MICROWAVE CHARACTERISTICS OF SNOW

By

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Introduction

The objective of this program is to develop a better fundamental understanding of microwave signal-snow material interaction. Microwave signals nondestructively penetrate snow, but they are modified by the material properties of snow (density, moisture content, resistance, temperature, etc.). There is a distinct possibility of developing miniaturized microwave instrumentation to remotely sense and measure those undisturbed snow properties as a function of depth.

Initial experiments were done in cooperation with the U.S. Forest Service at Berthoud Pass, Colorado, in 1973 and 1974. The experimental procedure developed for those experiments was to record an electromagnetic profile of the snow at a selected test point with a Time Domain Reflectometer (TDR). A resistance profile was then measured with a rammsonde using the standard Forest Service field equipment and data gathering and processing techniques. Finally, a pit was dug to visually characterize the snow by grain size and type, and to measure density and temperature profiles.

Experimental Approach

Electromagnetic Systems

The current emphasis is to use a variety of measuring systems to measure the microwave scattering properties of different snowpack formations (Alpine and modified deposition) in Colorado and Wyoming. All measurements are made in situ with the snow in its natural state.

A portable (toboggan mounted) FM-CW radar system was developed to measure and record profiles of snow packs down to ground level. This system was used to monitor changes in snow stratigraphy as a function of time of day. The system is continuously swept in frequency over the bandwidth 8-12 GHz. Snow depths up to 4 meters have been measured with it.

An Automatic Network Analyzer (ANA) system was also used to measure the electromagnetic scattering properties of snow at discrete frequencies over the range 500 MHz--18 GHz. The scattering properties are a function of the snow stratigraphy. These data were collected in the frequency domain and computer processed on site with a Fast Fourier Transform (FFT) into the time domain. The final output is a synthetic TDR electromagnetic profile of the snow.

Two antennas were used in all experiments; one for transmitting the incident signal into the snow and the other to receive the reflected signal. The antennas were mounted side-by-side above the snow's surface. All of the results reported here were obtained with the antennas at near normal incidence (< 5° with respect to the normal to the snow's surface).

A 500 MHz resonant cavity was used to measure the permittivity of snow as a function of snow density. The cavity is designed with a removable, constant volume, cylindrical shaped, sample holder. The holder was carefully pushed into the snow to obtain a sample in its natural state. It was then weighed to determine sample density, and finally placed into the cavity for the microwave measurement.

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Physical Analysis

In some cases electromagnetic measurements of the snow at a selected point were continued for several days. The snow was left in its natural state until the electromagnetic measurements portion of the experiment was completed. Then a rammsonde* profile was measured at the midpoint of the antenna focus spot on the snow. A pit was dug to obtain density, stratigraphy, and temperature profiles.

One experiment included a free liquid water measurement at the snow surface during the electromagnetic measurement portion of the experiment. Samples for the free liquid water measurement were collected adjacent to the area where the microwave antennas were focused.

Ambient Conditions

Global radiation was monitored during two of the experiments. The radiometers were mounted on the microwave antenna structure, at the same level above the snow surface as the antennas.

Air and snow temperatures were noted during the later experiments.

Experimental Results

The data given in Figures 1-5 are typical of that collected this year. Three field trips were made to an area near Pass Lake on Loveland Pass, Colorado, and two field trips were made to an area near Arlington, Wyoming, during this past winter. The total snow depth at the Pass Lake area built up from 110 cm for the initial experiments in January to 170 cm for the final experiments in March.

The experiments in Wyoming were done on one of the drifts which formed behind the snow fence system that was designed by the Forest Service to minimize blowing snow events on Highway 1-80. The drift depth was 310 cm during the initial experiments in February and 390 cm during the final experiments in March.

A complete sample of data for one of the Pass Lake experiments is given in Figure 1. An electromagnetic profile for the test point was measured and recorded with the FM-CW microwave system. The data shown is the actual output from that system recorded on site at that time.

Next, a resistance profile was measured at that same test point with a rammsonde. Then, a pit was dug to obtain the visual characterization, the temperature profile, and the density profile. All of the data are plotted with respect to a common depth scale on Figure 1.

An experiment was designed to monitor a point on the snow surface with the FM-CW system throughout the day to measure the changes at the surface and within the snowpack as the ambient conditions change. The surface results obtained from this experiment are given in Figure 2. The snow temperature was obtained with a thermometer that was placed approximately 2 cm into the upper layer of snow.

As shown on Figure 2, the surface dielectric constant decreased during the time 1000 until 1300 hours. There was no surface melt at that time. It is not yet understood what caused that surface dielectric constant to decrease during that time span; however, it was noted during this experiment that the density of the surface layer of snow varied also as the day progressed.

Between the hours 1300 and 1600 there was some surface melt which caused the surface dielectric constant to increase as expected. Beyond 1600 hours there was no surface melt; however, after falling to the expected low value at sundown (1600 hours), the surface dielectric constant began to increase and essentially returned to its early morning value.

Considerable activity was underway within the upper 10-20 cm of snow as the day progressed. Figure 3 is a composite of the surface reflection recorded between the hours 1130-1400.

*A commercially available device designed to detect layering within a snow pack and to measure relative hardness.

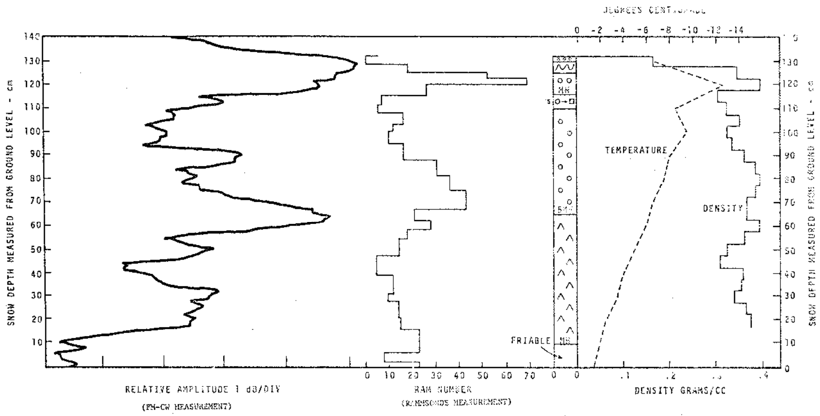


FIGURE 1. PROFILE DATA FOR A TEST SITE NEAR PASS LAKE.

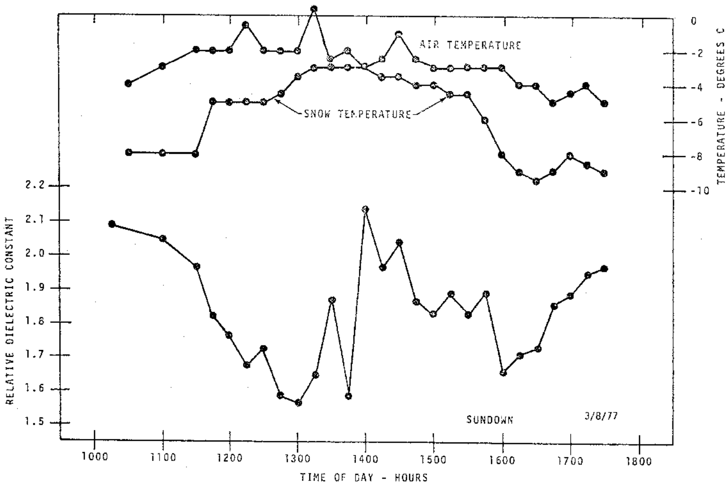
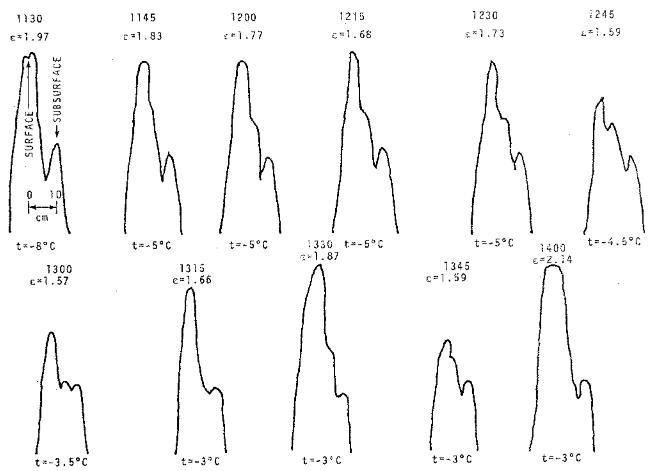


FIGURE 2. SURFACE DIELECTRIC CONSTANT AND TEMPERATURE DATA NEAR PASS LAKE



ACTIVITY WITHIN THE UPPER 15 cm OF SNOW AS ITS TEMPERATURE INCREASED

FIGURE 3. COMPOSITE OF SURFACE RETURN SIGNALS NEAR PASS LAKE.

At 1130 two surfaces were clearly measured as evidenced by the large response (air-snow interface, e = 1.97) and a smaller response which corresponds to an interface 10 cm within the snowpack. The smaller response is caused by a hard layer of snow that was found 10 cm below the surface at that point. As time progressed up to 1300 hours, it can be seen that the surface and the subsurface structure within the upper layer changed considerably, even though there was no surface melting. At 1315 and 1330 hours as shown on Figure 2, some surface melt occurred, as evidenced by the increased air temperature and the increased surface dielectric constant. At 1345 hours the temperature decreased and the surface froze, resulting in the multilayered response shown in Figure 3. Beyond that time, as Figure 2 shows, there was considerable surface melt until sundown.

Figures 4 and 5 contain all of the experimental permittivity vs. density data obtained with the resonant cavity. Also shown are lower and upper theoretical bounds that have been derived for various snow configurations. The symbol "u", called the Formzahl, is dependent upon the shape of the snow particles and their orientation with respect to the electromagnetic field. Several particle shapes are shown on Figure 4 with their corresponding numerical Formzahl. Snow particles in general are not perfect spheres--they are disc shaped, prolate spheroids, or spheroids with an indentation. The experimental data appears to fall about the curve for u = 3.5 as long as there is no free water in the sample. It appears possible to determine the density of a snowpack with this type of measurement.

Figure 5 is the loss tangent of the snow as a function of density. These data show that snow having no free liquid water is a very low loss material at microwave frequencies. The addition of liquid water to a sample increases the loss tangent significantly. It appears possible to determine the amount of liquid water in a snowpack through this type of measurement.

Figures 6 and 7 are the surface results obtained at the Wyoming test site over a two-day duration of the experiment. A global radiometer was used to monitor the solar radiation as the day progressed, and liquid water measurements were made at a site within 3 meters of the point where the microwave system was focused on the snow. These data are plotted on Figures 6 and 7. From those results it appears that there is an experimental correlation between global radiation, liquid water, and microwave response.

Figure 8 is a comparison of the microwave responses obtained in Wyoming with the FM-CW system and with the ANA. The ANA data have been transformed into the time domain with an FFT. The snow surface, the ground, and some of the strata have been detected by both systems. The FM-CW data was obtained at microwave frequencies 8-12 GHz, while the ANA data was obtained at microwave frequencies 0.24-2.0 GHz.

Summary

An FM-CW microwave system, an Automatic Network Analyzer, and a resonant cavity system were used to measure the microwave properties of snow.

Measurements of resistance, density, and temperature were measured at the selected test sites.

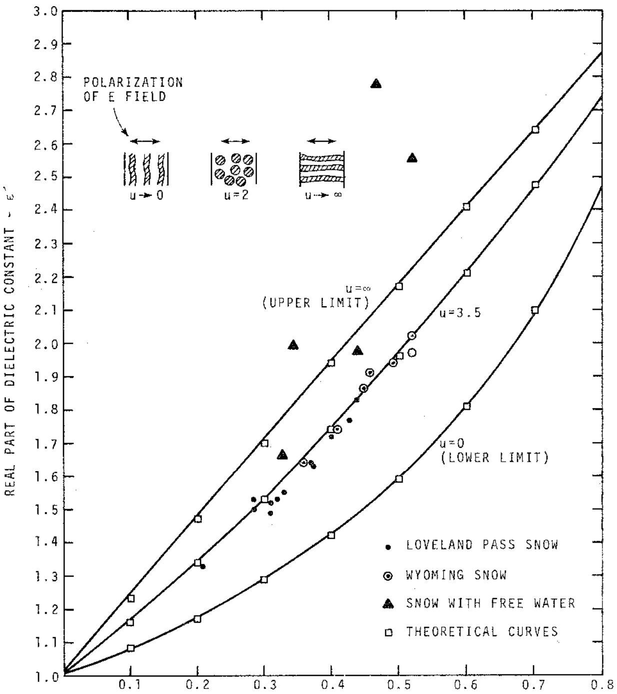
Some experiments included the measurements of global radiation and the liquid water.

All measurements were made in situ with snow in its natural freefall or wind-driven formations. Measurements were made near Pass Lake on Loveland Pass, Colorado, and on the drifts behind the snow fence system designed by the Forest Service near Arlington, Wyoming.

Strata within a snowpack was detected with a microwave system and verified through physical analysis.

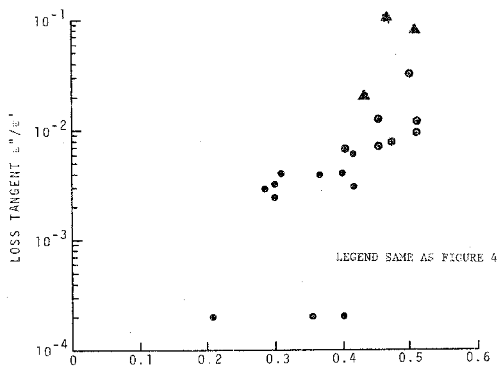
Considerable activity was detected within the upper layer of snow at both the Colorado and the Wyoming test sites as the ambient conditions changed. The activity was detected by changes in both electromagnetic and physical characteristic.

Permittivity vs. density data obtained from samples removed from the snowpack agrees well with previous published results. It was found that some of the snow structure



DENSITY - gm/cc 500 MHz DIELECTRIC CONSTANT MEASUREMENTS

FIGURE 4. REAL PART OF THE DIELECTRIC CONSTANT AS A FUNCTION OF SNOW DENSITY.



SNOW DENSITY - gm/cm 500 MHz LOSS TANGENT MEASUREMENTS

FIGURE 5. LOSS TANGENT AS A FUNCTION OF SNOW DENSITY

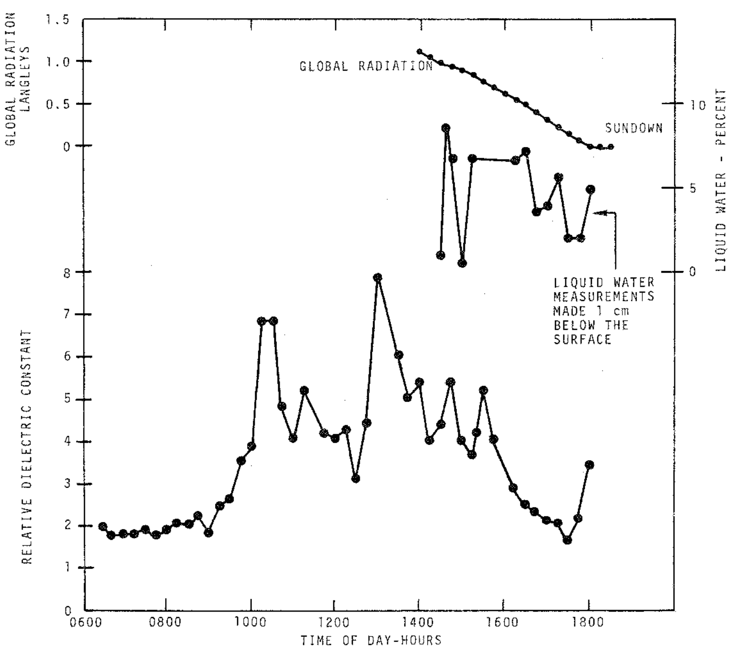


FIGURE 6. SURFACE DIELECTRIC CONSTANT AND AMBIENT CONDITIONS NEAR ARLINGTON, WYOMING.

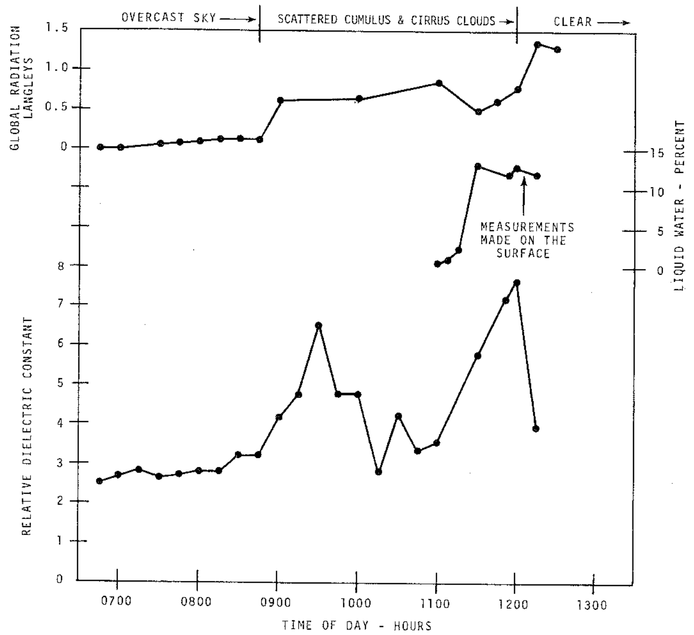


FIGURE 7. SURFACE DATA NEAR ARLINGTON, WYOMING.

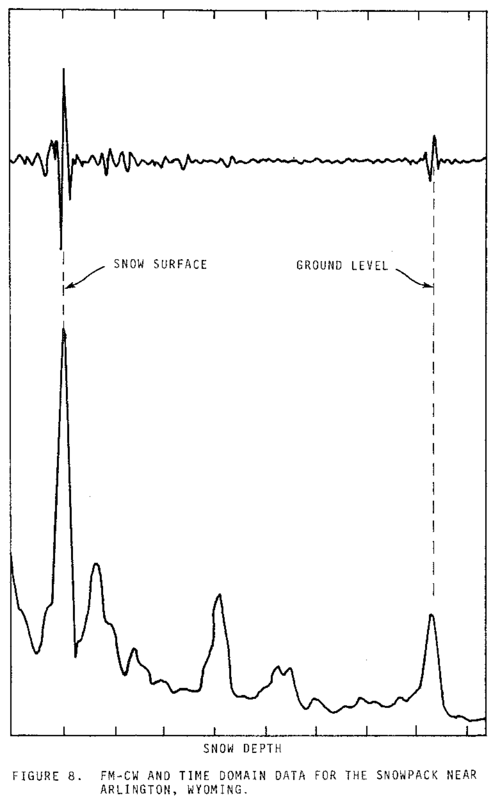


FIGURE 8. FM-CW AND TIME DOMAIN DATA FOR THE SNOWPACK NEAR ARLINGTON, WYOMING.

cannot be retained when removed from its natural state; thus laboratory results may be misleading. For example, there is a very fragile ice layer above the depth hoar layers. The ice layer appears to be rigid enough to prohibit the penetration of free water in situ, but it crumbles when pressed into the cavity sample holder for measurement.

ACKNOWLEDGMENTS

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