SCATTERING PROPERTIES OF SNOW IN THE 10- TO 90-GHz RANGE

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ABSTRACT

The transmission loss of several samples of refrozen and newly fallen snow was measured as a function of sample thickness between 10 GHz and 90 GHz. The temperature of the samples was -20°C. The extinction coefficient was determined for each snow type. The experimental results were compared with theoretical calculations using the Mie theory. For samples of refrozen snow, the loss due to surface scattering effects was observed to be substantial at 90 GHz.

INTRODUCTION

The frequency range of both radiometer and radar measurements of snow cover and utilization of the satellite data have recently been extended to millimeter wavelengths [1-4]. However, the basic tool for interpreting these data in snow studies, namely the scattering properties of snow, are not known with satisfactory accuracy. Additionally, in spite of its wide use, the applicability of the Mie theory to calculating the extinction coefficient of snow has not been verified.

Dielectric measurements of dry snow have been reported at microwave frequencies up to 13 GHz [5] and those of wet snow up to 37 GHz [6]. According to the Mie theory, volume scattering by ice particles is the dominant loss mechanism in dry snow at frequencies above 14 GHz (assuming a grain size of 1 mm). Consequently, by measuring the transmission loss of snow slabs as a function of sample thickness, information on both the volume and surface scattering effects can be obtained.

Previous investigations concerning the transmission loss of dry snow samples are not documented in a detailed manner [7-8]. The available information is limited to the density, temperature, and type (refrozen or new) of snow samples. In this study it is shown that the extinction coefficient and the loss due to surface scattering are determined by the average grain size and the surface roughness, respectively.

MEASUREMENT PROCEDURE

Five free-space transmission systems, operating at 10 GHz, 18 GHz, 35 GHz, 60 GHz, and 90 GHz, were used to measure the transmission loss of snow samples. The diameter of each sample was 38 cm. The sample thickness varied from 20 cm to 3 cm. The sample holder was made of styrofoam and coated with plastic. In order to eliminate any moisture effects, the samples were cooled down to -20°C in a freezer. They were insulated with additional styrofoam during the measurement to prevent their temperature from changing. After completing the measurement in the 10- to 90-GHz range, each sample was cut thinner and the measurement procedure was repeated. The average grain size and the surface roughness were determined from photographs of the samples.

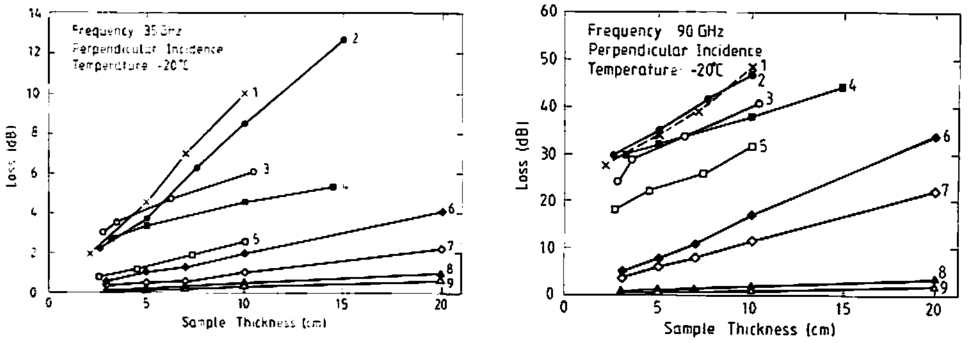
RESULTS

The physical properties of the snow samples are given in Table 1. The measured loss values at 35 GHz and 90 GHz are depicted in Figure 1 as a function of sample thickness. The loss increases linearly with increasing sample thickness in all cases. Although the loss values at 90 GHz are considerably higher for refrozen snow than for new snow, much of the difference can be attributed to surface scattering effects. For new snow, the loss for small thicknesses is practically zero, thus indicating that surface scattering is negligible.

Table 1. Physical properties of the snow samples.

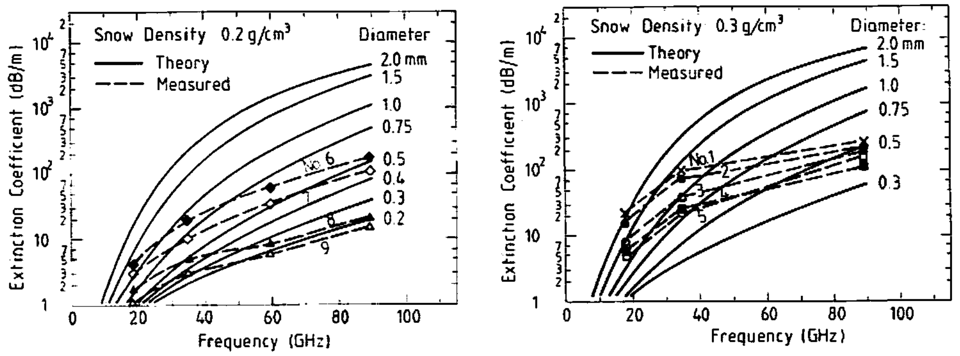
Sample No.	Density $[\mathrm{g/cm^3}]$	Average Grain Size [mm]	Surface Roughness [mm]	Snow Type Description
1	0.409	1.4	2...3	Very hard refrozen snow. The ice structure is continuous throughout the sample.
2	0.360	1.4	~2	Hard refrozen snow. The ice structure is continuous throughout the sample.
3	0.347	1.0	1...5	Refrozen snow. The ice structure can be easily broken to produce separate ice particles.
4	0.319	0.7	1...2	Refrozen snow. Structure nonhomogeneous including large air voids.
5	0.305	0.9	1...2	Refrozen snow. Structure slightly nonhomogeneous. The surface includes several large holes.
6	0.217	0.7	<1	Newly fallen snow. Acquired from the bottom layer of the snow cover. Ice crystals elongated.
7	0.194	0.5	<1	Newly fallen snow. Acquired from the middle layer of the snow cover.
8	0.323	0.3	<<1	Wind-driven 5-day old snow. Acquired from the top layer of the snow cover.
9	0.172	0.3	<<1	One-day old snow.

The total attenuation in a medium is described by the extinction coefficient (sum of power absorption and scattering coefficients). The extinction coefficient for the snow types at each frequency was obtained from the slope of the measured loss vs. sample thickness. Figure 2 shows the extinction coefficient for each sample as a function of frequency. The values at 10 GHz are not shown because they are too low to be accurate. The experimental results are compared with theoretical values for snow densities of 0.2 $\mathrm{g/cm^3}$ (new snow) and 0.3 $\mathrm{g/cm^3}$ (refrozen snow). The theoretical calculations were made using the Mie theory and assuming the ice particles to be identical spheres. The complex dielectric constant of ice as a function of frequency was obtained from [9].



(a) (b)

Figure 1. Measured transmission loss of snow samples at (a) 35 GHz and (b) 90 GHz.



(a) (b)

Figure 2. Comparison of experimental extinction coefficients with theoretical values (Mie theory) for snow density of (a) 0.2 g/cm^3 and (b) 0.3 g/cm^3.

Figure 2 indicates that the experimental extinction coefficients over the 10- to 90-GHz range do not agree with the theoretical values obtained for any single grain size. This suggests that the nonspherical ice particles of variable sizes in snow cannot be replaced in theoretical calculations by spherical ice particles with a single radius.

CONCLUSIONS

The measured values of the transmission loss for samples of refrozen and newly fallen snow indicate that the loss increases with increasing grain size and increasing frequency. For refrozen snow, a substantial fraction of the loss is due to surface scattering effects. The frequency behavior of the experimental extinction coefficients does not follow that predicted by the Mie theory.

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