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Organized Moist Convection in the Tropics: CAM vs. SP-CAM

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Introduction

Studies have shown that climate models are unable to capture the frequency and locations of mesoscale convective systems (MCSs), which contributes about half of the observed tropical rainfall. This discrepancy is mostly a result of the large-scale convective parameterization in climate models. The cloud-permitting CAM (i.e., SPCAM) is widely accepted as an alternative to generate more realistic mesoscale organization. Therefore we compared the timestep-wise characteristics of mesoscale systems in CAM and SPCAM and attempt to quantify the errors due to convective parameterization.

Tropical View of the MCSs

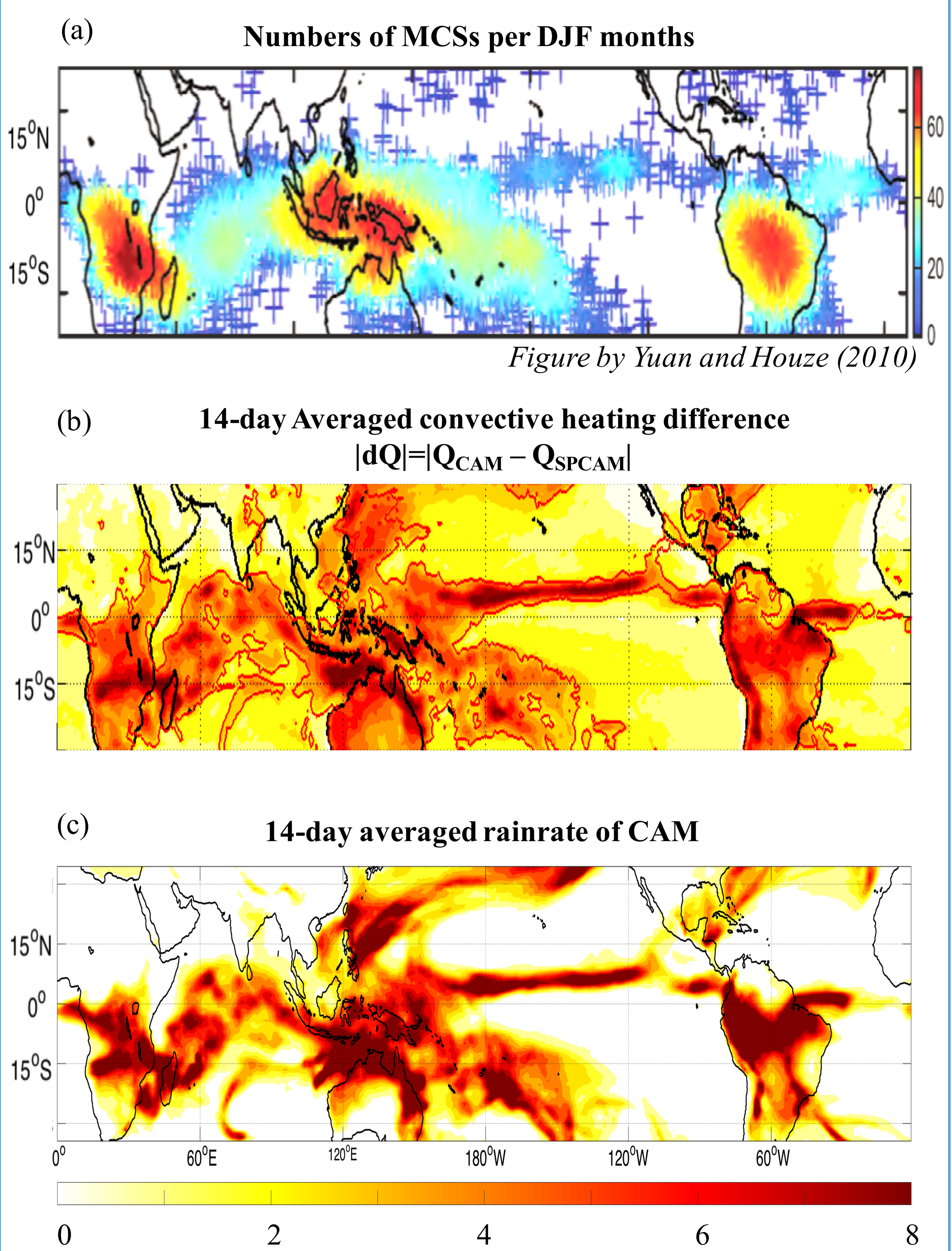

Figure 1: **MCSs, |dQ| and rainrate pattern.** *Geographical distributions of (a) frequency of large separated MCSs during winter months (DJF), (b) 14-day averaged tropical maps of vertically averaged |dQ| and (c) surface precipitation rate. The MCS frequencies seems well correlated to the |dQ| and rainrate strength. We know that CAM does not produce realistic MCS, and the areas with largest mismatch are where most MCS occurs.*

Convective Heating (Q)

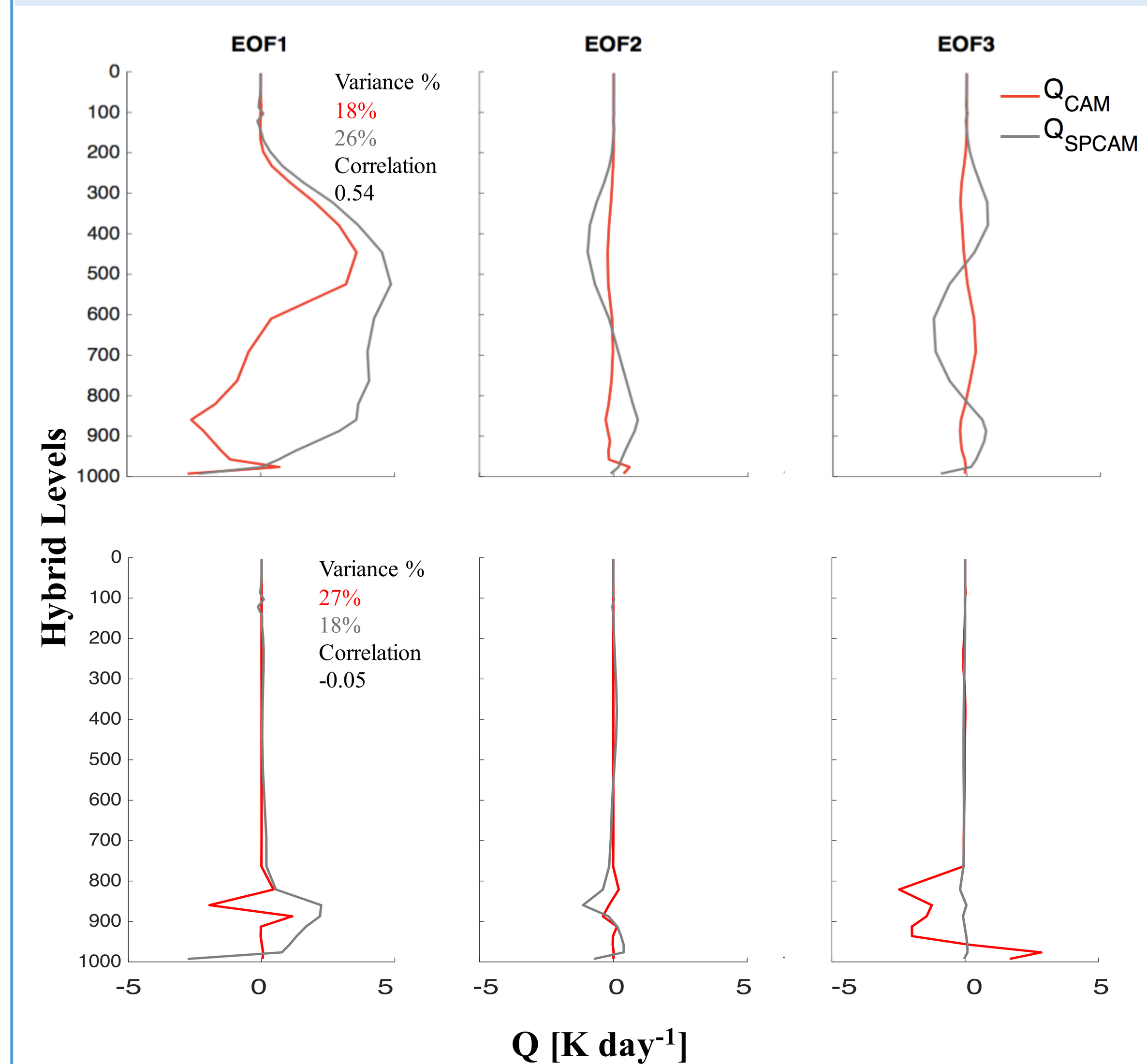

Figure 2: Q vertical modes. *Tropical EOF modes for Q sampled at spatio-temporal grid points only when CAM deep (shallow) convective precipitation is triggered. 1st (2, 3) Column is the time-averaged Q projected onto its 1st (2, 3) EOF mode. The striking difference between the EOF1 of Q_{CAM} and Q_{SPCAM} shows an "unobserved" lower level cooling in CAM that dominates the tropical deep convection variability. Whereas SPCAM fisrt two modes are similar to TOGA COARE (Zhang and Hagos 2009). The 1st deep mode in SPCAM also reflects a lower percentage stratiform precipitation in MCS (approximately 40% as shown in Fig 9.72, Houze 2014).*

Convective Heating & Upward Mass Flux (M_u)

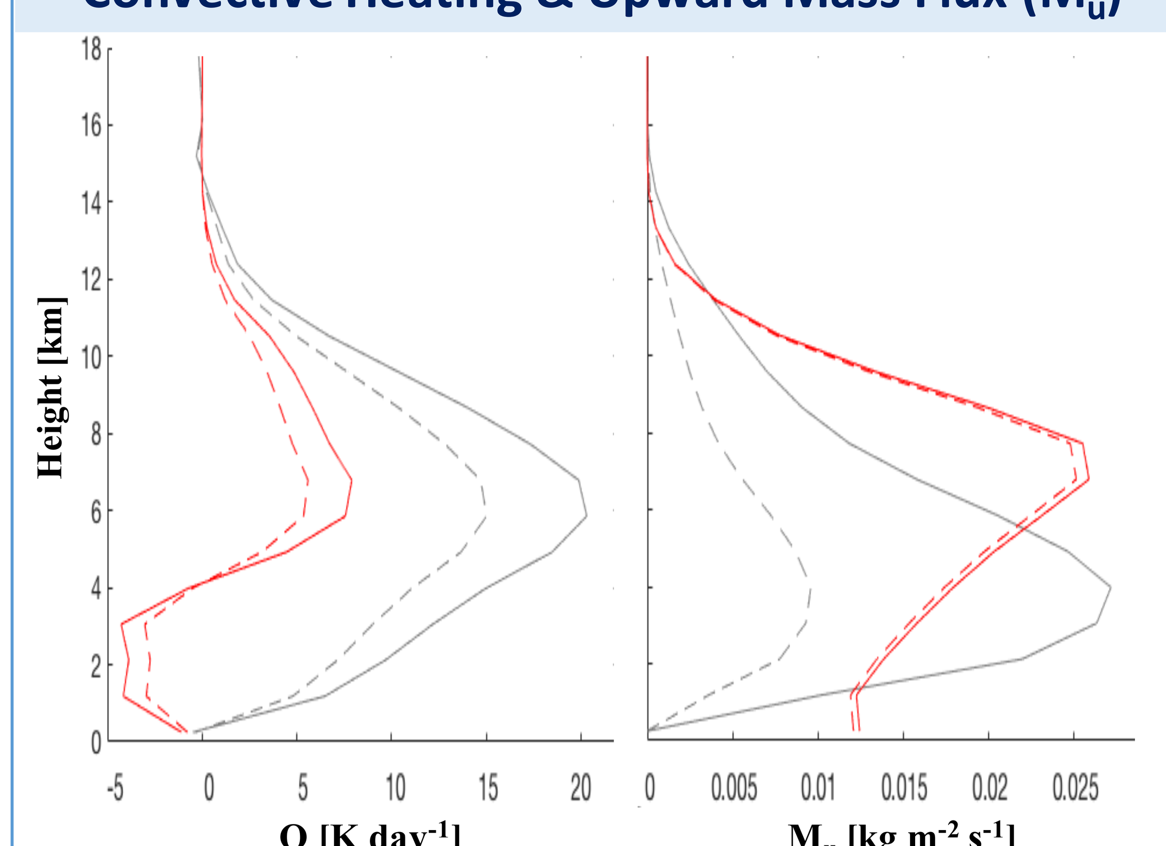

Figure 3: Q & M_u on first EOF mode. *CAM (red) vs. SPCAM (grey) convective heating (left) and upward mass flux (right) conditioned on strong deep heating ($max_z(Q_{SPCAM}) > 5$ K day^{-1}). Mean (solid) and median (dashed) of the PC series are projected onto the 1st EOF mode for both variables. Notice M_u for SPCAM shows median mode (dashed-grey) much weaker than mean mode (solid-grey), suggesting a frequent and mild convection mode causing strong heating. This is opposed to the frequent and strong convection causing weak heating mode in CAM. CAM M_u also shows a constantly strong updraft near the boundary layer, which is consistent with the conclusion that CAM doesn't delay for deep convection (Zhu et al 2009).*

Rainrate (P)

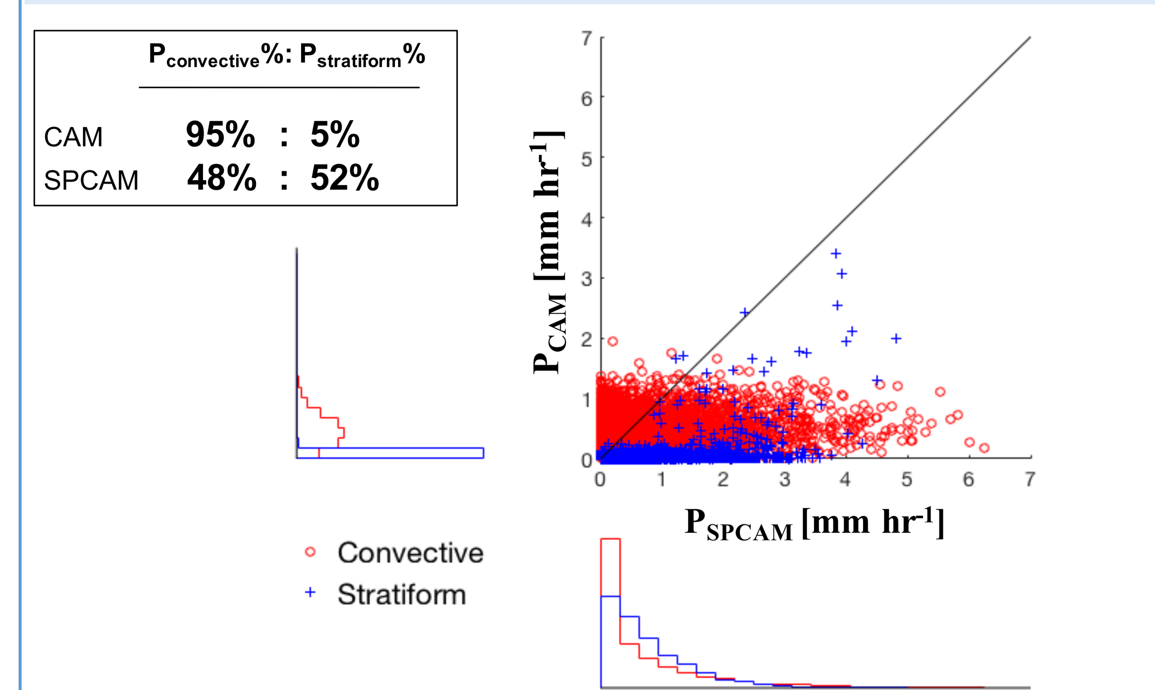

Figure 4: Rainrate of MCC-sized system. *CAM vs SPCAM large-scale convective (red) and stratiform (blue) averaged rainrate of MCC-sized systems. CAM's convective and stratiform rainrates are extremely weak, and largely distributed near zero when SPCAM is mild (1-3mm hr^{-1}). The variance of rainrate is also much greater in SPCAM for both convective and stratiform, and the distibution shapes are very similarly skewed. Whereas the distribution shape for CAM are skewed for the stratiform but mildly skewed for the convective.*

Wind Shear (|dU|)

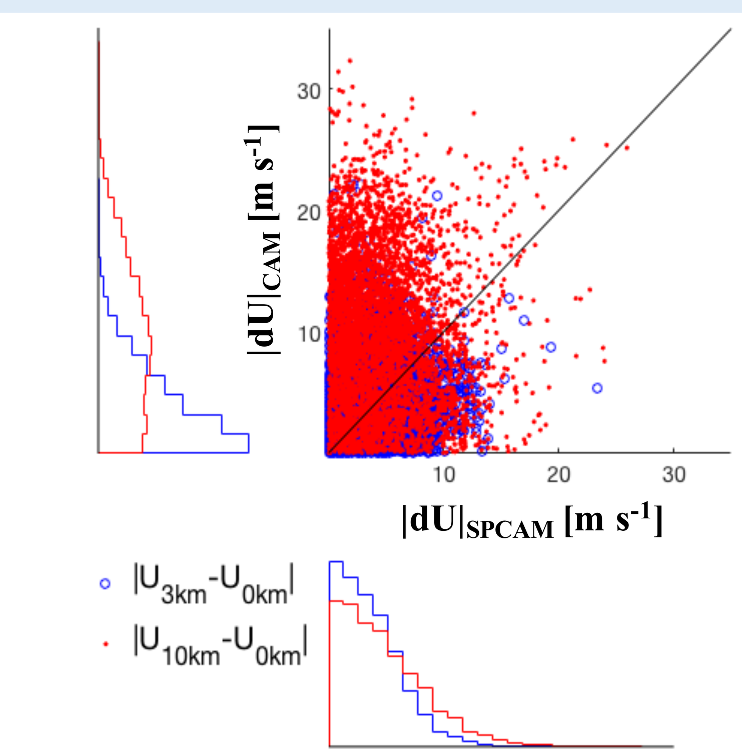

Figure 5: Wind shear of MCC-sized system. *CAM vs SPCAM large-scale shallow (blue) and deep shear (red) of MCC-sized systems. CAM's deep shear is significantly stronger, highly varied, and peaks at 10m/s which is unseen in SPCAM. SPCAM has both shears skewed towards weak shear for both deep and shallow case.*

Relative Humidity (RH)

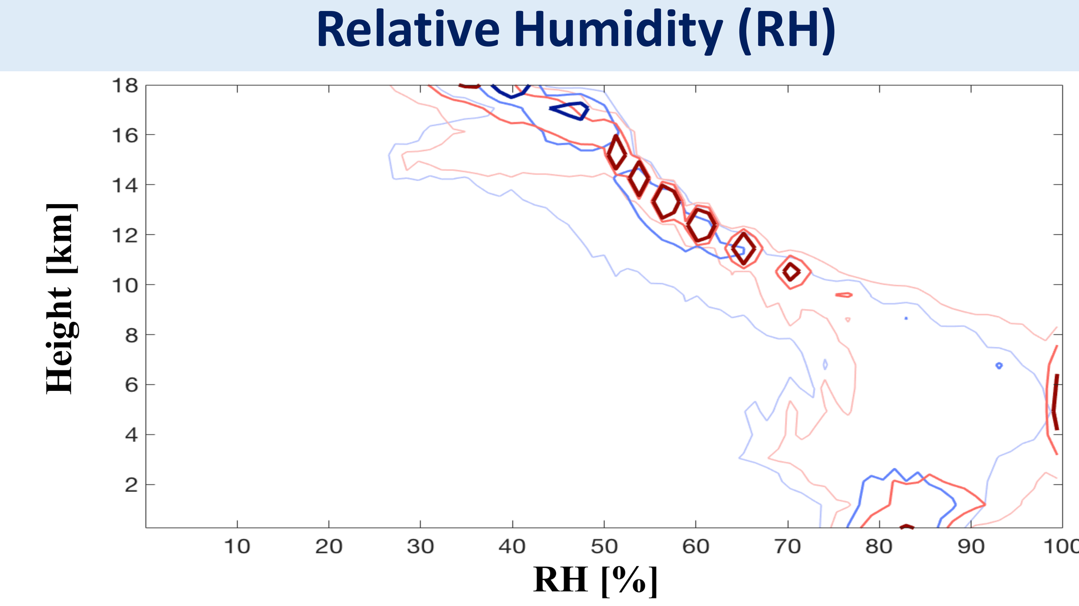

Figure 6: Relative humidity of MCC-sized system. CAM (red) vs. SPCAM (blue) *contoured frequency of RH with height. Three contours in both colors shows frequency increasing with darker color. CAM's frequently saturated at 4-6km, and narrowly peaked above 10km showing its behavior is limited to certain values at those levels. SPCAM's distributions are shifted to lower values at all levels compared to CAM.*

Liquid (w_l) & Ice (w_i) Water Mixing Ratio

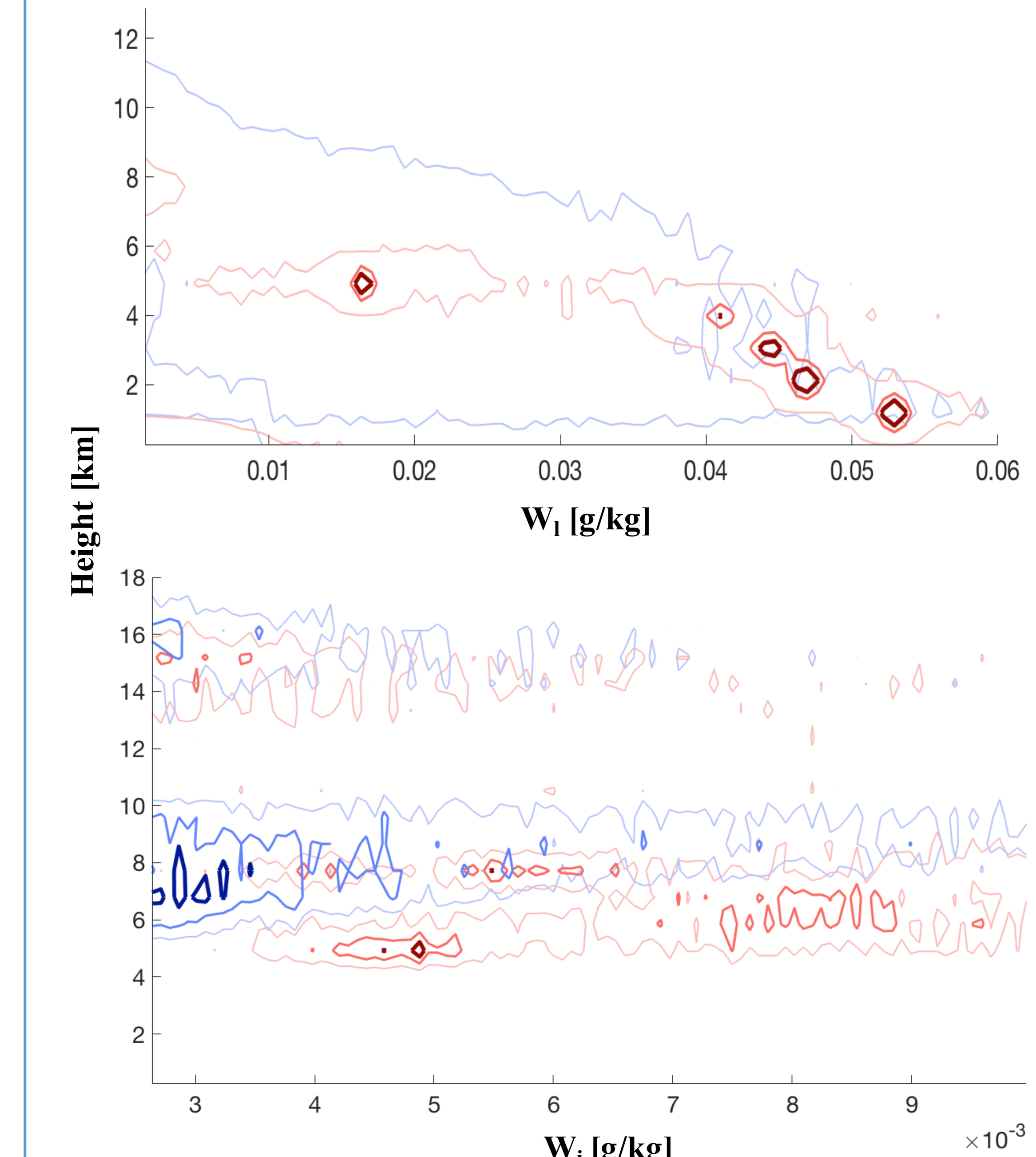

Figure 7: Water mixing ratio of MCC-sized system. CAM (red) vs. SPCAM (blue) contoured frequency of w_l *(top) and* w_i *(bottom)* with altitude. *Three contours in both colors shows probability increasing with darker color. Both models have high frequencies of near zero w_l values at <1km and 8km heights (not shown). CAM has exceptionally higher density concentrated at higher w_l values throughout <6km heights. SPCAM w_l is uniformly distributed at nearly all levels. CAM (SPCAM) has w_i peaking from 5-8km (6-10km) at much higher (lower) values than SPCAM (CAM).*

Conclusion Table

	CAM	SPCAM
Q_{deep}	Unobserved dominant mode spawns the tropics.	More realistic modes in the tropics.
M_u	Frequent and stronger bottom upward mass flux, and a peak at 8km.	Upward mass flux peaks at 4km.
P	Much weaker stratiform rainrate.	Higher variance and equal portion of both cloud types.
|dU|	Frequent and stronger deep shear.	Both deep and shallow shears are similarly distributed.
RH	Frequent saturation at 4-6km, and narrowly distributed >10km.	Distribution at all levels shifted to lower values.
w_l	Frequent and higher liquid water below 6km.	Uniformly distributed throughout all levels
w_i	High variance from 5-8km.	Higher variance from 6-10km