Comparison of Simulated Scattering Characteristics of Large Rain Drops and a Special Form of Melting Hail and Relation to C, S and X band Radar Observations

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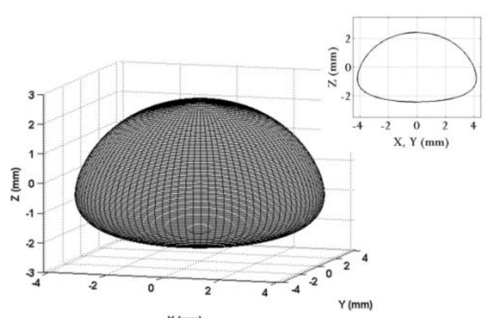
1. Introduction:

Rain drops and melting hail differ not only in their shapes and sizes but also in terms of their dielectric properties. Previous polarimetric radar observations at C-band have identified regions where a much larger differential attenuation between the horizontal and vertical polarizations have been noted (Tabary et al., 2009). Here we address this by comparing the propagation characteristics of large rain drops with those of a special form of melting hail where the initial stage of melting ice is assumed to occur around the 'equator' (as has been observed in wind-tunnel experiments, Rasmussen, and Heymsfield, 1987). Simulations are carried out at C band as well as S and X bands. For C-band, results of specific differential attenuation, differential phase, and differential reflectivity for such hydrometeors have already been published (Thurai et al., 2015). We present the corresponding results for S and X bands, and additionally discuss CSU-CHILL S and X band radar observations during a rain with small melting hail mixed event.

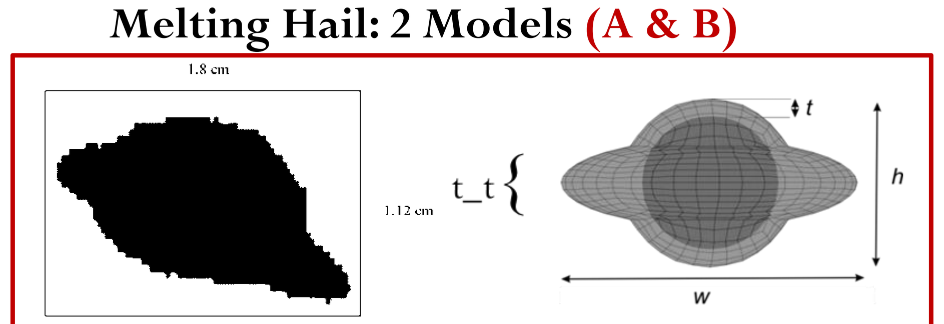
2. Hydrometeor Shapes and Dimensions

Rain drops

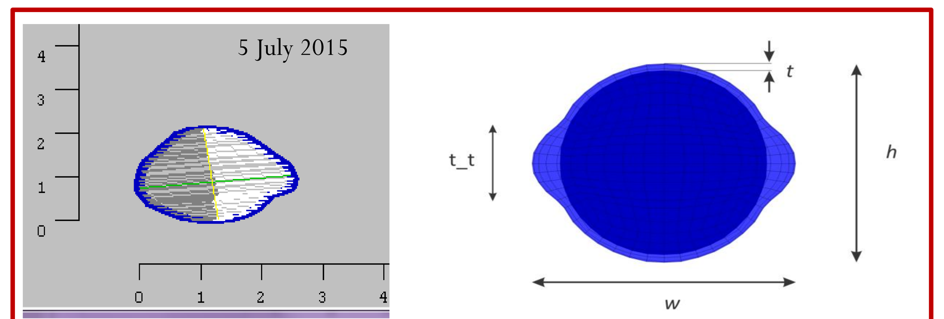


7 mm D_{eq} rain drop, and the projections on to x-z and y-z planes. *(from Thurai et al., 2007)*

Melting Hail: 2 Models (A & B)



Model (A): based on aircraft probe image given in Fig. 7.46 of *Bringi and Chandrasekar (2001)*



Model (B): based on the 2DVD image obtained during a rain-hail event which occurred in Greeley, CO

3. Electromagnetic Scattering Modelling

Method of Moments Scattering Analysis

Consider a dielectric scatterer situated in the free space and excited by a time-harmonic electromagnetic field of complex field-intensities $\mathbf{E}_i$ and $\mathbf{H}_i$. We use the surface equivalence principle and model the surfaces of a scatterer by means of generalized curved quadrilateral patches of arbitrary geometrical orders K_u and K_v, and described analytically by

$$\mathbf{r}(u,v)=\sum_{k=0}^{K_u}\sum_{l=0}^{K_v}\mathbf{r}_{kl}L_k^{K_u}(u)L_l^{K_v}(v)$$

where L represent Lagrange interpolation polynomials, and $\mathbf{r}_{kl}$ are position vectors of interpolation nodes. Electric and magnetic equivalent surface current density vectors, $\mathbf{J}_s$ and $\mathbf{M}_s$, over quadrilaterals in the model are approximated using hierarchical-type vector basis functions of arbitrary current-expansion orders N_u and N_v

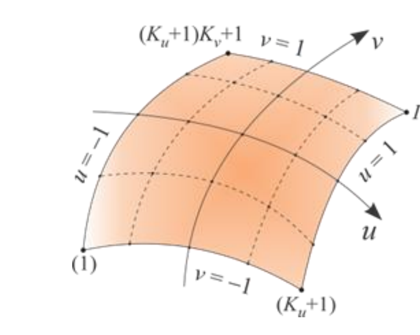
$$\mathbf{J}_s=\sum_{i=0}^{N_u}\sum_{j=0}^{N_v-1}\alpha_{ij}^{(u)}P_{ij}^{(u)}(u,v)\frac{\mathbf{a}_u}{\mathfrak{I}}+\sum_{i=0}^{N_u-1}\sum_{j=0}^{N_v}\alpha_{ij}^{(v)}P_{ij}^{(v)}(u,v)\frac{\mathbf{a}_v}{\mathfrak{I}}$$

The boundary conditions for the tangential (t) components of the total (incident plus scattered) electric and magnetic field vectors on the boundary surfaces yield

$$[\mathbf{E}(\mathbf{J}_s,\mathbf{M}_s,\varepsilon_0,\mu_0)]_t+(\mathbf{E}_i)_t=[\mathbf{E}(-\mathbf{J}_s,-\mathbf{M}_s,\varepsilon,\mu)]_t$$

$$[\mathbf{H}(\mathbf{J}_s,\mathbf{M}_s,\varepsilon_0,\mu_0)]_t+(\mathbf{H}_i)_t=[\mathbf{H}(-\mathbf{J}_s,-\mathbf{M}_s,\varepsilon,\mu)]_t$$

where $\mathrm{E}(\mathrm{J}_s, \mathrm{M}_s, \varepsilon, \mu)$ and $\mathrm{H}(\mathrm{J}_s, \mathrm{M}_s, \varepsilon, \mu)$ are the scattered electric and magnetic fields and ε and μ are dielectric parameters of the considered domain of the scatterer. These equations represent a set of coupled surface integral equations (SIEs) for J_s and M_s as unknowns, which can be discretized and solved for the unknown current-distribution coefficients employing Galerkin method.

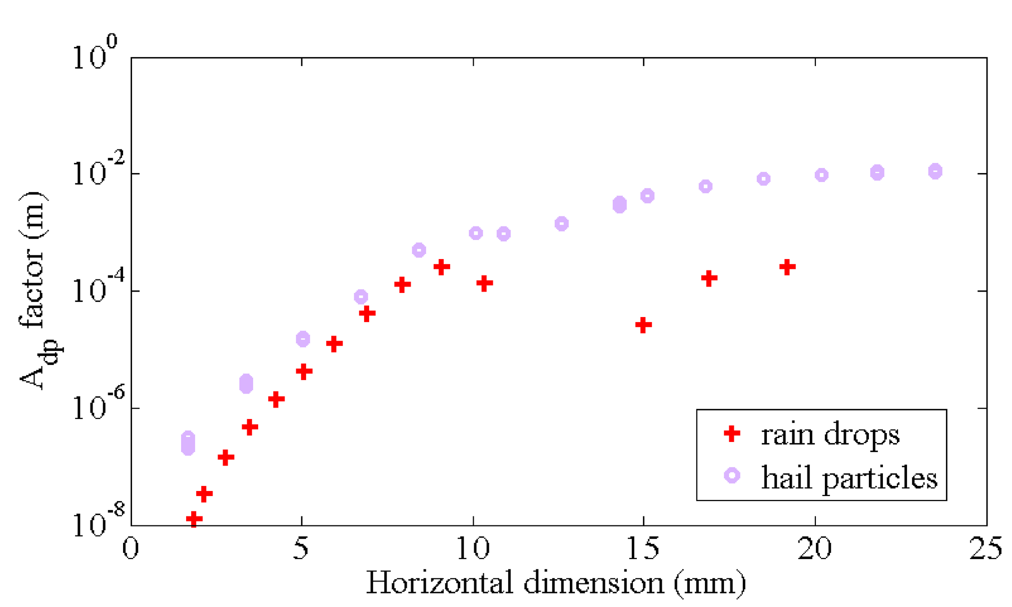


Generalized curved quadrilateral patch for MoM-SIE scattering modeling of melting hail. Model B is meshed with 1360 quadrilateral elements and 5440 unknown coefficients of current expansion.

4. Results at C-band for Individual Hydrometeors

- C-band results have been published in Thurai et al., 2015.
- For rain → D_{eq} is chosen to range from 2 to 10 mm.
- For hail → hydrometeors based on model (A), with w ≈ 16.8 mm, h ≈ 9.7 mm and t ≈ 0.4 mm.
- Then dimensions of h, w, and t were varied from 50 – 150 % of the original value

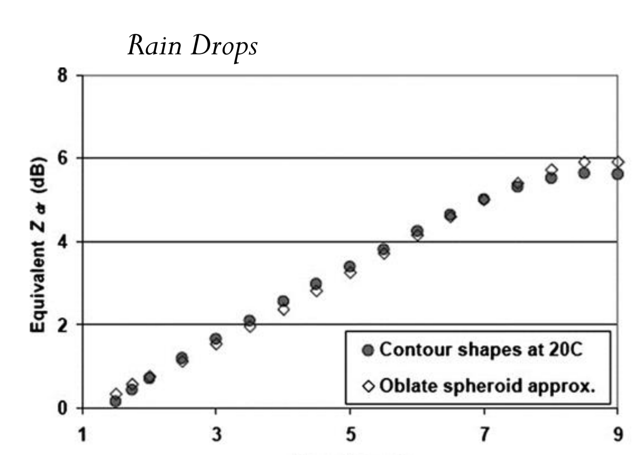
A_{dp} factor, given by $Im\{f_{hh}-f_{vv}\}$

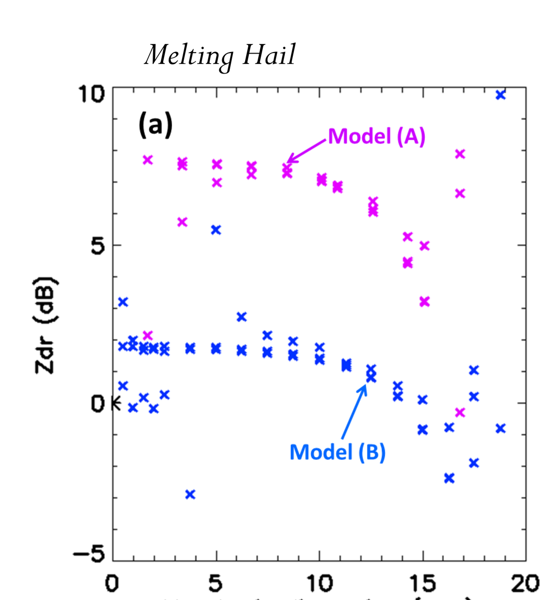


A_{dp} factor for hail particles tend to be higher than for rain

5. S-band Results:

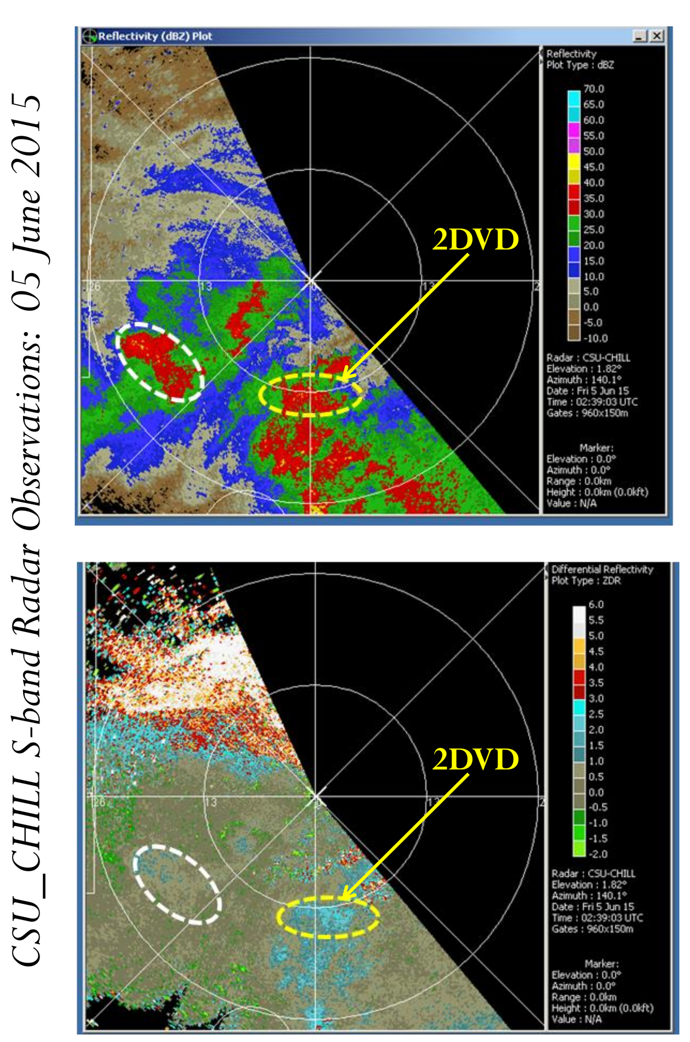
Same calculations for rain drops and hail particles. For hail, model (B) was also considered, with h~2.12 mm, w~2.5 mm, t_t~0.85 mm, t~0.08 mm; then downsize and upsize as before.





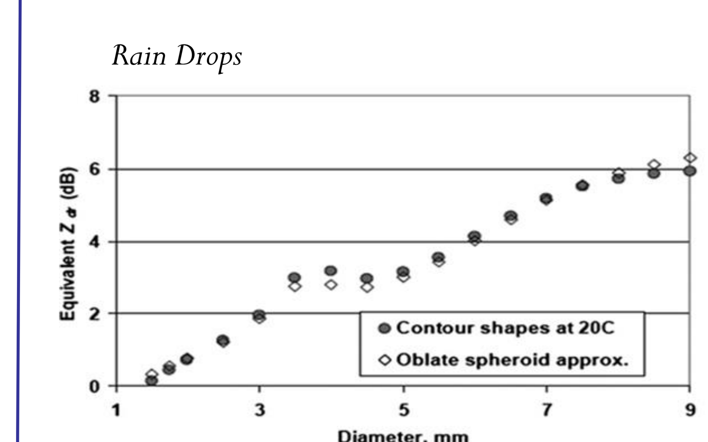
For hail, results are sensitive to the model used

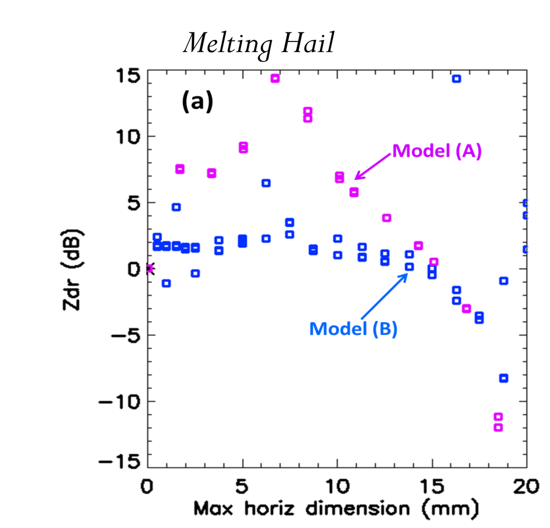
CSU_CHILL S-band Radar Observations: 05 June 2015

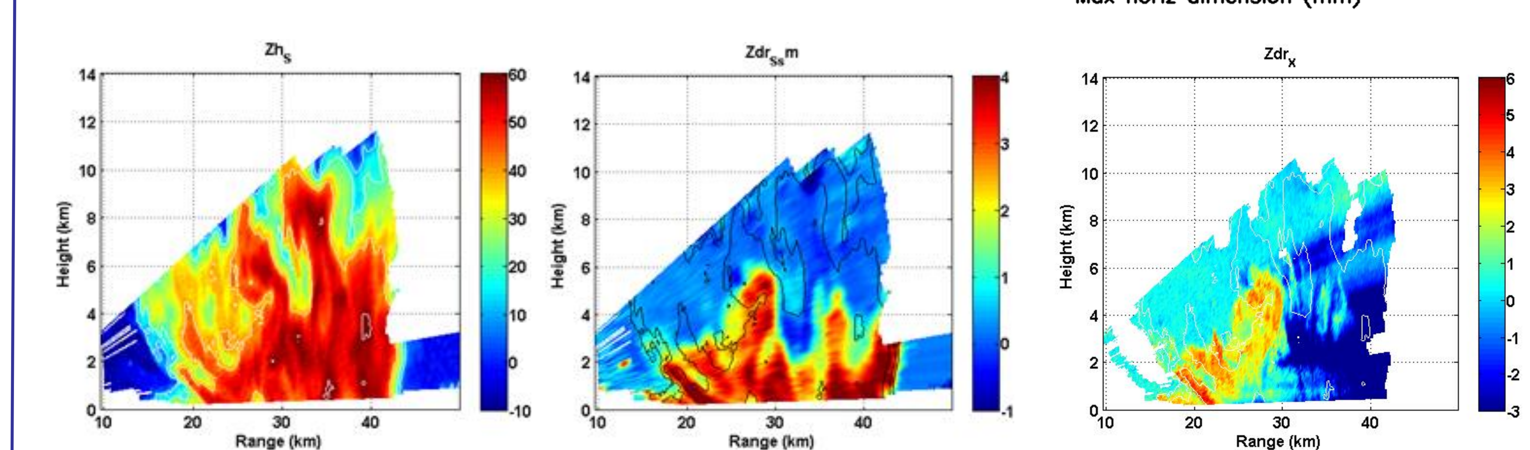


White-circled regions show moderate Z_h and low Z_{dr} (expected for rain) whereas yellow-circled regions show moderate Z_h but relatively high Z_{dr} (consistent with results for model B hail particles).

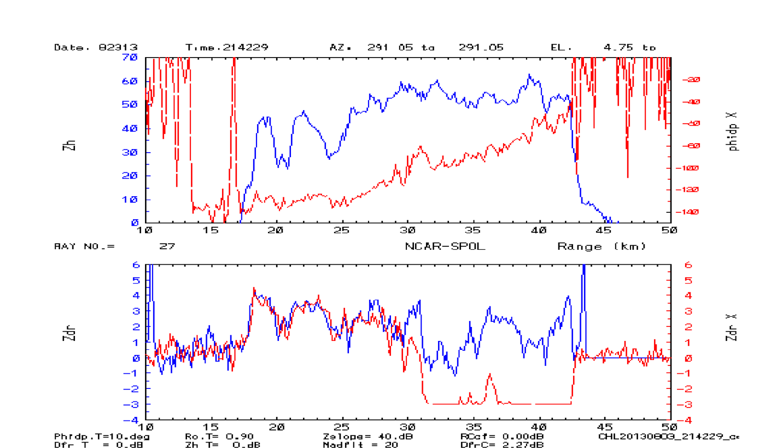
6. X-band Calculations







CHILL X band radar observations show a 'wall' of negative Z_{dr} (well below -3dB) at ~30 km range which may well be scattering effects, c.f. our results for the larger hail particles.



References:

Djordjević, M., Notaroš, B. M., 'Double higher order method of moments for surface integral equation modeling of metallic and dielectric antennas and scatterers', IEEE Transactions on Antennas and Propagation, 2004, 52, (8), 2118-2129.

Rasmussen, R. M., Heymsfield, A. J., 1987: 'Melting and Shedding of Graupel and Hail. Part I', *J. Atmos. Sci.*, 44, pp. 2754–2763.

Tabary, P., Vulpiani, G., Gourley, J. J., Illingworth, A. J., Thompson, R. J., Bousquet, O., 2009: 'Unusually High Differential Attenuation at C Band: Results from a Two-Year Analysis of the French Trappes Polarimetric Radar Data', *J. Appl. Meteor. Climatol.*, 48, pp. 2037–2053

Thurai, M., Huang, G. J., Bringi, V. N., Randeu, W. L., Schönhuber, M., 2007: 'Drop Shapes, Model Comparisons, and Calculations of Polarimetric Radar Parameters in Rain', *J. Atmos. Oceanic Technol.*, 24, pp. 1019–1032

Thurai, M., Chobanyan, E., Bringi, V. N., and Notaroš, B.M., 2015: Large Raindrops Against Melting Hail: Calculation of Specific Differential Attenuation, Phase and Reflectivity, *Electronics Letters*, 51, Issue 15, p. 1140 –1142

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