GROUND-BASED REMOTE SENSING OF CLOUD LIQUID WATER

- A CASE STUDY

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ABSTRACT

A new method to determine cloud liquid water profiles from multispectral microwave radiometer, millimeter wave radar and additional information is presented. Simultaneously the algorithm is able to retrieve temperature and water vapor profiles in a physical consisten way. The algorithm is applied to a case study during the BALTEX Bridge Campaign (BBC). The good performance even within a strong inversion on top of a thick cloud demonstrates the potential of combined remote sensing for continous monitoring of atmospheric profiles. Future develoment of the method could include additional intruments and are discussed.

INTRODUCTION

In order to evaluate and improve the forecast of clouds and precipitation in numerical weather prediction (NWP) and climate models, the BALTEX Cloud Liquid Water NETwork (CLIWA-NET) was initiated. In NWP models clouds are represented by their cloud liquid water content (LWC), which is a prognostic variable in most operational models. Cloud liquid water path (LWP) and integrated water vapor (IWV) can be retrieved quite accurately by two channel microwave radiometer measurements. However, the vertical distribution is more difficult to obtain. Even when more microwave frequencies are considered the information content is weak and very indirect. A promising approach is the combination with measurements of radar reflectivity by a cloud radar. The direct conversion of radar reflectivities to LWC is problematic due to their high sensitivity to the drop size distribution. Additional information about temperature and height of the cloud base can be extracted from infrared radiometer and lidar ceilometer measurements, respectively.

For CLIWA-NET a continental scale network comprising of 12 stations in Europe was established for two periods each two months long. Each station was equipped with a microwave radiometer, an infrared radiometer, a lidar ceilometer and some with a cloud radar. In a third campaign a regional scale network was operated in the Netherlands. Two weeks of the third campaign were devoted to a MIcrowave Intercomparison CAMpaign (MICAM) where seven different radiometers were operated at Cabauw, the central facility of the Dutch weather service. During MICAM additional remote sensing measurements (three cloud radars, high power lidar, three lidar ceilometers, five infrared radiometers, RASS, etc.) were performed and about forty radiosondes were launched. For all campaigns cloud parameters including LWP were derived and model runs by four major European NWP models were performed.

Up to now methods to derive LWC profiles merge radar reflectivities with LWP measurements by a passive microwave radiometer [1],[2]. Here we will present an advanced method which makes use of the multispectral information of the passive microwave radiometer MICCY [3], radar reflectivities measured by the 95 GHz cloud radar MIRACLE [4], the closest radiosonde measurements of temperature and additional ground measurements. This allows to simultaneously retrieve temperature and humidity profiles. Measurement examples from the BBC-campaign are discussed.

ALGORITHM DESCRIPTION

The algorithm is based on the *optimal estimation* theory [5] and an extension of [2]. The algorithm input consists of 19 brightness temperatures from MICCY, cloud base height from a lidar ceilometer, profiles of radar reflectivity, operational radiosonde temperature and pressure profiles and ground measurements of humidity. The ceilometer allows an accurate determination of cloud base, whereas cloud top can be derived from the reflectivity profile, hence leading to a valuable constraint. In the first algorithm step a first guess is made concerning the LWC and humidity profile. A forward model is then used to simulate the resulting measurements. Within the optimal estimation, the difference between simulated measurement and instrument measurement are minimized via an iteration procedure. If Gaussian

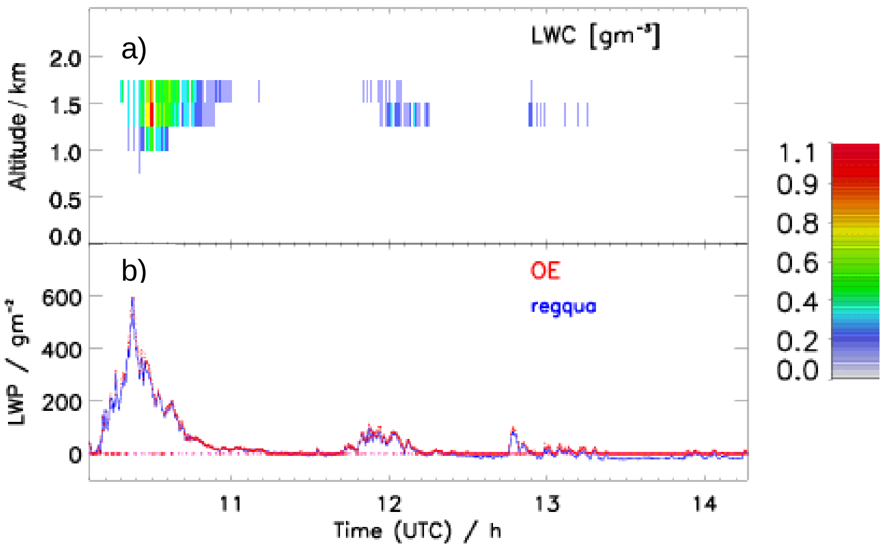

Fig. 1. a) Time series of liquid water content (LWC) derived from co-located radar (MIRACLE), passive microwave radiometer (MICCY) and additional data measured at Cabauw, The Netherlands, on August 1, 2002. b) The vertically intergrated LWC profile from a) (red) and the LWP derived by a statistical algorithm (blue). Cases when the algorithm was not applicable were set to zero.

error characteristics are assumed, the result will be an optimal retrieval of LWC, temperature and humidity, where the forward simulated measurements will be within their error ranges, which are determined by the corresponding covariance matrices. These covariances are determined prior to algorithm application, using radiosonde data and model output of a 1.5 dimensional microphysical cloud model. In cases of drizzle when the radar reflectivity is dominated by very few drops the algorithm is not applied.

MEASUREMENT EXAMPLE

In order to show the potential of the method described above we focus on an extreme case with a strong inversion on top of the boundary layer. The retrieved LWC profile reveals the passage of a thick cloud with maximum values of 1 gm^{-2} within less than 40 min (Fig. 1). Thinner clouds ocurred later in the day. Drizzle was detected only within very few measurements. If the LWC profile is vertically integrated it agrees very well with the results of a statistical LWP retrieval which involves brightness temperatures at 22.985, 28.235, 50.8 and 90 GHz. When the algorithm does not detect a cloud the LWP is set to zero while the statistically derived LWP can become negative.

The advantage of microwave remote sensing is that even in the presence of heavy clouds temperature and humidity can be determined with good accuracy (Fig. 2). However, because the vertical resolution is relatively coarse (about 1-2 km [6]) sharp inversions can't be resolved completely. The comparison of the retrieved humidity profile with a radiosonde measurement one hour later shows that the smoothing effect occurs in the humidity, too. The discrepancy at ground level is consistent with the observed decrease in humidity.

SUMMARY AND DISCUSSION

We have shown for a challenging atmospheric situation with a strong inversion and a heavy cloud that reasonable profiles of cloud liquid water, humidity and temperature can be retrieved simultaneously. The two months of data from the BBC campaign will be used in the future to validate the profiles. The method can be extended in the future by integrating infrared radiometer measurements and the respective radiative transfer calculation. This approach will be extremely valuable in cases of thin clouds with low LWP. These are often not detected by cloud radars due to their

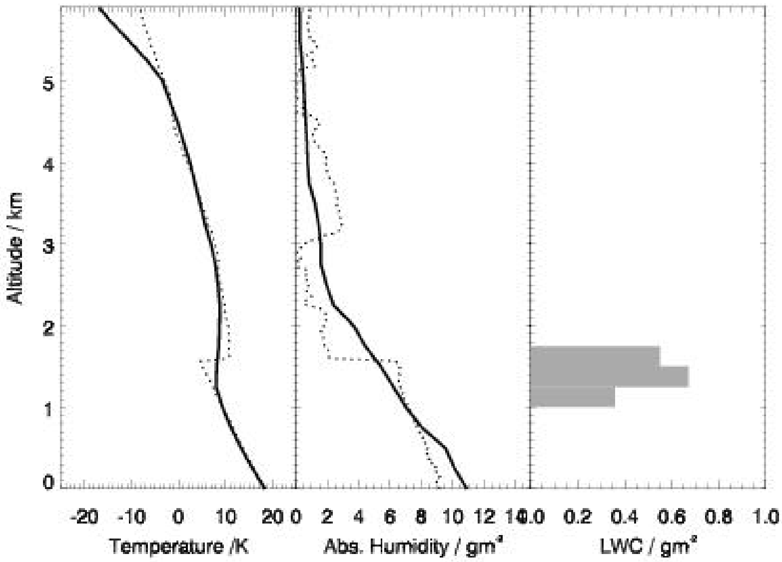

Fig. 2. Temperature, humidity and LWC profile at 10:18 UTC on August 1, 2002derived using the optimal estimation method (solid line) and the closest radiosonde ascent from 11:17 UTC (dotted line).

small droplet sizes. Due to absolute uncertainties in the microwave brightness temperatures (gas absorption, absolut calibration) LWP offsets can be in the same order as the signal. However, due to their radiative effects these clouds play an important role in the atmosphere's energy budget.

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