WP1 : Exploit Existing Cloud Data Sets.

A number of field experiments involving radar and lidar have been carried out in the last few years. Four of them (Clara'96, Clare'98, Carl'99, Clare'00) have involved in situ aircraft measurements which allow retrieval algorithms combining lidar and radar data to be directly validated. Thus far such data have not been fully analysed. The two other data sets are only involving ground-based measurements. However they allow the analysis of long time series allowing statistical approaches, and there is also much work to be done in analysing these data in the context of parametrisation development.

In this report we provide details on these external data sets which will be analysed in the CLOUDNET project. One of the aims of this package is to organise the data sets into such a form that they can be used in work package 3 together with the new data acquired in work package 2 for the further development and refinement of algorithms. It is the objective of this report to give the main characteristics of the campaigns from which data will be used, and summarise available data and their access.

1. CLARA'96 (Coordinator : André Van Lammeren, KNMI)

Three 20-day continuous observation periods in 1996 in the Netherlands with a 3GHz radar which can detect clouds, 2 lidars, 20/30/50/ GHz radiometers, infrared radiometer and Doppler sodar. 10 smaller stations with lidar ceilometer and infrared radiometers plus 40 hours of aircraft in -situ measurements mainly in liquid water clouds.

2. CLARE'98 (Coordinator : Anthony J. Illingworth, UR)

The Cloud Lidar and Radar Experiment CLARE ,98 campaign is part of the ESA's Earth Observation Preparatory Programme (EOPP). The objectives of the CLARE '98 campaign are to collect and analyse radar and lidar as well as in-situ data to support the development of retrieval algorithms and to consolidate the scientific requirements of the future Earth Radiation Mission.

The campaign took place during the period 5-23 October 1998 at the Observatory of Chilbolton, Hampshire, UK, to take advantage of a number of supporting ground-based observations. The larges instrument is the 3GHz radar CAMRa with its 25 meter antenna.

Mission #	Day (October 98)	Comment
1	7	8 legs C-130 and ARAT through low level stratocumulus.
2	13	16/10/10 legs by the three aircraft through low level stratocumulus and then some high cirrus.
3	14	14/8/8 legs, low level Sc, then C-130 (only) some cirrus.
4	16	14 C-130 legs - v strong winds - Sc only.
5	20	28/18/18 legs Successful co-ordinated flights through ice and mixed phase clouds.
6	21	8/6/6 legs Successful co-ordinated flights though ice and mixed phase.
7	22	C-130 legs. very strong winds. Mostly Sc.

Table 1 : missions performed during CLARE'98 over Chilbolton area.

Three aircraft were involved in the campaign. The C-130 and ARAT aircraft were present throughout the campaign. The German Falcon was present from 12-23 October. Seven missions were flown and sampled a wide variety of liquid water, mixed phase and ice clouds. Flights were made along wind with the two (three) aircraft flying several times on the same track in the same plane. Track were ending over the Chilbolton site were all ground-based instruments were installed.

A summary of the seven flights is given in Table 1.

The C-130 measured temperature, wind humidity, particle size spectra, bulk water, radiation - broad band and narrow band plus microwave.
The ARAT aircraft has a 94GHz radar and the LEANDRE lidar and an array of radiometers.
The DLR Falcon was equipped with the ALEX lidar, the FUBISS spectrometer together with short and long wave radiometers.

On the ground were:
RAL: 3GHz scanning and 94GHz vertically pointing radars. 22/28/78/94 GHz zenith pointing radiometers. UV lidar, ceilometer, standard Met instruments and a cloud camera.
CRA 35GHz scanning radar 35GHz radiometer
GKSS 95GHz vertically pointing radar.

KNMI IR radiometer, video camera, VIs-IR radiative fluxes.
TU-Delft/TU Eindhoven 21.3, 23.8, 31.65, 51.25, 53.85 54.85 GHz ESTEC radiometers.

Further details can be found at http://www.met.rdg.ac.uk/radar/clare98.html where there is a link to the ftp site where all the data is stored.

Publications

1. R. J. Hogan, H. Flentje, P. N. Francis, A. J. Illingworth, M. Quante and J. Pelon: Characteristics of mixed phase clouds. Part1: Lidar, radar and aircraft observations from CLARE '98. Submitted to Q J R Meteorol Soc, Dec 01.

3. CARL'99 (Coordinator : Jacques Pelon, IPSL)

The CARL project has been supported by the European Communities in the frame of the 4th Framework programme. It involved three partners in Europe (The Institut Pierre Simon Laplace in France, The GKSS in Germany and the University of Athens in Greece). It has allowed the development of new algorithms for retrieving ice water content and particle effective diameter. They are based on both a direct analytical approach and a numerical iterative analysis involving statistical relationships. Comparisons of results from combined radar lidar analysis with in situ measurements were made on selected cases from observations made during two dedicated campaigns. Analyses and in situ data were also compared to model simulations.

Two main field experiments have been performed in 1999 and 2000. The first one was conducted on the IPSL experimental site in Palaiseau. This campaign planned during the first year had to be delayed as problems occurred with the ground-based radar. It involved ground-based lidar-radar

and radiometry measurements as well as in situ validation measurements from aircraft. Passive remote sensing was used in CARL'99 to help improving the analysis of cold clouds and retrieve small size particles. After the airborne radar has been developed at IPSL, the second campaign has been made in Brest involving this new system.

After the first year, KNMI interested in a collaboration was involved in the field experiments and in data analysis. Data acquired during CARL campaigns have thus been complemented using KNMI remote sensing systems.

Instruments involved in CARL

Ground-based Radar MIRACLE (GKSS)
Manufacturer: CPI
Wavelength: 3.2 mm (94.92 GHz)
Peak Power (EIA) : 1.7 kW
Pulse repetition frequency : 50Hz-80 kHz
Duty cycle :1.2 %
Antenna diameter: 120 cm, 2 channels (two-polarisations transmit/or receive), Doppler processing
Observation angle: elevation: 0 to + 90 deg (manual adjustment)
Measurement range: 0-15 km
Range resolution : 15-300 m
Implementation : transportable shelter

Merlin Aircraft (Meteo-France)/In situ sondes (GKSS)
Basic thermodynamics and radiation measurements (Météo-France)
- Temperature
- Humidity
- Wind
- Liquid water (bulk water) Geiger probe
- Radiometry (Eppley pyranometers and pyrgeometers)

Specific in situ measurements (GKSS)

For the determination of the microphysical properties, the MERLIN IV of Météo-France will be equipped with the GKSS cloud particle measuring system consisting of several sizing probes and one probe to estimate the Liquid Water Content (LWC) and the Total Water Content (TWC).

Instrument	Purpose	size range / µm
PMS FSSP-100	cloud particle properties	2.0 – 49.0
PMS OAP-2D2-C	cloud / drizzle particles	25.0 – 800.0
PMS OAP-2D2-P	precipitation particles	200.0 – 6400.0
Nevzorov LWC/TWC probe	LWC/IWC measurements	-
SEA M200	data acquisition system	-

Table 2 : Microphysical Instruments installed onboard the Merlin IV of Meteo-France by GKSS for the CARL campaigns

The 2D2-C and 2D2-P from PMS belongs to the OAP (Optical Array Probe) family of probes. The MERLIN was equipped simultaneously with 4 particle sizing probes and one Nevzorov probe. The main characteristics of the probes are given in Table 2. The instrumentation is described among other things in more detail at the GKSS microphysics group's home page (http://w3.gkss.de/Pms/microphy.htm).

Shadow images of cloud particles in a size range depending on the probe are focused on a diode array with 32 elements which is read out with a maximum repetition frequency of up to 5 MHz. The Nevzorov sonde is a constant temperature hot wire probe, designed for aircraft use. The probe consists of two separate sensors for measuring the LWC and TWC (liquid plus ice water content) of clouds and fog in the range between 0.003 gm^{-3} and 3 gm^{-3}.

Ground-based backscatter lidar SLIM (IPSL/SA)
Manufacturer: IPSL
Wavelength: 532 nanometer (Nd-Yag laser)
Energy : 20 mJ @10Hz
Receiver type: 30 cm diameter telescope, 2 channels (cross-polarisations) Photomultiplier tubes, responsivity at 532 nm: 65 A/W
Observation angle: elevation: 0 to +90 deg (manual adjustment)
Measurement range: 0-30 km
Range resolution: 15 m
Integration time: 10 s
Interface: PC
Implementation : van

ARAT (CNRS/CNES/Météo-France/IGN)
Basic measurements (INSU/DT), temperature, humidity, wind, radiometry (Eppley pyranometers and pyrgeometers)

Specific Remote sensing instruments (IPSL)
- Backscatter lidar LEANDRE (IPSL/SA) operating at 532 nm, dual polarisation
- Cloud Radar RASTA (IPSL/CETP) operating at 94.92 GHz, dual beam antenna

CT75K ceilometer (KNMI)

Receiver type: Silicon Avalanche Photodiode, responsivity at 905nm: 65 A/W
Manufacturer: Vaisala
Wavelength: 905 nanometer (InGaAs laser diode) +/- 5 nm at 25 °C
Observation angle: elevation: 0 to +90 deg is possible
Measurement range: 0 to 75000 ft (0-22.5 km)
Range resolution: 100 ft (30 m)
Integration time: 30 s
Interface: PC
Dimensions: 1.210 m x 0.765 m x 0.510 m
Weight: 83 kg

Heimann IR radiometer (KNMI)
Receiver type: IR radiation pyrometer, lens system K6
Manufacturer: Heimann Optoelectronics
Spectral response: 9.6 to 11.5 micrometer

Observation angle: 0-90 deg
Opening angle: 50 mrad
Temperature range: -50 to + 50 °C
Integration time: 1 s
Temperature resolution: 0.5 °C
Interface: RS 232
Dimensions: 161 x 52 x 52
Weight: 0.45 kg

Time-lapse Cloud Video camera (KNMI)
Camera: Panasonic colour video camera, type WV-CL700. Lens:
WV-LA2.8, FOV 107 ° H, 88 ° V
Recorder: Panasonic S-VHS time-lapse recorder, type NVFS-88EG.
Recording speed: 4 frames/second.

Operation during CARL'99

During the carl'99 campaign, Western Europe and Western Mediterranean were under the influence of a low-pressure system with a weak pressure gradient over France and a stronger gradient over Italian and Iberian Peninsula. This resulted in a SE flow over the Gulf of Genoa veering to easterly over France. During the campaign the system progressed eastwards, while the synoptic conditions remained about the same

Measurements were taken over a 20 days period. Selected priority cases were defined as the 29th of April and 4th of May (see table 3) in order to identify complementary cases : one related to an upper level cirrus layer, the other one to a vertically more extended cloud layer including cirrus and mid-level clouds.

Bimodal spectra were frequently observed during the CARL campaign as most of the cirrus clouds included a precipitating part. An example is given below in Figure 1. This point must be emphasised as in the algorithms allowing a combined radar-lidar analysis, a strong hypothesis is made assuming a single mode distribution.

In the spectra given in Figure 1, FSSP measurements corresponding to the smallest value should not be considered, as errors may be due to large counting rates. Small particles have a large impact on radiation. The analysis of their size is made difficult as their number is large and as most of the time they are non-spherical. This point was partly addressed in Clare'2000 using additional instrumentation for their counting but is still an issue for the shape.

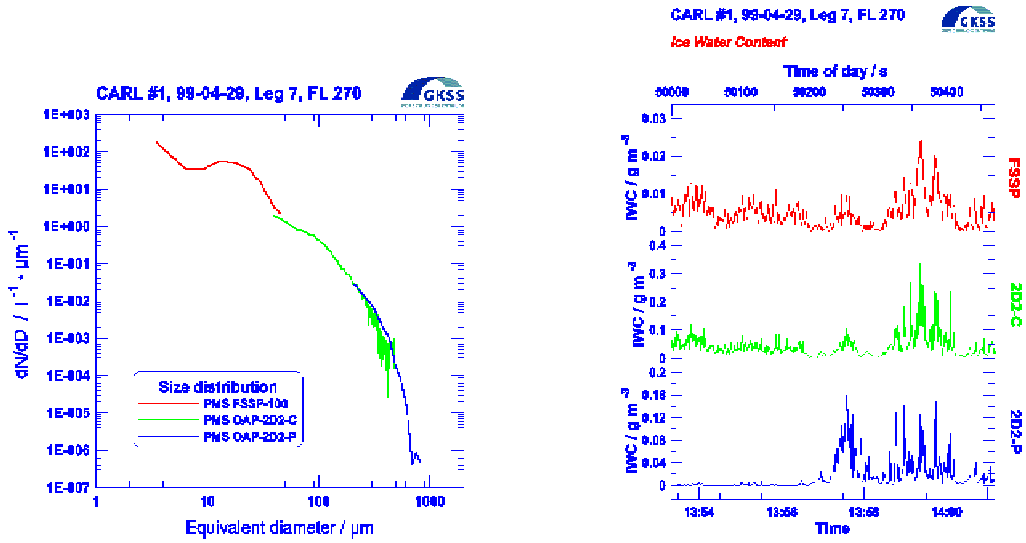

Figure 1 : Size distribution and ice water content (IWC) measurements during CARL'99 on April 29th in cirrus clouds at 8.2 km.

Operation during CARL'2000

This second campaign was held in Brest in November 2000. Ground-based systems have taken an active part to this campaign held in Brest. They are :

- Cloud Doppler radar MIRACLE operating at λ =3.2 mm – 94.9 GHz- (GKSS)
- Backscattering lidar SLIM operating at λ =532 nm (IPSL)

These instruments have been coupled with KNMI instruments

- Ceilometer at 905 nm (KNMI)
- Radiometry from KNMI (including a camera for a whole sky survey)

A Fourier transform spectrometer to retrieve cloud properties from vis-near IR FTIR OASIS (0.7-15 µm) (MPI) had participated to the end of the campaign.

Two aircraft were involved in the campaign :

- the ARAT from CNRS/CNES/Météo-France/IGN for remote sensing
- the Merlin from Météo-France for in situ measurements

The ARAT carried the airborne backscatter lidar LEANDRE 1 from IPSL/SA and the new airborne cloud radar RASTA from IPSL/CETP. Both aircraft were equipped with in situ standard sensors including thermodynamics and radiometry (upward and downward visible and IR fluxes).

The Merlin IV was equipped for the campaign with the PMS sondes of GKSS for analysing size distribution and shapes of cloud particles in all clouds (FSSP, 2DP, 2DC, see below). A complementary instrument was used to give additional information on the water and ice contents : the Nevzorov sonde. The installation of this sonde required specific implementation and tests before the campaign. The IPSL/CETP radar RASTA was flown only at the beginning of the campaign due to HV operation problem.

Publications

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CARL campaign in Palaiseau 26 April – 14 May 1999

Operation Days	Miracle (95 GHz) Operation GKSS	Backscatter Lidar (0.53 µm) IPSL	WIND Lidar (10.6 µm) IPSL	RONSARD Radar (5.5 GHz) IPSL	Ceilometer KNMI	Radiometers (2 IR, 1 Vis) KNMI	Merlin IV Flight Météo-France GKSS sondes	Meteorological situation	Observations
26.04	14 :00 – 15 :15	-	-	-	ok	ok	-		tests
27.04	7 :20 – 13 : 10	11 :20 – 13 :15	-	-	ok	ok	-		
28.04	-	12 :30 – 14 :45	12 :30-13 :10 (vertical)	-	ok	ok	-	High pressure system over England. Low pressure system over southern Portugal, with occluded front over southern France	End of installation of GKSS Probe on Merlin
29.04	8 :20 – 15 :15	8 :00 – 9 :20 11 :30 - 11 :50 13 :10 – 14 :30	7 :35-14 :35 (scanning)	-	ok	ok	11 :30 – 14.00		Thin cirrus between 7.5 and 10 km. No cloud below. Problems with Nevzorov and radiometer measurements on the Merlin
30.04	8 :00 – 11 :20	7 :40 – 8 :40 12 :00 – 12 :20 13 :05 - 15 : 45	-	-	ok	ok	-	Low over Spain moving to the east High pressure over north-east Europe	Altostratus between 4 and 6 km No possible flight (air traffic)
03.05	11 :15 – 16 :15	10 :10 – 12 :00 12 :30 - 15 :30	14 :30-14 :45 (scanning)	-	ok	1-IR vis/cam ok	-	Low over south-eastern France	Thin cirrus clouds between 7 and 11 km, dense patches at 13:30 15:30. Waves. No cloud below. No possible flight
04.05	6 :20 - 15 :50	9 :00 -11 :00 13 :00 - 15 :00	12 :10 – 14:00 (fixed 30 °)	11 :30 – 13 :15	ok	1-IR vis ok	11 :30-14 :00	Low over south-eastern France	Very good case : homogeneous cloud structure between 3.5 and 10 km during flight. Lower cloud disappearing after flight.
05.05	6 :30 – 14 :30	11 :15 – 14 :40	12 :20-13 :20 (scanning and	10 :00-10 :30		1-IR vis ok	11 :30-12 :30	Weak front over western France, warm sector.	Thin cirrus. Flight shortened : cirrus disappeared in the area

		15 :30 – 16 :30	vertical)						after take-off. Mid-level clouds after.
06.05	06:45 – 12:00	7 :45 – 11 :00	-	-		1-IR vis ok	-	Weak front over western France, warm sector. Front closer to Palaiseau.	Cirrus clouds between 6 and 10 km, some cumumlus.
07.05	7:10 – 12:00	11 :15 – 13 :00	-	-		1-IR vis ok	-		Precipitating altocumulus clouds, some cirrus at 7 km
10.05	8 :30 – 15 :00	11 :00 – 13 :20	-	12 :00 – 13 :00		1-IR vis ok	11 :30- 13 :30	Front over western France, warm sector	Dense cirrus between 6 and 8 km until 10:00 with altocumulus, disappearing during flight over the area. Thin cirrus again at 8 km after. 10 µm lidar failure
11.05	9 :15 - 13 :20	14 :15 - 15 :30	-	11 :00- 12 :00		1-IR vis ok	11 :30 - 12 :30	Front, south westerly flow. Low, middle and high clouds. Drizzle.	Flight shortened due to air control
12.05	6 :55 - 14 :25	7 :00 - 11 :00 11 :30 - 13 :30	10 :00-11 :00 (vertical)	-		1-IR vis ok	-	Front, south westerly flow. Middle and high clouds (4-10 km)	Poor quality of Lidar data at 532 nm
13.05	10 :15 - 11 :15	7 :55 - 12 :15	8 :45-9 :45 (vertical)	-			-	south westerly flow. High clouds (6-10 km)	
14.05	8 :30 - 10 :05	8 :10 - 12 :05 14 :05 - 15 : 00	8 :30-11 :00 (vertical)	-			-	south westerly flow. High clouds (6-9 km)	Thin cirrus

<u>Table 3 :</u> Summary of Operation during CARL'99, instruments involved and observations (All times are UTC)

CARL campaign in Brest 6 November – 24 November 2000

Day (Nov)	GKSS Radar MIRACLE	IPSL/SA Lidar SLIM	KNMI Ceilom_r	KNMI IR Radiometer	KNMI Cloud Camera	MPI FTS OASIS	Merlin	ARAT IPSL/CET PRASTA	ARAT IPSL/SA LEANDRE	Observations related to System operation	Cloud height (500 hPa temperature)	Meterological situation
Mo 6	-	-	-	X	X	-	-	-	-	No ceilometer since 5/11 No depolarisation channel on radar Miracle and lidar Slim	-	Cold Front, rain
Tu 7	-	-	-	X	X	-	-	X	X	-	Variable	Occluded Front, rain
We 8	-	-	-	X	X	-	-	-	-	-	-	Occluded Front, N. flow unstable, rain
Th 9	X	X	-	X	X	-	-	-	-	-	< 3 km and 5 to 7 km (-28 °C)	Occluded front evolving NW flow, some mid-level clouds
Fr 10	X	X	-	X	X	-	X	X	X	Leandre acquisition problem (one leg). Rasta failure at the end of ARAT flight	< 2.5km and 3 to 9 km (-28 °C)	Warm sector, mid and high level clouds
Sa 11	-	-	-	X	X	-	-	-	-	-	-	Pre-frontal situation : Low level clouds, rain at 10 UTC, cold front passing
Su 12	X	X	-	X	X	-	-	-	X	Merlin Flight cancellation Front wheel	<2.5 km and 6-10 km (-22 °C)	End of cold front band, passing in the morning, middle and

										problem parts from US needed No flight		high level clouds on the western edge
Mo 13	X	X	-	X	X	-	-	-	-	Depolarisation channel operating on Slim Arrival of MPI/FTS	< 2km, 4km and 5-7 km (-25 °C)	Northerly flow, occluded front, unstable, mid-level clouds prior to small cut-off low
Tu 14	-	-	-	X	X	-	-	-	-	-	-	Northerly flow, occluded front, unstable
We 15	X	X	-	X	X	X	-	-	X	-	< 2 km, 3 to 7 km	Warm sector ahead of cold front
Th 16	-	-	-	X	X	-	-	-	-	-	-	
Fr 17	X	X	-	X	X	X	-	-	X	ARAT flying back to Creil after mission	<2 km, 7 to 10 km and then 4 to 7 km + 7-10 km	Warm front reaching Brest at 15 UTC thin cirrus and As after
Sa 18	-	-	-	X	X	-	-	-	-	-	-	Warm sector, precipitations
Su 19	-	-	-	X	X	-	-	-	-	-		Cold front , precipitations
Mo 20	-	-	X	X	X			-	-	Ceilometer re-installed Merlin operational		
Tu 21	-	-	X	X	X			-	-	-		
We 22	X	X	X	X	X		X	-	-	No cloud over Brest		Warm front
Th 23	-	-	X	X	X		-	-	-	-		
Fr 24	X	X	X	X	X		X	-	-	-	<2 km, 7 to 10 km	Warm sector, some rain

<u>Table 4 :</u> Summary of Operation during CARL2000, instruments involved and observations (All times are UTC).

4. CLARE'2000 (Coordinator : Jacques Testud, IPSL)

The CLARE'00 campaign both included the ground-based counterpart of the second campaign of CARL and dedicated flights involving the radar and lidar onboard the ARAT, and in situ measurements from the Merlin IV.

Observations were dedicated to low- and mid-level clouds (below 6 km). A large number of observations were made in or close to frontal systems. They are reported in Table 4.

Date (Flight #)	Radar (ARAT)	Lidar (ARAT)	In situ (Merlin)	Meteorological situation	Observations
7 March (23)	x	x	-	Westerly flow after cold front passage Cu and Clear air	First test flight and radar calibration
8 March (24)	x	x	-	End of frontal passage Cu, Ac	Second test flight
9 March (25)	x	x	x	Warm sector Cu, Sc, As, Ac, Ci	Sc with iced top, As above with water and ice
12 March (26)	x	x	x	Cu, Cu Cg	Some precips
13 March (27)	x	x	x	Ac, Nb	Flight partly in clouds, precipitation of ice particles
16 March (30)	x	x	x	Warm sector ahead of cold front As, Ac, Ci	Ac between 3.5 and 4.5 km No supercooled water layers observed

Table 4 : Measurements performed during the phase 2 of CLARE'00

In Clare'2000, the water content and particle distribution were measured with probes operated by the Laboratoire de Météorologie Physique (LAMP) at Clermont-Ferrand (France). Several probes were used for particles smaller than 100 µm in diameter :

- King probe (Liquid water content, hot wire,10 Hz),
- Gerber probe (Liquid water contenet, forward scattering multiple particles, 80 Hz),
- FSSP (particle size distribution, forward scattering single particle 10Hz). Diametres smaller than 47 µm in 15 classes (3µm intervals).

Or larger

- Particle size distribution in precipitations are analysed using CDP and 2DC probes.

In order to better sample small particles, another probe was used during Clare

- FFSSP (Fast FSSP sampling >100Hz)

The 2DP used for CARL for very large particles was not installed and their occurrence was estimated from a specific analysis using the 2DC.

The King probe is not very sensitive to small crystals, so its measurements are more representative of super-cooled water content. The Gerber probe sensitive to all hydrometeors. For the 12/03/01 (measurements made in Cumulus congestus) the four values of the liquid water content are most of the time comparable, which is indicative of super-cooled water. For the other flights, a good correlation between measurements is not always observed, which reveals that particles are coexisting in different phases.

Composite spectra (2DC+CDP+FSSP) have been obtained showing again the bi-modal structure of the particle size distribution in this type of clouds.

CARL/CLARE Data availability

Data for CARL'99 and CARL/CALRE'2000 are available (some on request) from participant's web sites.
Radar data are available at http://w3.gkss.de/english/Radar/miracle_engl.html
In situ measurements data are available at GKSS from the radar web page and also available from the web site http://w3.gkss.de/Pms/carl/carl_mic.html.
Lidar data are available at http:/www.aero.jussieu.fr/MAE
Data for the ceilometer and IR radiometer for CARL'99 and CARL'2000 are available on the KNMI web site at http://www.knmi.nl/~bloemink/CARL/
In situ data from Clare'00 are available on the site: ftpobs.univ-bpclermont.fr/

5. C^2 : CLOUD CHARACTERISTICS MEASUREMENT AND STUDY (Coordinator : A. J. Illingworth, UR)

Two studies have been supported by ESTEC at Chilbolton which involve continuous monitoring of the vertical profiles of clouds using ground based lidar and radar. The first acquired data from October 1998 to the end of December 1999. The second from Jan 2000 onwards to the present day. The radar data comprises a value of reflectivity every 30 seconds with 60m vertical resolution. The lidar data is again recorded every 30 seconds but with a 30m vertical resolution. Archived together with this data is the vertical hourly profile of cloud and thermodynamic properties from the operational analyses of the ECWMF and Met Office models.

This dataset has namely been used to analyse the occurrence of supercooled layers in frontal systems and the vertical distribution of clouds and compared to model outputs.

The data set, a series of quick looks and further details can be found at:
http://www.met.reading.ac.uk/radar/realtime

and an archive of the data at
http://www.badc.rl.ac.uk/data/chilbolton

Publications
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6. The United States Atmospheric Radiation Measurement (ARM) Program.

The Atmospheric Radiation Measurement (ARM) Program is a large global change research program supported by the U.S. Department of Energy (DOE). The focus of the ARM program is on obtaining field measurements and developing models to better understand the processes that control solar and thermal infrared radiative transfer in the atmosphere (especially in clouds) and at the earth's surface

The ARM Program is a multi-laboratory, interagency program that was created in 1989 with funding from the U.S. Department of Energy (DOE). The ARM Program is part of DOE's effort to resolve scientific uncertainties about global climate change with a specific focus on improving the performance of general circulation models (GCMs) used for climate research and prediction. The ARM Program focus its data collection and research activities into six focus areas: 1) aerosols, 2) clouds, 3) longwave radiation, 4) shortwave radiation, 5) surface energy exchange (or flux), and 6) atmospheric state.

The following section gives a brief overview the ARM sites and measurements performed. More detailed information is available online at http://www.arm.gov. This web site address also allows to ask for ARM data from the different measurement sites.

ARM Sites

The ARM Program establishes and operates field research sites, called Cloud and Radiation Testbeds (CARTs), in several climatically significant locations. For each site, a large amount of data is collected on a continuous basis over extended periods of time from large arrays of instruments to study the effects and interactions of sunlight, radiant energy, and clouds on temperatures, weather, and climate. The current ARM CART sites are

- The Southern Great Plains (SGP) site.
- The Northern Slope of Alaska (NSA) site.
- The Tropical Western Pacific (TWP) site.

Figure 1. Location of the three ARM CART sites.

Southern Great Plains site

The U.S. Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site was the first field measurement site established the ARM program. The site consists of in situ and remote-sensing instrument clusters arrayed across approximately 55,000 square miles in north-central Oklahoma and south-central Kansas in the United States. Deployment of the first instrumentation to the SGP site occurred in the spring of 1992. Additional instrumentation and data processing capabilities have been incrementally added in the succeeding years. The cloud remote sensing instruments are mainly deployed at the SGP central site in Oklahoma located at 36 N, 97 W.

The continuous observations at the CART site are supplemented by intensive observation periods, when the frequency of measurements is increased and special measurements are added to address specific research questions. During such periods, nearly a gigabyte of data (one billion bytes) is generated daily. Both during intensive observation periods and at other times, scientists bring their own specialized instruments to the CART site, typically for several weeks.

SGP site instruments

The main remote sensing active instruments used for cloud measurements at SGP site are :

- **Millimeter-Wavelength Cloud Radar (MMCR)**
  NOAA/ETL designed the MMCR, a vertically pointing Doppler cloud radar, specifically to monitor clouds overhead at the CART sites of US ARM program (Moran et al., 1998: An unattended cloud-profiling radar for use in climate research, Bulletin of the American Meteorological Society, 79, 443-455). These radars monitor the clouds continuously at sites in Oklahoma, Alaska, and the Tropical Western Pacific Ocean. They are intended to operate at these sites with minimal manned assistance for at least a decade. The main purpose of this radar is to determine cloud boundaries (e.g., cloud bottoms and tops). The MMCR attains extraordinary sensitivity (as good as -50 dBZ at 5km height) for detecting extremely weak non-precipitating clouds through the use of a relatively large antenna (6-ft or 10-ft diameter), long sampling (~ 1 second), signal processing and pulse compression techniques, and the short wavelength (8.7 mm). Radar reflectivity (dBZ) of the atmosphere is thus reported up to 20 km. The radar possesses a doppler capability that will allow the measurement of cloud constituent vertical velocities.

- **Micropulse Lidar (MPL)**
  The Micropulse Lidar (MPL) is a ground-based optical remote sensing system designed primarily to determine the altitude of clouds overhead. Besides real-time detection of clouds, post-processing can also characterize the extent of the tropospheric mixing layer (the planetary boundary layer), or other particle-laden regions. This eye-safe system is designed for continuous operation.

Examples of measurements are given herebelow showing radar and lidar synergism for the analysis of high level (ice) and low level (water) clouds. Precipitations are also detected from lidar below the warm cloud and shows enhanced backscatter corresponding to cloud base (small particles not differentiated by radar).

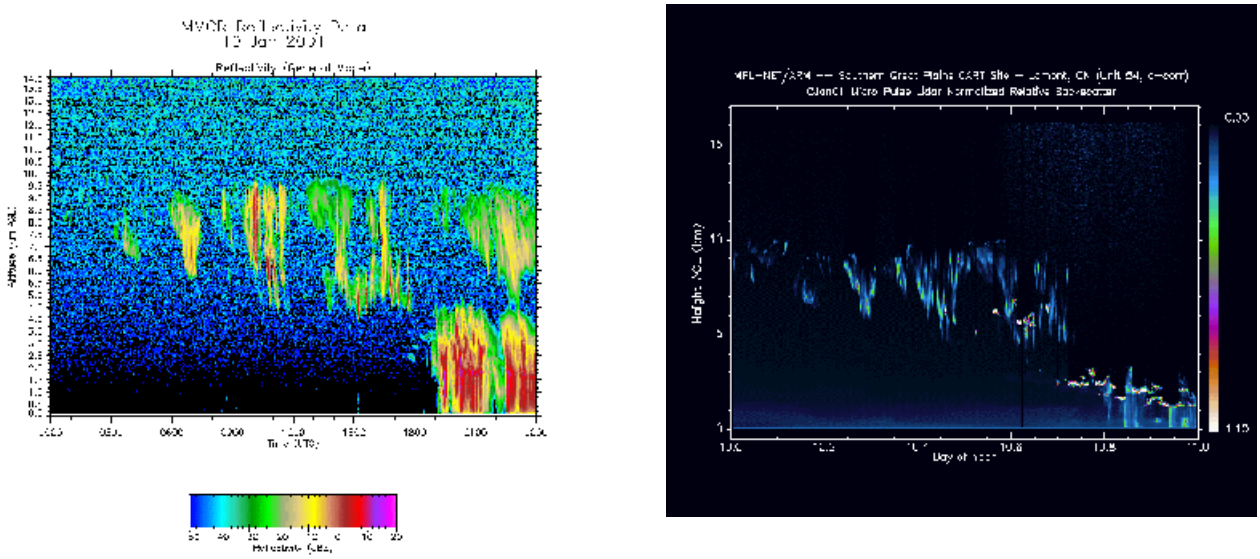

Figure : example of lidar (MPL) and radar (MMCR) data obtained over one day at SGP site

- **Vaissala Ceilometer (VCEIL) –replacing Belfort Laser ceilometer since summer 2000)**

The Vaisala Ceilometer is a self-contained, ground-based, active, remote-sensing device designed to measure cloud-base height at up to three levels and potential backscatter signals by aerosols. Model CT25K has a maximum vertical range of 25,000 feet. The ceilometer transmits near-infrared pulses of light (905 nm).

- **Raman Lidar (RL)**

The CART Raman Lidar (RL) is an active, ground-based laser remote sensing instrument that measures vertical profiles of water-vapor mixing ratio and several cloud- and aerosol-related quantities. This system is fully computer automated, and can run unattended for several days.

Other data for cloud analysis are collected from several other instruments among which :

- Microwave, LW, SW, UV Radiometers
- Pyranometers, Pyrgeometers, Pyrheliometers
- Sunphotometers and spectrometers
- Video Time-Lapsed Camera (VTLC), Whole-Sky Imager (WSI), …

Other instruments involve Surface Energy Flux, surface meteorology and aerosol measurements as well as Atmospheric Profiling (Balloon-borne Sounding System (BBSS), 50-MHz Radar Wind Profiler and Radio Acoustic Sounding System (RWP50), 915-MHz Radar Wind Profiler and Radio Acoustic Sounding System (RWP915), …)

North Slope of Alaska (NSA)

The North Slope of Alaska/Adjacent Arctic Ocean Cloud and Radiation Testbed (CART) site is providing data about cloud and radiative processes at high latitudes. These data are being used to

refine models and parameterisations as they relate to the Arctic. The main site is located at Barrow (71 N,156 W). It was established in 1997 and has been in continuous operation since.

NSA site Instruments

- Clouds
    - Vaisala Ceilometer (VCEIL)
    - Millimeter-Wavelength Cloud Radar (MMCR)
    - Micropulse Lidar (MPL)
    - Microwave Radiometer (MWR)
    - Whole-Sky Imager (WSI)
    -
- Radiometers
    - Atmospheric Emitted Radiance Interferometer: Extended-Range (AERI-ER)
    - Cimel Sunphotometer (CSPOT), Infrared Thermometer (IRT), Multifilter Rotating Shadowband Radiometer (MFRSR), Net Radiometer, Normal Incidence Multifilter Radiometer (NIMFR)
    - Pyranometers, Pyrgeometers, Pyrheliometers
    - Ultraviolet-B Radiometer (UV-B), Radiometric Instrument Systems
        - Upwelling and Downwelling Radiation
    - Surface Eddy Flux
        - Infrared Thermometer (IRT)
    - Surface Meteorology
        - 40-m Tower and Nearby Sensors at Barrow (BMET)
- Atmospheric Profiling
    - Balloon-borne Sounding System (BBSS), Microwave Radiometer (MWR)
    - Millimeter-wavelength Temperature Profiler (MMTP), 915-MHz Radar Wind Profiler and Radio Acoustic Sounding System(RWP915)

Tropical West Pacific Site

The Tropical Western Pacific (TWP) locale is the second Cloud and Radiation Testbed (CART) to be implemented by DOE'S Atmospheric Radiation Measurement (ARM) Program. TWP began phased operations in 1996 at its first site on Manus Island. The second site on Nauru Island was implemented in 1998. In 2001, work began on adding a third site in Darwin, Australia, to support the first two sites

The TWP locale is the area roughly between 10°N to 10°S of the equator from Indonesia to near Christmas Island. This region of the world plays a large role in the interannual variability observed in the global climate system. For instance, the El Nino/Southern Oscillation phenomenon has far reaching implications for weather patterns over much of the Northern Hemisphere, and perhaps the entire planet. The TWP consistently has the warmest sea surface temperatures on the planet and is referred to as the Pacific "warm pool." The warm pool supplies heat and moisture to the atmosphere above it, resulting in the formation of deep convective cloud systems, which in turn, produce high altitude cirrus clouds that spread out over much of the region. These cloud systems regulate the amount of solar energy reaching the surface of the earth and the amount of the earth's heat energy that can escape to space.

TWP site instruments

Atmospheric Radiation and Cloud Station (ARCS):

- Clouds
  - Millimeter-Wavelength Cloud Radar (MMCR)
  - Micropulse Lidar (MPL)
  - Vaisala Ceilometer (VCEIL)
  - Whole-Sky Imager (WSI)
- Radiometers
  - Atmospheric Emitted Radiance Interferometer (AERI)
  - Cimel Sunphotometer (CSPOT), Infrared Thermometer (IRT), Multifilter Rotating Shadowband Radiometer (MFRSR), Net Radiometer (RN)
  - Pyranometers, Pyrgeometers, Pyrheliometers
  - Ultraviolet-B Radiometer (UV-B)
  - Radiometric Instrument Systems:
    - Upwelling and Downwelling Radiation
- Surface Energy Flux
  - Infrared Thermometer (IRT)
- Surface Meteorology
  - Surface Meteorological Instruments (SMET)
  -
- Atmospheric Profiling
  - Balloon-borne Sounding System (BBSS), 915-MHz Radar Wind Profiler and Radio Acoustic Sounding System (RWP915), operated in cooperation with the National Oceanic and Atmospheric Administration (NOAA) Aeronomy Laboratory, Microwave Radiometer (MWR)

ARM Data Policy and Measurement Strategy

The ARM Program's primary objective is to test and improve General Circulation Model (GCM) parameterisations of clouds and their effect on the radiative energy balance. To meet this goal, data are being gathered to measure key aspects of the radiation field under a range of climatologically significant conditions. The primary means of data collection is through ground-based remote sensing instruments. However, satellite data is also archived as well as aircraft data from occasional intensive observation periods.

In addition to measurements, The ARM External Data Centre regularly collects analysis and forecast model products produced by the National Centres for Environmental Prediction (NCEP) and the European Centre for Medium-Range Weather Forecasting (ECMWF). These products are used to augment the instrument data collected at the ARM sites. We have models that are specific to each site (SGP, TWP, and NSA).

The data contained within the ARM data archive is widely available to the global Atmospheric science and climate community via a web-based interface. The data are arranged according to an easily understandable hierarchy of quality control levels. Both raw data and a range of derived products are available.

ARM Program Conference Proceedings and Publications

The ARM Program has published a number of its documents as PDF files (Portable Document Format files). Recent presentations at the ARM Science team meetings are available from the ARM web site such as reported in the last Proceedings of the Eleventh ARM Science Team Meeting (HTML TOC; PDF document), March 19 to 23, 2001, Atlanta, Georgia.