COMPARISON OF MODEL AND RADAR DERIVED CLOUD VERTICAL STRUCTURE AND OVERLAP

U. Willén[1] and S. Crewell[2]

[1]Rossby Centre, Swedish Meteorological and Hydrological Institute, 601 76 Norrköping, Sweden
[2] Meteorological Institute University München, Theresienstr. 37, 80333 München, Germany

1. INTRODUCTION

The vertical distribution of clouds has a large impact on the radiative heating and cooling rates of the atmosphere and the surface. Assumptions regarding the vertical cloud overlap in a grid column are required in climate models for the radiative transfer calculations. These various assumptions can lead to large differences in subsequent radiative heating rates of the atmosphere and the surface. The cloud overlap assumption can be evaluated by comparing the model output with ground based cloud profiling radar data for particular locations and limited time periods. In this study, we assess the cloud vertical structure and cloud overlap of four atmospheric models using two ground-based cloud profiling radars for the BALTEX BRIDGE Campaign (BBC) of CLIWA-NET.

2. DATA AND MODELS

The BBC campaign took place at Cabauw, the Netherlands, in August and September 2001. A full description of the CLIWA-NET project can be found at www.knmi.nl/samenw/cliwa-net. In this study, we use observational data from two radars operating at different frequencies (35 and 95 GHz). For evaluating the model vertical cloud distributions we create radar grid box values by averaging the high frequency radar observations over different time intervals to mimic the different horizontal resolutions of the models, and over different numbers of range gates to account for the model vertical levels. The ratio of the number of cloud filled pixels to the total number of pixels in each 'grid box' give a volume fraction which corresponds to the model plane-parallel cloud fraction.

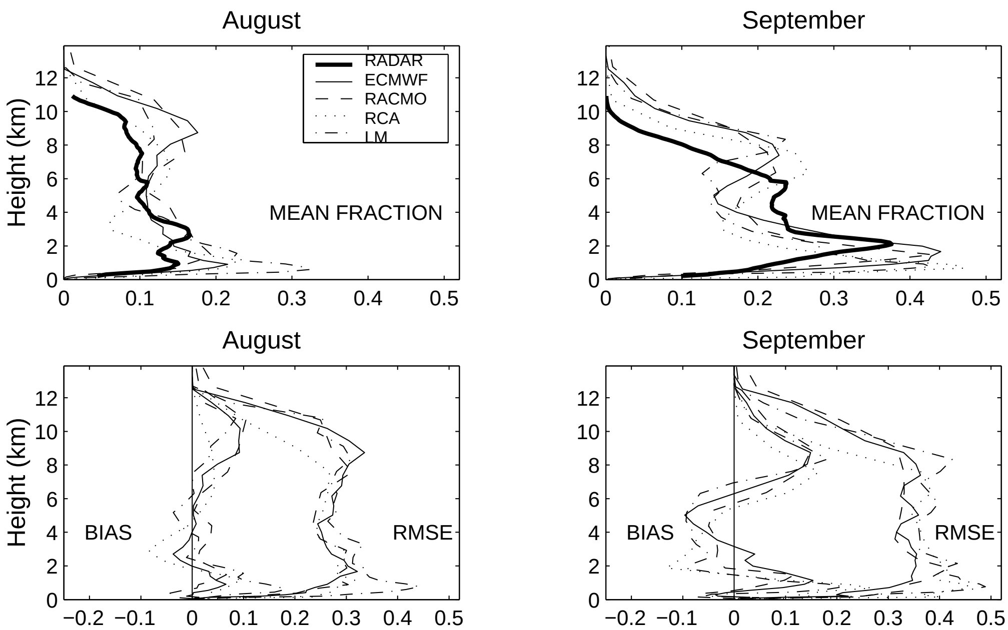

Figure 1: Mean cloud fraction (top row) for the 35 GHz radar on the original 90m resolution. The model values are given at their specific layer resolution. The bias and RMSE between model predicted and observed time series of cloud fraction is shown in the bottom row.

Corresponding author's address: Ulrika Willén, Rossby Centre, SMHI, SE-610 76 Norrköping, E-mail: ulrika.willen@smhi.se

Because the wind speed varies with time and height, in principal the temporal average should vary accordingly. For simplicity, we choose to calculate the radar cloud fractions for three fixed timescales for each model depending on the mean observed wind speed at three height intervals.

Model data from four European institutes, the ECMWF (European Centre for Medium range Weather Forecasts), KNMI (Royal Netherlands Meteorological Institute), SMHI (Swedish Meteorological and Hydrological Institute) and DWD (Deutscher Wetterdienst) were used. The ECMWF global forecast model was run with 55km horizontal resolution and 60 vertical eta levels, the regional climate models from KNMI and SMHI, RACMO and RCA respectively, were run with 18km horizontal resolution and 24 vertical eta levels. Finally, the non-hydrostatic local model, LM, from DWD was run at 7 km horizontal resolution and 35 vertical levels.

3. RESULTS

3.1 Cloud vertical distribution

The mean vertical cloud fractions for each model grid column closest to Cabauw and the occurrence of hydrometeors in each 90-m vertical range bin from the 35 GHz radar are shown in figure 1. The models capture some of the vertical structure and especially the difference between the two periods. August was a fairly sunny month with convective activity at Cabauw, while September was more overcast with persistence low level cloudiness. All models overestimate the occurrence of high clouds (above 7km) and underestimated clouds at mid-levels (mainly for September), similar to what Beesley et al (2000) and Hogan et al (2001) found for the ECMWF model for the Arctic and England, respectively. Below 2km all models overestimate the cloud occurrence.

In order to look at the forecast skill of the models, we calculated the mean error and the root-mean square error for the model compared to the radar derived time series of cloud fraction (Fig. 1). For this purpose the radar volume cloud fractions were calculated for each model vertical layer assuming the mean mid-tropospheric advective time-scale. The bias structure is fairly similar for all models, although the strong underestimation of clouds at mid-levels occurs at slightly higher altitudes for the ECMWF model than for the other models. In addition, the latter models show a narrower, and lower level maxima than the radar.

There are many possible explanations why the model and radar fractions could differ, such as, co-location errors due to the time-averaging approach, problems of the radar sensitivity, the model not representing everything detected by the radar, and what we really want to evaluate, any errors due to poor model performance. Hogan et al (2001) modified the model fractions to account for some of the known discrepancies between the measurements and the model variable. High thin clouds may be undetected by the radar and can be excluded from the model output. The underestimation at mid levels could be due to precipitating ice crystals or snowflakes, which are included in the radar derived cloud fraction but not in the model fractions.

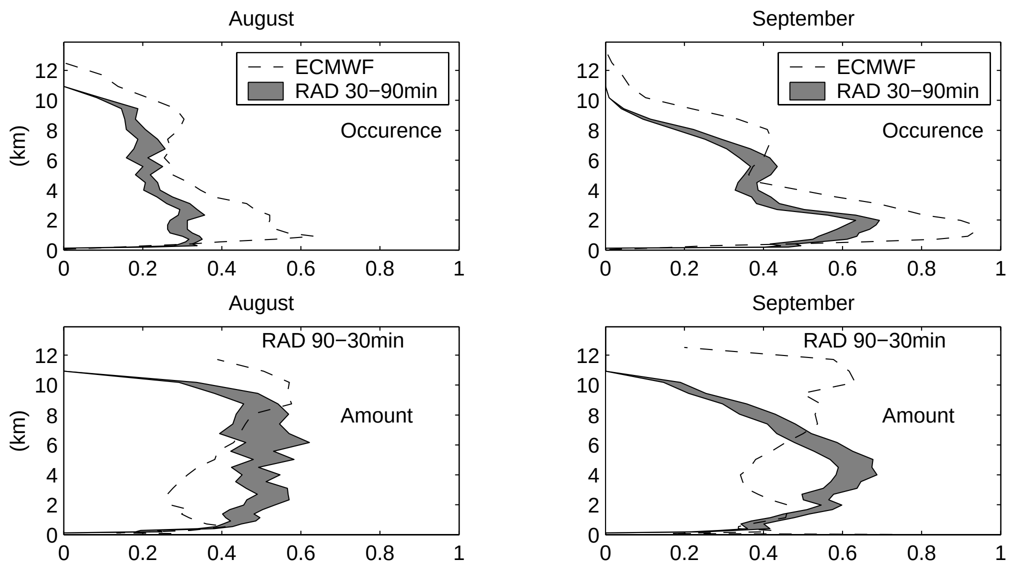

Figure 2: Frequency of cloud occurrence and amount when present (>5%) for ECMWF and for the radar at the corresponding vertical resolution. The bandwidth (grey shaded area) of the observation indicates the possible variation due to changes in advection speed.

Here, we have left the model output unchanged to compare the unaltered statistics. However, we used the minimum and maximum time averages to obtain a bandwidth of probable realizations from the observations as the time averages were chosen to represent maximum and minimum advection speeds for each model. We calculated the 'frequency of occurrence' and the 'amount when present' from the observations and the models (shown for ECMWF in Figure 2). It turns out that the occurrence and amount are fairly insensitive to the length of time intervals. Because longer time averages are more likely to contain more clear-sky the longer time averages give less amount and slightly higher frequency of occurrence. The models overestimate the occurrence of clouds at high and low levels and underestimate the amount of cloud from 1 km to 6 km. The errors above 7 km appear to be due to both a too high occurrence and too high amounts when present.

In figure 3 we compare the frequency distributions of cloud fractions for the ECMWF model with the distributions for the minimum and maximum radar advective time scales. Ideally, the model distribution should fall inside this 'uncertainty range' of the time-average approach. Generally, the model distributions are skewed and the occurrence of smaller cloud fractions (<50-60%) were overestimated at all heights by all models. On the other hand, the models underestimate clear-sky conditions and the occurrence of overcast.

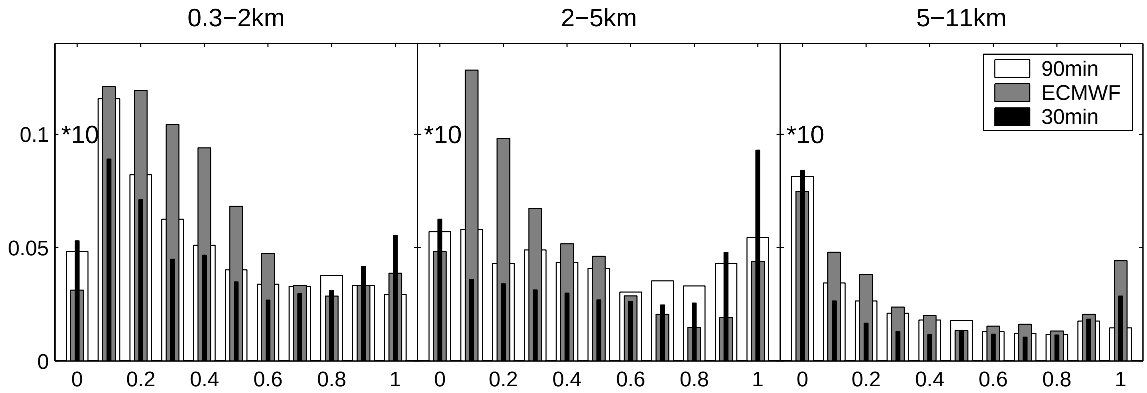

Figure 3: Frequency distribution of the cloud fraction for ECMWF, with the corresponding radar observations for low, mid and high clouds. The model distribution (grey bars) are compared to the observations averaged according to their minimum (white bars) and maximum (black columns) advective time scales. The first group of bars, the clear-sky values should be multiplied by 10.

3.2 <u>Cloud overlap</u>

For the overlap statistics we need to know the cloud cover at each level, i.e. the sub-grid scale overlap or 'the area fraction'. We derived the area fraction for the radar, by calculating the horizontal projection of cloud elements in each grid box. The area fraction is always equal to or larger than the volume fraction. It is important to know the typical thickness of the observed clouds, if they are thinner than the model vertical resolution, they will deviate from the plane-parallel (PP) assumption. This could lead to an underestimation of cloud cover and overestimation of the model cloud overlap even if the volume fractions were well predicted.

The difference between the volume and area fraction is fairly small at 60 vertical levels as illustrated in figure 4a, and therefore the overlap calculated from the ECMWF PP clouds was comparable to the radar overlap. Most cloud-radiation schemes are based on maximum-random (M-R) overlap, adjacent cloud layers have maximum overlap and clouds which are not in direct vertical connection have random overlap. Since the ECMWF model overestimated high clouds and underestimated at mid levels the mean value for maximum-random was fairly close to the observed value. This illustrates how error in the vertical cloud distribution might be concealed if only the ground or top of the atmosphere values are validated with observations.

We compared the radar true overlap with different cloud overlap assumptions calculated from the radar area fractions (figure 4b). The mean true overlap diverged from maximum overlap near the position of the maxima in cloud cover. Therefore, we tried a new simple version of M-R overlap, whereby random overlap was used also for continuous clouds when the cloud cover gradient was above a certain value. This improved the agreement with the true overlap for the whole BBC periods for all the tested resolutions. The M-R gradient overlap is also shown for the ECMWF model (Fig 4a). It is closer to the observations at the surface, but still for the wrong reasons.

In many large-scale models a cloud overlap matrix is used in the radiation scheme. The matrix contains the accumulated cloud covers between any two levels in the atmosphere and thereby the amount of clear and cloudy sky above and below any layer can be determined for the longwave and shortwave calculations. The accumulated cloud fractions in figure 4 are part of the cloud matrix. We derived the cloud matrix from the radar data for the BBC period and compared with different overlap assumptions. The mean bias and RMSE were smallest for M-R gradient overlap.

Other radar overlap studies have shown that continuous clouds are maximum overlap but tend to random at certain de-correlation lengths, Hogan and Illingworth (2000). However, Mace and Benson (2002) did not find a general expression for the overlap of two separate layers. A possible explanation to why the maximum-random gradient overlap worked so well also for different resolutions could be since it was a way of obtaining a 'general' de-correlation length, applicable for different thick clouds. Continuous clouds could be in maximum overlap in the interior, but near edges (top or bottom) where there is larger change in cloud cover they could be in random overlap even at small separations.

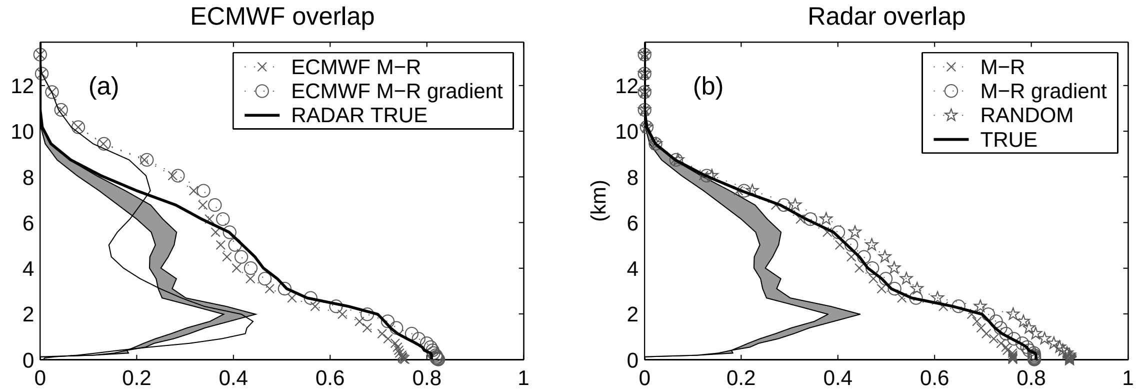

Figure 4: Accumulated cloud fraction as observed from above (top) and below (bottom) for different types of overlap assumptions for September and for the true overlap (bold line). The thin line (4a) is the ECMWF cloud fractions and the grey areas show the radar volume and area fractions.

4. CONCLUSIONS

We found that the cloud vertical distributions of the four models of different horizontal and vertical resolutions performed fairly well for the BBC period. However, the models overestimated high and low clouds and under estimated at mid-levels. Clouds occurred more frequently in the models, but with less amounts when present. The cloud fraction frequency distributions were more skewed for the models, and the observations more binary. The results were fairly independent of the assumed advection speed for the radar derived fractions.

The accumulated cloud fractions, or cloud overlap matrix was found to be in between maximum-random and random overlap. Using random also for continuous clouds when the cloud cover gradient was high improved the agreement with the true overlap.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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