PRELIMINARY TESTS AND EVALUATION OF A DIGITAL SNOW BOARD

Robert E. Davis[1] and Jerry Johnson[2]
Cold Regions Research and Engineering Laboratory
US Army Engineer Research and Development Center
[1]Hanover, New Hampshire
[2]Fairbanks, Alaska

Walter Rosenthal
Mammoth Mountain Ski Patrol
Mammoth Mountain Ski Area
Mammoth Lakes, California

ABSTRACT: Measurement of snowfall by automatic sensors in alpine and subalpine conditions has proven difficult. Those who require observations of snow loading have maintained regular measurement protocols using snow boards to observe the depth and density of snowfall on 24-hour and/or storm event bases. During the winter 1999-2000 we tested a prototype digital snow board that automatically senses snow fall depth and water equivalent. The system used an acoustic ranging sensor to measure snowfall depths with a resolution of about 3-5 mm up to 2 m, the maximum range allowed by the support frame. A set of three load cells measured the mass of snowfall accumulating on the active part of the board, a plate with diameter of 0.4 m within a collection area with 1 m diameter. The sensing plate had a resolution of 2.5 mm water equivalent, with calibrations indicating a finer resolution. The calibration of the sensing plate and a field calibration both indicate an accuracy of about ±4 mm SWE nominal Practitioner evaluation suggested improvements that would help digging out and dumping snow off the board, including making the system lower in overall mass and adding handles.

KEYWORDS: Snowfall, snow accumulation, snow measurements

1. INTRODUCTION

Avalanche forecasters, hydrologists and others have interest in the amount of snow that deposits during storm events. Snowfall has proven difficult to measure accurately using precipitation gages in wind-prone areas, even with substantial shielding (Yang et al., 1998). Avalanche workers often use snow plots as reference sites to assess the meteorological conditions over the area subject to avalanches (Marriott and Moore, 1984). At these sites one commonly finds snow boards, which provide an easy way to measure 24 hour snowfall and storm totals. To observe the accumulated snow, an observer measures the snow lying on top of the board, and then resets the board on the snow surface after sweeping it clean. Measured off the board, depth and density characterize snow amount at a point, the product of which yields snow water equivalent, or the precipitation quantity (WMO, 1992). Many practitioners have adopted the use of acoustic ranging devices to remotely measure snow surface height either from a snow board or from the ground (e.g., Gubler, 1984; Goodison, et al., 1988; Judd, 1993a; 1993b, Labine, 1996; Painter et al., 2000). But one must make manual measurements to obtain the water equivalent. This paper reports on the performance evaluation of a prototype "digital" snow board, outfitted with instrumentation that measured both snow depth and snow water equivalent (SWE) of storm events.

2. METHODS

The snow board consisted of a circular sensor, consisting of a plate, 1 m in diameter, with a set of braces holding an acoustic snow depth sensor 2 m above the board, as shown schematically in Figure 1. Air temperature

[1] *Corresponding author address*: Bert Davis, US Army ERDC-CRREL, Hanover, NH 03755-1290; tel: 603-646-4219; fax: 603-646-4397; email: bert@crrel.usace.army.mil

measurements from a shielded sensor provided suitable corrections to readings from the ranging device.

The initial SWE sensor design (*patent submitted*) used three load cells connected to an active plate, 0.4 m in diameter, for measuring snow mass (Figure 1). The sensor contained a side plate and side mounted vent connector to help keep the interior air pressure of the sensor equal to the outside pressure and to maintain a dry air environment inside the plate. The body of the plate also held desiccant bags to help maintain dry conditions.

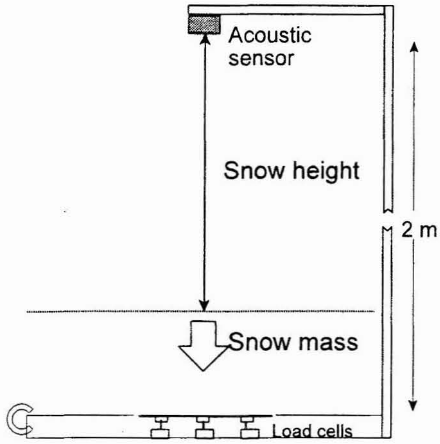
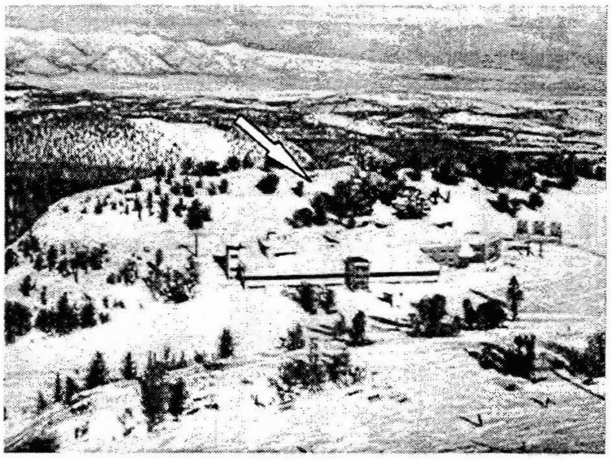


Figure 1. Schematic diagram of digital snow board.

The design used load cells selected to measure SWE to a resolution of 2.5 mm. The full scale capacity of the cells corresponded to about 3000 mm water equivalent. A data logger supplied the cells with an excitation voltage of 12 VDC, which yields load cell output in the millivolt range. Prior to snowfall we calibrated the mass sensor by placing an open ended cylinder (sheet metal) with a plastic bag over the active plate. By gradually filling the plastic bag with water, we incrementally applied a load to the active plate where the height of the water directly related to the output of the load cells. Linear fits to the calibration point allowed estimation of the zero-load voltage offsets.

During the 1999-2000 snow season we operated the digital snow board at the Mammoth Mountain cooperative snow study plot (Painter et al., 2000). This site lies in the Sierra Nevada, California, at about 2926 m elevation (37° 39'N, 119° 02'W) and at the transitional timberline. The plot occupies a terrain bench that has extensive fetch from south, through east to west-northwest (Figure 2). The site receives continual sun on clear days with no shading from terrain and only slight shading from nearby trees. Average maximum snow accumulation reaches slightly over 3 m, representing about 1000 mm of SWE by April. However, the maximum snow depth at the site can range to over 5 m, which requires substantial structures to support meteorological instrumentation.

Figure 2. Photograph of study plot on Mammoth Mountain, California. Arrow shows location of study plot.



3. RESULTS

<u>*3.1 Calibration*</u>

Calibration of the sensor showed a steady linear response to increasing height of water as shown in Figure 3. We also performed a calibration in the field by excavating snow and measuring 9 samples of snow in terms of both density and water equivalent (Figure 4). The snow accumulated a depth of 22 cm of snow with a water equivalent of 37.4 mm. This field test showed an agreement between the recorded and mean of the measured snow water equivalent to within 2 percent and the depth to within 4 percent of the total of this particular storm event.

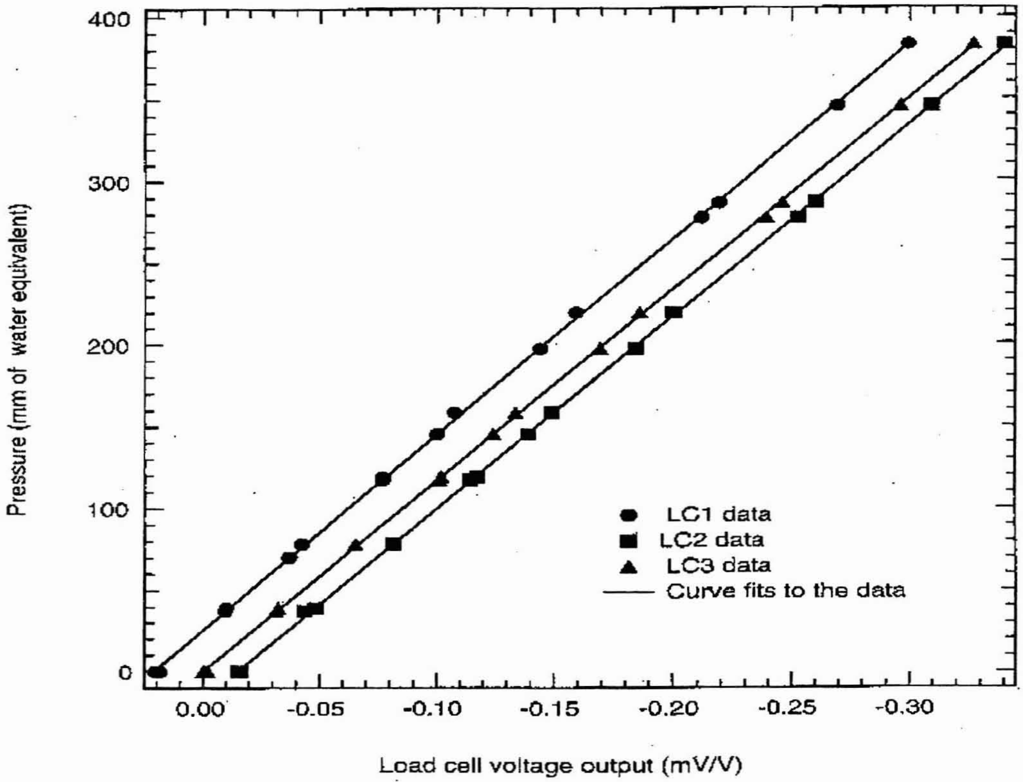


Figure 3. Results of calibration of active plate of snow sensor in digital snow board.

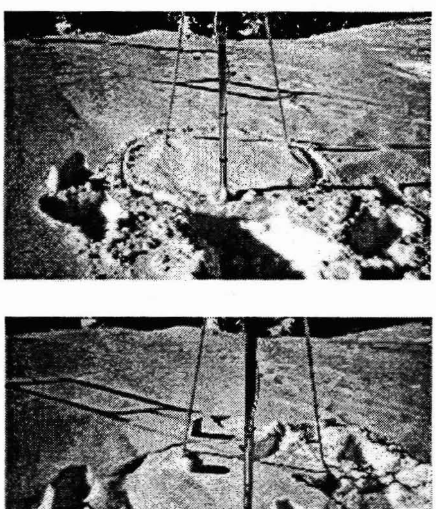


Figure 4. Field calibration of digital snow board.

3.3 Depth Sensor Noise

Unsmoothed sensor readings of snow depth over the digital board showed a diurnal cycle and ranged from 2 to 3 cm, except during periods of strong winds and blowing snow when the noise increased. This amounted to about half that seen on the master depth sensor during similar conditions, primarily due to vibrations and other movement of the tower support of the master sensor. Figure 5 shows plots of the snow depths measured by the master sensor and by the sensor over the board during the fall 1999.

3.2 SWE Sensor Noise and Drift

The SWE sensor exhibited a diurnal noise cycle, similar to the depth sensor and amounting to about 2.5 - 7 mm. Moreover, the sensor showed mass changes in snow on the board in the hours and days after storm onset. Figure 6 shows the depth signal from the board along with the SWE

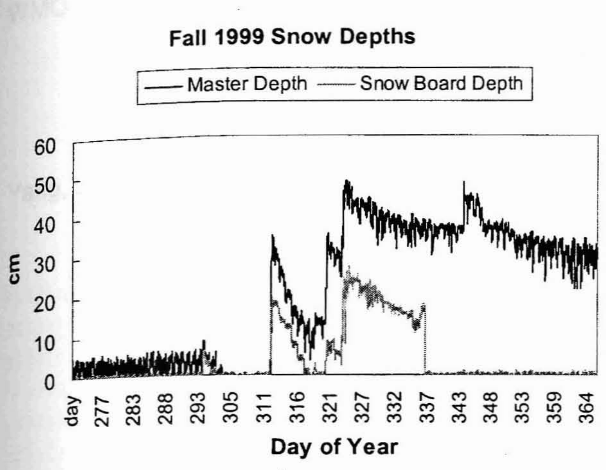


Figure 5. Snow depth measured from a master stake and over the snow board during Fall, 1999.

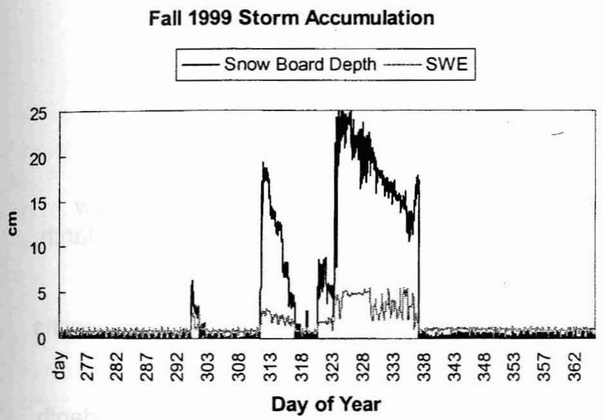


Figure 6. Snow depth and SWE over snow board Fall, 1999.

signal for the Fall 1999, the same period as for Figure 5. After both moderately sized storms, snow depth and SWE decreased until the ski patrol swept the board clean.

3.4 Overall Performance and Discussion

The seasonal cumulative snow depth and snow water equivalent agreed to within 5% with the maximum accumulation as measured by an acoustic sensors on a master stake and a snow pit at maximum accumulation. Figure 7 shows the seasonal progression of snow depth at the site, along with water equivalent measured by the snow board. The snow board registered and recorded SWE for every storm event throughout the year with no failures. Moreover, it measured several events that a nearby precipitation gage with a Wyoming shield missed entirely. Thus we feel the snow board appeared to measure a reasonably accurate record of snowfall and drift deposition at this site, given the calibration results and the field test. The decreases in SWE on the board after snowfall ended may indicate wind scour, but this requires further investigation.

As seen in Figure 7 some storms brought significant accumulation. After these storms, digging the snow board out to reset it on the snow surface proved burdensome. In this regard, operation of a device like this could improve with a reduction in the overall mass of the board and the provision of more robust handles for the operator.

4. FUTURE DEVELOPMENT

We consider the test of this device sufficient to move to another design that uses the same general concept, but that addresses some of the issues shown by these evaluations. These include the size and weight of the equipment, the diurnal cycling of the noise level and the number of channels required on the data logger. The next design iteration should have lower mass, a thinner sensing plate, a single sensor if possible and some data processing to address the noise levels.

5. CONCLUSIONS

This study carried out an assessment of a prototype digital snow board that measured snow depth and density of storm accumulation. The study showed that depth observations from 2 m over the surface have greater precision, in terms of signal to noise, than similar sensors placed on master stakes. Calibration exercises with the SWE sensor showed measurements with a diurnal noise cycle, but an overall accuracy of about ±4 mm. We feel that signal processing and some changes to the design can improve this accuracy by about half.

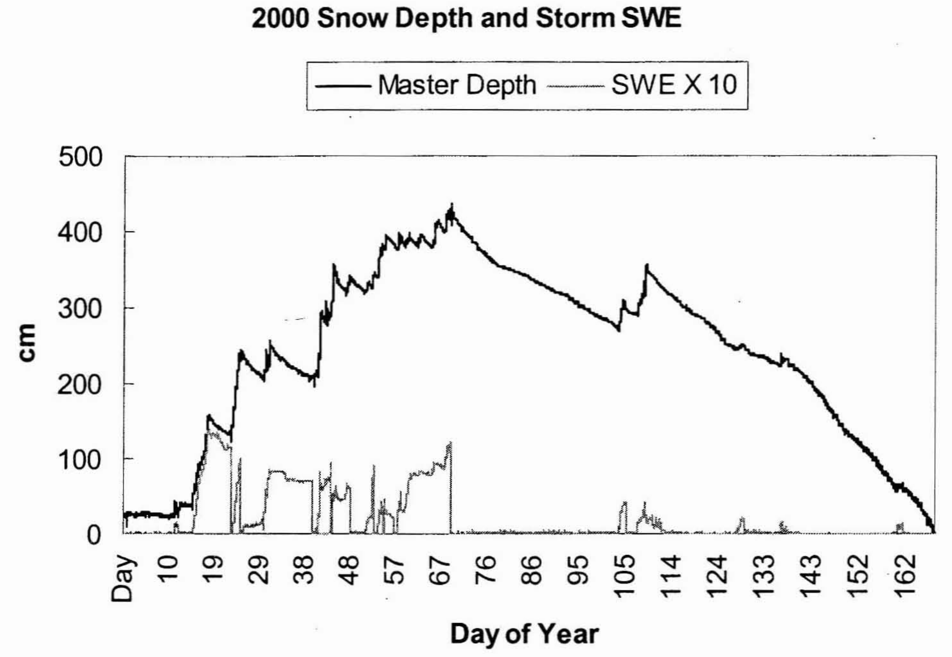


Figure 7. Snow depth from master stake and SWE from digital storm board at Mammoth Mountain, California.

6. ACKNOWLEDGMENT

The U.S. Army Project 4A762784AT42 and NASA Grant NRA-92-OSSA-1 helped fund the analytical work to evaluate developmental measurements at this study plot. We thank the ERDC – CRREL technical and research staff for designing and building sensor mounts and other specialty equipment. The US Army Engineer Sacramento District, Water Management Section (CESPK-ED-D). We also gratefully acknowledge Mammoth Mountain Ski Area and the Valentine Eastern Sierra Reserve for their support in acquiring field data.

7. REFERENCES

Goodison, B.E., Metcalfe, J.R., Wilson, R.A., Jones, K., 1988, Canadian automatic snow depth sensor: a performance update, Proc. 56th Western Snow Conference, p.178-181.

Gubler, H., 1984, Remote instrumentation for avalanche warning systems and snow cover monitoring. Proc. ISSW'84, Snow Science Workshop, Mountain Rescue-Aspen, Inc., p. 137-142.

Judd, D., 1993a, Working with ultrasonic snow depth sensors, Avalanche Review, March, 11(5), p.6-7.

Judd, D., 1993b, Depth sensors, part 2, Avalanche Review, March, 11(6), p. 6-7.

Labine, 1996, Automatic monitoring of snow depth, Proc. ISSW'96, International Snow Science Workshop, The Canadian Avalanche Center, p. 179-183.

Marriott, R.T. and M.B. Moore, 1984, Weather and snow observations for avalanche forecasting: An evaluation of errors in measurement and precipitation. Proc. ISSW'84, Snow Science Workshop, Mountain Rescue-Aspen, Inc., p. 143-154.

Painter, T.H., R. E. Davis, J. C. Dozier, D. Donahue, W. Li, R. Kattelmann, D. Dawson, C. W. Rosenthal, J. Fiori, B. Harrington and P. Pugner, 2000, The Mammoth Mountain cooperative snow study site: Data acquisition, management and dissemination, Proc. ISSW'00, International Snow Science Workshop.

WMO, 1992, Snow cover measurements and areal assessment of precipitation and soil moisture, World Meteorological Organization, Operational Hydrology Report No. 35, WMO-No. 749, 283 p.

Yang, D.Q., B.E. Goodison, J.R. Metcalfe, V.S. Golubev, R. Bates, T. Pangburn, and C.L. Hanson, 1998, Accuracy of NWS 8" standard nonrecording precipitation gauge: Results and application of WMO intercomparison. J. Atmos. Ocean. Tech., 15(1) pt. 1: 54–68.