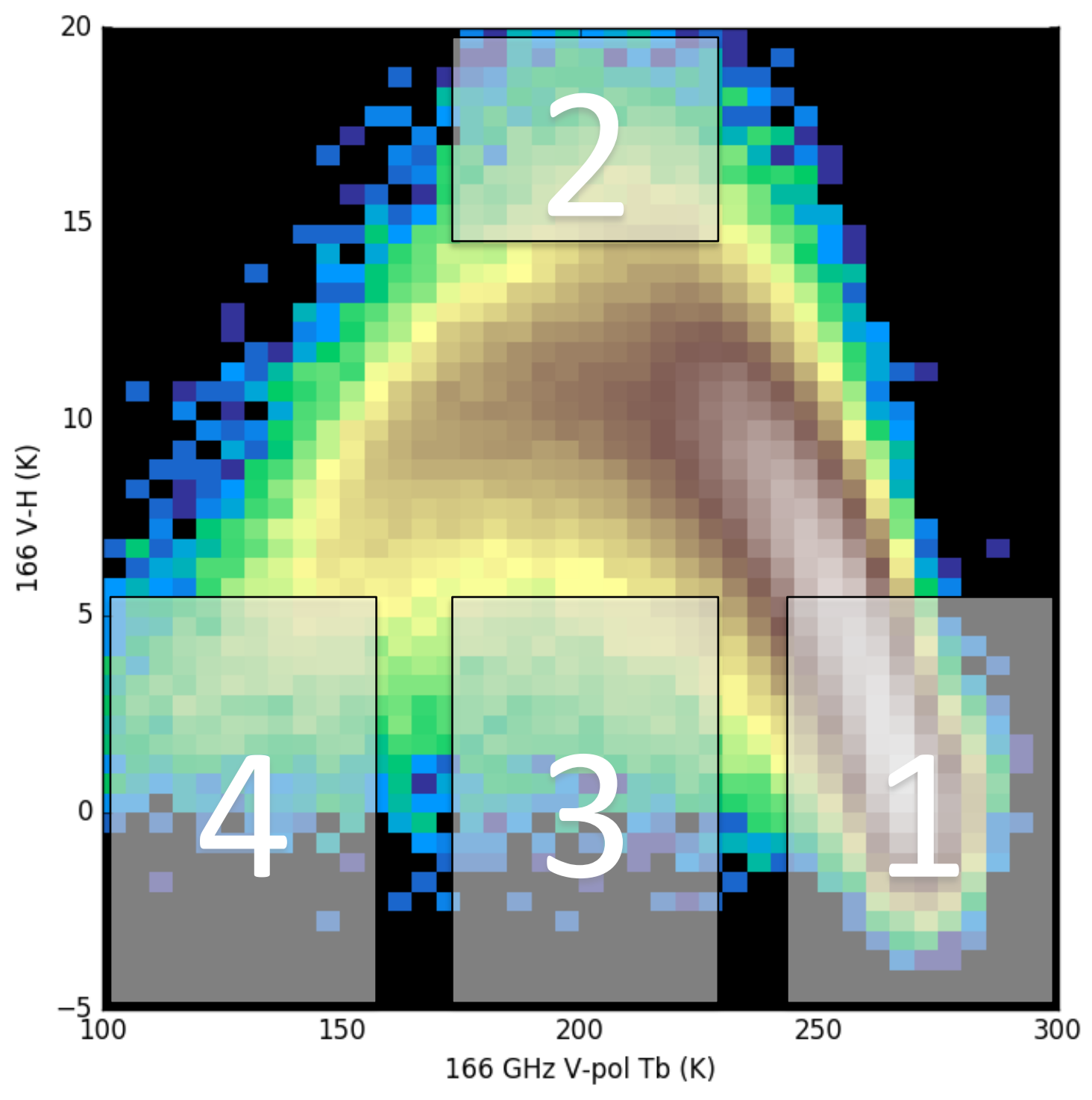
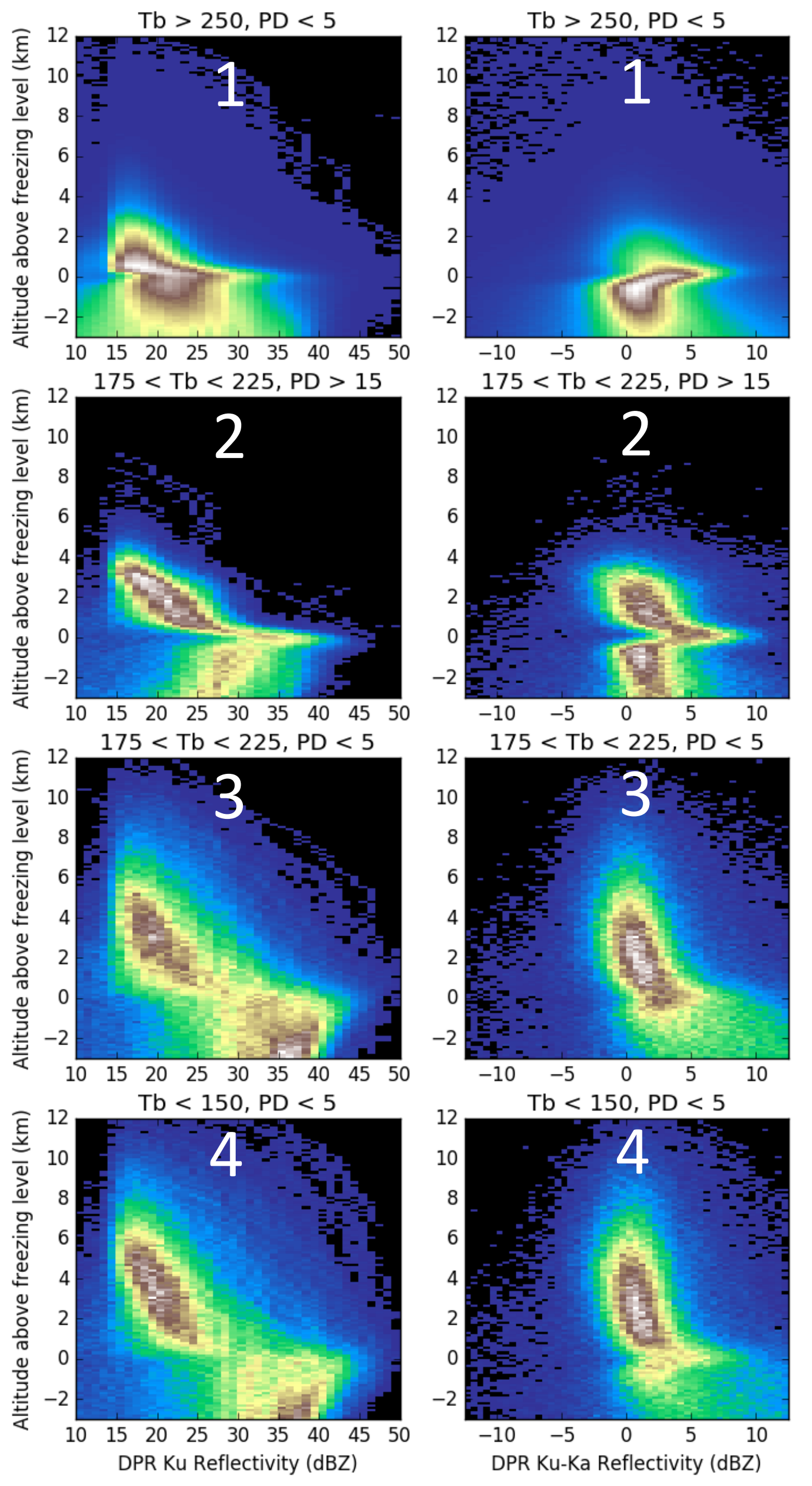
An Investigation of Precipitation-Induced Polarization at 166 GHz Observed by GMI

S. Joseph Munchak[1], Ian S. Adams[2], Benjamin T. Johnson[3,4]

1: NASA Goddard Space Flight Center 2: Naval Research Laboratory 3: Atmospheric and Environmental Research and NOAA/NESDIS/STAR



Above: 2D histogram of 166 GHz vertically-polarized Tbs and 166 GHz polarization difference (V-H) for precipitation profiles with an echo top above the freezing level and column water vapor > 20 mm. Labeled regions correspond to CFADs of Ku reflectiivty and Ku-Ka dual-frequency ratio below.



Introduction

The GPM Microwave Imager (GMI) is the first conically-scanning passive microwave radiometer to measure polarized radiation at 166 GHz from space. At this frequency, the atmosphere is essentially opaque to the surface when column water vapor exceeds 20mm. Thus, observations of polarized radiation in these environments must be induced by preferentially-oriented non-spherical particles in the atmosphere.

Regional Analysis

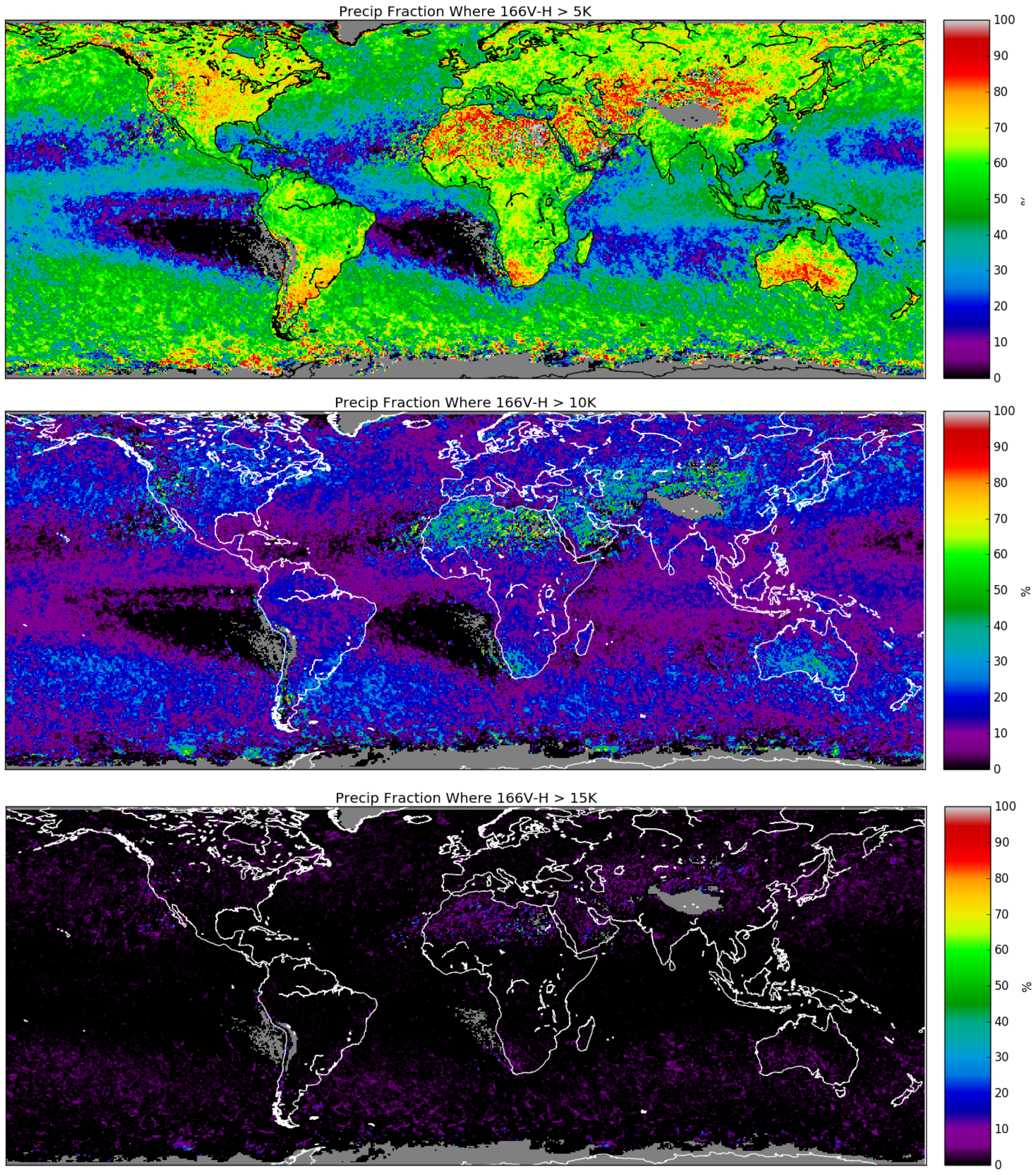
Polarization differences (PDs) at 166 GHz of more than 5K are present in more than half of precipitation over nearly all regions except those areas of the tropics and subtropics where warm rain (no ice phase) is dominant. There is a noticeable land-ocean contrast, with land regions having a higher rate of polarization, which is likely due to a combination of the lower frequency of warm rain and inability of the GPROF algorithm to detect precipitation without an ice phase over land. When PDs exceeding 10K and 15K are considered, the land-ocean contrast is reduced and mid-latitude regions have a higher occurrence than the tropical convective regions.

Histogram and CFAD Analysis

The two-dimensional pdf of the 166 GHz vertically-polarized Tb and the polarization difference (PD) is characterized by an inverted U-shape, with the largest PDs associated with Tbs of 180-210K, whereas both colder and warmer Tbs are less strongly polarized. The DPR instrument allows us to examine the vertical profiles of reflectivity to further examine these differences in four regions in Tb-PD space, representing warm Tbs/low PD (1), mid-range Tbs with high (2) and low PD (3), and cold Tbs with low PD (4).

The CFAD diagrams of Ku reflectivity and dual-frequency ratio (Ku-Ka reflectivity) reveal significant differences between the four regions. Zone 1 consists of light precipitation extending generally less than 2km above the melting level, with a weak bright band and echoes of 20-25 dBZ below the melting layer. Zone 2 contains profiles reaching 3-4 km above the melting level and displaying a strong bright band, especially in the DFR, and echoes of 25-35 dBZ below the melting layer. Zones 3 and 4 are the most similar, displaying echoes reaching 5km or more above the melting level, weaker bright band signatures, and echoes frequently exceeding 35 dBZ below the melting layer.

These characteristics imply that polarization is strongly related to stratiform profile characteristics and may be an ideal way to classify profiles as convective or stratiform from GMI data, e.g., for use by latent heating algorithms. Whether the polarization is actually caused, at least partially, by the bright band, or is simply a product of the ice layer when it contains the same microphysical characteristics that produce the bright band signature, is a question that can be explored with radiative transfer model experiments or analysis of GMI observations in cases where there is no melting layer (snow reaching the ground). However, the latter situation may be complicated by surface polarization.



Above: Maps of the fraction of precipitation (defined as GPROF > 0.5 mm/hr & column water vapor > 20 mm) where GMI –observed polarization differences are greater than 5, 10, and 15 K for March 2014-June 2016.

Case Study

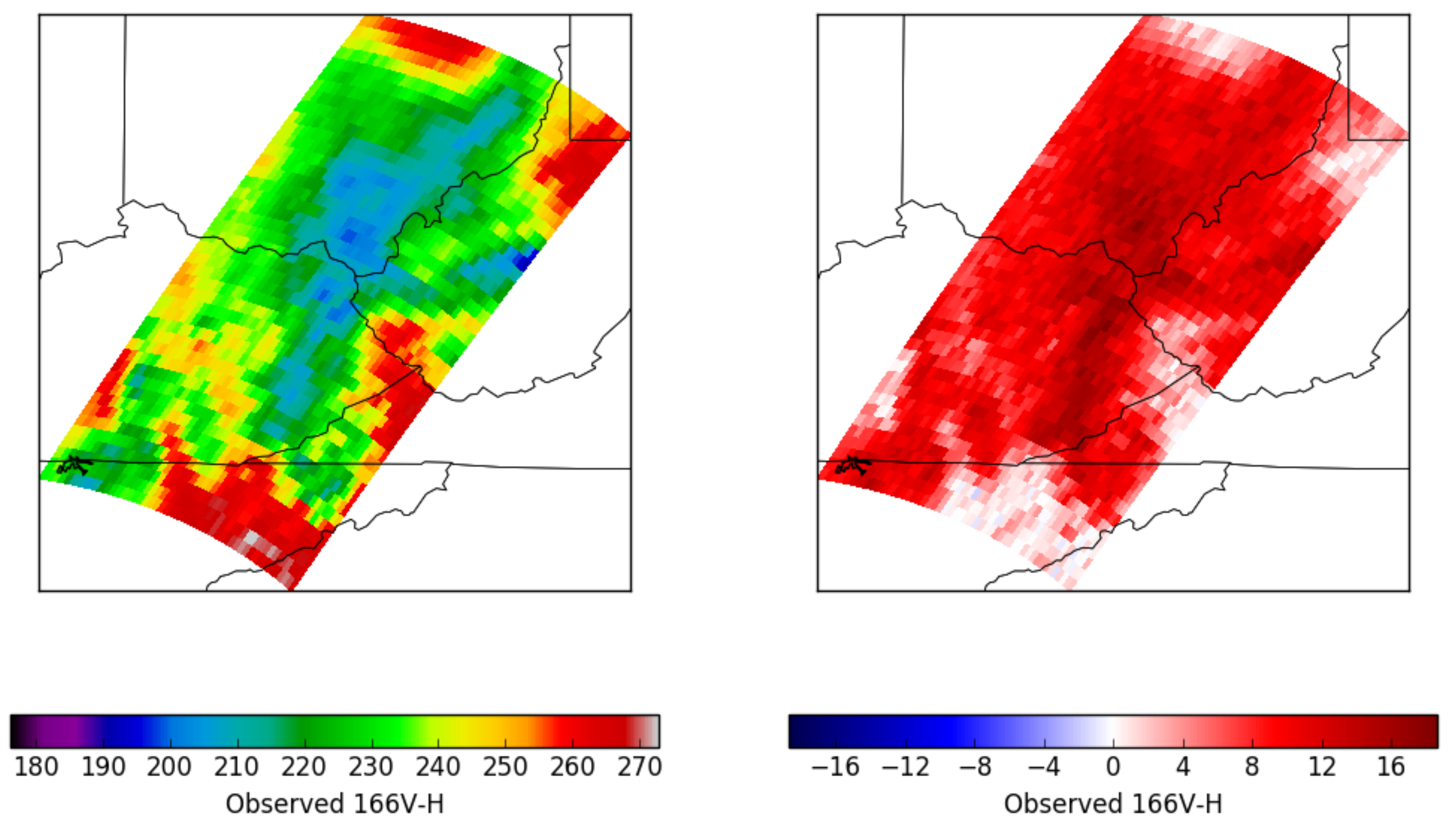
Some important questions with implications for GPM precipitation algorithms are raised by the observance of 166 GHz PDs:

1. Can observed Tbs and PDs be reproduced with non-spherical particles and polarimetric radiative transfer models, particularly when constrained by observed reflectivity profiles?
2. Do PDs offer any additional constraint on the ice PSD or particle shape not already present in the Tbs and reflectivity?

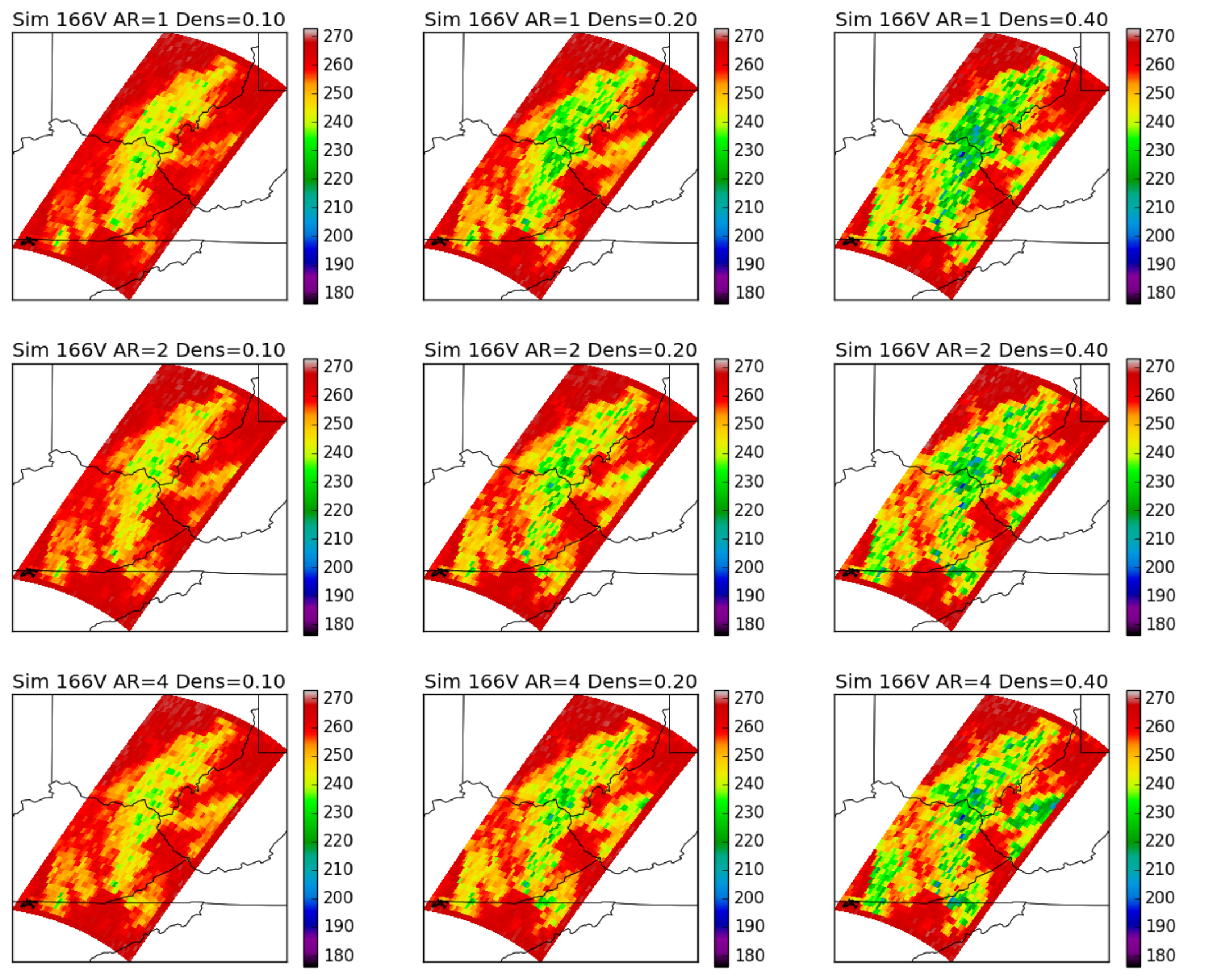
To investigate these questions, a case with high PDs exceeding 10K over a large area was selected for forward modeling using different particles. Scattering properties of oblate spheroids with densities ranging from 0.1-0.4 g/cm^3 and aspect ratios from 1-4, preferentially oriented horizontally with 9° standard deviation, were calculated with the T-matrix method. Next, lookup tables relating radar reflectivity to mean particle size (D_m) and ice water content were used to replace the GPM combined-algorithm-derived profiles for each particle shape and density while maintaining consistency with DPR Ku- and Ka-band observations. The updated profiles were then used to calculate 166 GHz Tbs using the Atmospheric Radiative Transfer Simulator (ARTS) 3D Monte Carlo radiative transfer model. These simulations provided the following insights:

- Ice water content is highest when using low-density, less oblate particles. This is mainly because these particles produce higher dual-frequency ratios (Ku/Ka reflectivity) at a given particle size, leading to the retrieval of PSDs with smaller D_m and higher IWC for a given Ku/Ka reflectivity pair.
- Despite the lower IWC, the lowest Tbs are produced with the denser particles. Particle shape does not have as much impact on Tb, and simulated Tbs are still generally higher than observations.
- The largest polarization differences are produced with the denser, more oblate particles, but still not as large as observed.

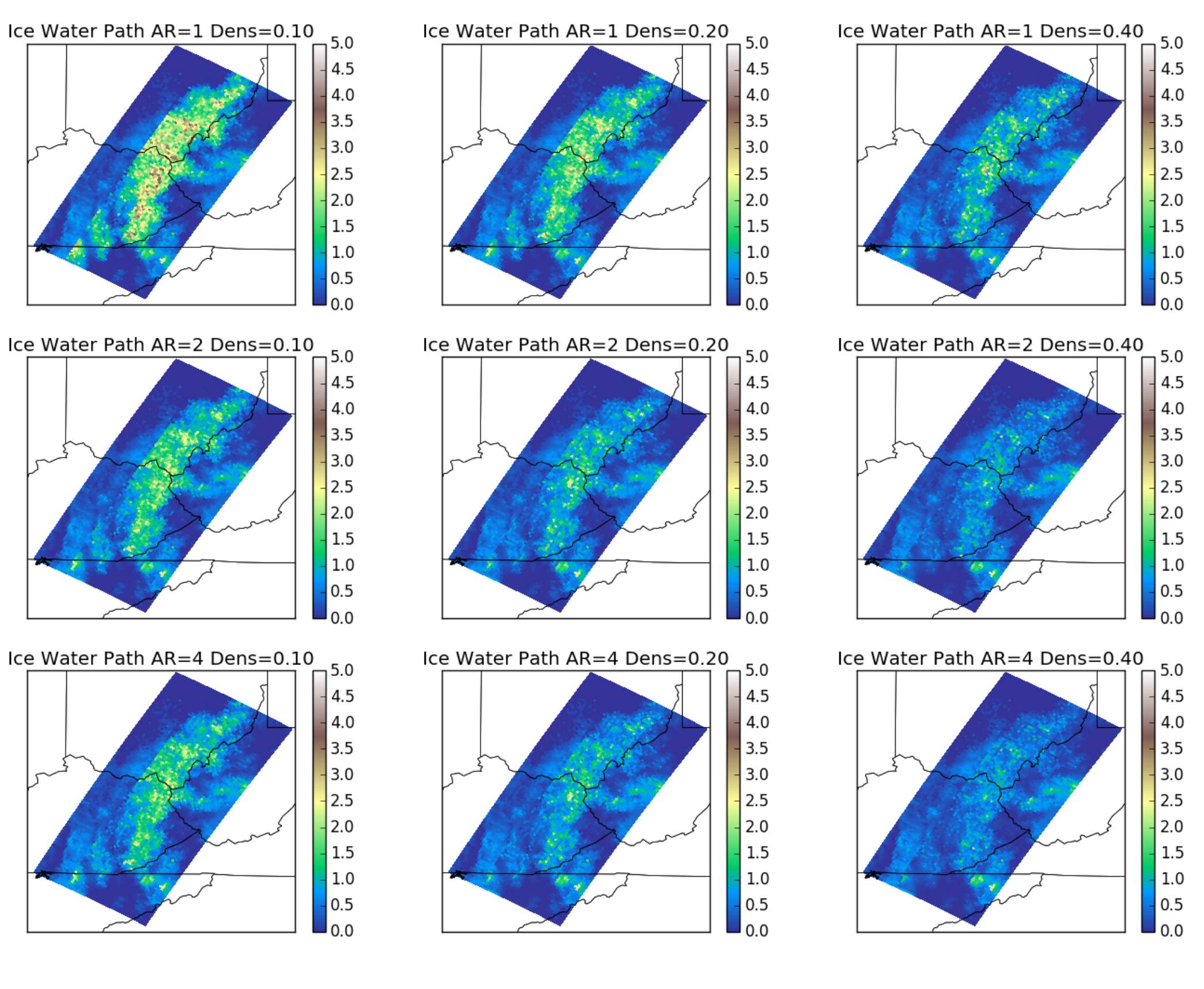
Further experiments with DDSCAT-derived ice scattering properties are currently underway.



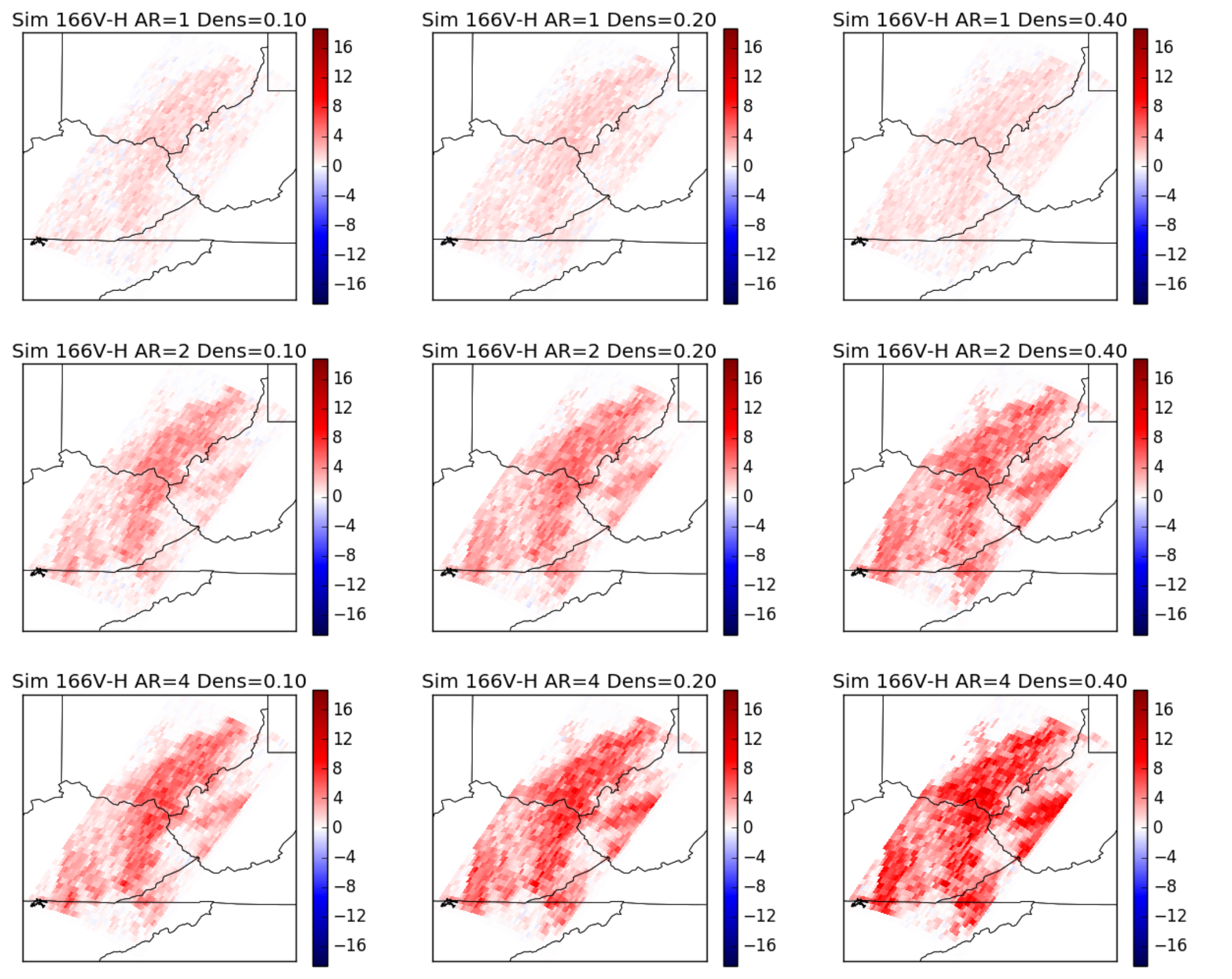
Above: Observed GMI 166-GHz vertically-polarized Tb (left) and 166 GHz V-H polarization difference (right) over the Ohio Valley in the east-central USA, at 0535 UTC on 4 January 2015.



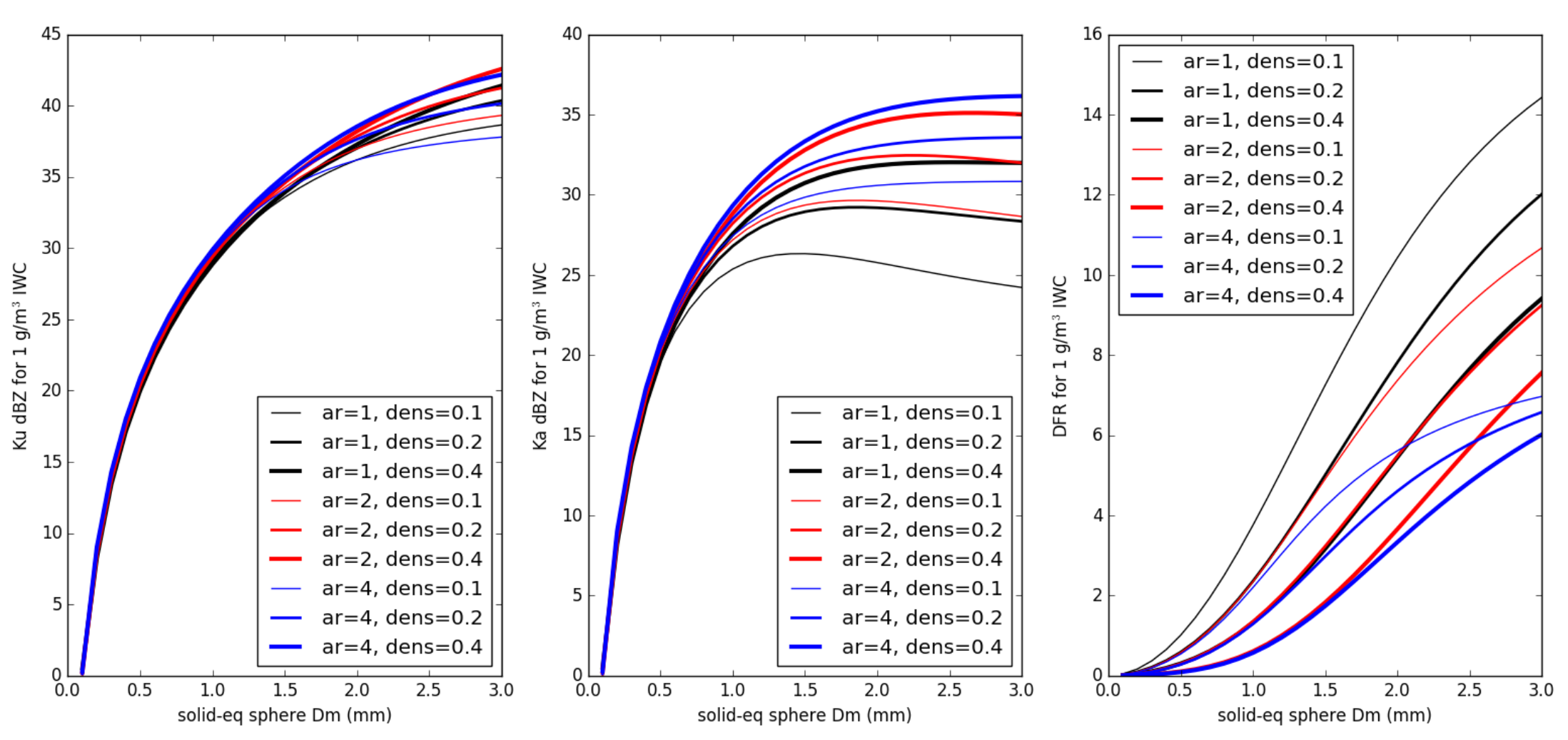
Above: Simulated vertically-polarized Tb at 166 GHz.



Above: Ice water path, in kg/m^2, derived from DPR Ku- and Ka-band reflectivity profiles following various particle shape and density assumptions.



Above: Simulated polarization differences at 166 GHz.



Left: Ku-, Ka-, and Ku-Ka reflectivity (nadir view) for ice particle size distributions containing 1 g/m^3 water content, D_m ranging from 0.1 to 3 mm, aspect ratio from 1 to 4, and density from 0.1 to 0.4 g/cm^3.