ULTRASONIC SNOW DEPTH SENSOR ACCURACY, RELIABILITY, AND PERFORMANCE

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ABSTRACT

The Natural Resources Conservation Service Snow Survey Data Collection Office (DCO) in Boise, Idaho began installing Judd Communications Snow Depth Sensors in the late-1990s. Since that time the number of SNOTEL sites in the DCO with snow depth sensors has increased to 76 out of a total of 117 sites. Over the years 348 depth sensor ground truth measurements have been made each time snow water equivalence was measured at a site. Telemetered SNOTEL snow depths compare very well with manually sampled depths with a high degree of accuracy (R^2 = 0.98). To test the reliability of the sensor during the accumulation phase of winter, hourly data between 12/1/2007 – 3/20/2008 were analyzed to determine the number of missed measurements (full-scale readings). Results showed that out of 228,798 hourly readings, 14% were full-scale. No clear relationship was found between the age of the depth sensor and its reliability; more research is needed in this area to determine the optimal replacement age. In 1999 the Idaho DCO began editing daily snow depth data. This editing process has provided an opportunity to observe the performance of depth sensors. Case studies from individual SNOTEL sites were collected during the winter of 2007-2008 that illustrate performance issues that were experienced. Performance related to damaged transducers, transducer obstruction, wind effects, sensor misalignment and storm effects are discussed.

INTRODUCTION

The Idaho Data Collection Office (DCO) began installing Judd Ultrasonic Snow Depth Sensors (USDS) at SNOTEL sites beginning in 1998. Since then the sensor has been deployed at 76 of 117 SNOTEL sites in the Idaho DCO network. It is considered a standard sensor and is being installed at all new sites and there is an effort under way to upgrade sites without the sensor as resources allow. Hourly snow depth data are collected. The first of day readings (generally midnight) are edited and quality checked. The USDS are mounted above the snow pillow at heights ranging from 2.8 - 6.8m dependant on the maximum snow depth that accumulates at the site. This paper investigates the accuracy, reliability and performance of USDS in the Idaho data collection network.

ACCURACY

Previous studies such as Goodison, et al. (1984, 1988) and Bergman (1989) studied the accuracy of similar ultrasonic snow depth sensors that preceded the Judd Communications instrument which the NRCS currently uses. These early studies compared the telemetered depth sensor measurements to manually sampled depths at controlled locations over one or two winters and found excellent correlation (R^2 = 0.96 – 0.99). This study explores how well Judd USDS measurements compare to manual snow observations from remote field sites over the entire lifespan of the instrument as deployed by the Idaho DCO over the past ten years (1998-2008). 348 sample pairs at 48 different sites were used to compare the depth measured during ground truth trips to the Judd measurement recorded through SNOTEL. Figure 1 illustrates that the Judd sensor snow depth agreed with manually measured data with a high correlation (R^2 = 0.98).

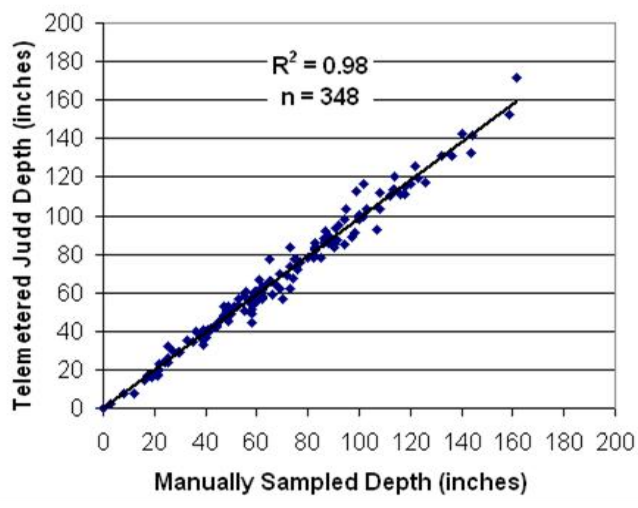

Figure 1. Manually sampled snow depth vs. telemetered Judd snow depth for 348 ground-truth pairs

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RELIABILITY

Reliability of the USDS was calculated by comparing the percent of measurements that are unreliable (full scale) versus the total number of measurements. To understand what produces a full scale measurement, it is important to be familiar with how the sensor operates. USDS utilize a transducer that sends a sound pulse to measure the distance from the sensor to the snow; this measurement is corrected for air temperature using a thermocouple attached to the underside of the sensor. The snow depth is calculated by subtracting the distance from the sensor to the snow from the height of the sensor above the bare ground. During each measurement cycle two initial measurements are made by the USDS. If the difference between the two distances is less than 1 centimeter, then the second sample is saved, and output. If the difference between the two samples is greater than 1 centimeter, then the oldest sample is discarded and another measurement is made and compared to the saved measurement. This retry algorithm continues up to a maximum of ten times. When a valid measurement can not made, or no echo is returned, the Judd senor outputs a zero value. Subtracting a zero output from the sensor height gives a full-scale reading equal to the sensor height; this is the most common erroneous reading that users observe. Due to the internal error checking, it is assumed that a non-full scale measurement provides a reliable measurement.

This study analyzed sensor reliability based on hourly data collected between 12/1/2007 – 3/20/2008 at 76 SNOTEL sites. The analysis determined that out of 228,798 hourly measurements, 14% or 28,455 were full-scale (Figure 2). Figure 3 indicates that the majority of sites (40 out of 76) recorded less than 5% full-scale readings for the period. The majority of full-scale readings (54% or 15,520) came from 10 sites; this is mainly due to the Idaho DCO's policy of not making site visits to repair only snow depth sensor problems unless there is also a problem with the snow water or precipitation measurements. The occurrence of full-scale measurements ranged none at Smiley Mountain SNOTEL to a high of 90% at Bunchgrass SNOTEL (Figure 5). Overall these results show a high degree of reliability considering that most of the full scale readings came from a minority of sites.

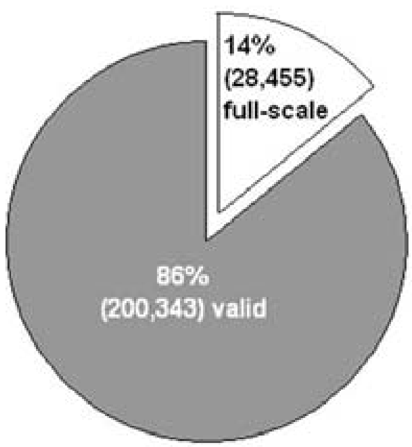

Figure 2. Percent of full-scale snow depth readings for hourly data from 76 SNOTEL sites from 12/1/2007 to 3/20/2008

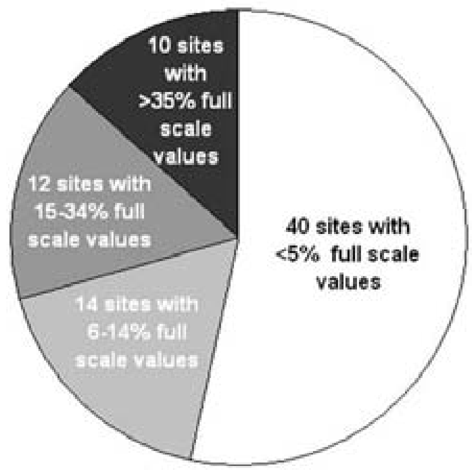

Figure 3. SNOTEL sites sorted by percent of full-scale snow depth readings using hourly data from 76 SNOTEL sites from 12/1/2007 to 3/20/2008

These data were also sorted by the year the sensors were installed to see if older sensors were less reliable than newer ones (Figure 4). No clear relationship was found between the age of the depth sensor and its reliability; however the analysis only looked at current sensors and did not look at sensors that have already been removed or at data from previous years. From personal communication with Dan Judd, he has observed that different production runs have had components with differing performance issues. This may explain some of the variation between years. More research is needed in this area to determine if there is an optimal replacement age.

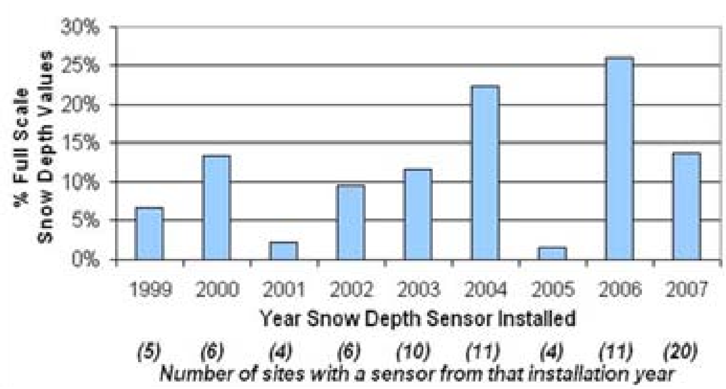

Figure 4. Percent full-scale depth readings per install year using 12/1/2007 - 3/20/2008 hourly snow depth data from 76 SNOTEL sites (n = ~2650 readings per site)

PERFORMANCE CASE STUDIES

Unreliable USDS measurement can result from a number of causes. The Judd USDS manual (Judd, accessed 2008) states the most likely causes of erroneous measurements include: the sensor is not perpendicular to the target surface, the target is small and reflects little sound, the target surface is rough and uneven, the target surface is a poor reflector of sound such as low density snow (< 5%), the transducer is obstructed by ice or debris, and strong winds are blowing the echo out from under the sensor. The Idaho DCO has experienced performance issues stemming from a number of these, below are example that illustrate them.

Damaged Transducer

Transducers can be damaged in a wide variety of ways. Figure 5 provides three examples of damaged transducers that have been removed from sites. As the transducer fails, full scale readings often become more common. As the sensor fails there are generally enough valid readings to estimate daily snow depth changes by looking at hourly data.

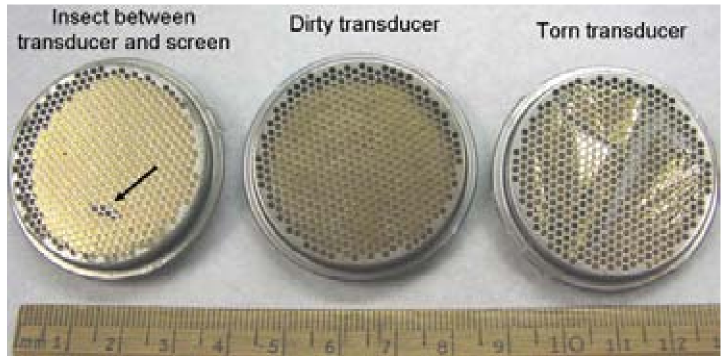

Figure 5. Examples of damaged transducers

Transducer Obstruction

Snow building up on the thermocouple located near the transducer can obstruct depth measurements. This was observed at Quartz Peak SNOTEL (Figure 6). Once the snow was knocked off the thermocouple, the sensor began functioning well again.

Figure 6. Judd USDS close-up (left), Quartz Peak SNOTEL depth sensor with snow build-up on thermocouple that obstructed the transducer (right).

Wind Effects

Strong winds have been cited as a cause of erroneous measurements (Judd, accessed 2008). Brazenec (2005) noted wind speeds in excess of 15 mph were a main cause of poor performance. The winter of 2007-2008 brought multiple wind events to Idaho, closing roads throughout the state because of drifting snow. One of strongest wind events occurred from February 5 - 8, 2008. This event occurred during a relatively dry period that followed a very snowy period, in other words conditions were ideal for wind transport of snow. While performing quality checks on data from Sourdough Gulch SNOTEL the data editor noticed indicators of snow drifting on to the pillow; specifically the pillow gained more than four times the water equivalent as the precipitation gage (2.1 inches on the pillow versus 0.5 in the precipitation gage), as well as, a total of 57 hours during a 3 day period when maximum wind speeds exceeded 15 mph. Surprisingly, the site had no full-scale snow depth readings during the wind event. The analysis was continued for all six SNOTEL sites in the Idaho data collection network that collect both snow depth and wind data. Similar results were found at all sites (Table 1). Out of a total of 170 different hours with maximum wind speeds greater than 15 mph there were 19 full-scale snow depth readings; 18 of these full-scale readings came from Secesh Summit SNOTEL, a poor performing snow depth site that on average had 25% full-scale readings throughout the winter. Maximum wind speeds at these six sites ranged from 21 – 38 mph. This case study suggests that winds between 15 - 38 mph accompanied with snow drifting near the ground surface may not be a significant cause of full-scale snow depth readings.

Table 1. Wind, snow depth, precipitation and snow water equivalence (SWE) data summary for February 5-8, 2008 wind event for six Idaho DCO SNOTEL sites

SNOTEL Site	Number of hourly readings with average wind speed >15 mph	Maximum wind speed recorded during period (mph)	Number of full-scale depth readings	SWE increase during wind event (inches)	Precipitation Increase during wind event (inches)	Snow Depth increase during wind event (inches)
Bogus Basin	13	29.2	1	0.9	0.4	4
Myrtle Creek	28	26.4	0	1	0.6	4
Long Valley	11	35.5	0	0.8	0.7	4
Secesh Summit	50	38.3	18	2.5	1.1	15
Sourdough Gulch	57	36.5	0	2.1	0.5	7
Van Wyck	11	21.6	0	0.8	0.7	4

Sensor Misalignment

Savage Pass SNOTEL – After 7 days of hourly full-scale depth readings during a dry period the depth sensor was set inactive. Later, when the precipitation gage became plugged and a site visit was made; a cap was found on the precipitation gage and the depth sensor was found misaligned, it had spun and was now pointing at the trees near the site. The sensor was realigned and the problem was corrected.

Storm Effects

Grand Targhee SNOTEL – At 9,260 feet on a western slope of the Teton Range, this SNOTEL site is exposed to the full brunt of winter including lots of precipitation accompanied by blowing snow. As of April 9, 2008 the ski resort had measured over 550 inches of cumulative snowfall at the SNOTEL site during the 2007-2008 season. The SNOTEL snow depth data indicates the sensor is more likely to yield full-scale values during stormy periods. In contrast, during dry inter-storm periods the sensor works better. Targhee's famed low density snow may also play a role as a poor reflector of the sonic pulses from the sensor. Unfortunately these explanations are a frustration to recreational users who want to see hourly powder totals adding up during storm periods.

CONCLUSIONS

Snow depth measurements made with the Judd Ultrasonic Snow Depth Sensor are highly correlated to manually measured values ($R^2 = 0.98$) using field data from ten years of sensor use in the Idaho Snow Survey data collection network. Hourly data collected during the accumulation phase of the winter (12/1/2008 – 3/20/2008) indicates that 40 out of 76 sites had less than 5% full-scale reading. Case studies supported the claims of previous studies related to the performance of the sensor; the only exception to this was data collected during the February 5-8, 2008 wind event in which sensor performance was better than expected suggesting that winds between 15 - 38 mph accompanied with snow drifting near the ground surface may not be a significant cause of full-scale snow depth readings.

LITERATURE CITED

Bergman, James A. 1989. An Evaluation of the Acoustic Snow Depth Sensor in a Deep Sierra Nevada Snowpack. Proceedings of the 57th Annual Western Snow Conference, April 18-20, Fort Collins, CO

Brazenec, W.A. 2005. Evaluation of ultrasonic snow depth sensors for Automated Surface Observing Systems (ASOS). M.S. thesis, Colorado State University, Fort Collins, CO, Fall 2005.

Goodison, B.E., B. Wilson, K. Wu, and J. Metcalfe. 1984. An Inexpensive Remote Snow-Depth Gauge: An Assessment. Proceedings of the 52nd Annual Western Snow Conference, April 17-19, Sun Valley, ID.

Goodison, B.E., J.R Metcalfe, R.A. Wilson, and K. Jones. 1988. The Canadian Automatic Snow Depth Sensor: A Performance Update. Proceedings of the 56th Annual Western Snow Conference, April 1-21, Kalispell, MT.

Judd, D. 2005. Judd Communications Online Manual. www.juddcom/ds2manual.pdf Accessed 9 April 2008.