Point have been adjusted to approximate the local wind speed at 10 meters.

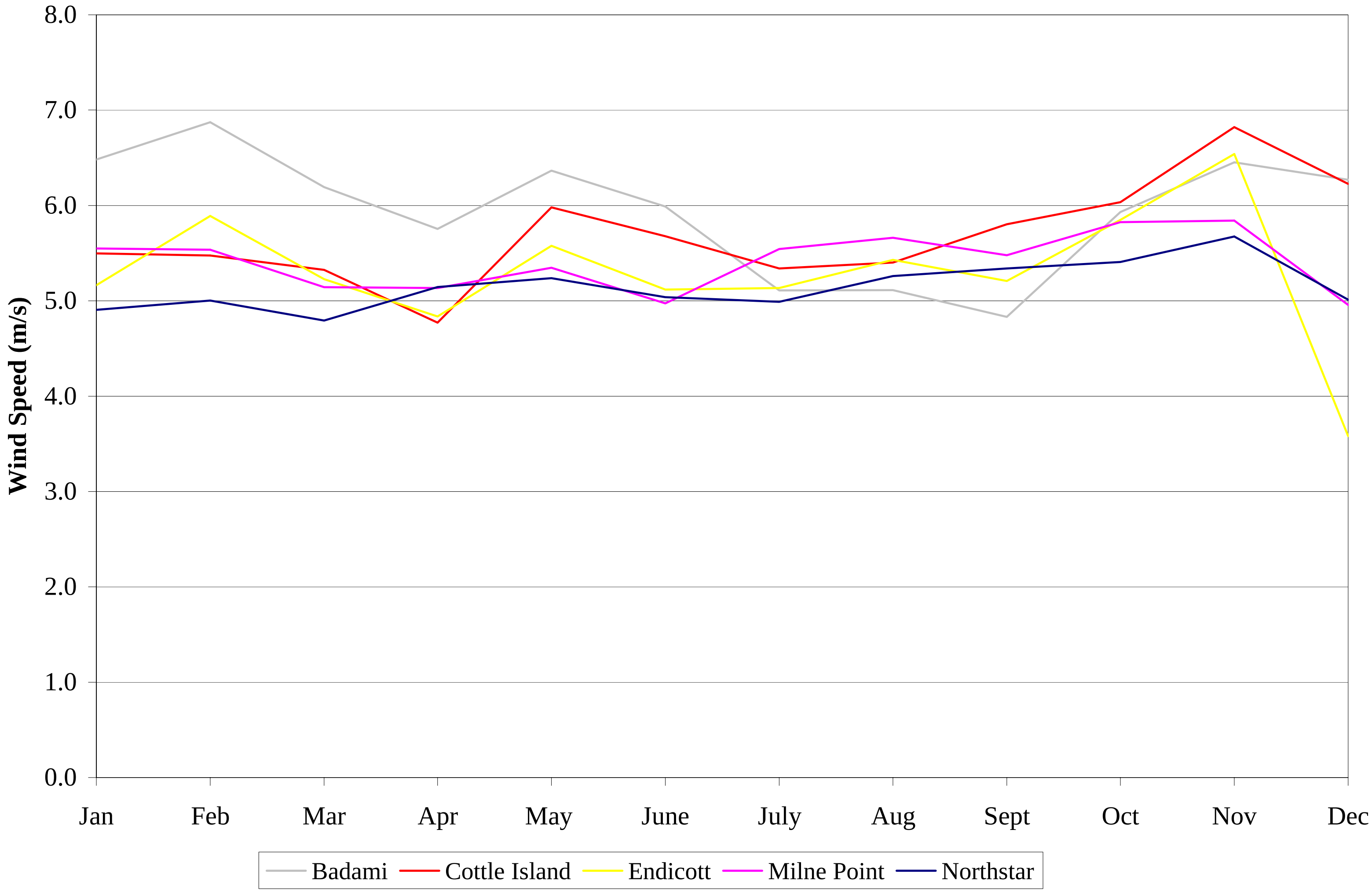
Descriptive statistics for wind speed are presented in Table 4-2 below. The low mean wind speed at Endicott may be partially due to anemometer icing problems (see Section 5.2). Northstar's wind speed may have been biased due to interference from on-site obstacles (see Section 5.1). The higher wind speed observed at Badami corroborates the findings of Kozo [1986], whose model indicates higher wind speeds closer inland toward the Brooks Range under most conditions (see Section 1.1).

Table 4-2 Descriptive Statistics for Wind Speed (m/s)

	Badami	Cottle Island	Endicott	Milne Point	Northstar
Mean	5.98	5.71	5.29	5.40	5.13
95% Confidence Interval (Mean)	5.93 – 6.02	5.66 – 5.76	5.25 – 5.32	5.37 – 5.43	5.10 –5.15
Standard Deviation	3.98	3.76	3.52	3.33	3.00
Median	5.00	4.86	4.40	4.67	4.61
Maximum	27.87	24.96	23.69	24.91	24.92

Annual variations in wind speed are presented in Figure 4-3. Wind speed is not particularly seasonal compared to the other variables. Endicott shows a marked drop in December, probably due to anemometer error (see Section 5.2). Badami wind speed measurements appear to reflect a real cycle that is not observed at the other sites, with lower wind speeds during July through September and higher wind speeds in winter.

Figure 4-3 Mean Adjusted Monthly Wind Speed



4.2 Wind Direction

Four and one-half year wind roses for each site are provided in Figure 4-5 through Figure 4-9. Wind Roses depict the frequency of occurrence of winds in each of 16 direction sectors (every 22.5°) and six wind speed classes (shown in Figure 4-4) for a given location and time period. The wind roses were generated using the Lakes Environmental Software, WRPLOT View. Monthly composite wind roses are provided in Appendix C. Figure 4-10 provides a map of the spatial distributions of wind roses for the five meteorological stations.

Discussion of the results can be found in Sections 5.3 through 5.5.

Figure 4-4 Wind Rose Wind Speed Legend (m/s)

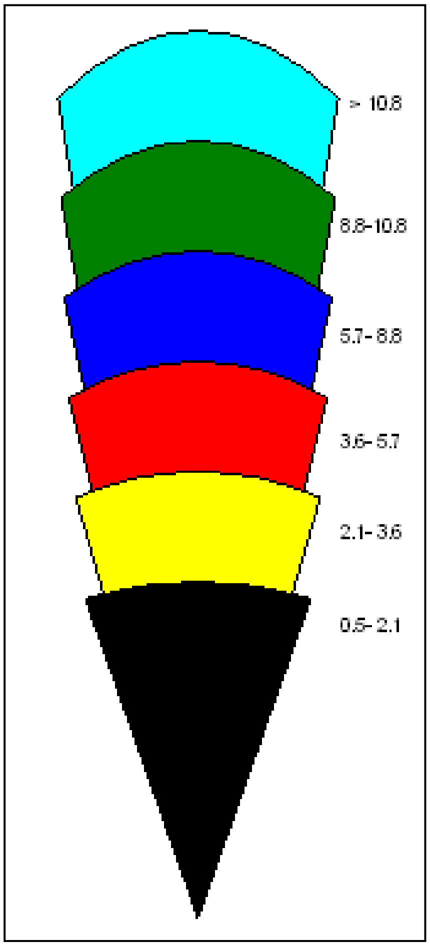


Figure 4-5 Mean Badami Wind Rose

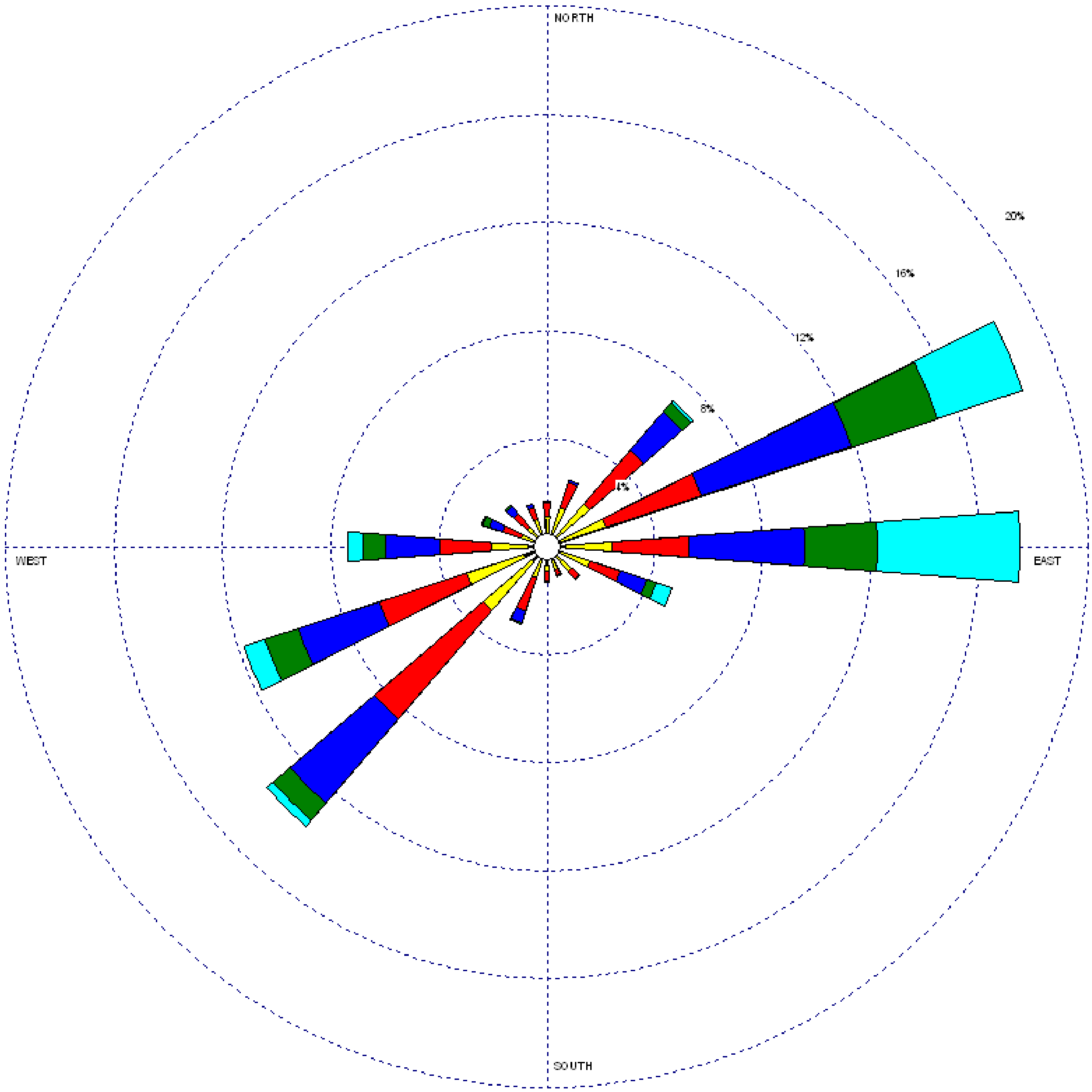


Figure 4-6 Mean Cottle Island Wind Rose

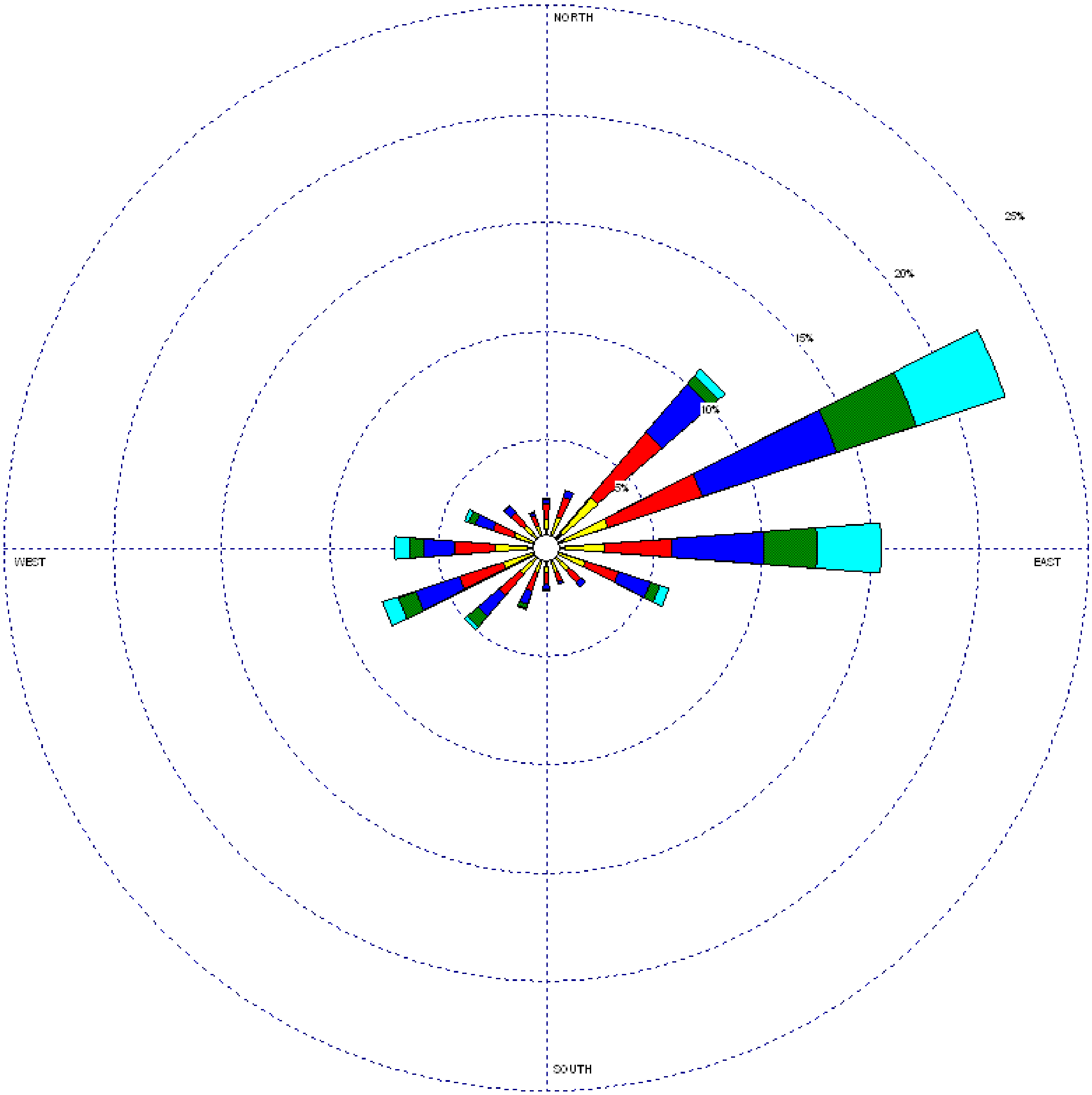


Figure 4-7 Mean Endicott Wind Rose

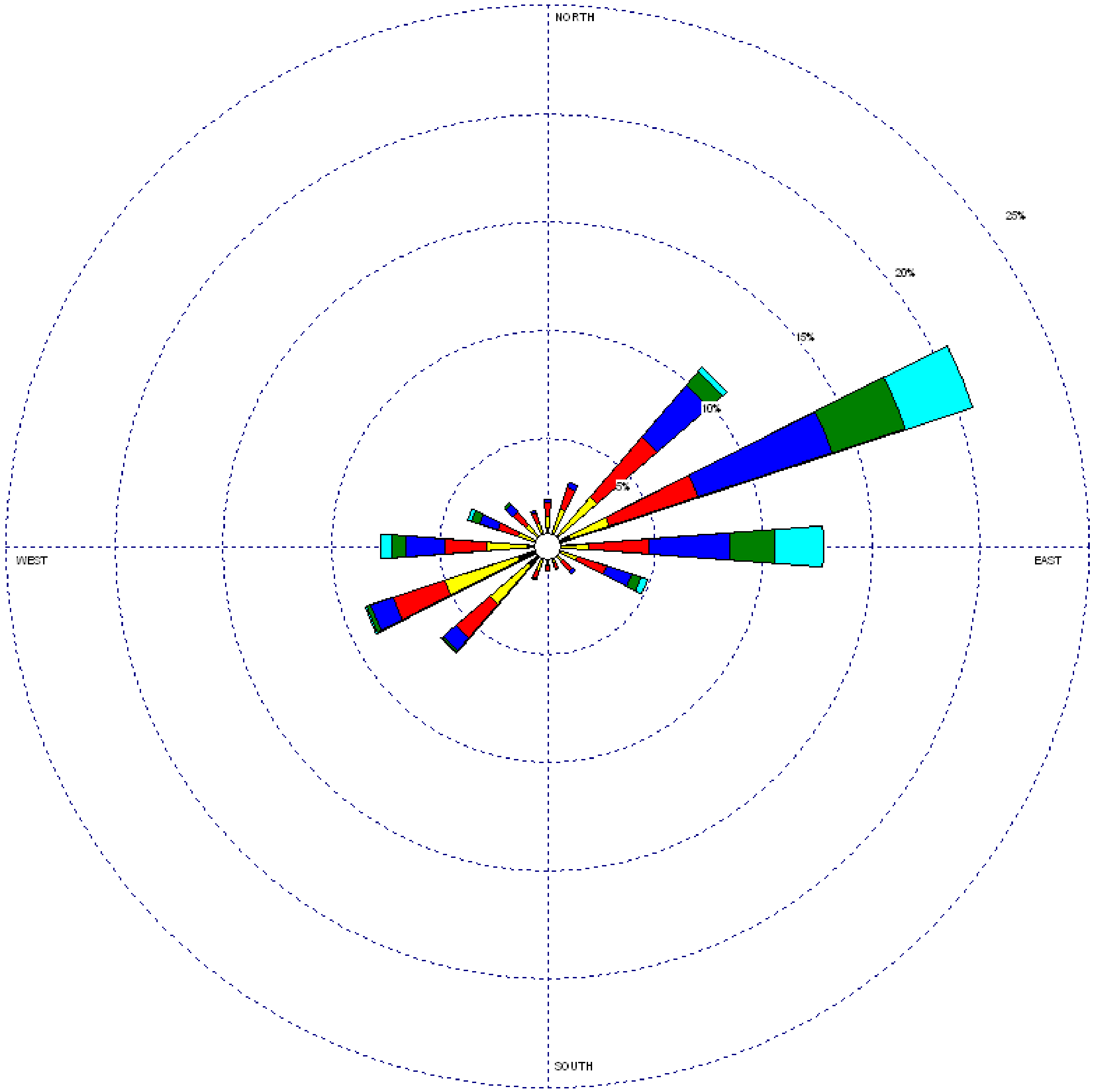


Figure 4-8 Mean Milne Point Wind Rose

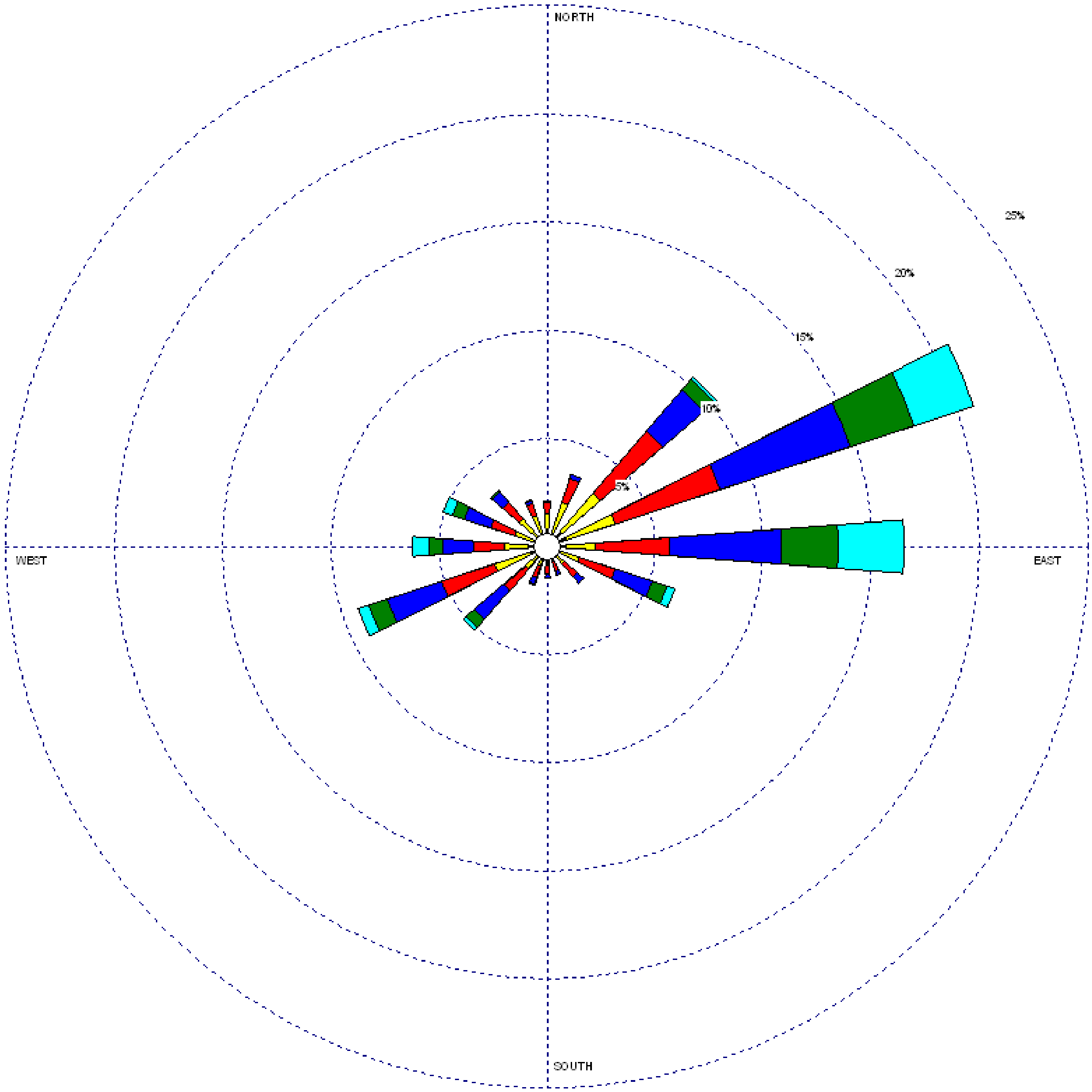


Figure 4-9 Mean Northstar Wind Rose

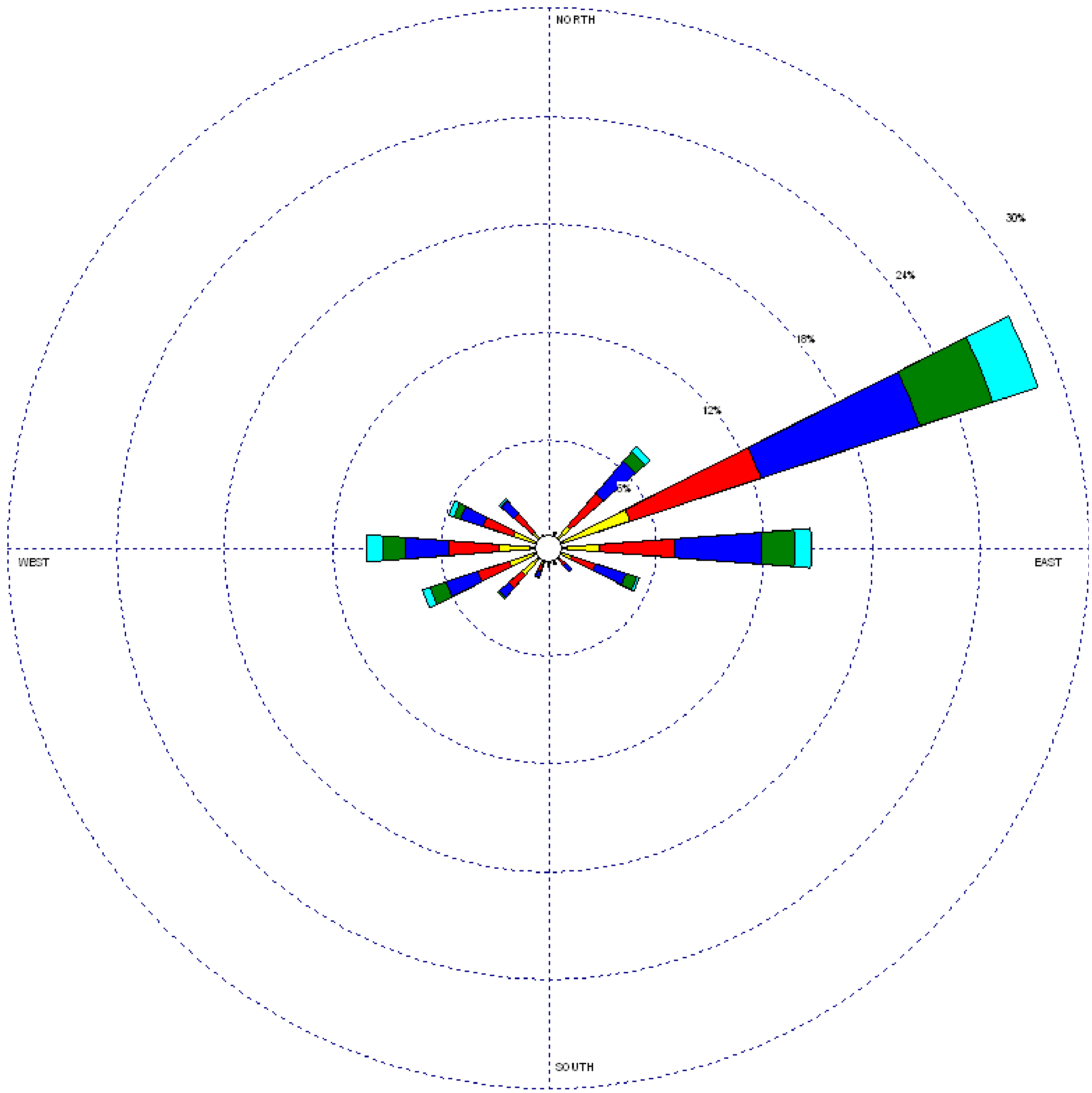
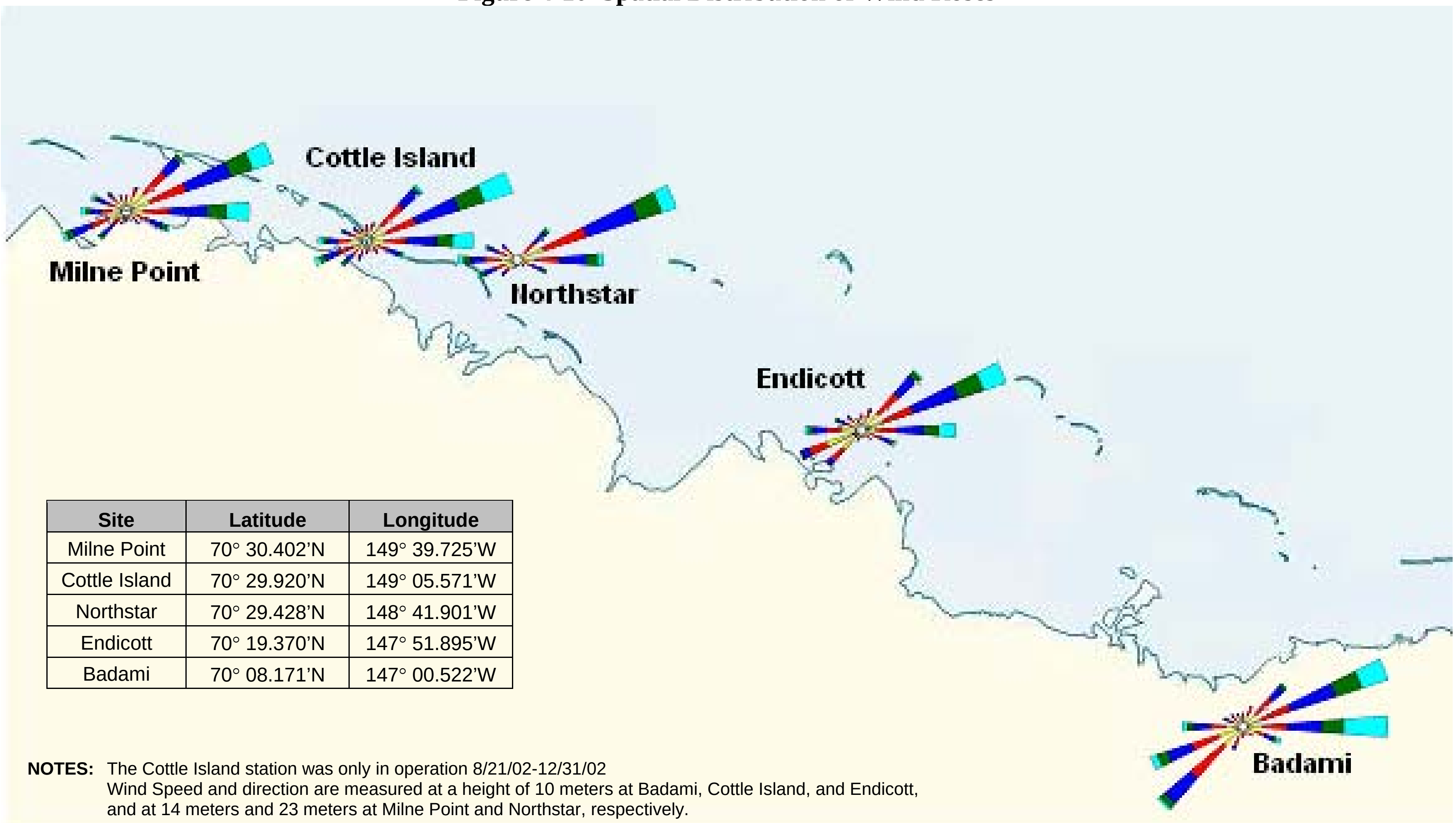


Figure 4-10 Spatial Distribution of Wind Roses



Site	Latitude	Longitude
Milne Point	70° 30.402'N	149° 39.725'W
Cottle Island	70° 29.920'N	149° 05.571'W
Northstar	70° 29.428'N	148° 41.901'W
Endicott	70° 19.370'N	147° 51.895'W
Badami	70° 08.171'N	147° 00.522'W

NOTES: The Cottle Island station was only in operation 8/21/02-12/31/02
Wind Speed and direction are measured at a height of 10 meters at Badami, Cottle Island, and Endicott, and at 14 meters and 23 meters at Milne Point and Northstar, respectively.

4.2.1 Wind Direction by Category

An in-depth categorical summary of wind direction and duration for the five stations was performed. The wind direction categories were onshore (from between 310-90°), offshore (130-27°), and shore parallel (270-310° and 90-130°). The results of the analysis are presented in Table 4-3, Table 4-4, and Figure 4-11 through Figure 4-14.

Table 4-3 shows the average number of days per year the wind blew from one of these directions for more than 16 hours. A day was considered "variable" if no one condition persisted for 16 hours or more. Wind direction was not counted for calm periods (wind speed <0.51m/s).

Table 4-3 Frequency of Wind Direction by Category (Days/Yr)

Meteorological Station	Offshore	Onshore	Shore Parallel	Variable
Badami	107	129	23	106
Endicott	64	159	21	122
Milne Point	62	163	35	106
Cottle Island	60	169	25	111
Northstar	44	191	34	97

Onshore winds were the most common at every site; all five stations spend about half of an average year in the onshore wind direction category. Note that onshore winds were more frequent the further out into the Beaufort Sea each station was. Offshore winds, by contrast became more common as one moved farther from the ocean. Shore parallel winds were the rarest condition at all sites. Badami displays a much stronger offshore wind component compared to the other stations. This is discussed further in Sections 5.4 and 5.5.

Table 4-4 shows the average uninterrupted hourly duration of winds by category. Only wind conditions which persisted for 3 hours or more were counted towards duration.

Table 4-4 Duration of Wind Direction by Category (Average Hours)

Meteorological Station	Offshore	Onshore	Shore Parallel	Calm
Badami	21	24	9	20
Endicott	18	33	9	48
Milne Point	18	31	11	21
Cottle Island	16	31	8	15
Northstar	15	44	9	44

Onshore winds are not only the most common condition, but also the most persistent. Like frequency, the duration of onshore winds increase seaward. Offshore winds increased in duration as one moved landward. The high duration of calm conditions at Endicott may be a result of the anemometer icing problems (see Section 5.2).

The annualized data in Table 4-3 mask the highly seasonal nature of wind direction. The following four graphs display the average days each condition occurs each month. The frequency of offshore winds is the most exceptionally seasonal, becoming almost non-existent in June. Onshore winds by contrast are most dominant in the summer. Shore-parallel winds are most common in the fall, while variable conditions are most likely in the late summer/early fall.

Figure 4-11 Frequency of Offshore Winds

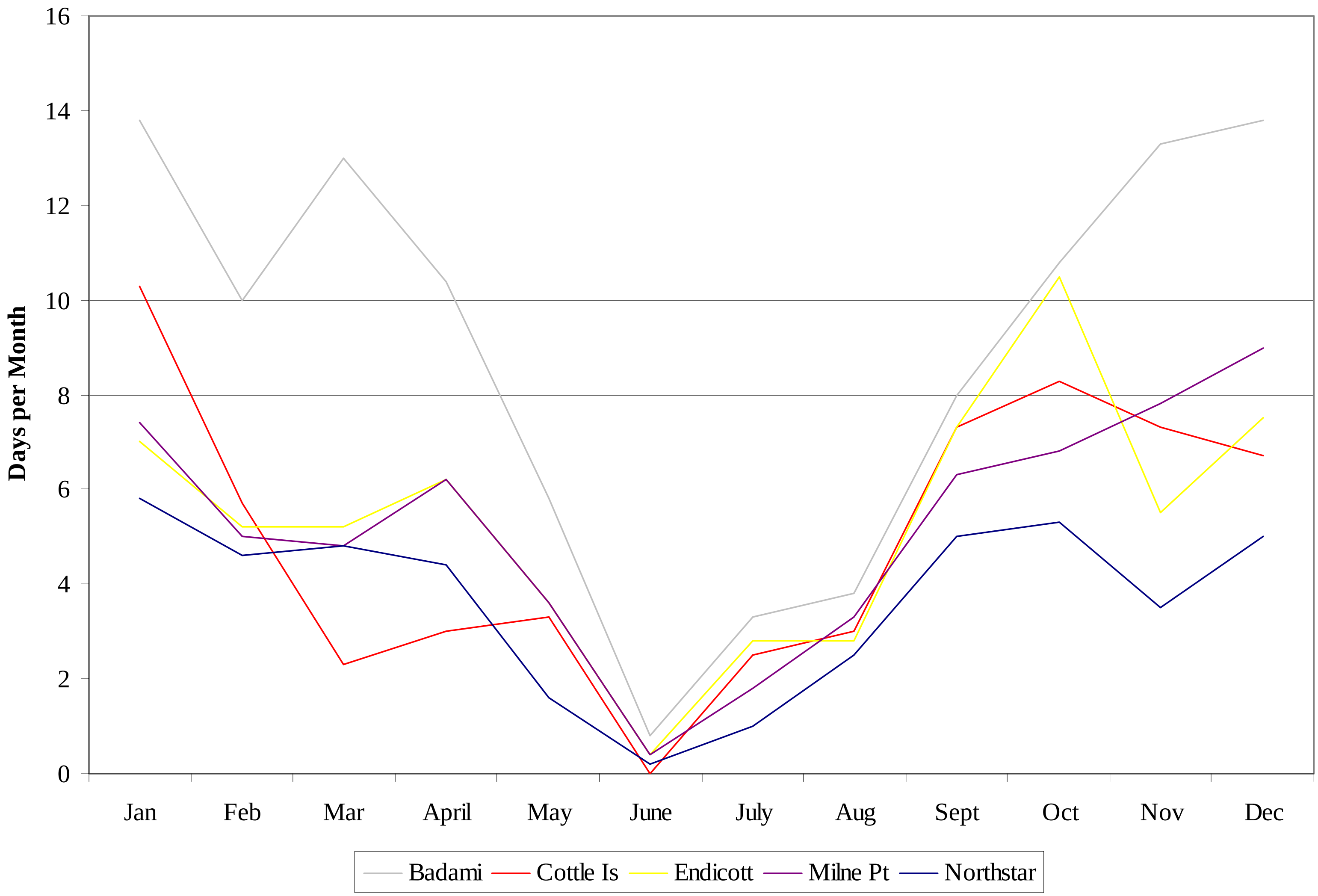


Figure 4-12 Frequency of On-Shore Winds

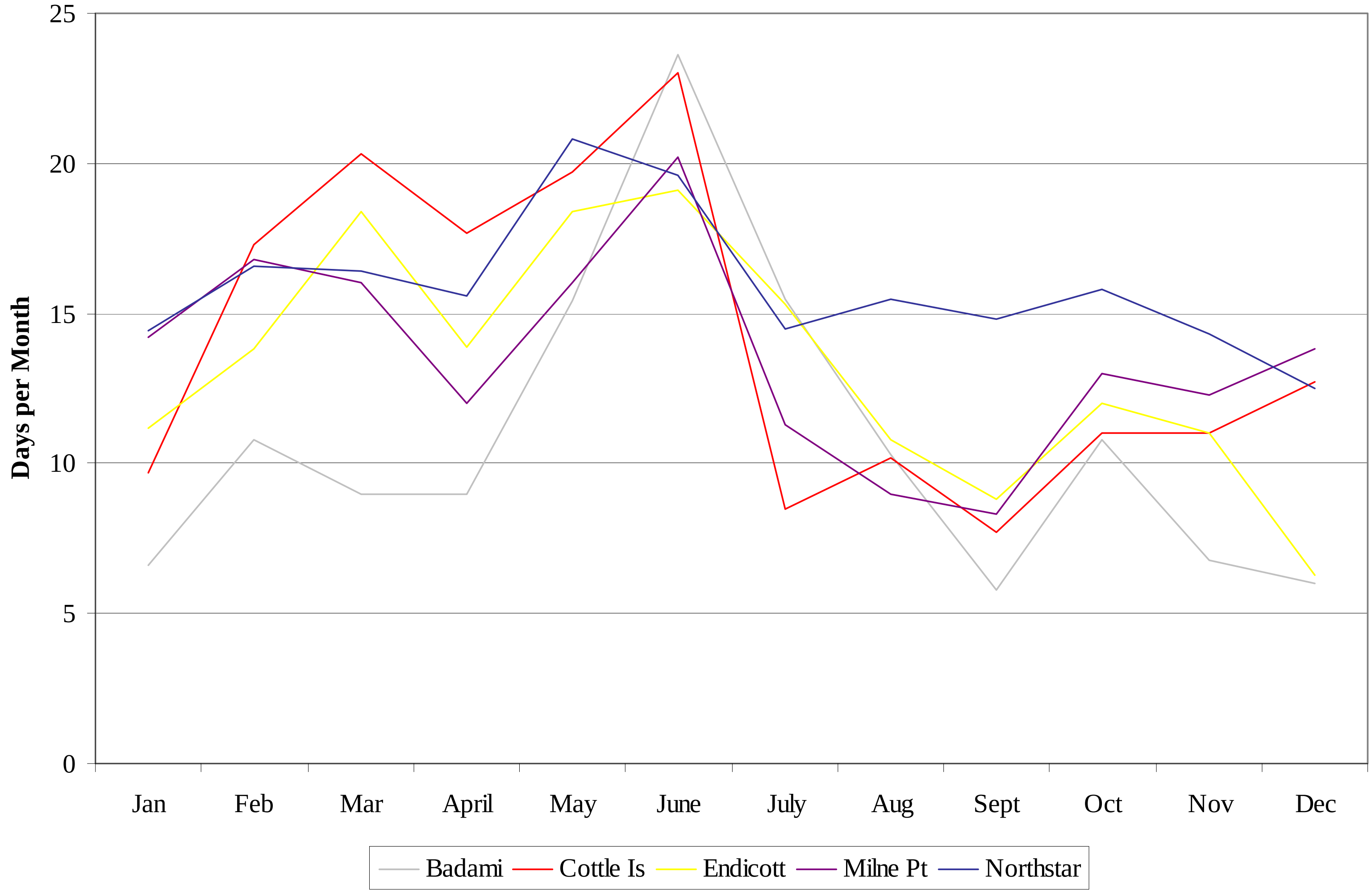


Figure 4-13 Frequency of Shore-Parallel Winds

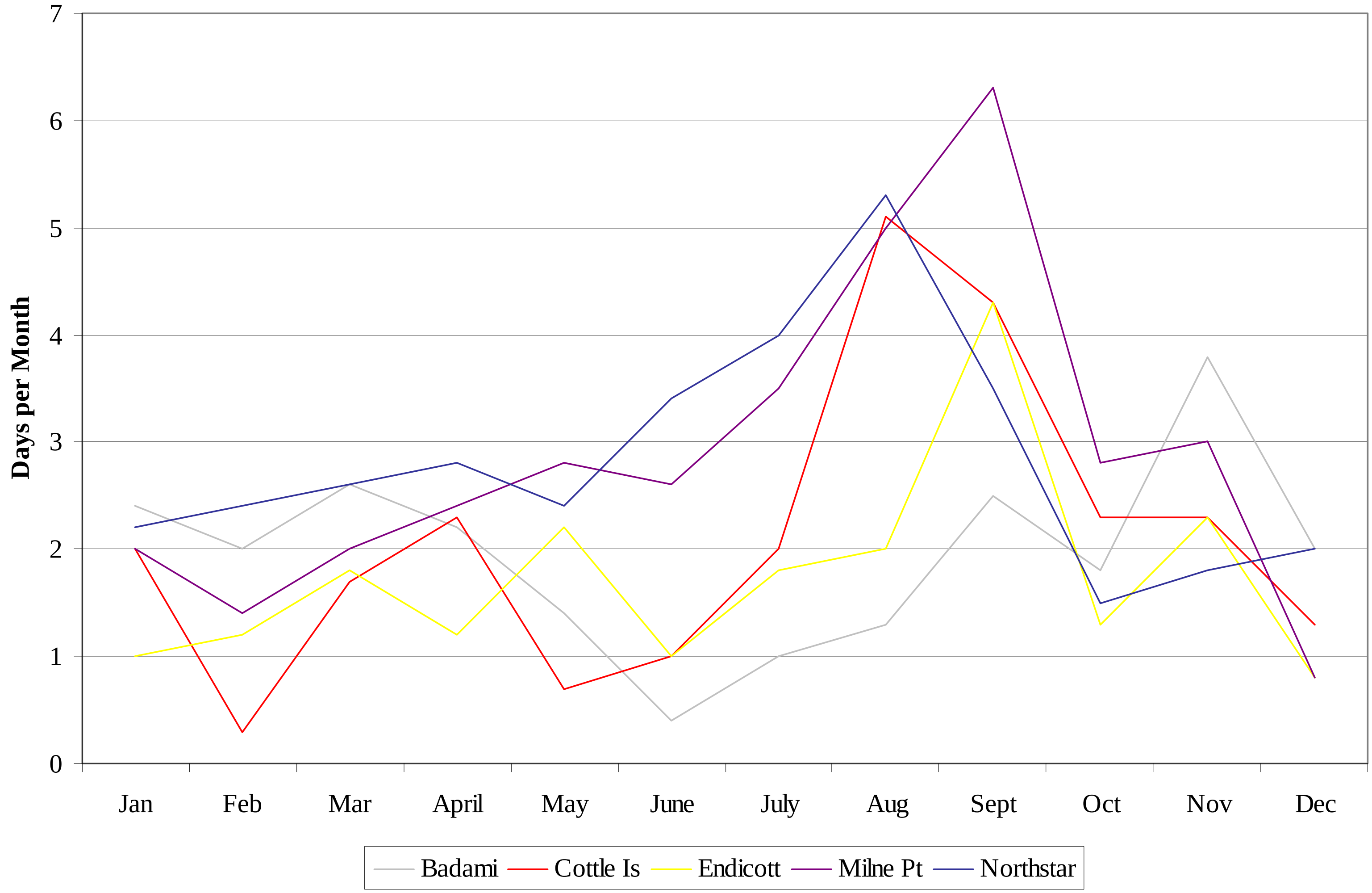
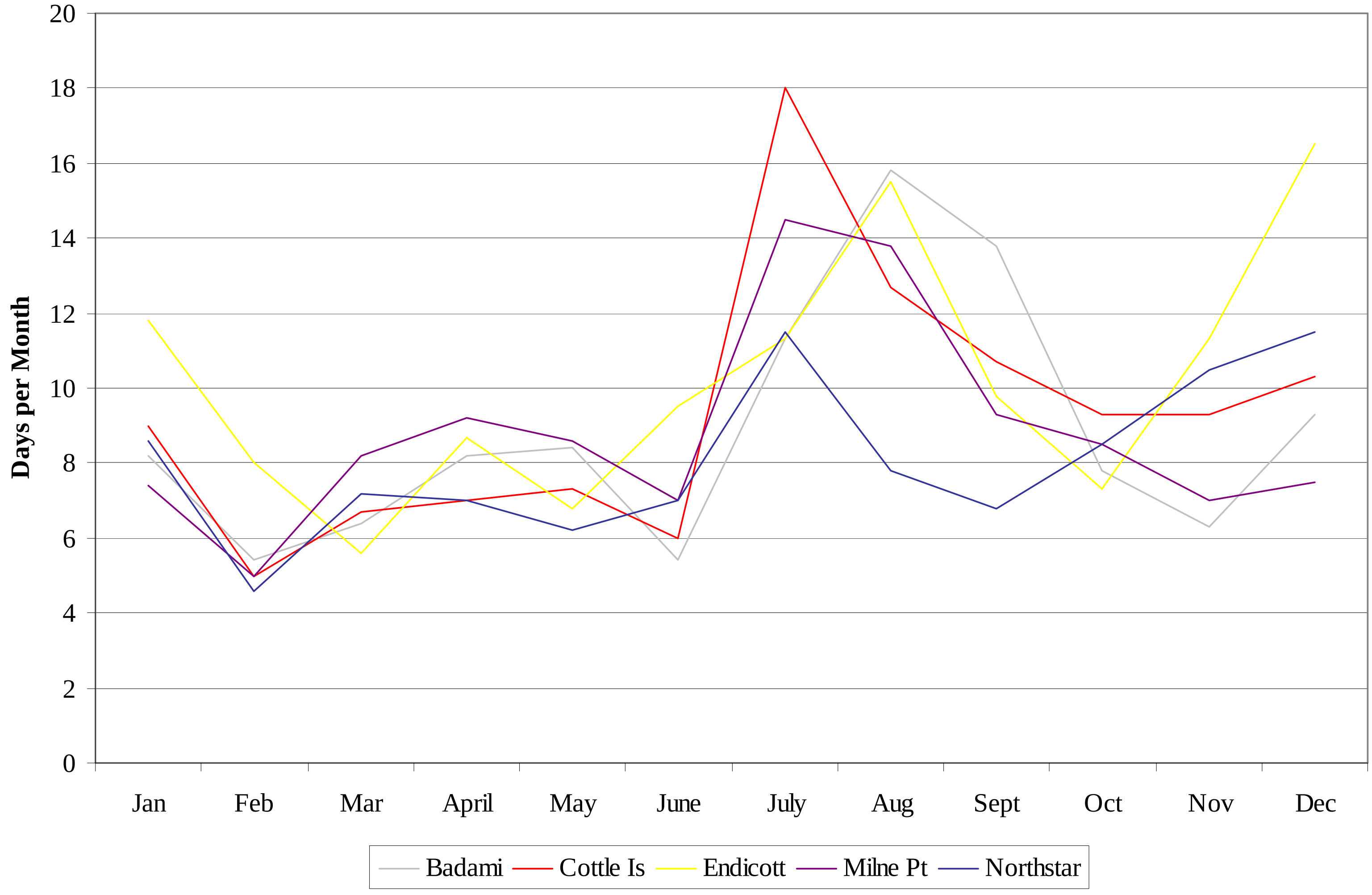


Figure 4-14 Frequency of Variable Winds



4.3 Wind Sigma

Table 4-5 provides a summary of wind sigma data for the five stations for the period of January 2001 to June 2005. Wind sigma is measured at a height of 10 meters at Badami, Cottle Island, and Endicott, and at 14 meters and 23 meters at Milne Point and Northstar, respectively. There is no sound method for adjusting wind sigma for height. Annual wind sigma graphs are provided in Appendix B, Annual Graphs.

Table 4-5 Wind Sigma Summary (º)

Monitoring Station	Mean	Max
Badami	6.7	74.8
Cottle Island	6.4	83.1
Endicott	7.6	77.1
Milne Point	6.5	81.7
Northstar	13.3	98.2

The most striking property of the wind sigma data is that the mean at Northstar (13.3) is 71 percent larger than the second highest average wind sigma (Endicott). This is indicative of turbulence generated in an obstacle-rich environment at Northstar (see Figure 5-1).

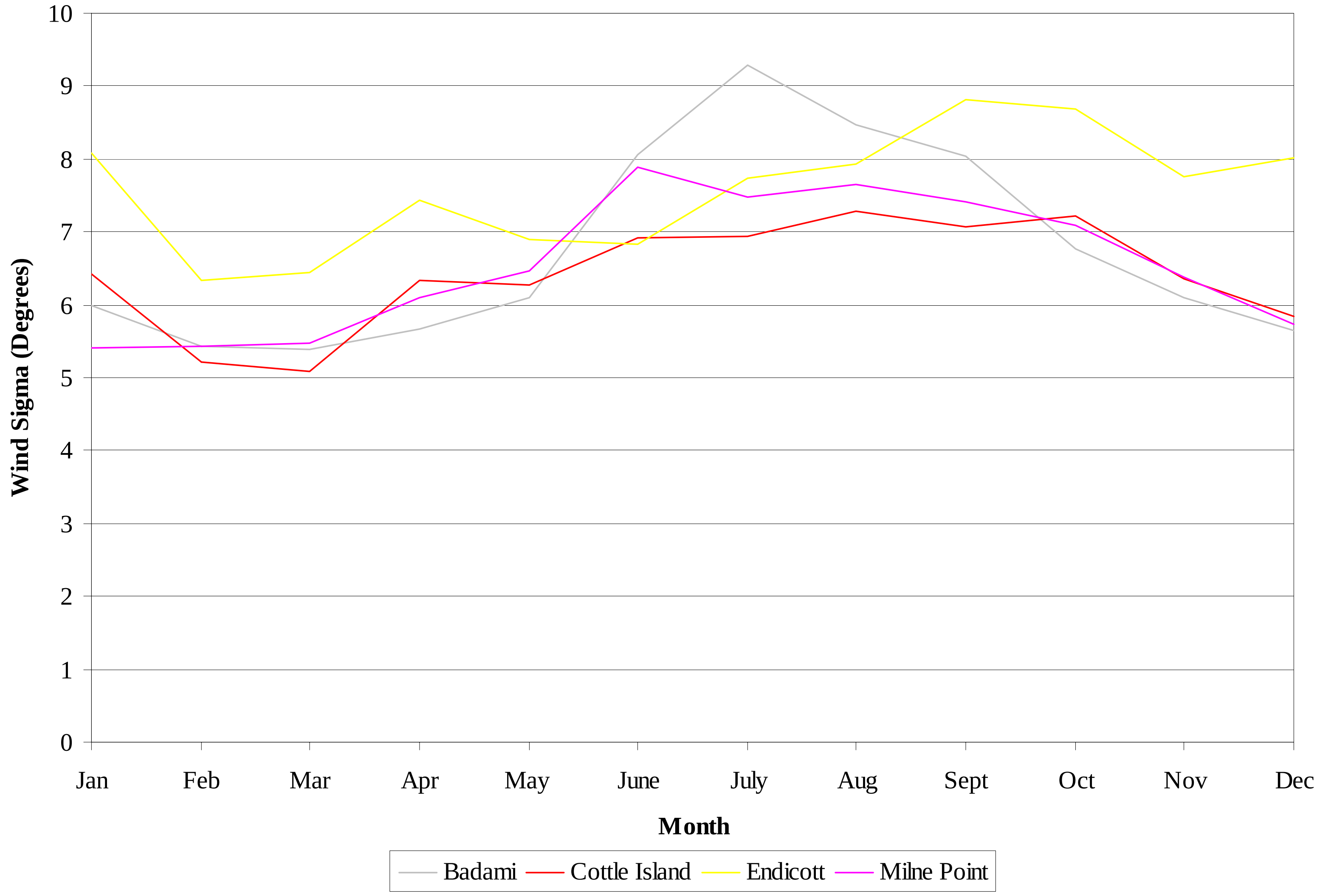
Descriptive statistics for wind sigma, presented in Table 4-6 below, show that the mean wind sigma is statistically different between the different stations, although this is probably more of an artifact of the station's local environments rather than the area at large. Endicott is not nearly as prone to interference as Northstar, but the presence of a large number of structures on the same island as the station to the south and east no doubt increases the wind sigma above background. The sites with the lowest means are Milne Point, Badami, and Cottle Island, reflecting the relatively uncluttered environment at these sites. Cottle Island is the only site without man-made obstacles nearby. We expect the true value for the region is in the 6.4º – 6.7º range.

Table 4-6 Descriptive Statistics for Wind Sigma (º)

	Badami	Cottle Island	Endicott	Milne Point	Northstar
Mean	6.68	6.45	7.76	6.51	13.27
95% Confidence Interval (Mean)	6.62 – 6.74	6.39 – 6.51	7.50 – 7.62	6.46 – 6.56	13.12 – 13.41
Standard Deviation	6.06	4.69	5.91	5.41	13.63
Median	5.05	5.32	5.45	4.85	8.79
Minimum	0.22	0.19	0.00	0.20	0.00
Maximum	74.80	83.10	77.10	81.70	98.20

Mean annual variation in wind sigma is shown in Figure 4-15 for all sites but Northstar. Northstar was excluded because its wind sigma is not reflective of nature (as discussed in Section 5.1) and detracts from the seasonal pattern shown at the other sites. While there is variation between sites, wind sigma follows a similar pattern of troughing in February and March and peaking in the late summer or fall.

Figure 4-15 Mean Monthly Wind Sigma



4.4 Temperature

Table 4-7 summarizes temperature measurements during the study period. Seasonal temperature variation was pronounced in the region, ranging between -45°C and 26°C. For the majority of the year, temperatures are below freezing. Mean temperatures are above freezing from about June 14 to September 19, with the average year having 100 days above freezing and 265 days below.

Descriptive statistics for the sites are shown in

Table 4-8. Annual variations in temperature are presented in Figure 4-16. Graphs of hourly average temperatures for the period of January 2001 to June 2005 are presented in Appendix B, annual graphs.

Table 4-7 Temperature Data Summary

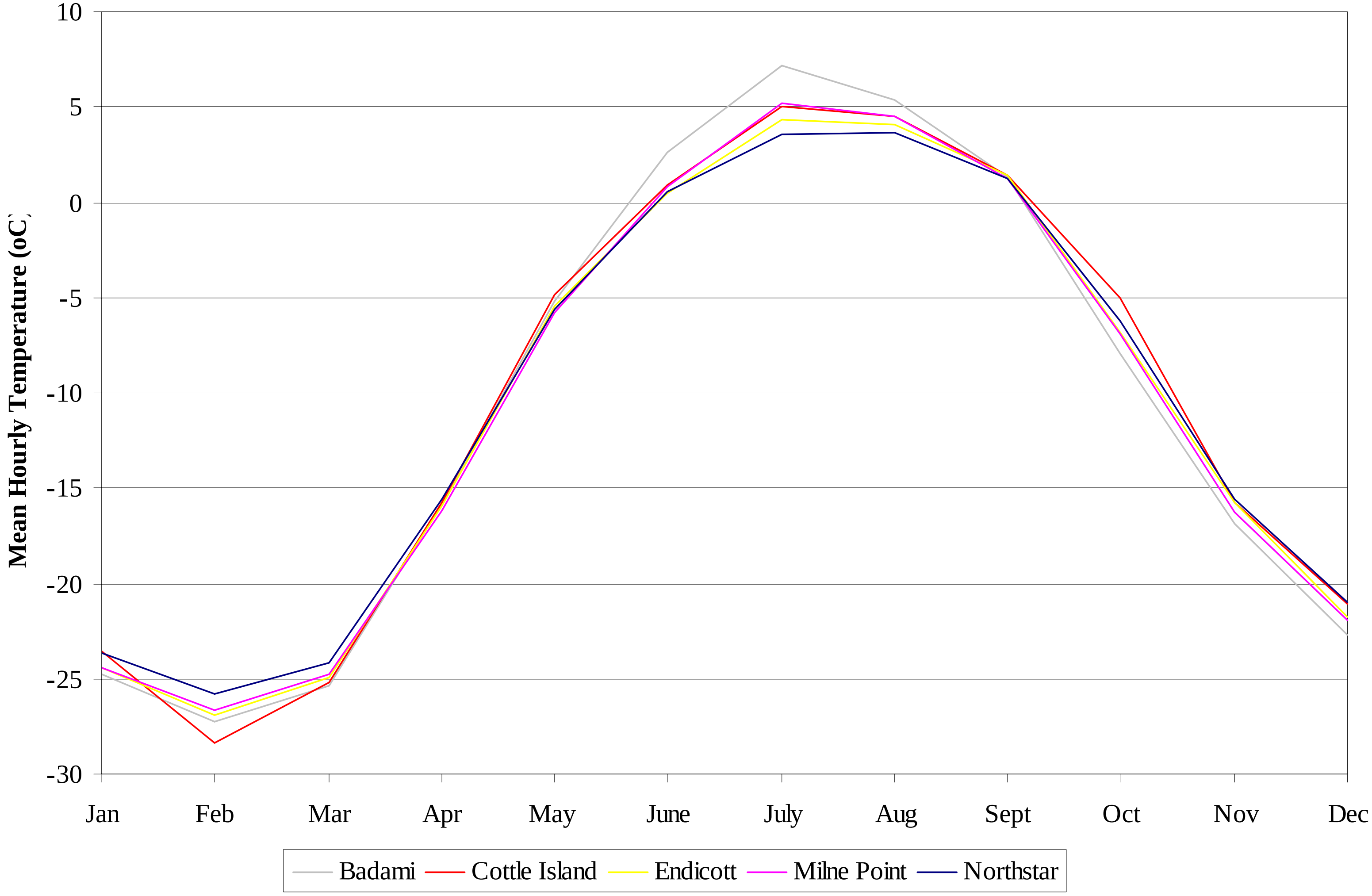
Monitoring Station	Temperature (°C)		
	Min	Mean	Max
Badami	-45.3	-11.3	26.1
Cottle Island	-45.1	-11.3	18.2
Endicott	-42.2	-11.0	19.1
Milne Point	-43.6	-11.4	22.0
Northstar	-41.3	-11.2	19.9

Table 4-8 Descriptive Statistics for Temperature (ºC)

	Badami	Cottle Island	Endicott	Milne Point	Northstar
Mean	-11.26	-11.29	-11.00	-11.43	-11.22
95% Confidence Interval (Mean)	-11.39 – -11.12	-11.46 – -11.13	-11.14 – -10.87	-11.56 – -11.30	-11.35 – -11.10
Standard Deviation	13.93	12.82	12.84	13.01	12.32
Median	-10.57	-9.51	-9.31	-10.79	-10.33
Minimum	-45.28	-45.13	-42.16	-43.6	-41.28
Maximum	26.05	18.17	19.09	21.95	19.93

Mean annual temperature was not found to be significantly different among the sites. By contrast, the standard deviation does depend on the distance of the station from the shore, owing to the damped diurnal cycle at the offshore sites.

Figure 4-16 Mean Monthly Temperature



Temperature histograms at every site, such as the example shown in Figure 4-17, show an interesting bimodal distribution. The data indicates two distributions which have different means and shapes. Two distinct thermal regimes appear to exist in the area. During open water periods, a relatively mild coastal regime exists with the temperature not deviating significantly from 0 ºC. During closed ice periods the climate becomes colder and more "continental" with wider swings in temperature. These two distinct temperature regimes are shown independently in Appendix D.

Summary tables for each period are shown in Table 4-9 **and**

Table 4-10. Open water was approximated to exist from June through October. Once these two periods are separated, a significant difference in the mean temperatures between the offshore and onshore sites is revealed, with the onshore sites being significantly warmer in the open water periods and significantly cooler in the ice season than the offshore sites.

Table 4-9 Descriptive Statistics for Temperature During Open Water Periods

(ºC, June-October)

	Badami	Cottle Island	Endicott	Milne Point	Northstar
Mean	1.74	0.95	0.69	0.96	0.56
95% Confidence Interval (Mean)	1.63 – 1.86	0.85 – 1.05	0.60 – 0.78	0.87 – 1.06	0.48 – 0.64
Standard Deviation	7.07	4.87	5.52	5.85	5.10
Median	1.77	1.06	0.89	0.92	0.71
Minimum	-29.94	-23.64	-25.93	-25.25	-23.77
Maximum	26.05	18.17	19.09	21.95	19.93

Table 4-10 Descriptive Statistics for Temperature During Ice Periods
(ºC, November-May)

	Badami	Cottle Island	Endicott	Milne Point	Northstar
Mean	-19.64	-19.13	-19.14	-19.38	-18.73
95% Confidence Interval (Mean)	-19.77 – -19.51	-19.29 – -18.98	-19.27 – -19.01	-19.51 – -19.26	-18.86 – -18.62
Standard Deviation	10.37	9.85	9.86	9.70	9.34
Median	-19.99	-20.06	-19.48	-19.97	-19.28
Minimum	-45.28	-45.13	-42.16	-43.60	-41.28
Maximum	11.55	6.62	9.18	7.86	6.65

Figure 4-17 Temperature Histograms for Northstar 2001-2002

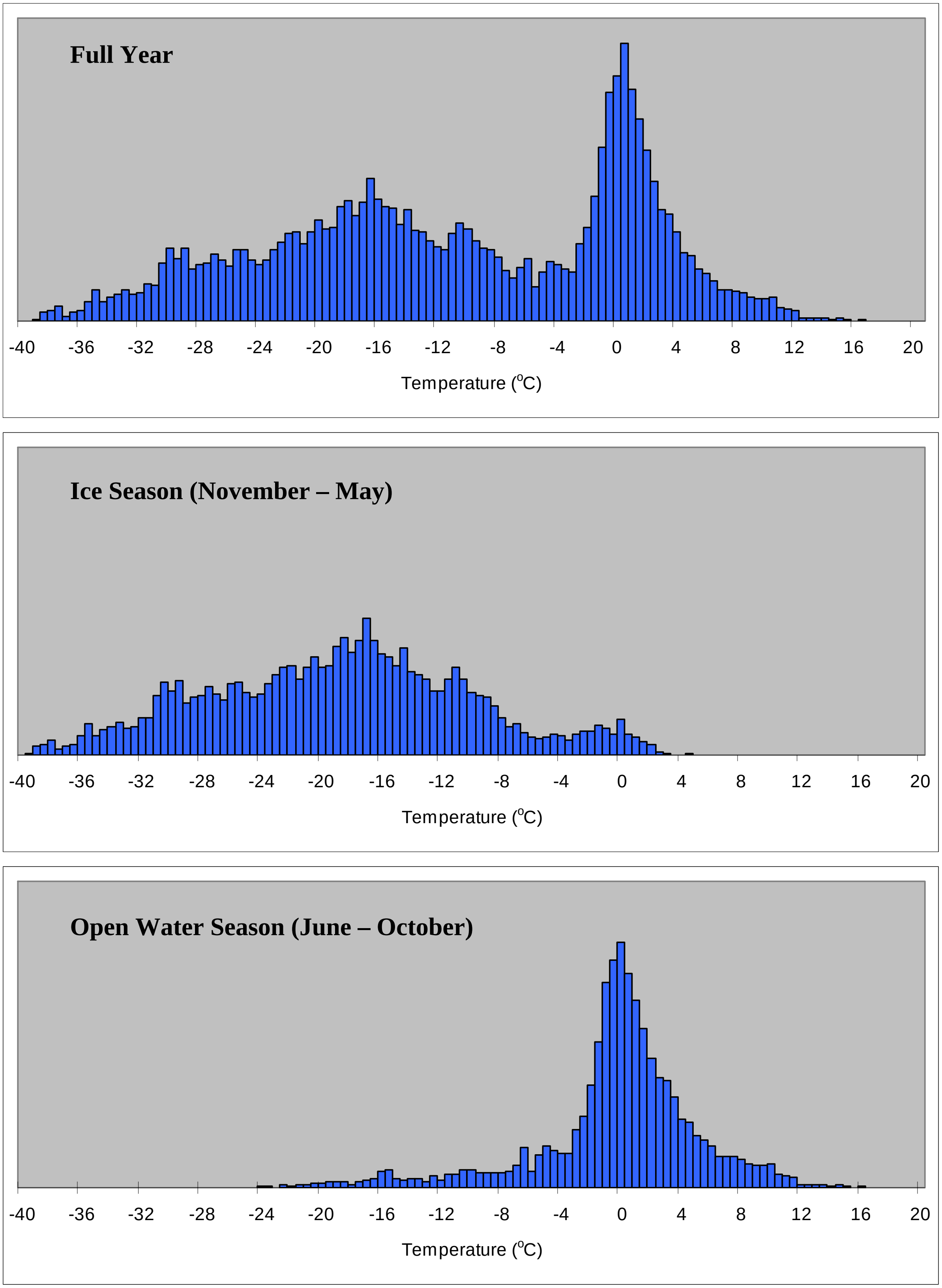


Table 4-11 gives total and monthly mean degree day statistics for degree freezing days, degree above freezing days, and heating degree days. The table shows the mean year July – June because the "freezing year" and "heating year" during which freezing and heating degree days are accumulated begins July 1. Degree freezing days measure the daily negative difference between the mean temperature and 0°C. Degree above freezing days measure the daily positive difference between the mean daily temperature and 0°C. Degree heating days measure the daily negative differences between the mean temperature and 18.3°C (65°F), a value set by the U.S. National Oceanic and Atmospheric Administration to approximate the level of energy used to keep inhabited structures warm.

Table 4-11 Degree Day Statistics

Month	Degree Freezing Days	Degree Above Freezing Days	Heating Degree Days
July	0	157	411
August	0	138	429
September	11	49	510
October	203	0	771
November	482	0	1,031
December	673	0	1,240
January	750	0	1,318
February	754	0	1,266
March	771	0	1,339
April	475	0	1,024
May	168	0	736
June	2	35	516
Total	**4,290**	**379**	**10,591**

4.5 Barometric Pressure

Table 4-12 provides a summary of the barometric pressure at each site over the study period. Descriptive statistics for barometric pressure are presented in Table 4-13. Where noted, pressure has been adjusted to sea-level as described in Section 3.3.3 in order to provide a more meaningful comparison.

Sea-level pressure ranged from 982 mb to 1,057 mb. After adjusting pressure to sea-level, Milne Point had the highest mean pressure, followed by Badami. The difference in means between Endicott and Cottle Island was not statistically significant. Northstar has a lower mean pressure than the other sites, even after adjusting the readings to sea-level.

Table 4-12 Barometric Pressure Data Summary (mb)

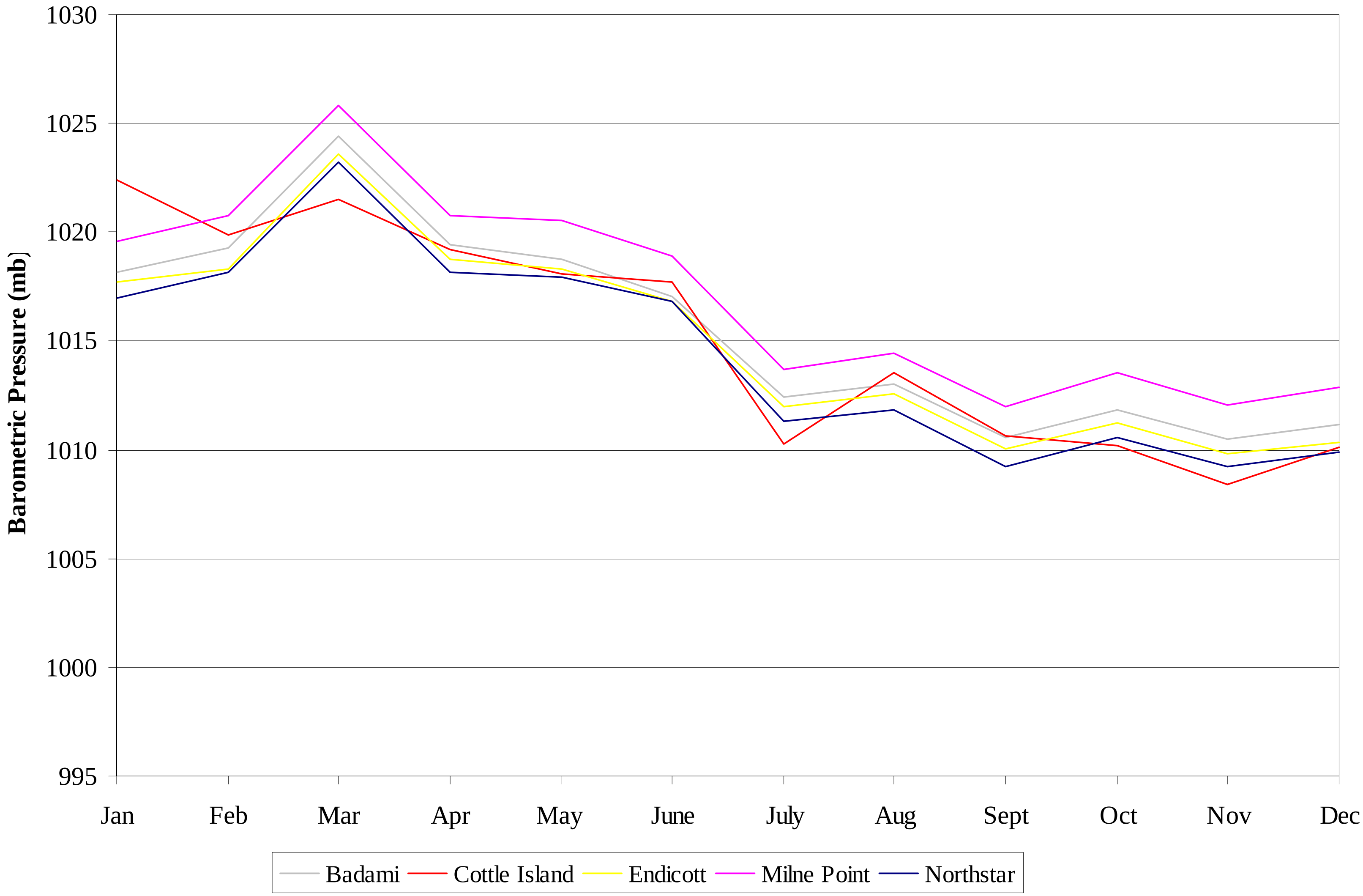
Monitoring Station	Pressure			Sea-Level Pressure		
	Min	Max	Mean	Min	Max	Mean
Badami	980	1054	1014	982	1056	1016
Cottle Island	982	1051	1015	983	1052	1015
Endicott	982	1055	1015	983	1056	1015
Milne Point	983	1056	1017	984	1057	1017
Northstar	979	1052	1012	982	1055	1015

Table 4-13 Descriptive Statistics for Barometric Pressure Adjusted to Sea-Level (mb)

	Badami	Cottle Island	Endicott	Milne Point	Northstar
Mean	1016.0	1015.3	1015.4	1017.5	1014.9
95% Confidence Interval (Mean)	1015.9 – 1016.1	1015.2 – 1015.4	1015.3 – 1015.5	1017.4 – 1017.6	1014.8 – 1015.0
Standard Deviation	10.8	10.9	10.8	10.8	10.8
Median	1016.0	1015.6	1015.6	1017.8	1014.9
Minimum	982.0	982.6	982.6	983.8	981.9
Maximum	1056.0	1051.6	1055.6	1056.8	1054.9

Barometric pressure shows a consistent seasonal pattern at all sites, as shown in Figure 4-18. It remains relatively low from July through December, then rapidly increases, peaking in March. The mean monthly pressure in March is higher than November by 13 to 14 mb at all sites.

Figure 4-18 Mean Monthly Barometric Pressure Adjusted to Sea-Level



4.6 Solar Radiation

As expected, solar flux is enormously seasonal in the study area, as shown in Figure 4-19 and Figure 4-20. Sensor output is mean hourly W/m^2. However, for a summary of mean solar flux by month, it is also worth considering mean total daily flux since this captures not only the seasonal variation in intensity, but also in duration of daylight. Because there is very little site-to-site variation, Figure 4-19 shows only Milne Point.

Since any sea-breeze effect in the area would be driven by the difference in the heat rate of land and sea, it would seem that such an effect would be much stronger earlier in the summer. For instance, the mean daily solar flux in June at Milne Point is roughly 2.5 times higher than in August and roughly 4.5 times higher than in September.

Figure 4-19 Mean Daily Solar Flux at Milne Point

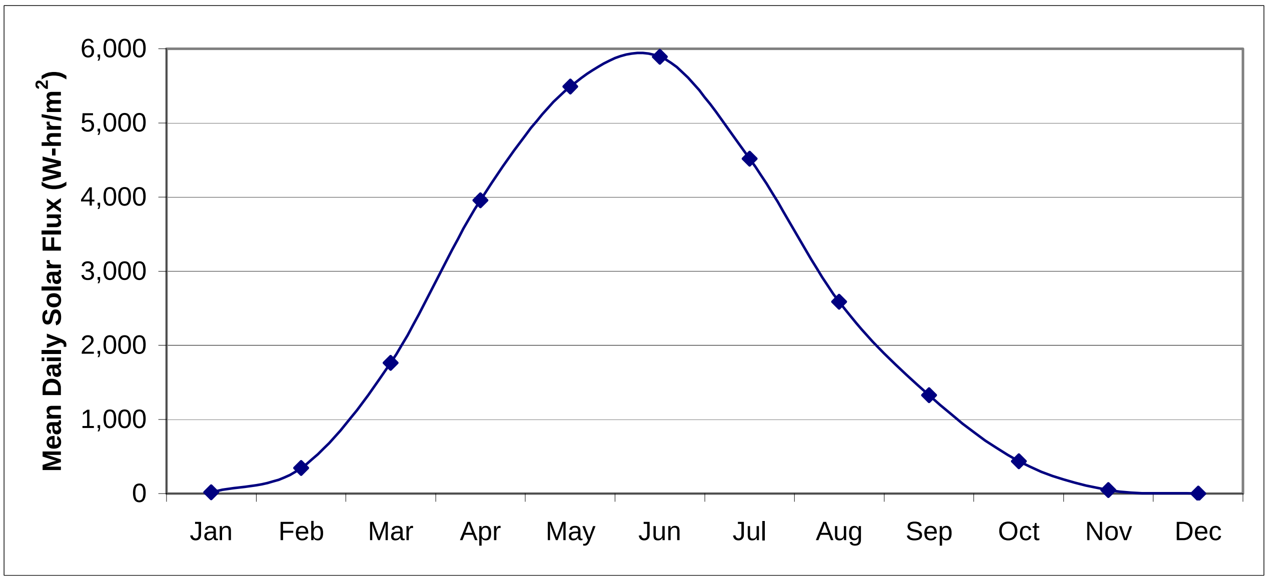
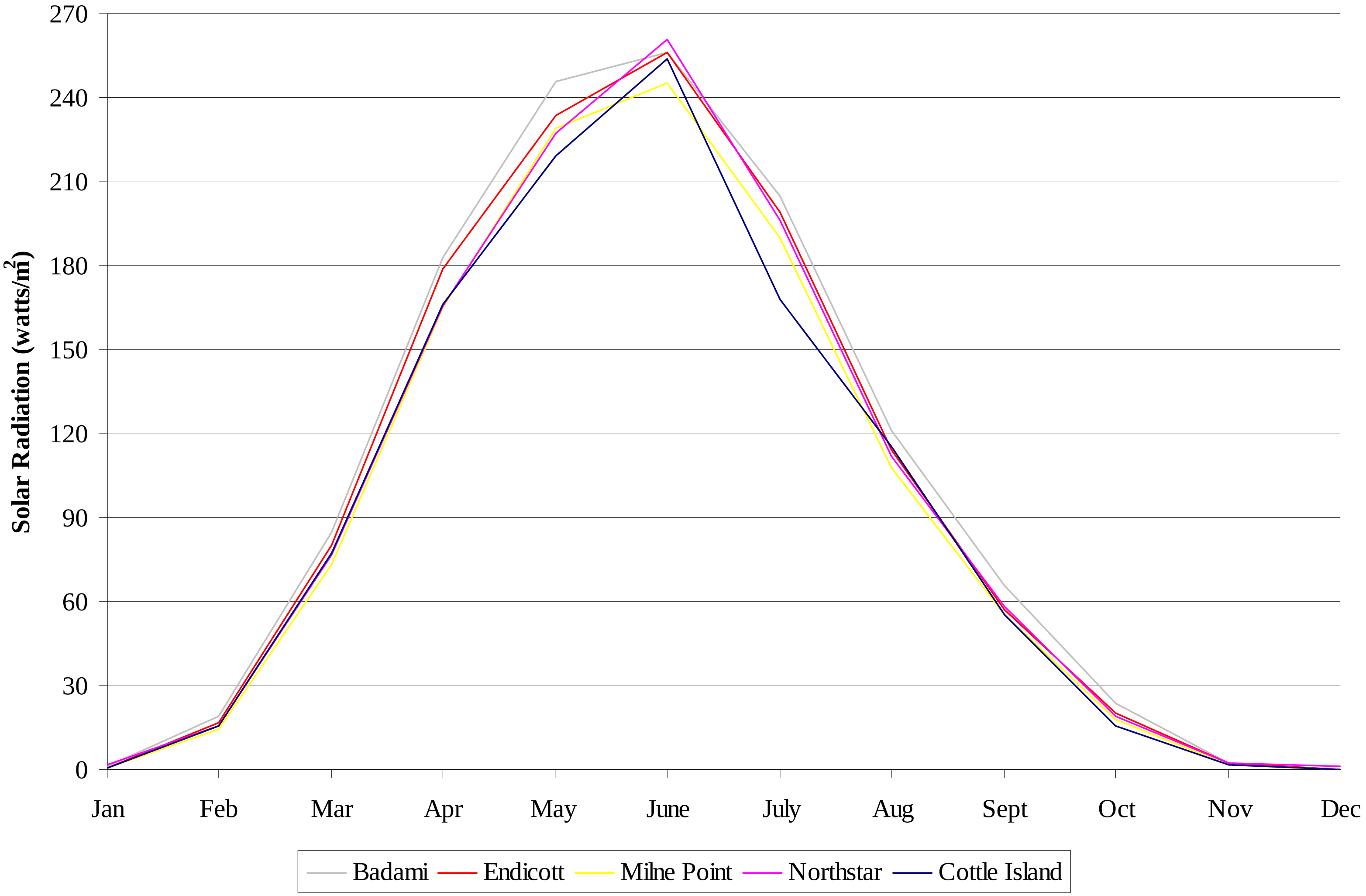


Figure 4-20 shows the mean monthly solar flux for each site. Solar flux is quite unevenly distributed about the summer equinox, probably due to significantly increased cloudiness during the open-water period. Cottle Island appears to experience a cloudier July than the other sites, although it should be noted that there is a shorter time series at Cottle Island than at the other sites, so some variability should be expected.

Figure 4-20 Mean Monthly Solar Radiation



4.7 Relative Humidity

Table 4-14 provides a summary of the relative humidity at each site over the study period. Relative humidity generally ranged between 70 and 90 percent. There was little real difference between the various sites, except that the Northstar relative humidity appears to remain higher in the winter. Instrument error for relative humidity is ±3 percent, so no real certainty exists that any of these sites display significantly different means for relative humidity.

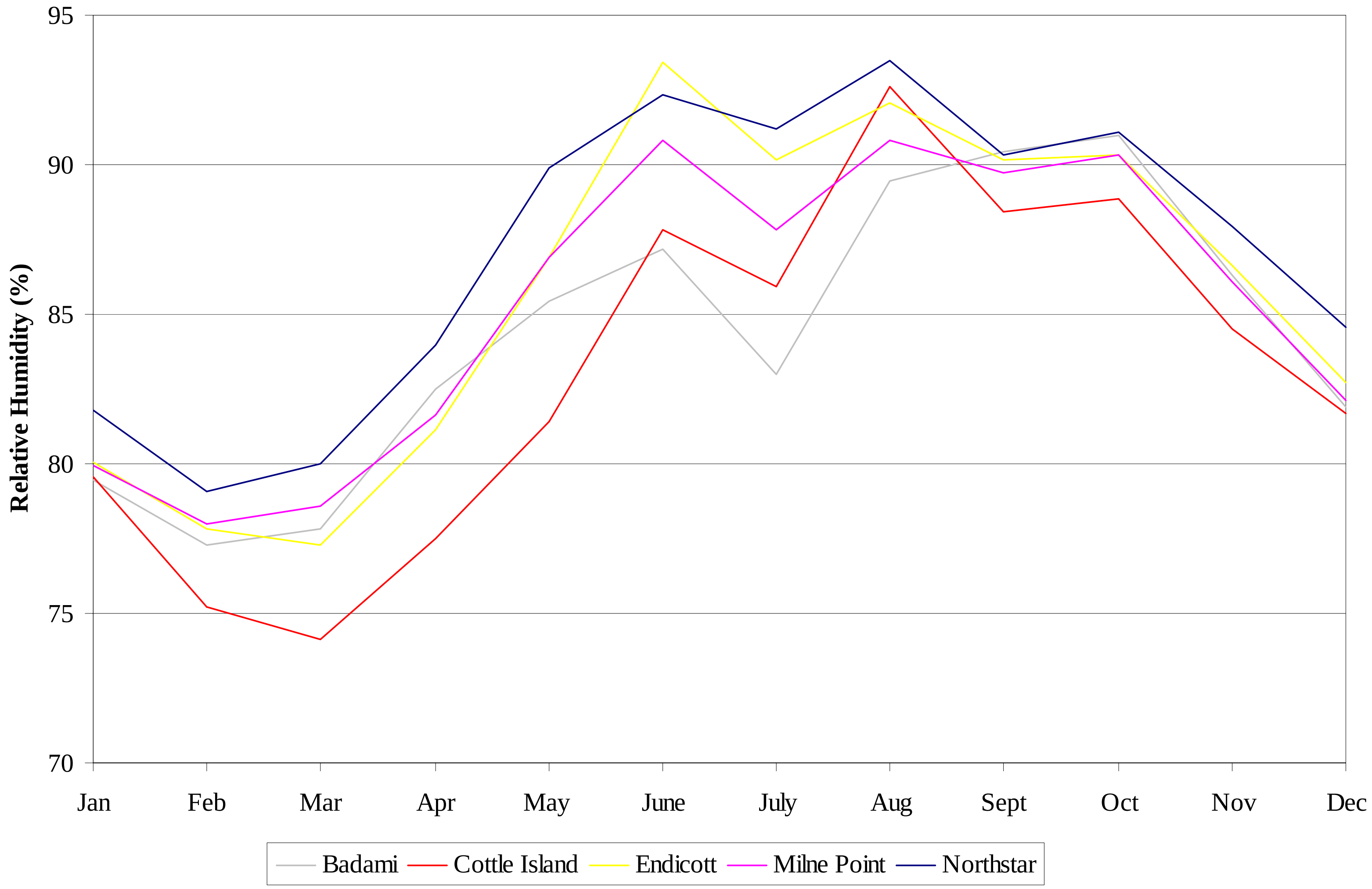
Table 4-14 Relative Humidity Data Summary

	Badami	Cottle Island	Endicott	Milne Point	Northstar
Mean	84%	85%	85%	85%	86%
Standard Deviation	10%	9%	9%	9%	9%
Minimum	30%	31%	39%	30%	45%
Maximum[1]	100%	100%	100%	100%	100%

Relative humidity shows a consistent seasonal pattern at all sites, as shown in Figure 4-21. The humidity is higher during the months of May through October, likely because of the presence of surface water.

[1] Actual sensor readings occasionally exceeded 100% due to the instrument error of ±3%.

Figure 4-21 Mean Monthly Relative Humidity



5 DISCUSSION AND CONCLUSIONS

5.1 Data Quality at Northstar

The data quality at Northstar station is markedly poor compared with that of the other four MMS stations. Despite the ideal geographical location, the number of large obstacles makes it impossible to have confidence that the wind data collected is representative of the larger region. Figure 5-1 shows the problematic structural environment surrounding the Northstar station. The current site is overshadowed by other structures and does not sit at 10 meters. Wind speed is probably close to accurate, but wind direction and wind sigma data are unreliable due to the presence of a process module, drill rig and crane, all of which exceed the height of the meteorological tower.

The meteorological station was installed on top of the permanent living quarters (PLQ) in December 2000 with wind instrumentation at 23 meters. The large building in Figure 5-1 is the South Process Module, which is approximately 36 meters tall and located 100 meters north of the monitoring tower. The drill rig and crane are taller than the process module and mobile. When the process module was installed on August 10, 2001, alternative station sites on the island were investigated but none could be identified.

The Northstar station has also experienced unusual equipment corrosion, which led to data problems when a corroded tail fell off of the wind vane.

Figure 5-1 Aerial View of Northstar Showing Meteorological Station Location

5.2 Icing at Endicott and Cottle Island

Measured winter wind speeds are biased at Endicott and, to a lesser degree, Cottle Island due to rime ice impeding and occasionally stopping the anemometer. The measured winter wind speeds at these sites should be viewed with this caveat in mind, although icing will obviously not be problematic during warmer months.

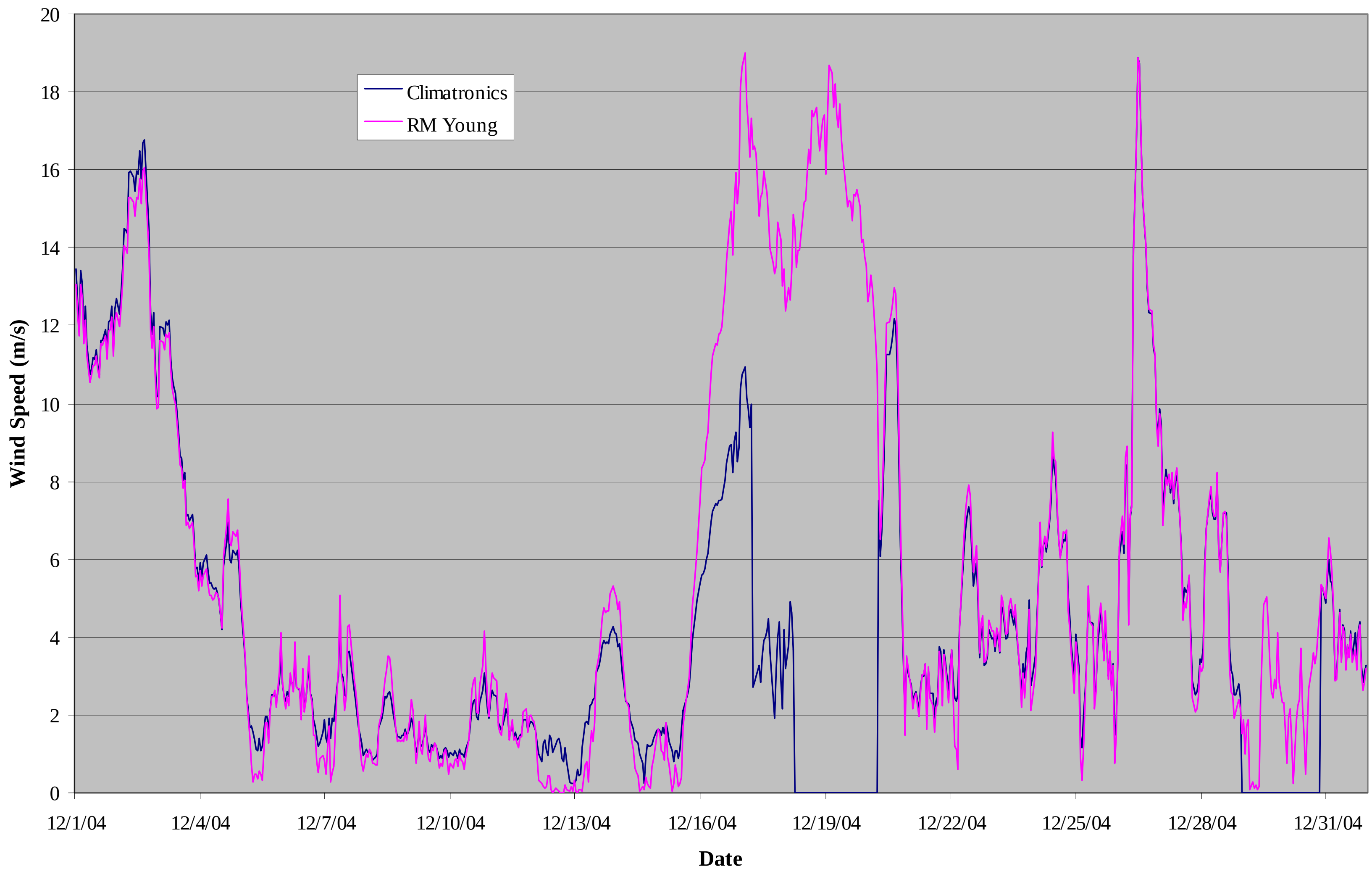
Endicott and Cottle Island wind speed was primarily measured by a 3-cup anemometer, which computes wind speed by the number of revolutions per second the sensor makes. The mass of the cups increases as snow and ice freeze onto the cups. Therefore the same amount of wind stress will cause the iced-over cups to experience fewer revolutions. As the anemometer became more sluggish, it became possible for the instrument to completely freeze. Six site visits were made to repair or replace frozen anemometers. Additionally, there were occasions the anemometer became unstuck of its own accord, or was merely slowed (these periods could not be detected without redundant equipment).

Heating the cups would not have been effective even if line power were available on-site. This is because heat applied to the main body of the instrument would not radiate effectively down the long, thin, spinning arms connecting the sensor body to the cups.

While the 3-cup anemometer design is the most popular for weather stations, another design using a propeller is also common. We theorized that this design would prove to be more resistant to icing for a number of reasons. First, and most importantly, there were no cups which could fill up with snow and ice. Second, the propeller-style anemometer rotates 2.5 times faster at any given wind speed than the 3-cup design. Lastly, the anemometer shaft is horizontal as opposed to vertical, making it harder for blowing snow to accumulate around the shaft.

We conducted an intercomparison of wind sensors at Endicott and Cottle Island by installing RM Young O5305AQ propeller anemometers as redundant wind sensors in October 2004. Endicott's system was removed in December 2005, but Cottle Island's continues to operate. The three-cup and propeller anemometers gave identical wind speeds most of the time, but in the winter there were periods when the propeller anemometer gave substantially higher readings than the co-located 3-cup anemometer. Wind speed measurements from the two systems at Endicott for the month of December 2004 are shown as an example in Figure 5-2. Since it is extremely unlikely that an anemometer could over-read wind speed, the fault almost certainly lies with the 3-cup anemometer.

Figure 5-2 Climatronics vs. RM Young Measured Wind Speed



5.3 Orographic Effects

The Badami monitoring station sits relatively further inland compared to the other sites. The greater mean velocity of winds and the greater proportion of easterly winds (as opposed to ENE) at Badami corroborate the predictions of Kozo [1986], suggesting that orographic effects influence the eastern part of the study area. Kozo's model results indicate that perturbations of wind speed and direction due to orographic effects should become greater as one moves east. If further monitoring efforts are conducted, more emphasis should be put on the eastern side of the area of interest, where more spatial variability is expected.

5.4 Sea Breeze Effects

Kozo [1980] predicted the existence of a unidirectional onshore sea breeze effect within a 40 km area centered along and running parallel to the Arctic coastline during the summer. This phenomenon is driven by a thermal gradient between the relatively warm land and cold sea. Unlike coastal areas at lower latitudes, this flow does not reverse at night due to 24-hour sunlight during the Arctic summer.

The frequency and duration analyses discussed in Section 4.2.1 show that most winds at all sites are either onshore and seaward as winds parallel to the shoreline represent a minor component. At all sites, onshore winds dominate seaward winds, both in terms of frequency and average duration. This appears to support the influence of a sea-breeze effect on the measured winds; however it is difficult to differentiate sea breeze effects from those of greater synoptic conditions since both favor winds from the E and NE.

The wind roses in Section 4.2 show that there is a predominance of onshore winds from the E, ENE, and NE (34° to 101°), while seaward winds from the W, WSW and SW (214° to 281°) represent a secondary, yet significant component[2]. The dominance of landward winds over that of the seaward winds can be represented as the ratio of the frequency of landward winds to the frequency of seaward winds (i.e., the number of hours when winds are from the E to NE divided by the number of hours winds are from the W to SW).

The ratio of landward to seaward wind frequencies at Badami is at least half that of the ratios observed at the other sites. Other onshore stations at Deadhorse and Kuparuk also display more frequent offshore (W to SW) winds compared to the coastal sites. Figure 5-3 shows the seasonal dominance of onshore breezes at the MMS stations, Kuparuk, and Deadhorse[3]. As expected, the sea breeze effect is most pronounced at the sites closest to the coastline and is most evident during the summer months.

While Kozo's research used only August data, Figure 5-3 shows that the effect is most pronounced in June. In late May and most of June, snow cover over land has diminished lowering the land-surface albedo. This allows for a greater transformation of solar energy into thermal energy over the land-surface than the ocean, which remains covered with reflective snow

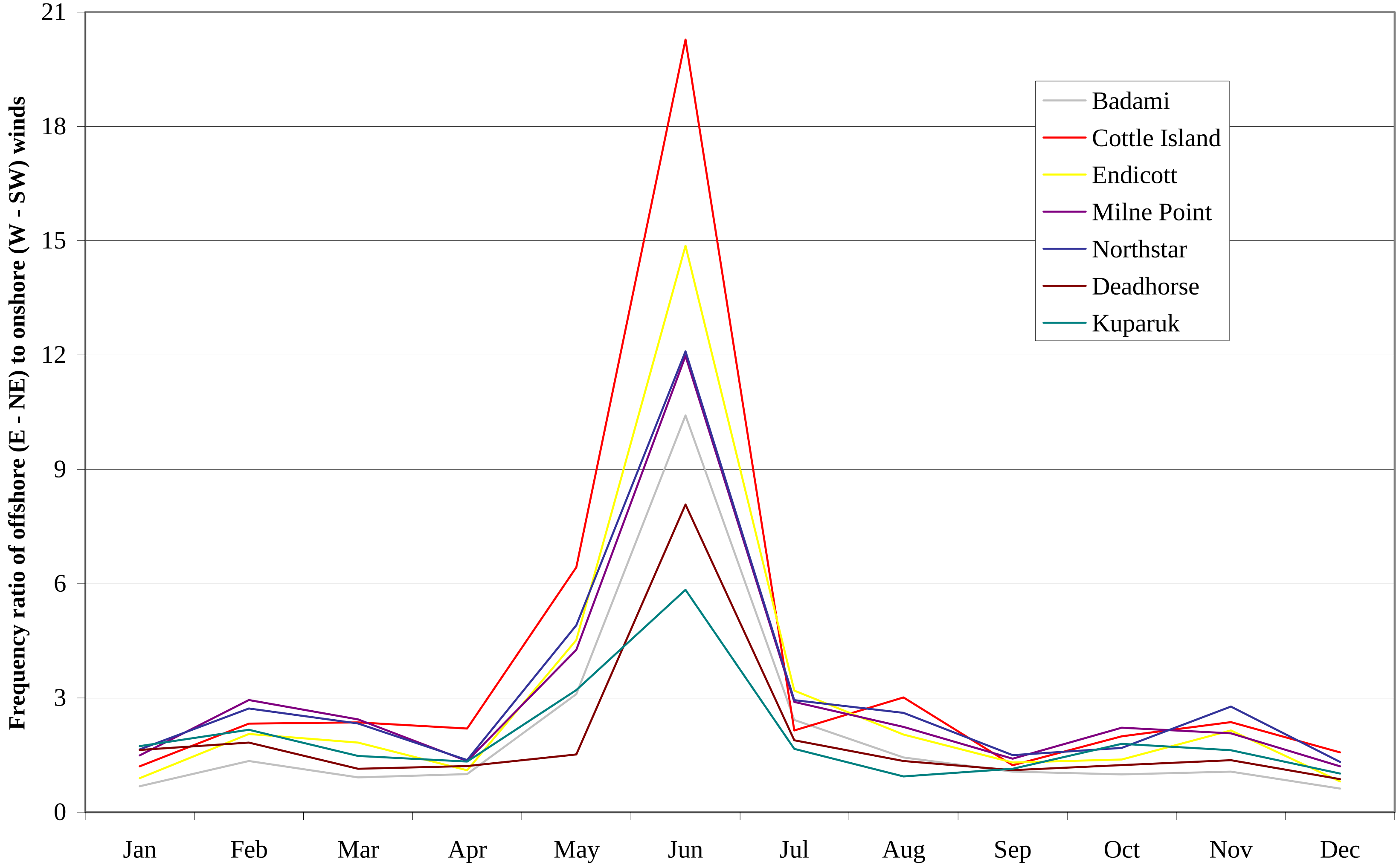
[2] Note that the definition of "seaward" and "landward" winds in this section is distinct from the "onshore" and "offshore" winds discussed in Section 4.2.1

[3] These data sets are from the period 1/1/01-12/13/04 for the Deadhorse and Kuparuk airports. These sites sit 12 km and 20 km inland, respectively.

and ice during this period. This can exaggerate the land-sea thermal gradient leading to a magnified sea breeze effect. June also has the highest daily solar flux, as shown in Figure 4-19. Mean daily solar flux in June is 2.5 times greater than in August, and 4.5 times greater than in September.

The MMS data is in agreement with Kozo's statement that there is a seasonally dependent sea breeze effect in coastal regions. However, because the MMS stations are at or situated relatively close to the coast, more offshore data would need to be gathered before any prediction could be made about the distance offshore that the effect might reach.

Figure 5-3 Frequency Ratio of Offshore (E - NE) to Onshore (W - SW) Winds by Month

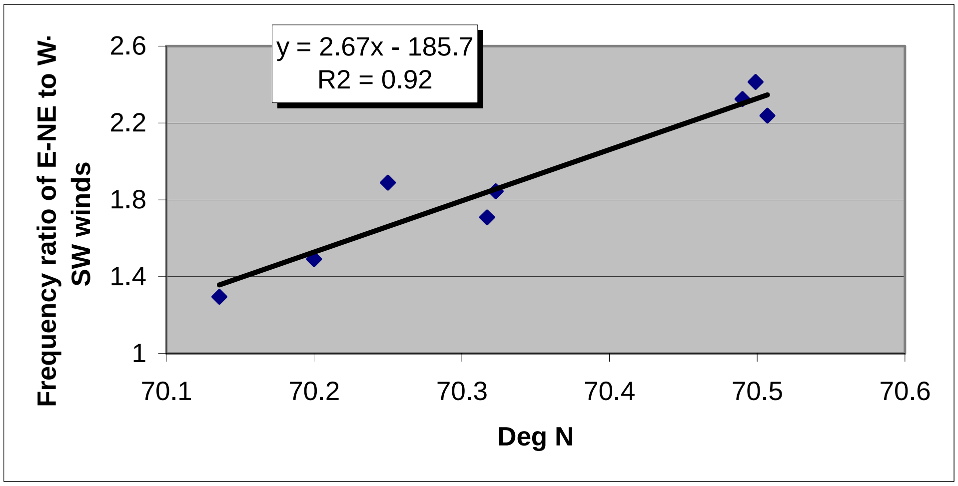


5.5 Latitudinal Effects

Differentiating a summer sea breeze effect from Arctic climatology is difficult since both favor winds from the E – NE. However, it is worth noting that the dominance of winds from the E – NE correlates very well to latitude, but poorly to distance from shore.

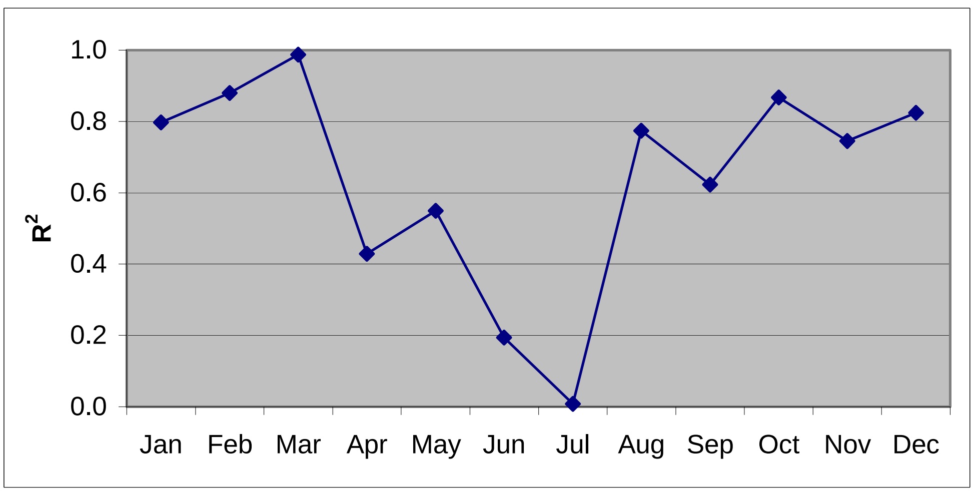
As shown in Figure 5-4, the ratio of E – NE winds to W – SW winds can be predicted in the area of study as a function of decimal degrees north. The eight stations graphed are the five MMS stations, Prudhoe Bay (1995-99), Deadhorse (2001-04), and Kuparuk (2001-04). While this linear correlation is strong ($R^2 = 0.92$), the correlation of the wind frequency ratio to distance offshore is quite weak by comparison ($R^2 = 0.33$).

Figure 5-4 Frequency Ratio of E to NE to W to SW Winds vs. Latitude



There is strong seasonality to this correlation. Looking at the R^2 values by month at the five MMS stations, it is clear that the correlation weakens substantially during the summer. However, it is not replaced by a better correlation to distance offshore.

Figure 5-5 Monthly Correlation of Frequency Ratio of E – NE to W – SW Winds vs. Latitude



5.6 Cross Correlation Analysis

Correlation patterns among the various stations were examined to investigate the relationship of wind speed at the various stations. Values of the cross correlation function were determined for various time lags for each set of two stations. A summary of the cross correlation function between simultaneous readings (lag = 0) is shown in Table 5-1.

Table 5-1 Value of Wind Speed Cross Correlation Function at Lag = 0

	Badami	Endicott	Milne Point	Northstar	Cottle Island
Badami	1.00	0.848	0.815	0.778	0.868
Endicott	0.848	1.00	0.880	0.847	0.885
Milne Pt	0.815	0.880	1.00	0.905	0.915
Northstar	0.778	0.847	0.905	1.00	0.882
Cottle Is	0.868	0.885	0.915	0.882	1.00

The most notable observations about the Table 5-1 are:

- Badami has relatively distinct winds from the other stations.
- Cottle Island is most representative of the other stations.
- Cottle Island and Milne Point have the strongest mutual correlation (0.915).
- Otherwise, the overall wind speed correlations are fairly good, with an average cross correlation value of 0.862.

It is worth re-emphasizing here that the Cottle Island station has a slightly shorter data set than the other stations.

Figure 5-6 through Figure 5-10 show the wind speed cross correlation results by station at lag -12 through +12 (hours). As an example, a graph of Badami versus Endicott would plot the correlation between the wind speed at Badami at time ***t*** and the wind speed at Endicott at time ***t + k***, where ***k*** is the lag.

One of the most interesting features of the graphs is that the peaks are not symmetric about lag 0. Wind speed at Milne Point at time ***t*** actually correlates best with wind speed at Endicott at ***t+1***. Wind speed at Milne Point at time ***t*** also correlates equally well with wind speed at Northstar at ***t*** and ***t+1***. Most of the cross correlation curves seem to "lean" one direction or the other. A curve leaning to the right, as for Milne Point versus Endicott, indicates that variations in wind speed at Milne Point tend to precede those at Endicott. For a curve leaning to the left, the reverse is true. Overall, a suggestion exists of west-to-east wind speed patterns over the recorded time period.

Figure 5-6 Cross Correlation of Wind Speed between Badami and Other Stations at Various Lags

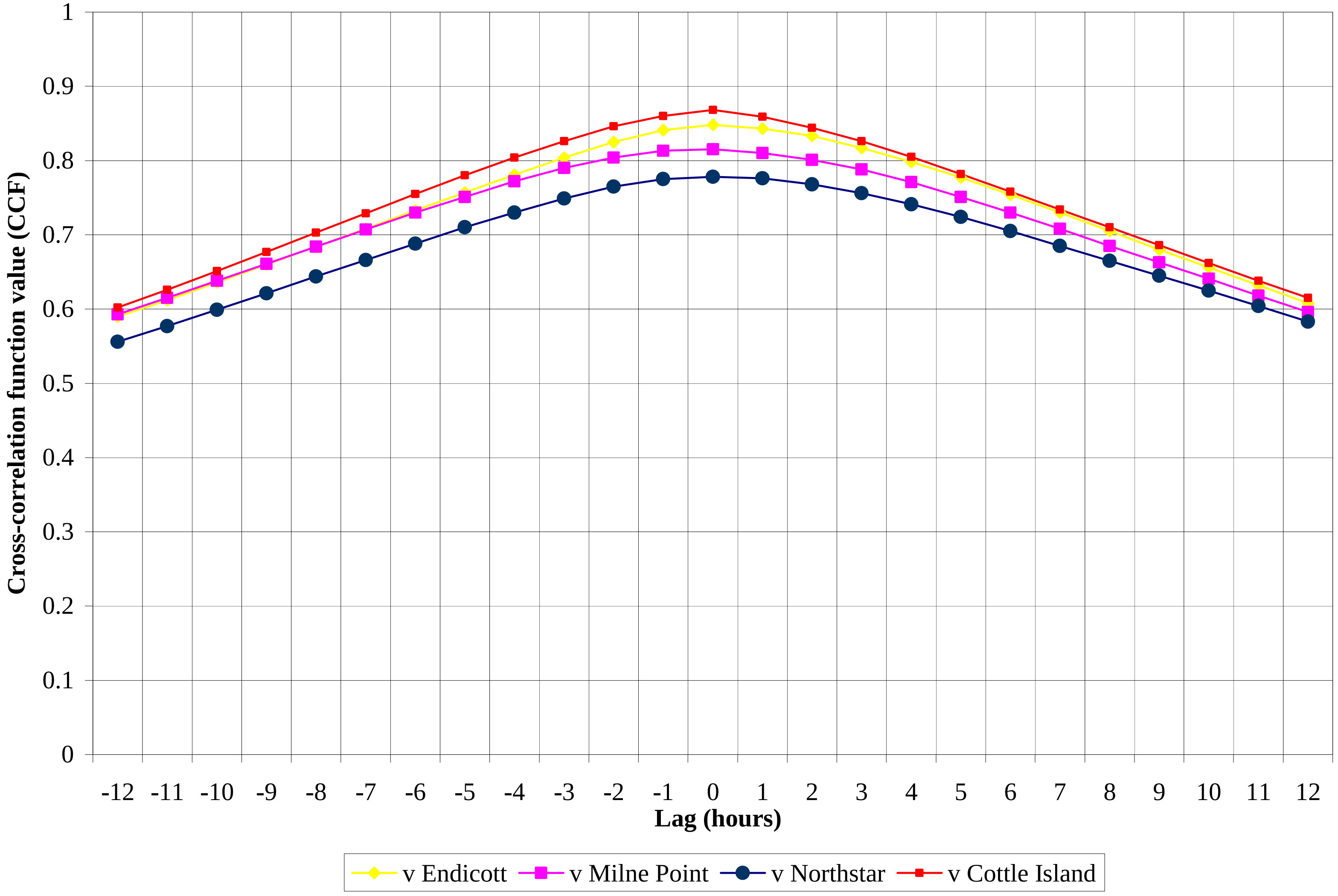


Figure 5-7 Cross Correlation of Wind Speed between Endicott and Other Stations at Various Lags

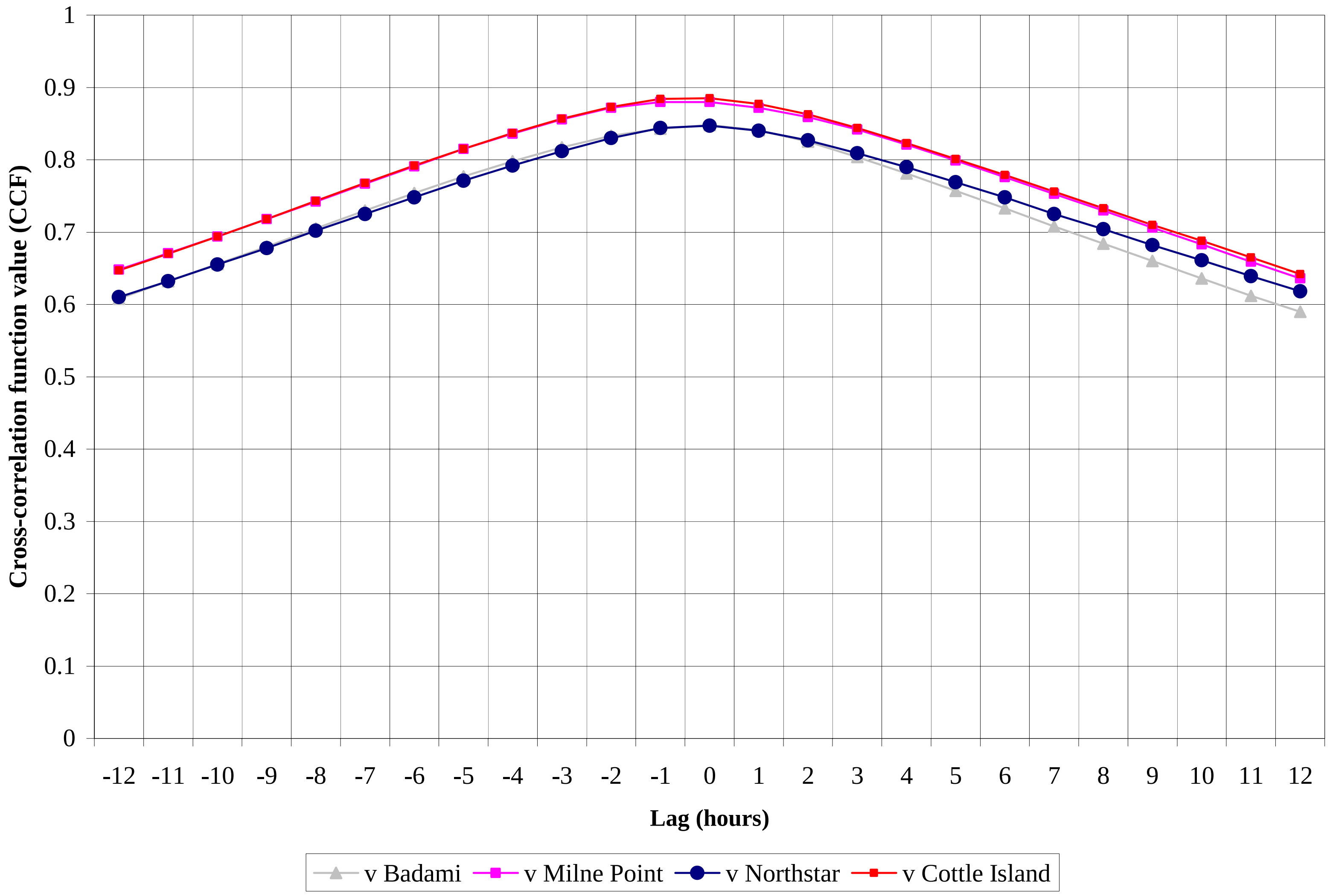


Figure 5-8 Cross Correlation of Wind Speed between Cottle Island and Other Stations at Various Lags

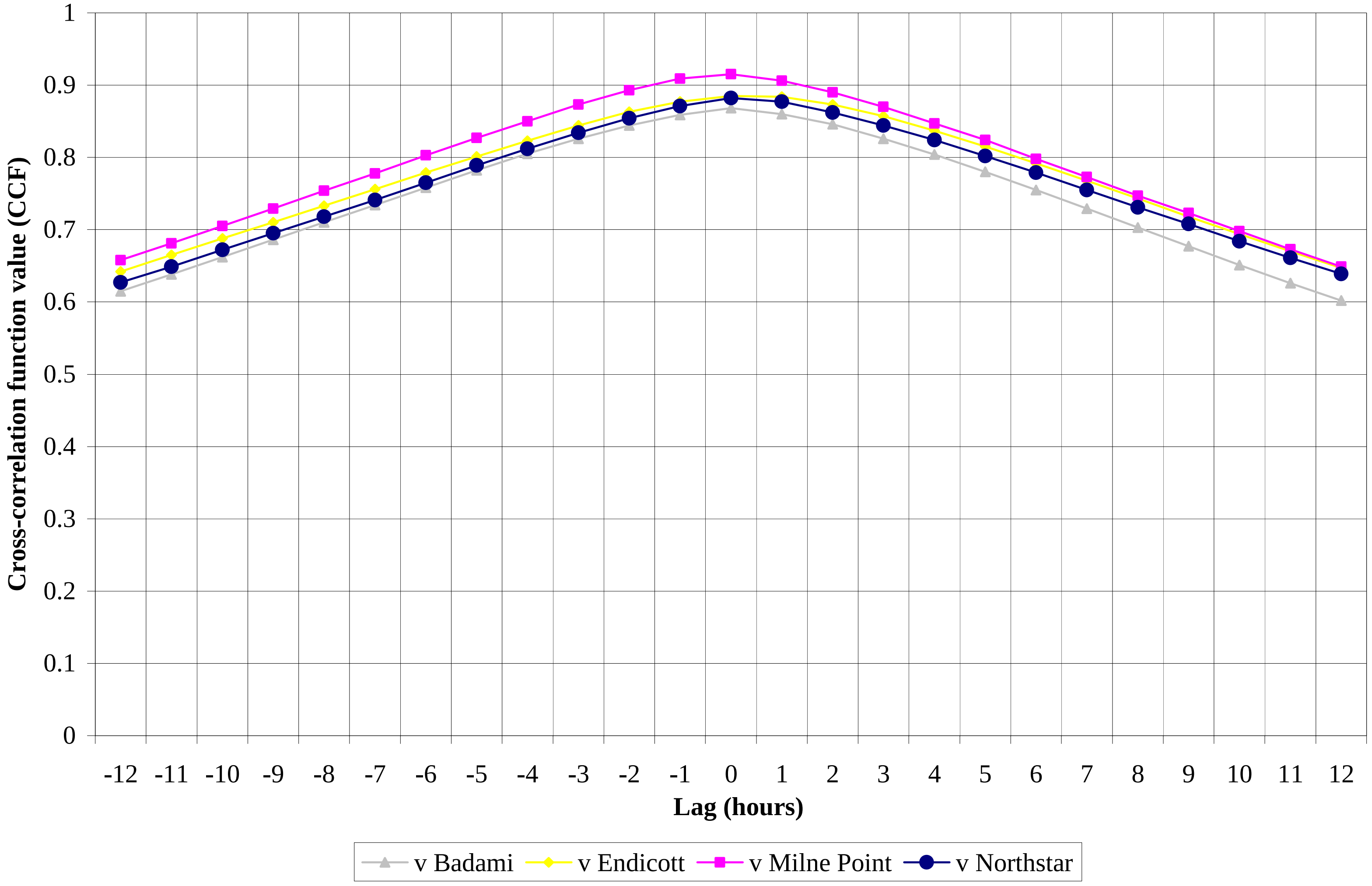


Figure 5-9 Cross Correlation of Wind Speed between Milne Point and Other Stations at Various Lags

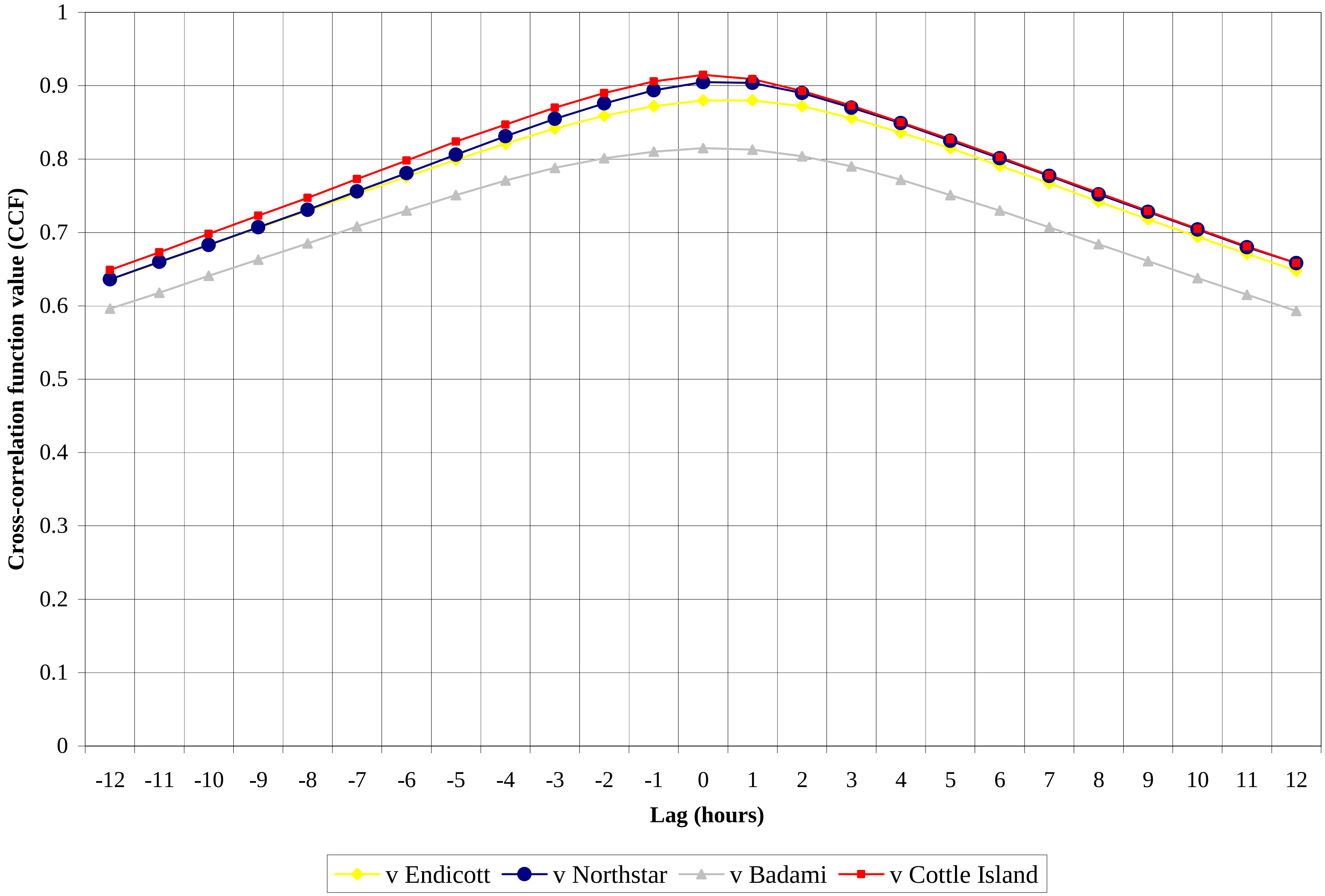
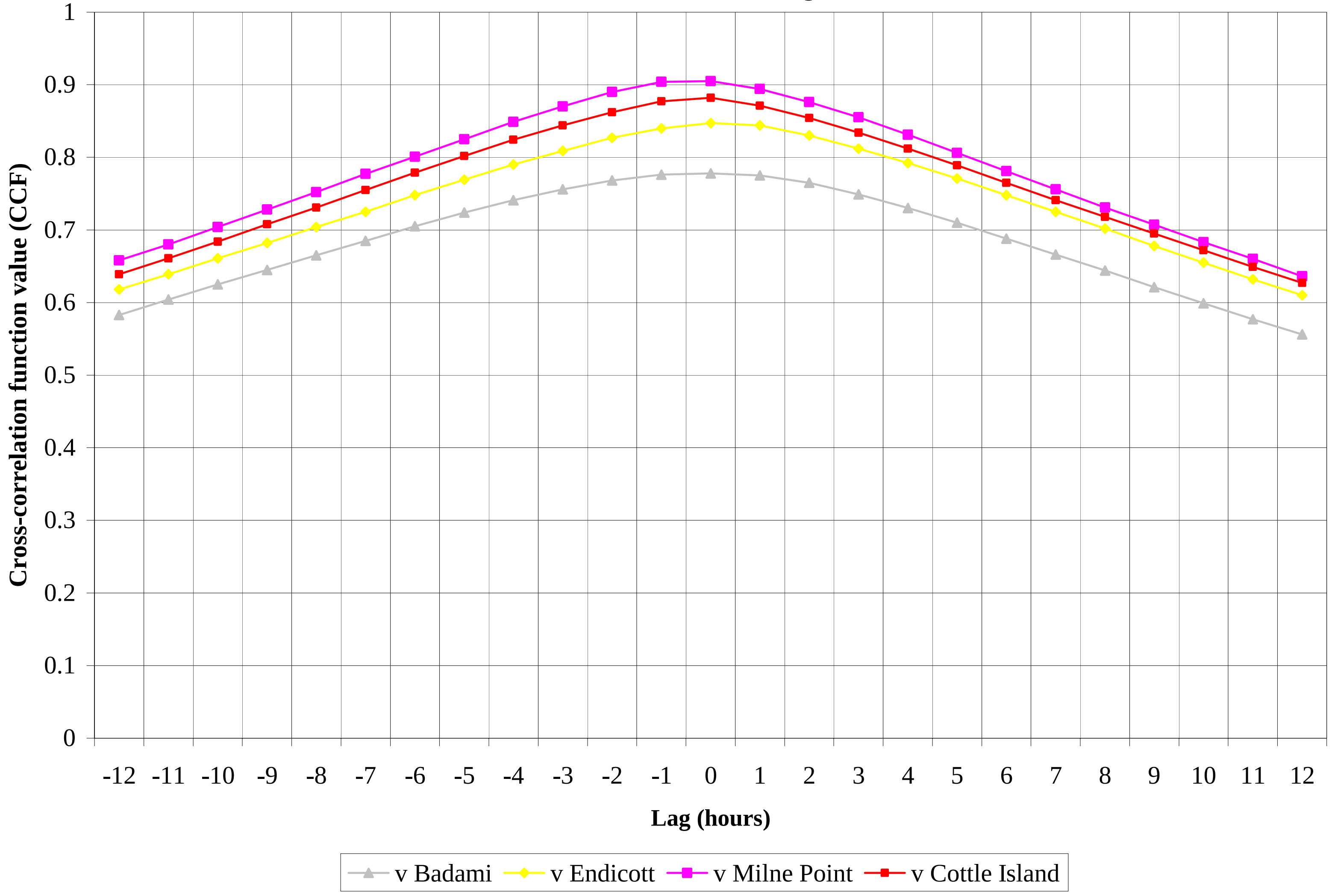


Figure 5-10 Cross Correlation of Wind Speed between Northstar and Other Stations at Various Lags



5.7 Conclusions

The primary goal of this study was to collect scientifically sound meteorological data for the nearshore Beaufort Sea region. The data collected from the new monitoring stations are among the most extensive meteorological data collected from this region to date. The data set available through June 2005 will provide valuable data for researchers and modelers.

Wind data collected at Northstar are suspect due to wind field perturbations caused by the nearby structures overshadowing the station (drill rig, process module, and crane). The Northstar wind rose lacks a northerly component due to the process module blocking wind from the north. Wind speed should have been less affected by the obstacles than wind direction and turbulence (wind sigma).

Cottle Island was originally installed to address concerns about the quality of data being collected at Northstar. The data collected at Cottle Island since August 2002 suggest the station correlates very well with all other stations except Badami. Table 5-1 shows that wind speed at Cottle Island and Milne Point correlate particularly well, with a correlation coefficient of 0.915.

Northstar is also similar to Milne Point, although it is about twice as far as Cottle Island. The Northstar station includes interference by the process module, drill rig, flare and crane, and is often difficult to visit for station servicing or repairs due to its island location. These factors suggest that Northstar may also be a redundant station with compromised wind data.

Based on the previous discussion, there is support for dropping one or two stations from the study for future monitoring. Meteorological monitoring at Northstar should be discontinued due to data quality concerns. Monitoring for the western part of the study area should be continued at Cottle Island and/or Milne Point. Both sites have distinct advantages. Cottle Island is further offshore, has fewer obstacles, and is more representative of Northstar. Milne Point offers easier access than Cottle Island and has on-site power.

The four and one-half years of data collected during the study have also shown that nearshore stations are sufficiently representative of conditions eight kilometers offshore and within the study area.

6 RECOMMENDATIONS

6.1 Improvements to Monitoring

As discussed in Section 5.2, propeller-style wind sensors are far more resistant to icing than three-cup anemometers. We have shown that 3-cup anemometers can under-read wind speed during the winter months and, in some circumstances, freeze up entirely. This may represent a source of bias that may affect many historical data sets as well, as the use of 3-cup anemometers is very common. We strongly recommend using only propeller-style anemometers for future monitoring in this or any other region where icing is likely to occur.

Redundant sensors save money and improve data capture. The cost of site visits in this area is very high relative to the cost of equipment and on many occasions site visits proved to be impossible. Redundant sensors should be installed for all important measurements, especially wind speed and direction. Since propeller-style wind sensors combine wind speed and direction sensors into one instrument, our ideal configuration would consist of a horizontal crossbar with a propeller-style wind sensor at either end and positioned at the 10 meter height.

6.2 Monitoring Network Efficiency

Mid-winter monitoring is costly and far less useful for oil-spill modeling. Winter site visits are difficult and designing a power system allowing for daily cell-phone calls for uploading data requires the installation of a wind turbine. Wind turbines are more expensive than solar panels and need to be replaced almost annually.

Large savings could result from emphasizing the warmer part of the year. Solar capacity should be boosted (from 40W to 85W, for example) and wind turbines eliminated. Communications would be programmed to shut down at the end of November, and resume in mid-March. The station would continue to record data but would not turn on its cell phone (or radio, as discussed below). When the station resumed communicating it would upload all of the data it had collected during the mid-winter. If station repairs were required, they would be deferred until spring.

Semi-annual audits and calibrations were probably excessive. We would recommend a single annual calibration in the spring. For remote site access close to the road system, transport via snowmobile in April/May is a low-cost, effective option with access by small plane a preferred alternative. Helicopter access is very expensive relative to the other costs. Boat access during open water periods has shown potential and is low-cost, but has proven to be unreliable due to unpredictable sea conditions.

6.3 Station Communications

The best way to communicate with the stations would be to use spread-spectrum radios to transmit data to Ethernet-connected hubs. This would conserve power, eliminate the charges associated with cell phones or satellite communications, and allow for much more frequent uploads. This could be used to create a real-time monitoring network.

Communications are by far the biggest power drain on the meteorological systems and alternative modes of communication that use minimal power makes station design and maintenance less expensive. A freewave spread-spectrum radio draws 500 mA of power compared to 3000 mA used for cell phone communications. More importantly, a freewave spread-spectrum radio would use only 5 mA during standby compared to 300 mA for a cell phone.

With a range of 50 miles, any conceivable offshore site could transmit to an Ethernet port at a facility somewhere on the North Slope. This type of data transmission could be used to create a real-time monitoring network, updating a website hourly, for instance.

If the above suggestion for concentrating on the warmer part of the year is put into effect, the stations could potentially transmit hourly data from April through October and be scheduled to transmit data on a weekly, or less frequent, basis throughout the winter.

6.4 Future Site Selection

Northstar is not a good location for a meteorological station due to several obstructions detailed in Section 5.1. It is recommended that data collection at the site be discontinued. Other sites, such as Cottle Island, provide data that correlates well enough with the Northstar station that the differences may have more to do with the structures interfering with wind than with the geographical distance between the two stations.

For any future monitoring in the region, there are two possible objectives to be considered. One would be to gather more research data to help computer modelers better understand the weather systems along this section of Beaufort Sea coast, which are near industrial activity. The other objective would be to establish a semi-permanent monitoring network to provide data in the event of an oil spill.

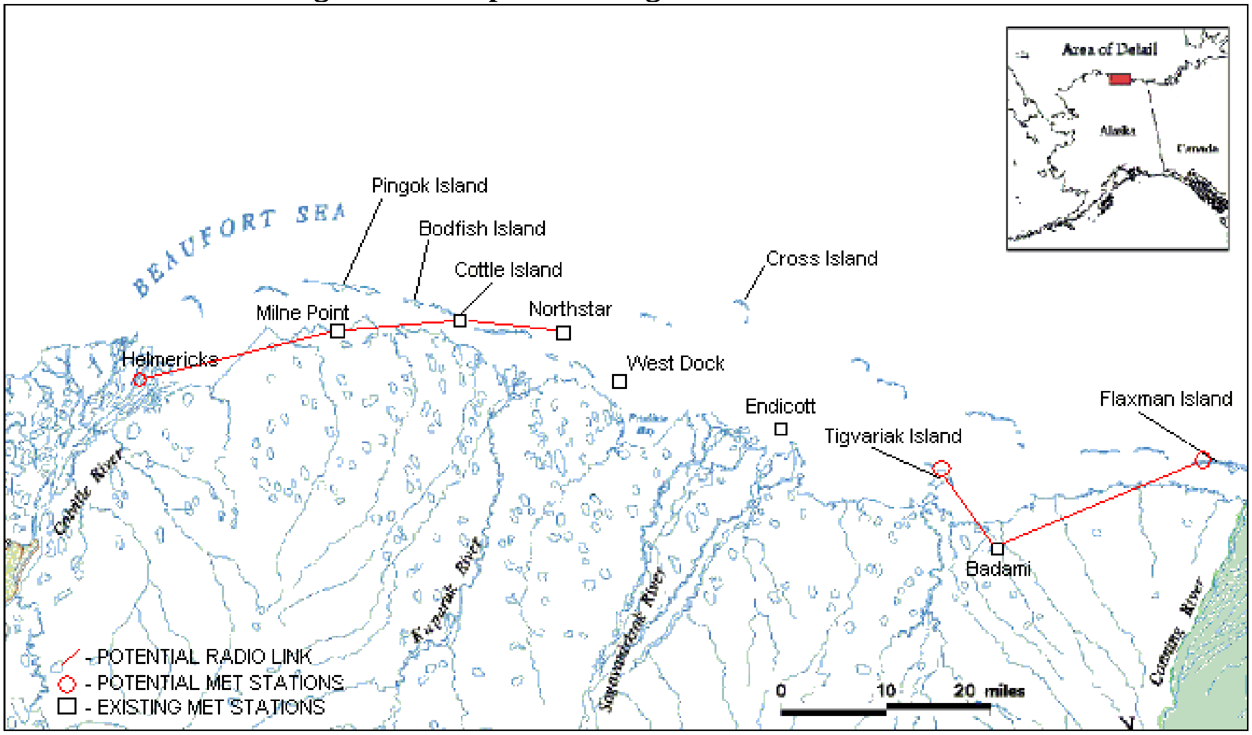
If improving current understanding of the climatology of the region is an objective, then more data from eastern sites is recommended. Badami clearly stands out from the other four stations, and Kozo and Robe's model results [1986] suggest that perturbations of wind speed and direction due to orographic effects should become greater as one moves east. If further monitoring efforts are conducted, more emphasis should be put on the eastern side of the area of interest where more spatial variability is expected. Tigvariak Island and Flaxman Island would be ideal sites in this regard. Both can both be accessed by plane, are offshore, and could transmit to Badami by spread-spectrum radio. Endicott would be maintained as a monitoring site along with one other station; preferably Cottle Island but possibly Milne Point if cost is a primary consideration. If the suggestions noted above are put into effect, the annual cost of running these sites would be considerably reduced.

It may also be worth considering extending the study area to the west to the Colville Delta since, 1) oil and gas development is expanding in that direction, 2) the area is of special ecological interest, and 3) there is a paucity of data in this region (Nuiqsut airport is over 20 km inland). The ideal location would be the Helmricks homestead ("Colville Village"). Colville Village currently hosts a small weather station, but it does not collect research-quality data.

If the main goal is to focus on areas where a spill is most likely to occur, the focus should be on the existing infrastructure. In this case, instilling a network using Endicott and Cottle Island stations, and perhaps adding another station at West Dock, are recommended. West Dock is offshore, close to the center of oil infrastructure, and about half-way between Cottle Island and Endicott. An additional advantage is that this would co-locate meteorological monitoring equipment with the High Frequency Radar sites MMS is using to track surface currents in the area.

Figure 6-1 shows the existing sites as well as the potential sites and radio links mentioned above.

Figure 6-1 Map of Existing and Potential Stations



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