# A CAPACITANCE INSTRUMENT FOR THE IN-SITU MEASUREMENT OF SNOW WETNESS

By
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## INTRODUCTION AND BACKGROUND

Mid-winter rain on snow and excessive spring snow melt in the Sierra Nevada can pose a real flood threat to California's central valley. Existing remote sensors provide data on mountain snowpack water equivalent (SWE), but do not provide data on snowpack state of melt or liquid water content (wetness). Physical processes affecting snow metamorphosis, such as the compaction of individual snow layers, rain on snow, and mid-winter and spring melt, continuously alter the liquid-water holding capacity of snow. Tracking these layer-by-layer changes in snow wetness would provide forecasters with current information on the quantity and movement of liquid water within the snowpack. They could use this information to predict potentially excessive snowpack outflow when heavy melt or rain on snow is forecast. Information about snow wetness, combined with that on SWE and stream discharge data, would provide a more thorough outlook on the condition of the snowpack. In addition to SWE, snow wetness information is needed, especially during heavy melt and rain on snow, for more precise short-term runoff forcasts.

Freezing and melting calorimetry methods are accurate and consistent for manually measuring snow liquid water. However, these methods are destructive to the snowpack and cannot be used for determining in-situ snow wetness. More recently, methods have been developed which have the potential for overcoming this limitation. Linlor (1980) developed an electromagnetic system for measuring snow wetness by using microwave attenuation by snow. An array of transmitter-receiver pairs are set at predetermined heights above the soil. However, the snow volume measured by each sensor pair is small, and the measured snow volume is prone to settling out of view of the sensor.

The measurement of the electrical potential (capacitance) of snow has also been studied by Linlor (1980) and by Ambach and Denoth (1972). Capacitance may be defined as the property of an isolated material (conductor or condensor) that expresses its ability to keep the electrical potential low for a given charge. Snow capacitance was measured by inserting closely spaced parallel plates into the snow. The plates must be close together (<2.5 cm) to measure variations in material wetness. The parallel plate sensors work well when inserted into the snow, but they do not appear to be suitable for in-situ application. The close spacing of the plates can distort the accumulation of new snow, and the measurement volume is minimal.

This paper describes a multi-sensor instrument designed to provide an in-situ vertical profile of snow wetness by measuring the capacitance of thick snow layers.

## CONCEPT

The capacitance of each individual snow layer should be proportional to the wetness of that layer. Dry snow, as a conductor, will have a specific capacitance for a given induced charge. The ability of snow to carry an induced charge is determined by its wetness. Thus given a specific charge, the snow's potential to carry this induced charge should vary directly with the amount of liquid water in it. Snow wetness can be determined by measuring capacitance between two closely spaced parallel plates or measuring the field capacitance surrounding a thin disc.

The conceptual basis for the design described here is the measurement of capacitance surrounding a thin disc. The electrical field flux around a thin disc extends outward from the disc edge and then loops back toward the flat portion of the disc (Figures 1 & 2). Although more distorted than the illustration may show, the field is generally three-dimensional and butterfly-shaped. Within 10 diameters of the disc, 95 percent of the significant field flux is measured, and the three-dimensional induced field covers a much larger volume of snow than does the parallel plate measurement field.

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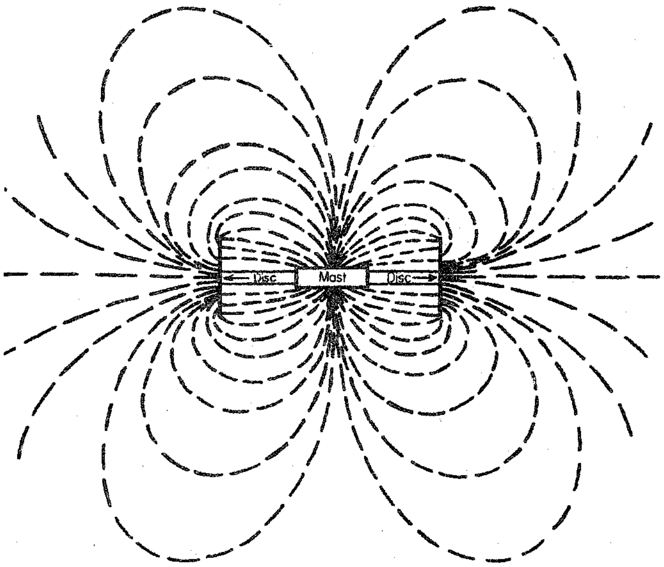

Figure 1. A dual disc sensor is surrounded by a three-dimensional electrical field.

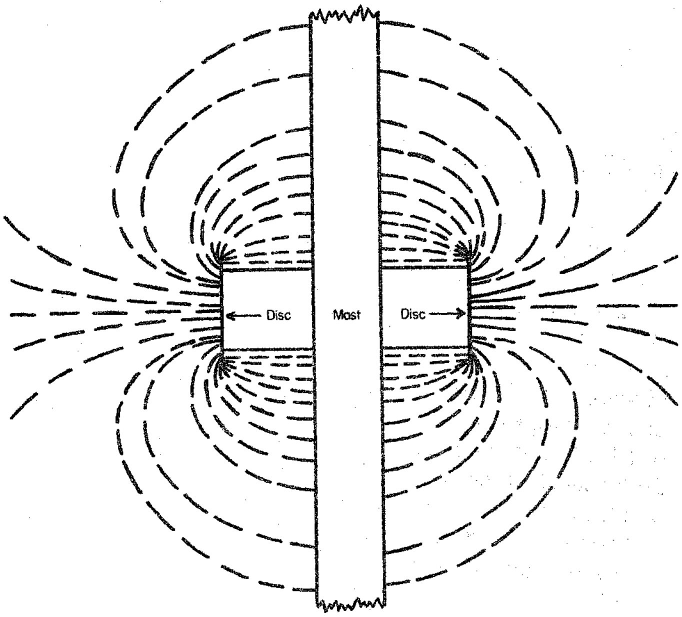

Figure 2. Side view of the electrical field that surrounds a dual disc sensor.

At 1 MHz frequencies, the detection of liquid water can be affected by grain shape and size. An intent of the large dual disc detection field is to integrate the effect of variable grain configuration on measured wetness. Because snow is not typically homogenous, one particular grain size or shape should not dominate the measured field.

## SENSOR DESIGN

A dual aluminum disc sensor was designed to measure about 22,000 $cm^3$ of snow, in two opposing views (Figures 1 & 2). Each disc is 10 cm in diameter and 3.1 mm thick. Beginning at 30 cm above the soil surface, eight disc pairs were mounted 61 cm apart on a 5-meter high aluminum mast. The discs are electrically isolated from the mast by 10-cm by 2-cm acrylic spacers. Sensors are spaced so that the measurement field between each sensor pair overlaps by 15 cm.

The capacitance field around each sensor pair is measured by a Hewlett/Packard "Q" meter with adjustable frequency ranges. Capacitance is measured at a specific frequency by using an induction coil whose range spans the given frequency, in this case $5.4 \times 10^5$ Hz. Capacitance, in picofarads (pf), is measured when each sensor is balanced with the induction coil. A change in snow wetness is indicated when there is a ±2 pf capacitance change between measurements.

Separate high impedance coaxial cables connect each sensor pair. Since the length of the transmission line may affect the validity of the capacitance values, their effect had to be determined. The standing wave ratio (SWR) of a transmission line should be less than 0.25 λ (wave length). Any SWR greater than 0.25 will cause distortion of the capacitance values.

Wave length and SWR are computed by:

$$\lambda = \frac{\text{Wave Velocity in Vacuum (V)}}{\text{Measuring Frequency (F)}} = \frac{V}{F} = \frac{3 \times 10^8 \text{ m/sec}}{5.4 \times 10^5 \text{ Hz}} = 560 \text{ meters} \qquad (1)$$

$$SWR = \frac{\text{Transmission Line Length (TL)}}{\text{Wave Length } (\lambda)} = \frac{TL}{\lambda} = \frac{8.3 \text{ m}}{560 \text{ m}} \text{ to } \frac{12.6 \text{ m}}{560 \text{ m}} = 0.015 \text{ to } 0.023 \qquad (2)$$

These SWR values are considerbly below the 0.25 limit and indicate that no distortion of measured capacitance will be caused by transmission line length.

## SENSOR CALIBRATION

Disc fabrication was of such quality that the calibration of one dual disc sensor was intended to be representative of all units. Calibration consisted of the insertion of a dual disc unit, attached to a 76 cm long portion of mast material, into a cubic meter square box of fine kiln dry sand. Measured amounts of water, in increments equal to 1.7 percent by volume, were added to the sand until maximum detectable wetness was reached. After each incremental addition, the admixture was stirred to evenly distribute the moisture. Capacitance measurements were obtained until it was felt that sensor variation and instrument drift were accounted for (Table 1). Sand wetness appeared to be relatively proportional to capacitance change. Sand calibration wetness values and a predicted wetness curve from linear regression were plotted (Figure 3). Although simple linear regression produced a reasonably high correlation (r=0.90664), this relatively linear relationship may not continue for the higher wetness values.

Table 1. Calibration of dual disc sensor in sand.

| Wetness vol. pct. | Meas. | Mean $\bar{x}$ (pf) | Capacitance Change pf | Std. Deviation $S_x$ | Std. Error of Mean $S_{\bar{x}}$ |
|---|---|---|---|---|---|
| 0 | 5 | 444.6 | 0 | 0.07483 | 0.03347 |
| 1.73 | 6 | 422.5 | 22.1 | 0.37283 | 0.15221 |
| 3.46 | 6 | 395.8 | 48.8 | 1.37689 | 0.56211 |
| 5.19 | 27 | 373.6 | 71.0 | 6.22619 | 1.19823 |
| 6.92 | 61 | 361.5 | 83.1 | 6.58269 | 0.84283 |

Current "Q" meter limitations preclude measurement beyond 7 percent volume wetness in sand. However, since the mass of sand is much greater than that of snow, the wetness values obtained in sand have to be converted to snow wetness. The sand used in the calibration procedure had a density of 1.73 gm/cm$^3$. Snow, on the other hand, usually varies between densities of 0.1 and 0.5 gm/cm$^3$. A factor, obtained by dividing snow density into sand density, is used to calculate snow wetness for a specific snow density and capacitance change at each sensor level.

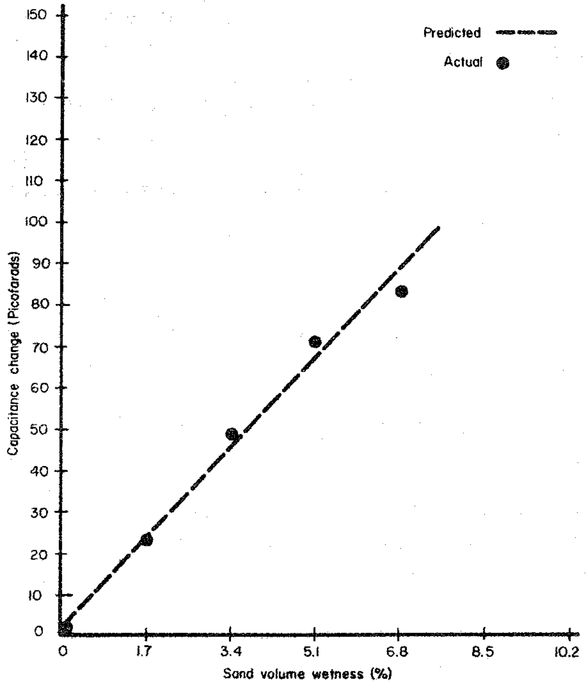

Figure 3. Capacitance and sand volume wetness were closely correlated.

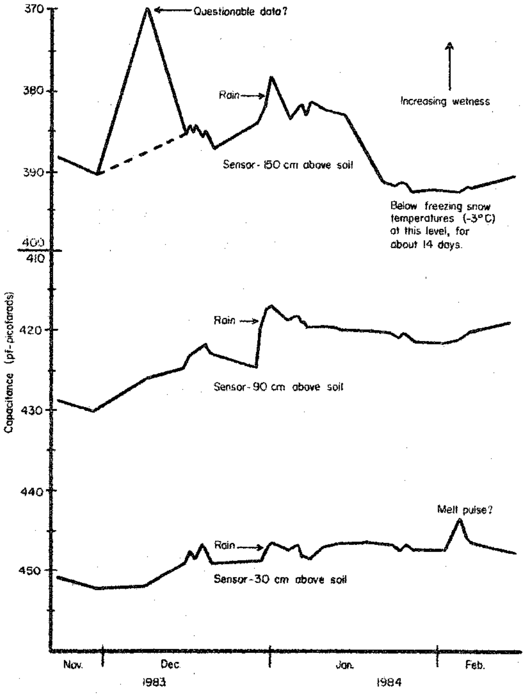

Figure 4. Capitance measurement of snow wetness varied among three buried sensors.
Note: Vertical axis reversed.

Since the calibrated disc pair is identical to those mounted on the field mast, the effect of the dielectric spacer was removed during the calibration procedure.

Due to length variation, it was necessary to standardize all eight sensor transmission lines. Capacitance change measurements were made between eight capacitors of known value. The results of the evaluation were used to normalize the effect of line length on sensor capacitance change.

## FIELD TESTING AND RESULTS

The sensor mast was installed at the USDA Forest Service's Central Sierra Snow Laboratory in late November, 1983. The Laboratory lies west of the Sierra Nevada crest at 2100-meters elevation near Soda Springs, California. The influence of maritime air masses cause winters of long duration and deep snowpacks. Snow comprises about 85% of the total precipitation. Snow storms are usually large, intense and of low wetness. Mid-winter rain on snow occurs at least once on a snowpack that reaches an average peak depth of about 4 meters.

Snow accumulation around the mast and sensors appears to be adequate. Early winter data indicated reasonable sensor response to snow melt and rain on snow. All buried sensors responded to a gradual increase in snow wetness by a decrease in measured capacitance over time (Figure 4). A stable level of wetness was indicated until rain on snow occurred on December 30 (Figure 4). After rain ceased, capacitance values returned close to their pre-rain on snow values. This type of recovery is consistent with snowpack drainage and possibly maximum snow wetness.

The effect of freezing was detected by the sensor nearest the snow surface. The disc pair located 150 cm above the soil indicated a decrease in wetness (increasing capacitance reading) during a period of very cold temperatures. Snow temperatures at this level had dropped below 0°C. When snow temperatures returned to 0°C, the sensor indicated no change in wetness. After about 40 cm of moderately wet new snow in mid-February, the sensor showed an increase in wetness, but not a complete recovery. The liquid water holding capacity of snow may change with the occurrence of freeze-thaw metamorphism and may have permanently lowered the wetness capacity of this layer (Figure 4).

## CONCLUSIONS

The sensors responded to the effects of snow melt, below-freezing snow temperatures, and rain on snow. But it is not appropriate to attach a snow wetness value to capacitance change because of insufficient data. Furthermore, no data are available for dry snow because of warm storm temperatures. Specific snow wetness cannot be determined if basal dry snow capacitance is unavailable. An alternative to dry snow capacitance may be the capacitance in air. If air capacitance is equal to that of dry snow, then this value might be substituted. Further calibration and extensive field testing are needed before a complete assessment of the potential utility of this technique can be made.

## LITERATURE CITED

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