12.1 EVALUATION OF THE CAMPBELL SR-50 SENSOR IN TRIPLICATE FOR AUTOMATION OF U.S.. SNOWFALL AND SNOW DEPTH MEASUREMENTS AND WORK TOWARDS OPERATIONAL STATUS

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1. INTRODUCTION

The measurements of both snowfall and snow depth are important to a variety of disciplines including transportation networks, climatology, emergency managers, and water supply forecasters, to name a few. Since the automation of many surface weather observations within the past twenty years, the observations of snow parameters are now lacking or missing from many stations nationwide. This has potential to impact long-term snow climatology at these stations. The automation of snow observations may provide consistent, real-time observations to those in need of these important climatological data.

This paper will briefly describe the current research goals and focus areas of snow observation automation. It will also provide results from the 2006-2007 data collection period with a focus on sensor signal properties as well as preliminary investigations toward a snowfall algorithm.

2. BACKGROUND

To date, much work has been done in the area of automation of snow observations using ultrasonic snow depth sensors. Different manufacturers of these sensors were tested and compared (Brazenec, 2005; Ryan, et al., 2008). Further studies included standardized installations in various climate regimes across the U.S. (including Alaska) for a complete, uniform analysis of sensor performance under a full suite of meteorological conditions (Ryan and Doesken, 2007). Favorable results have been obtained using the Campbell Scientific SR50 (now the SR50A) for measuring snow depth. The sensors typically can measure the snow beneath them within ±1 cm on average (Brazenec, 2005; Ryan, et al., 2008). In order for the sensors to compare well with the traditional manual observation of total snow depth, which is often an integration of several measurements, proper siting is a key factor. It is also important to realize that proper siting for temperature and precipitation measurements is not necessarily proper siting for snow measurements. As well, areas that are prone to wind blown snow create an interesting and difficult challenge for automation of snow measurements.

3. METHODS

Prior to the 2006-2007 test season, installation of the Campbell Scientific SR50 was standardized in a triplicate configuration at 17 sites across the U.S (Figure 1). These sites are mainly located at Weather Forecast Offices (WFO's). Table 1 provides the WFO three-letter codes that identify the station. Complete details on installation procedures are given in (Ryan and Doesken, 2007), however the general setup was each sensor installed 120 degrees from each other with one oriented to True North. A temperature probe was installed in the center of the plot. The sensors were pointed onto a 1.2 m^2 white snowboard similar to the manual observation snowboard used by the National Weather Service (NWS). Figure 2 shows completed installation photos for a few sites.

Table 1: WFO three-letter codes.

Station Location	Code
Aberdeen, SD	ABR
Buffalo, NY	BUF
Cheyenne, WY	CYS
Fairbanks, AK	FAI
Fort Collins, CO	FCL
Flagstaff, AZ	FGZ
Grand Rapids, MI	GRR
Wilmington, OH	ILN
Indianapolis, IN	IND
Johnstown, PA	JST
McGrath, AK	MCG
Milwaukee, WI	MKX
Marquette, MI	MQT
Pittsburgh, PA	PBZ
Salt Lake City, UT	SLC
Sterling, VA	SRD
Great Falls, MT	TFX

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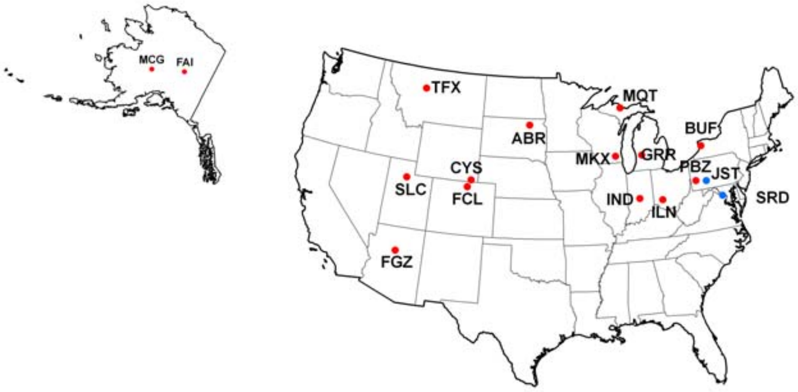

Figure 1: Station map (not to scale) labeled by WFO code.

Figure 2: Site photos of complete installation from left to right: ABR, FCL and FAI

Along with the automated data, manual observations were collected for comparison. Since most sites are located at NWS forecast offices, six hour and twenty-four hour manual observations of snowfall and snow depth are readily available. Additional manual observations included: depth of snow on each sensor board, six hour snowfall water equivalent, six hour gage precipitation and ground snow water equivalent core (taken once daily).

Automated data were compared to the manual observations. Each sensor was compared to the manual snow depth measurements taken off of its' snowboard for verification that they were working properly and calibrated to zero correctly. Each sensor was then compared to the traditional total snow depth measurement from each location. Since the sensors are measuring a snow depth, a snowfall value needs to be backed out of snow depth signal algorithmically. This work is still in preliminary stages since work is still being conducted to reduce signal noise. Current work is focused in the area of digital signal processing (DSP) to extract strong signal values and smooth the time series. The noise in the sensor can potentially produce "false alarms" from the snowfall algorithm. This term refers to when the algorithm calculates a snowfall value when none was observed or measured manually. Interesting sensor behavior and characteristics will be shown.

4. RESULTS

4.1 *Depth from Snowboards*

Figures 3 and 4 provide summary statistics for the comparison of manual depth taken on each sensor snowboard compared to that sensors' reading. The graphs include statistics for each snow sensor. One sensor is oriented to the North, one to the SE and one to the SW. Figure 3 shows the Mean Absolute Error (MAE) between the measurements and Figure 4 shows the Root Mean Squared Error (RMSE) which is normalized by average snow depth to make them comparable between sites. The MAE is a measure of the "small scale" error, while the RMSE is a measure of "global" error in the measurements. The following sites were not included in this analysis due to limited datasets for comparison or due to problems with the dataset: ILN, JST, FAI, GRR, MCG, PBZ and SRD.

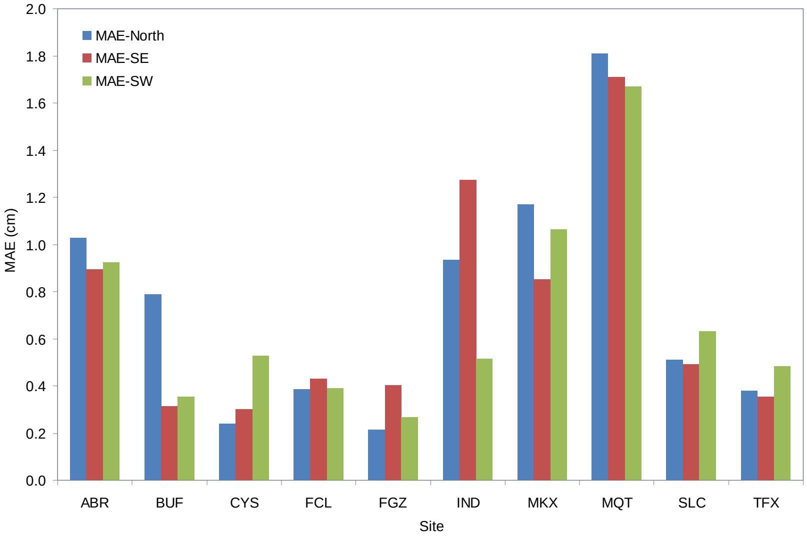

Figure 3: Mean absolute error between sensors and manual snow depth taken from each sensor board.

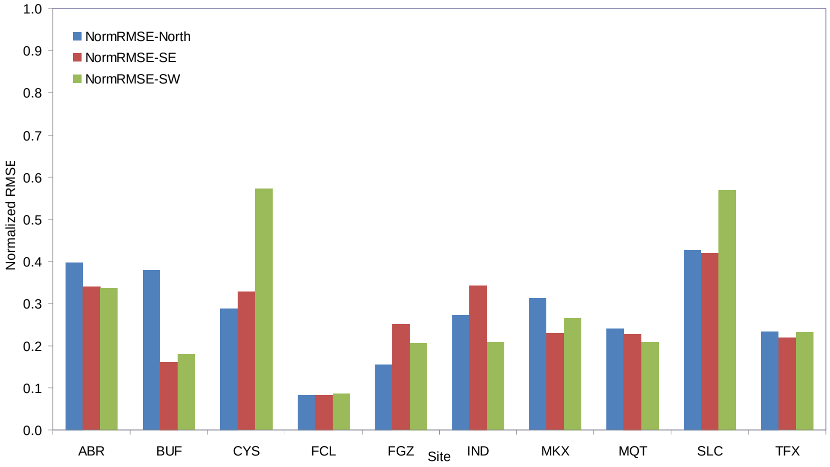

Figure 4: Root mean squared error between sensors and manual snow depth taken from each sensor board.

The MAE for all sites is less than 2.54 cm (1 in), which is the accuracy level used in reporting snow depth. Although most locations reported these depths to 0.25 cm (0.1 in), ABR, MKX and MQT reported to the 2.54 cm (1 in) which inflated their error slightly, IND reported snow depth readings to the nearest 1.27 cm (0.5 in). The RMSE's are reduced even further because they are normalized by average snow depth. This normalization makes the errors more comparable between locations. The errors seen here are likely due to variations in snow depth on the large snowboards because the sensors will report the highest point they see which may not be where the observer measures on the boards. Overall, these results are quite favorable and illustrate that the sensors are reporting what is beneath them.

4.2 *Total Snow Depth on Ground*

The same statistics as above were used to quantify differences between the sensors and the traditional measurement of total snow depth. This measurement may take an average of several measurements (depending on how variable the snow cover is) to get a representative sample. Higher errors in these comparisons will illustrate sites with highly variable snow cover due to wind scouring/redistribution, as well as point to sites with non-ideal siting. The statistics are shown in Figures 5 and 6.

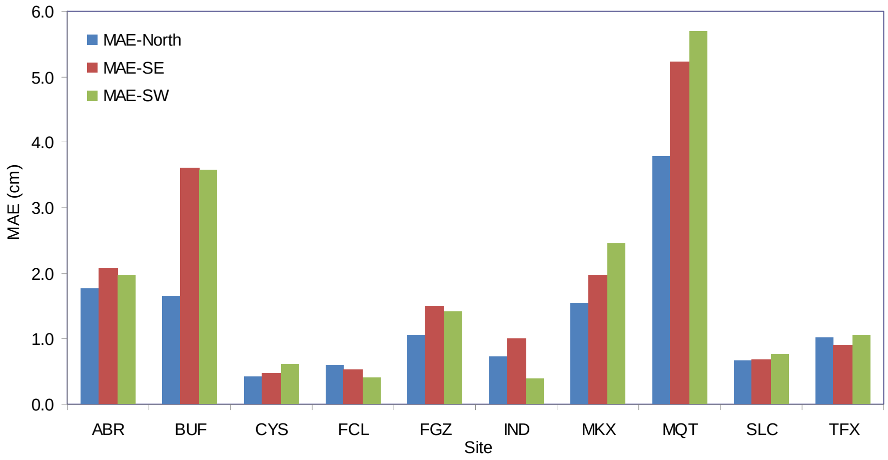

Figure 5: MAE between sensors and traditional total snow depth measurement

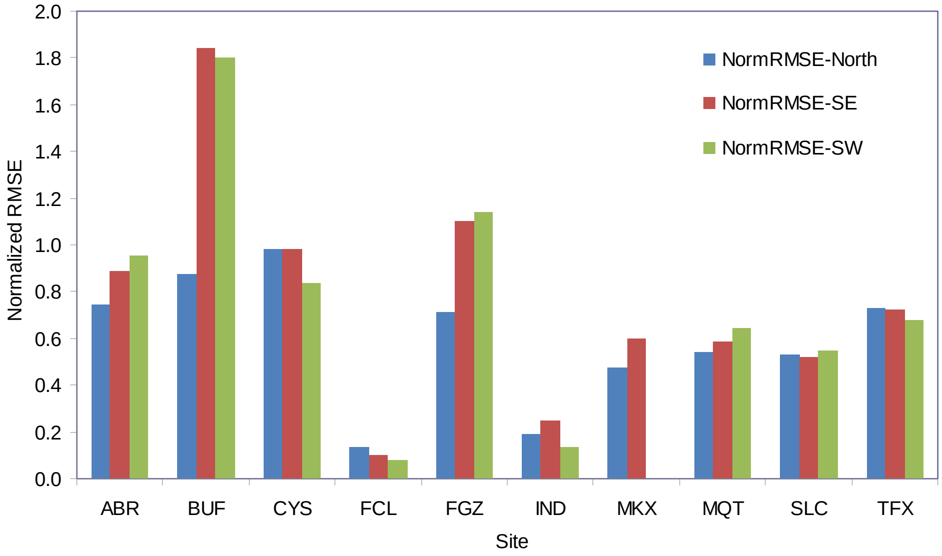

Figure 6: Normalized RMSE between sensors and traditional snow depth measurement

It is not surprising that both the MAE and normalized RMSE increases when looking at this parameter and it is important to remember that there is a degree of uncertainty in both the automated and manual measurements. The MAE in the measurements at BUF, MKX and MQT are over 2.54 cm. The main cause of these larger errors is spatial variability due to wind scour/redistribution which is not being captured by the sensor point measurements. The reporting resolution of the manual data (i.e. 2.54 cm vs. 0.25 cm) also plays a role here but does not explain all the error seen. BUF had their sensor boards elevated over the ground surface which caused increased wind scour at this location resulting in larger errors. Due to this error in installation, it was difficult to accumulate snow on the sensor boards resulting in large error terms in both the MAE and RMSE. In areas prone to wind scour/redistribution, the same is true and finding ideal siting conditions is quite difficult.

4.3 Digital Signal Processing

In order to confidently calculate snowfall from the sensor snow depth, digital signal processing is being explored to extract the best possible snow depth signal from the combination of signal and noise that is currently present in the data.

For example, there is a diurnal fluctuation in reported sensor snow depths at some stations, even when no snow is present. This characteristic has been most often noted at the sunnier, higher elevation stations in the Western U.S. This may be due to more rapid temperature changes than at lower elevation stations to the East. Figures 7 a and b illustrate this pattern.

BUF is at an elevation of 218 m while FCL is at 1525 m. It is clear from figures 7 a and b that the higher elevation site experiences a diurnal variation in the snow depth signal. FCL shows close to 20 degree C changes each day whereas BUF shows more synoptically driven temperature variations and smaller temperature changes from day to day. This pattern is seen at other locations as well. Figure 8 quantifies average rate of change in temperature by elevation for a few locations. The higher the site elevation the larger average rates of change in surface temperature along with larger standard deviations of temperature rate of change. The changes in snow depth seen here could be due to: increased solar energy, faster rates of change in temperature or a change in the speed of sound in air not being accounted for by temperature alone. This situation is currently under investigation as these diurnal fluctuations are not easily removed by averaging alone.

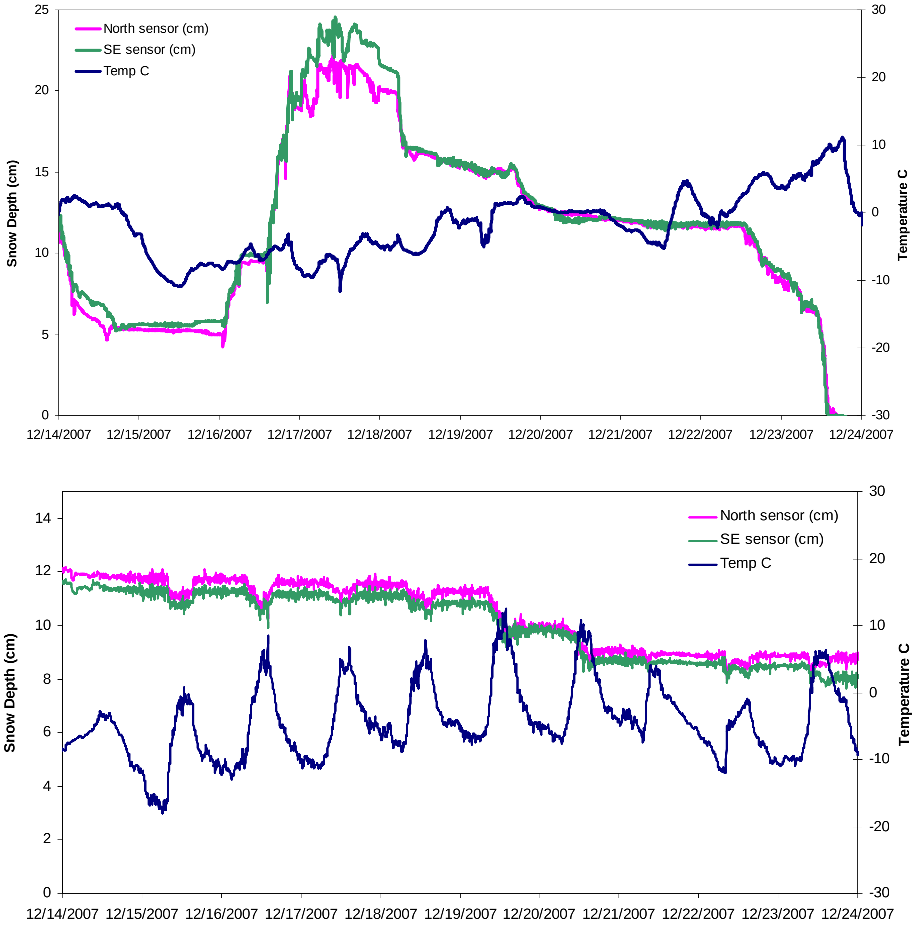

Figure 7: Top (a) shows BUF (elevation 218 m) data and Bottom (b) shows FCL (elevation 1525 m) data.

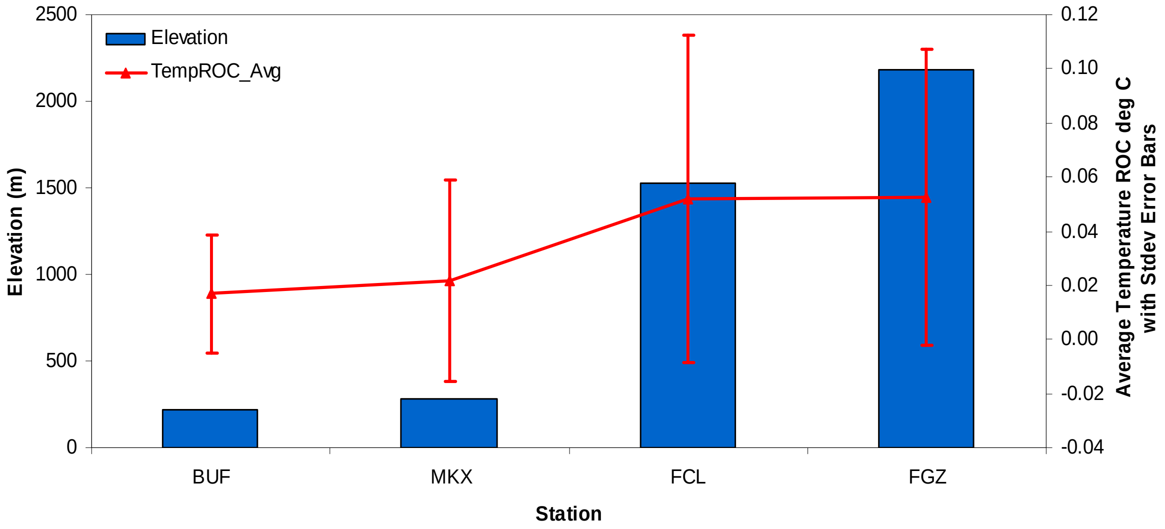

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Figure 8: Bars indicate station elevation with the line showing average temperature rate of change. Error bars are the standard deviation.

4.4 Snowfall Derivation

The derivation of snowfall from snow depth is a challenging task. Snowfall is traditionally defined as the accumulation of new snow over a specified time period, typically 6 or 24 hours. Due to “noise” in the sensor signal, processing of the data is crucial to deduce changes from new snow accumulation only. The data consists of both large scale “spikes” and small scale variations in the readings. The “spikes” are easily identified and removed, and they usually indicate when the sensor was unable to obtain a measurement or when high winds or blowing snow were present. The small scale variations are what cause the “false-alarms” when reporting the snowfall calculations and must be smoothed to increase confidence in our snowfall estimates. The signal processing of the data is in preliminary stages, but early results show interesting behavior.

An interesting feature of the ultrasonic snow sensor data that will aid in snowfall estimation is the Quality Number (QN). The QN is a unitless number that indicates how strong the return pulse to the sensor is compared to the original pulse sent out by the sensor The QN ranges from 0 to around -700. A measurement of good quality is greater than -210. A QN of zero indicates that a measurement was not obtained (Campbell Scientific, 2005). The main factor that reduces the quality number is the presence of snowfall (Figure 9). It is clear from Figure 9 that each time there is a snow event the QN is reduced dramatically. The exception to this is on 12/31/2007 when there is no new snow. This was a blowing snow event associated with high winds. This number will be incorporated into the snowfall algorithm in an effort to try and reduce the number of snowfall “false-alarms” and also as an indicator of blowing snow events.

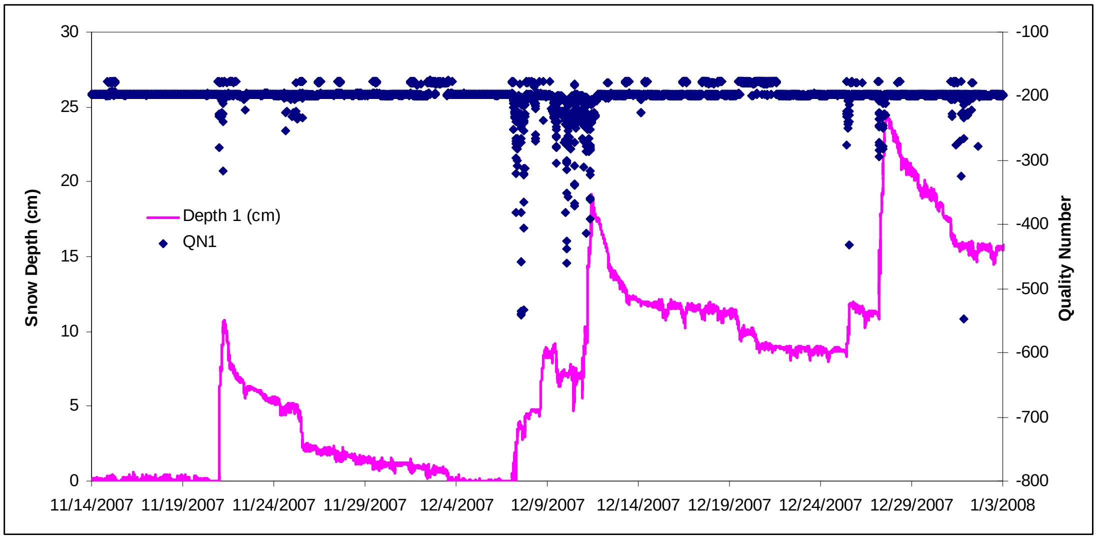

Figure 2: FCL snow depth data with quality number.

5.0 CONCLUSIONS

The use of ultrasonic snow depth sensors to automate snow measurements in the U.S. has thus far provided promising results. The siting of the sensors is critical for obtaining representative snow depth and snowfall data, especially in areas prone to wind blown snow. Favorable results were obtained from the 2006-2007 test season when comparing sensor reading to the depth of snow below the sensors, indicating that the sensors indeed measure what is below them within ±1 cm. The errors associated with the total snow depth measurement are larger due to spatial variability of the snow cover due to wind blown snow.

The derivation of snowfall is still being investigated. Progress is being made in understanding the sensor signal characteristics and how to smooth the signal so that there is more confidence in the snowfall estimates produced by the snowfall algorithm. Once a reliable algorithm is derived, it will be put through rigorous testing to see how, when and where it fails to accurately and confidently produce snowfall estimates.

6.0 ACKNOWLEDGEMENTS

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7.0 REFERENCES

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