Discrimination of cloud and rain liquid water path by ground based polarized microwave radiometry: Method, instruments, and results

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ABSTRACT

Microwave radiometers with two or more frequencies have been used for decades to retrieve liquid water path (LWP) for water clouds, using the assumption that all drops in the field of view are small enough to ensure an emission efficiency independent from the details of the drop size distribution (DSD). In case of DSD with significant numbers of larger (falling) drops, the emission efficiency of the liquid rain drops is different from the small particle assumptions and no longer independent of the drop size. Without a-priori knowledge of the microphysical details, especially the DSD, the received microwave intensity cannot be unambiguously converted to a LWP. By using polarization as an additional signal, this fundamental problem can be overcome: This additional source of information is caused by the size-dependent non-spherical rain drop shape. The polarization signal allows for some classification of the microphysical cloud/rain properties and thus improved the retrieval accuracy for LWP. By using three-frequency dual polarized radiometers with full steerability, the discrimination of cloud and rain fractions within the total LWP will be possible.

1. THE PROBLEM

Two-channel (or multi-channel) microwave radiometers have proven to be a very well suited measurement system for LWP in cloudy situations [1]. The robustness and usefulness of this approach originates from the fact that cloud droplets are usually small compared to wavelength, which makes them Rayleigh scattering particles.

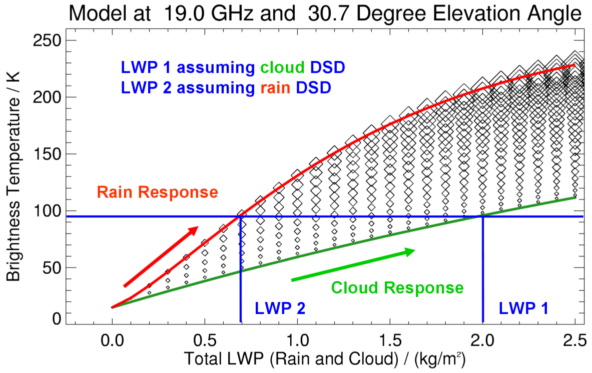

Figure 1. *Brightness temperature (TB) response to total LWP. In case of pure clouds (only small particles, green line), the sensitivity of TB to LWP is much less than in case of pure rain (red line).*

As a consequence, the emitted microwave radiation is only proportional to the total water mass in the cloud and independent of the details in the DSD (green curve in Fig. 1). The inversion of a measured brightness temperature into LWP can be done without the need for other information than just the TB measurement.

In case of rain drops in the field of view, the situation is quite different. The drops have a size comparable to wavelength, Rayleigh scattering is no longer applicable, all interaction parameters for microwave radiation need to be calculated according to Lorenz-Mie theory. The emission of TB for the same amount of water mass is significantly increased when large (Mie-scattering) drops are assumed in contrast to small (Rayleigh scattering) cloud droplets. In addition to different TB-sensitivities, the rain TB-LWP relationship (red curve in Fig. 1) is non-linear due to saturation effects.

The inversion of a measured TB into LWP will now critically depend on the cloud microphysical situation, namely the drop size distribution, which is generally unknown. Usual LWP retrieval schemes assume a cloud particle DSD, which in many cases (apart from very thin clouds) may not be strictly valid due to in-cloud or below-cloud rain rates.

2. PROPOSED METHOD

The method to overcome this ambiguity was proposed in [2]. The idea is to use dual-polarized observations

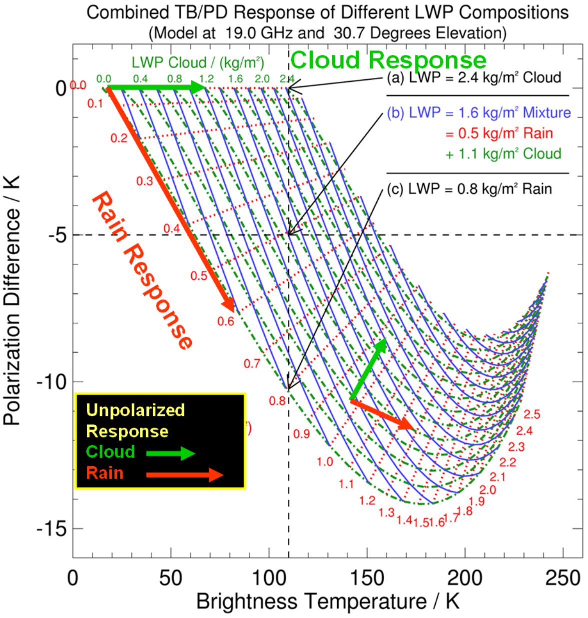

Figure 2. *Combined brightness temperature and polarization difference (TBv-TBh) response to varying mixtures of cloud and rain LWP. Along red lines, the LWP-rain is constant, along green lines the LWP-cloud is constant.*

instead of TB only. The observed polarization difference (PD, defined as TBv - TBh) is caused by non-spherical (oblate) rain drops. These drops are to big to satisfy the conditions of Rayleigh scattering and thus cause problems by changing the emission efficiency of liquid water within the cloud. At the same time, these drops show a non-sphericity which depends on their size, and thus produce a polarization signature in the observed microwave signals.

Figure 2 shows the TB and PD sensitivity of a mixed rain and cloud atmosphere at the example of 19 GHz observation (30 degree elevation). Starting at a clear sky atmosphere (PD=0, lowest TB, upper left corner of the graph), any added LWP will increase the TB signal. Adding only cloud-LWP (green arrow) will increase TB while leaving PD at zero (cloud particles are too small and still spherical). Adding rain water (according to a Marshall-Palmer DSD) will increase TB even stronger than in the cloud case, but in addition raising a polarization signal with TBh larger than TBv, leading to negative PD.

The previously undistinguishable response to rain and cloud LWP now becomes separable. An (unpolarized) example measurement of TB=110 K may be converted to either 0.8 kgm^{-2} or 2.4 kgm^{-2}, depending on the microphysical assumptions. With the additional PF measurement of PD= -5 K, the LWP can be pinned down to 1.6 kgm^{-2} with the additional benefit of knowing the partitioning of total LWP to cloud and rain fractions.

The possible implications of varying DSD and multi-angle/multi-frequency approaches have been discussed in [2], while [3] presented evidence of the simulated microwave signals in real measurements, as shown in Fig. 3.

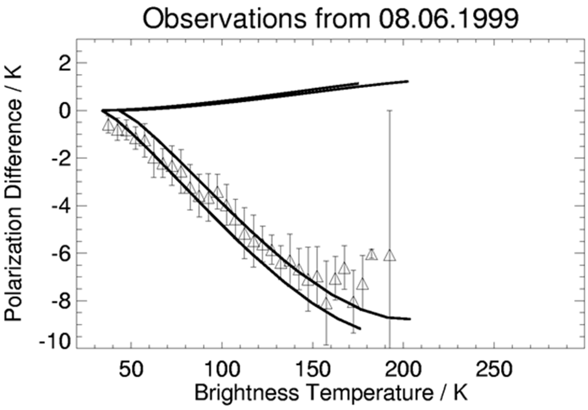

Figure 3. *Evidence of rain induced polarization signal due to oblate hydrometeor shape: lines with positive PD assume spherical rain drops, lower two lines assume oblate drops, but at 2 temperature profiles with standard lapse rates and shift of 5 K in all temperatures. Triangles indicate histogrammed observations and their standard deviation.*

3. INSTRUMENTS

In recent years, the idea proposed in [2] was picked up again by Battaglia [4] and the ADMIRARI instrument was designed by Radiometer Physics GmbH (RPG) to make dual-polarized observations at 10.7 GHZ, 21.0 GHz, and 36.5 GHz (Fig. 4,5).

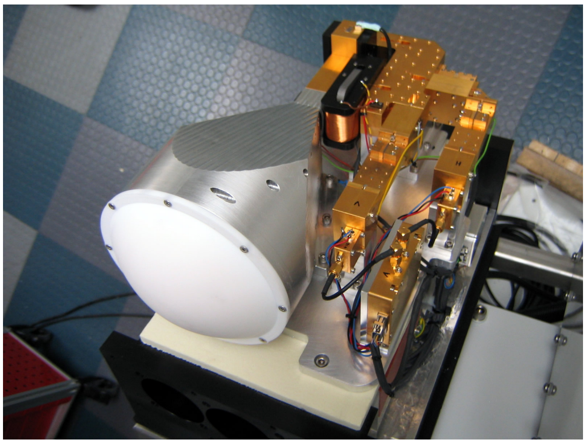

Figure 4. *ADMIRARI dual-polarization receiver frontend and feedhorn for 10.7 GHz.*

The ADMIRARI instrument is mounted on a trailer for easy deployment. Scanning in azimuth and elevation is possible, all three channels have rain protection to prevent wet reflectors or radome sheets under most conditions. At a later stage, a Micro Rain Radar (MRR, Metek) was added with coincident pointing (Fig. 5).

The instrument facilitates a sophisticated calibration scheme with noise-injection and magnetical Dicke switches to maintain the calibration while still pointing to the scene.

Figure 5. *ADMIRARI three-frequency dual polarization radiometer at RPG facilities. The fully steerable radiometer is mounted on a trailer. A Micro Rain Radar is attached to the scanning mechanics.*

Several instruments of this scanning dual-polarization multi-channel radiometers have now been built at RPG.

4. MEASUREMENTS

Figure 6 shows a time series of a RPG dual polarization radiometer with 18.7 and 36.5 GHz receivers at February 16, 2009. The observations were made at RPG facilities in Meckenheim, Germany.

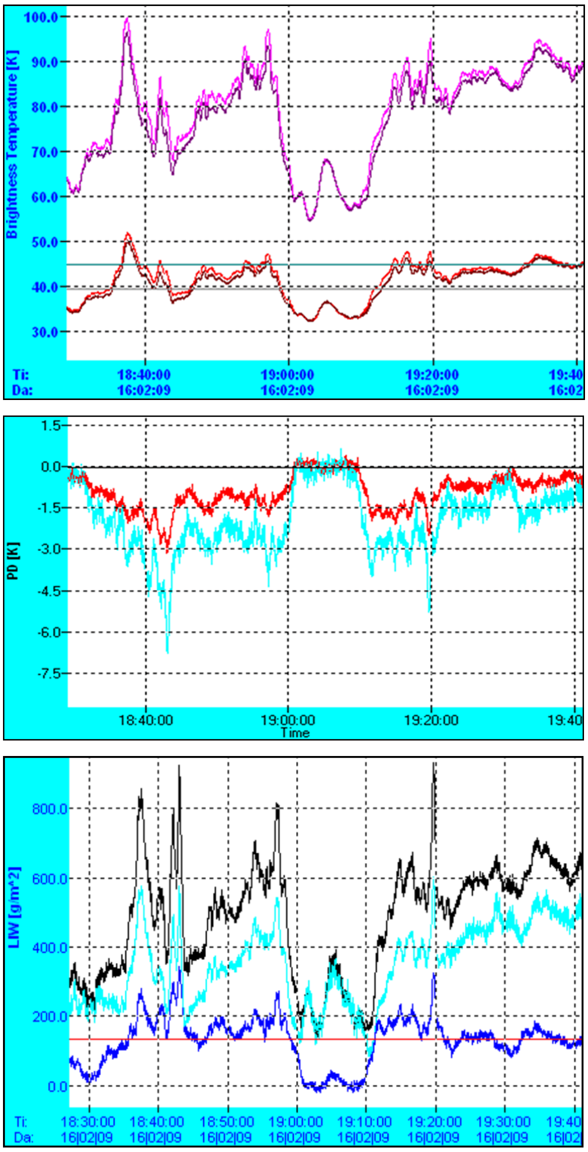

Figure 6. *One hour time series at 18.7 and 36.5 GHz. Uppermost panel shows TB (36 GHz larger than 18.7 GHz), the middle panel shows TB (18 GHZ red, 36 GHz blue), the lowest panel LWP (black: total LWP, dark-blue: rain LWP, light blue: cloud LWP).*

Over most of the time series, there was rain and cloud mixture in the field of view, leading to strong variations in TB as well as non-zero PD signals. Nevertheless, at 19:00 we observed a period without PD signals (and still showing TB variations). The retrieved cloud-LWP drops to near-zero during this time, while total LWP rises to nearly 400 gm^{-2}. This shows the fundamental capabilities of this dual polarization approach.

5. OUTLOOK

The above mentioned retrieved products in Fig. 6 were obtained with a very simplistic statistical retrieval, utilizing an insufficiently small database of one dimensional cases. Due to the limited data base, we expect the coverage of all possible meteorological situations to be quite poor, leading to instable retrievals. Additionally, 3D effects are not covered at all by this simple approach.

Battaglia et al. show in [5] a better suited approach to use the information of the three-frequency observations of the ADMIRARI instrument. Based on this progress, the observation of clouds with dual-polarized multi-channel radiometers offers an elegant way to improve LWP estimates in thick clouds and rainy atmospheres. In addition, limited insight into the cloud microphysical properties seems to be possible.

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