A Comparison of Tropical Convective Processes in the CAM and the Super-Parameterized CAM

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Overview

Accurate representation of large scale tropical intraseasonal variability, such as the Madden-Julian Oscillation (MJO), has proven to be very difficult for many global climate models (GCMs). Without a generally accepted theory of the processes behind the initiation, development, and propagation of the wave, further model development will inevitably be hindered. The Discharge-Recharge Theory as proposed by Blade-Hartman (1993) has shown promise in observational studies.[1,8] Recently, an AMIP-style run of the Community Atmosphere Model (CAM) and the Super-Parameterized CAM were performed at Pacific Northwest National Laboratories. While the CAM shows very little MJO activity, the SP-CAM produces a very large and vigorous wave. This report looks at several processes which are necessary for the operation of the Discharge-Recharge feedback, including the vertical transport of moisture and destabilization of the free troposphere during the recharge phase, as well as the intense drying and restabilization of the column by downdrafts and westerly windbursts following the wave. For each process, evidence is presented from both models showing the quality of representation.

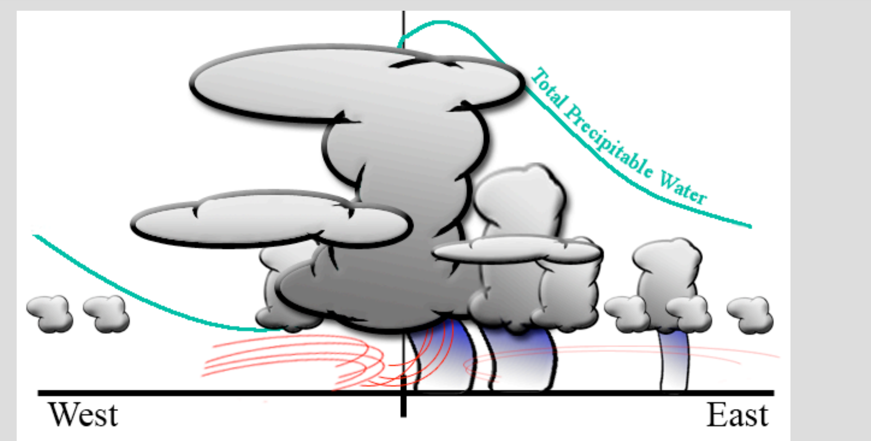


Figure 1: The Discharge-Recharge theory describes a cycle of moist convective processes that help to determine the periodicity of occurrence of the MJO as well as influencing the phase speed of the wave. The cycle begins with shallow and mid-level convection lifting moisture through the tropical troposphere which destabilizes the area. Stochastic forcing from mid-latitudes detonates intense convection, which then rapidly dries and restabilizes the air behind the wave.[2]

About the Models

Both models in this study were run using AMIP-style forcing, and the CAM 3.0 (finite volume DC) model as the frame work. However, in the SP-CAM, the standard cumulous parameterizations were replaced with a 2D cloud resolving model (CRM) oriented in the east-west direction of each GCM grid cell. The 2D CRM has the same vertical resolution as the CAM, but a horizontal resolution of 4km.[5]

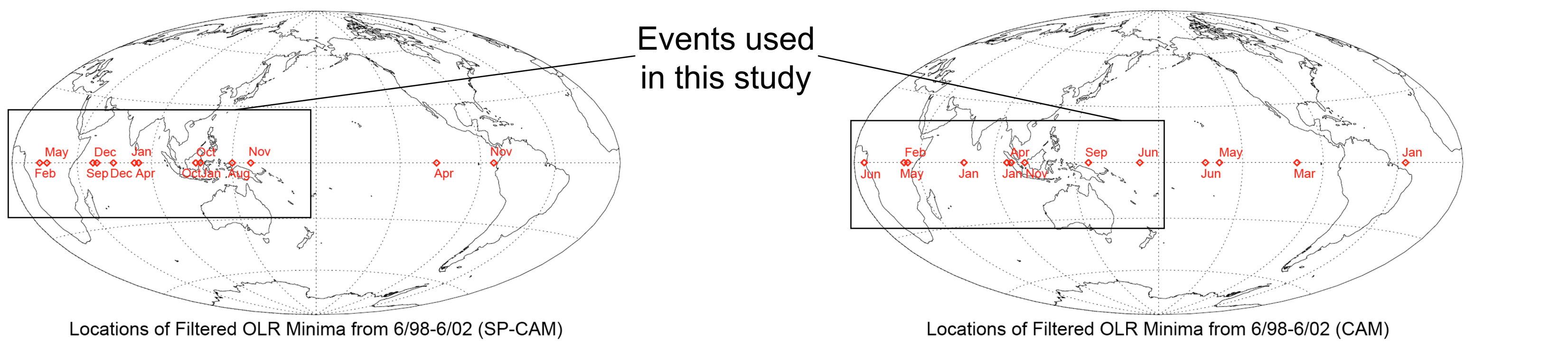


Figure 2: Maps of the longitudinal location of the point of minimum filtered OLR for events exceeding 1-sigma during the four years of data provided for this study. Also shown is the month in which the event occurred. Only events in the eastern hemisphere were used for analysis.

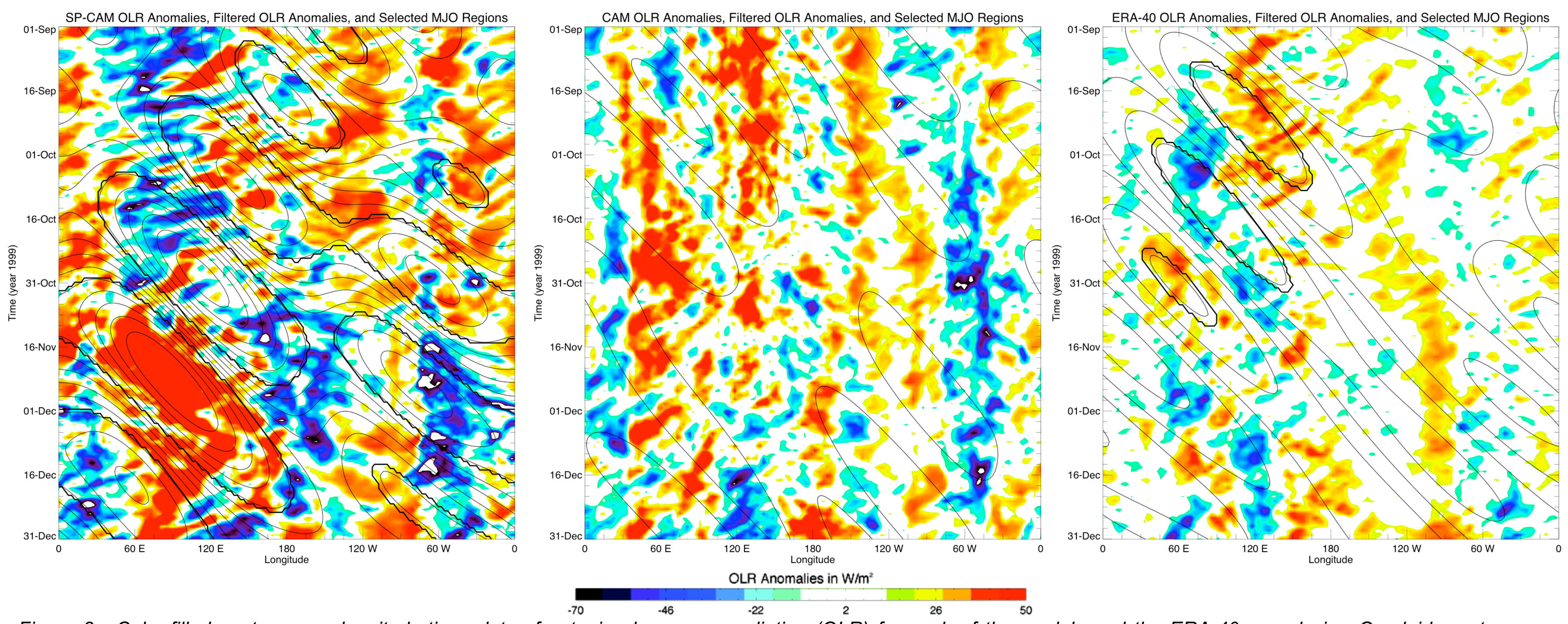
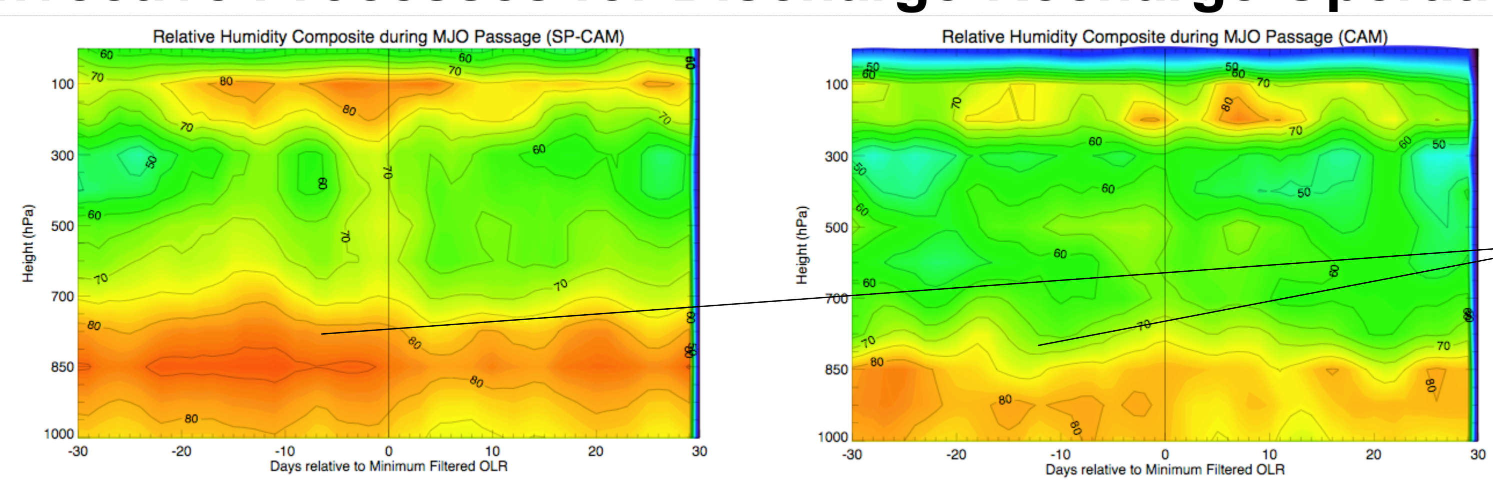


Figure 3: Color-filled contours are longitude-time plots of outgoing long-wave radiation (OLR) for each of the models and the ERA-40 reanalysis. Overlaid on top are longitude-time line contours of filtered OLR, which show only wavenumber 1-3 and period 30-70 day wave anomalies. The SP-CAM produces an extremely vigorous MJO, while the traditional CAM shows little organization of large-scale eastward propagating anomalies.

Necessary Convective Processes for Discharge-Recharge Operation Within a Model

1. Convection must lift vapor and detrain and re-evporate at many levels, adding moisture through the column, and deepening the low-level relative humidity.[2,3,8]

Figure 4 (right): Contour plots of the composite relative humidity profiles during the passage of the wave for the SP-CAM and CAM.

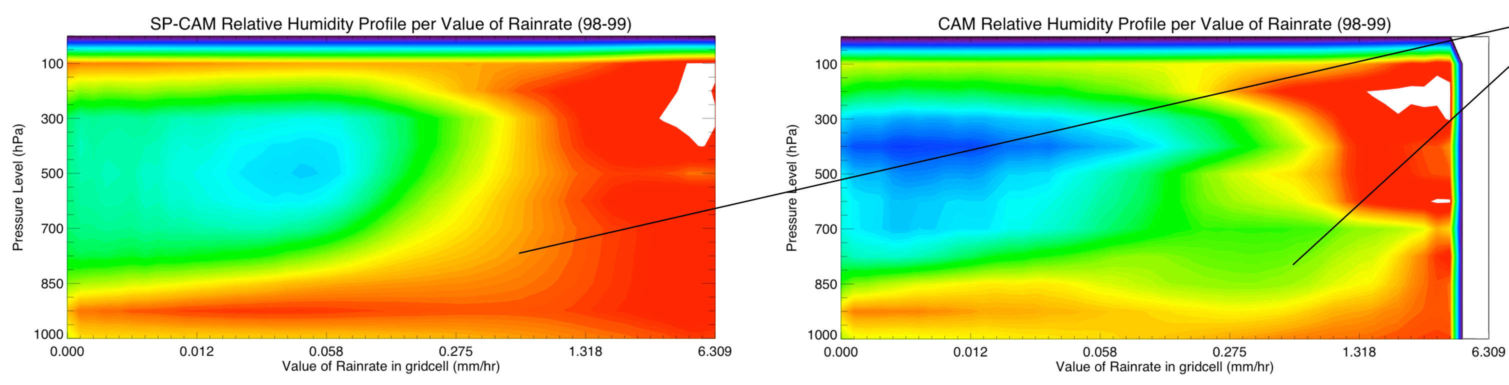


The CRM in the SP-CAM appears to do a much better job of both increasing relative humidity through the column, and loading the lowest levels with water vapor.

The traditional CAM is much dryer through all heights in the tropics, but the dry area around 850mb is very dramatic, and could be due to low amounts of rain re-evaporation and a lack of shallow cloud detrainment.

2. Strong convection should not occur until lower level humidity has reached a critical level.[8]

Figure 5 (right): Contour plots of the composite daily average relative humidity profiles for the value of daily average precipitation rate in the column. These values are for all days in the area 15N-15S and 50E-180E.



Rainrates in the SP-CAM can be much higher than those seen in the traditional CAM, but they also occur with a much higher relative humidity between 700mb and the surface.

TOGA-COARE data tends to support the need for a deep layer of moisture below 700mb for high levels of precipitation.[4]

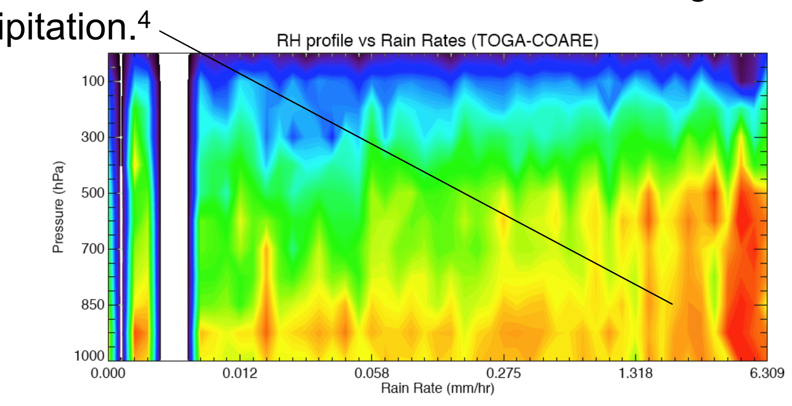
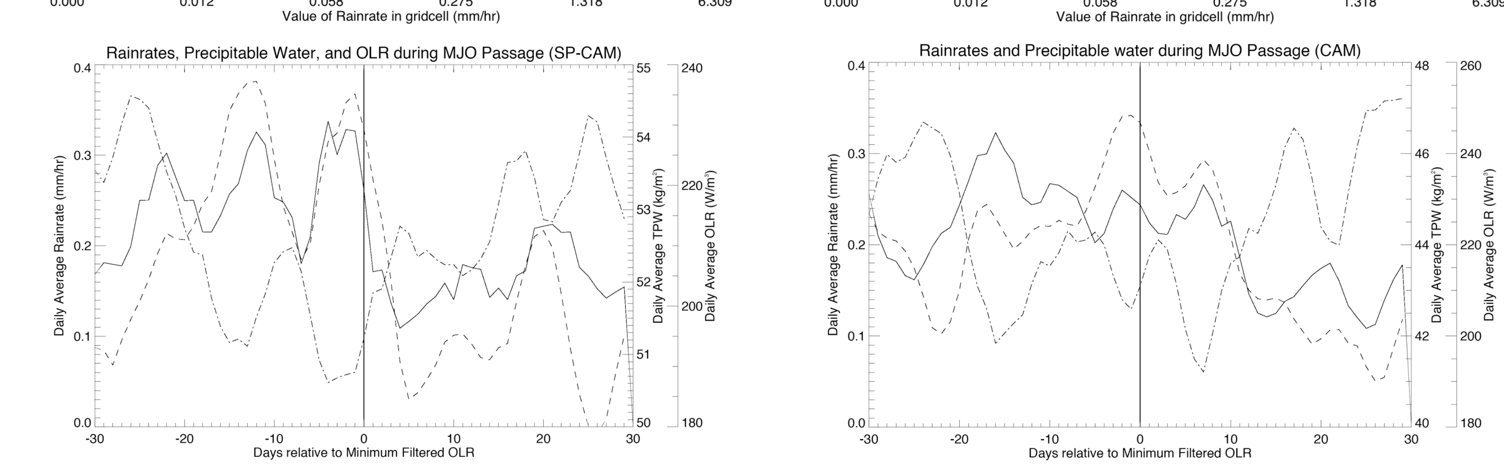


Figure 6: As in Figure 5, but using daily averaged sounding data and daily average tipping-bucket precipitation at each station in the TOGA-COARE project, for the duration of the intensive observation period (1 Nov 1992 - 28 Feb 1993).

3. Discharge-recharge timescale is important.[2] ***The periodicity of strong convection acts as an oscillating heat source, influencing both how often events occur and the phase speed of the wave formed.***

Figure 7 (right): Composite daily average values of Rainrate (solid line), Total Precipitable water (dashed line) and OLR (dashed-dotted line) during the passage of the wave.

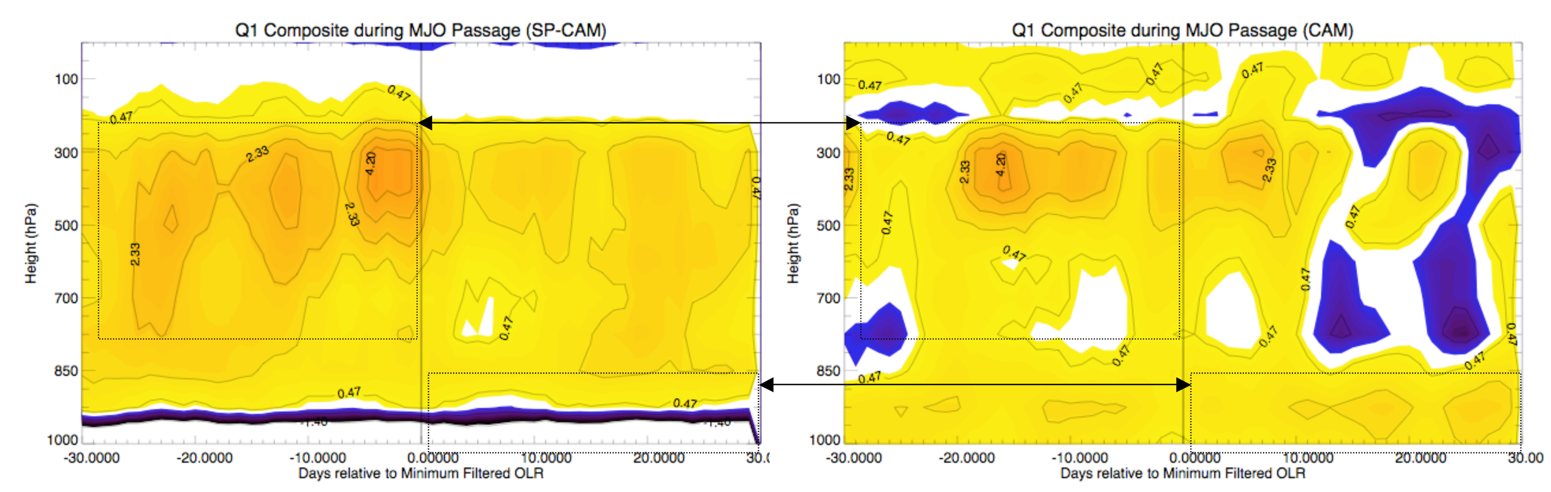
While the SP-CAM shows a coherant pattern of increased rainfall and TPW before the wave, and a quick and dramatic clearing and drying after, the traditional CAM has little gradual build-up and a much slower clearing.



In the SP-CAM, convection in the CRM does a very good job of heating through a large portion of the upper troposphere as the wave approaches. A higher relative humidity through the column (as shown above) could force most new vapor to condense, thus increasing precipitation efficiency and increasing latent heating throughout the convective column.

4. Convection must act to restabilize the layer, by warming above and cooling below.[3]

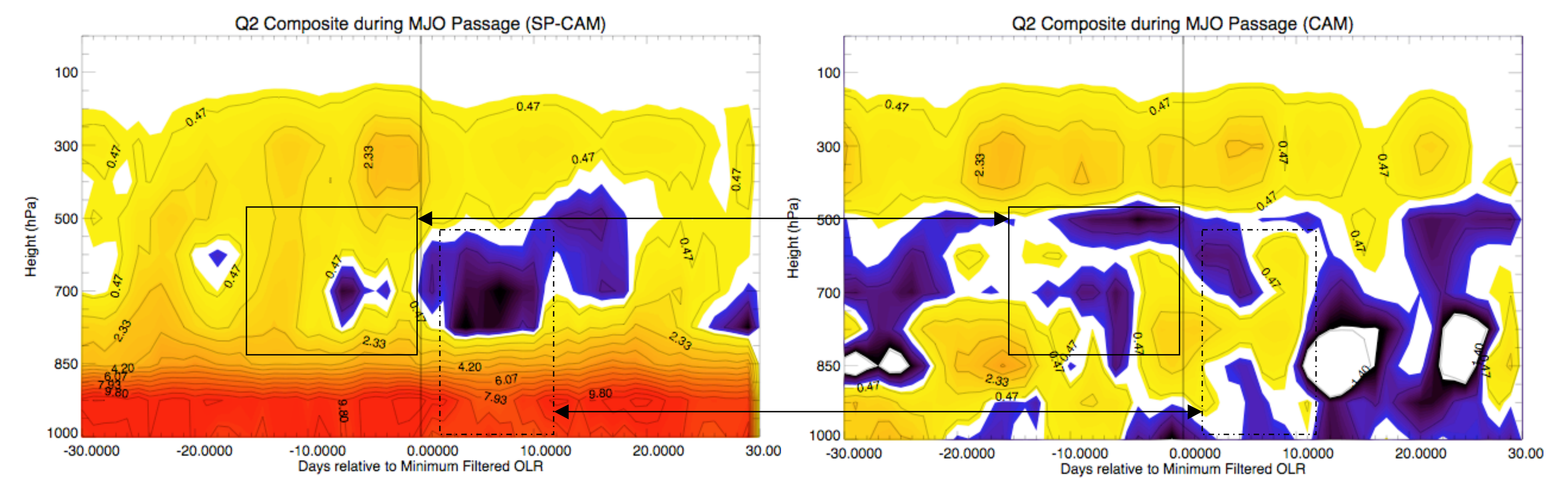
Figure 8 (right): Contour plots of the profile of the composite daily average Q1 heating during the passage of the wave. This heating is analogous to that defined in Yannai et al. (1973), and includes all CRM temperature forcing in the SP-CAM and all 'physics' temperature processes in the CAM.



This much stronger tropical heat source does a better job when feeding back to the large scale dynamics, and the dry wave dynamics follow, creating a large scale flow similar to what is seen in observations, unlike in the traditional CAM.

5. Downdrafts and westerly windbursts need to be able to dry out the lowest levels behind the wave, and shut down convection to the west.[4]

Figure 9 (right): As in Figure 8, but for daily average Q2 heating. Again, this heating is analogous to that defined in Yannai et al. (1973), and includes all CRM water vapor forcing in the SP-CAM and all 'physics' water vapor processes in the CAM.



Also, in the SP-CAM, convection is constantly acting to dry and cool the lowest levels, which allows for a rapid stabilization after the passage of the wave, and continued suppressed convection for weeks afterwards.

The parameterized physics processes in the CAM have a much thinner layer of intense heating, and, in general, is not as well organized. Thus, the local destabilization before and restabilization after the wave passage is not as dramatic or as effective.

Conclusions

The data used in this study provide a unique view into the representation of moist convective processes in the tropical latitudes of a very widely-used atmospheric model. Interesting deficiencies of the CAM parameterizations include a lack of low-level water vapor (below 700mb), and extremely inconsistent heating, possibly due to inadequate precipitation formation and re-evaporation processes, as well as too little detrainment from shallow clouds. The SP-CAM shows much better distribution of vapor through the column and during the wave passage. However, it is not all-together realistic. The intense drying and cooling of low levels by CRM simulated downdrafts and intense cloudiness are far more powerful than those of nature.

The Discharge-Recharge framework allows us to apply these problems to the issues of creation and maintenance of a realistic MJO signal. As shown in Figure 10, the cycle of moistening and drying the the traditional CAM is not nearly as intense as that of the SP-CAM or observations, especially during the peak of the wave. It seems that without strong convective moistening and heating, the intraseasonal wave cycle in the traditional CAM is unable to exhibit appropriate organization or variability.

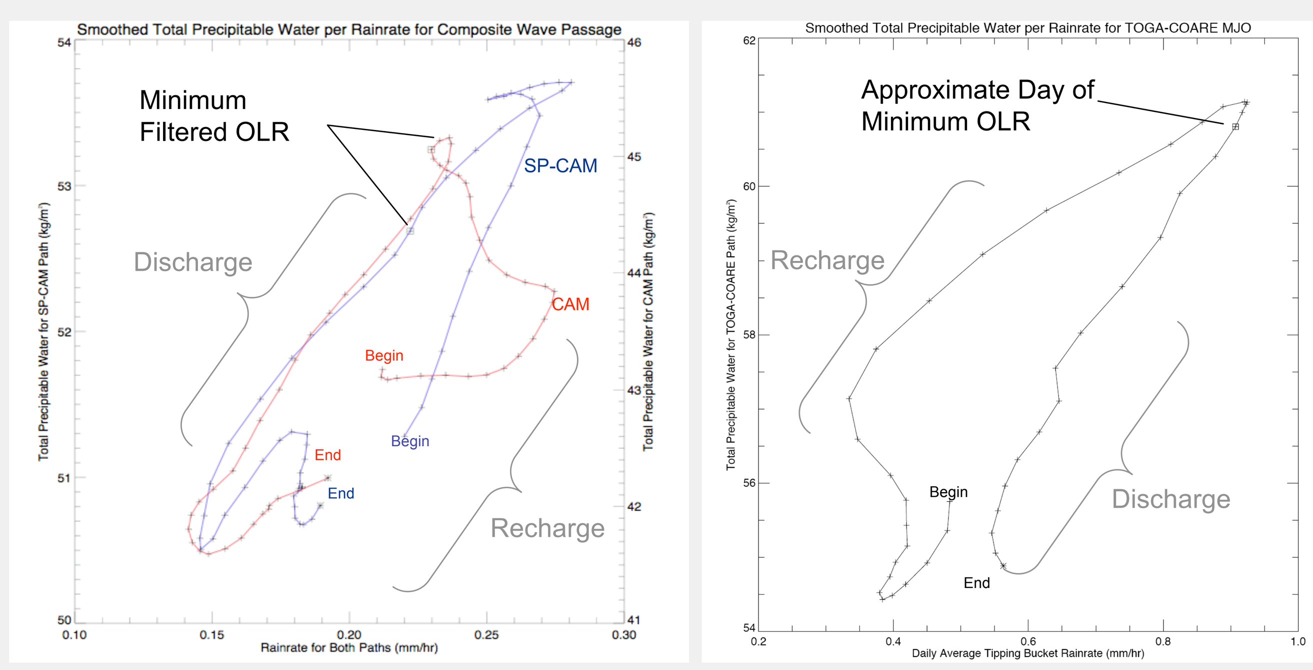


Figure 10: Composite plots of TPW vs Rainrate, during the passage of the wave (as in Figure 7). Left figure is the composite of all events in the SP-CAM and CAM data. Right figure is the first MJO during the TOGA-COARE IOP at 5 stations averaged and smoothed.

References

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