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ULTRASONIC SNOW DEPTH SENSORS FOR MEASURING SNOW IN THE U.S.

Wendy A. Brazenec*, Nolan J. Doesken, and Steven R. Fassnacht

Colorado State University, Fort Collins, CO

1. INTRODUCTION

In the early and mid 1990s the National Weather Service (NWS) deployed the Automated Surface Observing System (ASOS) at airport locations across the U.S. The introduction of automated sensors for measuring surface weather conditions led to the abandonment or curtailment of snow measurements at many sites as there was no suitable device available for measuring and reporting both snowfall and snow depth. In subsequent years, NWS has worked to find ways to augment or supplement ASOS observations with nearby manual snow measurements at some of the nation's airports. These arrangements have been difficult to maintain and in some cases expensive. Efforts to modernize the NWS's Cooperative Observer Network are also coming face to face with the issue of snow measurement. The Cooperative Network is the nation's most extensive surface observing network capable of reporting snowfall, snow depth and water content. If the network is updated to include automated measurements, it must retain snow measurement capabilities. As a result, the NWS is now exploring technologies for automated snow measurements.

One existing technology already being used for some snow applications is ultrasound. Ultrasonic depth sensors have been in use for years to measure the depth of fluids in tanks and more recently has been applied to snow measurement. The sensors send out a 50 kHz sound pulse, measures the time it takes to return to the sensor. The ultrasonic pulse has a beam width of 22 degrees. It is important that nothing such as trees, wires, installation hardware, etc. interferes with the 22 degree cone. The time for the pulse to return to the transducer is then adjusted for the speed of sound in air based on measured air temperature, and the timing is converted to a distance via an internal algorithm. Two manufactures currently sell sensors specifically for snow depth measurements. Judd Communications® sells a fairly low cost system that has been popular for measuring deep snow environments in the western U.S. Campbell Scientific Inc® has a more expensive unit originally designed for snow measurement applications in Canada (Figure 1). The Judd sensor has a built-in temperature probe and radiation shield. A temperature probe and radiation shield must be purchased separately for the Campbell SR-50 sensor. Other snowdepth measuring devices and technologies may exist, but these two systems were readily available here in the U.S. and reasonably priced. But do these new sensors measure and report snow in a manner that accurately depicts true snow accumulation, and do they compare favorably to traditional manual snow measurements used for many climate applications? This paper describes the results of a recent comprehensive test and evaluation of ultrasonic technology and presents results from a variety of locations and weather conditions across the country.

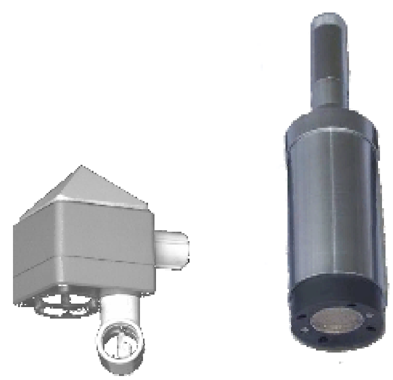

Figure 1. Judd (left) and Campbell Scientific (right) ultrasonic snow depth sensors (from Judd, 2005 and Campbell, 2005).

2. DATA AND METHODS

Several ultrasonic snow depth sensors (USDS) and data logging systems were purchased and distributed to selected National Weather Service Offices and Cooperative Network observers. Manual and automated data from Judd sensors were collected during the 2003-2004 snow season from 4 sites: Flagstaff, AZ, Fort Collins, CO, Stove Prairie, CO and New Brunswick, OH. For the 2004-2005 season, 11 additional sites were added (Figure 2). Nine sites had side-by-side measurements with both Judd and Campbell instruments. The other sites had only one or the other. Each site equipped with electronic USDS also agreed to take 6 and 24 hour manual measurements of snowfall, snow depth, snow water equivalent and gauge precipitation. An example site is shown in Figure 3. Additional measurements were taken of elements such as temperature, snow crystal

* Corresponding author address: Wendy A. Brazenec, Department of Department of Forest, Rangeland and Watershed Stewardship, Colorado State University, Fort Collins, CO, 80523; email: wab134@cnr.colostate.edu

type, wind speed, and visibility to see what factors may influence USDS performance.

Figure 2. Site map showing locations of sites where ultrasonic snow depth sensors were installed and compared to manual observations.

Figure 3. Site configuration of the Judd and Campbell sensors and manual observations in Buffalo, NY.

3. PERFORMANCE CHARACTERISTICS OF USDS OVER A RANGE OF WEATHER CONDITIONS

Data from all sites were examined and compared to manual observations. The USDS occasionally produced spurious data (Figure 4). In most cases, meteorological conditions could explain such data. The situations that resulted in degraded data quality from the sensors included extreme cold (temperatures below -20°C), blowing snow, heavy snow, dendrites and large conglomerate snow crystal, and high winds. Heavy snow and blowing snow attenuated the sound wave resulting in less reliable return signals. Dendrites and conglomerate crystals produced a soft and uneven snow measurement surface that sometimes caused ambiguous return signals. High winds, even with no snow on the ground, resulted in lost return signals at times, and this appeared to be related to how firmly mounted the USDS's were. The cause of failure at cold temperatures is not known but has been shown to be a problem with these sensors in the past. Fortunately, spurious high-amplitude data fluctuations typically occurred very briefly, even during adverse weather conditions, so that overall snow accumulation patterns could still be tracked in reasonable detail.

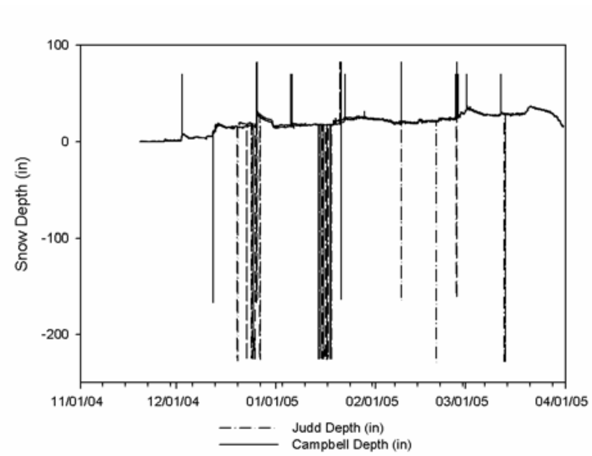

Figure 4. Example of high amplitude variability in sensor data from Marquette, MI.

One very important observation throughout this study was the fact the USDS output is not totally stable. Even with no snow on the ground and perfectly smooth and even snow measurement boards for calibration, fluctuations in signal output were common (Figure 5). These fluctuations averaged several tenths of an inch, especially for the lower cost Judd units. And while these fluctuations did not interfere with tracking of general snow depth patterns, they did become a problem in the computation of estimated snowfall from changes and rates of changes of snow depth over short time intervals.

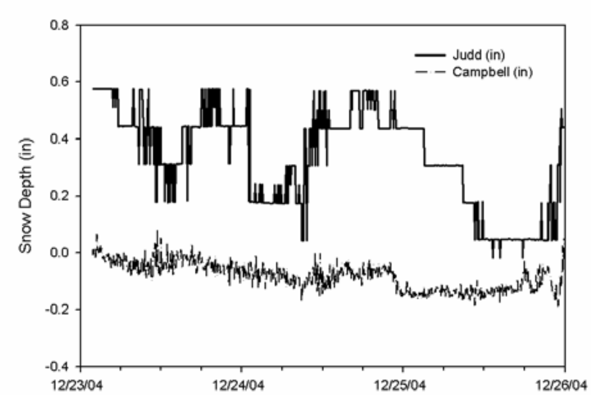

Figure 5. Example of small amplitude variability from Milwaukee, WI during a snow-free period.

4. COMPARISON WITH MANUAL MEASUREMENTS

Ultrasonic snow depth sensor data were compared to manual measurements taken at two locations: 1) manual measurements taken immediately adjacent to the USDS snow boards and 2) manual measurements (including an average of multiple measurements when the snow surface was uneven) taken at the traditional observing location which may be 10 to 100m away from the USDS installations.

At most sites, manual measurements and ultrasonic depth measurements compared very favorably especially when compared to the adjacent depth measurements (Figure 6). Mean differences between manual and automated measurements over the entire 2004-05 winter season were only on the order of a few tenths of an inch. Manual measurements were often slightly higher, especially when compared to the observations from the standard observing site at each station. Large differences were often associated with storms where high winds and drifting were an issue. Not surprisingly, station configuration, siting and how firmly the USDS's were installed were all important to assure representative data.

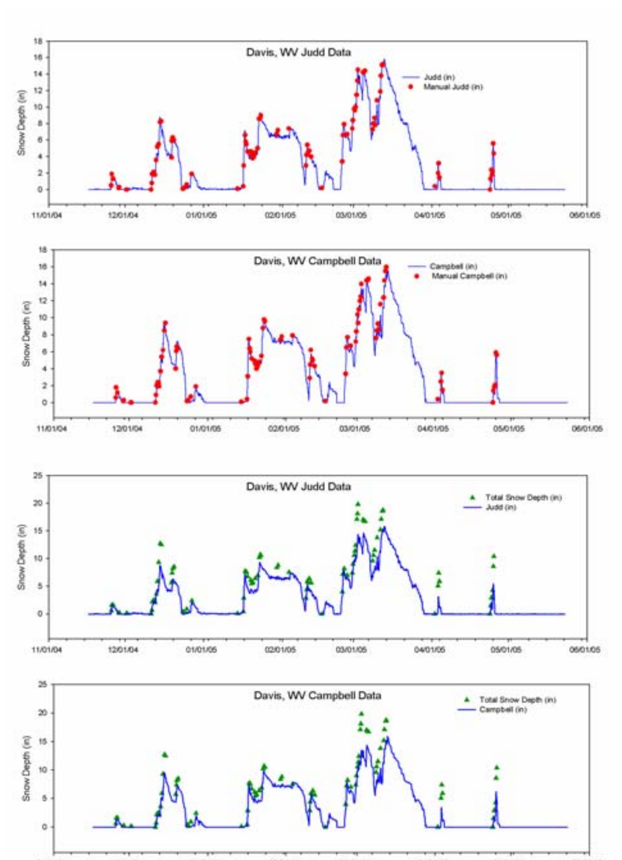

Figure 6. Example of Davis, WV of sensor vs. manual depth at sensor shown in red (top two figures) and sensor vs. total snow depth shown in green (bottom two figures).

5. ESTIMATING "TRADITIONAL" SNOWFALL FROM SNOW DEPTH OUTPUT

For many snow-related applications, there is a desire to derive incremental snow accumulation (snowfall) data from changes in observed depth. Using data from both sensors, algorithms were developed, tested, and compared which summed incremental changes in observed snow depth from the USDS and compared those to 6-hour observed manual snowfall totals (Brazenec, 2005). Because of small amplitude variations in the output of USDS, two degrees of data smoothing were required. Both a one hour moving average (1HRMA) and three hour moving average (3HRMA) were applied to both sensors. Snowfall was calculated by taking the change in snow depth over five minute periods (5MSA) and summing the positive values over the six hour observation periods. Each calculation of snowfall was then run through compaction routines (Jordan, 1991) for both metamorphism and overburden. Comparative results of observed and estimated cumulative snowfall for the 2004-05 winter season are shown in Figure 7. Both USDS's were prone to occasional false reports. Cumulative snowfall totals were sensitive to the degree of data smoothing.

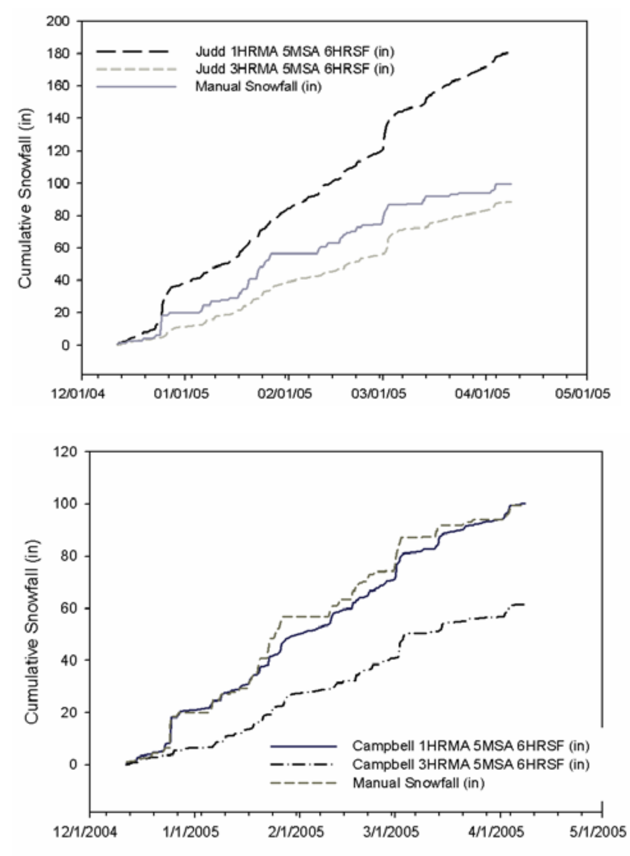

Figure 7 Results of 5MSA to estimate seasonal snowfall from continuous measurements of snow depth for Buffalo, NY. Top is Judd sensor, bottom is Campbell sensor.

6. CONCLUSION

Ultrasonic depth sensors appear to track total snow depth very well. Standardizing instrument siting will improve data quality, but there will be periodic brief periods during heavy snow and/or blowing snow situations when accurate data will not be provided. High frequency small amplitude noise is inherent to this technology, and is an impediment to computing accurate snow accumulation estimates in real time, especially if increments of 0.1 inches are required. Nevertheless, this technology and the existing sensors already available to the NWS have the potential to greatly improve snow monitoring and our understanding of snow accumulation, settling and melting.

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