2.1 THE EUROPEAN BALTEX CLOUD LIQUID WATER NETWORK: AN OVERVIEW

Erik van Meijgaard*, Anne Mathieu and Arnout Feijt
Royal Netherlands Meteorological Institute (KNMI), De Bilt, Netherlands

Susanne Crewell
Meteorological Institute University of Bonn (MIUB), Bonn, Germany

1. INTRODUCTION

Cloud water and cloud ice and their vertical distribution in the atmosphere are essential parameters linking dynamics, radiation and precipitation. Unfortunately, their amounts and distributions are quite difficult to measure which has seriously hampered the representation of clouds in large-scale atmospheric models in the past decades. With the recent advance of powerful instruments like cloud radar and multi-channel microwave radiometer and the ongoing development of synergy algorithms to consistently interpret the measurements from different instruments the experimental outlook has improved considerably. The most accurate method to determine the liquid water path (LWP) is ground-based passive microwave radiometry. The cloud base height is obtained from several instruments (e.g. cloud lidar ceilometer and infrared (IR) radiometer), while vertical profiles of the liquid water content (LWC) might be inferred from a combination of passive microwave radiometer and cloud radar measurements.

The main objectives of the Cloud Liquid Water Network project (CLIWA-Net) are 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. (see http://www.knmi.nl/samenw/cliwa-net)

2 OBSERVATIONAL SETUP

Within CLIWA-Net a prototype of ECON is implemented by coordinating the use of existing, ground-based passive microwave radiometer instruments and profiling instruments. High quality cloud information from this network at very high temporal resolution but poor spatial resolution serves as calibration of satellite-inferred estimates of LWP at high spatial resolution. The CLIWA-Net Network (CNN) consisted of twelve stations (Figure 1) and was operated in two continental-scale experiments in August/September 2000 (CNN I) and in April/May 2001 (CNN II).

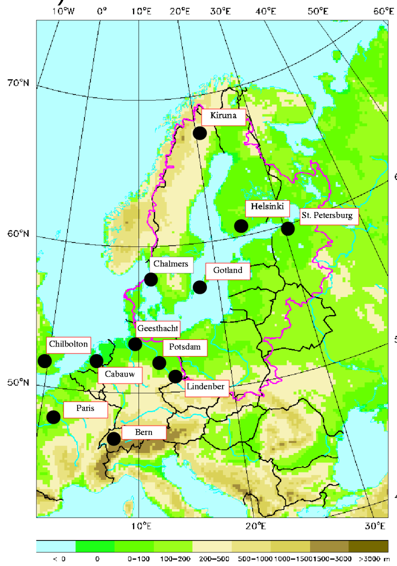

***Figure 1**. The CLIWA-Net (CNN) network. The purple line indicates the Baltic catchment area.*

In a third campaign, conducted in August/September 2001, and hereafter referred to as the BALTEX BRIDGE Cloud campaign (BBC), all available ground-based instruments were brought together in a 100x100 km^2 region in the Netherlands. Coordinated from the central facility in Cabauw a comprehensive local-scale experiment was organized in cooperation with other projects. Observations included microphysics and radiation measurements with aircraft and during part of the campaign the cloudy boundary layer was probed with tethered balloons. The BBC-campaign set out with a 14-day intercomparison of the microwave radiometer instruments involved the CLIWA-Net campaigns. Observations taken during the BBC are still under analysis and first results will be presented at a workshop organized in Leipzig, May 2002.

Measurements during the CNN-campaigns are collected and organised per day and per site like illustrated in Figure 2. Liquid water path (LWP) and integrated water vapour (IWV) are

*Corresponding author address: Erik van Meijgaard, Royal Netherlands Meteorological Institute (KNMI), PO Box 201, 3730 AE De Bilt, Netherlands; e-mail: vanmeijg@knmi.nl.

retrieved with statistical algorithms based on a 10-year data set of European radio sondes. The LWP accuracy for the different stations ranges between 15 and 35 gm^{-2}, and the IWV accuracy between 1.0 and 1.5 kgm^{-2}, but it is noted that these values are derived from the instruments' specifications and are purely theoretical.

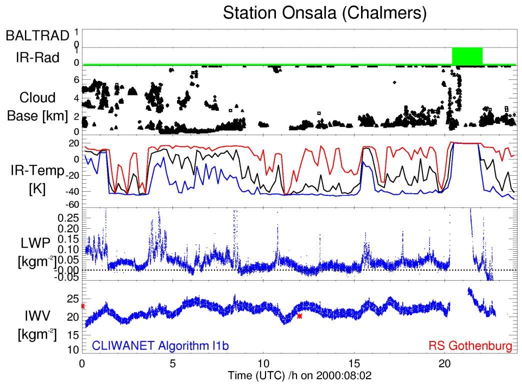

***Figure 2**. Time series of LWP and IWV, cloud base temperature and height, derived from microwave radio-meters, IR radiometer and ceilometer measurements, resp., at Onsala on 2 Aug 2000. The series denoted BALTRAD and IR-Rad indicate events of precipitation.*

Measurements during precipitation are rejected from further analysis, since the microwave radiometer does not return reliable information when the apparatus is wet.

Table 1 summarizes the statistics of the oerved cloud properties during CNN I (Crewell at al., 2002). The time of operation expressed as a percentage of the total experiment period refers to the amount of time that valid measurements were available from the microwave radiometer, the IR radiometer and the lidar ceilometer. IR Conditions were said to be cloud free when the temperature was below –30^{o}C and no ceilometer cloud base was detected. The presence of water clouds was defined by IR temperatures above 0^{o}C and a cloud base below 4000 m. Clouds with ice or mixed phase at cloud base are not classified, but non-precipitating clouds with an ice or mixed phase content above a liquid cloud base may fall in the cloudy class.

The LWP for clear sky situations is of special interest, since it might be used to define the systematic error of the LWP retrieval from the individual instruments at the different locations. The biases range from 6 gm^{-2} at Geesthacht to -15 gm^{-2} at Paris. The bias of 55 gm^{-2} derived for St.Petersburg is due to severe instrumental drift, which has not been corrected. It is noted that the given values are strictly valid for the specific algorithm (Löhnert and Crewell, 2002) and the thresholds for cloud detection. Yet, the values presented are within the expected range of uncertainty and demonstrate that reasonable LWPs can be derived at different locations within Europe covering a variety of climates.

3 EVALUATION OF MODEL PREDICTED LWP

The distributions of LWP and IWV from model predictions are compared with those inferred from the microwave radiometer measurements during CNNI. Observed distributions for Onsala and Paris are shown here along with predictions made by the ECMWF model (effective mesh 40 km, 60 layers) and by the KNMI regional model RACMO, (18 km mesh, 24 layers). The latter model facilitates the package of physics parameterisations from the ECHAM4-GCM. Initialisation and lateral forcing of the RACMO

Station	Rain (%)	T_{all} (%)	Cloud (%)	Clear (%)	zb_{cloud} (m)	Tir_{cloud} (C)	LWP_{cloud} (g m^{-2})	IWV_{cloud} (kg m^{-2})	Tir_{clear} (C)	LWP_{clear} (g m^{-2})	IWV_{clear} (kg m^{-2})
Bern	4.6	69.5	20.7	43.0	–	2.4	76	24.8	-36.8	0.9	18.2
Geesthacht	9.9	51.5	35.0	42.6	1500	6.8	87	21.7	-41.8	5.7	14.5
Helsinki	2.7	13.1	26.6	41.9	1920	1.4	93	22.9	-42.9	1.5	17.2
Kiruna	4.4	28.0	50.5	24.3	1510	3.7	90	15.9	-37.3	-0.8	12.1
Lindenberg	5.6	77.2	31.1	34.4	1430	4.3	88	24.3	-45.4	-8.5	17.3
Onsala	10.2	56.7	31.3	47.2	1330	5.0	103	21.4	-47.9	-8.7	14.9
Paris	3.0	45.5	34.0	52.7	–	5.8	67	26.2	-42.6	-14.7	20.9
Petersburg	6.2	20.6	17.1	40.3	840	5.3	121	22.4	-45.9	55.0	16.8
Potsdam	3.9	88.7	46.8	45.3	1600	–	70	23.5	–	-11.6	18.9

***Table 1**: Mean cloud base height (z_b), infrared temperature (T_{IR}), liquid water path (LWP) and integrated water vapor (IWV) for the stations within the CNN I network during cloudy and clear sky conditions (for definition see text) . T_{all} indicates the relative amount time at which valid measurements could be inferred from all available instruments. (At Bern and Paris no lidar ceilometers were installed, Gotland and Cabauw were not operational during CNNI, whereas Chilbolton suffered from instrumental problems.)*

run is based on ECMWF analyses. The model statistics is calculated on the basis of 12-36 hour forecasts.

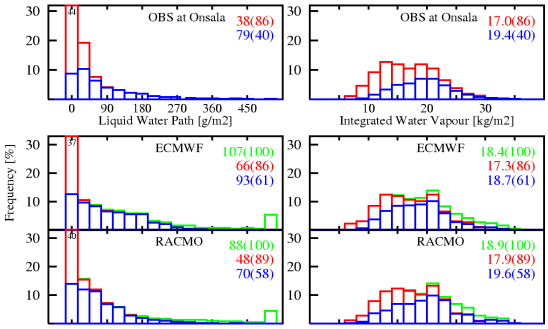

Figure 3. *Observed and model predicted distributions of LWP (left) and IWV (right) for Onsala(Chalmers) during CNN I. Red indicates all non-precipitative events. Blue bar events are further restricted to cloud base temperatures inferred from IR radiometers of at least –10 ^{o}C. . (Only models: Green bars include events with precipitations; values larger than 500 g/m^2 binned together.) Values in plots A(N) indicate average (relative occurrence).*

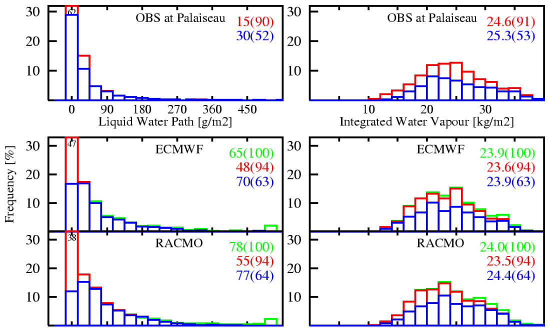

Figure 4. *Like Figure 3 but for Paris*

In accordance with the observations, all model predicted values of LWP and IWV commensuring events of precipitation in the model are discarded in order to come to a meaningful comparison. The distribution of liquid water clouds is probably best represented by the blue bars. It appears that for Onsala the average LWP is reasonably well captured by the models, but that the frequency of occurrence is overpredicted. A reverse conclusion seems to hold for a location much further to the south, at Palaiseau near Paris. However, the latter is possibly related to a systematic miscalibration of the Paris radiometer detected during the BBC intercomparison of microwave radiometers leading to an underestimation of LWP and an overestimation of IWV.

4 VIEW FROM SATELLITE

Within CLIWA-Net, the satellite-based Advanced Very High Resolution Radiometer (AVHRR) is used to compile spatial distributions of liquid water path. At KNMI, an automated cloud detection and cloud property scheme is developed, referred to as KLAROS (Feijt, 2000). In order to optimise the result, the AVHRR inferred LWP values are compared with and, when required, recalibrated by the LWP time series inferred from the ground-based measurements. This procedure is expected to improve the quality of the derived LWP field. The satellite compiled LWP fields can then be used for the evaluation of model predicted LWP fields.

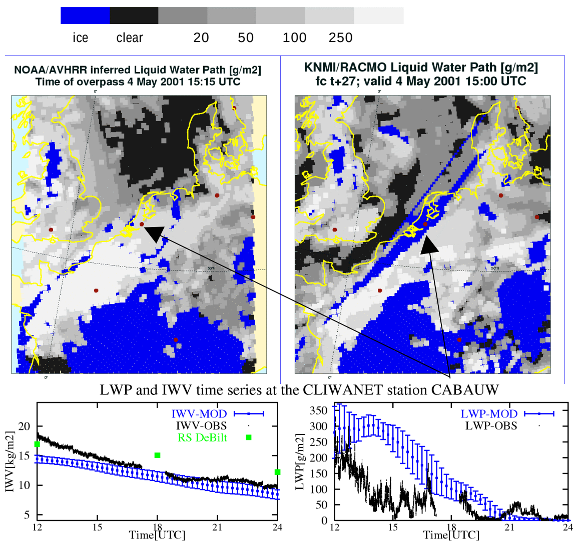

Figure 5 *Upper left panel shows satellite inferred LWP (left) projected from a nominal 1 km resolution on the 18 km model grid mesh. Upper right panel shows the corresponding model prediction(right). Ice is flagged at a cloud top temperature of –13 ^{o}C. Lower panels show time series of observed and model predicted IWV and LWP at Cabauw during overpass.*

A qualitative example taken from CNNII (May 4, 2001) is presented in Figure 5, showing that the large-scale features of the LWP-fields are reasonably well in agreement. (Feijt at al., 2002) Synoptic conditions in the Netherlands were governed by high pressure over the North-Atlantic. In a northerly flow air was advected over the relatively cool North Sea, picking up sufficient moisture to generate and maintain boundary-layer clouds, but not enough to generate precipitation, apart from isolated patches of drizzle. In the coarse of the day a strong inversion developed which was brought down by persistent subsidence. Moreover, due to a slight turning of the flow to north east the moisture supply from the sea was cut off. As a result the cloud deck became thinner and finally dissolved.

The time series in Figure 5 show that the model is overpredicting LWP, however the north-south and west-east oriented transects shown in Figure 6 indicate that at the time of the satellite overpass the LWP-field at Cabauw is in a local minimum, evidently not captured by the model. The larger-scale features of the LWP-field, i.e. rising from north to south, and decreasing from west to east are reasonably.

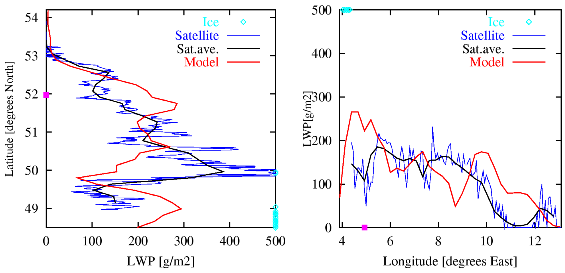

Figure 6 *Right panel shows a transect of LWP-values along the 52 North parallel inferred from the satellite at measurement resolution and averaged at model resolution. Diamonds indicate the detection of ice clouds from the satellite. Also shown is the model predicted transect. Similarly, the left panel shows the north-south oriented transect along the 5 East meridian. The squares indicate the location of Cabauw.*

well reproduced by the model, although the model fails to capture the maximum at 50 North and 5 East.

5 DISCUSSION AND OUTLOOK

The recent European CLIWA-Net campaigns have provided a wealth of cloud parameters, including LWP inferred from ground-based and satellite observations.

Mean cloud parameters are presented for the first CLIWA-Net campaign. The mean bias in LWP for 8 out of 9 stations is well within the expected accuracy. However, the size of the biases puts a limit on the detection of low LWP values, which are of relevance in affecting the atmospheric radiation. Whether the found biases are caused by instruments' calibration or due to the LWP inferring algorithm may be answered by the instruments' intercomparison campaign conducted during the BBC. In the analysis of the observations it is crucial to have knowledge on ongoing or recent rainfall. It is moreover recommended to protect the instrument from getting wet due to rainfall in order to minimize the loss in measuring time.

Evaluation of model predicted LWP shows that models tend to overpredict LWP and the occurrence of liquid water clouds. In evaluating model predicted LWP with microwave radiometer measurements it is imperative to discard LWP values associated with events of model precipitation at the surface.

A new approach is presented to derive spatial distributions of liquid water path from satellite observations. Accuracy is improved by calibration of the satellite measurements to LWP time series obtained from ground-based measurements. A case study is discussed to demonstrate the potential added value of this type of analysis in the evaluation of large-scale atmospheric models relative to a direct comparison of model output and ground-based measurements. The CLIWA-Net data set contains six months of observations, which may enable a statistical evaluation of model output. In future, the approach of retrieving spatial distributions of cloud water may be applicable to the platforms of the Meteosat Second Generation, MSG, because its passive imager includes the relevant spectral channels.

6 REFERENCES

Crewell, S., M. Drusch, E. van Meijgaard, and A.C.A.P. van Lammeren, 2002: Cloud observations and modelling within the European BALTEX Cloud Liquid Water Network, *Boreal Env. Res*. (submitted).

Feijt, A.J. 2000: Quantitative Cloud Analysis using Meteorological Satellites, Ph.D Thesis, Wageningen University.

Feijt, A.J., D. Jolivet, and E. van Meijgaard, 2002: Retrieval of the spatial distribution of liquid water path from combined ground based and satellite observations for atmospheric model evaluation, *Boreal Env. Res*. (submitted).

Löhnert, U., and S. Crewell, 2001: Accuracy of cloud liquid water path from ground-based microwave radiometry. Part I: Dependency of cloud model statistics, *Radio Sci.* (submitted).

Acknowledgements: *Members of the CLIWA-Net team are thanked for their considerable efforts in making available measurements and model results. Part of this work is sponsored by the EU under contract number EVK2CT-1999-00007*.