Inigok Meteorological Data Substitution
Feasibility Analysis

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Table of Contents
EXECUTIVE SUMMARY ........................................................................................................ 3
INTRODUCTION ...................................................................................................................... 4
BACKGROUND ........................................................................................................................ 4
WEATHER IMPACTS ............................................................................................................... 5
POTENTIAL SUBSTITUTION SITES ..................................................................................... 6
METEOROLOGICAL DATA REVIEW ................................................................................... 8
BAROMETRIC PRESSURE COMPARISON ........................................................................ 10
CONCLUSIONS ....................................................................................................................... 14
APPENDIX A ..........................................................................................................................15

Table of Figures

Figure 1. Umiat, Alaska (Industry PSD Met site), Winters 2014/2015 and 2015/2016 1st and 4th quarter wind roses ................................................................. 6
Figure 2. Nuiqsut, Alaska, Winters 2014/2015 and 2015/2016 1st and 4th quarter wind roses. . 7
Figure 3. Range reference map of NPR-A Meteorological site (Inigok PSD), distance to Nuiqust and Atqasuk ................................................................................................... 9
Figure 4. Barometric Pressure time series for the winter 2014/15 ........................................... 10
Figure 5. Barometric Pressure time series for the winter 2015/16 ........................................... 10
Figure 6. Temperature °F time series for the winter 2014/15 ................................................... 12
Figure 7. Temperature °F time series for the winter 2015/16 ................................................... 12
Figure 8. Wind Speeds MPH time series for the winter 2014/15 ................................................ 13
Figure 9. Wind Speeds MPH time series for the winter 2015/16 ................................................ 13
Figure 10. Combined January – March 2015/16, 1st Quarter Wind Roses ....................................... 13
Figure 11. Combined October – December 2014/15, 4th Quarter Wind Roses ............................. 13
Figure 12. Umiat 1st Quarter Wind Rose (2015/2016) ............................................................. 15
Figure 13. Umiat 4th Quarter Wind Rose (2014/2015) ............................................................. 15
Figure 14. Nuiqsut 1st Quarter Wind Rose (2015/2016) ............................................................. 16
Figure 15. Nuiqsut 1st Quarter Wind Rose (2014/2015)............................................................. 16
EXECUTIVE SUMMARY

The Bureau of Land Management (BLM) has established a meteorological monitoring station in Inigok, Alaska, a remote location in southeastern National Petroleum Reserve – Alaska (NPR-A). The purpose of this site is to fill a meteorological data void with high quality climatological data representing the region between the Brooks Range foothills and the North Slope Coastal Plain. The meteorological data collected is intended to support BLM management decisions for the area through air modeling and to provide information for the BLM and other agencies with study interests in the NPR-A.

The climate at the meteorological monitoring site, called the Inigok Prevention of Significant Deterioration (PSD) in this report, is classified as Arctic, consisting of long, bitterly cold winters and short, cool summers. Extreme wintertime weather conditions present significant challenges to data capture. Over prolonged exposure to this environment, the meteorological equipment will gradually become inoperable due to soft and hard rime ice accumulation, therefore invalidating data. During the past two winters (October – January, 2014/2015 and October – January, 2015/2016), the horizontal wind sensors (primary and redundant sensors) were inoperable during six different occasions for more than three days. During one period, the sensor(s) were frozen for 2.5 months before either an operator or wind broke the ice off of the sensor(s). While freezing of wind sensors invalidates data, other meteorological stations on the North Slope may be able to provide surrogate data during ice-over events. Through an assistant agreement between BLM and the Alaska Department of Environmental Conservation, Division of Air Quality (ADEC), ADEC has compared the Inigok PSD meteorological data to surrounding meteorological stations to determine if any can provide surrogate data for invalidated Inigok PSD data.

ADEC reviewed meteorological data from the Atqasuk Automated Weather Observing System III (AWOS III), the Nuiqsut Automated Surface Observing System (ASOS), the Inigok Remote Automatic Weather Station (RAWS), the Umiat (industry PSD meteorological site) and the Inigok PSD meteorological site. ADEC found the Atqasuk site to be the best fit for data substitution. The Atqasuk and Inigok PSD sites are situated on similar terrain features that have minimal influence on local weather patterns. This report contains a comparison of barometric pressure, temperature, wind speeds, and wind direction between the Atqasuk and Inigok PSD sites.

After reviewing meteorological data from the Atqasuk and Inigok PSD sites, ADEC believes that substitution of data during a stable air mass environment occurring at both locations would meet PSD quality standards. For data loss occurring during unstable environments (frontal systems, high winds), an in-depth analysis of the weather pattern would need to be conducted to determine the best course of action for data substitution. For the greatest accuracy of substituted data, weather events should be monitored in real-time, comparing forecast model output and current observations to estimate timing/accuracy errors for data manipulation/adjustment.
INTRODUCTION

The objective of this project is to compare the meteorological data from the NPR-A Inigok Prevention of Significant Deterioration (PSD) meteorological monitoring site (called Inigok PSD site in this report) to surrounding stations to determine if any station might be suitable to act as a surrogate during the winter months, when data capture at the Inigok PSD site is too low to characterize wintertime conditions. Achieving the BLM data completeness goal of 90% has been challenging due to the remoteness of the Inigok monitoring site. Data capture between the winter months (i.e. November and February) of the 2014/2015 and 2015/2016 has been significantly lower than the BLM 90% data completeness goal. The main cause for lost data was wind sensor rime icing. This study focuses on wintertime comparisons between the Inigok PSD site and surrounding stations.

BACKGROUND

The BLM established a meteorological monitoring station in a remote location of the southeastern NPR-A where there is a lack of high quality meteorological and climatological data representing the region between the Brooks Range foothills and the North Slope Coastal Plain. The meteorological data collected at the Inigok PSD site is intended to support BLM management decisions for the area through air quality modeling and provide information for the BLM and other agencies with interest in the NPR-A. The Inigok PSD site was installed on March 25, 2014 approximately 110 miles west-southwest of Deadhorse, Alaska and 114 miles north of the Brooks Range. The station is situated approximately 170 feet above mean sea level.

Due to the remote location of the site and logistical issues, the only scheduled visits to the sites have been for calibration checks and performance audits. According to the station’s 2014 quality assurance plan, a calibration check is required if an instrument has been out of operation for more than three days.

During the past two years data shows that the horizontal wind sensors (primary and redundant sensors) were inoperable during six different occasions for more than three days. During one period the sensor(s) were frozen for 2.5 months before either an operator or wind broke the sensor(s) free. Data capture rates were low due to these events.

- 2014 4th Quarter: 51% data capture;
- 2015 4th Quarter: 66% data capture;
- 2016 1st Quarter: 47% data capture.

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1 BLM, National Petroleum Reserve – Alaska Meteorological Monitoring Station Quality Assurance Project Plan (QAPP) section B.7, Instrument Calibration and Frequency, September 2013
WEATHER IMPACTS

The winter months’ extreme weather patterns at the Inigok PSD site present a significant problem for data capture. The climate at this North Slope monitoring site is classified as ET\(^2\) (Tundra Climate), having long, bitterly cold winters, and short, cool summers. Winter lasts from late September/early October until late April/early May. October through January are typically the snowiest months with snow tapering off from February to May. The average winter low temperatures range from 11°F (−12°C) in October to -24°F (−31°C) in January, but extremes can range from 49°F (9°C) to −58°F (−50°C).

One of the main conditions that interferes with meteorological sensors is soft and hard rime icing. Soft rime ice, also called hoar frost, forms when humid air comes in contact with very cold surfaces. Rime icing occurs on cold, clear nights with little wind. At the Inigok PSD site, extreme cold temperatures averaging close to -25°F, relative humidity above 80%, and winds less than 1 m/s for the winter months create ideal conditions for equipment to ice up without constant monitoring and maintenance. Hard rime ice is a more dense form of soft rime ice and generally occurs in environments with higher relative humidity and slightly higher winds approaching 2-3 m/s. Over prolonged exposure in this environment, meteorological equipment will gradually ice over due to soft and hard rime ice accumulation. With the passing of low pressure systems, the equipment can ice over more rapidly due to higher moisture content, greater winds, and extreme low temperatures associated with the low. After the low passes, higher wind speeds and solar radiation are two factors that can help free an iced wind sensor. From the data reviewed, wind speeds of 9 m/s (20 mph), appear to be the major contributing factor in breaking ice off meteorological equipment when there is no operator on site.

\(^2\) http://koeppen-geiger.vu-wien.ac.at/usa.htm
POTENTIAL SUBSTITUTION SITES

For the initial review, the Alaska Department of Environmental Conservation (ADEC) reviewed meteorological data from the following sites: Atqasuk (AWOS III), Nuiqsut (ASOS), Inigok (RAWS), Umiat (Industry PSD meteorological site) and the Inigok PSD meteorological site. The Inigok RAWS located at the Inigok airstrip would have been the closest choice, but it experiences the same icing issue, is also unmanned, and the data loss was comparable to or exceeded that of Inigok PSD site.

The Umiat PSD site was ruled out for data substitution due to the site’s location in the foothills of the Brooks Range, which makes the sites less comparable. Umiat sits at 267ft (81.6m) along the upper Colville River. The river valley is orientated NE to SW with the Shivugak Bluff (est. 1000ft) on the north banks. The elevation to the south is just as high but there is a more gradual slope to the terrain. The surrounding terrain features create directional change of low level gradient wind flow patterns and channeling of valley winds along the NE and SW quadrants (see Figure 1, corner inserts). The wind roses associated with Umiat corroborate significant terrain influences on local wind patterns in the winter. The associated wind direction and velocity recordings did not make data substitution applicable for Inigok PSD site. For closer review, larger Umiat wind roses are located in Appendix A.

Figure 1. Umiat, Alaska (Industry PSD Met site), Winters 2014/2015 and 2015/2016 1st and 4th quarter wind roses.
The Nuiqsut data was the last to be ruled out for data substitution. The Nuiqsut site is located 50 miles from the Inigok PSD meteorological site and experiences the same weather patterns; the main difference is the terrain influence. Nuiqsut sits along the Colville River at an elevation of 45ft (13.8m), terrain elevations on both sides of the river increase slightly to the west and even greater to the east. Under cold stable conditions the general wind flow is from the south, influenced by the flow of the river and terrain, once the river ices up the terrain elevation provides and funnel/channeling effect on the micro scale low level winds. The valley to the south channels drainage flow winds (red arrows in Figure 2) from the higher elevations down into Nuiqsut. As a result, one sees higher frequencies of north/south wind directions compared to that of Inigok PSD site. The terrain also plays a role in deflecting the wind direction during periods of increased winds (5-10 mph). In cases where the gradient wind flow is from the west (yellow arrows in Figure 2), the higher elevation terrain to the southeast and south redirects the low level winds towards Nuiqsut. The associated wind direction and velocity recordings (Figure 2, corner inserts) under stable conditions did not make data substitution applicable for the Inigok PSD site. For closer review, the Nuiqsut wind roses are located in Appendix A.

Figure 2. Nuiqsut, Alaska, Winters 2014/2015 and 2015/2016 1st and 4th quarter wind roses.
METEOROLOGICAL DATA REVIEW

The Atqasuk (AWOS III) and Inigok PSD sites are both located over 100 miles north of the Brooks Range, on the North Slope with relatively smooth tundra terrain and no river valleys. The vegetation found on the North Slope lacks tree growth and consists mostly of shrubs, grasses, and mosses that exert little frictional influence on boundary layer (surface) winds. Terrain with little frictional influence does not significantly impact boundary layer wind direction or speed. The distance from the Brooks Range and flat terrain results in no wind channeling or drainage winds affecting either site.

Based on the location and terrain features impacting the Umiat, Nuiqsut, and Inigok (RAWS) data, this report will focus on comparing data from the Atqasuk (AWOS III) station to data from the Inigok PSD site for the two winter seasons of 2014-2015 and 2015-2016 October-March. Below are the detailed information for the two meteorological sites.

**Atqasuk Edward Burnell Sr. Memorial Airport, Atqasuk AK:**
- METAR ICAO: **PATQ**
- Location: 70.4671 N / -157.4357 W, approximately 106 miles from Inigok PSD
- Field Elevation: 101.3ft/30.9m
- Maintained by: FAA

**AWOS III:** Wind speed and wind gusts (in knots), wind direction (from which the wind is blowing) and variable wind direction (in degrees of the compass), temperature and dew point (in degrees Celsius), altimeter setting and density altitude, visibility and variable visibility (in miles), sky condition (in oktas), cloud ceiling height (in feet), and liquid precipitation (in inches)

**Inigok PSD, Inigok Airport, AK:**
- METAR ICAO: **NA**
- Location: 70.0038 N / -153.0776 W
- Field Elevation: 191ft/58.2m
- Maintained by: BLM

**BLM PSD Meteorological site:** Wind speed (in meters per second), wind direction (from which the wind is blowing), vertical wind speed (in meters per second), ambient temperature (in degrees Celsius), vertical temperature difference (in degrees Celsius), total solar radiation (in Watts per meter squared), relative humidity (in percentage), and barometric pressure (in millibars)
Figure 3. Range reference map of NPR-A Meteorological site (Inigok PSD), distance to Nuiqsut and Atqasuk
BAROMETRIC PRESSURE COMPARISON

The barometric pressure is the pressure exerted by the atmosphere, also described as the weight of column of air directly over a site specific point. The following charts compare winter barometric pressure readings from the Atqasuk (AWOS III) and Inigok PSD sites.

Figure 4 and Figure 5 Barometric Pressure time series: On average the combined wintertime barometric pressure at the Atqasuk site is **0.20 inHg** higher than at the Inigok PSD site. The PSD accuracy standard is ±3 mb/0.21 inHg. Only hours with pressure readings were used to calculate winter averages. The greatest difference (0.36 inHg) between the two sites occurred on
6\textsuperscript{th} Nov, 2015. The resulting higher barometric pressure readings were due to a high pressure center located closer to the Atqasuk than the Inigok PSD site.

TEMPERATURE COMPARISON

Temperature readings for the Inigok PSD site have been converted from Celsius to Fahrenheit for comparison with Atqasuk (AWOS III) data.

Figure 6 and Figure 7 Temperature time series: On average, the combined winter months Atqasuk is 0.21°F higher than Inigok PSD site. PSD accuracy standard is ±0.5°C/1.8°F. Only hours with temperature readings were used to calculate winter averages. The greatest temperature difference (24.6°F) between the two sites occurred on 28\textsuperscript{th} Feb, 2015. The resulting
higher temperature readings were due to a weather system moving through the region. Figure 7 shows the data loss at the Inigok PSD site during December through February.

**WIND COMPARISON**

Wind speed readings for the Inigok PSD site have been converted from meters per second to miles per hour for comparison with Atqasuk (AWOS III) data.

![Figure 8. Wind Speeds (MPH) time series for the winter of 2014/2015](image)

![Figure 9. Wind Speeds (MPH) time series for the winter of 2015/2016](image)

Figure 8 and Figure 9 Wind Speed time series: On average, the combined winter months wind speed for Atqasuk is 1.2 mph/0.54 m/s higher than Inigok PSD site. PSD accuracy standard is ±0.2 m/s + 5% of actual. Only hours with wind speed readings were calculated into winter
averages. The greatest wind speed difference (24.2 mph) between the two sites occurred on 20\textsuperscript{th} Nov, 2014. There was a tighter pressure gradient over Atqasuk (RAWS III) causing the higher wind speeds. Figure 8 and 9 show missing data at the Inigok PSD site.

Figure 10. Combined January – March 2015/16, 1\textsuperscript{st} Quarter Wind Roses

Figure 11. Combined October – December 2014/15, 4\textsuperscript{th} Quarter Wind Roses

The Inigok PSD site lost 1,238 hourly wind direction data points during 1\textsuperscript{st} quarter 2016 (Jan-Mar) and 1,544 hourly data points of 4\textsuperscript{th} quarter 2014 (Oct-Dec) due to icing events. Due to data
loss, the Inigok PSD wind roses in Figure 10 and Figure 11 were recorded using a lower frequency scale, the 1st quarter Inigok maximum wind speed frequency is 0.1 (10%) and the 4th quarter Inigok maximum wind speed frequency is 0.08 (8%) compared to that of the Atqasuk site which recorded 0.2 (20%) wind speed frequency for 1st quarter and 0.18 (18%) wind speed frequency for 4th quarter.

On days with wind speeds above 10 mph the primary wind directions are from the west southwest (210-285°) and east northeast (45-110°). The days of increased wind speeds correspond to frontal passage or a tightening pressure gradient. Due to the separation of the sites by approximately 100 miles there is a time lag of up to 3-5 hours in comparable data. Though this is not indicated in the wind rose, one can refer back to charts 5 and 6 for clarification. On days of relatively low winds (0-10 mph), and stable environment, the wind direction for Atqasuk and Inigok PSD are within the ±5° allowable deviation for PSD wind direct measurements.

CONCLUSIONS

The objective of this report is to compare the meteorological data from the Inigok PSD site to surrounding stations to determine if any station might be suitable to act as a surrogate during the winter months, when data capture at the Inigok PSD site is too low to characterize winter conditions. After reviewing meteorological data from the Atqasuk and the Inigok PSD sites, ADEC has concluded that substitution of data during a stable air mass environment occurring at both locations would meet PSD quality standards under certain conditions. Data substitution in general is possible during:

- Stable air mass environments with wind speeds less than 10 mph; and
- Conditionally stable air mass environments with wind speeds 10-20 mph, and with gradient flow from the east (45-135°) or from the west (225-315°).

For data loss that occurs during unstable air mass environments (frontal systems, high winds), an in-depth analysis of the weather pattern needs to be conducted to determine the best course of action for data substitution. On average there has been a two to four hour lag time between all stations as weather systems, depending on geographical location, move through the North Slope range. For the greatest accuracy of substituted data, weather events should be monitored in real-time, comparing the Global Forecast System (GFS) or Weather Research & Forecasting model (WRF) to current observations. This will allow the meteorologist to estimate timing and accuracy errors for data manipulation/adjustment necessary for Inigok PSD substitution.
APPENDIX A.

Figure 12. Umiat 1st Quarter Wind Rose (2015/2016)

Figure 13. Umiat 4th Quarter Wind Rose (2014/2015)
Figure 14. Nuiqsut 1st Quarter Wind Rose (2015/2016)

Figure 15. Nuiqsut 4th Quarter Wind Rose (2014/2015)