Investigating the Radiative Impact Clouds Using Retrieved Properties to Classify Cloud Type

Nicky Chalmers[a], Robin J. Hogan[a] and Richard P. Allan[b]

[a]*Department of Meteorology, University of Reading, PO Box 243, Reading, RG6 6BB, UK*
[b]*Envirnmental Systems Science Centre, Harry Pitt Building, University of Reading, RG6 6AL, UK*

Abstract. Active remote sensing allows cloud properties such as ice and liquid water contents and vertical structure to be retrieved. The 2-stream version of the Edwards and Slingo radiative transfer scheme is used, with cloud retrievals and Numerical Weather Prediction (NWP) simulations of thermodynamic profiles, to simulate radiative fluxes throughout an atmospheric profile. These are verified against observed broadband fluxes at the top of the atmosphere, using Geostationary Earth Radiation Budget (GERB) on Meteosat 8, and at the surface, using the mid-latitude Baseline Surface Radiation Network (BSRN) site in Lindenberg, Germany. Retrieved cloud properties from Lindenberg are used to categorize the results with respect to cloud type, to understand the radiative impact of clouds. Observed cloud profiles are compared to cloud predictions by the ECMWF model and categorized by the same method to understand and quantify the radiative impact of errors in the representation of ice cloud particles.

Keywords: Active remote sensing, Cloud categorization, Cloud properties, Radiative impact.
PACS: 92.60. Vb.

INTRODUCTION

There are many estimates of the global impact that clouds have on the radiation budget of the atmosphere (Arking 1991, Kiehl and Trenberth 1997) but few relate this impact to cloud properties. Radar and lidar observations can be used to retrieve cloud properties therefore allowing the observed radiation budget at the surface and top of atmosphere to be categorized by cloud type. They also allow clouds to be represented in a radiation scheme which can simulate the radiation budget and heating rates throughout the atmospheric profile as well as allowing a more direct comparison with weather and climate models (Allan and Ringer, 2003).

In this report cloud property retrievals are used in the Edwards and Slingo radiation scheme and to categorize radiation fluxes by cloud type over Lindenberg during April, May and June in 2006. This method is then used to assess ECMWF fluxes with respect to cloud type.

CLOUD RETRIEVALS AND CATEGORIZATION

Surface based radar and lidar observations are used to retrieve cloud properties over Lindenberg, Germany by implementing the Cloudnet algorithms (Illingworth et al., 2007). This gives liquid water content (LWC) and ice water content (IWC), from which effective radii can be calculated, using a LWC dependant method for liquid particles (Matin et al., 1994) and a temperature dependant method for ice particles (Kristjánsson et al., 2000). Aerosol can be identified using lidar observations and the mass mixing ratio and characteristic size estimated. These properties are used in the 2-stream version of the Edwards and Slingo radiation scheme (ES96) (Edwards and Slingo, 1996) with modeled atmospheric thermodynamic variables and estimated surface characteristics, to simulate broadband radiation (BBR) fluxes throughout the atmospheric column every 30 seconds. Retrieved cloud properties offer the opportunity to model the radiative effect of clouds directly and also to then categorize the results of the simulation by cloud type. This will help understand the contribution of different cloud types to the overall radiative

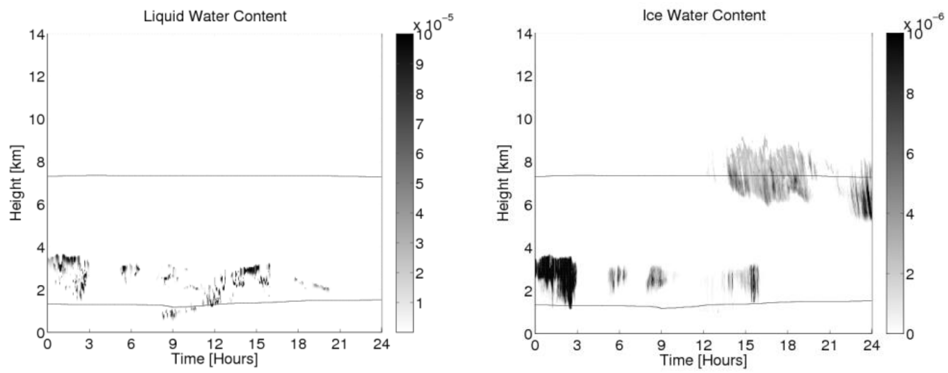

FIGURE 1. The retrieved liquid and ice water contents for 19th April 2006 over Lindenberg, Germany. The black lines represent the 0°C and -40°C isotherms determined by the ECMWF forecasted temperature field. These are used to categorize the cloudy profiles.

effect of clouds. Figure 1 shows an example of cloud retrievals and the method by which they are classified into type.

The 0°C and -40°C isotherms are used to classify the cloudy profiles giving three levels at which cloud can exist. These isotherms are chosen on a physical basis; warmer than 0°C cloud particles are only liquid, colder than -40°C, there are unlikely to be any liquid particles and between these temperatures, both phases of cloud particle can exist.

CLOUDY SKY RESULTS

The simulated fluxes are compared to BBR observations at the surface, and at the top of atmosphere (TOA) using the geostationary earth radiation budget (GERB) instrument on Meteosat 8. This gives retrievals of outgoing BBR fluxes every 15 minutes with a footprint of 9km by 9km (Harries et al., 2005). The results can be classified by cloud type as shown in Figure 2. This shows the results of the simulated radiation budget from ES96 during April, May and June over Lindenberg, compared to observations at the surface and TOA. These data have been classified by cloud temperature highlighting profiles with high cloud only and low cloud only. The high cloud cases show slightly cooler brightness temperature (from $L^{\uparrow}$ at TOA) than the low cloud only cases, however these clouds are likely to be optically thin, so not emitting close to a black body therefore the observation will be sensitive to radiation emitted at the surface. Most of the grey points in this plot, are clouds which occupy two levels (e.g. high and middle) so are more optically thick so emit more like a black body at cloud top temperature, which explains why there is less outgoing longwave radiation when these clouds are present. Also Figure 2 only highlights profiles that contain high cloud only. Profiles with multiple layers of cloud could have higher and colder cloud tops. The surface longwave flux is not sensitive to cloud type. The cloudy points are not very different to the clear points. The scatter in the clear sky (black) points for the shortwave plots, particularly at the surface is largely caused by including aerosol in the ES96 simulation, which is represented with a concentration proportional to the strength of the lidar backscatter. A fixed particle size is assigned based on likely aerosol type (in this case continental aerosol).

COMPARISONS WITH FLUXES FROM NWP MODELS

The retrieved cloud properties allow comparison between observed BBR fluxes and cloud profiles and modeled BBR fluxes and cloud profiles. This provides a method to evaluate cloud parameterizations and representation in NWP models with respect to the radiative errors caused by misrepresentation of cloud properties. Figure 3 shows the ECMWF modeled downward longwave flux against observations at the surface in Lindenberg. Highlighted in red are the profiles in which there is cloud present at all levels simultaneously, which show a negative bias in the ECMWF fluxes. This cloud is likely to be optically thick and contain ice particles. Hogan et al. (2001) found that the ECMWF model represents ice cloud particles until they grow and reach a size threshold at which point they are classified as falling snow. These particles are not represented in the radiation scheme of the model meaning the modeled cloud will be too optically thin and have a cloud base that is too high and cold. The optical depth of the cloud will have an effect on the shortwave flux with the cold bias in the cloud base temperature causing the

ECMWF model to underestimate the downwelling longwave flux as seen in Figure 3. Using the ES96 scheme would allow this hypothesis to be tested and the error quantified.

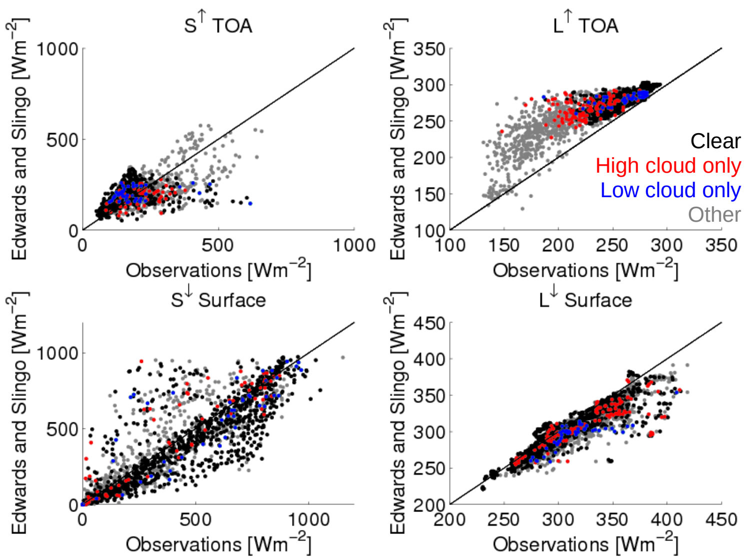

FIGURE 2. Scatter plots comparing modeled and observed BBR fluxes at the surface and TOA over Lindenberg, Germany for April, May and June 2006. Results have been categorized into four types: Clear sky (black points), high cloud only i.e. cloud at -40°C or cooler (red points), low cloud only i.e. cloud at 0°C or warmer (blue points) and other times (grey points).

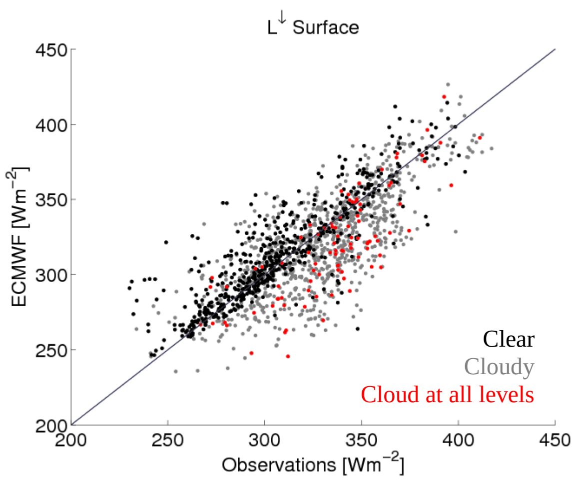

FIGURE 3. Scatter plot of ECMWF modeled downwelling LW flux at the surface against observations at Lindenberg during April, May and June. Clear sky points are in black, cloudy points in grey and points where cloud was present at all levels in red.

CONCLUSIONS

Retrieved cloud properties using surface based radar and lidar observations over Lindenberg during 2006 have been used to represent ice and liquid clouds in the 2 stream version of the Edwards and Slingo radiation scheme. This scheme simulates the broadband radiation budget throughout the atmosphere which has been compared to observations at the surface using the BSRN (Baseline Surface Radiation Network) site at Lindenberg and at the top of atmosphere using GERB. The retrieved cloud properties allow the results of the radiation calculations to be categorized by the temperature at which the cloud is present which reveals different tendencies in the modeled and observed fluxes, particularly in the longwave part of the spectrum. At the TOA low cloud emits more longwave radiation due to warmer cloud top temperatures. The longwave radiation at the surface is not as sensitive to cloud type.

The cloud classification method allows NWP model cloud profiles and fluxes to be compared with respect to cloud type. A negative bias in the ECMWF longwave fluxes at the surface is shown for profiles in which cloud is present at all levels simultaneously. This is consistent with the representation of falling and growing ice particles as snow beyond a size threshold. Snow is not represented in the radiation scheme resulting in a colder cloud base.

This methodology can be applied to Cloudsat and Calipso retrievals which give global cloud retrievals. Categorizing the cloud type in this way will help to understand the radiative impact of clouds and cloud properties.

REFERENCES

1. R. P. Allan and M. A. Ringer, "Inconsistencies between satellite estimates of longwave cloud forcing and dynamical fields from reanalyses", *Geophys. Res. Lett.,* **30**, 44.1-44.4 (2003).
2. A. Arking, "The Radiative Effects of Clouds and their Impact on Climate", *Bull. Am. Meteorol. Soc.*, **72**, 795-813 (1991)
3. J. M. Edwards and A. Slingo, "Studies with a flexible new radiation code I: Choosing a configuration for a large-scale model." *Q. J. R. Meteorol. Soc.* **122**, 689-719 (1996).
4. J. E. Harries et al., "The Geostationary Earth Radiation Budget project", *Bull. Am. Meteorol. Soc.*, **86**, 945-960. (2005)
5. R. J. Hogan, C. Jakob and A. J. Illingworth, "Comparison of ECMWF Winter-Season Cloud Fraction with Radar-Derived Values" *J. Appl. Meteorol*. **40**, 513-525 (2001).
6. A. J. Illingworth, et al., "Cloudnet - continuous evaluation of cloud profiles in seven operational models using ground-based observations" *Bull. Am. Meteorol. Soc.* **88**, 883-898 (2007)
7. J. T. Kiehl and K.E. Trenberth, "Earth's Annual Global Mean Energy Budget", *Bull. Am. Meteorol. Soc.*, **78**, 197-208 (1997)
8. J. E. Kristjánsson, J. M. Edwards and D. L. Mitchell, "Impact of a new scheme for optical properties of ice crystals on climates of two GCMs" *Journal of Geophys. Res.* **105**, 10,063-10,079 (2000).
9. G. M. Martin, D. W. Johnson and A. Spice, "The Measurement and Parameterization of Effective Radius of Droplets in Warm Stratocumulus Clouds" *Journal of the Atmospheric Sciences.* **51**, 1823-1842, (1994).