A Comparison of Cloud Properties Derived from the Manus Micropulse Lidar with ECMWF Analyses

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Introduction

Clouds in the tropics are an ever-present feature and their vertical and temporal distributions are very complex. The Tropical Western Pacific (TWP) is characterized by warm sea surface temperatures and frequent convection. This convection occurs on a wide range of scales, from hundreds of meters in the case of fair weather cumulus to thousands of kilometers in the case of mesoscale convective systems. Deep convection often reaches the tropopause, which is found at 16 km to 18 km in the tropics. Associated with convection are large-scale cirrus layers that are present much of the time. Convection in the tropics exhibits periodicity on various time scales, including the 40-day to 60-day Madden-Julian oscillation and the inter-annual El Niño/La Niña oscillation. An important goal of the Atmospheric Radiation Measurement (ARM) Program in the TWP is to improve the description of cloud distributions and to assess how well models are capturing these distributions.

The primary instrument for determining spatial and temporal cloud distributions at the Manus TWP ARM site (Mather et al. 1998) is the Micropulse Lidar (MPL). Backscatter data from the MPL provide a time series of cloud base at a temporal resolution of 60 seconds and a vertical resolution of 300 m. For optically thin clouds, vertical cloud distributions can also be obtained.

The European Centre for Medium-Range Weather Forecasts (ECMWF) routinely operates a forecasting model with global coverage that has similar treatments for cloud parameterizations as are found in climate models. Output from the ECMWF model is available over the ARM sites. Among the ECMWF output variables are measures of area cloud fraction and the mean density of liquid and solid phase water in each model layer. The model has 31 vertical levels and has a horizontal resolution of approximately 0.56 degrees (Mace et al. 1998).

In this study, we compare the cloud distributions from the ECMWF model output with distributions derived from MPL measurements (Clothiaux et al. 1998) for a five-month period in 1997. Comparisons include time series and frequency distributions of cloud base. We find good agreement between the model and the observations, particularly in the location of maxima in the vertical distribution of clouds. We do find differences, however, including the persistence of cirrus during an extended period of suppressed convection.

Daily Cloud Fraction

Figure 1 shows the vertical distribution of the daily cloud fraction reported by the MPL and the ECMWF model for a five-month period. The ECMWF model produces hourly horizontal cloud fraction in each vertical level. The MPL is a narrow field of view, vertically pointing instrument. So, rather than a horizontal cloud fraction, we calculate the frequency at which clouds occur at each level and make the assumption that this is roughly equal to the horizontal cloud fraction. The MPL statistics are further complicated, however, because in general, only the lowest cloud boundary can be reliably detected.

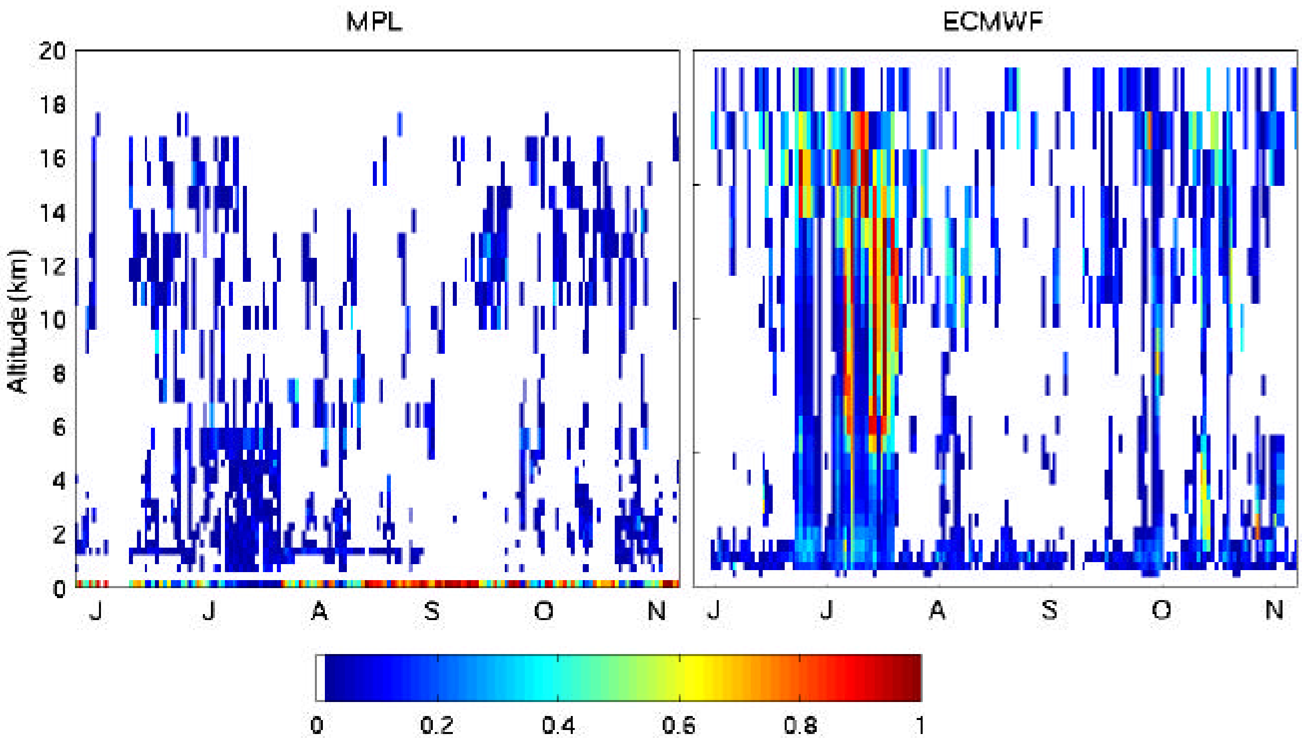

Figure 1. The time/height distribution of daily averaged cloud fraction reported by the MPL (left panel) and the ECMWF model (right panel). These data are from the period June through early November 1997. The color indicates the daily mean cloud fraction (with 1 indicating overcast).

To produce the MPL diagram, only the location of lowest cloud base was included so the frequency for mid and upper levels are underestimated. These limitations of the MPL are particularly evident when comparing the mid to upper troposphere during July. Despite the difference in how the cloud fractions are obtained, the time-height cloud distribution patterns are very similar. The timing of clear and convective periods is captured quite well. The vertical structure is also very similar although this is much better illustrated in the next figure.

In Figure 2, the cloud frequency is calculated for the entire comparison period for each height. Cloud fraction is interpreted here as before except that the ECMWF values have been scaled to account for the difference in vertical resolution of the two data sets. While the magnitude of these distributions do not agree, there is a strong correlation of the cloud fraction maxima.

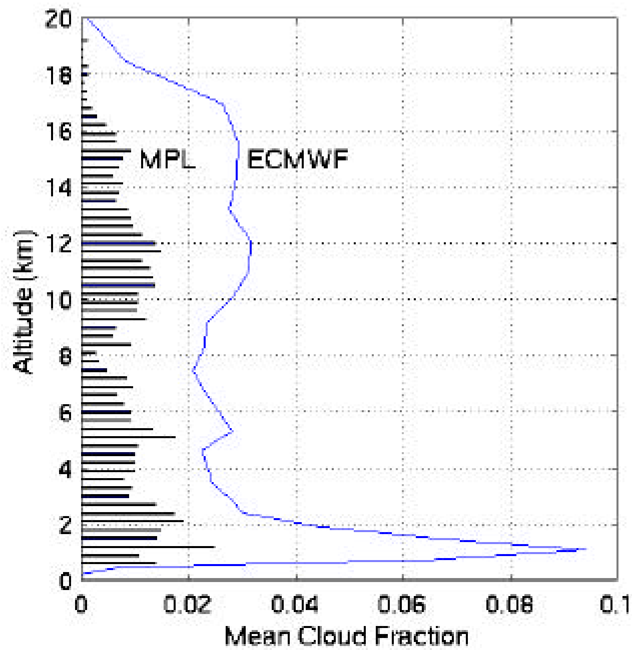

Figure 2. Mean cloud fraction reported by the MPL and ECMWF for the five-month study period. The ECMWF data have been scaled to account for vertical resolution.

The lowest peak corresponds to boundary layer clouds or bases of deep convection. The peak near 5 km falls near the freezing level. This is the preferred base for the stratoform region of mesoscale convective systems (Houze, Jr. 1989). The 16-km cloud frequency maximum falls just below the tropopause. Thin cirrus seem to be a persistent feature at this height. The reason for cirrus peak at 10 km to 12 km is unknown but is clearly present in both the model and the observations.

Cirrus Case

September 1997 was notably free of deep convection or precipitation. Because of the lack of low clouds, the MPL was afforded a particularly good and uninterrupted view of cirrus. The cirrus were generally optically thin so the MPL was able to observe the full vertical cloud profiles. Figure 3 shows another set of cloud distributions for a two-week period in September. Hourly values were used for this study for both the ECMWF and MPL cloud fraction. All levels at which clouds were observed were reported rather than cloud bases. During this period, the observed cirrus are more persistent and had considerably more structure than those reported by the model.

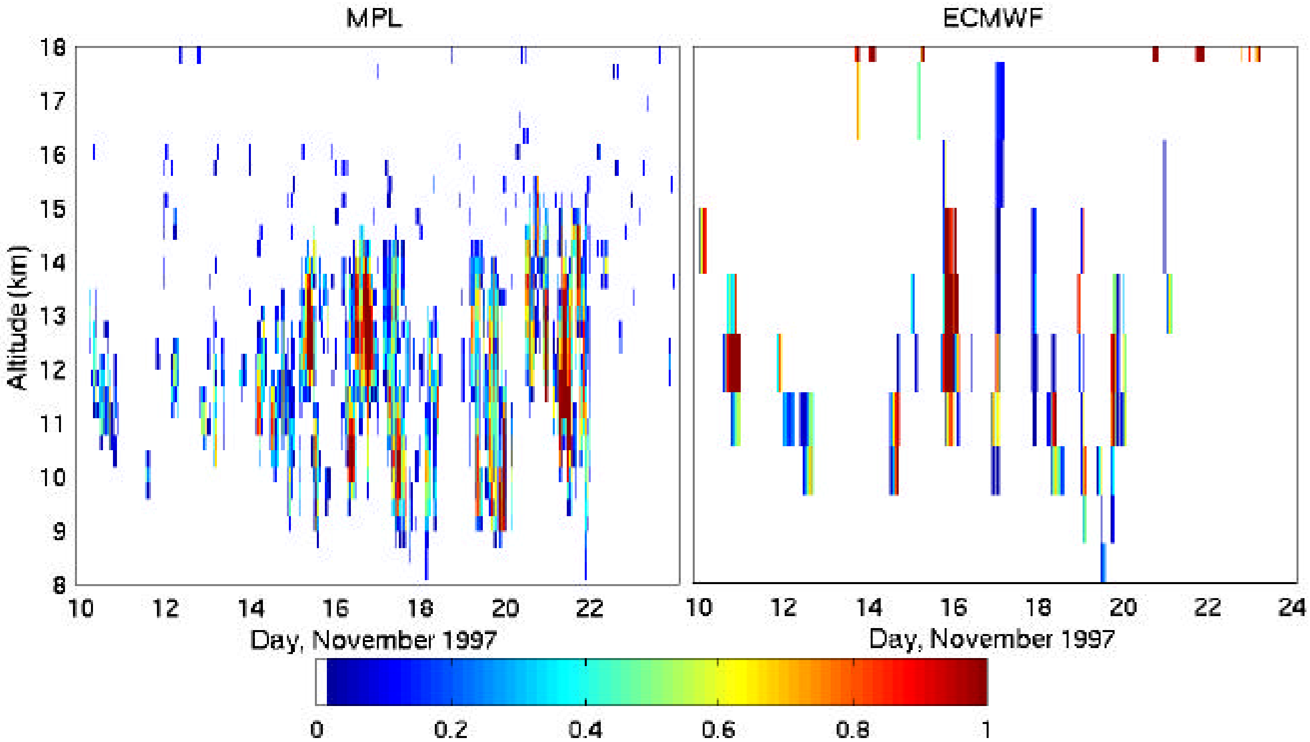

Figure 3. The time/height distribution of hourly averaged cloud fraction reported by the MPL (left panel) and the ECMWF model (right panel). These data are from the period September 10-24, 1997. The color indicates the daily mean cloud fraction (with 1 indicating overcast).

The MPL is very sensitive to cirrus so it is reasonable to ask whether the clouds shown in the MPL data in Figure 3 have a significant impact on the radiation budget. Figure 4 shows top of atmosphere 10.8 micron brightness temperatures over Manus observed by the Geostationary Meteorological Satellite (GMS)-5 satellite for the same two-week period as the cirrus case study. These data indicate that the cirrus observed during this period do have a significant impact on the outgoing longwave radiation so it is important that cirrus be accurately captured in model simulations.

Conclusions

The timing of active and suppressed convective periods in the model closely matches observations. We attribute some of this agreement to the fact that the model is initialized each day with observations and that convective or suppressed conditions tend to persist for periods of days to weeks.

We also find remarkable agreement in the location of maxima in the vertical cloud distribution. The presence of a peak in the boundary layer is not a surprise and the preference for stratiform clouds near the freezing level has been well documented. The agreement in the location of the cirrus layers is more

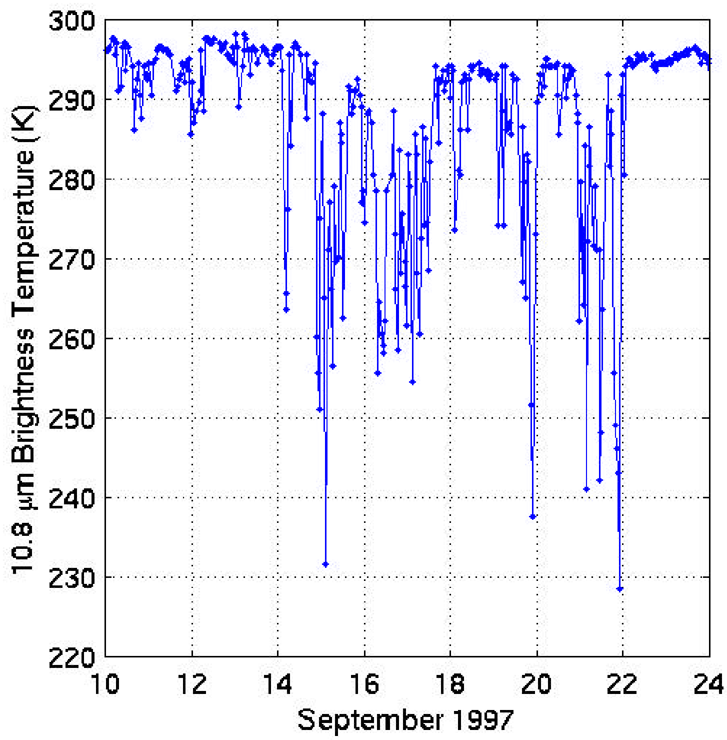

Figure 4. Top of atmosphere, 10.8 micron brightness temperature from the GMS-5 satellite for the cirrus case study period.

surprising and bears further investigation. The upper peak is likely associated with the tropopause but the peak near 11 km is harder to explain. Examination of the vertical distribution of thermodynamic parameters may provide clues to the origin of this layer.

In general, it is difficult to compare absolute magnitudes of cloud frequency because many clouds are optically thick to the MPL. Two exceptions to this problem are fair weather cumulus and cirrus during periods of suppressed convection. We have found that detecting fair weather cumulus with the 300-m resolution MPL, particularly in the presence of smoke or haze, is a challenging problem. We will be working on this next with the aim of assessing the ECMWF fair weather cumulus cloud fraction and its effect on the surface shortwave budget. In a two-week period of suppressed convection, we find that the modeled cirrus is more intermittent than the observations. The observed cirrus has a significant impact on the top of atmosphere infrared radiation budget. We will be continuing this work to quantify this impact better.

Acknowledgments

The authors would like to thank Christian Jakob of ECMWF for providing the model output for the Manus site.

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