EVALUATING CLOUD LIQUID WATER IN NWP AND CLIMATE MODELS USING MEASUREMENTS FROM THE BALTEX CLOUD LIQUID WATER NETWORK: CLIWA-NET

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1. INTRODUCTION

The main objectives of the BALTEX Cloud Liquid Water Network project (CLIWA-NET; 2000-2003) were i) to implement a prototype of a European cloud observational network (ECON), ii) to contribute to the program of the continental–scale experiment BALTEX, and iii) to objectively evaluate cloud related output of atmospheric models for weather and climate prediction.

ECON comprised ground-based and satellite-borne observations, thus combining high temporal resolution measurements at single stations with high-spatial resolution satellite observations. Within the ground-based network microwave radiometers were chosen as key instruments since this technique is by far the most direct and accurate method to determine the liquid water path (LWP). The network was established during three campaigns by co-ordinating the use of existing passive microwave radiometers, infrared radiometers, lidar ceilometers and, at a limited number of sites, cloud radar. The first two campaigns (CNNI: Aug/Sep 2000, and CNNII: Apr/May 2001) were conducted on the continental scale covering the Baltic catchment, while BBC (Aug/Sep 2001) focused on the regional scale.

For a future long-term implementation of ECON a low-cost microwave radiometer has been designed. Owing to external funding the first systems were already built (Fig. 1). Four European NWP/climate models were involved in an objective evaluation of cloud related output produced by short-term forecasts. In this contribution we focus on the evaluation of liquid water path and the vertical distribution of cloud liquid water based on observations from ground-based measurements.

2. LIQUID WATER PATH

Time series of observed LWP have been inferred from continuous microwave radiometer (MRAD) measurements on the basis of harmonized retrieval algorithms for the different radiometers involved

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Precise knowledge of rain events turned out to be critical for the validation of observations. Due to rainfall, MRAD-measurements are meaningless as long as the water on the instrument has not completely evaporated. Rain detection, preferably with in-situ instruments, was used to filter out all MRAD measurements synchronous with rain events. Based on this experiences the low-cost radiometer includes a rain sensor which controls a shutter system protecting the antenna in case of precipitation (Fig. 1).

Information on cloud base parameters inferred from synchronous and collocating measurements with lidar ceilometer and IR radiometer was found very useful in classifying the cloud component of the atmospheric conditions. It has been used to identify the presence and altitude of clouds, allowing the distinction of ice and water clouds.

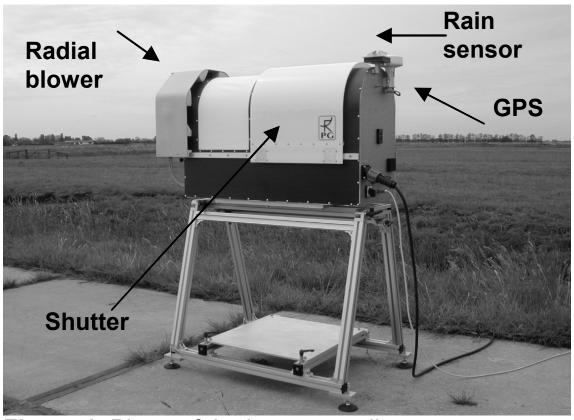

Figure 1. Photo of the low cost radiometer

Isolated periods with conditions free of water clouds have been used to assess MRAD inferred LWP biases. For the purpose of model evaluation a procedure has been developed to quantify the bias correction. Provided such conditions occurred with sufficient regularity this correction method is considered to significantly reduce the systematic bias in observed LWP that originates from instrumental drifts and uncertainties in the retrieval assumptions (mainlywater vapor absorption).

Four European institutes participated in the evaluation of model predicted cloud parameters. ECMWF with the global forecast model operated at an effective horizontal resolution of 45 km and with 60 layers in the vertical, DWD with the Lokal Modell (LM) operated in non-hydrostatic mode at a resolution of 7 km and with 35 layers in the vertical, the Rossby Center with a climate version of HIRLAM, here referred to as RCA, and KNMI with RACMO carrying the physics of the ECHAM4 model. The latter two models have been operated with a horizontal grid spacing of 18 km and with 24 model layers, and are forced from the lateral boundaries by ECMWF analyses. The output from all models refers to a 12 to 36 hour window taken from each daily forecast initiated at 12 UTC.

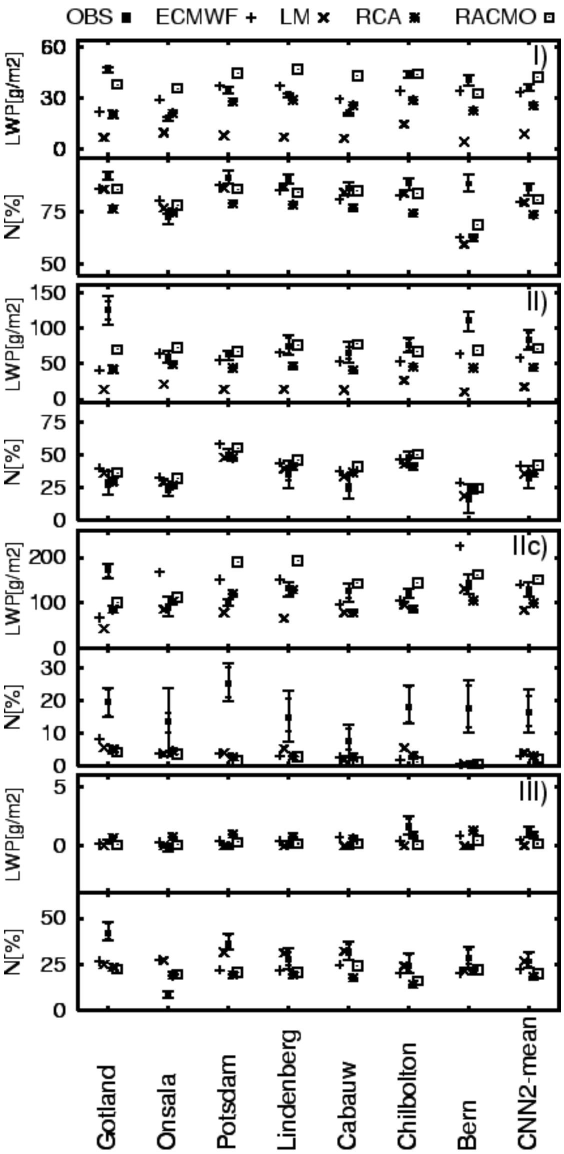

Figure 2. Model predicted and observed LWP and relative occurrence (N) for the CNN2 campaign. The classes I), II), IIc) and III) are described in the text. The central values in the observations refer to an aggregation time of 30 minutes. The uncertainty bars combine the sensitivity to variations in the employed cloud base thresholds and variations in aggregation times in the range from 10 to 60 minutes.

Results of a comparison of statistical properties derived from the observations and model predictions are shown in Figure 2. (*van Meijgaard and Crewell*, 2004). With the help of cloud base observations and rain detection various atmospheric conditions have been sampled. The model output has been processed in an equivalent way. In Figure2, the conditions are defined as follows from top to bottom: I) non-precipitating periods, II) non-precipitating water clouds with cloud base below 3000 m and warmer than 0^{o}C (e.g. pure water clouds), IIc) overcast conditions, being a subset of II) that is found fully cloudy during a time interval, and III) periods free of water clouds with cloud base above 5000 m and colder than -30^{o}C. Class II) and III) are exclusive and fall in class I). For each class the frequency rate of occurrence (N) and the mean LWP amount are shown.

In general, the model predictions are found very consistent in mutual respect, although exceptions can be noticed. Compared to the observations, all models tend to overpredict precipitation, in particular the RCA-model. The models tend to slightly overpredict the amount of non-precipitating water clouds. On average, three models predict LWP in the right order of magnitude, whereas the LM significantly underpredicts LWP. Concerning overcast conditions, model predicted LWP values are found in the same range as observed, but the spread among the stations is large. The occurrence of these conditions is greatly underestimated. During CNN2, models fairly well predicted the amount of (water) cloud free situations with the exception of Gotland and Onsala. It is nicely confirmed that observed mean LWP in this condition is indeed very close to zero.

3. CLOUD LIQUID WATER VERTICAL DISTRIBUTION

During the BBC-campaign centered at Cabauw in the Netherlands, the multitude of instruments including cloud radar revealed the complex vertical structure of clouds (Fig. 3).

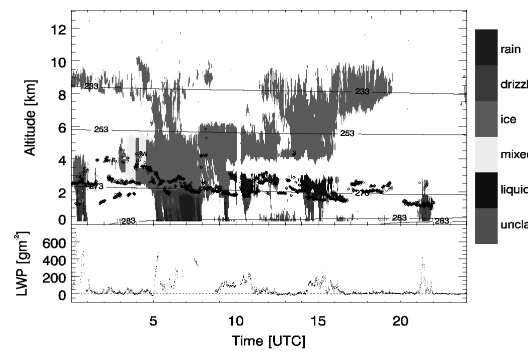

Figure 3. Cloud classification based on the synergy of different sensors and corresponding LWP time series.

In case only one liquid water cloud is present a new synergetic retrieval algorithm could be applied, which simultaneously derives cloud liquid water content (LWC), temperature and humidity profiles during non-precipitating conditions. This integrated profiling technique (IPT) combines brightness temperatures measured at 19 frequencies, cloud radar reflectivity profiles, cloud base height, and operational radiosonde data within an optimal estimation framework (*Löhnert et al.,* 2001 and 2004).

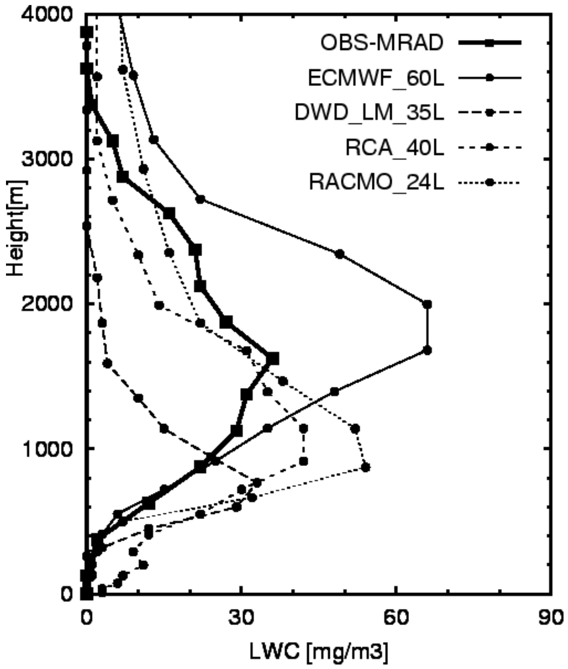

Figure 4. Mean retrieved and model predicted liquid water profiles at Cabauw during about 7% of the BBC campaign time. Model profiles are synchronous with the IPT retrieved profiles.

The model predicted vertical structure of cloud liquid water has been evaluated on the basis of the IPT retrievals at Cabauw. Results are shown in Figure 4. The model predictions are confined to time slots for which profile information was successfully retrieved from the measurements. Model predicted profiles are furthermore restricted to cases without (model) precipitation reaching the surface. Significant differences are found between the various model predictions both in total LWC-amounts as in the altitude where the LWC is largest on average. RCA and RACMO predict this height to occur at 1000 m, which is significantly below the observed height of about 1600 m. The LWC amounts found by these models are in the same order of magnitude as observed. The ECMWF model, on the other hand, puts the level with largest LWC at almost 2000 m, which is beyond the observed height. LWC-amounts in the ECMWF-model are considerably larger than observed. Contrary to this result, the LM predicts the level of the maximum below 1000 m and its profile exhibits much smaller amounts of LWC than is observed.

4. CONCLUSIONS

The recent CLIWA-NET observational campaigns have provided a wealth of cloud parameters, including liquid water path and vertical profiles of cloud liquid water. In analyzing the observations precise knowledge of rainfall occurrence turned out to be critical. In general, all models overpredict the occurrence of precipitation. On average, models predict LWP values in the right order of magnitude as observed, but the spread among the models is considerable. The ability of models to represent certain cloud scenes varies from reasonable to poor. In particular, the occurrence of overcast conditions is greatly underestimated by all models. With respect to the vertical distribution of liquid water the models show huge differences among themselves and no model is capable of matching the retrieved LWC profiles. Numerous possible reasons can be thought of to explain the found shortcomings of these state-of-the-art atmospheric models in representing cloud liquid water parameters. The challenge in future will be to go beyond an evaluation of the model performance and to exploit the observational datasets for testing and improving the actual cloud parametric assumptions.

Acknowledgements

Part of this work was done within the CLIWA-NET project sponsored by the EU under contract number EVK2CT-1999-00007.

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