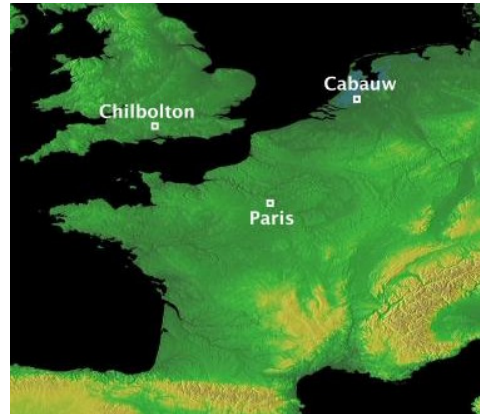


6.3.2. Operate three cloud remote sensing stations. Work Package 2.

Section 1 summarises the cloud net stations, section 2 lists the instruments operating at the various stations and their performance is described in section 3. An overview of the four breakthroughs achieved is in section 4. Section 5 recommends instrument specifications.

1 CloudNET operations at cloud remote sensing stations.

To achieve the scientific objectives of CloudNET, remotely sensed cloud data has been collected quasi-continuously from a network of three cloud remote sensing stations (CRS-stations) during an extended period in which the measurement activities at the three sites have been co-ordinated, and data formats have been harmonised. Archived data from the same network has also been used to this end. Significant and valuable experience regarding the operation of the deployed instruments has been gained. The cloud data sets collected have been used for the development and implementation of cloud remote sensing synergy algorithms, and also to evaluate the representation of clouds in six major european weather forecast models.



CloudNET CRS-stations

<i>Cabauw (The Netherlands)</i>	<i>51.97N 4.93E</i>
<i>Chilbolton (United Kingdom)</i>	<i>51.14N 1.44W</i>
<i>Palaiseau-Paris (France)</i>	<i>48.71N 2.20E</i>

The CloudNET observations have demonstrated the value of operating CRS-stations as a network. One of the challenges facing the project has been the identification of an optimum mix of instruments from which to retrieve the desired cloud parameters. It soon became clear that a colocated vertically pointing cloud radar and backscatter lidar were essential for each site. In addition, it was considered desirable, but not essential, to have multifrequency microwave radiometers and an ability to detect the presence of rain. The CloudNET CRS-stations were established prior to 2001 and have a variety of instruments with different specifications. Additional instruments at each site have been operated during the project to calibrate the core instruments, to gain an understanding of the comparative operational performance of different implementations of the core instruments, and to assist with interpretation of the measurements. A better understanding of several key operational considerations has been achieved; these include (1) the instrument maintenance schedules that are necessary to ensure '24 hours a day / 7 days a week' observations, and (2) the lifetimes to be expected from a number of major components including transmitter amplifiers. We have demonstrated the importance of monitoring instrument performance, and the implementation of rigorous data quality assurance procedures. The experience gained has helped to define the optimal combination of instruments required for a practical Global Climate Observing System (GCOS) CRS-station.

Following the recommendations of the GEWEX-CAP (Cloud and Aerosol Profiling Group) meeting in September 2004, the CloudNET processing algorithms have been tested on, and applied to, data from sites that have similar remote sensing capabilities to the CloudNET CRS-stations. These are the five sites supported by the U.S. Department of Energy (DOE), Atmospheric Radiation Measurement (ARM) program, and the Meteorological Observatory Lindenberg. Those stations are:

ARM-SGP (Oklahoma) 36.62N 97.5W
ARM-TWP (Manus) 2.006S 147.425E
ARM-TWP (Darwin) 12.425S 130.891E

ARM-NSA (Barrow) 71.32N 156.62W
ARM-TWP (Nauru) 0.521S 166.916E
Lindenberg (Germany) 52.21N 14.12E

2 Data collected using instrumentation at the cloud remote sensing stations

Most of the key cloud remote sensing instruments were operated quasi-continuously (24/7) throughout the four years of the CloudNET project. There were inevitably occasions when one or more of the instruments was unavailable for a period because of component malfunction or maintenance. For that reason operations are described as quasi-continuous. The following data sets for the key-instruments were collected at CloudNET's three CRS stations:

2.1 Cabauw

35 GHz Doppler radar	[CESAR]
3.3 GHz FM-CW Doppler radar (TARA)	August 2001 - June 2005
905nm lidar ceilometer (CT75K)	August 2001 - September 2005
22-channel microwave radiometer (MICCY)	August 2001 - August 2005
3-channel microwave radiometer (RESCOM)	August 2001 - August 2003
	December 2004 - September 2005



Cabauw: View of the cloud sensing instruments from top of the met. tower

2.2 Chilbolton

94 GHz Doppler radar (GALILEO)	[CFARR]
	August 2001 - March 2002
	April 2003 - April 2004
35 GHz Doppler radar (COPERNICUS)	April 2004 - September 2005
905nm lidar ceilometer (CT75K)	September 2001 - September 2005
3-channel microwave radiometer (CMR)	May 2003 - September 2005



Chilbolton: View of the cloud sensing instruments alongside the 25m antenna

2.3 Palaiseau-Paris

[SIRTA]

95 GHz Doppler radar (**RASTA**)

October 2002 - September 2003 *

1064/532nm X-Pol lidar (**LNA**)

October 2003 - September 2004

905nm lidar ceilometer (**LD-40**)

October 2002 - September 2005

2-channel microwave radiometer (**DRAKKAR**)

January 2003 - October 2004

July 2002 - September 2005

(* For this year RASTA was operated Mon – Fri between 8:00 and 20:00)



Palaiseau: View of the remote sensing site and key instruments

Full details of the key remote sensing instruments operated on behalf of CloudNET can be found in the Appendix to this report. The table below summarises their properties.

Instrument	Frequency / Wavelength	Range	Range Resolution	Products	Location
Doppler radar	34.86 GHz / 8.6 mm	0.2 – 13 km	90 m (adjustable)	Reflect. (Z_v), Radial Vel. (V)	CABAUW
TARA FM-CW Doppler radar	3.3 GHz / 90.9 mm	0 – 15.4 km	30 m	Reflect. (Z_v), Radial Vel. (V)	CABAUW
GALILEO Doppler radar	94.00 GHz / 3.2 mm	0.1 – 16 km	60 m	Reflect. (Z_v), Radial Vel. (V)	CHILBOLTON
COPERNICUS Doppler radar	34.96 GHz / 8.6 mm	0.3 – 15 km	60 m (adjustable)	Reflect. ($Z_{v\&H}$), ZDR:LDR: V : ϕ_{DP}	CHILBOLTON
RASTA Doppler radar	95 GHz / 3.15 mm	0.1 – 15 km	60 m	Reflect. (Z_v), Radial Vel. (V)	PALAISEAU
CT75K Ceilometer	905 nm	0 – 11 km	30 m	Backscatter	CABAUW
CT75K Ceilometer	905 nm	0 – 11 km	30 m	Backscatter	CHILBOLTON
LNA Lidar	1064 nm & 532 nm	0.1 – 15 km	15 m	Backscatter [Co & X pol]	PALAISEAU
LD-40 Ceilometer	905 nm	0.1 – 15 km	7.5 m	Backscatter	PALAISEAU
MICCY Radiometer	22-channels 22.23 to 90.0 GHz	Integrated	N/A	IWV & LWP	CABAUW
RESCOM Radiometer	21.3, 23.8 & 31.6 GHz	Integrated	N/A	IWV & LWP	CABAUW
CMR Radiometer	22.2, 28.8 & 37.6 GHz	Integrated	N/A	IWV & LWP	CHILBOLTON
DRAKKAR Radiometer	23.5 & 36.5 GHz	Integrated	N/A	IWV & LWP	PALAISEAU

Each of the three sites operated in addition a large array of surface measurements, including broad band radiometers and raingauges.

2.4 Additional data sets for CloudNET

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.

3. 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.

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.

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.

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.

4. Improvements to observation procedures & the quality of data collected

4.1 Development of a calibration technique for 94 GHz radars

Establishing an accurate calibration for the radar measurements of the observed reflectivity (Z) was essential if full use was to be made of the collected data. Based on experience, engineering budget estimates of system performance can be in error by significant amounts. A new method has been developed during CloudNET that relies on the theoretical 94 GHz radar reflectivity of rainfall above 2mm/hr being reduced by Mie scattering so that it is constant and close to 19dBZ; there is little dependence on the raindrop concentration or the shape of the spectra. The calibration method is to adjust the value of Z measured in rain to be 19dBZ when observed with a vertically pointing radar at a range of only 250m to minimise attenuation. In practice, there was a difficulty associated with rain water landing on the radome of the radar as this introduces another 9-14dB of attenuation. To overcome this problem, a procedure that involves operating the radar at lower elevation angles and deploying a shelter to keep the radome dry was implemented. When this was done, averaging over several rainfall events during a month was sufficient to calibrate the radar to within 1dB (25%).

4.2 Development of a technique for auto-calibration of cloud lidar

A traditional method of calibrating visible wavelength lidars is to monitor the level of the known Rayleigh backscatter that is expected from air molecules. This technique will not work for ceilometers which traditionally operate at longer wavelengths that are closer to 1 micron.

To overcome this problem a method of automatically self-calibrating such lidars has been developed which can be used whenever thick layers of low-level stratocumulus cloud are present. The method devised adds the lidar backscatter (in /m/sr) at each gate until the signal is extinguished to give the 'integrated backscatter'. The lidar calibration is then adjusted until the integrated backscatter is about 15sr. This method provides a calibration that is accurate to about 10%.

4.3 Observed cloud products displayed on a web site in near-real time

A system has been developed that converts the raw radar and lidar backscatter signals into the types of cloud parameters that are held within operational forecasting and climate models.

The stages of the process can be summarised as follows:

- Raw measurements from the radar and lidar, the rain rate, and the liquid water path from the microwave radiometers are displayed as monthly time series profiles.
- Downwelling shortwave and longwave fluxes are displayed as monthly time series.
- Calculated profiles of attenuation at 94 GHz are displayed as monthly time series. The gaseous attenuation is calculated from the values of the model humidity and temperature. The liquid water attenuation is computed from the values inferred from the radiometers.
- Targets are classified and displayed using a scheme that categorises them by combining radar, lidar, and operational model data. (The procedure is described in Deliverable 10).
- Cloud fraction products are displayed as monthly time series profiles. They are produced by volume and by area of the grid box, for a one hour period, and for the equivalent to a 60km distance computed using the model winds.
- Ice water content derived from Z and T alone is displayed as monthly time series profiles with associated error flags and retrieval status.
- Derived values of turbulent dissipation energy rate is displayed as monthly time series profiles.

The data from each site is made available on the web as quicklooks for every month, and for each day.

4.4 Absolute cross-calibration of cloud radars at the three CRS stations

As previously stated, accurate radar calibration is of major importance because radar reflectivity is one of the inputs to the cloud microphysical, radiative and dynamical properties retrieval algorithms. A successful cross-calibration of three CloudNET radars was achieved during March and April 2004. The **RASTA** radar was initially operated at Chilbolton and then moved onto Cabauw. At Chilbolton **RASTA** was calibrated against the 94 GHz **GALILEO** radar that had been previously calibrated using a method developed by Hogan et al (2003). This was achieved by performing a point-to-point comparison using no-precipitating ice clouds as targets. (Both radars operating in the Mie region). Next the **RASTA** radar was installed alongside the 35 GHz radar at Cabauw to ensure that all three radars had the same calibration. This procedure was more complicated because of the difference in frequency. Careful selection of a target (an ice cloud that was not too deep in order to avoid Mie scattering) was required to ensure a satisfactory result. It was concluded that the 94 GHz **GALILEO** radar and the Cabauw 35 GHz radar compared well (within 1 dBZ), while 6.5 dBZ had to be added to the **RASTA** radar reflectivity.

5 Recommendations for ground-based GCOS observations of cloud

Experience gained during the course of CloudNET was used to define the optimum combination of ground based remote sensing instruments for monitoring of essential cloud properties. The objective being to infer vertical profile of cloud properties so that they can be compared with those properties carried as prognostic variables within an operational or a climate model. The CloudNET algorithms require inputs from three types of ground-based remote sensing instrument; (1) vertically pointing Doppler radar, (2) vertically pointing lidar/ceilometer, and (3) vertically pointing dual-frequency microwave radiometers. It has become apparent during the course of this project that in order to be of maximum benefit to GCOS those instruments should be able to measure atmospheric profiles with ~50/60 m resolution once every 30 seconds, 24 hours a day, 365 days a year. They also need to be robust enough to be operated by non-radar specialists. A detailed specification for a GCOS observing station is presented and discussed in Deliverable 14, the report of WP-5.