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Field tests with the Snow fork in determining the density and wetness profiles of a snow pack.

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ABSTRACT

A radio wave sensor, the Snow fork for determining the density and wetness profiles of a snow pack with a single measurement was developed at the Helsinki University of Technology [1]. Recently the instrument has been further developed and it includes now all measurement electronics and a data logger for effective field work. The operation of the Snow fork is based on measuring the dielectric properties (real and imaginary part) of snow around 1 GHz. The sensor is a parallel wire open resonator.

The Snow fork has been tested in several different locations and in different conditions. First a snow pit is made and the snow pack is measured with the Snow fork in great detail (2 cm steps). After this the snow is sampled and measured with the conventional weighing methods. The results show a high correlation between the Snow fork and conventional methods.

INTRODUCTION

Data of snow properties, such as layer thickness, density, structure and wetness, is important for detailed snow analysis in many applications. The measurement of layer thickness is simple, and therefore it often is the only measurement carried out. Snow density can be measured by a rather simple operation using the snow scale. Density alone, however, gives little information on snow properties. The structure of snow is usually described by using a subjective classification method. The free water content is tedious to determine and it is therefore seldom measured.

A microwave snow sensor, Snow fork, is a new tool for assessing snow properties. It consists of a small fork shaped sensor and a measuring/recording unit. It has been designed specially for rapid data collection in field.

PRINCIPLE OF OPERATION

The operation of the Snow fork is based on measuring the relative dielectric constant of snow. The studies on the dielectric constant of snow show that, by measuring the real and the imaginary part of the dielectric constant, it is possible to determine both the density and the liquid water content of snow [1],[2]. The imaginary part of the dielectric constant is directly related to the wetness and the real part is dependent on both the density and the wetness. Formulas explaining the dielectric properties of snow at the frequency of 1 GHz have been published by Tiuri et. Al. [2], Eq.(1),(2).

(1) $\varepsilon' = 1 + 1.7D + 0.7D^2 + 8.7W + 70W^2$

(2) $\varepsilon'' = 0.9W + 7.5W^2$

where

- ε' is the real part of the relative dielectric constant of snow,
- ε'' is the imaginary part of the relative dielectric constant of snow,
- D is the "dry density" of snow relative to the density of water (the density of snow when all liquid water in it is replaced by air),
- W is the wetness by volume.

The relative dielectric constant can be measured with a resonator that is filled with the material to be measured. The Snow fork resonator is a section of a parallel-wire transmission-line. It is open-circuited at one end and short-circuited at the other end, thus forming a fork with two spikes. The fork is connected with cables to the electronics that measures the resonance curve of the resonator. When the fork is pushed into the snow the resonant frequency is shifted due to the real part of the dielectric constant and the resonance curve is broadened due to the imaginary part. This phenomena is used to calculate the relative dielectric constant.

DESCRIPTION OF THE INSTRUMENT

In order to have results in real time the measurement is automated. The block diagram of the instrument is shown in figure 1. The fork is connected with two cables to the electronics box. The electronics include a microwave oscillator that is controlled with a microprocessor (CPU). The system measures the resonance curve of the fork and then calculates the snow properties. The user communicates with the system through a hand-held keyboard - display. The instrument has also a solid state data memory. The measurement results can be stored with additional information, for example the date and a code number. The data can be printed out or transmitted to a computer for further analysis.

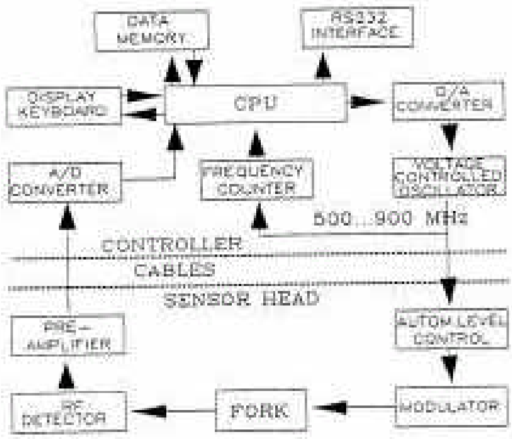

Fig.1. The block diagram of the instrument.

The whole system is portable and battery operated. It can be handled by one person. One measurement is performed in less than one second. Thus it is possible to measure the density and wetness profile of a snow pack very accurately, for example in two centimeter intervals. The fork does not compress the snow pack and the measurement is easily repeatable.

FIELD TESTS

The Snow fork has been used in several measurement campaigns to collect data in field. First a snow pit has been made and the snow pack has been measured with the Snow fork in 2 cm steps from the ground upwards. The measurement has been repeated several times. After this the snow has been sampled with a cylindrical sampler (volume 97,4 cm^3). The snow samples were measured with conventional weighing methods. The results have been transmitted to a personal computer and the Snow fork measurement results have been compared with the densities measured by sampling.

Figure 2 shows the density and wetness profiles measured in January at Otaniemi, in southern Finland. The measurement site was a plowed snow pack, 120 cm of height. The air temperature was around - 10 °C. The snow was fine grained and only few days old. The Snow fork measurement was repeated three times and the results are nearly equal. The sampling was made in 5 cm steps, the snow was easy to cut and the densities measured with different methods compare very well except at the top. This is probably due to an error in sampling. The wetness is very low from top to bottom.

Figure 3 shows the profiles measured in April at Kitee, in eastern part of Finland. The measurement site was a small opening in a forest, in a natural snow pack, 76 cm of thickness. The snow was fairly wet, the measurements show 2..3% by volume. The snow pack had different layers. The topmost layer, 65..75 cm, was fine grained freshly fallen snow. Between 55..65 cm the snow was more coarse, but not very old. Between 20..55 cm the snow was very coarse and the crystal size was large. The snow pack collapsed very easily. There were also ice lenses, 1..2 cm in diameter. This was perhaps caused by the snow falling from trees. Some pine twigs and small branches were also in the snow. At the bottom 0..20 cm the snow was less coarse and more stable. The ambient temperature was around 0 °C. The density profile measured by sampling shows higher densities in the very coarse snow. This can be a result of poor sampling, since it was very difficult to take samples in this snow. The Snow fork measurements compare with each other quite well.

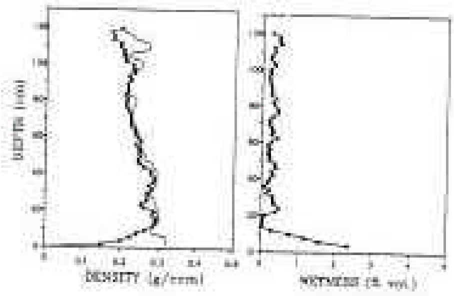

Fig.2. Snow profiles measured at Otaniemi in January. The Snow fork measurement was repeated three times and averages are shown with squares. A density comparison measurement is shown with a solid line.

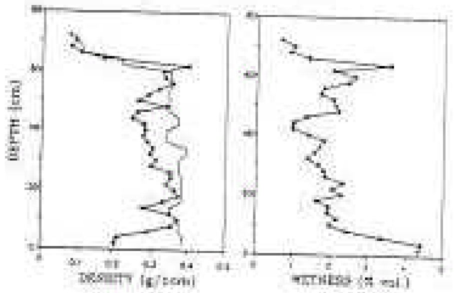

Fig.3. Snow profiles measured at Kitee in March. The Snow fork measurement was repeated three times and averages are shown with squares. A density comparison measurement is shown with a solid line.

References:
[1] A.Sihvola and M.Tiuri, Snow fork for field determination of the density and wetness profiles of a snow pack. IEEE Transactions on Geoscience and Remote Sensing, Vol. GE-24, No. 5, p. 717-721, 1986.
[2] M.Tiuri, A.Sihvola, E.Nyfors, and M.Hallikainen, The complex dielectric constant of snow at microwave frequencies, IEEE J. Oceanic Eng., vol. OE-9, no. 5, pp. 377-382, 1984.