Analysis of Bistatic Scattering of Electromagnetic Waves by Melting Layer

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Abstract
In this communication bistatic scattering of electromagnetic waves by the melting layer of precipitation has been presented. The bistatic radar reflectivities have been formulated and can be computed at 1- 100GHz by applying the Mie theory for raindrop-size distributions at rain rates below 12.5mm/h. It is very important to study the integrated interference effects all along the propagation path as well as of greatest interest for evaluating the impact of the melting layer effects on bistatic interference for communications.

Key words: Bistatic scattering, interference, hydrometeors, melting layer

Introduction
The bistatic scattering of electromagnetic waves by hydrometeors include not only the interference between terrestrial radio-relay stations, but also the interference between earth stations and satellites. This problem has been accepted and discussed by several authors (1-7). 10, 14, Kharadly et al [8] showed that melting layer where snowflakes melt and become raindrops can affect these interference problems. The bistatic transmission loss due to hydrometers in the melting layer may not be neglected because the bistatic radar reflectivity (the bistatic radar cross section per unit volume) is needed in the transmission loss evaluation [6] there are incentives for studying bistatic scattering of radio waves by the melting layer of precipitation. The bistactic radar reflectivity allows one to evaluate the interference caused by both copolarized and cross-polarized unwanted signals as well as the additional transmission loss due only to the bistatic scattering by the melting hydrometeors.

The monostatic radar measurements [9,10] showed a special case of the bistatic scatter from the melting layer as experimental evidences. The radar bright band at centimeter wavelengths [9,10] demonstrated that the radar backscatter from the melting layer is significantly larger than that from hydrometeors on both sides of the melting zone. The same has been experimentally shown for the forward scatter case [11] Russchenberg [9] demonstrated that at the top of the melting layer the vertical and horizontal reflectivities of snowflakes in the initial phase are equal. The differential reflectivity technique [12] has involved into a powerful remote sensing methodology. It was found [7] that the bistatic radar reflectivities computed by Mie- theory assuming spherical hydrometeors contain all necessary characteristics applied to the bistatic transmission loss computation. The established expectations for the bistatic effects within the melting layer. Although much previous work had been done in extending it to spheroids, the Mie theory could apply to the differential reflectivity and other polarization problem successfully.

Here in this article, we present bistatic radar reflectivities of the melting layer in the light of Mie theory.

Mathematical Formulation
The bistatic reflectivity γ_{ij}(the bistatic cross section per unit volume in m^2/m^3 is defined by $\gamma_{ij}=\gamma_{ij}$ (z) =

$$\sigma\int^{a_{max}} \sigma_{ij}(a_2)\ [Q + (1-Q)(a_{s0} + k_s a)^3 / a^3]^{1/3}\ N(a)\ da$$

In this equation, z is a depth below the top of the melting layer i.e, the 0ºC isotherm, a_z and a the melting snow particle and resultant raindrop radii, respectively, and a_{max} = 0.325cm is the max raindrop radius. Large raindrops may rarely be found at rain rates below 12.5mm/h. Here, a_{max} = 0.325 cm used is the up limit of the integration concerning the drop-size distribution N (a)- moreover, Q is the ratio of melted mass to total mass of a melting snowflake and has been related to physical constants and meteorological parameters [8] :k_s=1.37 and a_{so} = 0.005 cm. In the particular, σ_{ij} (a_z) is the bistatic cross-section [8] of a single melting snow particle, i and j denote the incident and received polarizations, respectively and the polarization refers to a plane determined by the z-axis and the incident or scattering direction. The bistatic scattering geometry is shown at Fig. 1.

The model describing the melting process was developed in [8]. It consists of the size distribution of melting snowflakes, the complex relative permittivity ϵ_{av} of a melting snowflake, the thickness Z_m of a melting layer and the density ρ_s of dry snowflakes on the top of the melting layer. Specifically, a_z relates a as

$$a_z^3 = a^3\left[Q + (1-Q)\frac{\rho_w}{\rho_s}\right] \qquad ....[2]$$

Where ρ_w = 1g/cm^3 is the density of water. The mass fraction Q = 0 corresponds to dry snowflakes. As a result, equation (2) becomes $a_2^3 \rho_s = a^3\rho_w$. This indicates the mass conservation. In the final phase of Q = 1, equation (2) leads to a_2 = a; snowflakes become raindrops.

Let dn be the melting snowflake number per unit volume at the melting snowflake radius interval of from a_2 to a_2+da_2. In equation (1), dn has been expressed as

$$dn = \left[Q + (1-Q)(a_{so} + k_s a)^3 / a^3\right]^{1/3} N(a)da\ .$$

Here, the density ratio of ρ_w/ρ_s has been written as $\rho_w/\rho_s = (a_so + k_s a)^3/a^3$. Specifically, z_m not only increase with a but also depends on other physical constant and meteorological parameters. The maximum thickness H ≈ 1417m is the value of z_m at amax = 0.325cm. In the later numerical result presentations, the ratio of z/H will be employed where z takes value in the interval of o≤ z ≤ H. The 0°C isotherm indicated by 0 in fig. 1 correspond to z/H = 0 or Q = 0. Specifically, γ_{ij} (z) can be computed for five raindrop-size distributions at rain rates below 12.5 mm/h. At the bottom of the melting layer, i.e., z/H = 1, all snowflakes melt and become rain drops. As such, equation (1) becomes well known bistatic radar reflectivity for raindrops as expected.

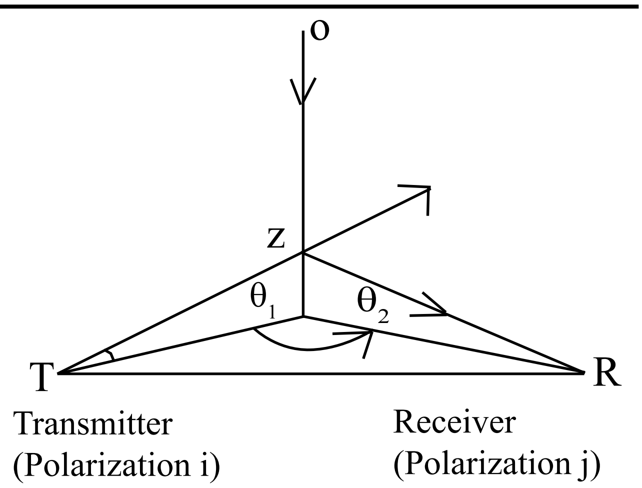

Fig 1. The bistatic scattering geometry for calculating bistatic radar reflectivity

In special case $\theta_1 = \theta_2 = 90^o$ and $\phi = 0^o$, the equivalent reflectivity factor z_{eq} (z) [8] can be derived from equation (1). It has been shown [8] that results computed at 3-10 Gh_z are adequate for describing the radar bright band. Further more, results computed at 35 and 94 GH_z indicate the fact that the radar bright band observed at centimeter wavelength can be absent at millimeter wavelengths [10]. In conclusion, Z_{eq} (z) computed applying the Mie theory agrees with radar observation of the melting layer at 3-94GH_z.

3. Numerical Results

Numerical calculations can be performed at 1-100 GHz by applying Mie theory [13]. In table-1, the complex relative permittivity ϵ_{av} at 35GH_z as a function of Q for ρ_s = 0.3485g/cm^3 has been listed. In the initial phase of Q=0, ϵ_{av} has the value of permittivity ϵ_s dry snowflakes. These dry snowflakes consist of ice and air. Therefore, ϵ_s depends on the volume fraction of ice and, hence, on ρ_s. The density ρ_s has been related to the resultant raindrop radius a [8]. The initial density ρ_s=0.3485 g/cm^3 corresponds to the dry snowflakes that melt and become raindrops with a = 0:1cm. In the final phase of Q =1, table-1 shows $\epsilon_{av} = \epsilon_w$, where ϵ_w is the 0°C water Complex relative permittivity [14] at 35 GH_z.
Also, γ_{ij} (Z) can be computed for studying the interference between earth stations as well as that between earth stations and satellites [15]. These bistatic radar reflectivities cooperating with the

bistatic radar equation [16] would allow one to deal with the three kind interference problems including the melting layer effects for engineering purposes.

Table 1

The complex relative permittivity ϵ_{av} of melting snowflakes at 35GHz for initial density $\rho_s = 0.3485 g/cm^3$

Q	Re{ ϵ_{av}}	I_m { ϵ_{av} }
0.0	1.670	9.418 E-04
0.1	1.898	4.024E – 01
0.2	2.167	8.822 E – 01
0.3	2.489	1.466
0.4	2.882	2.190
0.5	3.371	3.114
0.6	3.999	4.332
0.7	4.829	6.012
0.8	5.977	8.473
0.9	7.653	12.42
1.0	10.25	19.75

4. Conclusions

An analytical study on bistatic scattring of electromagnetic waves by the melting layer has been presented. The bistatic radar reflectivity has been formulated (1-100GHz) by applying the Mie theory for raindrop – size distributions at rain rates below 12.5mm/n. It is very important to study the integrated interference effects all along the propagation path. The relative contribution of the melting layer's contribution to this integrated effect from the entire propagation path is of the greatest interest for evaluating the impact of the melting layer effects on bistatic interference.

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