CLOUDNET (EVK2-2000-00611)
SUMMARY OF SCIENTIFIC PROGRESS DURING YEAR ONE

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1. INTRODUCTION.

The overall objectives of the CloudNET project are:

a) To optimise the use of existing data sets to develop and validate cloud remote sensing synergy algorithms.

b) To demonstrate the importance of an operation network of Cloud Remote Sensing stations (CRS) to provide data for the improvement of the representation of clouds in climate and weather forecast models and for the use of GCOS.

This involves:

c) Development of algorithms for deriving ice and liquid water content from ground based lidar, radars and radiometers.

d) Showing that the cloud properties inferred can be usefully compared with the prognostic variables held in the model grid box for four European operational forecasting models and so improve such models.

e) Collaboration with European industry so that the instrument techniques and algorithms developed can be implemented to provide operational data for these forecasting models.

In section 2 we briefly discuss management issued, then in section 3 we summarise the scientific progress made in the first year from 1 April 2001 – 31 March 2002 and how they apply to headings a)-e). The scientific papers are listed in section 4.

2. MANAGEMENT ISSUES.

The work has concentrated on WP1, analysis of existing data sets, and WP2, Operate existing data sets, as in the approved timetable. Because of difficulties with the high technology apparatus we are negotiating a one year no –cost extension so that the two year intensive data gathering period will start in October 2002 rather than October 2001 and the project will finish on 31 March 2005. No other management difficulties have been encountered.

3. SUMMARY OF SCIENTIFIC PROGRESS.

Ten scientific papers have been submitted for publication and a further seven are in preparation. The numbers refer to the list of papers in section 4.

3.1.1 Use of existing data sets (a) for the development of algorithms for deriving ice and liquid water (c).

Current climate models carry average amounts of liquid (LWC) and ice water content (IWC) for the present climate which differ by an order of magnitude. If forecasts of global warming are to be credible such inconsistencies must be reduced and reliable observations of water content be obtained. The following aspects have been explored in CloudNET.

1. *Identification of supercooled clouds* .An algorithm for identifying supercooled cloud of liquid water at temperatures below freezing has been developed by

identifying their high lidar return and low radar return and has been validated by aircraft in-situ measurements confirming the existence of supercooled liquid droplets. (1)

2. *Frequency and radiative impact of supercooled clouds.* An analysis of two years radar and lidar data in the UK shows that on over 25% of occasions when cloud is observed supercooled layers are present and that typically such supercooled clouds change the radiation flux by about 100W/m^2. Such clouds are presently scarcely represented in climate and weather forecasting models yet these observations suggest they have a significant effect on the global radiation balance, when compared with the direct radiative effect of 4 W/m^2 of doubling CO_2. (2).
3. *Inhomogeneity of ice clouds*. This is not yet represented correctly in models; instead a mean in-cloud IWC is used. The radiative effects of these variations in ice water content within a vertical stack of grid boxes are important, and fluxes are very different if the higher IWC regions are stacked on top of one another or randomly scattered over the grid box area. Analysis of two years of Chilbolton data has provided an expression for the fractional variance of the IWC as a function of grid-box size and wind shear and also an expression for the vertical decorrelation of optical extinction coefficient derived. An expression has been derived so that this inhomogeneity could be represented in an operational model. (3)
4. *Simultaneous radar measurement of LWC and IWC*. A new method for simultaneously measuring both liquid water content and ice water content has been developed using triple frequency radar, which derives liquid water content from differential attenuation and the ice water content from the dual wavelength ratio due to Mie/Rayleigh scattering (4) .
5. *Radar/lidar retrieval of LWC*. Retrieval of liquid water content from a radar and lidar is difficult because the lidar return is extinguished by the water cloud and the radar return can be dominated by the occasional drizzle drops. A method of determining liquid water content by the ratio of the optical depth from the lidar and the radar reflectivity which is unaffected by the drizzle has been developed (6) and evaluated using radar/lidar observations and an independent measure of integrated vertical liquid water path from a radiometer. (7).
6. *Identification of ice using polarimetric radar*. The cross polar return can be useful for giving an indication of the presence of melting ice particles and also to give an indication of the shape of dry ice particles (8).
7. *Terminal velocity as a function of IWC.* The lifetime of cirrus clouds is prescribed by the assumed terminal velocity of the ice particles. Studies comparing a forward and vertical pointing airborne cloud radar enable the dynamical motions and the terminal velocity of the particles as a function of IWC to be inferred. (9)
8. *IWC and Size of Ice Particles.* The radiative properties of ice clouds depend both upon the IWC and the ice particle size. To a first approximation the ratio of the radar reflectivity to the unattenuated lidar backscatter is proportional to the fourth power of the particle size. The most problematic aspect is to correct for the severe lidar attenuation – a new technique is described which relies on relations such as that between the attenuation and ice water content once they are divided by the normalised ice particle concentration. Validation with in-situ measurements confirm the efficacy of the new algorithm. (10).

9. *Ice particle size and particle fall velocity*. Once the particle sizes have been established from the ratio of the radar reflectivity to the unattenuated lidar backscatter, then the radar Doppler velocity can be related to the particle terminal velocity and used as an additional constraint to the ice particle size spectrum and the ice particle habit and shape. Ice particle shape and habit affects the interaction of the particles with radiation. (17).
10. *Radar detection and climatology of stratocumulus clouds.* Many stratocumulus clouds contain only small cloud droplets and so cannot be detected by radar; however the presence of just a few larger drizzle droplets enables them to be seen by the radar. Comparison with the lidar, which detects them without any difficulty, with radar over two years at Chilbolton suggests that only 50% of stratocumulus can be detected by radar alone. (12).
11. *Retrieving stratocumulus drizzle parameters using radar and lidar.* Stratocumulus clouds are widespread over the cold oceans, but in spite of their radiative importance, most climate models have difficulty representing them. Their evolution and stability is affected by the amount of drizzle they produce. A new method of combining radar and lidar backscatter from drizzling stratocumulus, to derive a three parameter gamma function to describe the drizzle size spectra, and hence drizzle liquid water content, liquid water fluxes and also the vertical air velocities has been developed. This will enable the properties of real stratocumulus clouds to be compared with their model representation. (14).
12. *Stratocumulus LWC from dual wavelength radar.* Observations of differential attenuation between 35 and 94GHz radar reflectivity are converted into a high resolution vertical profile of LWC within stratocumulus. This new method appears to be the only means to observe vertical profiles of LWC. (15).

3.1.2 The use of existing data sets (a) to show that the cloud properties inferred can be usefully compared with the prognostic variables held in the model grid box for four European operational forecasting models and so improved such models (d).

Most GCMS represent clouds by two prognostic variables per grid box: the average cloud water content per grid box and the fraction of the grid box which is filled with cloud. The topics below within CloudNET have addressed these issues.

1. *Cloud fraction by area or volume*. In most GCMs the cloud fraction is calculated as the fraction of the grid box which is filled with cloud and this is used to calculate radiative fluxes which depend on the projected area of the box which is cloud filled. Analysis of observations shows there is an important difference between the two definitions. Clouds often appear in thin layers so that the cloud fraction by area is greater than that by volume. The average difference is 30% Models need to consider this difference. (11).
2. *Evaluation of IWC in models*. Analysis of 1 year’s radar data is used to derive IWC and compare with the IWC values in two operational models as a function of vertical height. Below 6km they agree to within the accuracy of the radar derived IWC retrieval, but above 6km the model IWC seems low. The probability distribution of IWC and fractional cloud cover is generally well captured by the models. (16)

3.1.4 Use of existing data sets (a) so that Collaboration with European industry so that the instrument techniques and algorithms developed can be implemented to provide operational data for these forecasting models (e).

In this section we describe two papers in which new calibration techniques for lidar and radar are developed and could be used in the cloud remote sensing stations.

1. *Calibration of 94GHz radar using rain as a target.* Accurate calibration of the 94GHz radar is essential if the derived quantities such as LWC, IWC and ice particle size are to be reliable, but calibration using a radar link budget is error prone. A new method accurate to better than 1dB (25%) has been developed and validated which exploits the quasi-constant short range reflectivity of rain at 94GHz. (5)
2. *Calibration of cloud lidar using stratocumulus clouds.* Again direct calibration of lidar from a theoretical power budget is difficult. A new method has been developed and validated which uses the backscatter recorded for the first few gates of a strongly attenuating liquid stratocumulus cloud which then completely extinguish the signal. The backscatter added up over these gates should be a known constant; the calibration is adjusted until the integrated power agrees with the theoretical value. (13).

4. List of published and submitted papers.

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. In revision. Q J Roy Meteorol Soc., 2002.

2. R J Hogan, A J Illingworth, J P V Poiraes Baptista and E J O'Connor: Characteristics of supercooled clouds: Part II A climatology from ground-based lidar. In revision. Q J Roy Meteorol Soc., 2002

3. R J Hogan and A J Illingworth: Parameterizing ice cloud inhomogeneity and the overlap of inhomogeneities using cloud radar data. In revision. J Atmos Sci, 2002.

4. N Gaussiat, H Sauvageot, A J Illingworth. Cloud liquid water and ice content retrieval by multi-wavelength radar. In revision. J Atmos Ocean Technol, 2002.

5. R J Hogan, D H Bouniol, D N Ladd, E J O'Connor and A J Illingworth: Absolute Calibration of 94-GHz radars using rain. In revision. J Atmos and Ocean Technol, 2002

6. Krasnov O and Russchenberg H: An enhanced algorithm for the retrieval of liquid water cloud properties from simultaneous radar and lidar measurements. Part 1: The basic analysis of in-situ drop spectra. In revision. Phys and Chem of the Earth. B. 2002

7. Krasnov O and Russchenberg H: An enhanced algorithm for the retrieval of liquid water cloud properties from simultaneous radar and lidar measurements. Part II

Validation using ground based radar. lidar and microwave radiometer data In revision. Phys and Chem of the Earth. B. 2002

8. Heijnen S H, H. Klein-Baltnink, H W J Russchenberg, W.F. Van der Zwan; Polarimetric cloud studies at 3.3.GHz. In revision. Phys and Chem of the Earth. B. 2002.

9. Protat A, C.Tinel and J Testud. Dynamic properties of clouds and dynamic/microphysical interactions from 94GHz radar and lidar.
In revision. Phys and Chem of the Earth. B. 2002

10. C.Tinel, J Testud, A. Protat, and J.Pelon. Microphysical and radiative properties of ice clouds using a cloud radar-lidar algorithm. In revision. Phys and Chem of the Earth. B. 2002

Papers shortly to be submitted:

11. M E Brooks, R J Hogan and A J Illingworth: The definition of cloud fraction in GCMs by area and by volume. To be submitted to J.Atmos Sci.

12 E J O'Connor, R J Hogan and A J Illingworth. Radar detection and climatology of stratocumulus clouds. To be submitted. J Appl Met.

13. E J O'Connor and A J Illingworth Automatic self calibration of cloud lidar. To be submitted J Ocean Atmos Technol.

14. E J O'Connor, R J Hogan and A J Illingworth. Retrieving stratocumulus drizzle parameters using radar and lidar. To be submitted to J Appl Met.

15. R.J.Hogan and A J Illingworth. Stratocumulus liquid water content from dual wavelength radar. To be submitted to J Ocean Atmos Technol.

16. M E Brooks, R J Hogan and A J Illingworth. Comparisons of radar derived values of IWC and their representation in operational models of ECMWF and Met Office.

17. D P Donovan: The relationship between lidar/radar effective particle size and Doppler fall velocity of cirrus cloud particles.