THE USE OF ACOUSTIC RANGING DEVICES AS SNOW DEPTH SENSORS: AN ASSESSEMENT

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Introduction

Snow depth information is important in many hydrological, agricultural and forestry applications and invaluable to winter resort and snow removal operators. It is often used as a substitute for snow water equivalent data when such data are unavailable. With the trend towards increased automation at Canadian observing stations and the establishment of unmanned stations at remote locations, the Atmospheric Environment Service (AES) has a requirement for an inexpensive automatic snow depth sensor. In response to this requirement AES has been investigating the application of an acoustic ranging device as a snow depth sensor.

Acoustic ranging devices have been commercially available for some time now to measure stream height, tide level, wave height and snow depth. Until recently, these sensors were either unreliable or too expensive for network use (National Weather Service, 1985). The Hydrometeorology and Marine Division and the Data Acquisition Services Branch of AES have co-operated in the development of an inexpensive automatic ultrasonic snow depth gauge which could be used at either manned or remote stations (Goodison et al., 1984, 1985). Recently, Belfort Instrument Company developed an acoustic depth gauge (cat.no.900) one of its uses being the measurement of snow depth (Wagner, 1986).

Performance Characteristics

Different sensor designs have been used by AES and Belfort Instrument Co.in their acoustic depth sensors. Both use Polaroid Corporations ultrasonic transducer (electrostatic microphone) and microprocessor based electronics to measure the distance from the sensor to the snow surface by timing the flight of an acoustic pulse from the transducer to the target and back again. Since the speed of sound in air is highly temperature dependent, a procedure to correct the speed of sound for changes in ambient air temperature must be included in the sensor. This correction procedure is where these two sensors differ most.

The Belfort sensor consists of a sensor head/boom arm assembly and a remote processor board which can be housed in a user supplied enclosure (i.e. data logger housing) or in an optional box. Users enter parameter data on sensor height above ground, sample interval and output voltage range into the processors non-volatile RAM via a key pad and display. Various signals and power supply lines are then enabled according to the resident program execution. The primary task of this program is to establish a factor to correct the speed of sound for temperature and pressure changes. This is accomplished by using a second Polaroid transducer aimed down the boom arm which contains two targets at pre-defined distances. An acoustic pulse is sent down the boom arm and echoes from the targets are received. The timing of these two echoes has a direct relationship to current ambient temperature and pressure at the site. A second downward looking transducer is then enabled and a measurement to the ground or snow surface is made. The sensor detects targets 15-250 inches (38-635 cm) from the sensor. The measurement to the surface is corrected using the previously calculated correction factor. Snow depth is then calculated and the output analog signal of 0-5 VDC is scaled accordingly. The resolution of the measurement is 0.1 inch (.25 cm). The Belfort sensor is defined as non-interactive in that it runs asynchronously, with user selectable sample periods, to any host system and has no handshake lines. The output analog signal is available continuously where as the remainder of the system goes into a sleep mode between measurements in order to conserve power. The sensor operates on 12VDC, 50mA average at one sample per minute.

The AES sensor consists of one box which houses the transducer, sonar module, microprocessor board and a solid state temperature sensor. The box is clamped to a boom arm with the transducer downward looking to the ground. The distance between the ground and the sensor is measured to establish the no-snow baseline distance (in centimetres). This value is entered into the user selectable switch as a BCD number (eg. 400). The sensor will then proceed according to one of two modes; automatic or interactive. The automatic mode has internal software to cycle into a measurement loop once per hour, whereas the interactive mode allows a remote data logger to request a measurement via a poll request. Output as snow depth data over a range of 48-1000 cm is available as a digital pulse train where 1 pulse=1 cm, or as a 20mA current loop ASCII message. The resolution of the sensor is 1.0 cm. Correction of the speed of sound for temperature change is done by measuring the air temperature at the sensor height and using a look-up table in memory for the correction factor which is used to correct the distance to target measurement. Snow depth is then calculated and sent over respective output lines. Watch-dog timer electronics ensure recovery of the microprocessor from power interruptions which tend to hang-up proper program execution. Automatic recovery after such interruptions greatly enhances performance and reliability at unattended sites. The sensor operates on 12VDC (at 90mA) or 110VAC.

Performance Trials

A Belfort 900 Acoustic Depth Gauge (on loan from Bendix Avelex, Montreal, PQ, the Canadian distributor for Belfort Instrument Co.) and an AES Snow Depth Sensor were deployed at the Downsview, Ontario, test facility in mid-February 1987. The purpose of this test was to verify that the performance of the sensors meets the AES needs for snow depth measurement under various operating conditions. Both sensors were tower mounted 300 cm above the ground and within 3 m of each other. During the test period sensor measurements were made every 10 minutes. No precipitation fell during the trial period.

COMPARISON OF AES AND BELFORT SNOW DEPTH SENSORS
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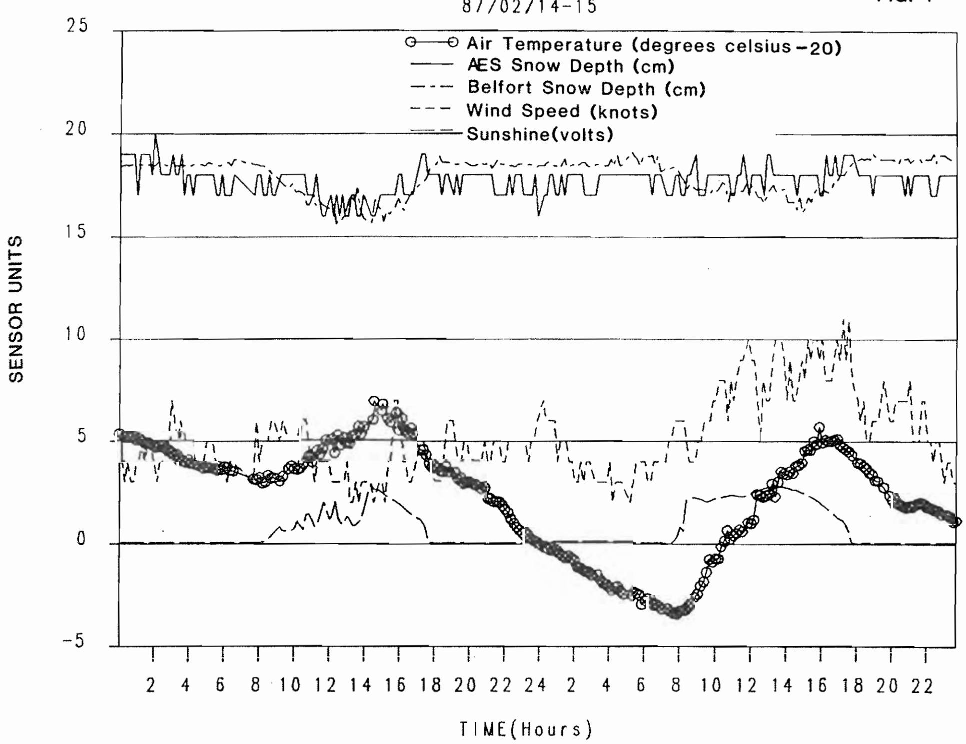
FIG. 1



Trial results (Fig.1) indicated that both the AES and Belfort acoustic sensors measured snow depth within 1.0 cm of the ruler measurement of 18.0 cm. On February 14, 1987 both sensors undermeasured by 2 cm during the daytime; the Belfort sensor also showed this tendency on February 15. It is suspected that solar heating of the sensors caused errors in the temperature correction. The magnitude of this error varies for each sensor and may also be affected by concurrent wind speed. Both sensors recovered from an AC power failure during the test period. The Belfort sensor ceased operation after 72 hours due to hardware related problems, at which time the intercomparison was halted.

Acoustic Snow Depth Sensor vs Climate Station Data

Snow depth on the ground is routinely measured at all synoptic and principal observing stations in Canada at 1200Z, and since about 1980, all climatological stations have been asked to measure daily snow depth as a standard observation. Snow depth measurements are made manually with a snow ruler. The observer uses his own judgement in obtaining a representative areal measurement at the station.

Previous testing by Goodison et al. (1985) have shown the ultrasonic snow depth sensor to be a viable method for remotely measuring snow depth. Following these initial tests, AES acoustic snow depth sensors were operated at Dorset, Ontario and Kortright Conservation Centre, near Kleinburg, Ontario during the 1986-87 winter season. Hourly measurements from the sensor were compared to daily ruler measurements taken at the nearby climate station. Figure 2 shows that acoustic depth data does replicate daily climate ruler values with few inconsistencies. Further analysis of these data (Fig.3 and 4) indicates that acoustic snow depth data are accurate to +/- 2.5 cm of ruler data. It should be noted that acoustic devices represent a point measurement as opposed to a series of ruler snow depth measurements which makes siting of this sensor crucial. Anomalies in the data were observed during periods of snowfall and/or drifting or blowing snow events; however, these data were easily quality controlled using hourly trends and snowfall precipitation data.

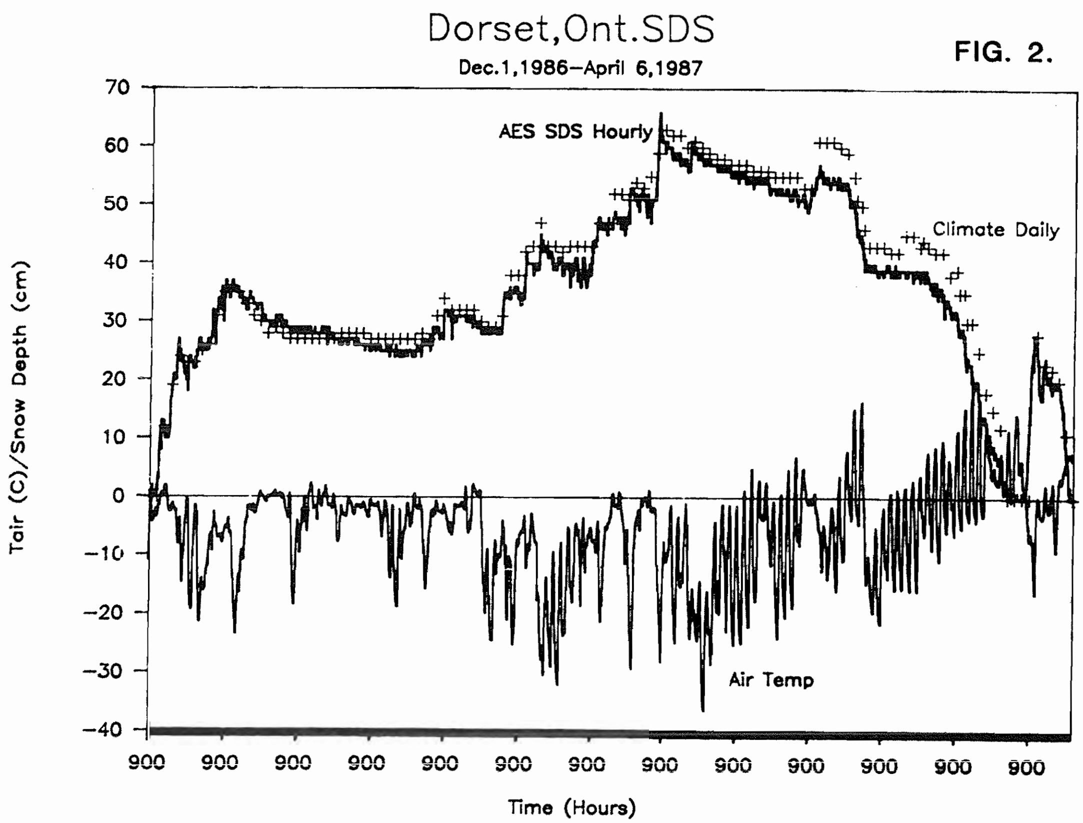


FIG. 2.

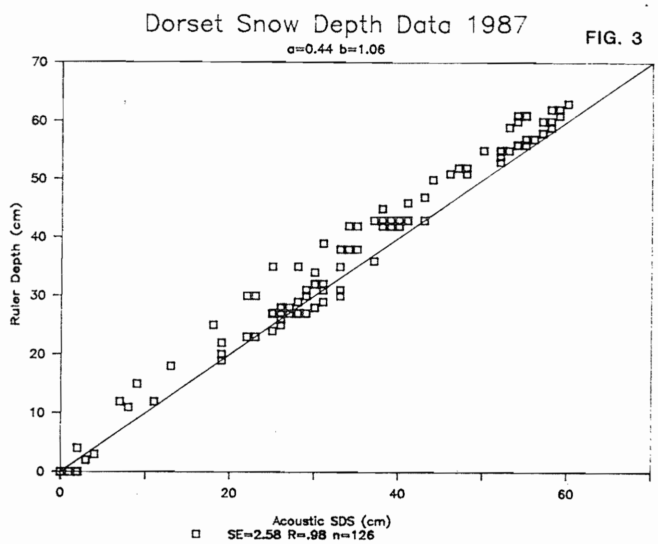


FIG. 3

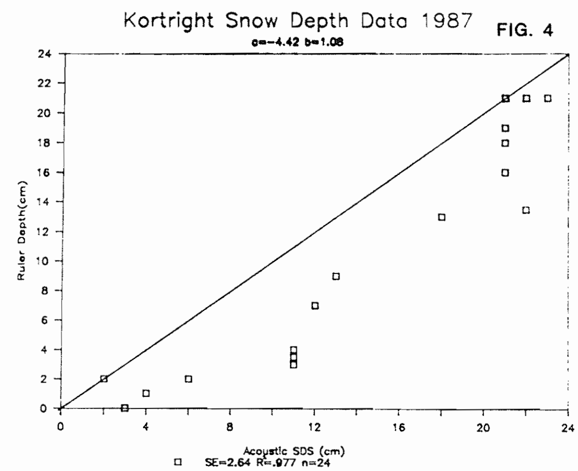


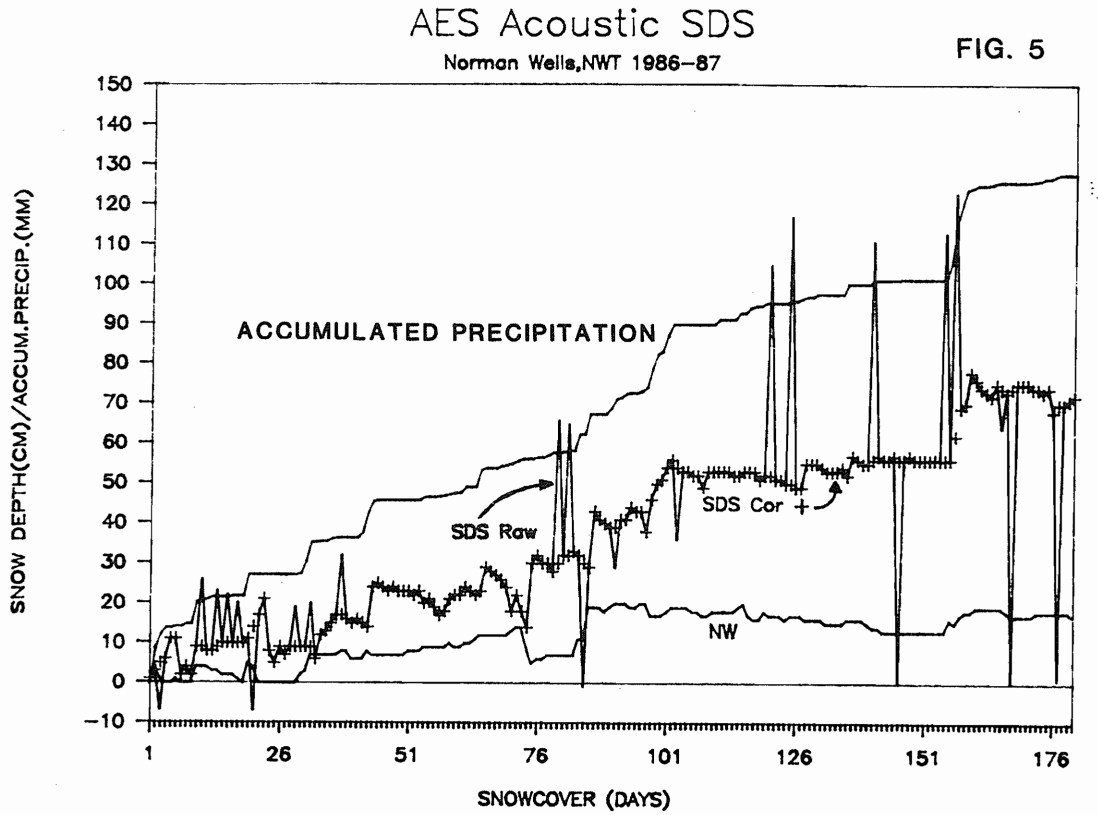
FIG. 4

An AES acoustic sensor was also operated 16 km southeast of Norman Wells, N.W.T., at a remote site along the Norman Wells to Zama Lake pipeline corridor to collect snow depth data remotely as part of a long-term permafrost and climate monitoring program in northern Canada (Etkin et al., 1987). Previous to the installation of an acoustic sensor at this site, other devices (eg. thermocouple strings) were used to determine snow depth with little success. Acoustic snow sensor readings were taken daily at midnight LST. Although coincident ruler measurements were not available on a regular basis during the season, several spot ruler measurements made at the site during the winter indicated the acoustic sensor to be +/- 1.0 cm of the actual depth at that time.

Figure 5 shows the AES acoustic sensor data before (SDS Raw) and after (SDS Cor) their quality control as well as daily snow depths from the Norman Wells airport site (NW). Although the snow accumulation follows a similar seasonal pattern at the two sites, the airport site accumulated 30% less snow than at the permafrost study site. This is to be expected when comparing snow cover at an open airport site to snow cover in a sheltered forest environment. When compared to accumulated snowfall data from the Norman Wells airport (Fig. 5), the occurrence of erroneous snow depth measurements from the acoustic sensor generally coincide with snowfall events.

Conclusions

Although the acoustic sensor represents a point snow depth, as opposed to a series of ruler snow depth measurements, in most cases, with proper siting, it provides a reasonable and accurate measurement of snow depth. For real-time or operational snow depth monitoring, data should be collected at least hourly. An ultrasonic snow depth gauge operating at a remote location in conjunction with a weighing type precipitation gauge and transmitting hourly can provide users with an acceptable estimate of snow water equivalent, as well as, information on timing and type of precipitation.



References

Etkin, D., M. Smith, M. Burgess, H. Granburg and A. Headly, 1987: A Long-Term Permafrost and Climate Monitoring Program in Northern Canada. 15TH International Conference on Permafrost, Trondheim, Norway, August 2-5, 1988. (in preparation)

Goodison, B.E., B. Wilson, K. Wu and J. Metcalfe, 1984: An Inexpensive Remote Snow Depth Gauge: An Assessment. Proc. Western Snow Conference, Sun Valley, Idaho, USA. April 17-19, 1984, 188-191.

Goodison, B.E., B. Wilson and J. Metcalfe, 1985: An Inexpensive Remote Snow Depth Gauge. Proc. TECIMO-II. WMO Technical Conference on Instruments and Methods of Observation Report No. 22, Geneva, 111-116.

National Weather Service, 1985: Performance of the Kaijo Denki Ultrasonic Snow Data Logger, Model SL-143. Internal memo, W/OTS:SMI, Feb. 25, 1985.

Wagner, N.B., 1986: Low Cost Determination of Snow Accumulation. International Snow Science Workshop, Tahoe, California, USA, Oct. 22-25, 1986.