6.3 Applied methodology, scientific achievements, and deliverables.

6.3.1 Exploitation of Existing Cloud Data Sets – Work Package 1.

a) Objectives

To organise the existing data in to a format accessible by other partners.
To test first versions of algorithms to derive cloud characteristics from the data set.
To analyse the in-situ cloud aircraft data to validate the retrievals.

b) Methodology and scientific achievements.

Data sets from the following campaigns have been used to develop some of the fundamentals for the analysis and algorithms during the first year of the CloudNET project: ARM, Clare 98, CLARA, KARL and others. Four breakthroughs have been identified which are summarised as follows:

1. Independent evaluation of retrieved ice cloud properties from radar and lidar.
   It is shown that the extinction coefficient can be derived from the radar and lidar and its value is independent of the assumed lidar ratio, ice particle size or ice particle density.
2. One years climatology of ice particle size as a function of ice water content and T.
   These results from the Oklahoma ARM site suggest a new size-temperature relationship.
3. New algorithms for deriving cloud properties of stratocumulus.
   A technique for retrieving the particle size spectrum and water flux of drizzle falling out of stratocumulus clouds. Drizzle plays an important role in the evolution of Sc.
4. Use of combined reflectivity and Doppler velocities to classify ice clouds .
   The first steps towards combining these two parameters for ice clouds, which lead subsequently to the RADON technique (see report on work package 4)

These results laid the foundations for many of the retrievals which are reported in work packages 3 (algorithms) and 4 (comparison with models).

1. Evaluation of new radar/lidar retrieval of ice particle size, water content and errors using blind tests.

Simultaneous radar and lidar backscatter return signals from ice clouds have the potential to provide, for the first time, accurate ice particle size and ice water content. Current retrievals are unreliable because it is difficult to correct for the severe attenuation of the lidar signal. Two new methods to correct for attenuation by using the radar return at the back of the clouds have been compared and evaluated in a series of blind tests. Theoretically, the radar return (Z) (= ND^6) and the corrected lidar return (B) (= ND^2) where N is ice particle concentration and D is their size, so D can be estimated from Z/B. The first method (KNMI) is to iteratively adjust the lidar attenuation of the cloud so that D on the far side of the cloud is well behaved and constant over the last few detectable gates, whereas the second method (IPSL) is to adjust the attenuation so that N is constant over the last few gates.

The results are displayed in Figures 1-4. Aircraft observations of ice particle size spectra were used to calculate profiles of ice water content, ice particle size, and radar and attenuated lidar backscatter (Fig 1). Note how the lidar backscatter is attenuated and only penetrates the top few km of the cloud. The two teams then fed the radar and attenuated lidar backscatter into their algorithms and reported back their inferred profiles of extinction coefficient (fig 3) and particle size (fig 4); the retrievals (dotted lines) are very close to the original data (solid lines) The extinction coefficient is the most important, as this controls the radiative fluxes, and is very accurately retrieved, with an accuracy sufficient to constrain the long wave fluxes to 10W m^{-2}. A fuller account of the work is given by Hogan et al (2006).

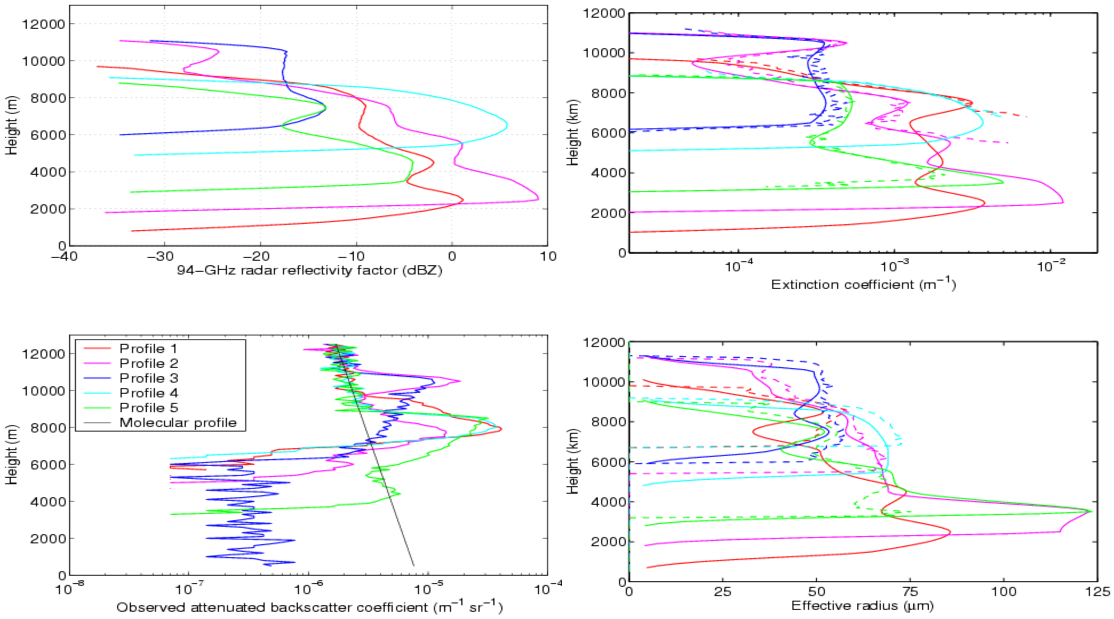

Figure 1-4

2 One year's climatology of ice particle size as a function of IWC and T over Oklahoma.

Radiative properties of ice clouds are controlled by their optical depth which is affected by the size of the ice particles. The KNMI retrieval method described in 1.3.1 has been applied to 7 months data from the US Government Atmospheric Radiation Measurement's (ARM) Southern Great Planes (SGP) site situated Oklahoma and is are displayed in figure 5. along with three other effective particle radius parameterisations derived from in-situ aircraft data. In general, our results confirm previous parameterisations, but there are some large differences probably due to differences in IWC.

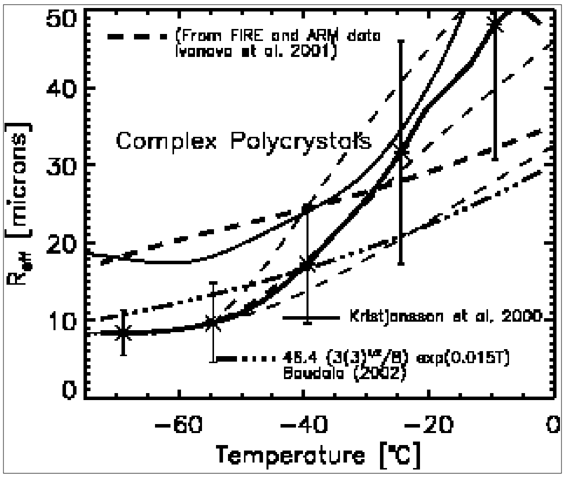

Figure 5. Comparison of the effective radius as a function of temperature from the ARM data with three other published parameterisations, which only depend on temperature. The thin-dashed lines show the new parameterisation at specific values of IWC while the dark line shows the composite result taking into account the observed behaviour of the IWC-vs-Temperature.

The results of this work have been used to formulate parameterisations of cirrus cloud effective particle radii and other relevant quantities that are suitable for inclusion in atmospheric models. This work strongly argues that in formulating ice-crystal size parameterisation that both IWC and temperature should be taken independently into account.

3. New algorithms for deriving liquid water content, drizzle size spectra, and attenuation within stratocumulus liquid water cloud.

A new algorithm for characterising the drizzle falling below stratocumulus exploits the four radar and lidar observables shown in figure 6. The ratio of the radar reflectivity (Z) and the lidar backscatter provides an estimate of mean drizzle droplet size, once the size is known then the value of Z fixes the concentration, the Doppler spectral width then fixes the width of the drizzle drop spectrum defined by μ. These three observables have now defined the three parameters in a normalised gamma function, which describes the drizzle drop size spectrum.

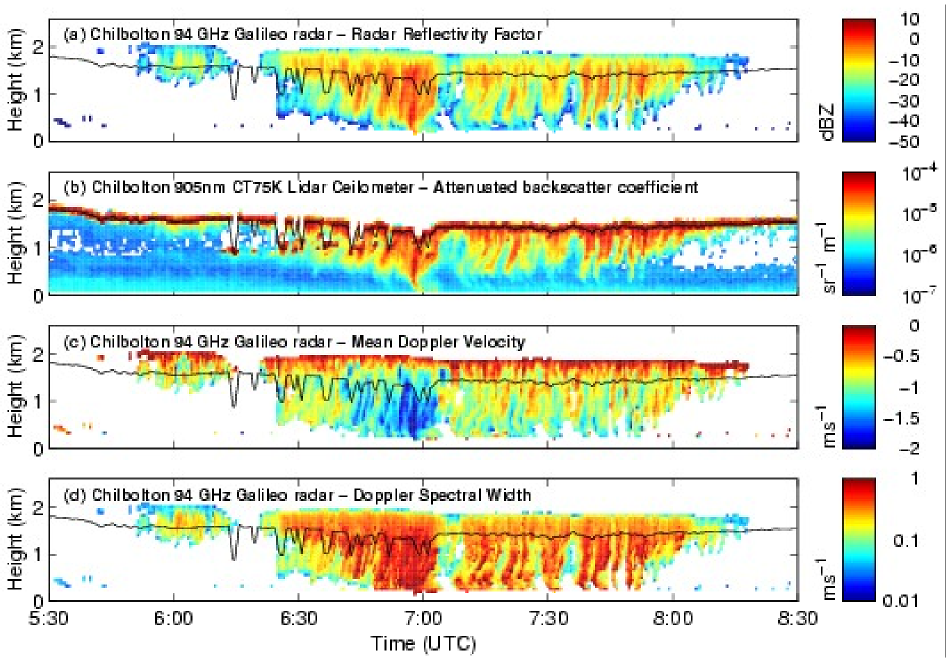

Figure 6

In Figure 7 are displayed the median diameter, and the derived value of μ for the size spectrum, then next panels show the liquid water content and liquid water flux computed from the size spectrum. The value of the Doppler terminal velocity of the drops can also be computed, and subtracted from the observed Doppler velocity in Figure 6 (which has not been used until now) to derive the up and down drafts in the stratocumulus. This revealed a cellular structure in this cloud with up and down drafts of about 1m/s with a wavelength of about 4km. A detailed account of the technique can be found in O'Connor et al (2005).

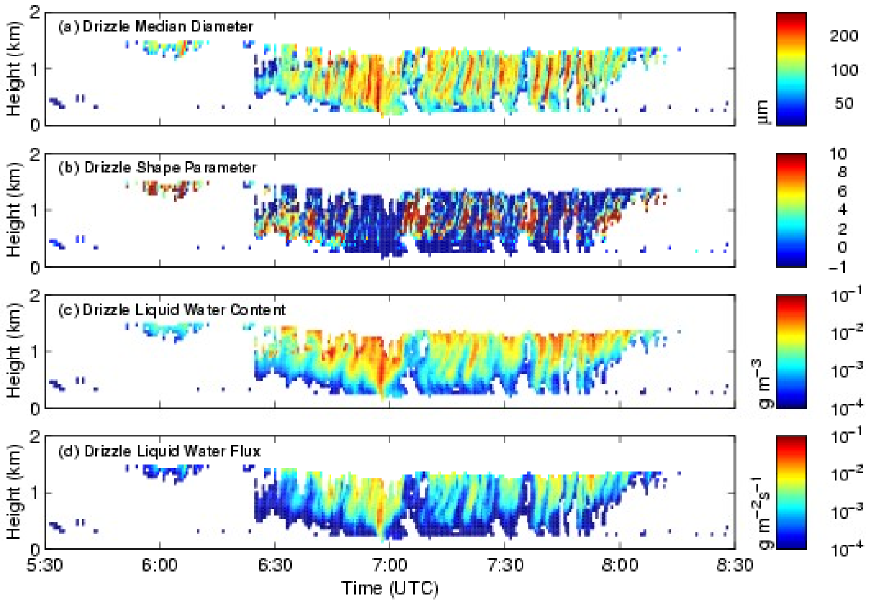

Figure 7

A second technique to retrieve the liquid water content of water clouds containing drizzle has been developed which combines radar, lidar and microwave radiometers together with a cloud classification technique. The method assumes a quasi-adiabatic water content with a corresponding height dependence of drop size distribution. The Cabauw data in Figure 8 show the retrieved LWC-profiles compared with the liquid water path retrieved from the radiometer.

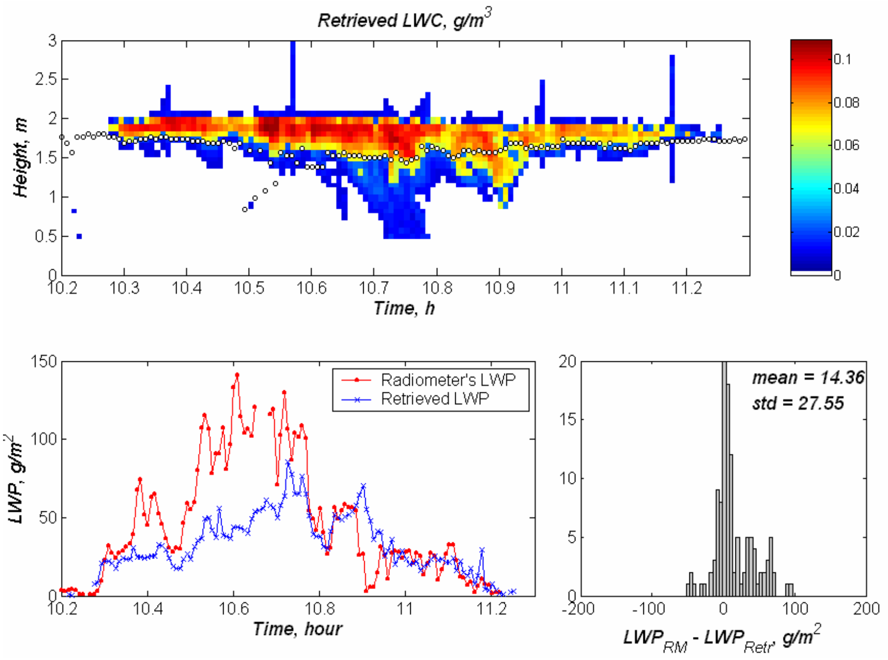

Figure 8: Retrieved LWC profiles and comparison with the radiometer-derived liquid water path. The dots in the LWC-plot represent the lidar-derived cloud base.

4. Use of combined reflectivity and Doppler velocity to classify ice particles.

The terminal velocity of ice particles is important in defining the lifetime of cirrus clouds. Current models assume a simple dependence of mean terminal velocity on ice water content, but in fact this velocity depends on ice particle shape, size and density, all of which are variable. Ice particle concentrations are very variable, so a given ice water content (IWC) could have a high concentration of small ice particles which would fall slowly, or a low concentration of larger ice particles which would fall more rapidly. To remove this dependence in Figure 9 the ice water content is divided by the normalised ice particle concentration, which effectively gives the mean mass of particles in the spectra. Once the concentration has been removed from the IWC expression then Fig 1 shows that the mean mass of the ice particles is much better correlated with the terminal velocity of the spectrum. The colour coding is for different altitudes, showing slower velocities for a given mean mass at higher altitudes, one assumes this is because at colder temperatures the density of the ice particles is lower. Subsequently this work as been developed using the CloudNET data and has lead to the RADON technique described in WP 3 and 4. (Delanoe et al, 2006).

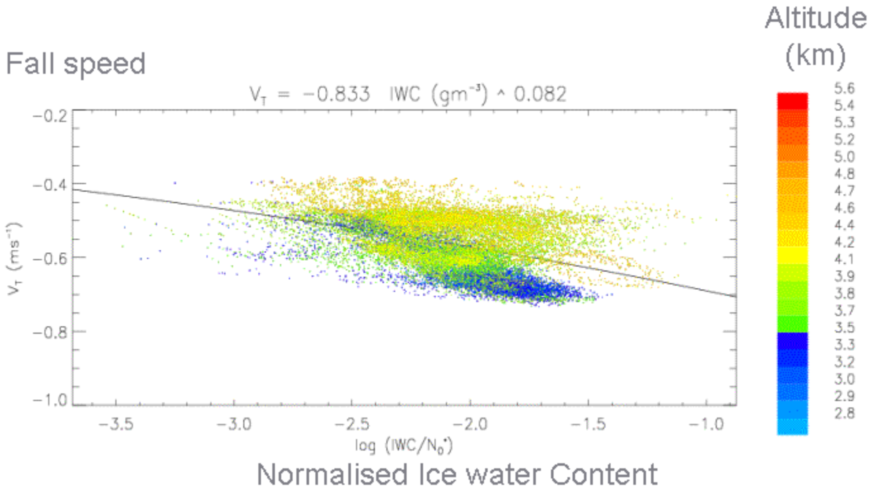

Figure 9: Plot of the ice water content normalised by the concentration as a function of fall speed.

References:

Delanoe, J., A. Protat, D. Bouniol, J. Testud, A. Heymsfield, A. Bansemer and P. Brown: RadOn; a new method for retrieval of the dynamical, microphysical and radiative properties of ice clouds from Doppler cloud radar observations Submitted J Atmos Oceanic Technol., 2006.

Hogan, R. J., D. P. Donovan, D. Tinel, M. A. Brooks, A. J. Illingworth and J. P. V. Poiares Baptista: Independent evaluation of the ability of spaceborne radar and lidar to retrieve the microphysical and radiative properties of ice clouds. J.Atmos.Oceanic Technol., 23, 211-227, 2006.

O'Connor, E. J., A. J. Illingworth and R. J. Hogan: Retrieving stratocumulus drizzle parameters using Doppler radar and lidar: J Applied Meteorol , 44, 14-27, 2005.

van Zadelhoff, G. J., D. P. Donovan, H. Klein Baltink, and R. Boers. Comparing ice-cloud microphysical properties using CloudNET and Atmospheric Measurement Program data. J Geophys Res., 109, D2414, doi 1029/2004JD004967, 2004