MICROWAVE ATTENUATION IN SLEET SNOWFALL SPACE

M. SUZUKI, K. SHA AND E. NAKAGAWA
Faculty of Eng., YAMAGATA UNIVERSITY

1. Introduction

Though rain attenuation is the major factor affecting propagation of microwaves, one must consider the effects due to other hydrometeors such as wet snow, sleet, or hail.

As already known, such attenuation will remarkably change depending upon the wetness of snowflakes. At the same precipitation rate, dry snow cause less attenuation than rain, but wet snow sometimes causes six or seven times larger attenuation than rain.1) But many points are still unknown about the basic characteristics of snowfall in its microwave propagation particulary for wet snow or sleet.

In general, however, both measured and theoretical data on attenuation by falling snowflake is not readily available.

That's the point! Sleet's necessary features are the size distribution, falling velocity, and etc, and furthermore, these features are only significant when they are taken at the same time.

In order to measure both at once, the following new technique has been developd. That is, the moving snowflakes are photographed by two cameras (one camera measures the falling velocity, and the other one measures the size)against a dark background.

This paper describes some results of this new observation test and a few considerations on the particular relationship between the magnitude of microwave attenuation coefficient and the effective scattering cross-section of falling snowflake(sleet).

2. Methods Adopted and Others

The new observation apparatus shown in Fig. 1, are set up on the flat rooftop (270 meters above sea level).

The shutter speeds of the two cameras are set at 1/30 and 1/1000 second.

Since both of them are operated simultaneously, two pictures for the same snowflakes are obtained. From the short streak in the picture with a slow shutter speed, the velocity is measured. From the camera with a faster shutter speed, the size and number of the snowflakes are obtained. The actual size is magnified by a factor of 1.5 by a slide projector. Thus, the size, falling velocity and mean concentration of falling snowflakes are measured simultaneously from each film.

The falling velocity and shape of sleet snowflakes observed by this method in Dec. 1979, Feb. 1980, Feb. 1981 and Mar. 1982, were simultaneously plotted in together with open air temperature in Fig. 2.

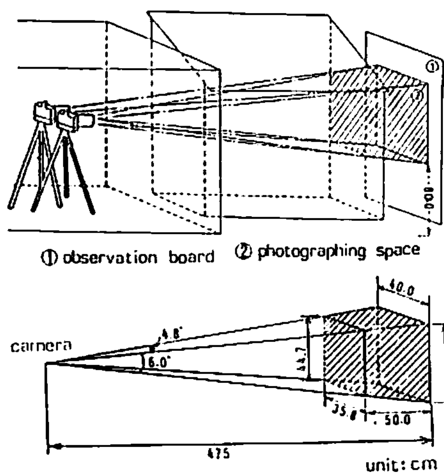


Fig.1. Measurement system

The theory of scattering and absorption of electromagnetic waves due to spherical particles are well known, as developed by G. Mie, J. A. Stratton etc.

Denote the absorption cross-section by Qa, scattering cross-section by Qs and the total attenuation cross-section by Qt, then

$$Q_t(r_s,\lambda)=Q_s(r_s,\lambda)+Q_a(r_s,\lambda)$$
$$=-\frac{\lambda^2}{2\pi}Re\left\{\sum_{n=1}^{\infty}(2n+1)(a_n+b_n)\right\} \qquad \cdots\cdots(1)$$

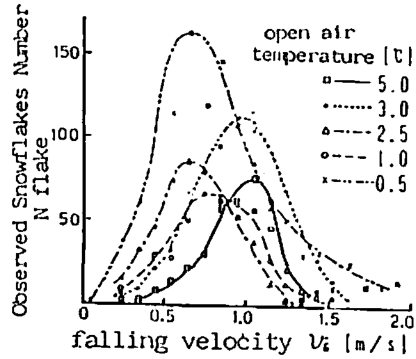


Fig.2. Snow falling velocity VS. observed snowflakes number

$$a_n=-\frac{j_n(\rho)[m\rho j_n(m\rho)]'-j_n(m\rho)[\rho j_n(\rho)]'}{h_n^{(2)}(\rho)[m\rho j_n(m\rho)]'-j_n(m\rho)[\rho h_n^{(2)}(\rho)]'}$$

$$b_n=-\frac{m^2 j_n(m\rho)[\rho j_n(\rho)]'-j_n(\rho)[m\rho j_n(m\rho)]'}{m^2 j_n(m\rho)[\rho h_n^{(2)}(\rho)]'-h_n^{(2)}(\rho)[m\rho j_n(m\rho)]'}$$

$$j_n(\rho)=\sqrt{\frac{\pi}{2\rho}}J_{n+\frac{1}{2}}(\rho),\quad h_n^{(2)}\rho=\sqrt{\frac{\pi}{2\rho}}H_{n+\frac{1}{2}}^{(2)}(\rho),\qquad \rho=\frac{2\pi r_s}{\lambda}$$

where $m^2=\varepsilon=\varepsilon'-j\varepsilon''$ is the complex dielectric constant of a snowflake, r_s is the snowflake of the effective radius, and λ is the wavelength.

A falling snowflake may be considered to be an assembly of water, ice and air. The complex dielectric constant of water and ice are given by the dispersion formula due to Debye, and the dielectric constant of a snowflake can be obtained with the use of the theory of mixed dielectrics due to Wiener.

Hence, the attenuation cross-section of a snowflake can be calculated with the use of dielectric constant, the diameter of the snowflake and the wavelength. An example of the results of these computation is shown in Fig.3 (a),(b),

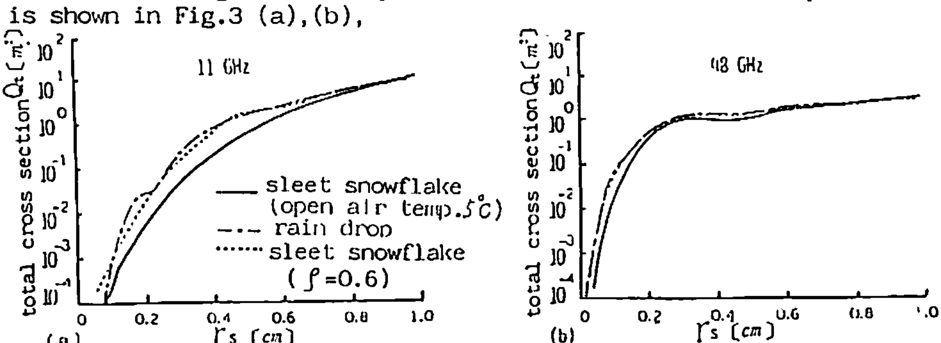


Fig.3. Snowflake's effective radius VS. total cross section

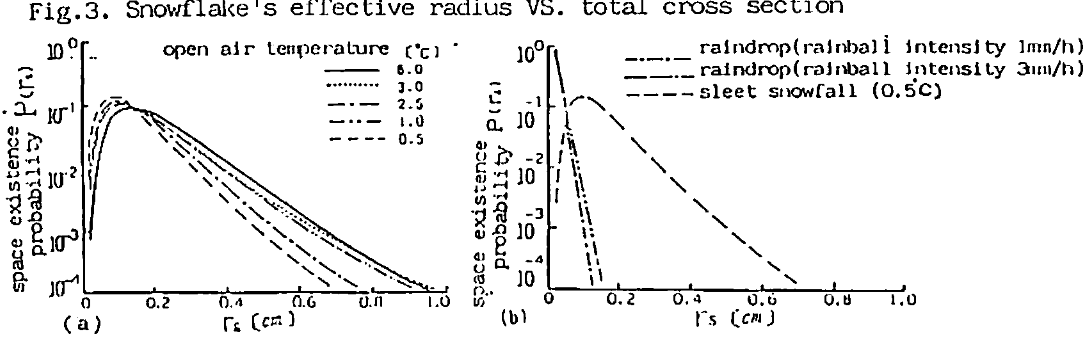


Fig.4. Snowflake's effective radius VS. space existence probability

Fig.4(a) represents the snowflake size distribution of sleet together with open air temperature. Previously usual raindrop size distributions near the ground which are experimentally determined are often written as an exponential from such as the Marshall and Palmer, (Fig.4(b))

Now, the effective total cross sections of snowflake and raindrop are given by

$$Qte=(r_{\varsigma},\lambda)=Qt(r_{\varsigma},\lambda)P(r_{\varsigma}) \qquad (2)$$

where $P(r_{\varsigma})$ is the probability for snowflake and raindrop existence in space.

At the open air temperature (5°c, 0.5°c) the above computation results from sleet's effective total cross-sections are shown in Fig.5(a),(b).

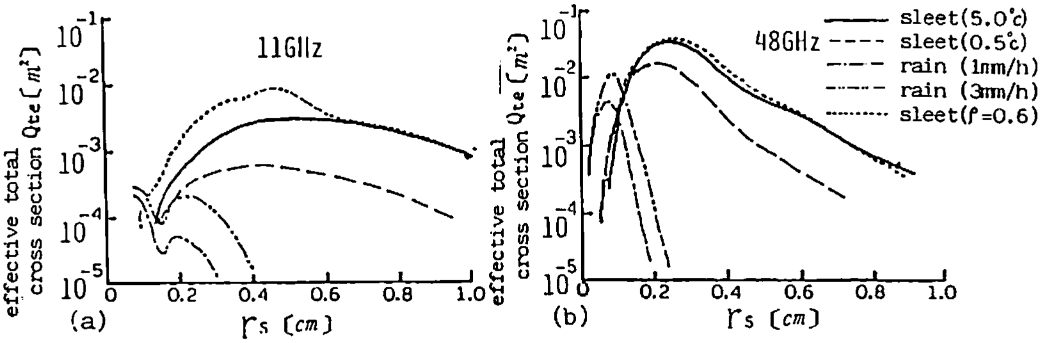


Fig.5. Snowflake's effective radius VS. effective total cross section

In the propagation path, the sleet attenuation A(λ) at a wavelength is given by

$$A(\lambda)=c\int_0^L \underline{\int_0^{r_{sm}} Q_t(r_s,\lambda)\cdot N(r_s,Z)dr_s dZ} \qquad (3)$$

where C is constant, $Qt(r_{\varsigma},\lambda)$ is total cross-section for a spherical snowflake with effective radius r_{ς}, $N(r_{\varsigma},\lambda)$ is snowflake size distribution at Z=z, L is the path length and $r_{\varsigma m}$ is the maximum radius of a snowflake.

Next, an underlined part of (3) is rewritten as follows:

$$\int_0^{r_{sm}} Q_t(r_s,\lambda)\cdot P(r_s)dr_s\cdot\int_0^{r_{sm}} N(r_s)dr_s \qquad (4)$$

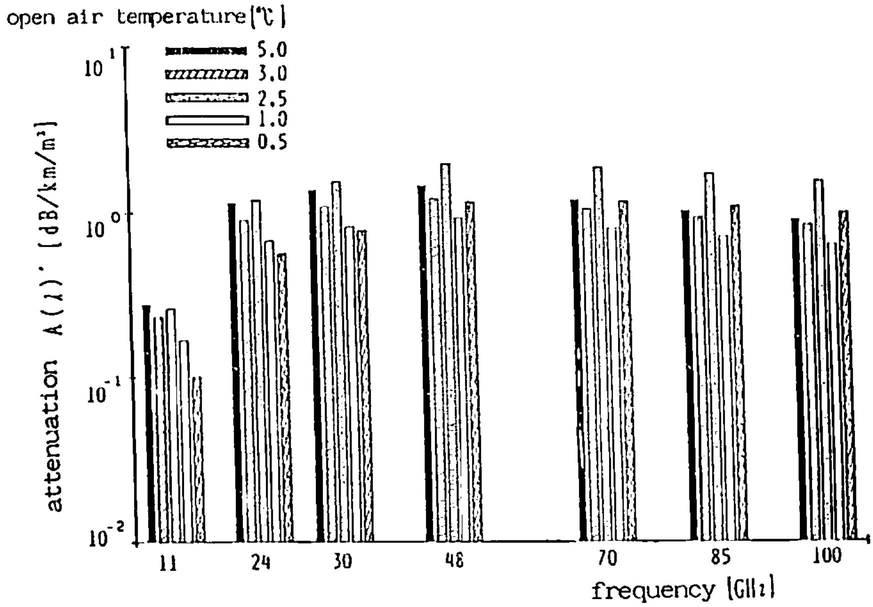
that is

$$\int_0^{r_{sm}} Q_{te}(r_s,\lambda)dr_s\cdot\int_0^{r_{sm}} N(r_s)dr_s \qquad (5)$$

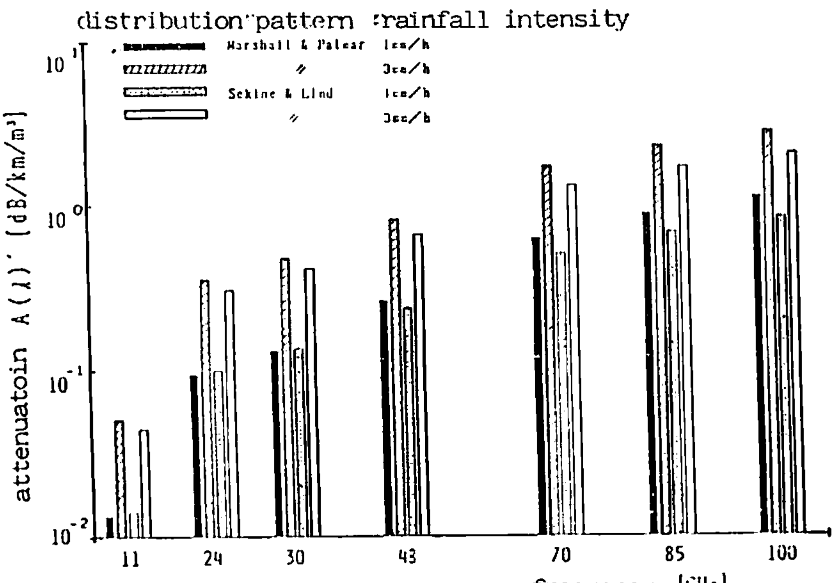
From the result of the above integration (from $r_{\varsigma m}$=0 to $r_{\varsigma m}$=1.0 cm), the sleet attenuation A(λ) is given by Fig.6(a). Similarly, the rain attenuation is shown by Fig.6(b).

3. Summary

These very complex forms of sleet's precipitation have attenuation characteristics that vary remarkably at centimeter and millimeter wavelengths. We have seen that liquid water is a strong attenuation of microwaves; therefore sleet, which is consist of mixture of rain and wet snow, can also produce very high attenuations. In fact, these attenuations may exceed those of rain from these new experimental results in Fig.6(a),(b).



(a) sleet snowflake falling space



(b) rainfall space

Fig.6. Sleet snowflake and rainfall attenuation

Reference.

1)M.Takada and S.Nakamura:11Gc snow damage field test report ,NTT Product Report NO.1989, P.1~31, 1963