11.6 EVALUATING SODAR PERFORMANCE AND DATA QUALITY IN SUBARCTIC WESTERN ALASKA

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1. INTRODUCTION

In September 2008, a Sonic Detection and Ranging (SODAR) antenna and two Radio Acoustic Sounding System (RASS) antennae were installed in a remote location of southwestern Alaska approximately 300 miles west-northwest of Anchorage. Figure 1 depicts the approximate location of the monitoring site. The purpose of the monitoring program is to document the regional atmospheric baseline and to collect adequate data in preparation of an air quality permit application.

Meteorological data were collected at three locations in addition to the SODAR station. Site A, consisting of a 10-meter tower, was located approximately 2.5 kilometers (km) southeast of the SODAR and was approximately 95 meters (m) above the SODAR ground level. Site B, consisting of a 10-meter tower, was located approximately 4 km east-northeast of the SODAR and was 370 m above the SODAR ground level. Site C, consisting of a 10-meter tower and a precipitation gauge, was located approximately 0.5 km northwest of the SODAR and was 14 m above the SODAR ground level. All sites collected wind speed and direction, vertical wind speed, temperature at 10 and 2 meters, and solar radiation. Barometric pressure was collected at sites B and C, and relative humidity was collected at sites A and C.

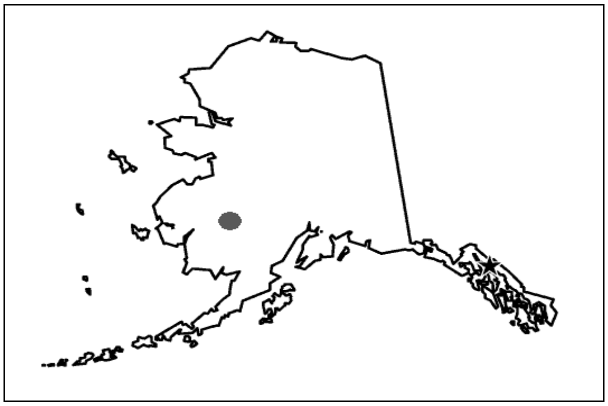

Figure 1: Approximate site location

2. SYSTEM INFORMATION

The SODAR was a Scintec XFAS with optional RASS units. To satisfy the monitoring needs of the project, the SODAR selected had to operate under specific conditions which the Scintec XFAS met. Wind and temperature data were needed from ground level to one kilometer above ground level, with 20-meter range gates. The entire system was required to operate within the ambient temperatures of -40°C to +25°C.

The Scintec XFAS SODAR antenna operated at a frequency range of 825 to 1375 Hz. The antenna measured 4.76 feet long (145 cm) and it weighed 317 pounds (144 kg). The RASS unit operated at 1290 MHz (Scintec, 2008), whose radio waves were Doppler shifted by density perturbations (see Figure 2).

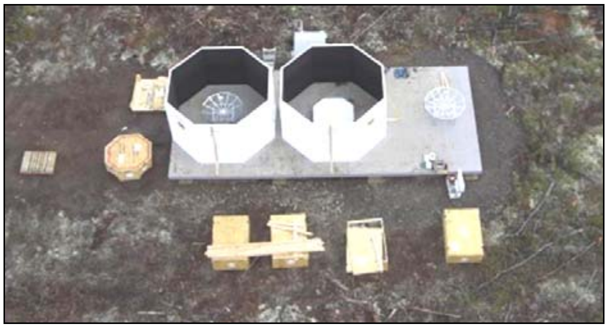

Figure 2: Aerial view of SODAR with RASS units

SODAR uses acoustic pulses to measure three-dimensional horizontal and vertical wind profiles. The RASS (Radio Acoustic Sounding System) uses both acoustic and electromagnetic waves to measure virtual temperature. The SODAR system reports winds and temperature at the midpoint altitude of the layer directly over the measurement site (Scintec, 2008).

Data are downloaded via FTP (File Transfer Protocol) daily and are checked for completeness and reasonableness. At the SODAR location, site checks and hardware checks are completed once a week. A self test is also performed on a weekly basis. This test checks the signal emission and reception quality of the SODAR and RASS antennae. The test also administers a noise test to check the levels of acoustic and electronic noise present.

Data parameters currently collected or calculated at the site include wind speed, wind direction, sigma theta, U V W components and sigmas, PG stability, temperature, inversion height, and mixing height. For a full list of parameters collected, see Table 1.

3. YEAR IN REVIEW

At the conclusion of one monitoring year, a review of the installation and data collection processes was completed.

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Variable	Symbol	Unit
Height	z	m
Wind Speed	speed	m/s
Wind Direction	dir	deg
Wind U (east)	U	m/s
Wind V (north)	V	m/s
Wind W (vertical)	W	m/s
Sigma U	sigU	m/s
Sigma V	sigV	m/s
Sigma W	sigW	m/s
Sigma Theta	sigTheta	deg
Sigma Phi	sigPhi	deg
PG Stability Profile	PGz	1
Backscatter	bck	1
Temperature	T	°C
Temperature (virtual)	T_v	°C
Temperature ID	T_ID	1
Error code	error	1
PG Stability	PG	1
Inversion height	h_inversion	m
Mixing height	h_mixing	m
Surface heat flux	H	Wm^{-2}
Monin Obukhov length	L*	m
Friction velocity	u*	m/s

Table 1: Parameters collected by the SODAR

The installation was straightforward and there were very few problems. The complete system was installed by two people and operational in less than one week, with the exception of requiring an updated version of software than what was provided from the manufacturer to operate the RASS units. This installation included a modified wind protection system to keep the enclosure intact during high wind events.

On-site training was provided by the manufacturer approximately one month after installation. The training lasted three days and consisted of overviews of the hardware, software, and data processing system. Data collection officially began November 1, 2008 and went though one complete monitoring year, ending October 31, 2009.

At the end of October 2008, the SODAR indicated a high level of electronic noise in self-tests. The emission and reception quality of the SODAR also started to fall as time progressed and the system started to occasionally fail self-tests. After eliminating any possibility of an ambient noise source, the manufacturer was contacted for assistance. Scintec believed the decreased emission and reception quality, as well as the electronic noise, should have no effect on data quality but may affect data recoveries and maximum attainable altitudes.

On March 18, 2009, the Signal Processing Unit (SPU) was replaced. This change eliminated the electronic noise source, but had a negligible effect on the emission and reception quality. At the end of July 2009, a switchboard was replaced in an effort to increase the emission and reception quality of the SODAR. This replacement was found to be ineffective. On August 1, 2009, an updated version of software was provided which had a reduced threshold for emission and reception quality in order to improve the results of the self-tests. It was determined by the manufacturer in order to improve the emission and reception quality, all fourteen transducers on the SODAR antenna would need to be replaced (Figure 3). This maintenance was completed at the end of September and was found to significantly improve the emission and reception quality of the SODAR.

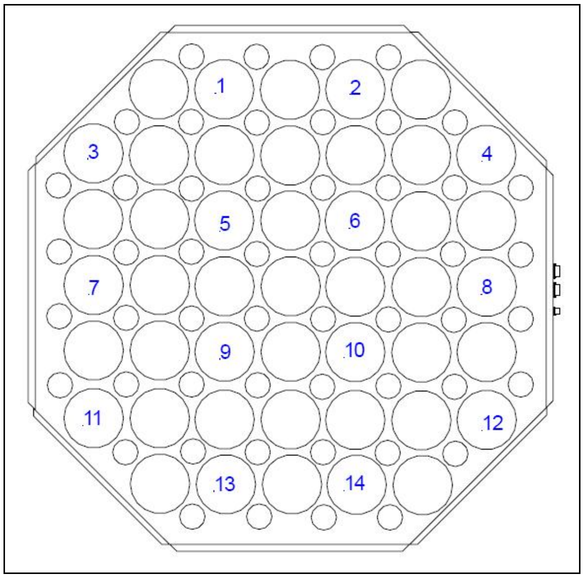

Figure 3: Location of SODAR transducers

4. DATA RECOVERY

Data recovery of the SODAR was highly variable and dependent on atmospheric conditions at the various sampling heights. It was common to have levels of invalid or missing data, particularly at ground level. This was often due to a lack of measurable turbulence at these levels. Equipment performance may have also been compromised by extremes in meteorological conditions such as extreme high or low temperatures and high wind speeds.

Periods of high wind speeds or precipitation were not excluded from the calculated data recovery rate. These natural phenomena may have resulted in decreased SODAR performance due to the increased ambient noise levels associated with these conditions. These additional noises can interfere with the ability of SODAR to detect return echoes.

Data recovery was calculated as the ratio of the number of observations actually reported at a sampling height to the total number of possible observations at that height and was reported as a function of altitude. Each parameter was measured at elevations between 40 and 1000 meters above ground level, at 20-meter intervals. All parameters were processed to produce 60-minute averages. Data recoveries for this reporting period are summarized in Table 2 and Figure 4.

Elevation (m-AGL)	Wind Speed Annual (%)	Temperature Annual (%)
40	28.9	98.2
60	33.9	98.2
80	75.2	98.2
100	85.6	98.3
120	90.8	98.3
140	96.3	98.3
160	97.4	98.2
180	97.7	98.1
200	97.8	98.1
220	97.7	97.9
240	97.7	97.7
260	97.7	97.0
280	97.7	96.1
300	97.7	94.6
320	97.6	92.6
340	97.4	90.1
360	97.2	87.3
380	96.8	84.1
400	96.4	80.1
420	96.1	75.8
440	95.6	71.0
460	95.0	65.8
480	94.3	60.1
500	93.5	54.2
520	92.5	--
540	91.8	--
560	90.8	--
580	89.6	--
600	88.4	--
620	87.0	--
640	85.1	--
660	83.4	--
680	81.2	--
700	79.1	--

Table 2: Wind speed and wind direction data recoveries with respect to altitude

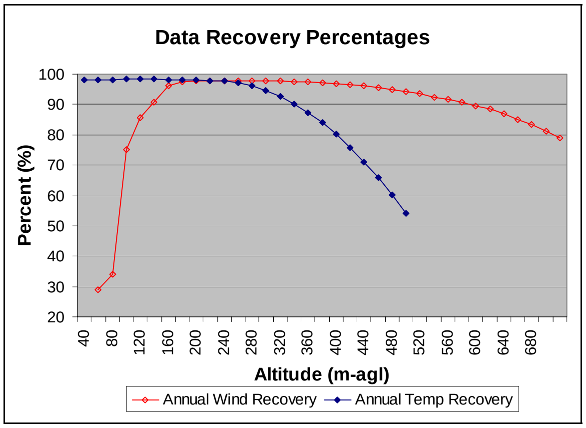

Figure 4: Annual wind and temperature data recovery

As seen above, SODAR wind data immediately above ground level was susceptible to poor data resolution and recovery due to ground clutter, noise, and signal scattering. Optimal data recoveries for this monitoring year were from near ground level up to 700 meters for wind data and from ground level up to 500 meters for temperature. Data up to 1000 meters are available and may have future use but were omitted from this publication.

5. DATA COMPARISONS

When comparing the SODAR to other types of meteorological instrumentation, one must take into account the differences between the two monitoring systems. First the SODAR takes a volume measurement whereas a cup or propeller type anemometer is a point measurement. The SODAR also averages a vector, where cup and prop anemometers use scalar averaging. The typical deviations between the varying measurement systems can be anywhere from 2-6%. Typically, a SODAR will measure slightly lower wind speeds than a cup or prop anemometer, which can be attributed to overspeeding of the cup and prop sensors, as well as the long term volume averaging of the SODAR (Stawicki, 2008).

An AnaSonde-2G radiosonde made by Anasphere was used to validate the SODAR data on a quarterly basis. The system used a helium-filled balloon to fly an instrument package. It included radio telemetry to send the data to the ground station. The system used a fast response thermistor to measure temperature and a global positioning receiver to obtain information about its location in the horizontal and vertical dimensions. These location data were then used to calculate altitude, wind direction and wind speed. To obtain high resolution data, the sonde system worked in two steps. First, it gathered the data as the balloon ascended. Second, upon reaching approximately 457 meters (1500 feet), it transmitted the data to the ground station.

The sonde system took a snapshot of the atmospheric conditions every second as it ascended into the atmosphere following the wind. Its ascent rate was controlled by the amount of helium introduced into the launch balloon. The ascent rate of all sonde launches during this monitoring period ranged from 100 to 297 meters per minute, with an average of 173 meters per minute. This is different than the SODAR system in that the SODAR was stationary and sampled the volume of air directly above. In addition, SODAR data is reported in range gates rather than specific altitudes, defining the 100 meter measurement as the average of the conditions from 90 to 110 meters.

A total of twelve sonde comparisons were completed within the monitoring year, of which this report will only highlight two. The first sonde versus SODAR comparison occurred on October 7, 2008. The sonde was launched at 1430 AST and ascended with an average rate of 200 meters per minute. This sounding was compared to the 1500 AST SODAR data and can be seen below in Figures 5-1 through 5-3.

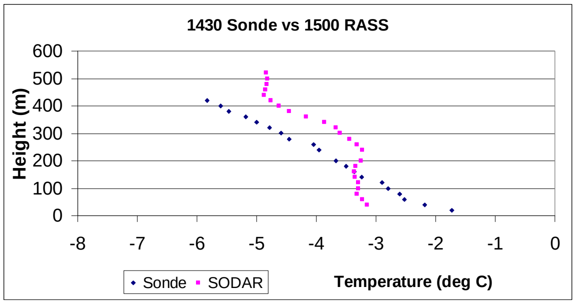

Figure 5-1: Temperature comparisons between the AnaSonde and the RASS

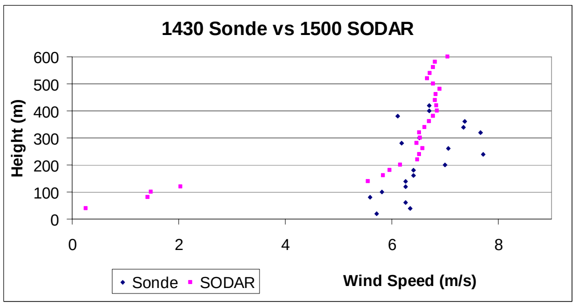

Figure 5-2: Wind speed comparisons between the AnaSonde and the SODAR

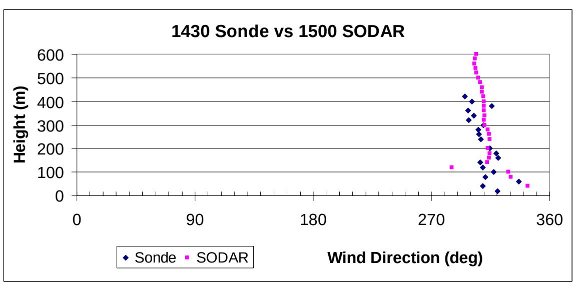

Figure 5-3: Wind direction comparisons between the AnaSonde and the SODAR

Figures 6-1 through 6-3 below show another sonde to SODAR comparison, which occurred on April 18, 2009. The sonde was launched at 2038 AST and ascended with an average rate of 206 meters per minute. This sounding was compared to the 2100 AST SODAR data.

Figures 8-1 through 8-3 show SODAR wind speed, wind direction, and RASS temperature data graphed with data from the three nearby meteorological stations A, B, and C (see Figure 7) for January 7, 2009 for hour 1800. Note sites A and C both agree well with the SODAR measurements. Site B wind speeds were recorded by an ultrasonic anemometer located on a hill top and may be overestimating the winds due to a topographically induced Venturi effect.

Figures 9-1 through 9-3 show SODAR wind speed, wind direction, and RASS temperature data graphed with data from the three nearby meteorological stations A, B, and C for June 28, 2009 for hour 1800. Note sites A and C seem to indicate an

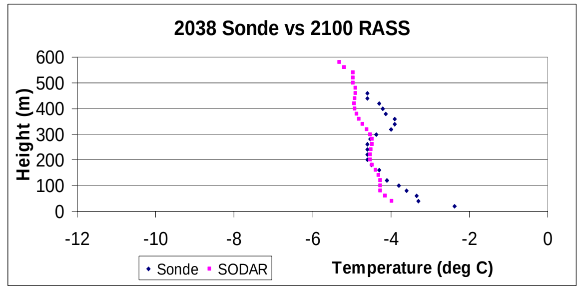

Figure 6-1: Temperature comparisons between the AnaSonde and the RASS

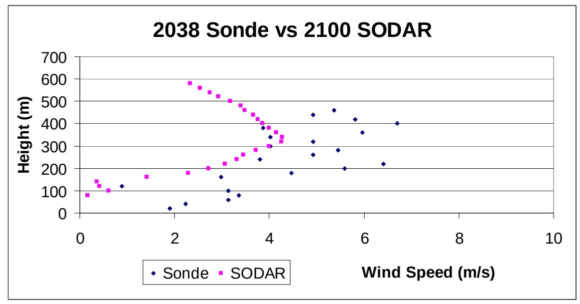

Figure 6-2: Wind speed comparisons between the AnaSonde and the SODAR

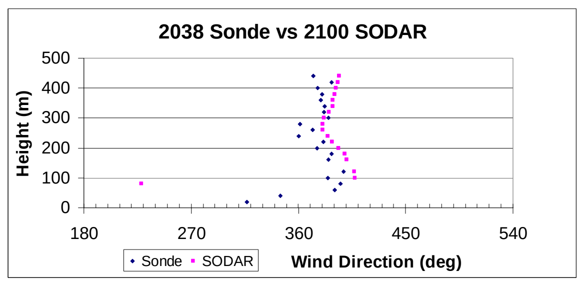

Figure 6-3: Wind direction comparisons between the AnaSonde and the SODAR

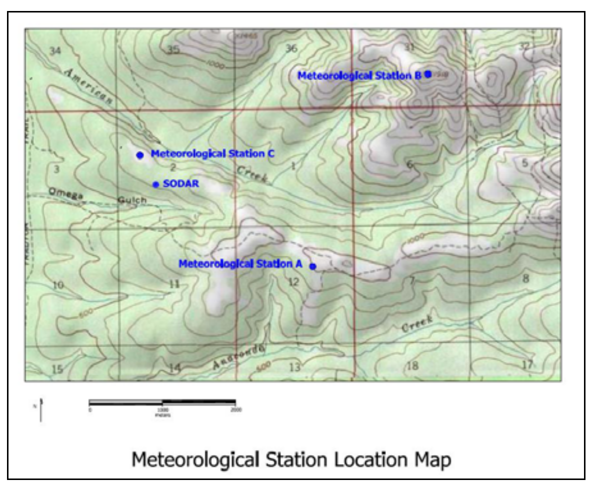

Figure 7: Location of meteorological sites A, B, and C

underestimation of surface wind speeds by the SODAR. Site B wind speeds were again recorded by an ultrasonic anemometer located on a hill top and may be overestimating the winds due to a topographically induced Venturi effect.

This project site was prone to severe rime ice accretion. With strong northerly winds, high relative humidity, and subzero temperatures, rime ice accretion was inevitable. This made data comparisons difficult at times. Due to the enclosure surrounding the SODAR and a heater in the antenna, the SODAR remained relatively clear of ice and snow through the monitoring year. Meteorological sites A, B, and C were prone to rime ice accretion for the months of September through April, which can, at times, eliminate wind speed or wind direction data at these sites. If the magnitude of ice accretion is great enough, wind turbines that power Site B ceased to operate, which, in turn, could prevent measurement and collection of the remaining meteorological parameters.

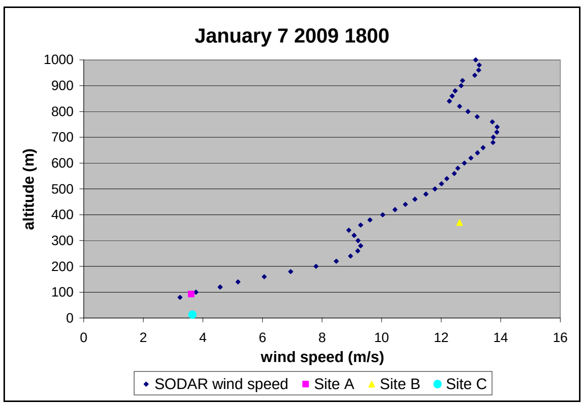

Figure 8-1: Wind speed comparisons between the SODAR and meteorological stations A, B, and C for January 7, 2009 hour 1800.

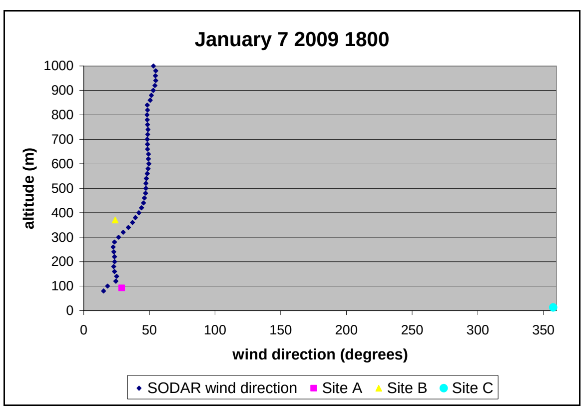

Figure 8-2: Wind direction comparisons between the SODAR and meteorological stations A, B, and C for January 7, 2009 hour 1800.

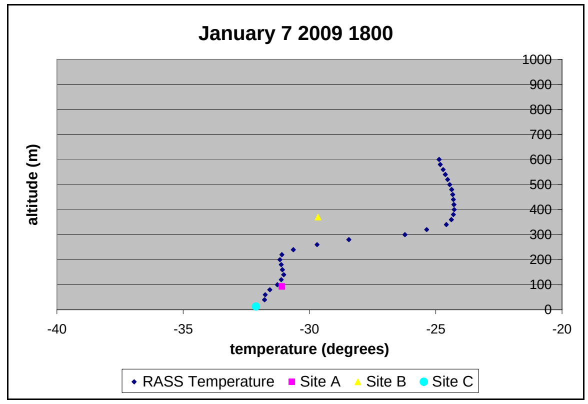

Figure 8-3: Temperature comparisons between the RASS and meteorological stations A, B, and C for January 7, 2009 hour 1800

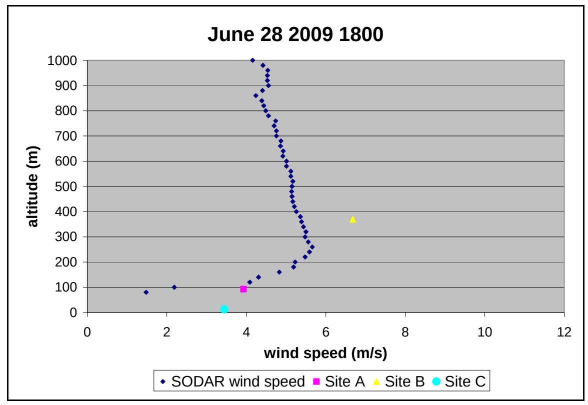

Figure 9-1: Wind Speed comparisons between the SODAR and meteorological stations A, B, and C for June 28, 2009 hour 1800

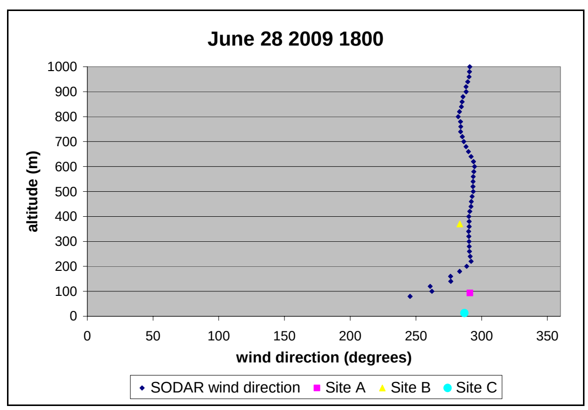

Figure 9-2: Wind direction comparisons between the SODAR and meteorological stations A, B, and C for June 28, 2009 hour 1800

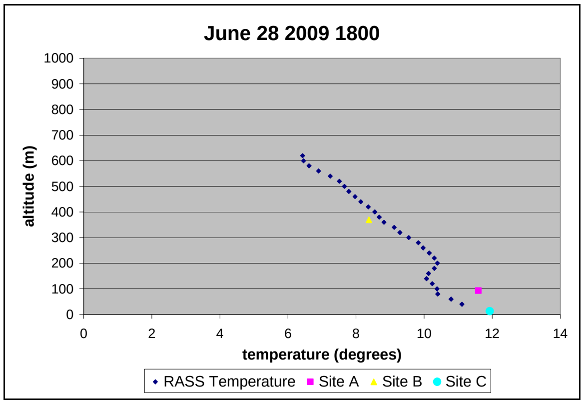

Figure 9-3: Temperature comparisons between the RASS and meteorological stations A, B, and C for June 28, 2009 hour 1800

6. METEOROLOGY

The project location is susceptible to unique meteorological conditions not commonly found in the contiguous United States, which has made data collection and quality assurance challenging at times. Temperatures commonly fall to near -40°C (-40°F) in the winter and can reach 27°C (80°F) in the summer. With regard to annual atmospheric stability, unstable conditions occur 15% of the year, neutral conditions 67%, and stable conditions 18% of the year.

The annual average wind speed at sites A and C were 3.8 m/s (8.5 mph) and 3.3 m/s (7.4 mph), respectively. The highest hourly average wind speeds measured at sites A and C were 19.6 m/s (43.8 mph) and 16.9 m/s (37.8 mph), respectively. Site C also received approximately fifteen inches of liquid equivalent precipitation per year. Site B had an annual average wind speed of 9.2 m/s (20.6 mph), and the highest hourly average wind speed measured this monitoring year was 29.4 m/s (65.8 mph).

This site is very prone to long lasting inversions due to the mountainous terrain and long cold winters. Air cools over the mountain slopes and flows down and collects in the valleys, resulting in an increase of temperature with height (Whiteman, 2000). Twenty-four hour temperature profiles from the RASS can be seen below in Figures 10, 11, and 12.

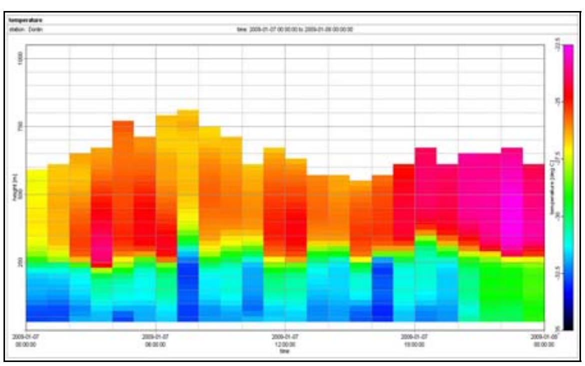

Figure 10: RASS temperature data showing a strong inversion on January 7, 2009 00:00 - 24:00 AST

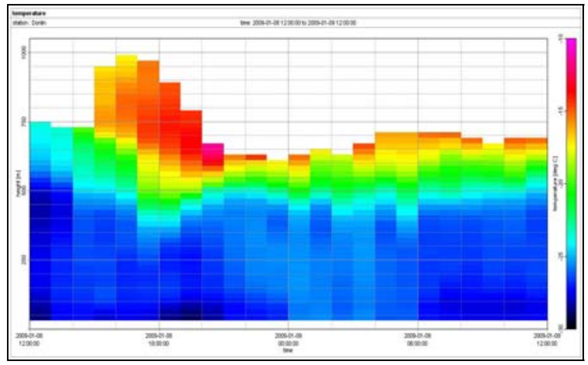

Figure 11: RASS temperature data showing an inversion on January 8, 2009 12:00 – January 9, 2009 12:00 AST

Neighboring meteorological stations are helpful with regard to validating the SODAR and RASS data, but there have been occasions where the SODAR and RASS data was used to validate the data collected at sites A, B, and C. Figure 13 below shows twenty-four hours of meteorological data collected at site B. There appears to be questionable data between 1800 and 1900 on October 22, 2009, with a spike in the temperature, wind speed, and wind direction data. Over a one hour period, 10-meter temperature rose and fell 10°C. This behavior is odd when compared to the data continuity of the first eighteen hours of the day. Sites A and C did not show this temperature spike, which left only one way to validate or invalidate the data.

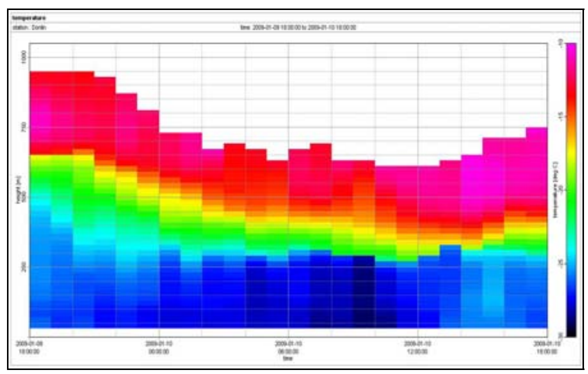

Figure 12: RASS temperature data showing an inversion on January 9, 2009 18:00 – January 10, 2009 18:00 AST

Figure 14 below is the temperature profile from the RASS over the same twenty-four hour period as figure 18. The black and white dotted line shows the approximate altitude of site B on this image. For hours 1800 and 1900, this same temperature spike is visible and reports similar temperatures as measured at site B.

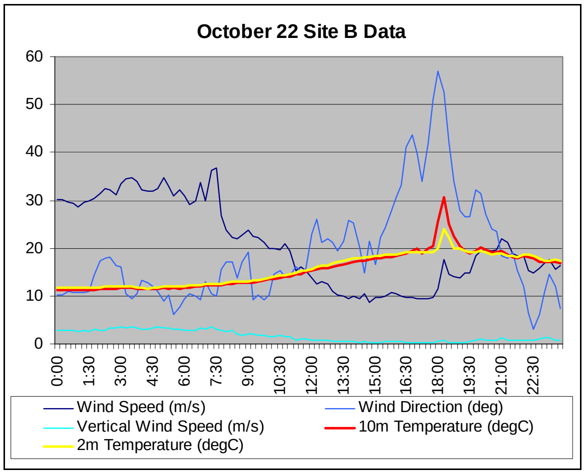

Figure 13: Meteorological data from site B

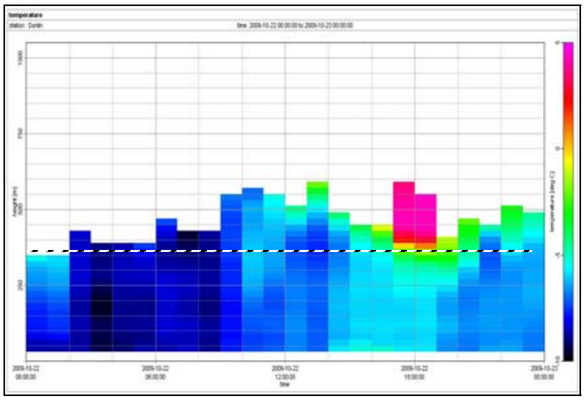

Figure 14: Temperature data from the RASS validates the unusual temperature data from site B.

7. CONCLUSION

In conclusion, operating a SODAR in subarctic western Alaska was challenging at times but provided good data. The installation and operation were straightforward and problem free. Data quality was good up to approximately 700 meters above ground level with regard to wind speed, with the exception of data within the first 100 meters. Data recoveries were low at these near ground altitudes, and the data that were received seemed to underestimate the wind speeds when compared to the reference measurements of nearby meteorological stations and radiosondes, as seen in previous examples. Temperature data on the other hand had high data recoveries starting at ground level up to approximately 500 meters and had good agreement with radiosonde and reference measurements. Finally, the SODAR was able to, in turn, validate unusual meteorological data seen at other meteorological stations.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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