1R.3 CLOUDNET: EVALUATING CLOUDS IN SIX OPERTAIONAL FORECAST MODELS USING CLOUD RADAR AND LIDAR OBSERVATIONS

Anthony J. Illingworth, Robin J Hogan and Ewan O'Connor and the CloudNET team
JCMM, Department of Meteorology, University of Reading, UK

1. INTRODUCTION

The correct representation of clouds is crucial to models used to provide short term weather forecasts and predict future climate change. Such models now typically have one or two prognostic variables to simulate the clouds, such as cloud fraction and ice/liquid water content which are available every hour with a vertical resolution ranging from 100 to 500m. Evaluating the performance of such models is not easy. Satellites tend to see cloud top, ground observers only cloud base, so only active techniques such as radar and lidar can provide the resolved vertical structure held in the models. Interpreting the radar and lidar returns is not trivial for the non-expert. Insects give radar returns which can easily be mistaken for extensive low level clouds; it is not obvious how to convert radar backscattered power into a cloud water content, and correction for lidar attenuation by thick clouds is difficult.

The EU CloudNET project has three aims: a) to develop cloud radar and lidar instrumentation and appropriate algorithms to derive the variables used to represent clouds in such models and, b) to obtain a continuous record of these cloud variables with their associated errors for three observing sites within Europe and then, c) to compare these observations with the representation of clouds over these three sites in four operational forecast models of ECMWF, the Met Office, MeteoFrance and Racmo. The CloudNET project has expanded in scope during the past year: the models of DWD (German weather service) and SMHI (Swedish weather service) have been incorporated within the analysis scheme. The observations from Lindenberg, Germany are also being analysed, and following a recommendation by the GEWEX Cloud and Aerosol Profiling (CAP) Group, data from ARM (Atmospheric Radiation Measurement) Program in the USA and the Tropical Pacific is also being analysed by the CloudNET system.

In this paper we outline the observation sites in section 2 and a summary of the algorithms development is provided in section 3, the data sets in section 4, and some early results of comparisons with the models are described in section 5. Full details of the papers produced from CloudNET can be found along with the data set at http://www.met.rdg.ac.uk/radar/cloudnet/.

Corresponding author address: Anthony J Illingworth, Department of Meteorology, University of Reading, Earley Gate, PO Box 243, Reading RG6 6BB, UK; E-mail: a.j.illingworth@reading.ac.uk.

2 CLOUDNET REMOTE SENSING STATIONS.

2.1 Observation Sites

The three original sites are located at Chilbolton UK (51.14N -1.44E), Palaiseau, Paris, France (48.71N 2.20E) and Cabuaw, The Netherlands (51.97N 4.92E). At each site a variety of ground based remote sensing instruments is deployed, most of which have been operating 24 hours a day and 7 days a week since the start of the intensive period of observations on 1 October 2002. The most important instruments are the vertically pointing Dopplerised cloud radars (94/95 Ghz at Chilbolton and Palaiseau, and 35 GHz at Cabauw) and 905 nm lidar ceilometers which provide profiles with 60m vertical resolution every 30 seconds. In addition there are down-welling broadband SW and LW radiometers, several microwave radiometers for providing water vapour and liquid water information and a 3 GHz radar at Cabauw. Other instruments such as 355 nm UV Raman lidar at Chilbolton and a polarimeteric lidar at Palaiseau have been run on an event basis.

2.2 Instrument Calibration

Accurate calibration is crucial when deriving cloud properties from the lidar and radar backscatter profiles.
Lidar Calibration. Traditionally lidars are calibrated by comparison with molecular Rayleigh scattering but this is not possible at wavelengths greater than 600 nm. Instead we use thick stratocumulus clouds to provide a self-calibration technique by adding up the backscatter β (in $m^{-1}\ sr^{-1}$) at each gate until the signal is extinguished. This gives us the 'integrated backscatter' which should have a theoretical value of 15 sr in liquid water clouds. The calibration factor is adjusted until this value is achieved and provides an absolute calibration accurate to about 10%.
Radar Calibration Absolute calibration via link-budget calculations is error prone. Instead we use the fact that at 94GHz Mie scattering leads to a radar reflectivity in rain above 2 mm hr^{-1} which is virtually constant and close to 19 dBZ. The reflectivity is measured at a range of 250 m to minimise any attenuation affects and provides an absolute calibration to within 1 dB.

3 DATA QUALITY AND ALGORITHMS

If the products are to be used for evaluating NWP model performance then the data must be rigorously quality controlled to avoid spurious artifacts being falsely identified as cloud. Once particular pixels have been categorised as liquid or ice clouds then the appropriate algorithm can be invoked to derive the liquid or ice water content from the backscattered signals.

3.1 Categorisation and Quality Control

Categorisation The first stage is to examine the lidar backscatter and Doppler data together with the temperature profile from the operation models and classify the targets into nine categories of targets: i) aerosols, ii) insects, iii) aerosols and insects, iv) ice and supercooled droplets, v) ice, vi) drizzle/rain and cloud droplets, vii) drizzle or rain, viii) cloud droplets only, and ix) clear sky.

Quality control This categorisation information is accompanied by a status flag. Firstly, the 94GHz radar must be corrected for attenuation by water vapour and oxygen which is straightforward using the operational model. Cloud liquid water attenuation can be corrected if good radiometer data is present, but very difficult for attenuating rain. Low level water cloud will extinguish the lidar return completely. This leads to ten status flags: i) Lidar molecular backscatter ii) Radar ground clutter, iii) Radar corrected for liquid attenuation, iv) No radar echo but known attenuation, v) Good radar echo only vi) No radar but unknown attenuation (rain), vii) Good radar and lidar echo, viii) Radar echo but uncorrected attenuation, ix) Lidar echo only, and x) Clear sky.

3.2 Retrieval Algorithms

The next stage is to derive the products which will be compared to the values held in the operational model output. Below is a summary of some of the algorithms which have been developed. Note the philosophy whereby operational model variables are used in some of the algorithms.

Cloud Fraction. The categorisation information can be used to identify which of the 60m/30second pixels contain a cloud, as opposed to, for example, a radar signal indicating drizzle below the lidar cloud base. A typical model grid box will contain over a hundred pixels so cloud fraction can be estimated to a few per cent. The spatial distribution of pixels within the grid box can be used to examine cloud overlap properties.

Ice Water Content from Z and T. The reflectivity values of those pixels within a model grid box categorised as ice can be converted into ice water content (IWC) either by a straightforward empirical IWC-Z relationship, or, for increased accuracy, an IWC-(Z,T) relationship using T from the operational model. A value of mean IWC within a grid box or a pdf of IWC within the grid box can then be derived together with its error. The error has two components, one associated with the IWC-Z or IWC-(Z,T) retrieval, and an additional error arising from the attenuation of Z and the confidence with which that attenuation has been corrected. During heavy rain we reject all data as being too error prone.

Ice Water Content and Size from Radar and Lidar When the categorisation indicates ice and the quality flag signals that there are good radar and lidar echoes, then a radar/lidar algorithm is invoked which uses the radar signal to correct for lidar attenuation, and then derives the ice particle size from the ratio of the radar backscatter to the attenuation corrected lidar backscatter. Once the size is known then a more accurate IWC can be calculated from the value of Z.

Stratocumulus with and without drizzle. It is difficult to derive liquid water content (LWC) of clouds from Z because the presence of occasional drizzle droplets dominates Z but contributes little to LWC. Techniques have been developed which use the Doppler and reflectivity radar observations with the lidar to isolate the drizzle component and derive the concentration and size of the droplets together with the drizzle flux. In the absence of drizzle, the cloud base is derived from the lidar and cloud top from the radar, the adiabatic liquid water can be computed and compared to the total liquid water path derived from the ground based radiometers and the degree of mixing within the clouds determined.

Turbulence. The rate of dissipation of turbulent kinetic energy (TKE) is derived from a new radar parameter: the variance of the mean Doppler velocities recorded every second over a period of thirty seconds. This new approach uses the wind, U m s^{-1}, from the operational model, so that the two limits for the spatial scale of the motions sensed by the variance of the mean Doppler are 30U m and (U+beamwidth) m. These two limits are within the inertial subrange, so by integrating an expression involving the variance of the mean Doppler between these two spatial scales, we can derive the dissipation rate of TKE in terms of the observed variance in the mean Doppler. The values of TKE in stratocumulus are found to be three orders of magnitude higher than in cirrus.

4 DATA SETS

The raw observations taken every 30 seconds with 60 m resolution are displayed on quick looks for each site every day in near real time together with monthly composite quick looks. The derived model quantities are plotted on the hourly model grid with the appropriate vertical resolution are also displayed on the web. All data are recorded in standard netCDF format for ease of subsequent processing.

The raw data plotted are profiles of i) radar reflectivity, ii) mean Doppler, iii) spectral width, iv) variance of the mean Doppler, v) lidar backscatter; integrated values of vi) rainrate , vii) liquid water path from the radiometers; profiles of viii) the 94GHz attenuation from oxygen and water vapour, ix) 94GHz attenuation due to lwp, x) broad band SW and LW downward fluxes. Then the derived profiles of xi) target classification xii) target status, xiii) cloud fraction calculated by area and volume, and for one hour or for a time equivalent to 60km estimated using the model winds. xiv) Integrated cloud cover computed four ways as for the cloud fraction profiles xv) Profiles of Ice water content from Z and T and associated errors and status xvi) Profiles of Ice water content, ice particle size and extinction coefficient calculated from simultaneous radar and lidar and associated errors xvii) Profiles of dissipation rates of TKE derived from the variance of the mean Doppler and its associated error.

These observed quantities can then be compared with the hourly profiles from the four operational models. The following values are archived for the grid point above the three stations: T, q_v, RH, LWC, IWC, u, v, w, and cloud fraction.

5 SAMPLE OF RESULTS

5.1 Fractional cloud cover

Cloud fraction is the most fundamental parameter which the models should represent. A typical month's cloud cover is shown in the upper panel of figure 1; the striking improvement in the performance of the MeteoFrance model in April 2003 is immediately obvious from the lower panel of Fig 2. Before 17 April the model was only ever able to make clouds which filled 20% of the grid box; after that date a new cloud scheme which diagnosed fractional cloud cover from the total water content was implemented and the cloud fraction was much more realistic.

The performance for seven different models over the year 2004 in predicting the correct cloud fraction is summarised in Fig.3 . The dashed lines are the unmodified model output, but because of the finite sensitivity of the radar, some low ice water content clouds held in the model will be below the detection threshold of the radar. The solid lines are the model output with this cloud removed. Note that the amount of low level cloud held in the different models differs markedly, whereas the profile of the ice cloud fraction is rather better. Extensive statistics of the model performance with skill scores for cloud fraction and other variables can be found at http://www.met.rdg.ac.uk/radar/cloudnet/.

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Figure 1: Cloud cover over Chilbolton for May 2003.

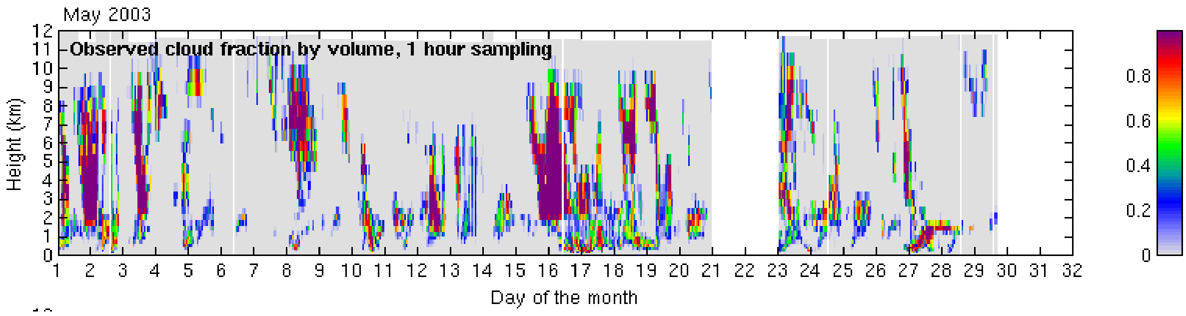

Figure 2:Cloud cover MeteoFrance l. April 2003

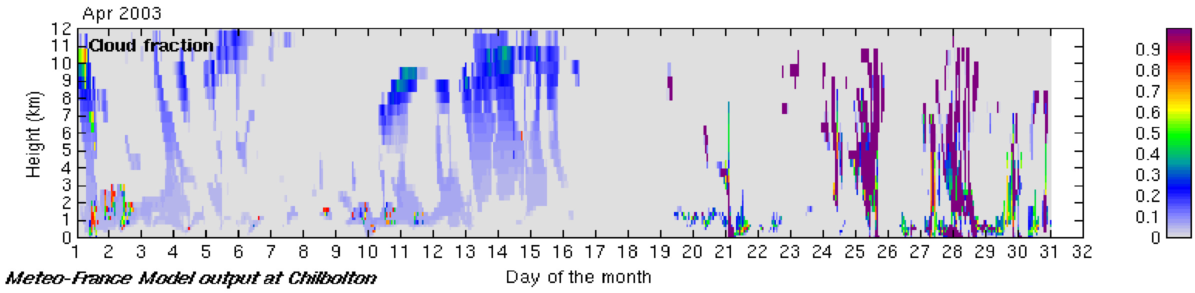

Figure 3: Model performance for the year 2004.