Shallow Clouds at Manus in Observations and GCM Simulations

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Part I: Variability and Moistening of Shallow Clouds through the Life Cycle of the MJO at Manus (Zermano and Zhang 2015)

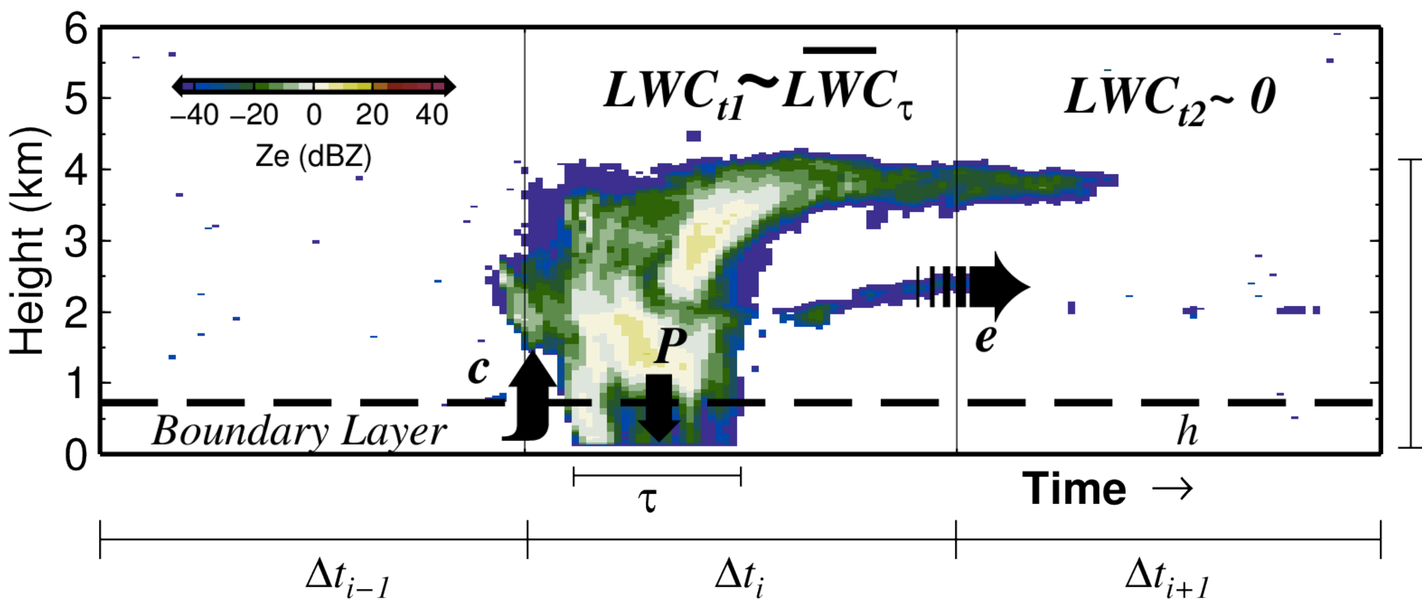

Figure 3 Illustration of approximations made to estimate the cloud moistening tendency due to evaporation of cloud liquid water content (LWC) into the free troposphere. It is assumed that all LWC enters a cloud from the boundary layer through updrafts, there is no horizontal advection of LWC into the cloud, and the moistening tendency is the total cloud LWC divided by cloud life span (30 – 90 min) minus removal of cloud LWC by rain.

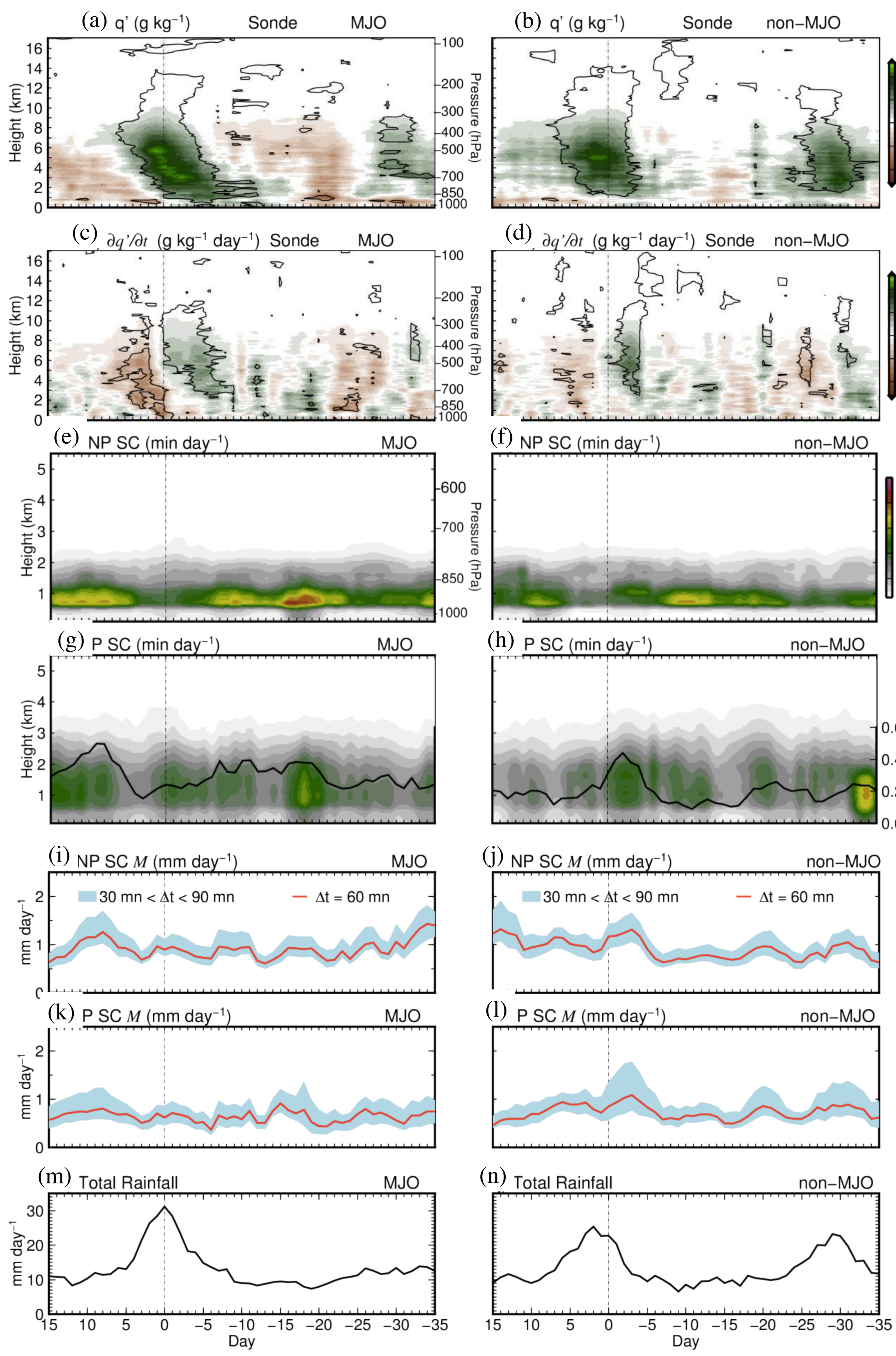

Figure 4 Composite time series of vertical profiles of (a, b) anomalous specific humidity and (c, d) its tendencies based on sounding observations, fractions of (e, f) non-precipitating shallow clouds and (g, h) precipitating shallow clouds, moistening by (i, j) non-precipitating shallow clouds and (k, l) precipitating shallow clouds, and surface rain rates (m, n) at Manus. Left column is for MJO events, right column for non-MJO events.

Conclusion:

Shallow convective clouds, precipitating or non-precipitating, vary randomly through the life cycle of the MJO. They provide important background moistening effect on the lower troposphere, but they alone do not explain the observed increases in lower-tropospheric moisture leading to rainfall peaks of the MJO.

Scientific Problems:

1. It has been commonly hypothesized that shallow convective clouds moisten the lower troposphere and there by provide a favorable condition for deeper convection to develop, especially during the initiation or shallow-to-deep convective transition period of the MJO (Fig. 1). This hypothesis needs to be evaluated quantitatively.

2. In the past comparisons between cloud radar observations and GCM simulations of shallow convective clouds in tropical deep convective regions, such as Manus, no treatment of rain attenuation was applied. This would lead to overestimate of observed shallow clouds.

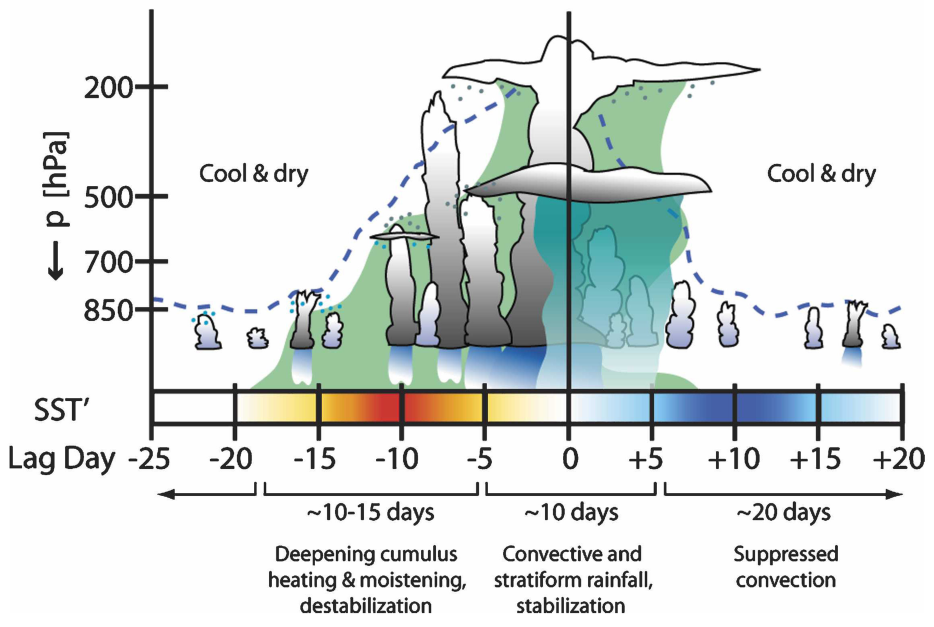

Figure 1 Illustration of shallow cloud moistening of the lower troposphere (red arrow) in the convective life cycle of the MJO. Green shades represent high humidity. From Benedict and Randall (2007)

Objective of this study:

1. Quantify the fraction of shallow convective clouds and their moistening through the life cycle of the MJO at Manus.

2. Use rain attenuation corrected cloud radar observations to evaluate CAM5 simulations of shallow convective clouds at Manus.

Data:

- Observations from MMCR, soundings, and other instruments at the ARM site of Manus (April 03, 2001 - March 07, 2011) – for composite of shallow clouds and their moistening
- TRMM daily precipitation:(0.25°x0.25°, 1998-2009) – for identify MJO and non-MJO large-scale convective events
- 24 – 48 hrs output at Manus grids from CAM5 CAPT simulations (May 2008-April 2010) – For validation of simulated shallow clouds against ARM observations at Manus

Definition of Shallow Clouds:

Cloud-base height is within the boundary layer; cloud-top height is below the freezing level

Rain Attenuation Identification and Correction:

- Compare KAZR echo-top height with the merged Cloud–Precipitation Radar Dataset at Addu Atoll during AMIE/DYNAMO (Feng et al. 2014)
- Remove attenuated cloud radar echoes in Part I (Fig. 2a) and correct them in Part II (Fig. 2b).

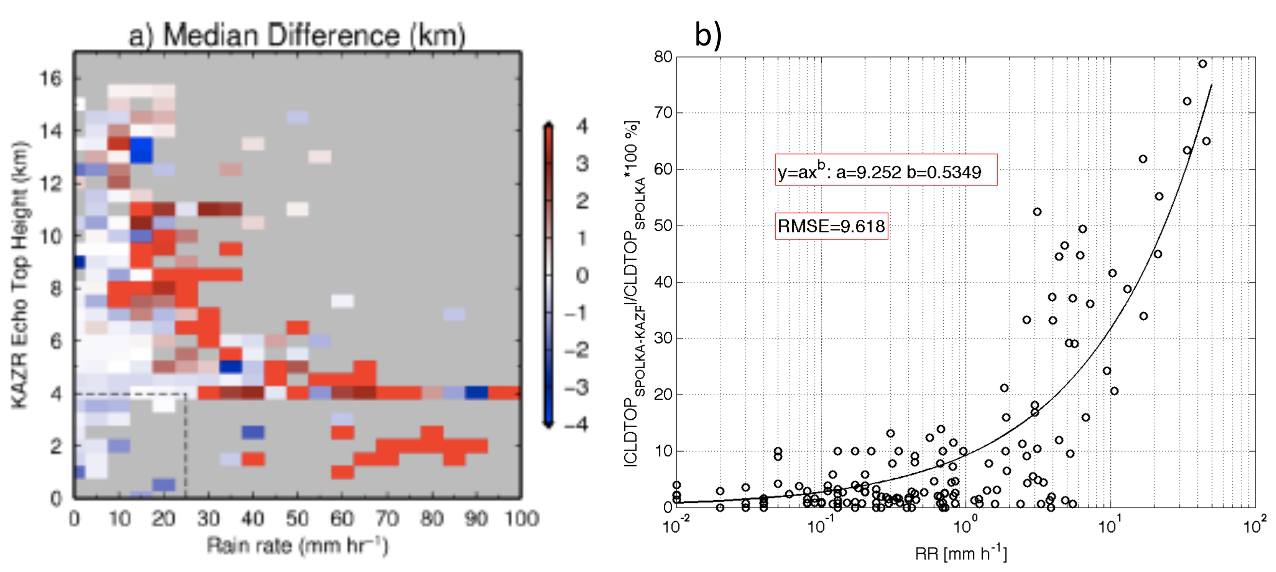

Figure 2 (a) Median differences between echo-top heights of the merged cloud-precipitation radar data and KAZR at Addu Atoll during AMIE/DYNAMO. (b) Scatter plot of percentage errors in KAZR cloud-top height due to rain attenuation as a function of surface rain rates at Gan Island during AMIE/DYNAMO. The black line indicate the power law ($y=ax^b$) fitted to the data .

Acknowledgement: This study was supported by DOE ASR program through Grant DE-SC0006808

Part II: Validation of CAM5 Simulations of Shallow Clouds against MMCR Observations at Manus (Arunchandra et al. 2015)

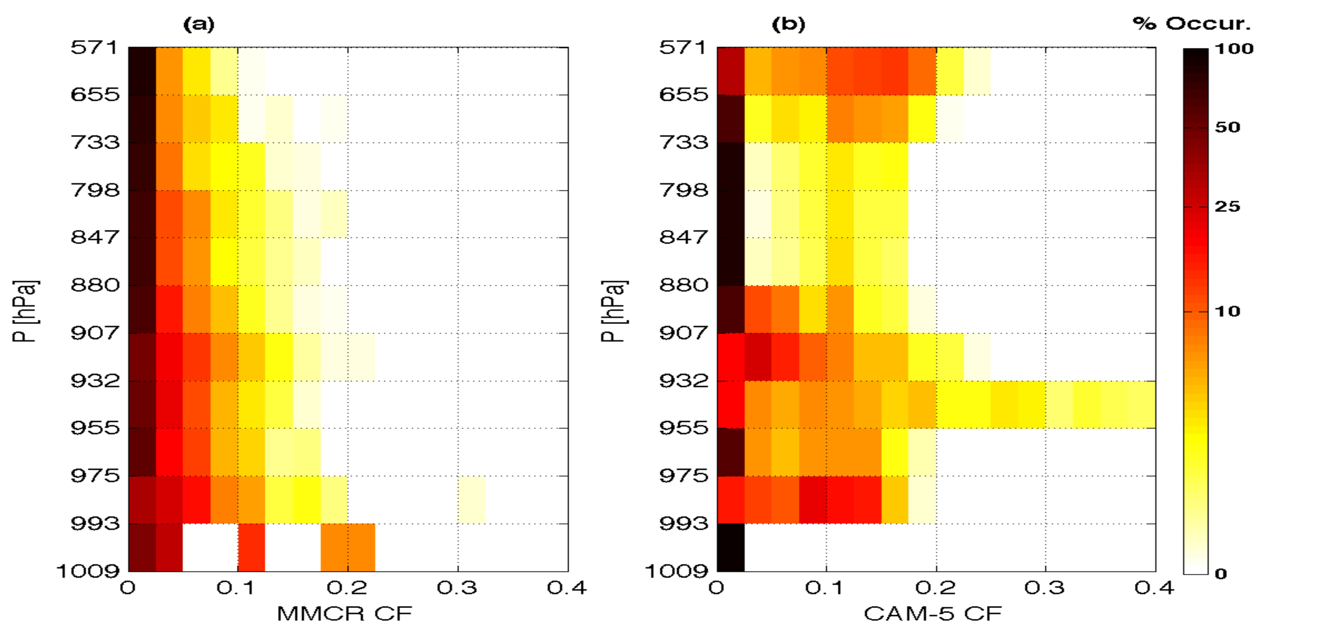

Figure 5 Frequency distributions of shallow cloud fractions from (a) MMCR observations and (b) CAM5 simulations at model levels. Cloud fractions from the MMCR are based on a 3-hour moving average window.

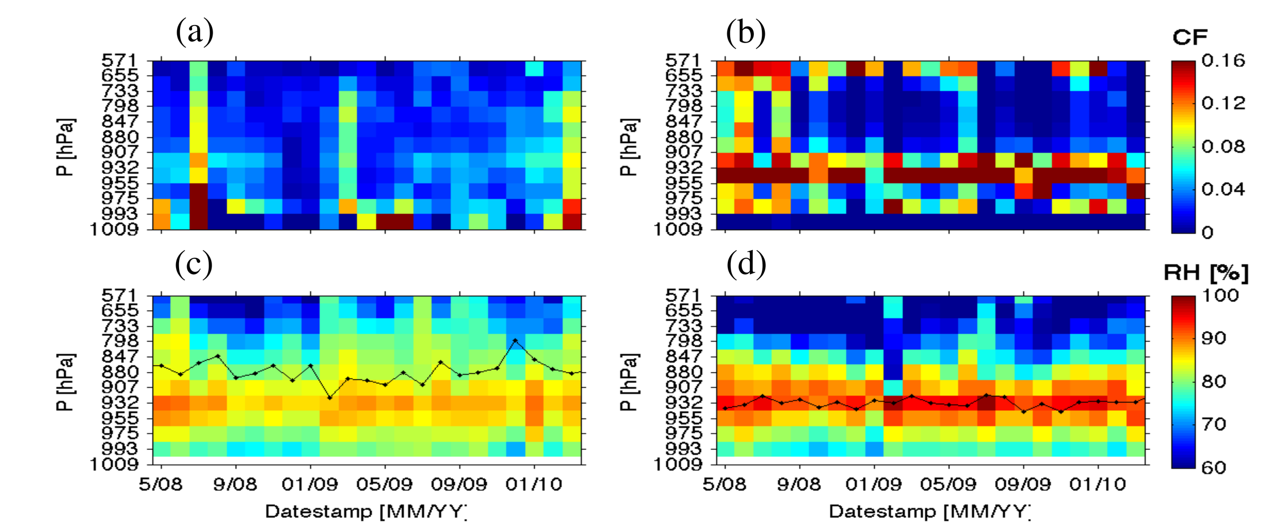

Figure 6 Time series of monthly mean 3-hourly shallow cloud fractions from (a) MMCR observations and (b) CAM5 simulations, and monthly mean values of relative humidity from (c) sounding observations and (d) CAM5 simulations overlaid with monthly mean boundary-layer heights (black lines).

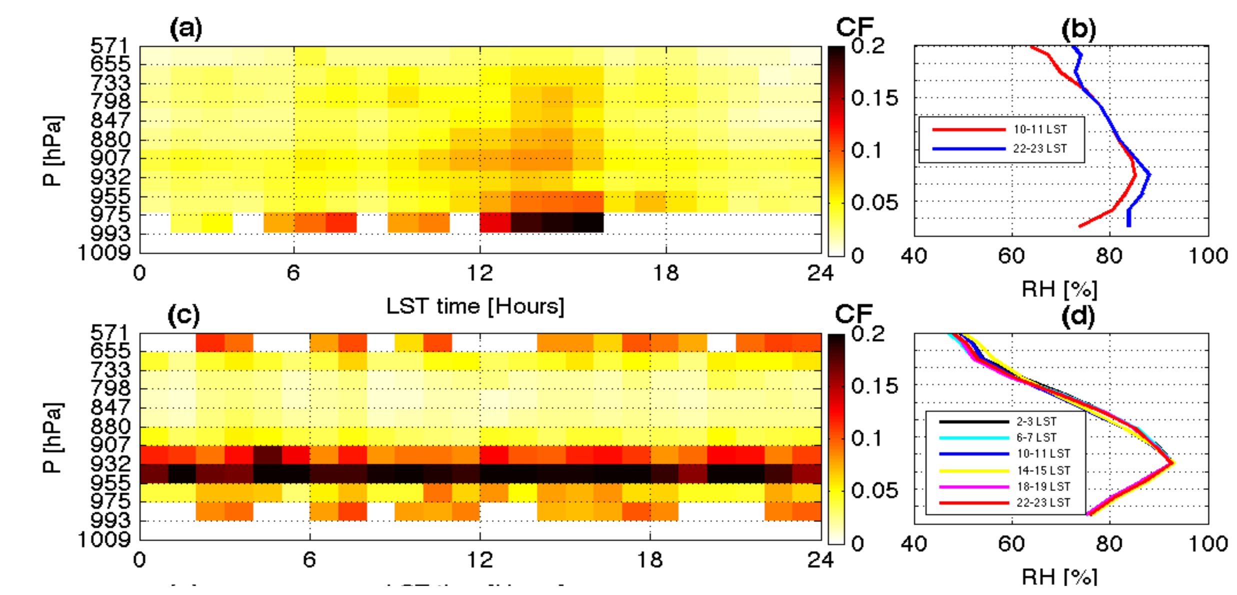

Figure 7 Composite diurnal cycles in profiles of shallow cloud fractions from (a) MMCR observation and (c) CAM5 simulations at model levels. Mean profiles of relative humidity for the low cloud events from (b) twice daily soundings and (d) CAM5 simulations six times per day.

	Low Cloud	Deep clouds	Other clouds (base above 1.5 km)
CAM5 (16536 hours)	12.54% (2071) *92.85 % (1923)*	85.90 %(14181) *99 % (14048)*	1.71% (283) *60.77% (172)*
MMCR (15180 hours)	47.73 %(6633) *26.59%(1764)*	25.23 % (3507) *97.03 % (3403)*	26.69 % (3756) *10.43 % (392)*

Table 1 Occurrence percentage of hourly cloud events (number of hours) from CAM5 simulations and MMCR observations at Manus. Percentages of precipitating clouds for each cloud type are given in italic.

Conclusion:

- CAM5 overproduces total clouds and their precipitation fraction but underestimates low clouds compared to the observations.
- CAM5 produces excessive shallow clouds in a thin layer between 954-930 hPa, and excessive humidity near the top of the boundary layer on monthly and diurnal time scales.
- It is hypothesized that insufficient turbulence mixing at the top of the boundary layer is responsible for the excessive humidity, which leads to excessive shallow clouds produced by the microphysics scheme of the model.