Chapter 5: Backscattering by Melting Particles
Large, Wet Particles

A. Backscattering by small, melting ice spheres (e.g. graupel)

Ryde (1946) studied the backscattering characteristics of small melting spheres, for which the Rayleigh approximation was valid. Ryde assumed that the particle consisted of a homogeneous mixture of water and ice during the melting process. From Debye (1929), the dielectric properties of a homogeneous mixture (neither component being a significant absorber) can be written as,

\[
\frac{K}{\rho} (M_i + M_w) = \frac{K_i}{\rho_i} M_i + \frac{K_w}{\rho_w} M_w
\]

(1)

where \( i \) denotes the ice phase, \( w \) denotes the water phase and \( \rho \) is density. Knowing the values of \( K \) (0.93 for water and 0.197 for ice), the backscattering cross section can be determined from:

\[
\sigma = \pi^5 \lambda^{-4} \left| K \right|^2 D_{i}^6
\]

(2)

Results of this calculation, for the so called homogeneous model, are shown in Fig. 5.1 from Battan. Knowledge of the particle diameter is also required.
Backscattering for Small, Melting Spheres

This homogeneous model is not very applicable for most ice particles. It is probably most suitable for melting aggregates, where water exists amongst the ice lattice. Higher density ice particles like graupel and pea-sized hail develop a water coat, or skin of meltwater, that increases in thickness as the particle melts. Aden-Kerker (1951) developed a theory for the backscattering cross section of a particle with a water coat. They used a concentric sphere model to simulate an ice particle with a liquid water shell. A key result was that the melting sphere behaved as an all water target for relatively thin water shells. Aden-Kerker applied full Mie theory to this geometry (with \( \alpha << 1 \)) and calculated the backscattering cross section \( \sigma \) as a function of melted diameter (or water fraction) and compared this to \( \sigma_m \), the backscattering cross section for the equivalent fully melted target. In this case, a water coat equal to 10\% of the radius of the particle behaves as an all water target, essentially.

![Graph showing variation in backscattering](image)

Note that when one tenth of the sphere has melted, the backscattering cross section is 90\% of the all water target. A 0.5 mm diameter graupel particle behaves essentially as an all water target with a water skin thickness of 0.05 mm. (for a wavelength of 3 cm). This result is wavelength dependent. A water coat thickness of approximately 0.165 mm would be required at S-band, for example.
An obvious consequence of the rapid increase in backscattering cross section with melting is the radar bright band, characteristic of stratiform precipitation. There ice particles, typically aggregates, drift downward and undergo melting over a depth of a few hundred meters. The sharpest radar bright bands are associated with very large aggregates, which may be 1 cm in diameter. An example of a radar bright band from the CSU-CHILL radar is shown below.
B. Backscattering by Large Spheres in the Mie Regime

Atlas et al. (1960) suspended large artificial hailstones from a tethered balloon and observed their backscatter characteristics as they melted. For large spheres, backscatter was observed to decrease as the hailstones became coated with liquid water due to absorption and increased scatter in the forward direction. Quantitative results were difficult to obtain in this experimental setup. Only qualitative results could be obtained. Hermann and Battan (1961) applied Mie theory to large ice spheres with liquid water annuluses. They made calculations at wavelengths of 3.21, 4.67 and 10 cm. Spheres of 0.2 to 8.0 cm were studied. They computed $\sigma$ as a function of water thickness from $10^{-8}$ cm to a sphere of all water. Results are shown in Fig. 5.3 from Battan (1973). This model would apply to wet hail, that is, hail in the wet growth regime where the surface of the particle is coated with liquid water. The thickness of the water coat that may be retained on the surface is typically thick enough to make the backscatter characteristics of the particle behave as an all water target.
For small values of $\alpha$, $\sigma_b$ (normalized cross section) increases as sphere melting proceeds. When $\alpha$ approaches unity or exceeds unity, variation of $\sigma_b$ with water shell thickness becomes very erratic, depending on diameter and wavelength. This erratic behavior for large $\alpha$ is associated with Mie effects including interference of waves reflected from the surface of the sphere, waves reflected from the ice-water transition, and waves scattered from the surface.
Spongy Hail

C. Spongy Hail

Spongy hail is defined as hail in the wet growth mode where the hail is an ice-water mix. Upwards of 50% of the mass may be water. The water is retained in an ice mesh. Battan and Herman (1962) calculated backscattering cross sections at 3.21 cm for both spongy ice and solid ice spheres coated with spongy ice. Water fractions in the spongy ice varied from 0 to 1. Dielectric factor of the ice-water mesh was treated as a non-absorbing dielectric, where the dielectric factors for ice and water are weighted by the relative volumes of ice and water respectively. Results are shown in Fig. 5.3 from Battan (1973).

Increasing water fraction

As the water fraction increases, maxima in $\sigma_b$ shifts towards smaller values of $\alpha$ as a result of absorption by the water. Also the amplitude of $\sigma_b$ decreases as the fraction of water increases, again due to absorption. These calculations are for spongy ice spheres.