GNSS Polarimetric Radio Occultations: Thermodynamical Structure Within Precipitation

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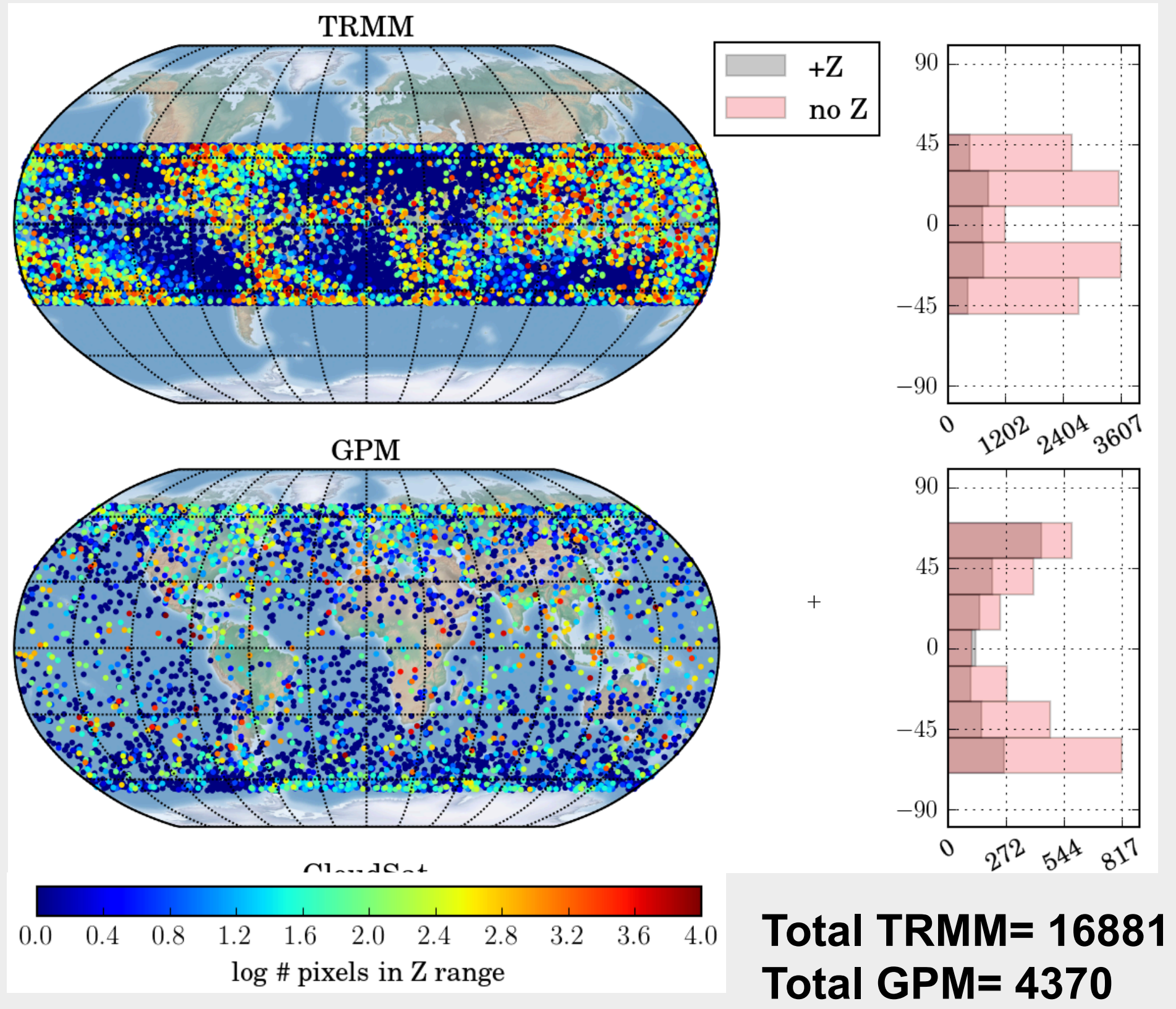
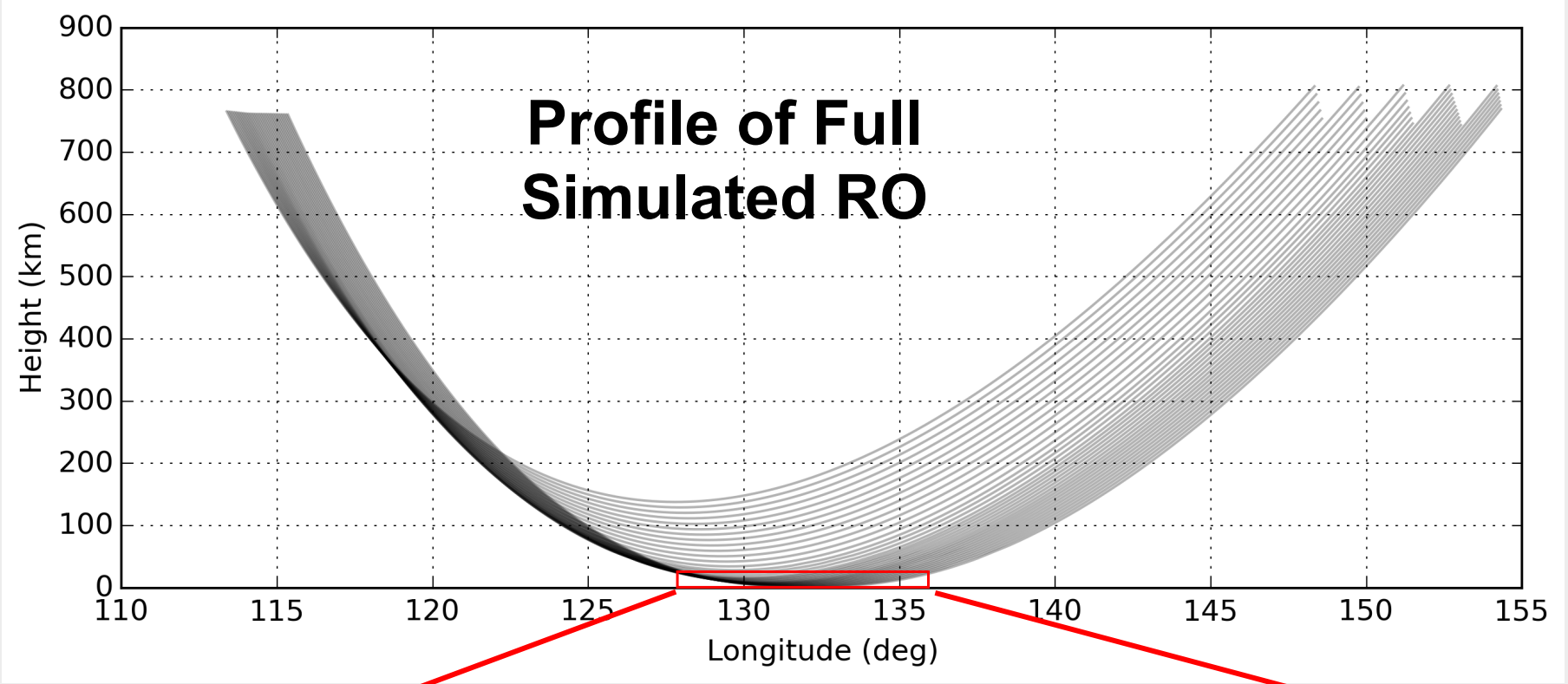
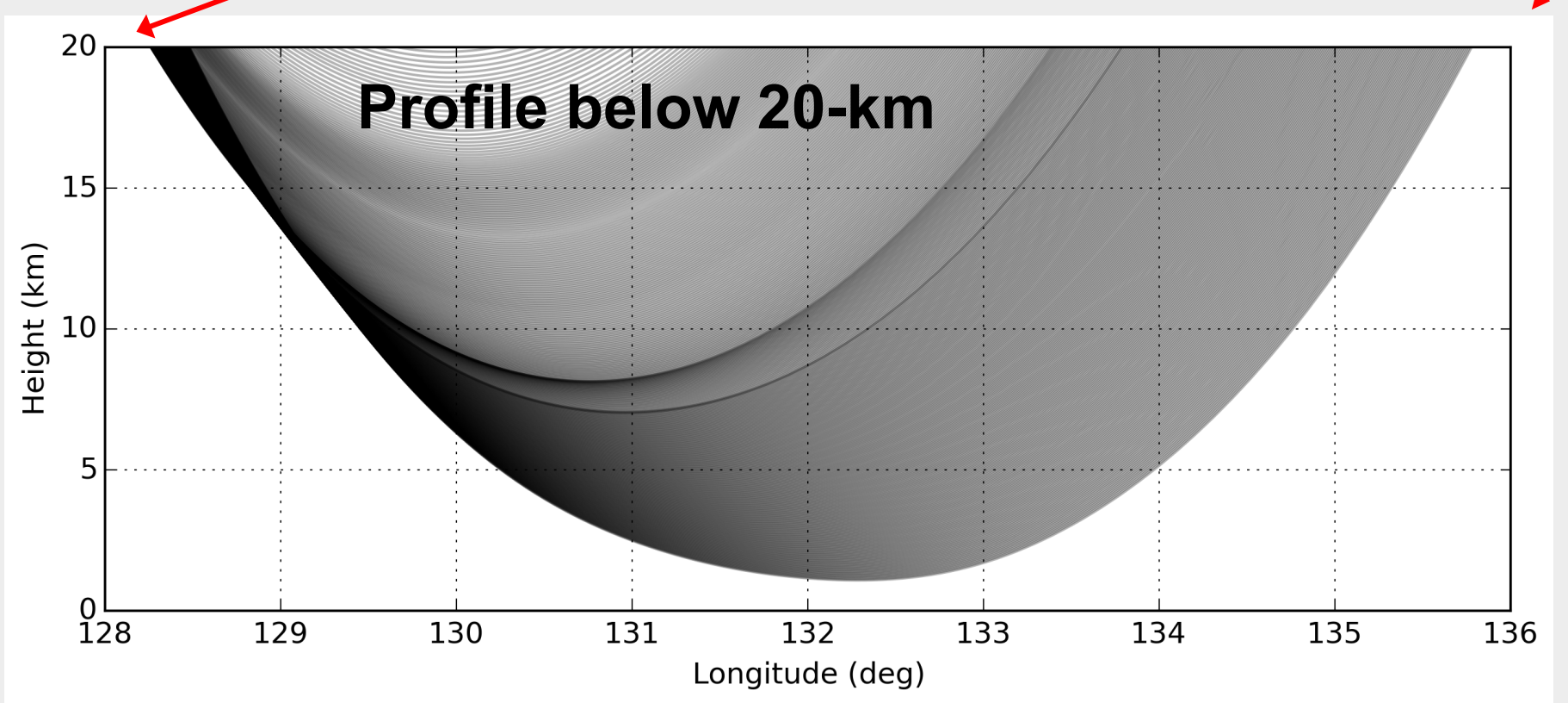
Observational Database

To simulate polarimetric RO observations under real-world rainfall conditions, the existing COSMIC RO dataset (2006-2016) was checked for 15-minute coincidences, within the ≈240-km swath of the Ku-band (13.8 GHz) Precipitation Radar onboard the Tropical Rainfall Measuring Mission (TRMM, 2006-2014) and the (Dual Frequency Precipitation Radar) Global Precipitation Measurement (GPM, 2014-2016) satellites. The image to the right shows the locations of these coincidences, where the color indicates the number (log scale) of TRMM or GPM radar bins where 30<Z<40 dBZ, associated with heavy rain conditions (Z= radar reflectivity factor). The shorter GPM era (March 2014-current) is also associated with reduced COSMIC data density.



Total TRMM= 16881
Total GPM= 4370

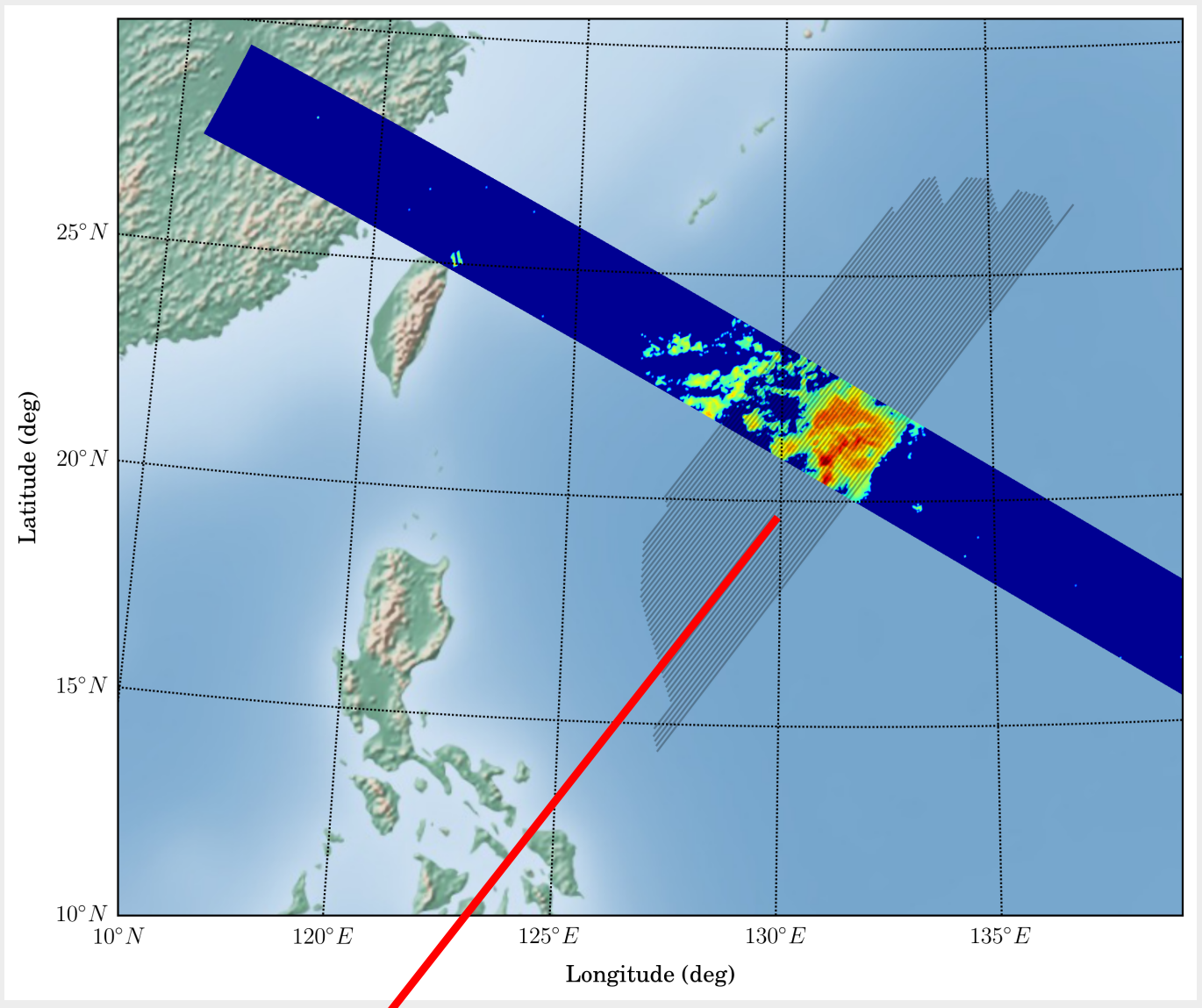




Ray Tracing

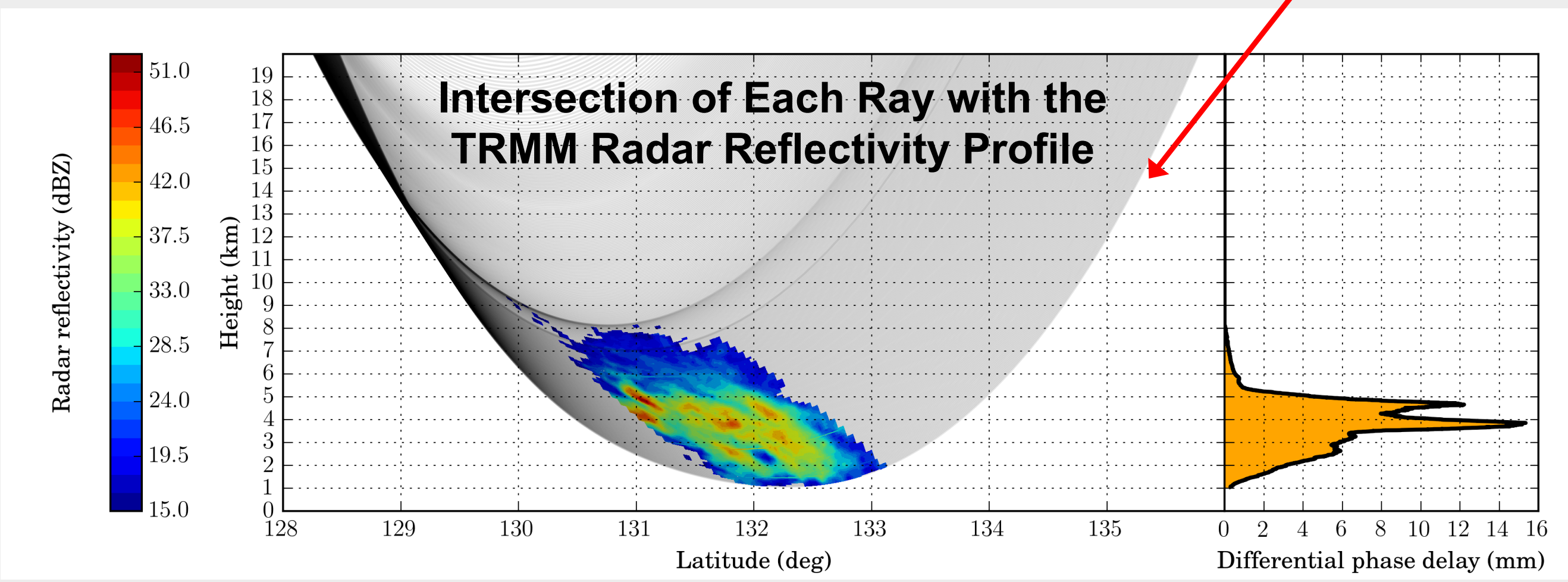
Using the refractivity profile and height positions produced by the University Corporation for Atmospheric Research (UCAR) COSMIC Data Archive Center (CDAAC) *atmPrf*, *atmPhs* and *ionPhs* datasets, the intersection of points along each ray within the PR radar reflectivity profile was determined. Where needed, interpolation was applied to extrapolate the lowest rays to near the surface.

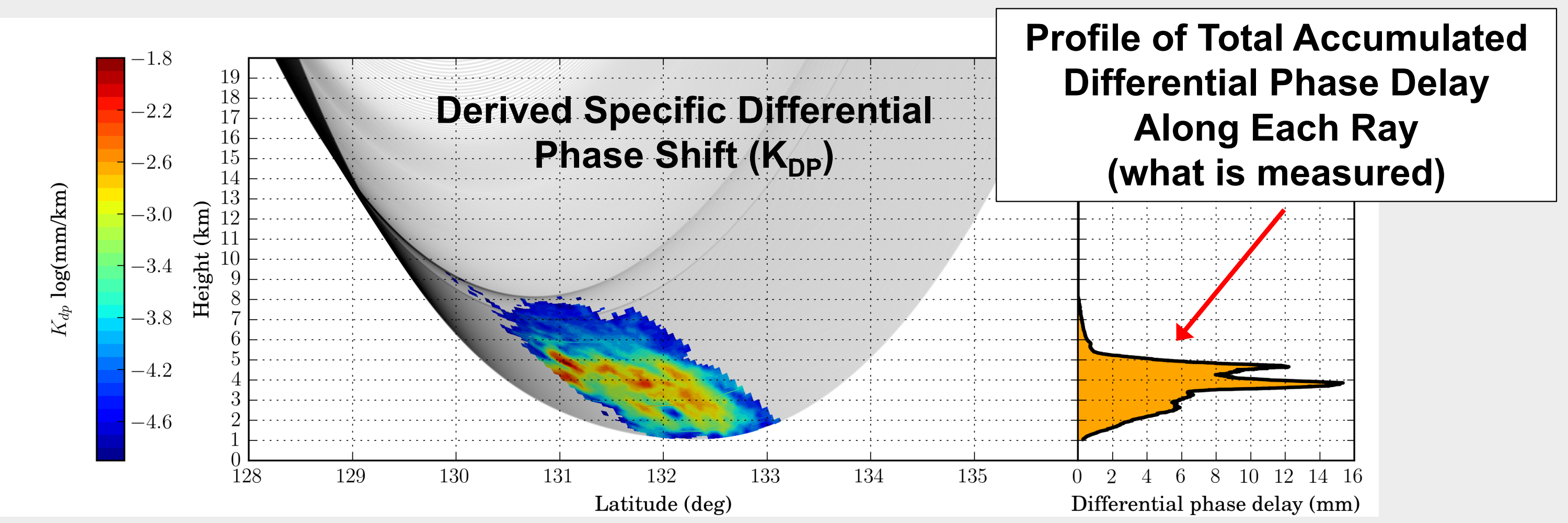
Example
TRMM 17 May 2008 1410 UTC
Near 22N 132E



Specific Differential Phase

The TRMM radar reflectivity interpolated to points along each ray below 20-km is shown below The associated L-band (1.4 GHz) specific differential phase shift K_{DP} was calculated using forward simulations with the PR-provided drop size distribution parameters and the T-matrix method (*Padulles et. al*., 2016).

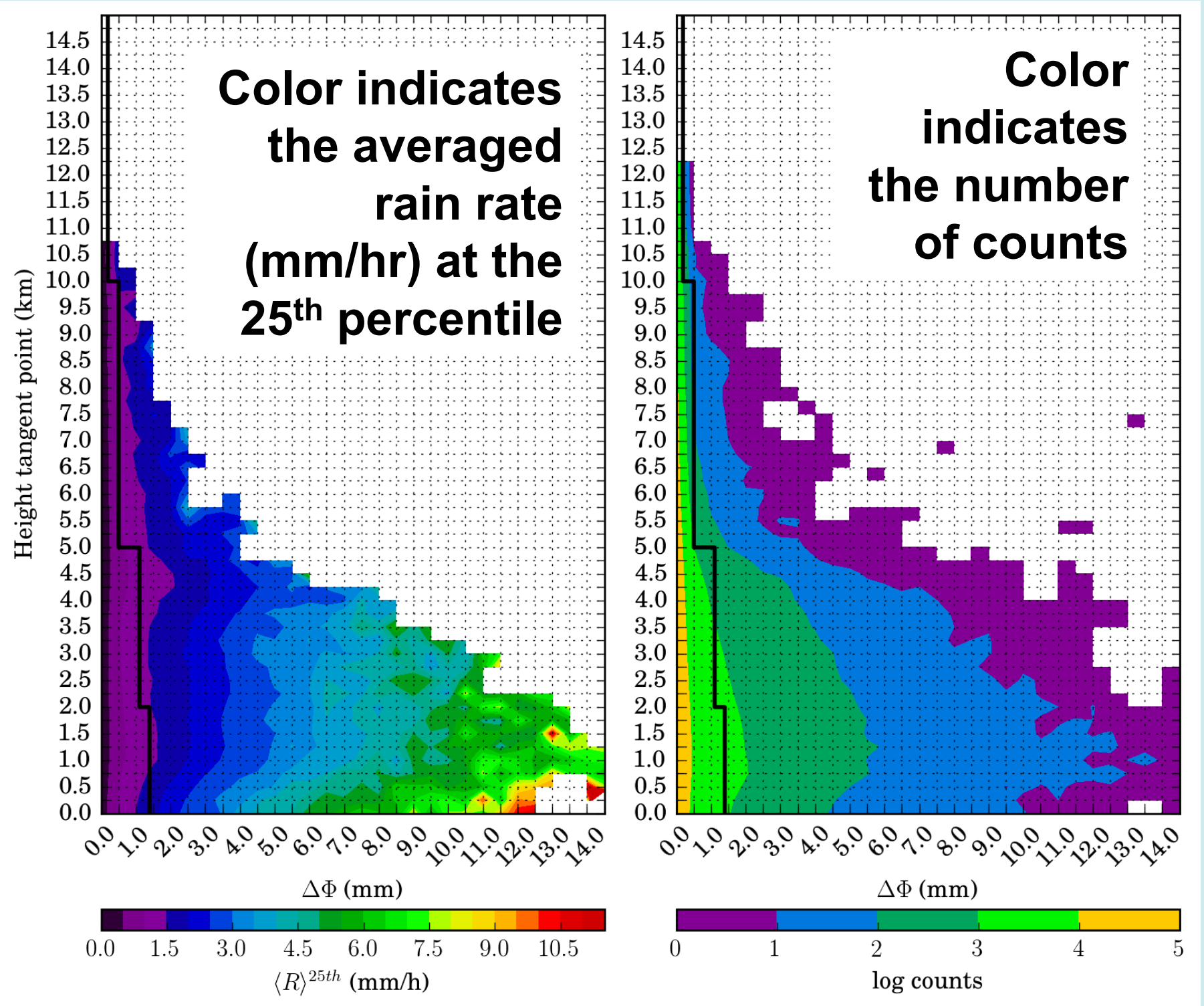




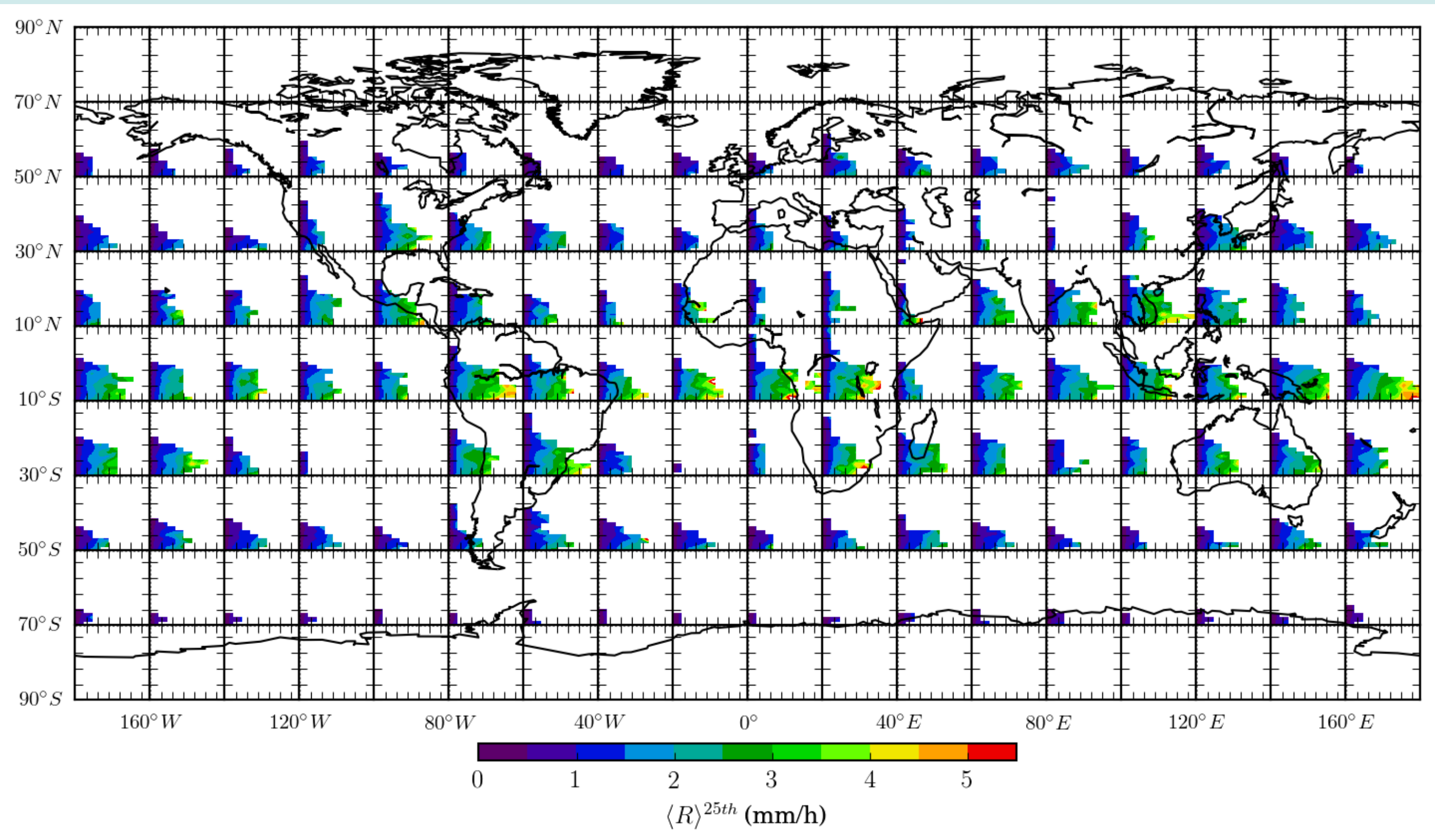
Expected Performance

Using this collection of simulated polarimetric RO observations under real-world precipitation conditions, the polarimetric phase shift was found to be sensitive to the path-integrated rain rate with a precision depending on the integration time used to smooth the phase measurements, and represents a tradeoff between sensitivity and vertical resolution. Based on the expected signal-to-noise ratio (SNR), the precision of the differential phase signal averaged over 1-sec has been estimated to be greater than 1.5 mm, with rain rates exceeding 5 mm hr^{-1} detectable above the instrument noise level 90% of the time (*Cardellach et. al*., 2014).

Overall Average Profile of Accumulated Differential Phase Delay, from all cases

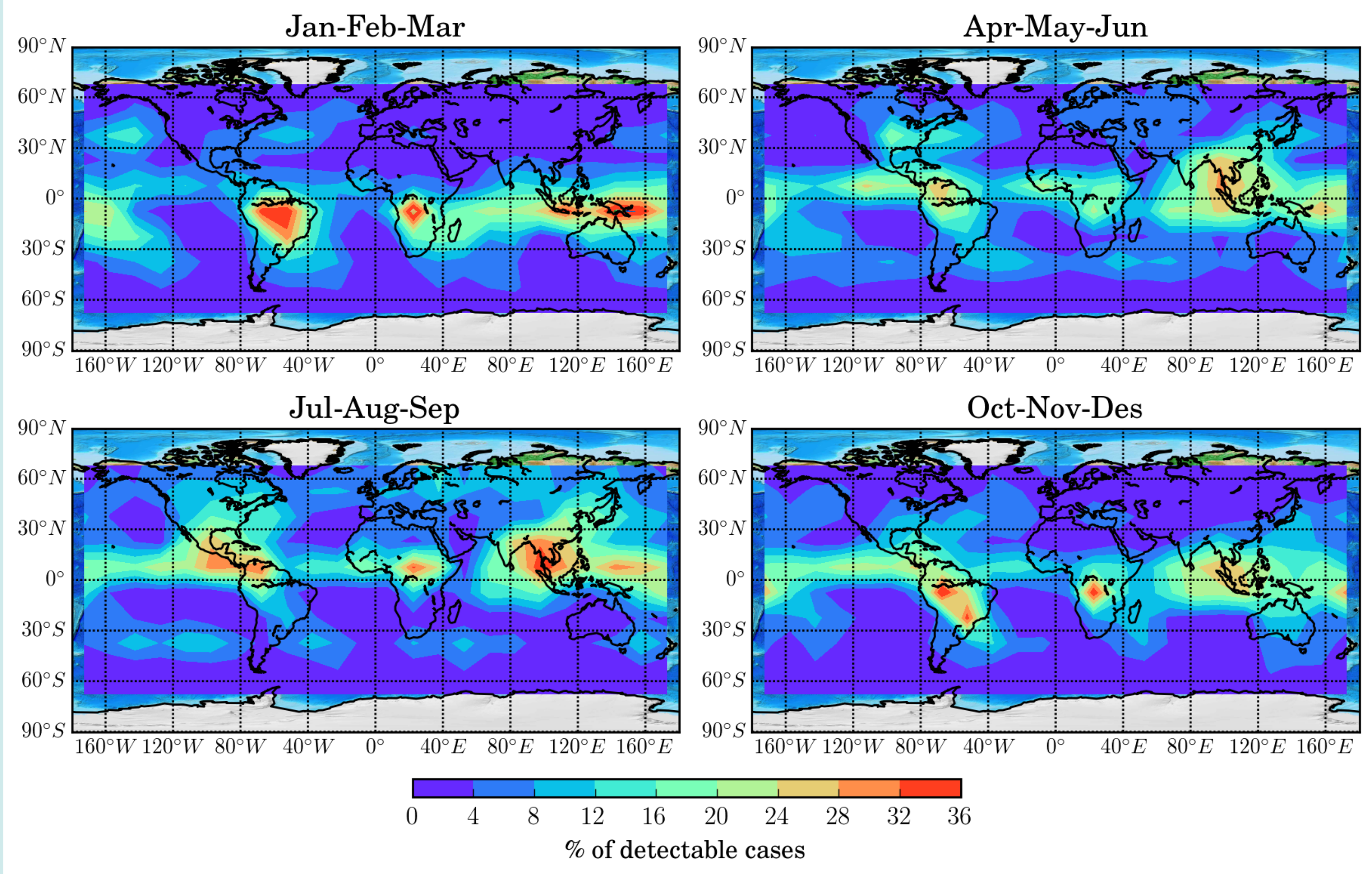


Average Profile of Accumulated Differential Phase Delay
(as above, but for each 20-degree latitude-longitude region)



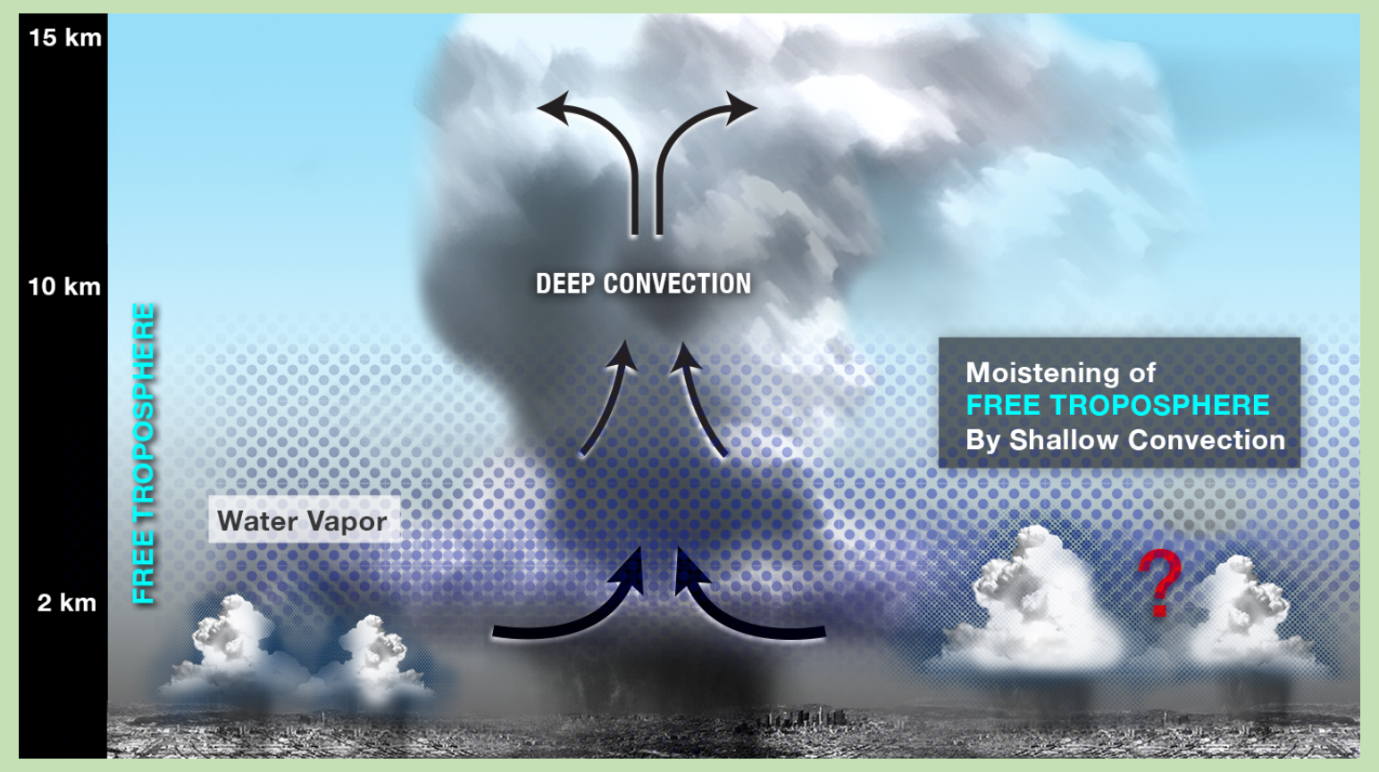
Regional and Seasonal Analysis

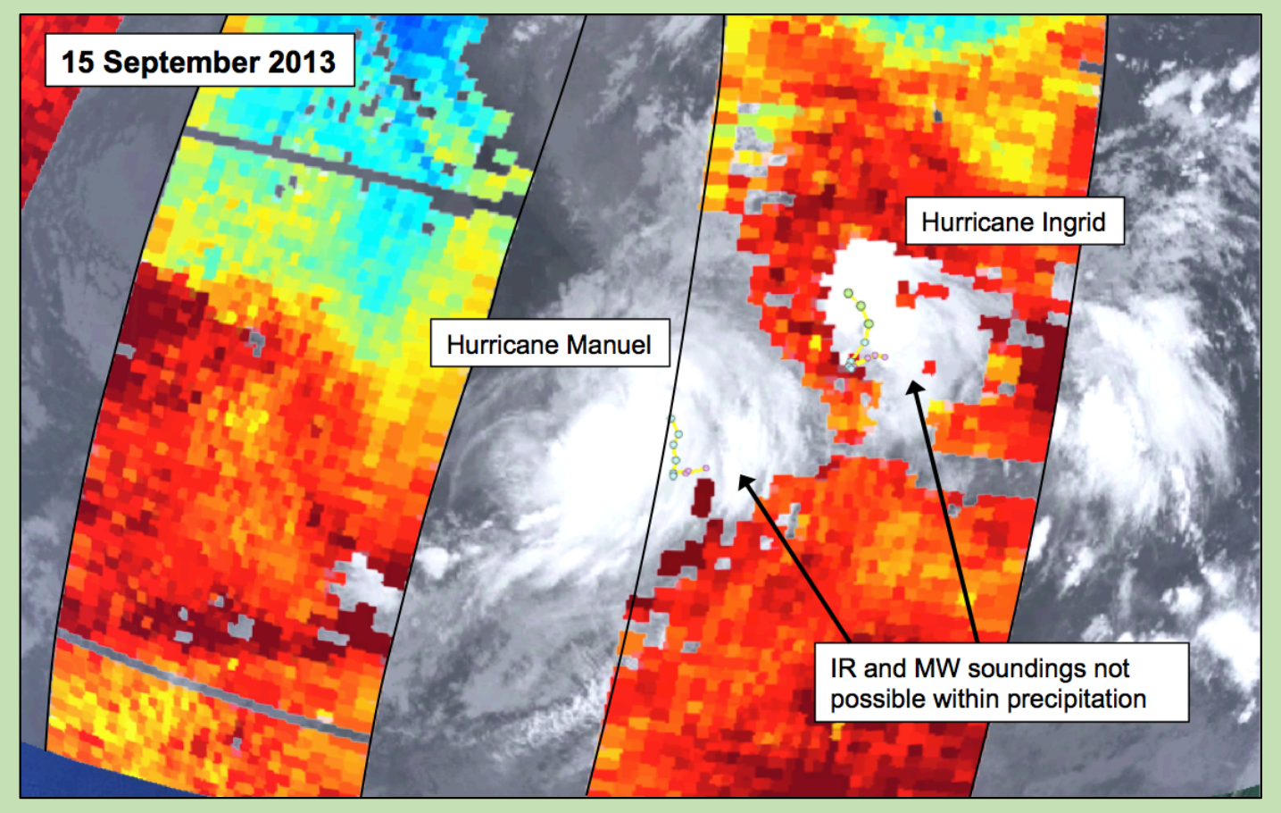
The figure below shows the percentage of time that a non-zero rain observation will be associated with a rain-induced differential phase delay exceeding 1.5 mm. Known areas of heavy precipitation (e.g., tropical Pacific, Amazon, ITCZ) exceed 30%, especially in the southern hemisphere summer months. Regions of heavy precipitation occur poleward of this band and will contribute to overall sampling, but heavy rain events are less frequent.



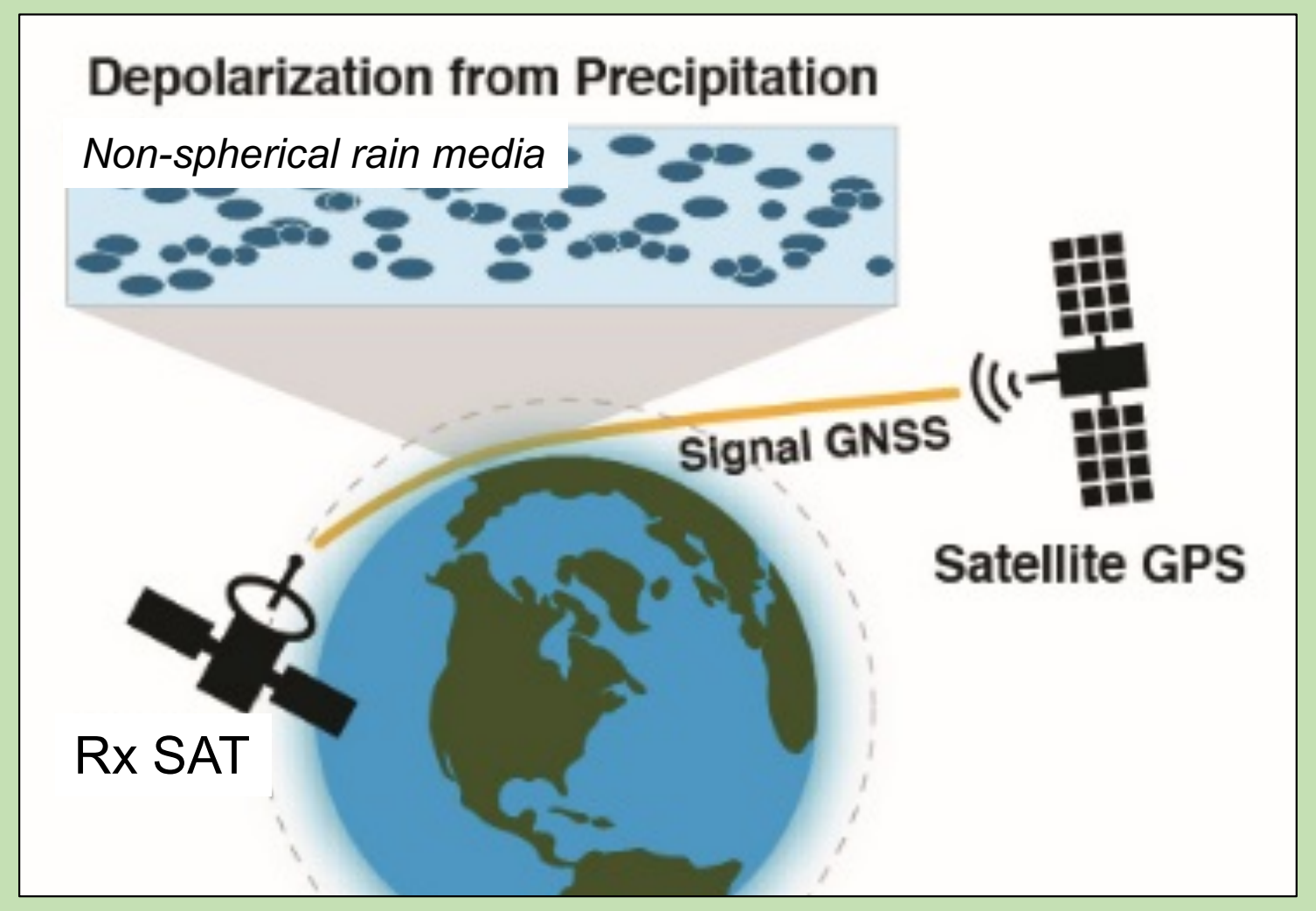
Summary

The temperature and moisture structure of the surrounding environment is the main control on the thermodynamical processes leading to the development of heavy precipitation, acting as the broader sink and source for moisture exchange between clouds and their surroundings. As precipitation develops, the condensation of water vapor leads to an evolving three-dimensional temperature and moisture structure in and near clouds that differs from the larger scale structure of the surrounding environment. Yet, the representation of the processes that link the condensation of water vapor and the growth and invigoration of convective precipitation are the processes that appear to produce the greatest disparities between cloud resolving models and current observations of convective cloud systems.





Near-simultaneous space-based observations of lower tropospheric water vapor vertical structure within precipitation are notoriously difficult to achieve, since conventional IR and microwave sounders do not sense near the surface in the presence of clouds and precipitation. Global Navigation Satellite System (GNSS) radio occultations (RO) have emerged as a low-cost approach for sounding the global atmosphere with high precision, accuracy and vertical resolution, through clouds and across land-ocean boundaries. However, current RO data are limited insofar that the received signal provides no direct information on the associated precipitation state.

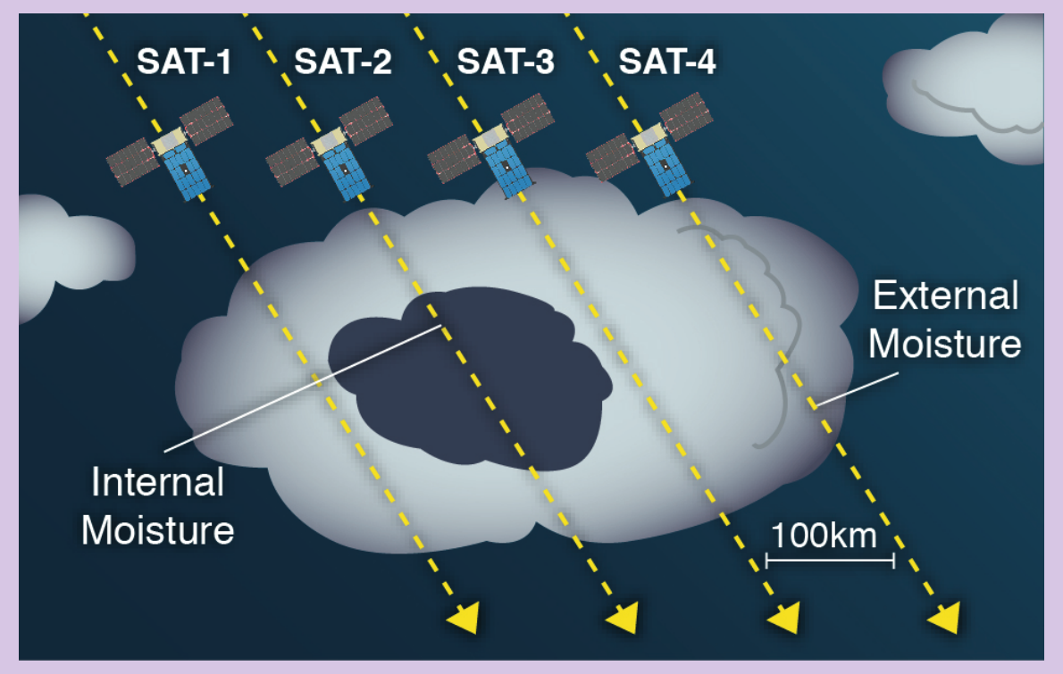


Polarimetric RO is predicated on the fact that since precipitation-sized hydrometeors are non-spherically shaped, a cross-polarized component is induced during propagation through clouds associated with heavy precipitation, recorded by a dual-channel RO receiver as a differential phase shift. Polarimetric RO would extend the capabilities of normal RO, with ***simultaneous*** measurements of the profile of water vapor and a indication of heavy precipitation intensity.

Observing System

The orbits of current (non-polarimetric) RO receiver constellations such as COSMIC and the upcoming COSMIC-2 are maximized for global sampling density, to benefit numerical weather prediction (NWP) data assimilation. Knowledge of the presence of heavy precipitation available from close-by polarimetric RO observations has potential for NWP data assimilation, which have already demonstrated positive impact from the assimilation of RO bending angle from existing RO data. For example, knowledge of the moist thermodynamic profile within precipitation is useful to improve and evaluate the microphysical parameterizations used in NWP forecast models, include their impacts on forward observation operators, and advance the state of rain-affected data assimilation near rapidly evolving weather events.

An alternative orbit strategy could involve a train-like sequence of polarimetric RO receivers separated by ≈5-minutes (below), which is a short enough interval such that each receiver would nearly always capture the same GNSS transmitter. Such a constellation would near-simultaneously capture the surrounding and internal moisture structure of some heavily precipitation cloud structures, with an indication of the presence of heavy precipitation along each ray.



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