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THE BALTEX BRIDGE CAMPAIGNS – A QUEST FOR CONTINENTAL CLOUD STRUCTURES

1. INTRODUCTION

In 2001 und 2003 two large field experiments were conducted around the central meteorological measurement facility of the Dutch Meteorological Service (KNMI) at Cabauw, the Netherlands. BBC1 (First BALTEX BRIDGE Campaign) ran for two months covering August and September 2001, while BBC2 (Second BALTEX Bridge Campaign) lasted for roughly one month, May 2003. Both campaigns were devoted to continental clouds with a focus on boundary layer clouds, their spatial variability, vertical structure, and diurnal cycle. Especially in BBC2 precipitation and its small scale variability influencing weather radar returns, has been an additional focus.

Both field experiments have been conducted in the framework of BALTEX (Baltic Sea Experiment), the European continental-scale experiment within GEWEX (Global Energy and Water Cycle Experiment) as a sub-programme of the World Climate Research Programme (WCRP). BRIDGE was the central field campaign within the first phase of BALTEX, which included several field experiments within a Central European modeling region with the Baltic Sea catchment area within its centre. The BBCs were funded from many national and international projects and organisations – the pillars being KNMI, which contributed with large internal funds and personnel, the Fifth Framework European Commission (EC) project CLIWA-Net (Cloud Liquid Water Network, www.knmi.nl/samenw/cliwa-net) and the 4DClouds project (www.meteo.uni-bonn.de/projects/4d-clouds/) in the AFO2000 (Atmosphärenforschungsprogramm 2000) research programme of the German Ministry of Research and Education (BMBF). Important contributions came also from the CAARTER-programme of the EC, MeteoFrance, the MetOffice and the military of the Netherlands and many university groups from the Netherlands, France, Poland and Germany. All in all about 25 research groups were involved with roughly 100 scientists.

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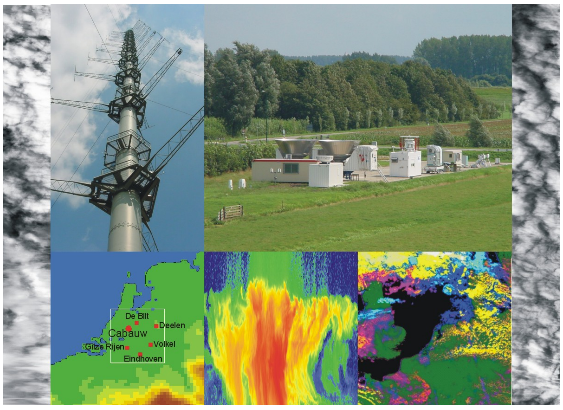

Figure 1. Schematic overview of the BBC components: Ground-based observations from the main experimental site at Cabauw, satellite observations from AVHRR, the regional network spread in an approx. 100x100 km^2 area and the three aircrafts based in Rotterdam. Cabauw is characterized by the high measurement tower and its green polder landscape. The three pictures at the bottom of the figure are the orographic map of the Netherlands with the stations of the regional network, a radar measurement of a cumulonimbus, and a cloud classification from AVHRR. The vertical stripes with *casi* cloud measurements at 753 nm depict the airborne component of the campaign.

2. GOALS OF THE BBCs

The focus of both BBCs was experimental research on the cloudy continental troposphere. Spurred by the large deficiencies in climate and weather forecast models related to clouds and precipitation (IPCC 2001) and the many boundary layer cloud experiments conducted already over ocean regions, the coordinators of the BBCs selected a continental site to deliver data for research on the following goals:

- Assessment of the quality of modeling the vertically integrated cloud liquid water in weather and climate models, which is the link between dynamic cloud processes and cloud radiation effects

- Assessment of the spatial variability of clouds in three dimensions and time to allow for the analysis of three-dimensional effects in cloud radiative transfer and to aid in the development of cloud parameterizations in weather and climate models

- Assessment of the spatial and temporal variability in number and size of precipitating particles below clouds to allow for the analysis of non-linear effects on the relation between radar reflectivity and precipitation intensity.

While the first goal has by large parts already been accomplished with the data in the framework of CLIWA-Net (see contribution by Crewell et al. 2004 in this issue) the other goals are currently being addressed. Some detailed results on the second topic can be found in Venema et al. 2004 (this issue).

3. EXPERIMENTAL SITE

The BBC campaigns were performed around the experimental facility at Cabauw ($51^o58.2'$ N, $4^o55.6'$ E), The Netherlands. Cabauw was in both campaigns part of a regional network consisting of ten remote sensing stations covering a region of 100 by 100 km^2 in the central Netherlands. All the aircraft observations, satellite analysis and atmospheric modeling for the BBCs (Fig. 1) were centered around Cabauw. BBC 1 began with a Microwave Intercomparison Campaign (MICAM) at Cabauw in the first two weeks. Then the microwave radiometers were distributed over the regional network. The network stations performed continuous cloud and radiation observations using lidar ceilometers, infrared-radiometers and pyranometers. In contrast to BBC1 during BBC2 the regional network did not host passive microwave radiometers,but three microwave radiometers were operating at Cabauw.

4. INSTRUMENTAL SETUP

During both campaigns a multitude of measurements of different cloud parameters and the cloudy atmosphere in general were taken by various instruments deployed both at the ground and air born (see Table 1 and 2 for details). The backbone of the measurements were provided by three cloud radars at different frequencies and a suite of different microwave radiometers, the combination of which allow for the quantitative estimation of cloud liquid water profiles. Backscatter lidars and lidar-ceilometers aided in accurately determining the cloud base development and gave valuable information to constrain profiling the atmosphere when precipitating particles were present below the clouds. A new fast Oxygen-A-Band spectrometer estimated solar photon path length distributions to evaluate the influences of cloud structures on the multiple scattering statistics of inhomogeneous clouds in order to challenge our current understanding of radiative transfer in the cloudy atmosphere. Four upward looking Mircro Rain Radars were deployed in array to cover roughly a signal return volume of the nearby DeBilt weather radar.

Table 1: List of instruments including home institutions deployed during BBC1

Radars: 1.29 GHz windprofiler + RASS (KNMI), 3 GHz radar TARA (TU Delft), 35 GHz radar (KNMI), 78 GHz radar (UKMO), 95 GHz radar MIRACLE (GKSS)
Lidars: 1064nm, 532 nm backscatter lidar (RIVM), CT75K ceilometer (KNMI), LD40 ceilometer (KNMI), CT25K ceilometer (U Bonn)
Microwave Radiometers: 22 channel MICCY (U Bonn), MARSS (UKMO), 24+37 GHz DRAKKAR (CETP), 24+31 GHz WVR 1100 (DWD), 12 channel WVP/TP 3001 (DWD), 21+31 GHz (Chalmers), Asmuwara (U Bern), 13+22+37+89 GHz (St. Petersburg)
Radiation: SW in & out, SW direct & diffuse, LW in & out (KNMI), Oxygen-A band spectrometer (U Heidelberg), IR radiometer (KNMI, U Bonn, (U Bern), Albedometer (IfT Leipzig), Sunphotometer (IfT Leipzig), CM21, LXG500, Metek USA1, Campbell KH2O, 8 channel interferometer (TU Dresden)
Cabauw 200 m tower (KNMI): temperature, dew point temperature, wind
Tethered balloons: pressure, temperature, humidity, wind (U Utrecht, 0 - 1.4 km), in-situ particle measurements (IfT+German army)
Radio soundings: 0,3,6,9,12,15,18,21 UTC (Cabauw or De Bilt; KNMI, UKMO or National Army)
Other instruments: GPS receiver (TU Delft),10 m meteo tower, sonic, Ly-a, SW, LW (U Utrecht), digital video cameras (KNMI, TU Dresden)
Cessna C207 T (FU Berlin): radiation, CASI (imaging spectrograph), FUBISS (spectrograph), MIDAC (FTIR)
Partenavia (IfT Leipzig): PCASP-X Nephelometer, PSAP, CPC 3010, CPC 3025, Fast FSSP (GKSS), OAP (GKSS) 2D-C, PVM-100A (GKSS), Albedometer
Merlin IV (MeteoFrance): Cloud m-physics (GKSS) FSSP 100, extended range Fast FSSP, 2D-C, 2D-P, Nevzorow, PVM

In both campaigns three aircrafts were employed for coordinated flights to measure in-situ cloud microphysical parameters and radiation below, inside, and on top of the clouds. A tethered balloon also equipped with cloud microphysics probes and radiation sensors was used to take vertical and horizontal profiles through the clouds. Wind profilers, temporally dense radiosonde ascents, a multitude of ground-based standard meteorological sensors including radiation measurements and turbulent flux devices, and last not least the 200 m meteorological tower completed the efforts to describe as good as possible the properties of the cloudy sky.

Table 2: List of instruments including home institutions deployes during BBC 2

Radars: 1.29 GHz windprofiler + RASS (KNMI), Sodar/RASS (IfT), 3 GHz radar TARA (TU Delft), 35 GHz radar (KNMI), 95 GHz radar MIRACLE (GKSS), C-band weather radar, 4 Micro Rain Radars (U Bonn, U Wageningen, U Marburg)
Lidars: Raman Aerosal Lidar ARAS (GKSS), HTRL backscatter lidar (RIVM), CT75K ceilometer (KNMI), LD40 ceilometer (KNMI), CT25K ceilometer (U Bonn)
Microwave Radiometers: 22 channel MICCY (U Bonn), 20+30 GHz HATPRO (U Bonn, RPG), 36+95 GHz radiometer (Attex)

Radiation: Operational and Quasi-BSRN SW and LW: SW in & out, SW direct & diffuse, LW in & out (KNMI), Oxygen-A band spectrometer (U Heidelberg), IR radiometer (KNMI, U Bonn), IR rad.meter downward looking (KNMI), IR Imager (CELAR), UV Spectrometer (RIVM), Albedometer (IfT Leipzig), Sunphotometer (IfT Leipzig), FUBISS (standard, ASA, Polas) (FU Berlin), Sunphotometer CIMEL (TNO), Total Sky Imager (KNMI)
Cabauw 200 m tower (KNMI): temperature, pressure dew point temperature, wind
Tethered balloons: pressure, temperature, relative humidity, wind (U Utrecht, 5 Heights between 0 - 1.4 km); in-situ particle measurements (IfT, German army)
Other instruments: GPS receiver (TU Delft), 10 m meteo tower, sonic, Ly-a, SW, LW (KNMI), Aerosol counters (TNO), rain gauges (U Wageningen), Video Disdrometer (U Wageningen), present weather sensor (U Wageningen), Video camera (KNMI), ground-water level (KNMI), soil heat-flux (KNMI)
Radio soundings: RS90 (Cabauw and De Bilt (KNMI), Dutch Army
Dornier (NERC): CASI (imaging spectrograph, FU Berlin), FUBISS (spectrograph, FU Berlin), IR-camera (FU Berlin), Airborn POLDER (U Lille), POLIS (Lidar, U Munich)
Partenavia (IfT Leipzig) : Albedometer (290-1000 nm), AFDM (305-700 nm; 2-3 nm), PCASP-X (Aerosol m-physics), Fast FSSP (GKSS), PVM-100A (GKSS)
Merlin IV (MeteoFrance): FSSP 100, extended range (GKSS), Nevzorow (GKSS), OAP 2D2-C, OAP 2D2-P (GKSS), fast temperature probes (U Warsaw), DIRAM (Multidirectional radiances; U Utrecht), King probe, PVM, Fast FSSP, Various pressure, temperature, humidity

All quality-controlled measurement data are stored in a central data base at KNMI. Fig. 2 shows an example of quicklooks for some of the ground-based sensors. Higher-level products, e.g. liquid water profiles derived from synergetic use of several sensors are also available. Requests to access to the data should be sent to one of the campaign coordinators

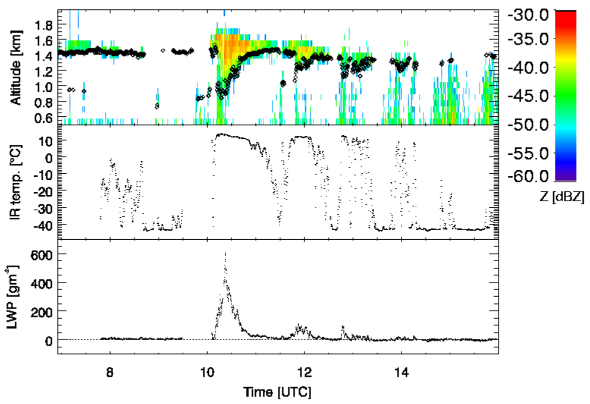

Figure 2. Time series of radar reflectivity, cloud base height derived from lidar ceilometer measurements (black dots), infrared temperature and liquid water path (LWP) measured at Cabauw on August 1, 2001 (BBC 1). The radar reflections below cloud base height are probably caused by insects because the radar signal is dominated by backscattering from larger targets. Hence, cloud base information from lidar is necessary to screen the radar measurements below the cloud

5 HIGH-LEVEL PRODUCTS

In the following we show some higher level products related to cloud and precipitation structurestill in an experimental stage obtained from the BBCs.

5.1 Scanning Microwave Measurements

Probably for the first time a microwave radiometer (MICCY, Crewell et al. 2001) was operated in a scanning mode in order to measure the spatial variability of cloud liquid water (Fig. 3). Both zenith and azimuth of MICCY can be controlled by software and the high spatial and temporal resolution of MICCY allows to scan the sky in minutes. Thus we have a closer look to spatial variability of clouds compared to time series from a radiometer with a fixed viewing angle

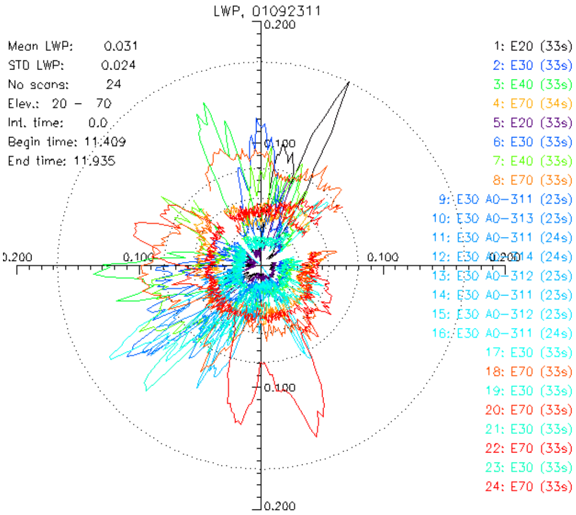

Figure 3: A set of 24 azimuth scans of the Liquid Water Path (LWP) measured by MICCY; plotted like a wind rose. At the origin the LWP is zero, at the top the direction is North, to the right is east. The azimuth scans were made at various elevations, the blue scans with 30 degree elevation and the red ones with 70

5.2 Spatial Cloud Structures and Surrogate Clouds

By no means can microphysical parameters of clouds be monitored directly. Any sensor, measuring directly or remotely, either from airplanes or from ground, probes only a very small volume of the cloudy atmosphere. For evaluation the radiation interaction of clouds or for parametrisation of clouds in dynamic models the three dimensional distribution of cloud microphysical parameters must be known. A way to obtain such cloud descriptions are so-called surrogate clouds. These are artificial clouds which share the statistical characteristics with the probed real clouds. Fig. 4 shows 3D example-surrogate cloud fields made from measured BBC-data. The surrogate cloud fields (middle) have the same horizontally isotropic power spectrum and LWC distribution as LWC profile retrievals (left). These LWC profiles (and corresponding R_{eff} (effective radius) profiles, which are not shown) were derived using an optimal estimation technique (Löhnert et al., 2003) which combines microwave radiometer brightness temperatures, with other measurements and with a priori information from a microphysical cloud model. To generate these surrogate clouds the iterative amplitude adapted Fourier transform algorithm was used, which is described in Venema et al. (2004; this volume). The 3D effective radius fields were created by permutating the R_{eff} values from the profile measurements just like the liquid water content values were permuted. The profile measurements of half an hour is converted in a distance scale in km by the wind speed at cloud height as measured by radiosondes.

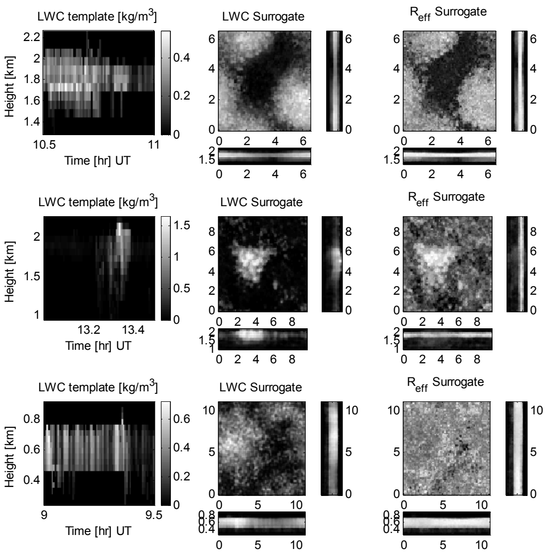

Figure 4: Three examples of 3D surrogate clouds (liquid water content, LWC) and effective radius (R_{eff}) derived from time series of liquid water profiles and effective radii inferred from a synergetic algorithm using passive microwave radiometry and cloud radar data.

6.3 Sub-Pixel Variability of Precipitation

Variability in raindrop size distribution inside the pixel or illuminated volume of a weather radar leads to greater ambiguity and to an often cited but till now unpredictable error when deriving rain rates from radar reflectivity. The vertical profile of raindrop spectra can be measured by vertically-looking so-called Micro Rain Radars, which analyze the spectral distribution of the Doppler return of radio waves. During BBC 2 we distributed four MRRs over an area roughly equivalent to the return volume of the DeBilt weather radar. Using the wind advection information from the nearby wind profiler the time series of the vertical profiles obtained from the MRRs could be transformed into slices of droplet size spectra, which represent the true spatial distribution of the measured raindrops. Fig. 5 shows one example exemplifying the large variability of radar reflectivity possible within a sub-resolution weather radar volume.

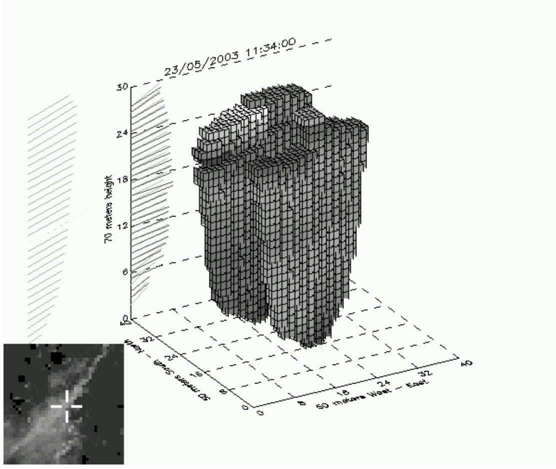

Figure 5: Slices of radar reflectivity measured with three Micro Rain Radars within a signal return volume of the DeBilt weather radar. The lower left sub-picture shows the PPI of the DeBilt weather radar indicating a highly convective situation. The cross gives the location of the three MRRs within the radar image. The usual assumption of equally distributed drops inside the volume (2 x 2 kilometers) will cause significant measurement errors.

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