Measurement and Modeling of Differential Phase Shift Upon Scattering in Polarimetric Weather Radars and its Use in Inferring the Presence of Large Hail

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ABSTRACT

In this paper, the extended boundary condition method is used to calculate the differential phase shift upon scattering, 6, from dry and melting hail. The scaterers are modelled as oblate spheroids. Actual radar measurements are shown wherein the effect of differential phase shift upon scattering is seen. The use of 6 for inferring hail size is discussed.

Introduction:

Polarimetric radars are currently, one of the best sensors for remote probing of precipitation. In such radars, the choice of linear polarization basis, with alternate pulse to pulse switching between horizontal (H) and vertical (V) polarization states, is used in several radars in the world. Most polarimetric radars are also coherent and often, for simplicity process only copolar returns. Such systems, in addition to measuring the reflectivity factor, 2, also measure the differential reflectivity, Z_{DR}, the differential propogation phase shift, K_{DP}, and the correlation coefficient between horizontally and vertically polarized echoes, ρ_{HV}. The processing and meteorological significance of Z, Z_{DR} [1], K_{DP} [2,3] and ρ_{HV} [4] are now well established. The polarimetric measurands, when interpretted together provide a framework for improved rain rate estimation, and hail identification and also an improved insight into the microphysics of precipitation.

Since the radar remote sensing is an inverse scattering problem, several forms of precipitation may also produce indistinguishable radar signatures. This often times happens in precipitaion forms that include melting ice and hail. Melting ice and hail, unlike rain drops are non-Rayleigh scatterers even at S-band frequencies and produce significant differential phase shift upon scattering, .

In this paper, the differential phase shift upon scattering is evaluated for a variety of melting ice forms. The hailstones are modelled as oblate spheroids of axis ratio ranging from 0.2 to 0.8, which spans the shapes of hailstones reported in the literature. The differential phase shift upon scattering has been computed for diameters upto 6 cm at 10.7 cm wavelength. The composition of the hailstones include the dry ice, water and mixture of water and ice. Actual radar measurements of the propogation phase shift ϕ_{DP} in a severe hailstorm is shown to illustrate the significance of 6 in inferring the presence of hail and possibly their size.

Dielectric constant and scattering models:

The dielectric constant of

water and ice at S-Band are taken as 80.255 + j24.313 and 3.16835 + j0.0249 respectively and are used to represent wet and dry hail. In practice, however, the melting hail is represented by a mixture of water and ice. Chylec[5] has studied three topologies of which two of them are amenable to the application of Maxwell-Garnett mixing rule. In this model, a material with dielectric constant ϵ_1 is embedded in a continuous matrix of dielectric constant ϵ_2. Such mixtures are conventionally modelled by layered spheres of core materials of dielectric constant ϵ_1 and the outside layer of material ϵ_2. The effective dielectric constant is then given by

$$\epsilon_{eff} = \frac{(\epsilon_1 + 2\epsilon_2) + 2f_1(\epsilon_1 - \epsilon_2)}{(\epsilon_1 + 2\epsilon_2) - f_1(\epsilon_1 - \epsilon_2)} \epsilon_1$$

where f_1 is the volume fraction of material 1. In this paper, the volume fraction of water is taken as 0.40, as an illustration of scattering by melting ice. Both cases of the embedded medium being water (Spongy ice, dielectric constant = 8.49 + j0.325) and the embedded medium being ice (Chylec, dielectric constant =27.21 + j7.56) are considered.

The shape of the hail is taken to be oblate spheroid and the axis ratios of 0.2, 0.4, 0.6 and 0.8 are considered.

Differential Phase shift upon Scattering:

The scattering co-efficients for both horizontal and vertical polarizations have been computed using the T-matrix method [6]. From the backscatter co-efficients, the differential phase shift upon scattering, δ, has been calculated and presented in figure 1. The scatterers are oriented with their minor axis vertical. It is seen from Fig 1.a (axis ratio b/a =0.8) that for ice, 6 increases with increasing diameter upto 5cm and decreases beyond, tending towards negative 6 at 6cm diameter. But, for water, the 6 exhibits negative excursions in the region of 0.65 cm to 1 cm lnd also from 4.85 cm to 5.35 cm. Spongy hail wherein the core material is water, exhibits δ variations similar to that of water but its first negative δ region is shifted to diameters between 1.5 cm to 1.7 cm. The variations of 6 in Topology II of Chylec, wherein the core medium is ice, a sharp negative region is seen around 2.9 cm diameter. though a more pronounced oscillatory variations beyond 3 cm is seen, 6 has remained positive.

Fig 1.b (b/a=0.6) shows variations of larger magnitude than in Fig 1.a asexpected from more oblate scatters.However, the regions of negative and positive 6 have remained almost the same as in Fig 1.a.

In Fig 1.c and 1.d (b/a = 0.4 and 0.2), the variations in 6 are far larger and particularly evident is the resonances in the regions beyond 3 cm diameter.

Radar measurements:

ϕ_{DP} when measured by a radar includes the differential phase shift due to both propagation and scattering. The propagation phase shift normally would increase with increasing range. Scatterers such as rain drops and smaller dry ice forms do not produce significant 6 and hence ϕ_{DP} in such a medium represents purely the propagation phese shift. Whenever large melting ice and hail are encountered, the monotomically increasing nature of ϕ_{DP} is altered. One such measurement is presented in figure 4. The elevation of the radar beam is 5.1° at the stars of the scan and reaches 5.6 at the end of the radial shown. In figure 2, it is seen that the reflectivity is higher than 45 dbZ at around 30 km range. This corresponds to a height of about 3 km which is below melting level on june 3, 1989. The presence of large 6 and the fact that the observation is made below the melting level, indicates that the melting ice size should be in the resonance region of the figure 1.a, which is between 1 cm. The resolution volumes from larger heights correspond to regions above the melting layer and hence may be predominantly populated by ice forms. As seen from Figs 1.a to 1.d, 6 from dry ice is small even upto 4 cm diameter. Because of this absence of 6 in the echoes from larger ranges, the ϕ_{DP}, which is the sum of both the propogation phase shift and the scattering phase shift (&), decreases. Beyond 38 Km range, ϕ_{DP} increases steadily. Thus, it is obvious that the signature of increasing and decreasing ϕ_{DP} is indicative of melting hail. The actual contribution by 6 to ϕ_{DP} can be obtained by filtering ϕ_{DP} with monotonically increasing function and between 2.5 and 3.4 Km altitude as shown by the dotted line in Fig 2. The variations of ϕ_{DP} from the dotted line is the actual 6, from which the hail size can be inferred.

Conclusion:

In this paper, the 6 from oblate spheroidal scatterers of various composions has been evaluated. Radar measurement in a severe hail storm is presented to illustrate the effect of δ on ϕ_{DP} and its significance in inferring the hail size.

References:

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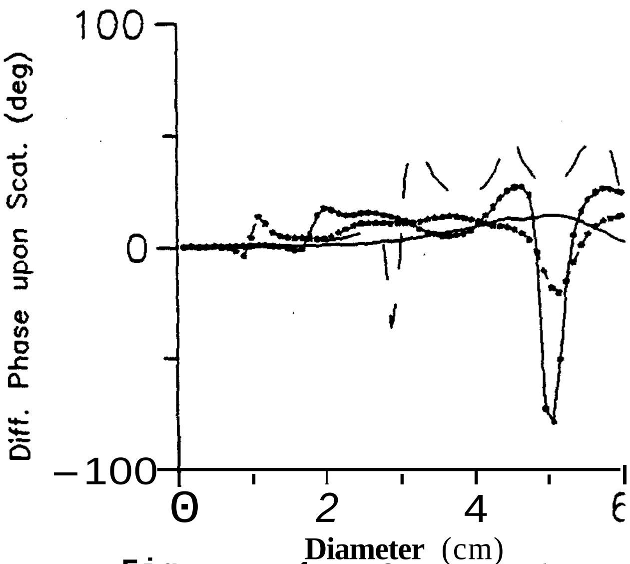

Fig. 1. a. Axis ratio=0.8

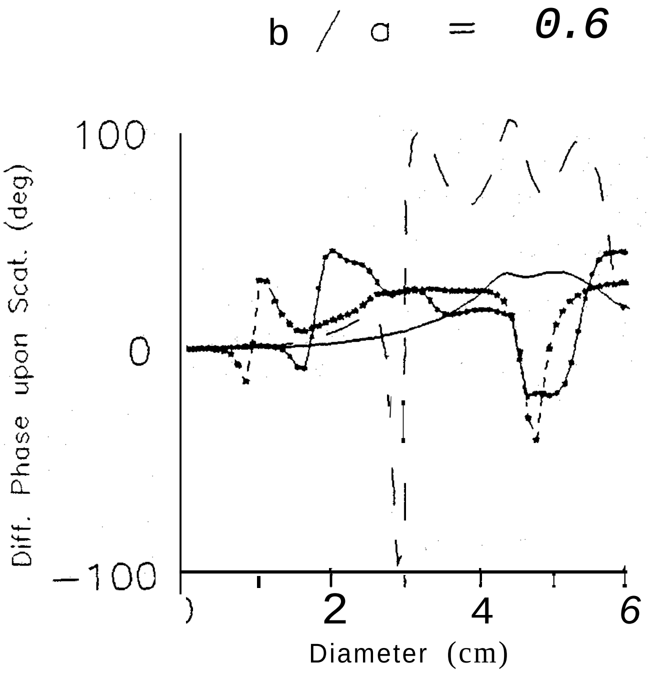

Fig 1.b.Axis ratio= 0.6

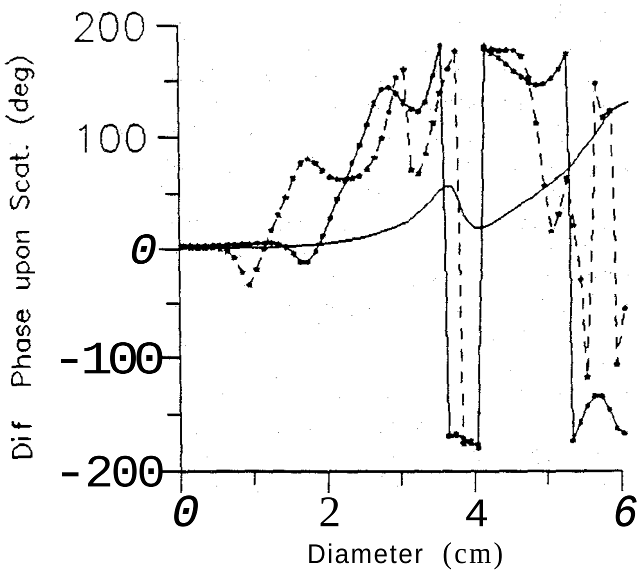

Fig 1.d Axis ratio =0.2

Legends for Fig 1.

————	**Dry Ice**
-* -*	**Water**
- - - -	**Chylec**
-*-*-*-*	**Spongy ice**

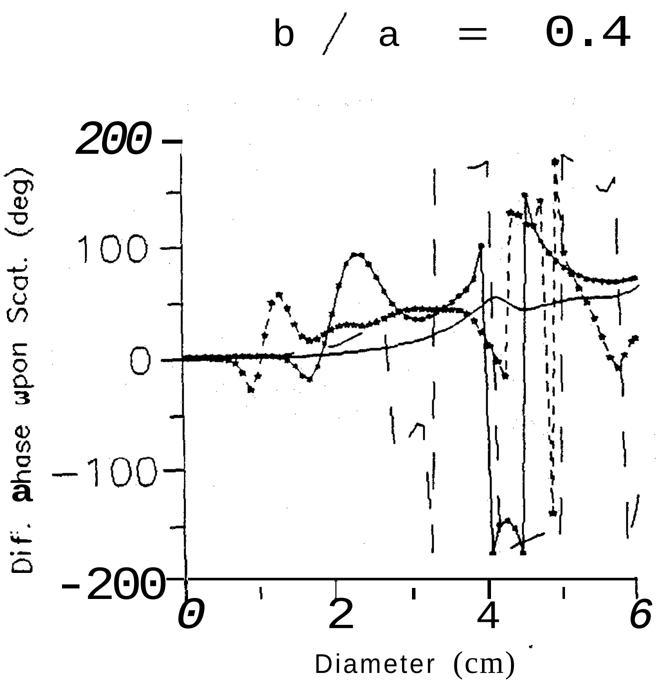

Fig 1.c Axis ratio =0.4

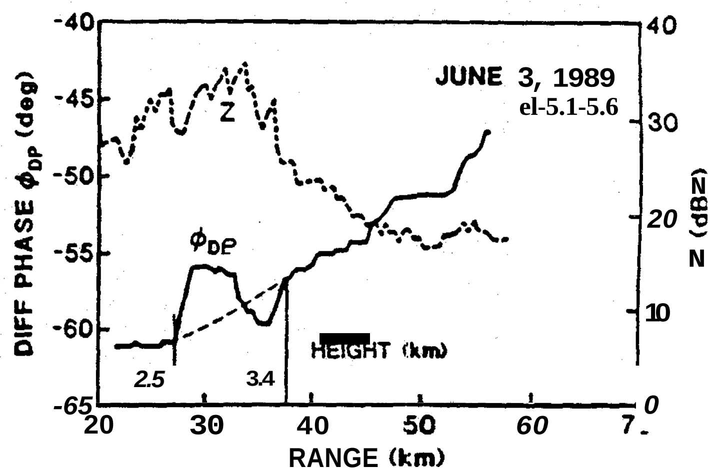

Fig 2.. Radar Measured ϕ_{DP} June 3, 1986 at Norman, OK, 'USA.