Uncertainties and recent improvements of liquid water path observations by ground-based microwave radiometers with some examples from long-term Cloudnet station records

Pospichal, B.¹, U. Löhnert¹, N. Küchler¹, and J. Bühl²
¹Institute of Geophysics and Meteorology, University of Cologne. ²Leibniz Institute for Tropospheric Research (TROPOS), Leipzig

1. Importance of cloud liquid water path observations

One major parameter when describing cloud properties is the amount of water which is contained in a cloud, the so-called cloud water path which can be separated into liquid (LWP) and ice water path (IWP). Ground-based microwave radiometers (MWR) have been widely used for measuring LWP, since these instruments can directly provide this quantity from the observed emission caused by cloud droplets. In the frequency range used (below 100 GHz), emission from ice particles can be neglected. However, in the presence of drizzle or rain, the measurements get unreliable due to the additional presence of scattering on the larger particles.

Within Cloudnet, MWR are a crucial component of the measurement setup to categorize and observe cloud properties. Therefore, we provide an error characterization and suggest possible improvements for measuring LWP.

2. Liquid water clouds in Cloudnet

The Cloudnet program provides continuous cloud classification at stations where a combination of ground-based remote sensing observations (millimeter cloud radar, lidar ceilometer and MWR) are available. The LWP observations from MWR are there a crucial part for analyzing liquid clouds. Below, an example for a Cloudnet target classification is shown (Fig. 1) where a persistent liquid cloud can be observed between 06 and 14 UTC.

In this study, we focus on pure liquid clouds, i.e. observations when only cloud droplets (light blue in Fig.1) were classified throughout the whole atmospheric column. These clouds are determined by their boundaries, detected by lidar (cloud base) and radar (cloud top) as well as their LWP. The adiabatic LWP between cloud base and cloud top can be calculated and then compared with the observed LWP. It can be shown that the degree of adiabaticity can vary strongly.

3. Cloud statistics

Cloud frequency depends on the location (see Tab 1 for the stations and time periods used for the comparisons). The distribution of three main variables are shown in Fig. 2. Cloud thickness is generally quite uniformly distributed with slightly thicker clouds at maritime sites. Cloud base height, however, tends to be rather variable. Liquid water path shows different distributions, especially for Potenza and Jülich which have higher average LWP than the other stations.

The differences can be partly explained by climatic conditions. Another important source for systematic biases are observation and calibration errors which can lead to substantial differences in derived cloud properties. The MWR errors will be discussed here.

4. Conditions for (sub-)adiabatic clouds

For ideal clouds, the liquid water content (LWC) can be described by the adiabatic liquid water content which corresponds to the amount of condensation by cooling a saturated atmospheric parcel. In many studies, clouds are assumed to follow the adiabatic LWC or have a constant sub-adiabatic LWC. We can show from Cloudnet observations that real clouds are mostly subadiabatic with a strongly varying sub-adiabatic factor fad (Fig. 3). The degree of adiabaticity for all single-layer liquid water clouds varies between the stations and between the seasons which might be caused by different climatic regimes. On the other hand, differences between the years are an indicator for retrieval or calibration uncertainties. (Fig. 3c)

5. Reduction of Uncertainties for MWR observations

LWP is usually derived by statistical methods from observed brightness temperatures. Most MWR use the water vapour absorption band at 22.235 GHz and a window region around 30 GHz to retrieve LWP with a statistical accuracy of about 25 g m⁻² (Fig. 5a). Other errors include systematic biases due to calibration uncertainties as well as instrument failures. In any case, a detailed error characterization as well as careful calibration monitoring is crucial for accurate LWP observations.

The newly developed W-Band radar (Fig. 6a) includes a 89 GHz passive channel which can increase the information content to substantially improve the LWP observations (Fig. 5b), in addition to the usual MWR observations (Fig. 6b) at JOYCE in Jülich. We are furthermore improving the automatic quality control of the MWR data and will serve as a calibration center for MWR.

- Cloudnet products depend on accurate observations
- Comparison of stations and periods (sub-adiabatic conditions)
- LWP from Microwave radiometers one uncertainty source
- LWP can be improved by adding more frequencies