Hail Retrieval and Climatology from GPM

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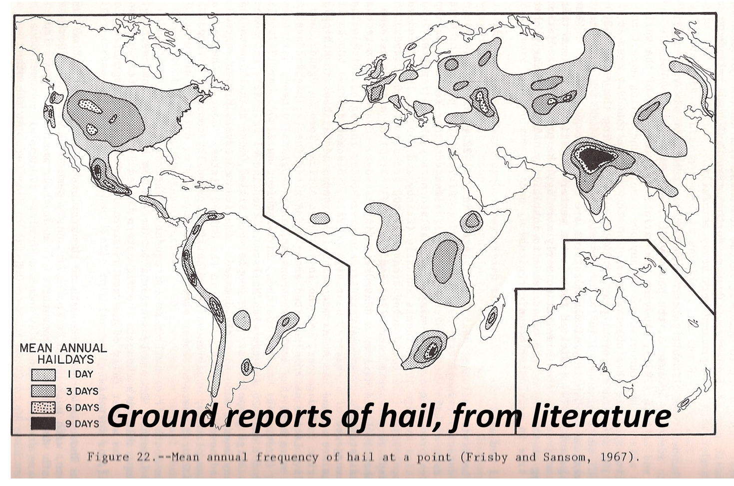
Why study hail using GPM, versus observations from the ground?

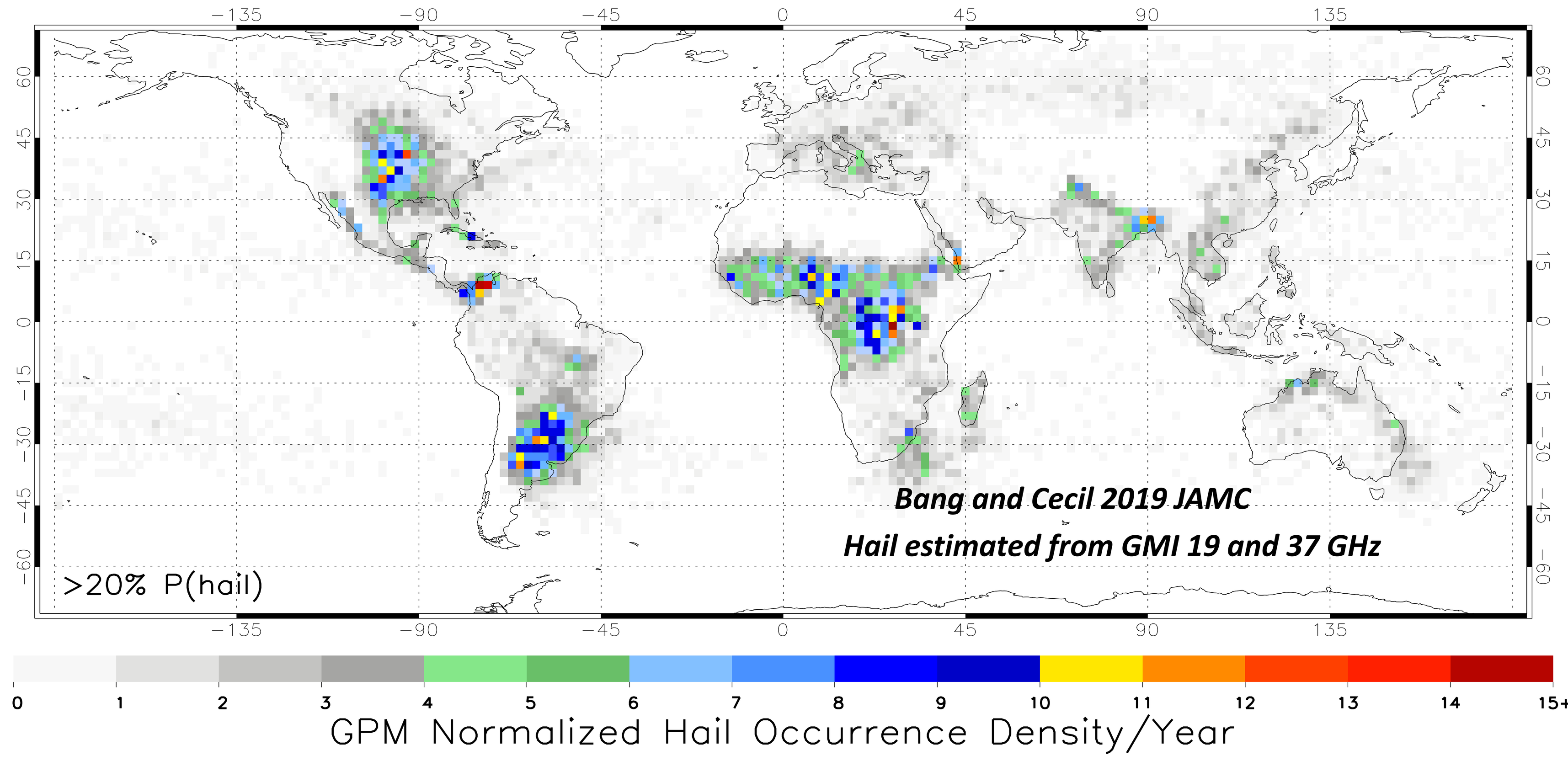
Hardly any global ground-based studies in literature. (Map below from Williams 1973, based largely on Frisby and Sansom 1967)

Reporting standards vary around the world, and through the years

Studies in different locations are not consistent…



Ground reports of hail, from literature



Bang and Cecil 2019 JAMC
Hail estimated from GMI 19 and 37 GHz

- GPM can compile **near-global maps** using a consistent approach and **uniform measurement standard**
- But measurements are only *proxies* for hail, or for storm severity.
- Accuracy of the proxies must vary with meteorological environment.

19 GHz channel is less sensitive to smaller particles than the higher frequency channels do. The smaller footprint size of the GMI 19 GHz channel (18x11 km) is more relevant to thunderstorms than on previous coarser-resolution imagers.

The likelihood of large hail (at least 1-inch, per reports in the USA) increases rapidly for 19 GHz PCT (polarization corrected temperature) decreasing below about 270 K. Below ~240 K, the estimated empirical probability of large hail approaches ~80%. We parameterize the empirical probabilities and treat them as approaching 100%, to account for under-reporting in the ground-based database.

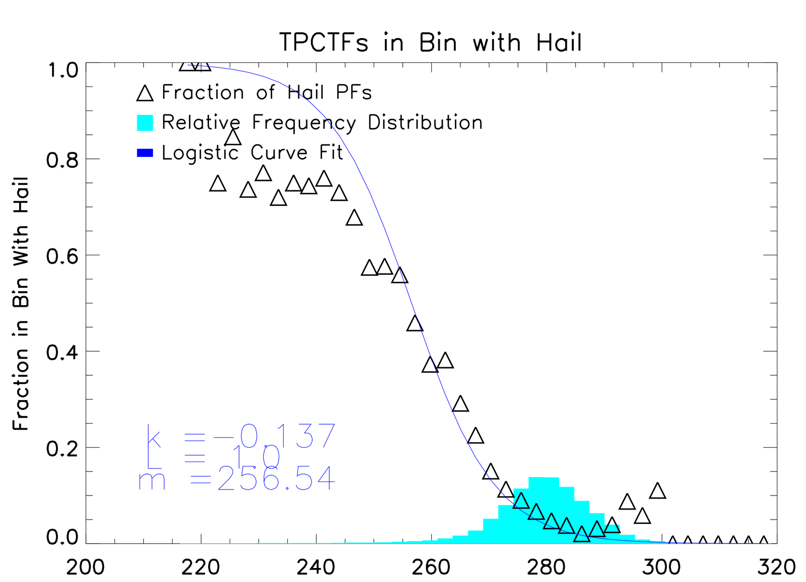
Passive microwave brightness temperatures decrease with increasing amounts of large graupel and hail.

We normalized the 37-GHz depression (maximum - minimum 37 GHz PCTs within a convective feature) by the height of the tropopause (LRT: lapse rate tropopause). This takes into account the effect of a vertically deep layer of graupel scattering away more radiation, even if the particle sizes are not larger than in a shallower layer.

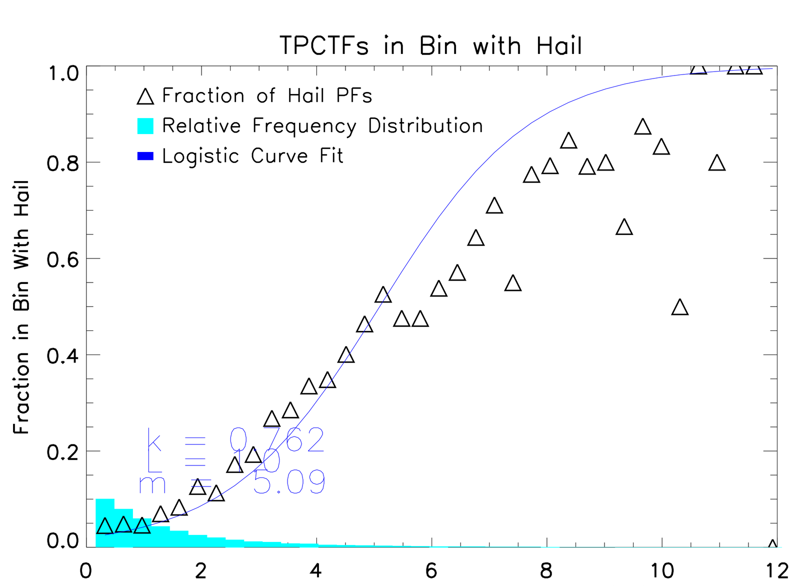
With this normalized 37-GHz depression increasing between values of ~2-8 K / km, the probability of large hail reports increases from ~10% to ~80%.

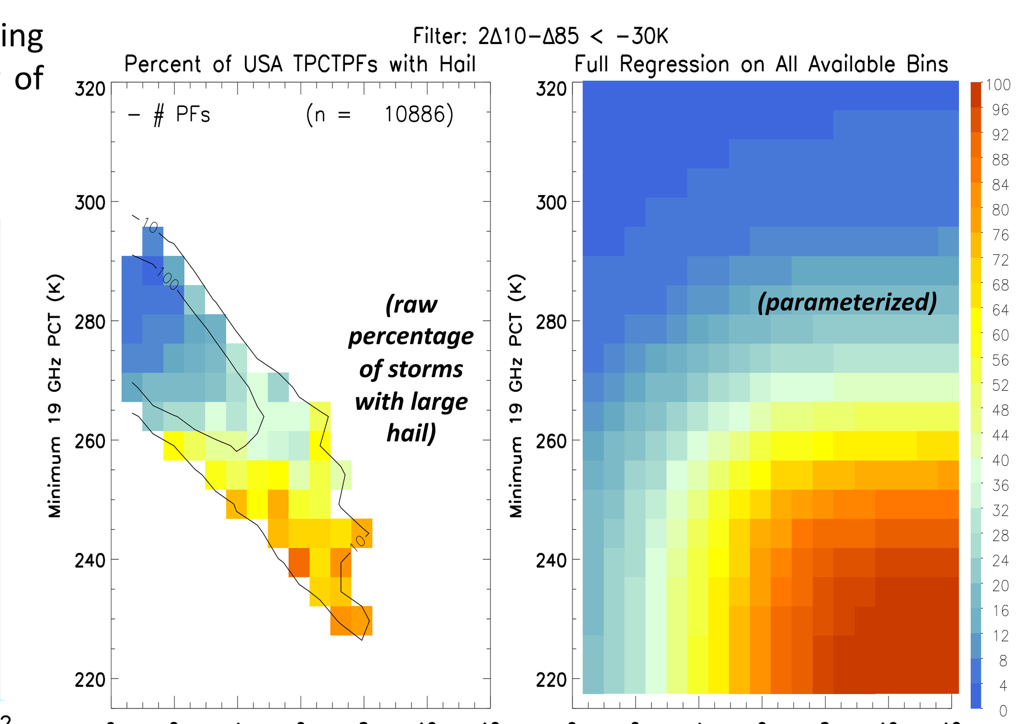
We combine the hail probabilities based on Minimum 19-GHz PCT and Normalized 37-GHz Depression (below).

The combination weights low hail probabilities from either channel more heavily than high probabilities. I.e., if a potential storm has a much stronger signature in one channel than in the other, that strong signature may be an artifact.



Minimum 19 GHz PCT [K]





Normalized 37-GHz Depression = ($Max37_{PCT}$ – $Min37_{PCT}$) / (Height of Tropopause) [K / km]

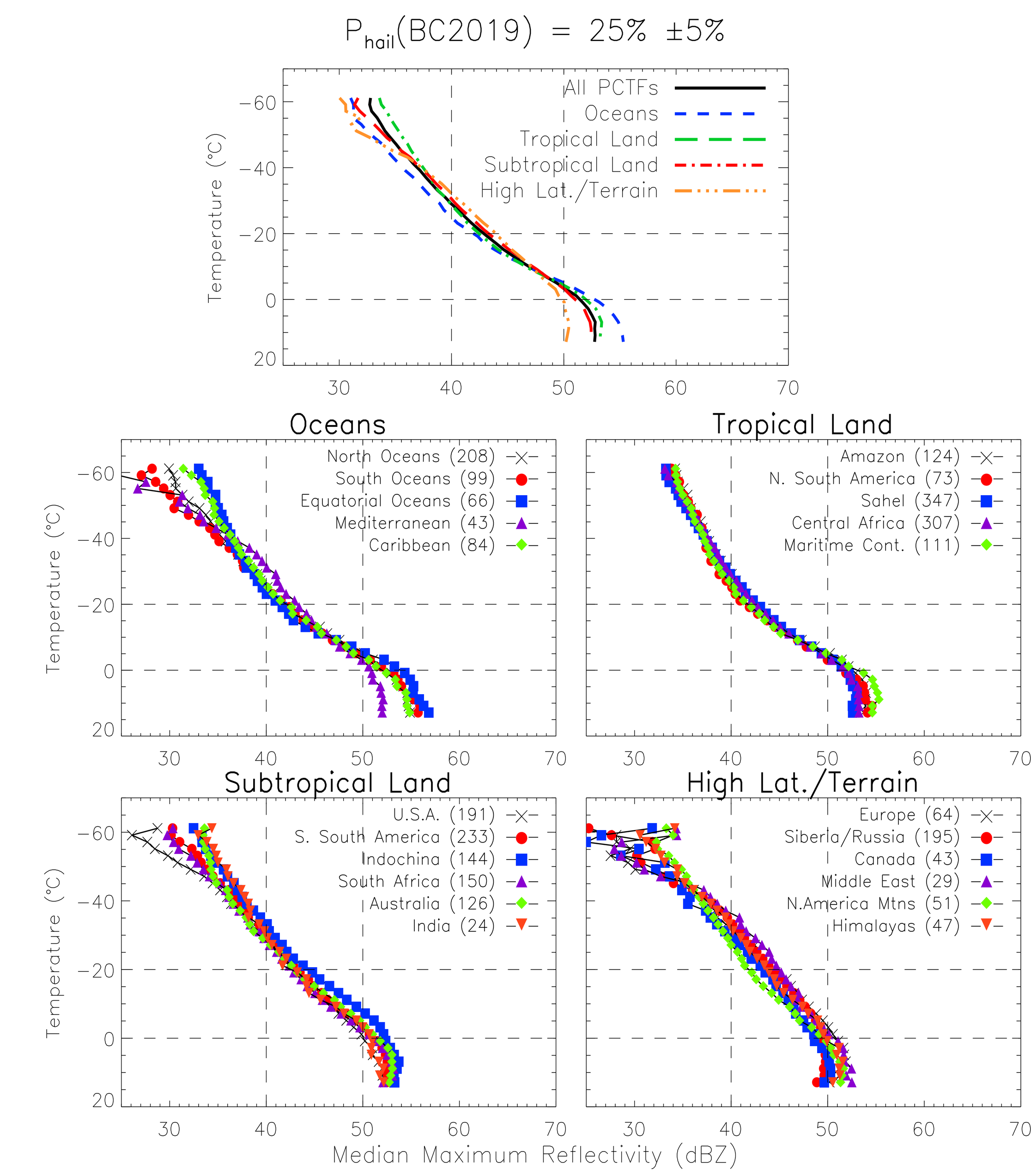
Are the hail estimates consistent across regions?

The hail probability algorithm is trained using reports of large hail (at least 1-inch diameter) from the Storm Prediction Center matched with TRMM-defined features in USA. Relationships between microwave brightness temperature, storm structure, and particle types likely vary with environmental conditions.

The GPM Ku-band radar (attenuation-corrected reflectivity product*) is used here to test how much variability there is for a given passive-microwave-based hail probability. If the radar profiles vary widely in the mixed-phase region, that probably suggests that the hail probability is being overstated in some regions and understated in others.

** Since these are deep profiles of high reflectivity, our confidence in the estimated radar reflectivity decreases downward toward the surface.*

Left: Features estimated as having 25% probability of hail

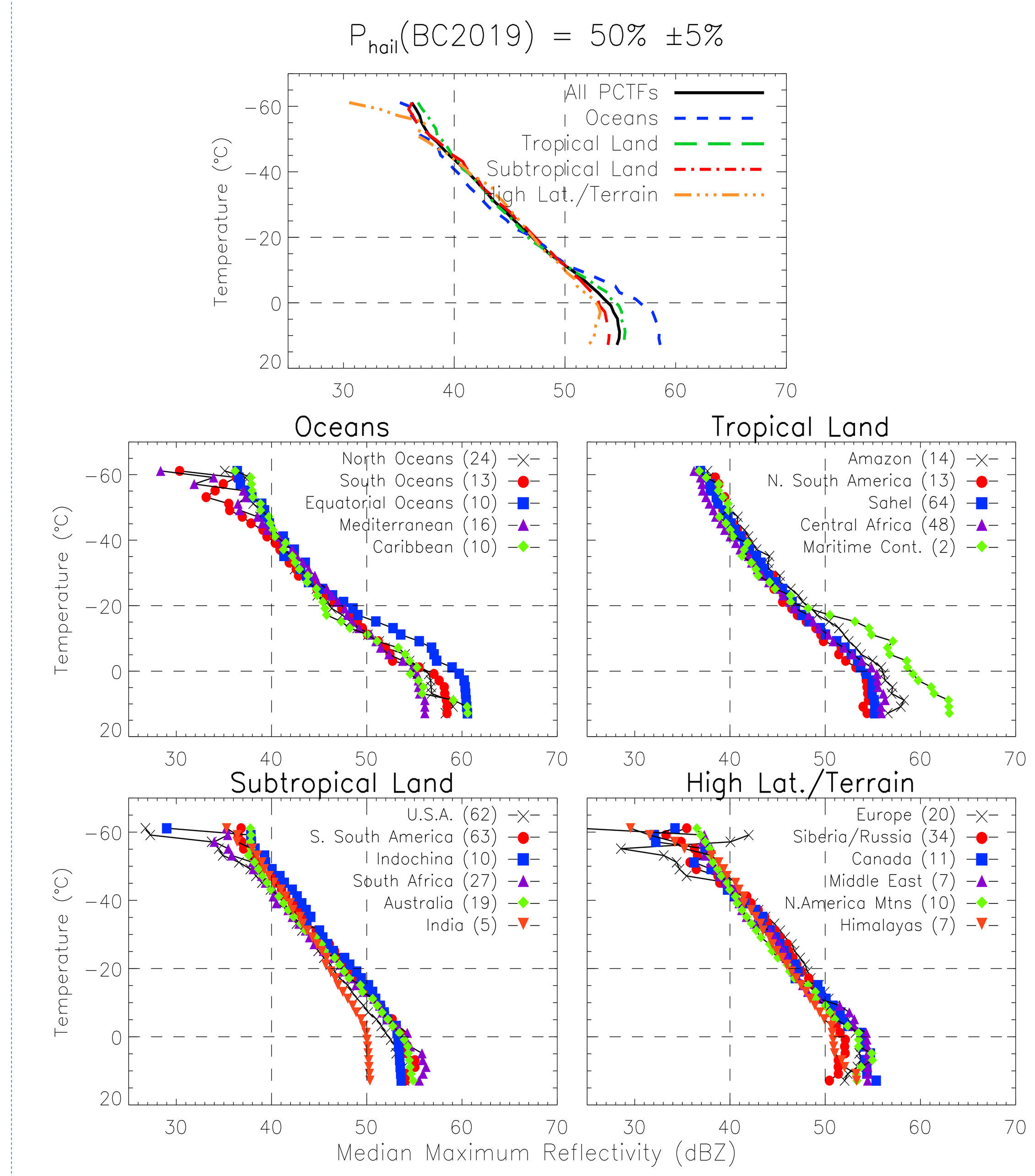


For a 25% probability of hail (based on the Bang and Cecil 2019 combination of Minimum 19 GHz PCT and normalized 37-GHz Depression), radar profiles for all the regions appear consistent with a plausible chance of large hail.

Oceanic regions have slightly lower reflectivity aloft for storms that satisfy this 25% hail probability, especially the Equatorial and Caribbean regions.

High latitude and high terrain features *that survive our snow screens* tend to have the highest reflectivity values aloft, especially those in Asia.

Right: Features estimated as having 50% probability of hail



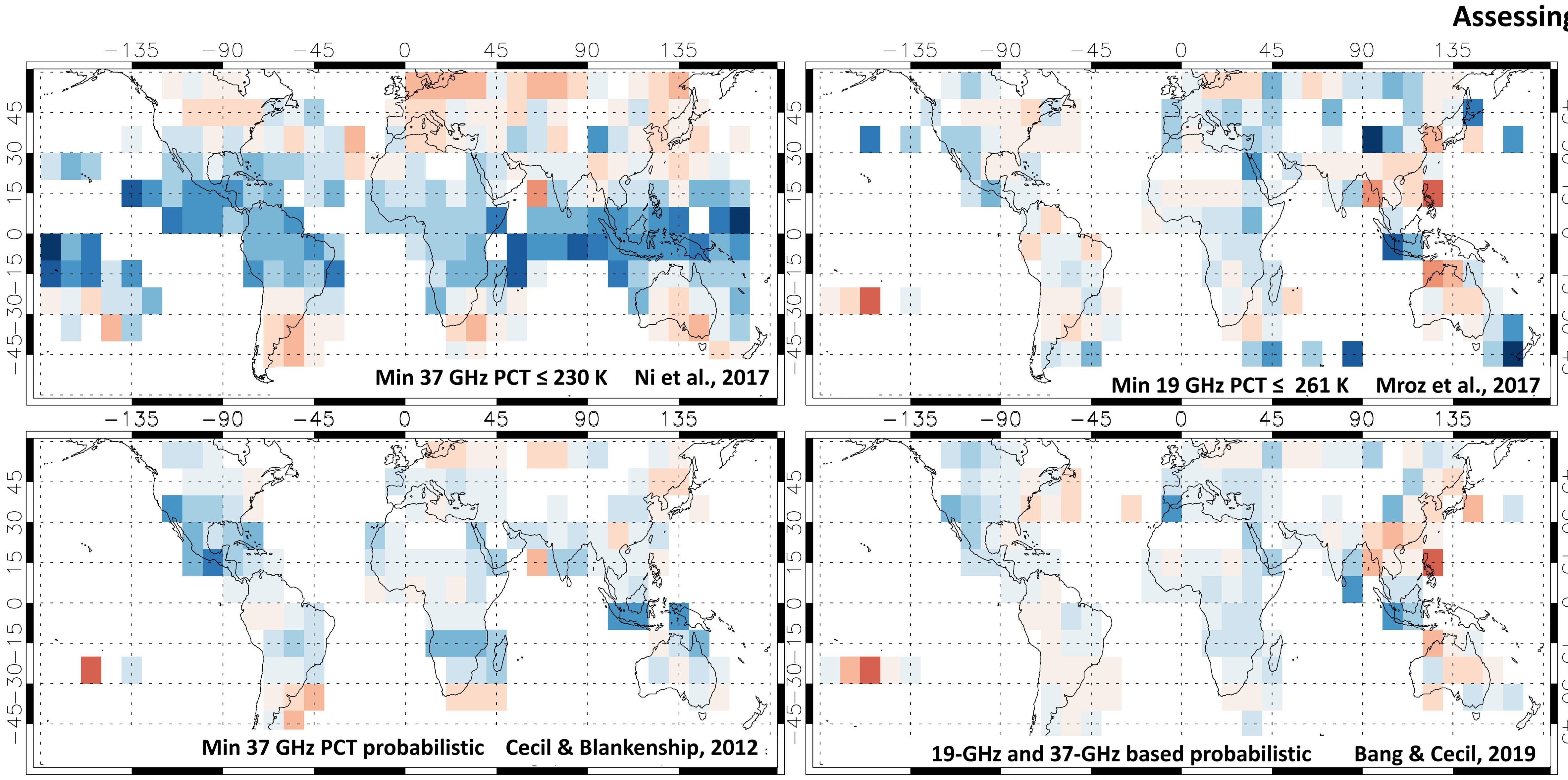
For a 50% hail probability, radar profiles from the different regions show close agreement at altitudes above -10° C.

Exceptions are the regions with very small sample sizes of storms satisfying this 50% hail probability.

The top plot shows the hail probability-weighted median profiles for all features meeting the probability criterion in the 4 geographic regimes.

Dashed lines at 40 and 50 dBZ (x-axis) and 0° and -20° C (y-axis) are for comparison across plots.

Assessing Global Climatologies of Hail

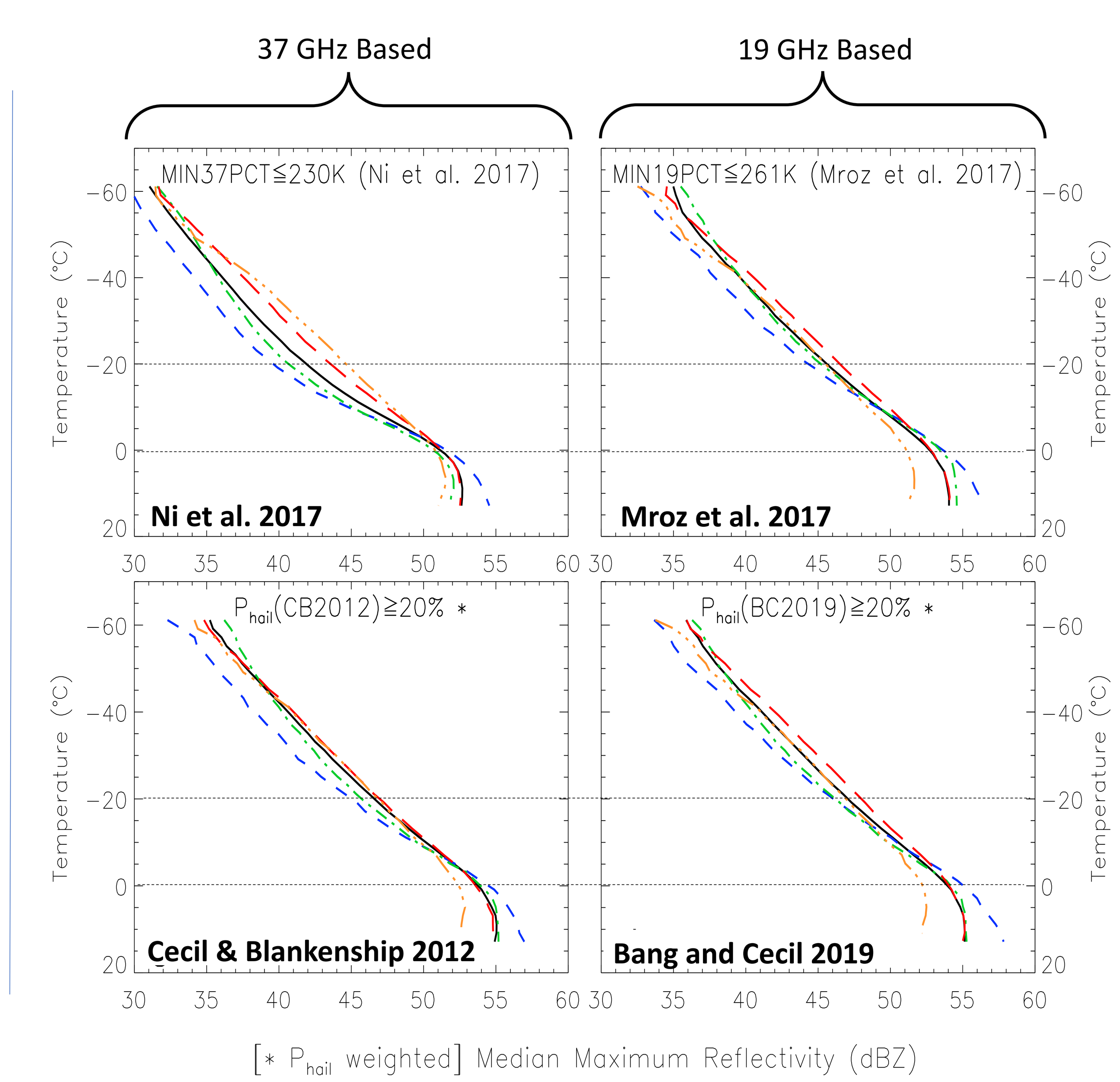


Red shades: Radar data stronger than expected, suggests an underestimate of hail

Blue shades: Radar data weaker than expected, suggests an overestimate of hail

Radar reflectivity at -10° C level is used to evaluate the hail estimates. For each feature identified as likely to have hail, its reflectivity at -10° C is compared to the median from the entire hail-likely sample.

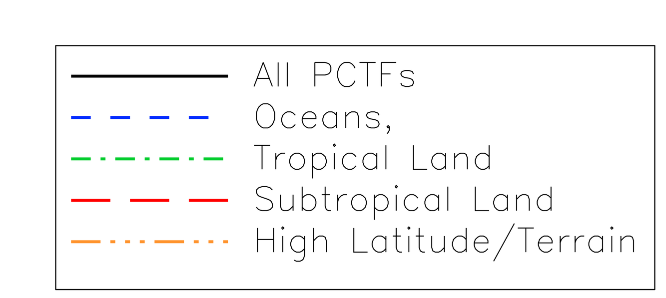
The bottom panels use probabilistic hail estimates, instead of binary thresholds, so their reflectivity deviations are weighted by the hail probability for each individual storm.



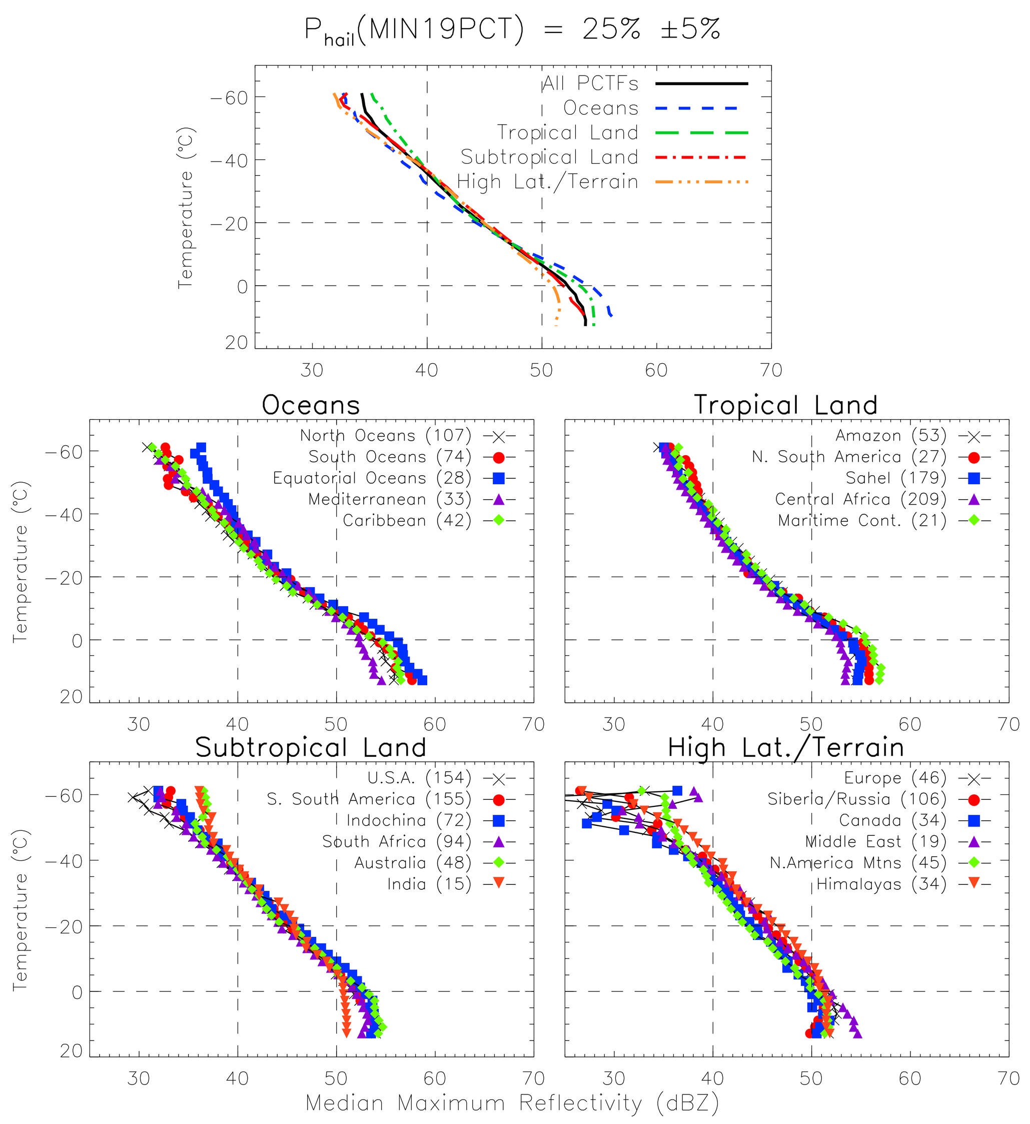
Including the 19-GHz channel (right panels; Mroz et al. 2017 and Bang and Cecil 2019) improves upon using only the 37-GHz (left panels; Ni et al. 2017 and Cecil and Blankenship 2012).

The newest approach (Bang and Cecil 2019), which employs both the 19 GHz channel and the 37 GHz channel (normalized by the height of the troposphere) appears to reduce much of the regional bias from prior approaches, as evidenced by the tight grouping of the profiles, especially above the freezing level.

Ni et al. (2017) noted overestimation in the tropics when using 37-GHz, compared to using radar. Cecil and Blankenship (2012) accounted for this by using different relationships in tropics vs extratropics.

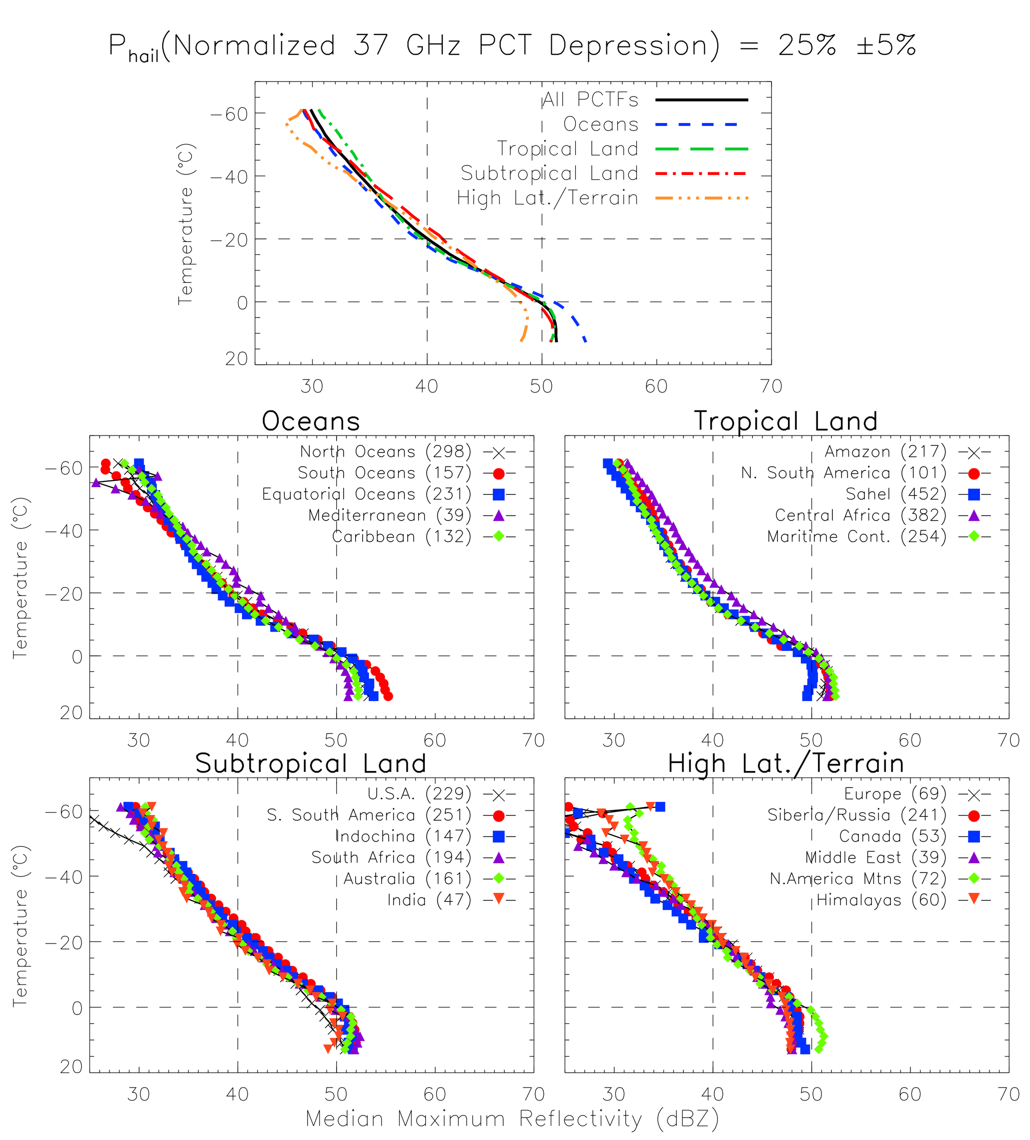


Since the Bang and Cecil (2019) hail probabilities involve a combination of estimates from the Minimum 19-GHz PCT and the Normalized 37-GHz Depression, those two parameters are examined individually in the panels below.



For 25% hail probability based on Minimum 19 GHz PCT by itself, radar profiles for all the regions do appear consistent with a plausible chance of large hail. These radar profiles are stronger than the ones for 25% hail probability from the combination of 19- and 37-GHz parameters (at left), or from 37-GHz by itself (below).

The profiles from different regions closely agree with each other above the -10° C temperature level, except for a bit more variability among the high-latitude or high-terrain regions.



For 25% hail probability based on Normalized 37-GHz Depression by itself, radar profiles are a bit weaker and show more variability between the regions. The tropical oceanic radar profiles are the weakest. While these do depict very strong convection, they are less suggestive of large hail than many of the other radar profiles.

The Tropical Land radar reflectivity profiles with 25% hail probability based on Normalized 37-GHz Depression are also a bit weaker than the profiles from Subtropical Land, High Latitudes, or High Terrain. Among the Tropical Land regions, Central Africa produces the strongest radar reflectivity profiles.

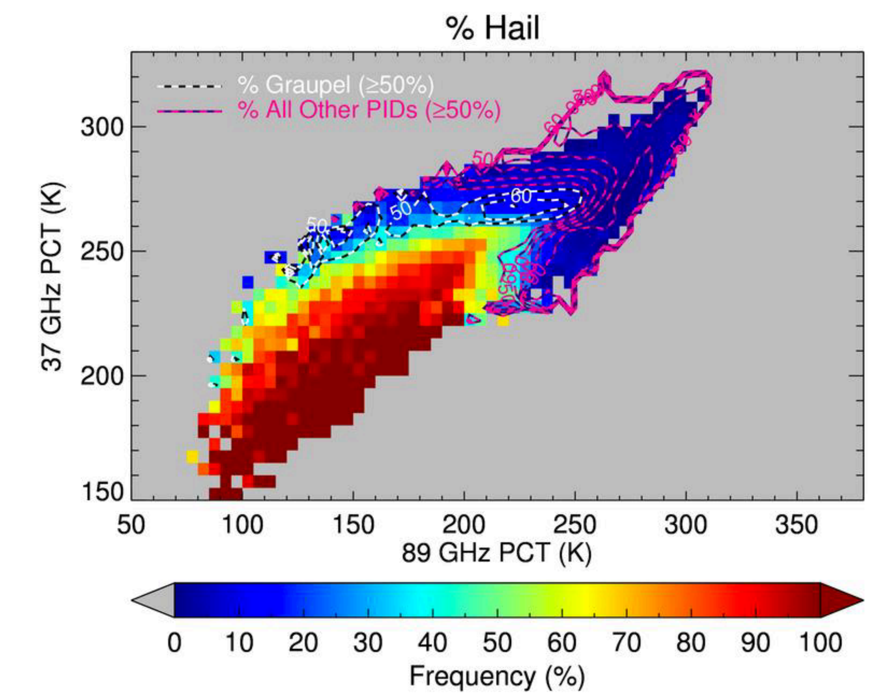
Our normalization of the 37-GHz Depression by tropopause depth does remove some of the differences between tropical and higher-latitude regions, but systematic differences do remain. Use of the 19-GHz channel removes more of these region-dependent differences.

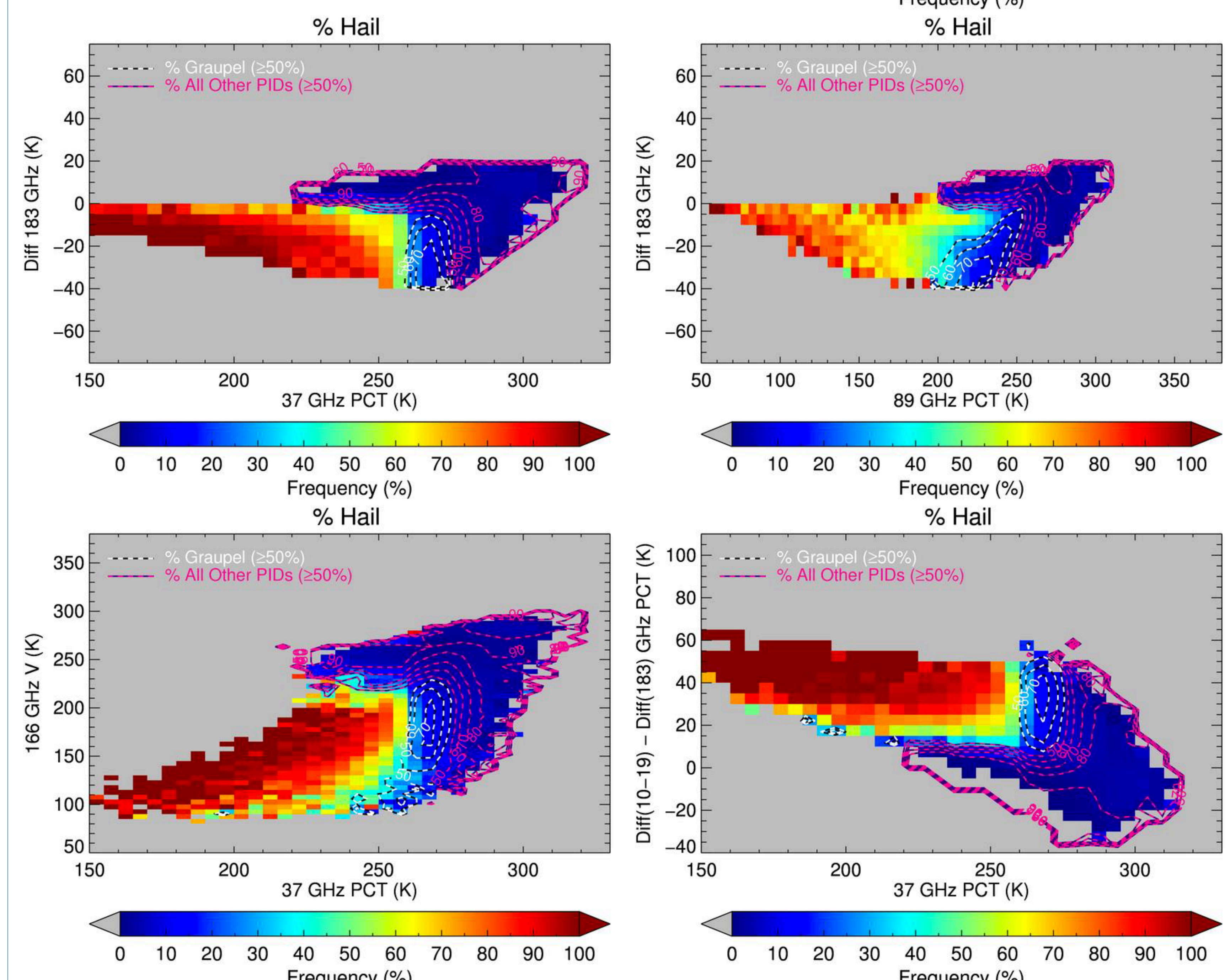
Assessment of Hydrometeor Type based on GMI and Dual-Pol Radar Comparisons

Using the GPM Validation Network dual-polarized radar database (mostly in USA), we generated empirical relationships between GMI brightness temperatures and hydrometeor types.

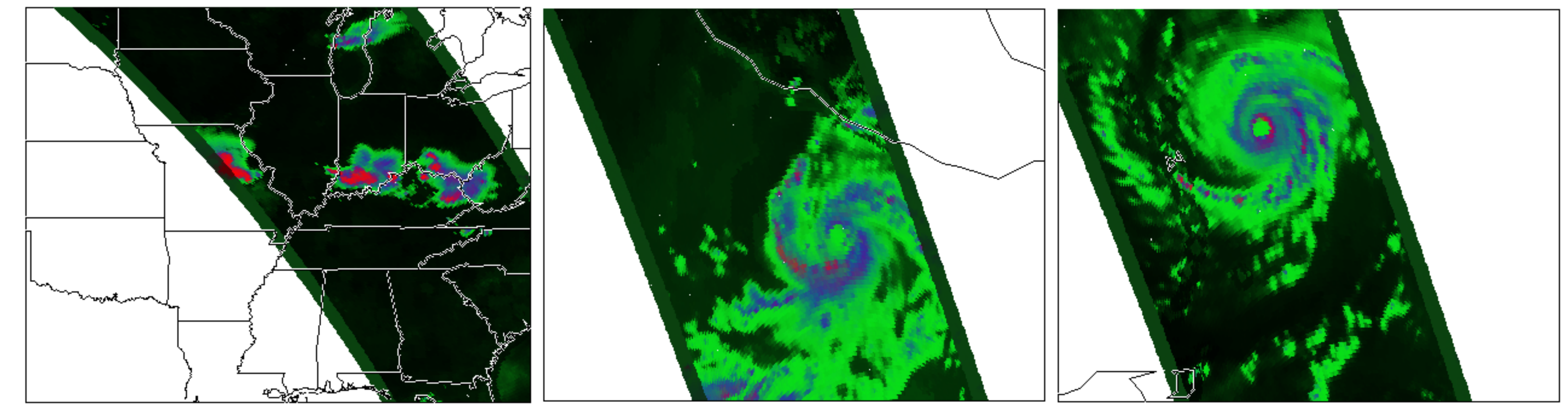
Each GMI pixel is assigned a probability that it has hail (along with any other particle types); graupel but no hail; snow or other ice except no graupel or hail; or only liquid. Those probabilities are further scaled by the GPROF Probability Of Precipitation.

The empirical probability of each hydrometeor type is computed separately for five different channel combinations. Then those five answers are averaged to get final estimates of the probability of each hydrometeor type for a given set of measured brightness temperatures.





Examples



Severe Thunderstorm Outbreak in Ohio Valley | Hurricane Patricia | Hurricane Irma

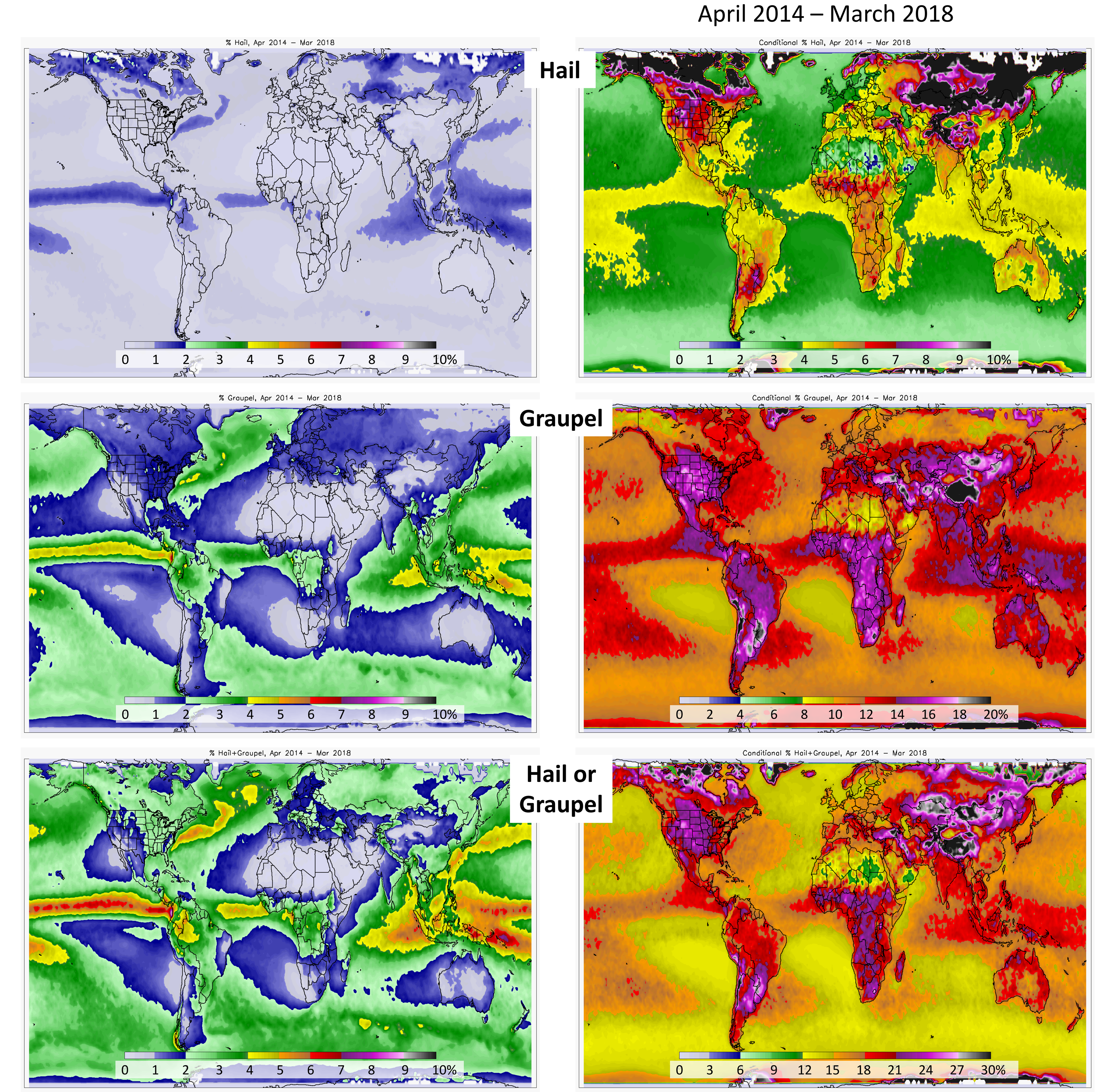
Red = Hail
Blue = Graupel
Green = Other Precip

So far, no surface snow / ice screen is applied. This leads to massive overestimation of hail and graupel at high latitudes, high terrain, and in the cold season, and likely other artifacts related to surface emissivity differences. [It's a work in progress!]

Training the retrievals with dual-pol radar gives a very different assessment of hail than training with ground-based reports of large hail. The dual-pol identifications of hail include smaller hailstones aloft that melt before reaching the surface. **As identified by dual-pol radar, hail is produced much more often and by weaker storms than as identified by ground reports of large diameter hail.**

Percentage of GMI pixels assigned as Hail or Graupel, April 2014 – March 2018

Conditional Probability of Hail or Graupel (normalized by precipitation occurrence), April 2014 – March 2018



Left Maps: Frequency of Occurrence
Right Maps: Conditional Probability of…

(1)Hail (with any other hydrometeor types)
(2)Graupel (with other types) *without hail*
(3) Hail or Graupel (with any other types)

Hail is retrieved most often in the ITCZ, and over warm currents (Gulf Stream, Kuroshio). These are locations where deep convection is common. 1-2% of GMI pixels there are estimated to contain hail. This is likely fairly vigorous convection that produces large graupel / small hail aloft that melts before reaching the surface. It is not what we think of as "hailstorms", but a reminder that the convective cores can be aviation hazards and may require microphysics schemes capable of representing large, dense ice.

The conditional probabilities (at right) turn attention more toward some of the places we think of for hailstorms, or at least very strong thunderstorm: Argentina / Southern Brazil / Paraguay / Uruguay; the Central USA; the Sahel in Africa… ~6-8% of the precipitating pixels there are estimated to have hail. In the ITCZ, only 4-5% of precipitating pixels are estimated to have hail.

This is very much a work in progress. *Artifacts from snow and ice cover have only been minimally filtered so far.* A next version will address filtering out surface-related artifacts better. Ratios between the conditional probabilities are each hydrometeor category may yield interesting patterns.