CLOUDNET

DEVELOPMENT OF A EUROPEAN NETWORK OF STATIONS FOR OBSERVING CLOUD PROFILES

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PART THREE – PROGRESS IN WORK PACKAGES 2-5

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PROJECT HOME PAGE: www.cloud-net.org

3.1 Introduction.

In the subsequent sections the progress made during the final 18 month in work packages is summarized 2, 3 and 4 is summarized. Greater detail can be found in the final report and the specific deliverables associated with each work package.

3.2 WP2 Operate the cloud observing stations.

During this final period additional data sets have been incorporated within the CloudNET project. A summary is also provided of the instrument performance at the baseline CloudNET stations.

2.1

Instruments at the DWD-Lindenberg site include a 35 GHz cloud radar, a LD-40 ceilometer, a Radiometrics microwave radiometer, and a large array of surface measurements, including broad band radiometers and raingauges. The ARM sites all maintain a 35 GHz Millimeter Cloud Radar (MMCR), a Micropulse Lidar (MPL), a Vaisala CT25K ceilometer, a Radiometrics microwave radiometer, and a large array of surface measurements, including broad band radiometers and raingauges. Lindenberg and the ARM sites are operated continuously, 24 hours a day, seven days a week, with occasional gaps in operation for instrument maintenance and repair. The following data is currently available to CloudNET from the additional sites:

DWD-Lindenberg:	April 2004	to September 2005
ARM-SGP:	July 2003	
ARM-NSA:	January 2001	to December 2002
ARM-Manus:	February 2003	to December 2003
ARM-Nauru:	September 2003	to December 2003
ARM-Darwin:	No data processed	

The CloudNET products that are currently available from the new sites include, categorization, classification, ice water content using reflectivity and temperature, and liquid water content using the scaled linear adiabatic technique. Ice water content (and additional parameters) using the radar/lidar technique ((Donovan, 2003; van Zadelhoff *et al.*, 2004) is available for some of the ARM sites. More data is available from the ARM sites but the processing is at the testing stage. The presence of a high powered lidar, the MPL, at the ARM sites increases the detectability of high ice clouds but, due to the shorter wavelength, requires that the corrections must be made for the molecular signal.

2.2 . Instrument performance during the CloudNET observation period

A key objective of CloudNET has been to demonstrate an ability to make long term unattended observations at the three CRS stations. This has been achieved and as a consequence the long-term performance of the three primary remote sensing instrument types has been established.

2.3.1 Cloud radars

Generally speaking the cloud radars operated for CloudNET have performed very well. A component which has caused some difficulties over the course of the project has been the Extended Interaction Klyston Amplifier (EIKA) tube that is used in the 94 GHz radars. The original EIKA in the **GALILEO** radar at Chilbolton operated for 3 years before failing in March 2002. During the last two years of its life there was a steady reduction in transmit power finally resulting in a value that was 20dB down before it ceased to work altogether. The EIKA is an expensive item that is on a long delivery, the **GALILEO** radar was not reinstated until April 2003. That radar was then operated continuously (24/7) and the second EIKA survived for one year before its performance had declined to a point where it was decided to switch the radar off. A comparison with the performance of the EIKA in the 95 GHz **RASTA** radar has revealed it suffered a similar loss of performance. Each EIKA was observed to suffer a 10dB loss of transmit power during a twelve month period of continuous operations. [Years: **RASTA** 2002-2003 / **GALILEO** I 1999-2000 / **GALILEO** II 2003-2004]. Discussions with the tube manufacturer have been ongoing and design modifications, particularly in the area of the cathode coating and operating temperature, have been made to try and address this problem.

An EIKA used in the newer 35 GHz **COPERNICUS** radar at Chilbolton has been operating for over one year without showing a significant loss of transmit performance. A travelling wave tube (TWT) amplifier used in the KNMI 35 GHz cloud radar based at Cabauw has experienced a 9.5 dB loss of transmit power over a four year operating period. The 3.3 GHz FM-CW **TARA** radar located at Cabauw has a transistor power amplifier (GaAs FET Class A-linear), there has been no degradation of its performance.

2.3.2 Lidars

Continuous operations with the commercial lidar ceilometers deployed at the three CRS-stations have proved to be very reliable. The only significant outages occurred when one of the four optical fibres from the receivers of the Vaisala CT75K broke and had to be replaced. Both of the units deployed at Cabauw and Chilbolton experienced this problem (3 were replaced at Chilbolton and 1 at Cabauw). Routine cleaning of the lenses has ensured that no sensitivity has been lost because of dirty optics. The SIRTA observatory in Palaiseau operated a dual wavelength polarization lidar on routine schedules (nominally 8am-8pm, M-F). The sensitivity of this high-power lidar remained stable (range 0-15 km) throughout the project with regular replacement of flash lamps and regular checks of optical alignment. The acquisition system was down for the greater part of July and August 2003 due to failure of National Instrument acquisition cards.

2.3.3 Microwave radiometers

The performance of the multi-channel radiometers, particularly those at Cabauw and Chilbolton, has been uneven. The 22-channel **MICCY** radiometer (UoBonn) operated at Cabauw until August 2003. Difficulties with the data acquisition program meant that unattended continuous operation was not really possible. This resulted in more data voids than expected. In addition there were problems with the radome-shroud that once wet because of rain or fog would often take a long time to dry. This had the effect of making brightness temperature measurements unreliable until the shroud had dried completely. Thermal instability problems with the 3-channel Chilbolton Microwave Radiometer (**CMR**) receivers meant that routine processing of the brightness temperature measurements has been problematical. Calibrations with liquid nitrogen have happened at intervals of once every two weeks throughout the period since May 2003. A method to improve the estimation of liquid water path derived from the brightness temperatures by making use of coincident ceilometer measurements to indicate periods when liquid water cloud is not present above the radiometers, has been shown to work effectively

3.3 Work Package 3 – Development of Retrieval Algorithms

This section summarises some of the innovations made in the areas of retrieving cloud properties from remote sensing by lidar, radar and microwave radiometer. Further details are given in the final CLOUDNET report and also in deliverable 10.
Cloudnet algorithms can be broadly classified according to the following scheme

- Cloud Macrostructure and phase (i.e. Target Classification and Cloud fraction)
- Liquid Water Cloud quantitative algorithms
- Ice Cloud quantitative algorithms

Those algorithms marked with an asterisk are highlighted within this Chapter.

Cloud Macrostructure and Phase algorithms

The Cloudnet target classification is a fundamental part of the CLOUDNET retrieval process. It combines lidar, radar and other measurements to identify specific pixels of 30second/60m vertical resolution to identify the target as cloud/no cloud to assess cloud fraction, cloud top and cloud base, and then identifies the clouds as liquid, ice or mixed phase as a guide to subsequent quantitative algorithms. The following classification/cloud property algorithms have been developed.

1. Data correction, quality control, and regridding.
2. Target classification and data quality flags.
3. Observed cloud fraction on the operational model grids.
4. Cloud Phase detection using lidar depolarisation.

Liquid Water Cloud Quantitative Algorithms

Once the target has been identified as liquid water the following algorithms can be called.

5 Liquid water path from microwave radiometers and lidar.
6 Liquid water content using scaled adiabatic method.
7 Radar-lidar liquid water content retrieval.
8 Drizzle Parameters from lidar and radar.

Ice Water Cloud Quantitative Algorithms

Ice cloud physical properties (i.e. effective radius, IWC) are a subject of considerable uncertainty with respect to atmospheric forecast and climate models. Considerable effort has occurred within Cloudnet to develop new approaches for ice cloud remote sensing and to apply and cross-evaluate new and existing methodologies. The main algorithm development related activities within CLOUDNET are listed below. As before the topics marked with an asterisk have will be highlighted as examples within this Chapter.

9 Ice water content from radar reflectivity and temperature.
10 RADON ice water content.
11 Comparison of Ice Water Content Retrievals.

Algorithms have been implemented on the data set, with retrieved parameters displayed on the web site. A comparison of the retrieved parameters and with the model representation of clouds in the various operational models is given in the next section.

3.4. (WP4) Model Evaluation using Cloudnet observations

This section describes the numerous ways that the Cloudnet observations have been used to evaluate the representation of cloud in the seven forecast model in the project. The work has been divided into 10 breakthroughs, which are summarised as follows:

1. **Evaluation of model cloud fraction.** Cloud fraction is the primary cloud variable in models requiring evaluation. We have compared the long-term statistics of cloud fraction derived from the observations with the corresponding statistics held in each of the models (in particular the mean, frequency of occurrence, mean amount when present and the probability density function) to identify the errors in the climatology of each model.
2. **Evaluation of model liquid water content (LWC) and supercooled water occurrence.** The long-term statistics of LWC have been compared with the models, which has highlighted the errors in the vertical distribution of liquid, particularly at temperatures below 0ºC where there is a large divergence in the way supercooled water is treated between models.
3. **Evaluation of model ice water content (IWC) using the reflectivity-temperature and RadOn algorithms.** Long-term statistics of IWC have been compared with models using two different radar algorithms, the first time IWC has been evaluated in such a comprehensive manner.
4. **High cloud sampling.** A problem with evaluating the model cloud fraction above around 8 km is that the radar can have difficulty detecting the small ice particles at this altitude. A sensitive lidar (e.g. the LNA at SIRTA) can detect these clouds but only in the absence of low liquid cloud that would block the beam. Statistical studies have estimated the optical depths of the clouds that are missed by the radar and show how careful lidar sampling can allow the high cloud in the model to be evaluated.
5. **Cloud area versus volume and cloud inhomogeneity.** The sub-grid structure of clouds is important for their radiative properties. The observations have been used to characterise the relationship between model-simulated cloud fraction by volume and the radiatively important cloud fraction by area. The sub-grid inhomogeneity of ice clouds have also been characterised using cloud radar.
6. **Regime analysis.** It can be difficult to diagnose what is responsible for the errors uncovered in the representation of clouds in models, but an approach has been developed in which the comparison statistics are decomposed by synoptic regime. This reveals, for example, that the ECMWF overestimate of low-level cloud occurs in neutral boundary-layer conditions but less so in the stable boundary layer.
7. **Skill scores.** The comparisons above all evaluate the model climatology, but pay no attention to whether the clouds are forecast at the right time. Skill scores have been used to quantify the skill of the models in simulating clouds as a function of time, height and forecast lead-time. The skill of the "persistence" forecast is shown for comparison.
8. **Change in the Meteo-France cloud scheme.** A change to the Meteo-France cloud fraction scheme was implemented in April 2003 and resulted in the previously substantial underestimate of cloud cover being largely corrected according to the Cloudnet comparisons. Surprisingly, the comparisons with synoptic observations of cloud *cover* showed a worsening of performance. However, this was found to be due to the additional change in the cloud overlap scheme, highlighting the need to get both cloud fraction and overlap right in models.
9. **Changes in the Met Office cloud scheme.** Various changes to the representation of clouds in the Met Office model have been tested using Cloudnet data, and we describe the results of changing the representation of mixed-phase clouds and the value of RHcrit, the grid-box-mean relative humidity at which cloud is first formed.
10. **Effective radius parameterization implementation in RACMO.** Analysis of Cloudnet radar-lidar retrievals of ice particle effective radius have shown that rather than parameterizing it as a function of temperature (as is ubiquitous in climate models), a better approach would be to parameterize it as a function of distance from cloud top. This has now been implemented in the RACMO model.

3.5 WP-5 Definition of instruments and algorithms for GCOS.

Work-package objectives:

> To define the optimum combination of instruments for inferring cloud properties which combines the most accurate retrievals with a design which is reliable and easy to operate by a non-expert.

The overall requirement is to detect all clouds with an optical depth above 0.05 with instruments having a vertical resolution of 60m in a sample time of 30seconds. The instruments should be able to operate in all weathers and be left unattended for several days at a time.

The three major findings of this work package are summarised in the final report.

1. An economic combination of a cloud radar with a simple ceilometer and low cost radiometer is sufficient to fulfil the specification.
2. An economic approach is to use low power FM/CW mm wave cloud radars and/or an X-band pulsed cloud radar.
3. Relaxation of radiometer specification is possible so that it can tolerate slow 5K drifs in the accuracy of the derived brightness temperatures.

Our recommendation to industry are in summary:

1. The mix of instruments with the specification in major findings 1.

2. Examine the economics of low power FM/CW mm wave cloud radars in comparison with an X-band pulsed cloud radar (major finding 2.)

3. Explore the costs of manufacturing a dual wavelength microwave radiometer with the relaxed specification (major finding 3).

4. We estimate that if the total cost of the cloud station can be reduced to the order of 250,000 euro then there is the expectation that each National Met Services may purchase several. Typical costs could be the order of 120,000 euro for the radar, 30,000 for the ceilometer and 100,0000 for the radiometers.