Hydrometeor Types Associated with GMI Brightness Temperatures

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Overview

The main goal of this project is to assess and understand how passive microwave brightness temperature values relate to particular hydrometeor types. The hydrometeor types are taken from dual polarization radar hydrometeor identifications in the GPM Validation Network database of matchups between the GPM Microwave Imager (GMI) and dozens of ground radars mostly in the U.S.

Hydrometeor types are computed for the GPM Validation Network following Dolan et al. (2013), and ranked in a hierarchy as:

1) Hail or Large Drops (from melted hail)
2) High-density graupel
3) Low-density graupel

Both graupel categories sometimes grouped together

4) Snow / Aggregates
5) Vertically Aligned Ice / Ice Crystals
6) Rain
7) Drizzle

For any given GMI footprint, the brightness temperatures (or polarization corrected temperatures (PCT) are assigned to the highest ranking hydrometeor category anywhere in that footprint, with ranking based on the hierarchy above.

For brightness temperature measurements in individual channels, brightness temperature differences between selected channels, and for multi-dimensional combinations of channels, we compute the conditional probability of a given hydrometeor type being present. Calculations are conditioned on precipitation being identified by the ground radar.

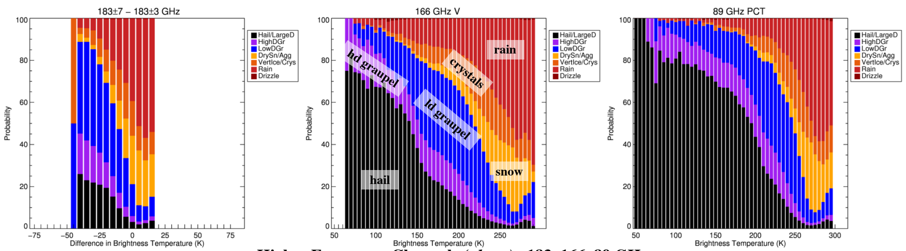
Currently the analyses are framed in terms of brightness temperatures being reduced due to particle scattering.

Notes on Methodology:

The approach here assumes that the highest-ranking particle types in our hierarchy (hail, then graupel, then snow / aggregates, etc.) are most important for generating a given GMI signature.

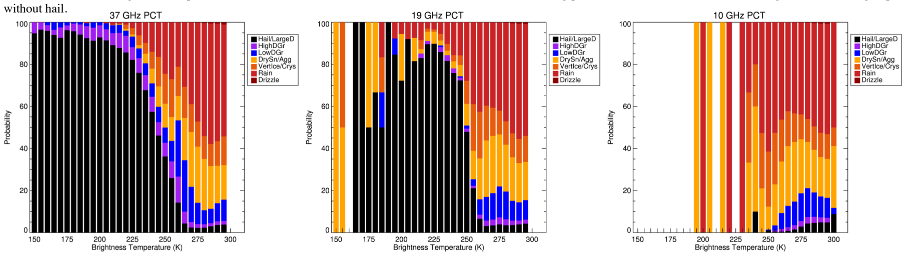
The lower-ranking particle types are often present in a footprint together with the higher-ranking types.
If a footprint is designated as having hail, it likely also has several of the other particle types present somewhere in the footprint.
If a footprint is designated as high-density graupel, by definition it lacks hail, but it likely has several of the other particle types.
If a footprint is designated as snow / aggregates, then it lacks hail and the graupel categories, but may include the lower-ranked categories.

PCT are computed following Cecil and Chronis (2018 JAMC) for 10 and 19 GHz, Toracinta et al (2002 MWR) for 37 GHz, and Spencer et al. (1989 JAOT) for 89 GHz:
$PCT_{10} = 2.5\ TB_{10v} - 1.5\ TB_{10h}$; $PCT_{19} = 2.4\ TB_{19v} - 1.4\ TB_{19h}$; $PCT_{37} = 2.2\ TB_{37v} - 1.2\ TB_{37h}$; $PCT_{89} = 1.82\ TB_{89v} - 0.82\ TB_{89h}$



Higher Frequency Channels *(above)* 183, 166, 89 GHz

The highest frequencies have strong sensitivity to graupel, and some sensitivity to snow/aggregates and hail. The likelihood of graupel occurrence – whether high or low density – rapidly increases with decreasing brightness temperature, or with the difference between (183+/-7 GHz – 183+/-3 GHz) channels becoming increasingly negative.
A strong signature in the (183+/-7 – 183+/-3) difference indicates that graupel is present, but does not particularly distinguish between low density graupel, high density graupel, and hail. The lowest brightness temperatures at 166 GHz and 89 GHz indicate about a 3/4 chance of hail being present, but about a 1/4 likelihood the signal results from graupel without hail.



Lower Frequency Channels *(above)* 37, 19, 10 GHz

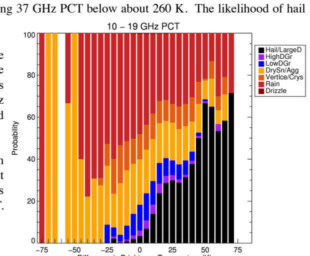
The 37- and 19-GHz frequencies have strong sensitivity to hail, with sensitivity to other hydrometeor types appearing to be mostly coincidental. This is not necessarily hail reaching the surface, but hail somewhere in the vertically slanted column. The hydrometeor identification does not distinguish hail size. A likelihood of graupel does increase with decreasing 37 GHz PCT between about 275-260 K. The likelihood of hail then rapidly increases with decreasing 37 GHz PCT below about 260 K. The likelihood of hail exceeds 90% for 37 GHz PCT below 210 K.

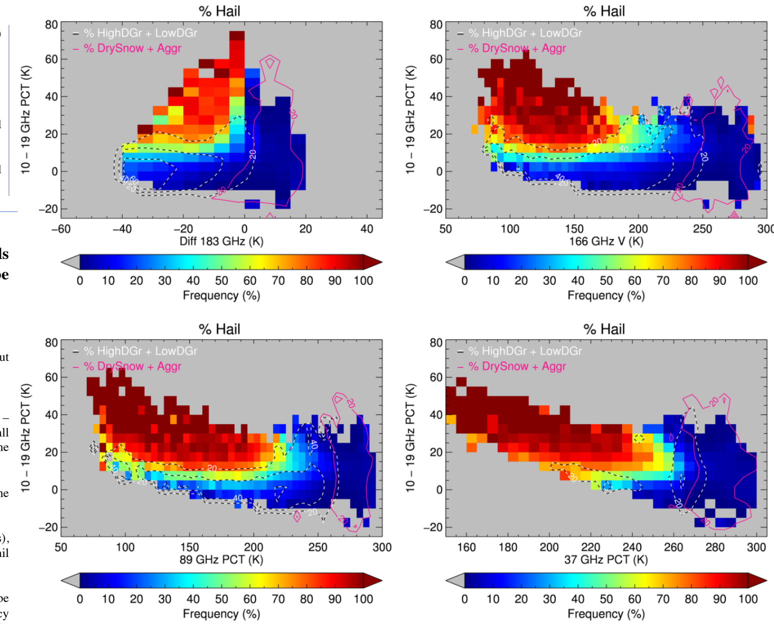
19 GHz PCT exhibits hardly any sensitivity to graupel without hail. Probability of hail rapidly increases with 19 GHz PCT decreasing below 255 K. Below about 215 K, probability of hail slowly decreases. This requires investigation, but one guess is that it may involve a combination of nonuniform beamfilling and surface snow or ice cover somewhere within the large 19 GHz footprint.

Relationships between 10 GHz PCT and particle type are not apparent. We suspect this is due to the large footprint size (32 km x 19 km). Individual cases have been noted where low 10 GHz PCT corresponds to hail, but this does not come through as an empirical result.

Since 10 GHz with its large footprint shows little sensitivity to particle type, we tested the difference (10 GHz PCT – 19 GHz PCT). We think of this as indicating the magnitude of the 19 GHz depression, relative to a less perturbed background state.

Increasing 10-19 GHz differences indicate an increasing likelihood of hail. However, the largest differences do not reach the high hail probabilities that are achieved by low values of 37 GHz PCT. This requires further investigation





At Right:
Combining information from multiple channels helps distinguish which particle types should be expected.

Color shading: Probability of hail.
Dashed, white contours: Probability of graupel, without hail.
Solid, pink contours: Probability of Snow / Aggregates without hail or graupel.
Contour intervals: 20%

Increasing 10-19 GHz PCT difference, decreasing (183+/-7 – 183+/-3) difference, and decreasing TB or PCT in other channels all suggest hail. So hail is favored in the upper parts of plots, and the leftward parts of plots.

For a given low brightness temperature (leftward parts of plots), the 10-19 GHz PCT difference helps make a hail / no-hail distinction.

For a given large 10-19 GHz PCT difference (upper parts of plots), the TB or PCT in higher frequencies helps make the hail / no-hail distinction.

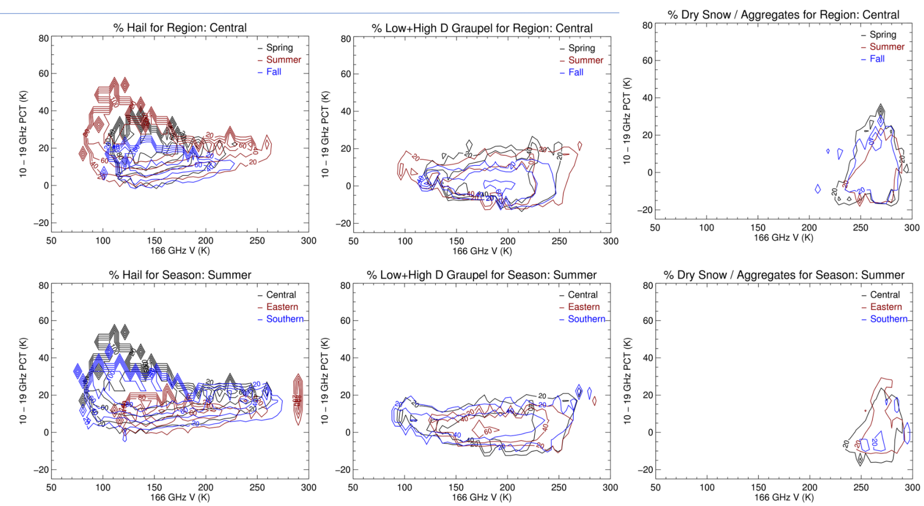
The distinction between graupel and snow/aggregates appears to be pretty well made by the TB or PCT in the higher frequency channels (left-right separation between dashed and solid contours in these plots). Similar plots using high frequency channels for both axes (instead of including 10 & 19 GHz) may help refine that distinction.

Dependence on region, season? *(at right)*

The data here primarily come from WSR-88D radars east of the Rocky Mountains, in the USA.

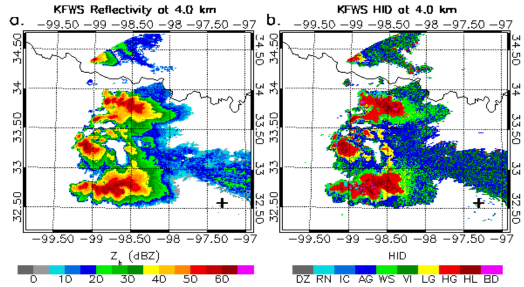
We separated radars by Central, Eastern, and Southern regions, and separated the four seasons. Winter is not shown in the plots here, because winter sample sizes including hail are small.

These separations suggest that the relationships between TB or PCT and particle type are very consistent. The main differences have to do with certain parts of the parameter space being occupied more often in certain seasons or regions than others. Values of 10-19 GHz PCT difference exceeding 20 K occur most often in Summer, and occur less often in the Eastern region than in Central or Southern regions. (Those 10-19 differences values over 20 K are suggestive of hail, unless there is a high 166 GHz TB… this pattern also shows up in all seasons.)



Radiative Transfer Modeling Overview

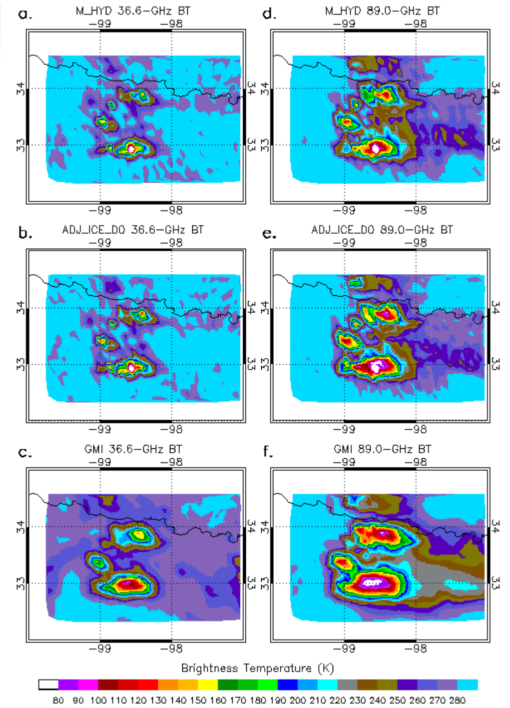
- GMI TBs were simulated using the Atmospheric Radiative Transfer Simulator over a case of severe hail near the Dallas/Ft. Worth WSR-88D (KFWS) on 26 May 2015.
- In the hydrometeor classification algorithm, a score is assigned to each possible hydrometeor type based on how well that type fits the polarimetric measurements.
- For calculating the particle size distributions (PSDs) of each hydrometeor type for the simulations, those scores are treated as representing the relative contribution to total radar reflectivity (Zh) from each hydrometeor type. For example, if a grid box has Zh = 50 dBZ (1 x 10^5 mm^6/m^3) with scores of 6 from hail, 4 from high-density graupel, and 0 from everything else, we treat that grid box as having 6 x 10^4 mm^6/m^3 (48 dBZ) from hail and 4 x 10^4 mm^6/m^3 (46 dBZ) from high-density graupel.
- The normalized gamma distribution was used as the form of the PSD of each hydrometeor type which has three parameters: intercept parameter, median diameter, and shape parameter.
- The median diameter (D_o) and shape parameter were specified for each simulation. The intercept parameter was then calculated such that the resulting calculated Zh matched that apportioned to each hydrometeor type described above. Thus, all simulations were performed under the constraint of constant mass or Zh.
- There are 2 specific goals of these simulations: A better understanding of 1.) how simulated GMI TBs respond to changing PSD parameters under conditions of fixed mass and 2.) how low would BTs be expected to achieve from realistic (albeit extreme) particle sizes or concentrations.



(Above) a.) Gridded reflectivity and b.) the associated hydrometeor identification from KFWS valid 2225 UTC 26 May 2015 at a height of 4 km.

The hydrometeor types are drizzle (DZ), rain (RN), ice crystals (IC), aggregates (AG), wet snow (WS), vertically-aligned ice (VI), low-density graupel (LG), high-density graupel (HG), hail (HL), and big drops (BD). The black cross indicates the location of the radar.

For the simulations, DZ and RN, IC and VI, and AG and WS are combined into 3 categories.

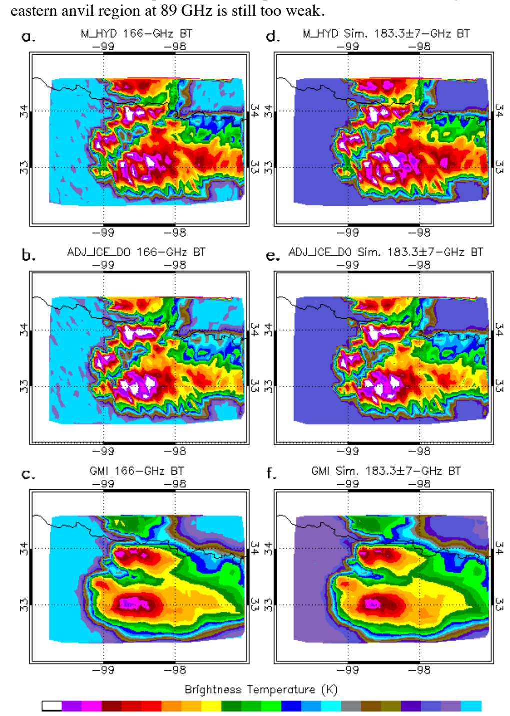


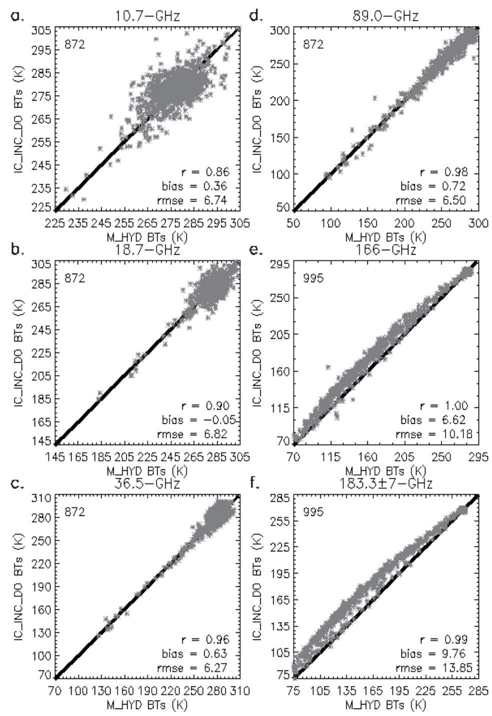
Maps of simulated TBs from the control simulation (M_HYD) are shown in the top row of the figure above and below, while the bottom row of each figure shows corresponding observed TBs.

At the two highest frequencies (below), simulated scattering is too strong in the anvil region but too weak over the hail core of the southern convective cell.

Based on results of prior simulations, simulations were conducted where D_o of ice was increased while D_o of hail and graupel were reduced (e.g., ADJ_ICE_D0) to get simulated TBs closer to those observed (middle row of figure above and below).

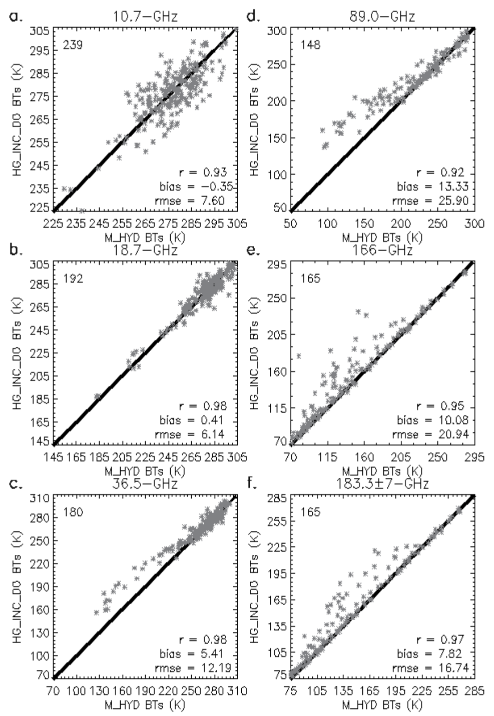
In general, there is better agreement between observed TBs and ADJ_ICE_D0 TBs than between observed and control TBs at frequencies ≥ 89 GHz with little impact at lower frequencies. However, scattering in the eastern anvil region at 89 GHz is still too weak.





(Above) Scatterplot of simulated TBs from IC_INC_D0 (D_o = 0.4 mm for ice) as a function of simulated TBs from M_HYD (control simulation; D_o = 0.2 mm for ice) valid at various frequencies (all horizontally polarized except 183 GHz). The correlation coefficient (r), bias, and root-mean-square error (rmse) are given in the bottom-right corner of each panel. Sample size is given in the top-left corner of each panel.

Increasing D_o (reducing concentrations) of ice crystals under fixed mass results in warmer TBs at the 2 highest frequencies and little effect at other frequencies.



(Above) Scatterplot of simulated TBs from HG_INC_D0 (D_o = 4.5 mm for HG) as a function of simulated TBs from M_HYD (D_o = 2.5 mm for HG) valid at various frequencies. Only pixels that sample HG are included here (sample size is given in the top-left corner of each panel).

Increasing D_o (reducing concentrations) of HG has little impact at 10 and 18 GHz, but results in less scattering at 36-183 GHz.

Changing PSD of LG, snow, and liquid hydrometeor types appears to have little effect at any frequency, but this may be due to the presence of other more dominant hydrometeor species.

Frequency (GHz)	20 cm Hail		0.5 cm Hail	
	Minimum	1st Percentile	Minimum	1st Percentile
10	230.1	251.3	109.9	126.5
18	237.1	260.5	33.3	41.9
36	231.4	260.2	22.1	26.0
89	260.4	270.7	46.1	51.7
166	277.1	277.8	100.5	108.6
183	263.9	264.3	106.2	114.9

Simulations were conducted with a single size of hail where the hail concentration was constrained by the observed Zh.

(Left) Minimum TB and first percentile TB from simulations that contained only 20-cm or 0.5-cm hail stones.

In general, the extremely low concentrations of 20-cm cause little scattering at any frequency. In contrast, the high concentrations of small hail cause very strong scattering.

Given fixed mass, these results suggest higher number concentrations may be more important than size for generating extremely low TBs