ELECTRICAL MEASUREMENTS OF SNOW WETNESS IN UNDISTURBED SNOW

By

James A. Bergman

Abstract: Snow wetness along with other factors can directly affect avalanche potential. During 2 recent winters, the wetness of undisturbed snow at the USDA Forest Service's Central Sierra Snow Laboratory in northern California, was measured at several levels within a snowpack by using a newly developed twin-disc capacitance sensor. Wetness increases of 5 percent by volume were recorded during rain-on-snow with subsequent drainage after rain ceased. Wetness increased 2 to 5 percent by volume over the winters, depending on snow maturity. A surface diurnal melt water flux of up to 2 percent by volume wasobserved when the sensor was exposed during spring snow melt.

INTRODUCTION

The liquid water component of snow (wetness) is vital to determining avalanche conditions in mountain watersheds (Schaerer, 1981). An increase in wetness may reduce the cohesiveness of the bond between snow layers, thereby increasing slide potential on avalanche-prone slopes. Bonding between individual snow grains is partially dependent on their wetness. Snow grains tend to loose their irregularity as they mature. During this metamorphism a thin film of water develops on the surface of the ice grain when snow temperatures approach $0^{o}C$. The development of this film may weaken the bonds between ice grains and increase the potential for avalanche. When snow temperatures drop below $0^{o}C$, liquid water freezes and the strength of the snow layer increases (Langham, 1981). The strength of the bond between snow layers may decrease as the snow thaws to near freezing and the ice grains become wet, thus raising the avalanche potential in unfrozen snow. Snow wetness information is needed to assess avalanche conditions. And this information would be most useful if it were obtained from undisturbed snow.

Determining the amount of liquid water in undisturbed snow is a major problem and is complicated by slope. Currently, snow pits are needed to measure the liquid water profile of a snowpack. Excavating a pit is a tedious process and each one can be used only once. Out of necessity many pits are excavated in relatively flat or gently sloping snow fields, away from dangerous slopes. Because snow conditions are different, wetness data obtained from these types of sites may be misleading if used to indicate conditions on avalanche-prone slopes.

Sensors mounted on tall masts, on steep snow-covered slopes, may be destroyed because of snow creep before useable data can be obtained from them. Placing such sensors on gradual or moderate slopes may be possible and wetness data would be more indicative of conditions on avalanche-prone slopes.

[1]Paper presented at the International Snow Science Workshop, Lake Tahoe, California, October 22-25, 1986.

[2]James A. Bergman is a hydrologist at the USDA Forest Service's Pacific Southwest Forest and Range Experiment Station Central Sierra Snow Laboratory, Soda Springs, California.

This paper briefly describes a newly developed twin-disc capacitance sensor designed to measure the wetness of undisturbed snow at a site in the Sierra Nevada, California, during the 1984-85 and 1985-86 winters.

TEST SITE AND SENSOR DESIGN

Test Site

The test site was the USDA Forest Service's Central Sierra Snow Laboratory (CSSL) located at 2100 m elevation west of the crest of the central Sierra Nevada near Donner Summit California. At this location average winter snowfall exceeds 1000 cm with an average peak snow depth of 305 cm. The influence of the maritime climate pattern causes large snow storms of low to moderate wetness. The seasonal snowpack begins to accumulate in November, with major accumulation from January through March. Mid-winter rain-on-snow normally occurs at least once per season, mainly in December and January.

Sensor Design

A sensor was designed to measure the capacitance field surrounding a thin disc (Bergman, 1984). Simply stated, capacitance is the ratio of a charge on a positive plate of a condenser to the difference of potential from a corresponding negative plate (fig. 1). The discs are the positive side and the mast is the negative side of the sensor. The dual disc sensor measures a 30 dm^3 volume of snow, and withstands snow loads of 0.15 kg/cm^2. Ninety five percent of the capacitance field is measured between the discs and within 8 cm of the edges and outer faces of the discs.

A frequency of 10.7 MHz is used when measuring the capacitance of each sensor. At frequencies above 10 MHz, the capacitance of the sensor is not influenced by snow grain size and shape (Ambach and Denoth, 1974). Snow capacitance is measured in picofarads (pf) by resonating the sensor with a coil of known inductance, mounted on a meter that measures snow quality (Q).

Each sensor is mounted on a mast that is permanently placed in the ground. Currently, twin-disc sensors are placed at 30, 90, 150, 210 and 270 cm above the soil surface. Duplicate sensors are also located at 30, 90, and 150 cm.

Top View

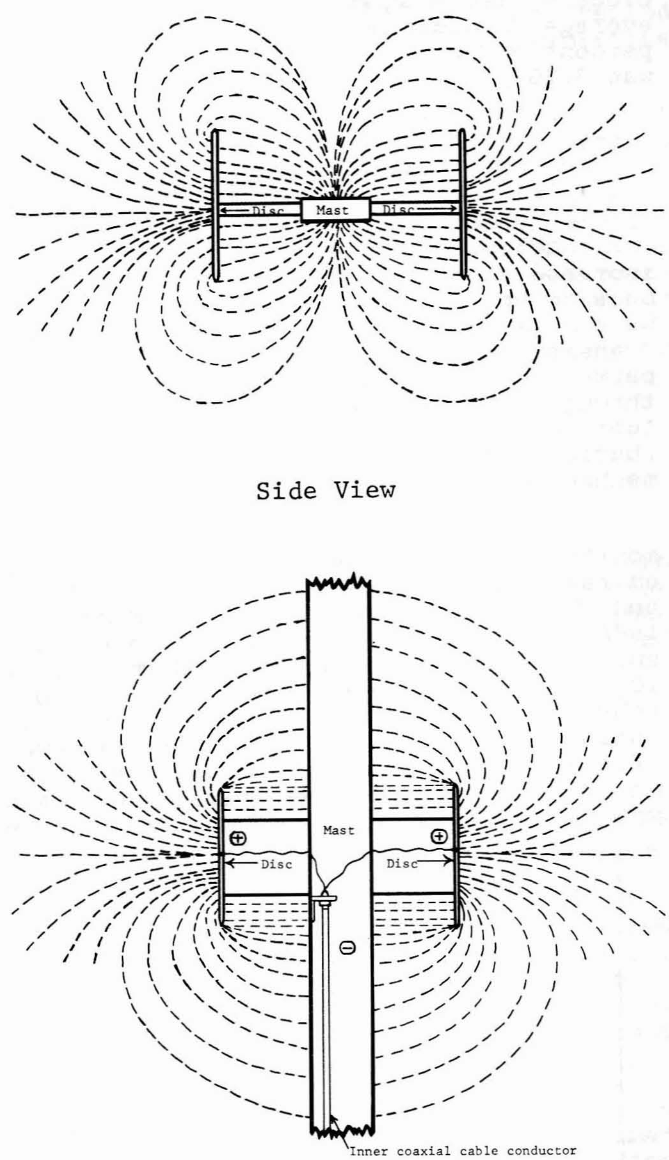

Figure 1. Three-dimensional electrical field surrounding a twin-disc sensor.

Calibration

A portable version of the sensor was used as a calibration base for all sensors (Bergman, 1986). This sensor was encased in a 64 dm^3 volume of moderately dry snow. Equal amounts of water, each equivalent to 0.5 percent volume wetness, were sequentially applied to the snow block by a small hand sprayer. Capacitance readings were obtained after each application until an equivalence of 3.75 percent volume wetness was reached. Wetness and capacitance change were closely correlated (R^2=0.99), and the average capacitance change for each 1 percent volume wetness increase in snow was 3.75 pf.

RAIN-ON-SNOW

Avalanche potential is likely to increase significantly during rain-on-snow because of the massive amounts of rain water in transit through the snowpack. Transitory water flows along less permeable lenses until it finds a path through them (Bergman, 1983). The lubrication of these snow layer interfaces (buried surface crusts) may provide the mechanism for snow release.

During the 1985-86 winter, I monitored two rain-on-snow events. A 1.9 cm rainfall occurred on December 28, 1985, and 4.5 cm of rain fell on January 5, 1986. Although these were relatively small events when compared with the usual 10 to 15 cm rain storm (the record February, 1986 rain event was not monitored due to a power outage), several of the buried capacitance sensors measured an increase in wetness caused by rain water in transit (figure 2). The sensors nearest the snow surface indicated a higher liquid water content than the more deeply buried sensors. The lessor response of the deeper sensors could have been caused by the interception and re-routing of rain water by intervening ice lenses. The diverted water flowed out of range of the sensor's detection field and was discharged elsewhere. After rainfall ceased, all sensors indicated a decrease in wetness due to snowpack drainage and post-storm wetness levels were nearly the same as those before rainfall.

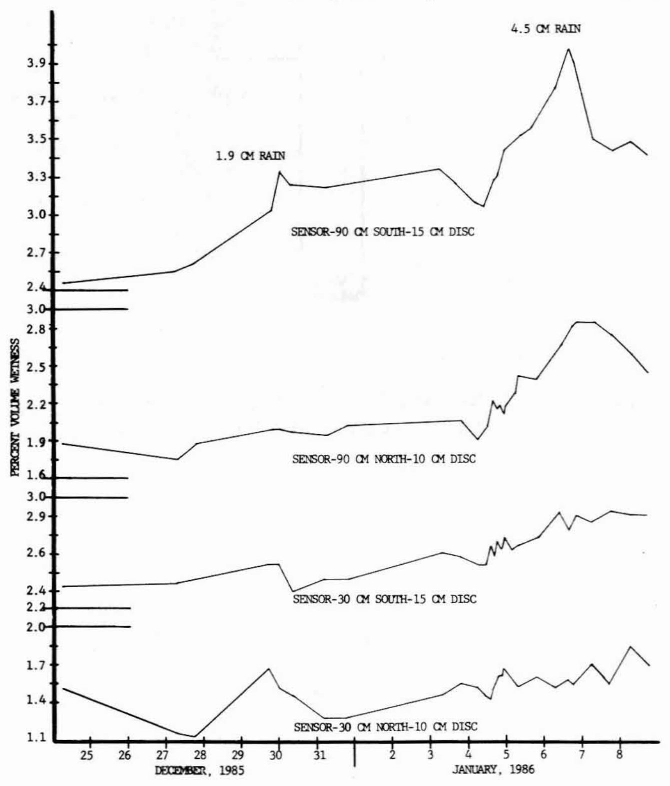

Figure 2. Response of four buried sensors to rain-on-snow events during the 1985-86 winter.

MELTWATER EFFECTS AND SNOW MATURITY

During spring melt, water enters the the snowpack in pulses caused by the diurnal freezing and thawing of the surface snow. Taken alone, the amount of water flow produced by this process would probably not trigger a snow release. But when combined with a weakened snow layer interface, the additional water flow over the fragile lens may be enough to cause a release (Kattelmann, 1984). During both the 1984-85 and 1985-86 winters, all sensors measured diurnal melt water fluxes of 0.5 to 2 percent by volume when they neared the snow surface. Surface wetness variation was measured during both mid-winter and spring melt periods (figures 3, 4). Water flow produced by early winter snow melt (December) may have a different impact than water flow caused by spring snowmelt (April). Water probably flowed through small small vertical channels and other preferential pathways in the less mature December snowpack(Kattelmann, 1985; McGurk, 1986). Because of flow channels which develop in immature, early winter snowpacks, water

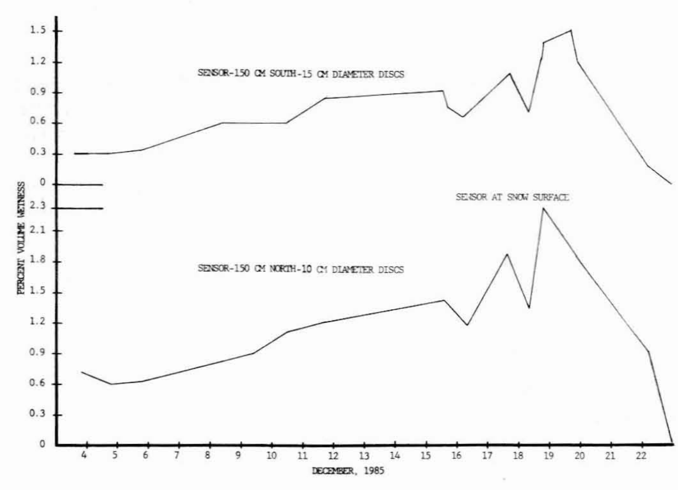

Figure 3. Response of two buried sensors to surface meltwater flux during diurnal freezing and thawing.

may flow at faster rates and affect more significantly the cohesiveness of a snow layer interface. The higher over-lens flow rates may cause a weakening of the layer boundary, increasing the potential for avalanche.

Another process affecting the flow of water into the snowpack is the gradual rise in snow wetness caused by slowly maturing snow in the absence of extreme events. Slow increases in snow wetness were indicated by buried twin-disc sensors during both the 1984-85 (Bergman, 1986) and 1985-86 winters (figure 4). All buried sensors measured a slow increase in wetness as the winters progressed, reaching maximum liquid water levels just before sensor exposure during spring melt. This slow process may affect the cohesiveness between snow layers.

CONCLUSIONS

Data collected during the 1984-85 and 1985-86 winters indicate that buried twin-disc capacitance sensors can measure gradual increases in wetness and sharp rises due to rain-on-snow and surface melt. The sensors measured snowpack drainage after each rain-on-snow event and the over-night freezing of surface snow. The laboratory calibration of a portable

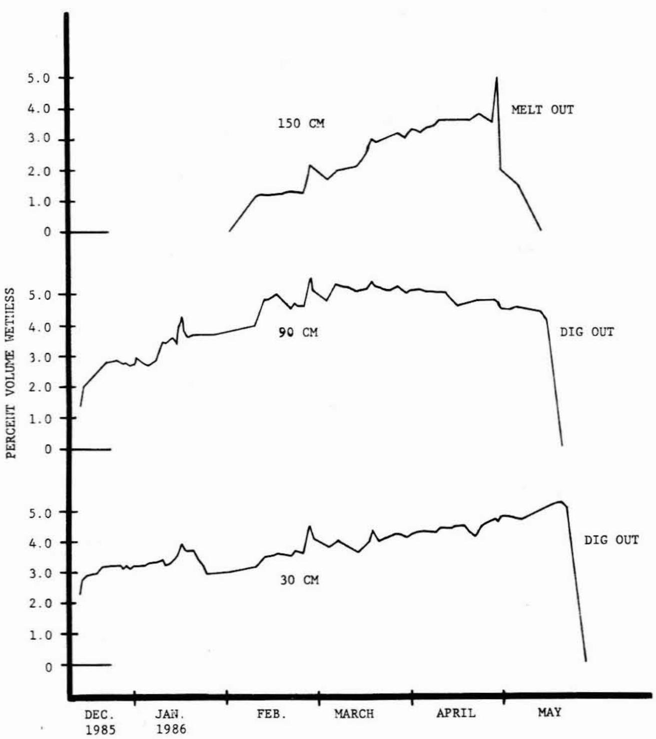

Figure 4. Snow volume wetness gradually increased during the 1985-86 winter.

twin-disc sensor indicated an excellent linear response to incremental changes in snow wetness. Data collection from additional sites and for a longer period are needed before statistical inferences can be made.

While the sensor worked well in level snowpacks, its applicability to sloping sites should be evaluated. The cost of sensor fabrication is low and on gradual slopes that do not avalanche, sensors could be placed on the snow surface after each significant storm. This placement would allow measurement of wetness at storm layer boundaries. If it is successful, steeper slopes could be tried in avalanche-prone areas.

LITERATURE CITED

Ambach, N. and A. Denoth. 1974. On the dielectric constant of wet snow. Proceedings of the International Symposium on Snow Mechanics, Grindwald. Inter. Assoc. Hyd. Sci., Publication 114, pp 136-144.

Bergman, J. A. 1983. Hydrologic response of Central Sierra snowpacks to rainfall. IN: Proceedings of the 51st Annual Western Snow Conference. April 19-23; Vancouver, WA, pp 141-144.

Bergman, J. A. 1984. A capacitance instrument for the in-situ measurement of snow wetness. IN: Proceedings of the 52nd Annual Western Snow Conference. April 17-19; Sun Valley, ID, pp 172-175.

Bergman, J. A. 1986. In-situ electrical measurements of snow wetness in a deep snowpack in the Sierra Nevada snow zone of California. IN: Proceedings of the American Water Resources Association Cold Regions Hydrology Symposium. July 21-25; Fairbanks, AK, pp 367-375.

Kattelmann, R. C. 1984. Wet slab instability. IN: Proceedings of the International Snow Science Workshop. October 24-27; Aspen, CO, pp 102-108.

Kattelmann, R. C. 1985. Observations of macropores in snow. Annals of Glaciology. pp 272-273.

Langham, E. J. 1981. Physics and properties of snow cover. IN: Handbook of Snow: Principles, Processes, Management & Use. ED: D. M. Gray and D. N. Male. Pergamon Press, Toronto. pp 275-337.

McGurk, B. J. and R. C. Kattelmann. 1986. Water flow rates, porosity, and permeability in snowpacks in the central Sierra Nevada. IN: Proceedings of the Amercan Water Resources Association Cold Regions Hydrology Symposium. July 21-25; Fairbanks, AK. pp 359-366.

Shaerer, P. A. 1981. Avalanches. IN: Handbook of Snow, Principles, Processes, Management & Use. ED: D.M. Gray and D. N. Male. Pergamon Press, Toronto. pp 475-518.