SNOW STRATIGRAPHY MEASURED WITH AN ACTIVE MICROWAVE SENSOR

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1. Introduction

The FM-CW active microwave system has a characteristic to detect the reflection from at the interfaces within the medium and enables us to obtain the record of a profile through the medium. Thus, this system is considered fairly effective in measuring and monitoring stratigraphic features within the snow-pack without giving any disturbance[1][2]. But still many ambiguous points remain in the interpretation of the data.

This paper reports on the measurements of stratigraphy within a snow-pack with a FM-CW system having the microwave frequency bands, and also on their results, which were interpreted in terms of physical parameters such as density and free water content.

2. Measuring system

The block diagram of the FM-CW radar system which was developed and used for our experiments is given in Fig. 1.

In our system, the emitting power is about 40 mW; and microwave frequencies ranging from 2-8 GHz and from 6-12 GHz are used, sweeping continuously over the bandwidth every 10 to 100 ms. A single antenna is used for emitting and receiving signals and is set at a near-normal incident with respect to the snowpack surface. Data collected in the time domain are processed with a Fast Fourier Transformer to the frequency domain. The location of the spectra displayed are functions of the distance from the antenna to each interface and their dielectric constant. They are presented as $d = c\Delta f / (2\sqrt{\varepsilon}\, df/dt)$, where d is a difference in distance between two interfaces and c the speed of light, ε the relative dielectric constant of snowpack, and df/dt the change of frequency of the system per unit time.

3. Laboratory experiments

Laboratory experiments were carried out, for simple-layered models of artificial snow such as glass beads and foamed polystyrene plastics.

Firstly, the relations of the thickness of each layer with the locations of individual spectra from the surface, the bottom and the interface within the model were obtained with respect to size and compactness, together with the system's parameters selected, such as frequency bandwidth, sweep time of oscillator and filter ranges.

From the results obtained for the dry snowpack model, the following were confirmed: (1) the configuration and apparent density of a layer, had a considerable effect on the relative dielectric constant of the layer; (2) the whole thickness of the model was obtainable with a considerable degree of accuracy. (3) reflection due to mismatch of the system's components and multi-reflection in the layer were not negligible for the interpretation of the spectra.

Secondly, foamed polystyrene plastic plates were piled up on the reflection plate; and, on the top surface of it, several sheets of filter paper were placed, and also a metal net having various mesh sizes were inserted parallel to the surface. Using this model, the locations of spectra and their intensities reflected from at the interfaces were measured by changing the volume of water contained in the filter paper.

One of the results obtained is given in Fig. 2 and the followings were confirmed: The intensity of a spectrum from the top surface of the block increased with increasing water volume but saturated when the water volume exceeded some extent; and remarkable masking of intensities of spectra from underlying interfaces within the block was observed with increasing water volume of the surface layer.

4. Field experiments

Field experiments have been carried out in northern Hokkaido since 1982, where in January and February, ambient temperature is usually kept fairly below 0 °C; so, the snowpack in this area is kept dry during these months, but in March and April, it rises above 0 °C and the snowpack becomes wet by melting.

A metal net having a mesh of 1 cm was placed on the ground as a reflection plate before the snow season and a tower was set above it. Measurements were made at the site of the tower through the snow season.

The stratigraphy and the profile of physical parameters such as grain size, density and temperature throughout the snowpack were measured at the same time as the experiments by digging a pit near the tower.

At the initial stage of the experiments in the dry-snow season, it was difficult to identify the spectra, corresponding to the interfaces within the snowpack. So that, a reflection plate was inserted into each visible interface from the pit wall.

Given in Fig. 3 is a relation between the actual depth of each interface where a reflection plate was inserted and the corresponding frequency of each spectrum. Stratigraphy of the snowpack is given in Fig. 4.

In Fig. 3, the difference in gradient of a line connecting each point expresses a difference in relative dielectric constant of each layer. From the comparison between Fig. 3 and Fig. 4, it can be noticed that there is a similarity between the profile of density and that of relative dielectric constant.

Continual observations of the stratigraphy of the snowpack were made on the morning of 8th of February, 1984. It had been snowing from the previous evening till the morning and the depth of the snowpack reached up to 105 cm.

Spectra obtained at 9:00 in the morning are given in Fig. 5. In the figure, spectra corresponding to the top and the bottom surface can be clearly recognized. For this measurement, Δf = 5,100 Hz, df/dt = 0.6 GHz/ms and d = 105 cm; so that we can obtain ε = 1.47 as the average value of relative dielectric constant of the snowpack.

Spectra obtained at 18:00 of the same day are given in Fig. 6. The difference in frequency obtained at the surface between at 8:00 and 18:00 was Δf = 150 Hz, and the relative dielectric constant of air, ε = 1; so that we can obtain d = 3.8 cm as the actual depression of the air-snow interface and the value corresponds to a decrease in actual depth of the snowpack. Also, we can estimate the average relative dielectric constant of the snowpack as ε = 1.65, by putting Δf = 5,200 Hz, d = 101.2 cm.

During that time span, the surface did not melt; so that these changes were caused mainly by the densification of fresh fallen snow within the upper layer of the snowpack.

Spectra obtained from the wet snowpack on April 4, 1984, are given in

Fig. 7. The spectrum corresponding to the surface can be recognized but that corresponding to the bottom cannot be identified.

It can be understood that an increase in free water content in the snowpack brings about an increase in the imaginary part of the complex dielectric constant of the snowpack; consequently, the attenuation of a microwave within the snowpack increases and the reflection from at the underlying interface decreases.

Changes in intensity of the spectrum corresponding to the air-snow interface with time are given in Fig. 8.

The behavior of the intensity with time can be explained as follows: During the nighttime, from 18:00 to 4:00, the layer is kept dry. But, with the lapes of daytime, free water within the layer increases due to melting. When meltwater which is kept within the layer reaches up the point of saturation, it flows down to the layers below and the free water content within the layer decreases. After 18:00 of the second day, the meltwater is still kept in the near surface layer without freezing but gradually decreases due to capillary flow down to the layer below.

5. Concluding remarks

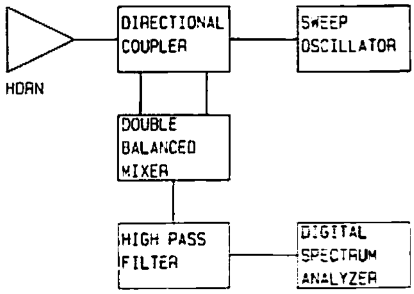
The stratigraphy of a snowpack has been obtained using a FM-CW radar system throughout several snow seasons. The results obtained demonstrate the potential use of the active microwave system for monitoring the snowpack.

From the practical viewpoint the following must be taken into account: (1) for eliminating ambiguities from the analyses and increasing the accuracy of measurements, it will be useful to adopt such typical values of relative dielectric constant for the seasonal and the dry/wet snowpack; (2) for obtaining an outline of the profiles of layers and densities within the snowpack, the use of the present system will be reinforced by adopting such a simple method of ram sounding that can be applied with relative ease compared with the pit method.

References

[1] D. A. Ellerbruch, H. S. Boyne, "Snow stratigraphy and water equivalence measured with an active microwave system", Journal of Glaciology, Vol.26, No.94, pp. 225 - 233 (1980)

[2] M. Suzuki, Y. Nakagawa, T. Matsumoto, D. Kuroiwa, K. Fujino and G. Wakahama "Measurement of snow stratigraphy with a FM-CW microwave sensor", National Conv. Rec. of IECE Japan, 2751 (1984)



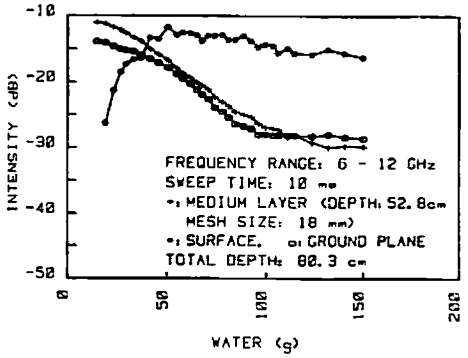
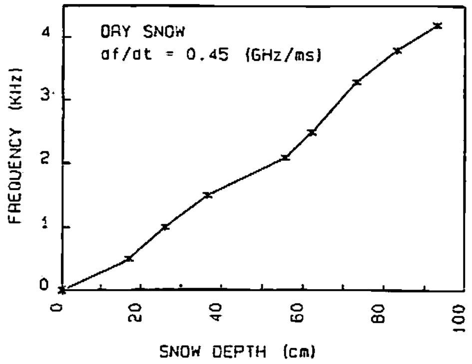


Fig. 1 Block diagram of the FM-CW radar system used for measurements. (L)

Fig. 2 Relation between water volume contained in filter paper on the surface and intensity of spectra from the interfaces. (R)



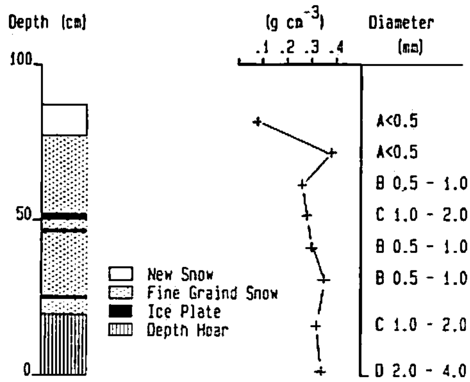
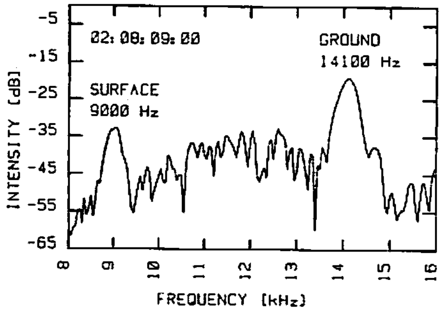


Fig. 3 Variation in frequency with snow depth examined by inserting a reflection plate. (L)

Fig. 4 Structure of a dry snowpack. (R)



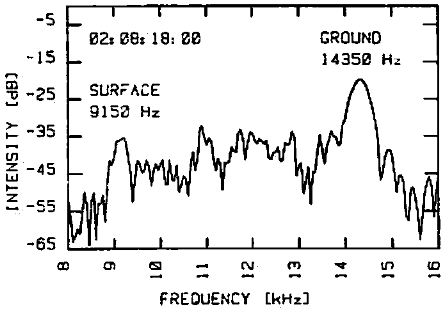
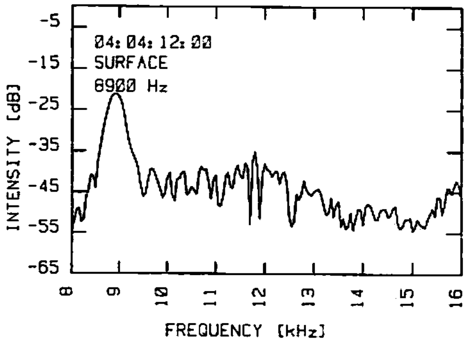


Fig. 5 Profile of spectra of the whole snowpack obtained at 9:00 on February 8, 1984. (L)

Fig. 6 Profile of spectra of the same snowpack as given in Fig. 6, obtained at 18:00 on February 8, 1984. (R)



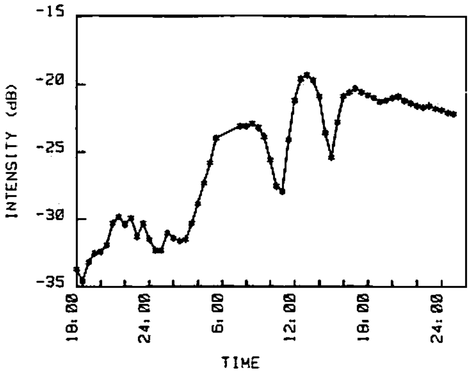


Fig. 7 Profile of spectra of a wet snowpack obtained at 12:00 on April 4, 1984. (L)

Fig. 8 Variation with time in intensity of spectra from the surface. (R)