Examining the MJO and Moisture Related Feedbacks in a Super-Parameterized Version of the CAM

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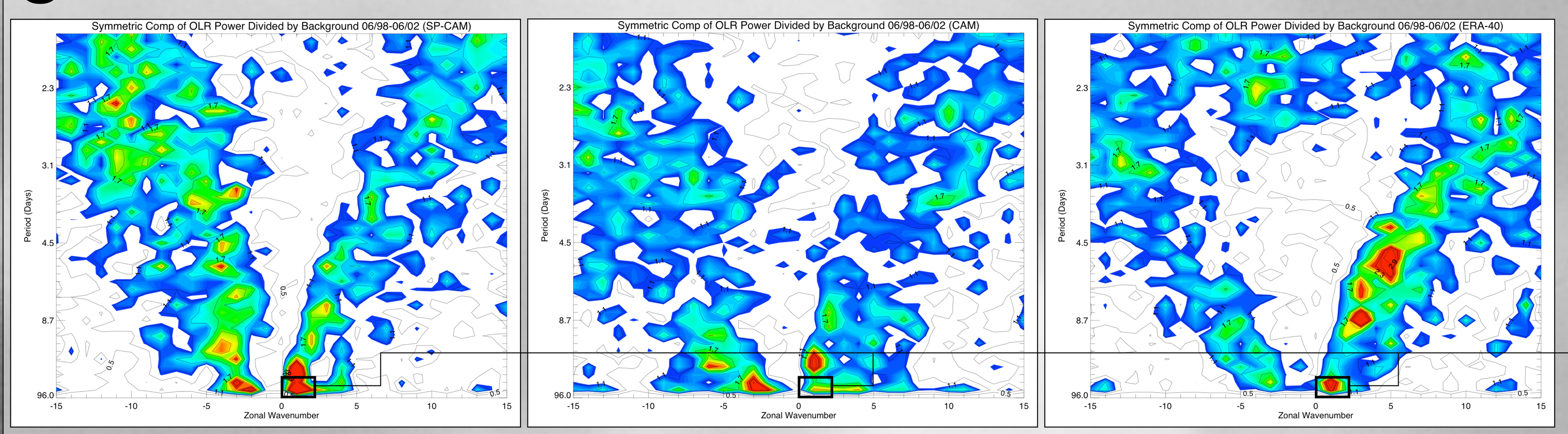
Overview

The super-parameterized version of the Community Atmosphere Model (SP-CAM) has been shown to be an improvement over the traditional CAM (v3.0) in many interesting ways. By including a two dimensional cloud resolving model (CRM) in each of the GCM grid cells of the CAM, the SP-CAM is able to explicitly simulate several cloud-scale processes that the CAM is only able to represent statistically through parameterizations. One of the most important improvements is an increased and more realistic amount of tropical variability. In particular, the Madden-Julian Oscillation (MJO) is almost entirely not present in the CAM, but is extremely active in the SP-CAM.

The MJO is a planetary-scale eastward propagating tropical wave. As described in many observational studies, the wave is usually characterized as having a period of between 30 and 60 days, and covering tens of degrees of longitude at a time (Madden and Julian, 1994). It generally includes a dry phase with clear skies and suppressed convection, and a wet phase with enhanced convection.

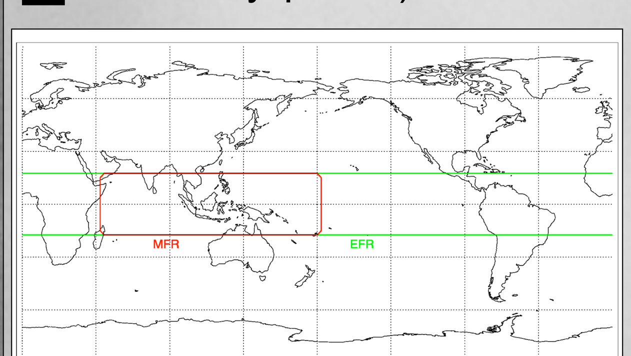
This study evaluates data from two model runs (one CAM and one SP-CAM) provided by Dr. Roger Marchand and colleagues at Pacific Northwest National Laboratories. Both runs use an identical large-scale resolution of 2° latitude and 2.5° longitude, and AMIP-style forcing for the time period of June 1998 through May 2002. Data from the same time period of the ERA-40 reanalysis are also used for comparison.



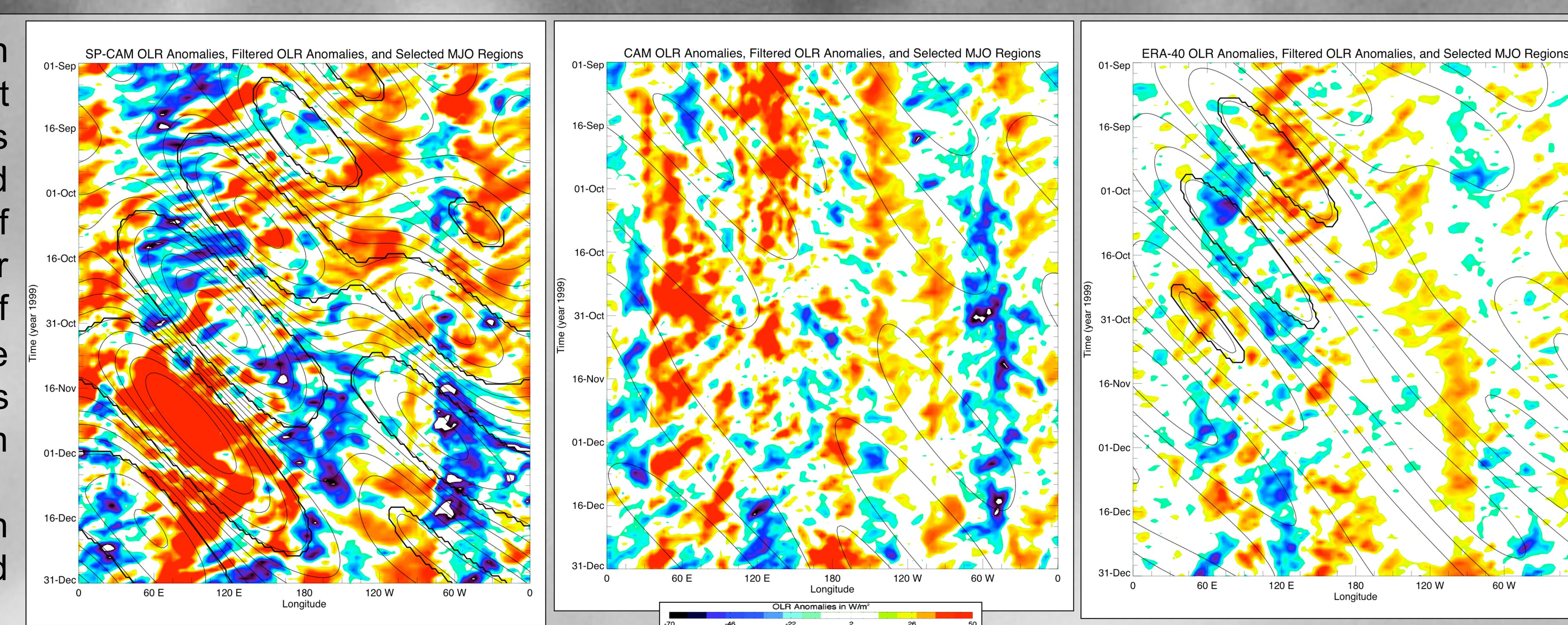
Spectral analysis of OLR anomalies (15N-15S) shows the SP-CAM has much more power in the large wavenumber/long period area which represents MJO waves than either the CAM or ERA-40 reanalysis.

Methodology

In order to isolate the MJO signal in each of the datasets, the outgoing longwave radiation (OLR) anomalies from 15N to 15S (within the Equitorial Focus Region shown below) are first converted to spectral space. A mask is then applied to all frequencies and wave-numbers outside of the MJO. The spectral conversion is then reversed, and the resulting filtered anomalies indicate the passage of the MJO, with each wave generally including an area of increased convection (colder OLR, wet phase) and an area of suppressed convection (warmer OLR, dry phase). The selection of warm and cold events for analysis is based on a cut-off value one standard deviation above and below the average maximum and minimum filtered ERA-40 values. This classifies all locations within the EFR as belonging to either an MJO warm (dry) event, an MJO cold (wet) event, or outside of any MJO.



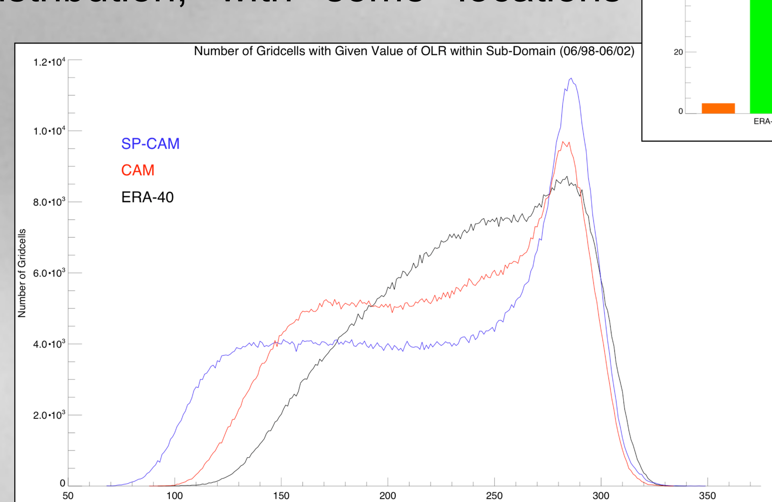
Finally, the data is further focused to the MJO Focus Region (MFR), where the most intense MJO variability is found, and analysis of unfiltered data is performed within this sub-domain.

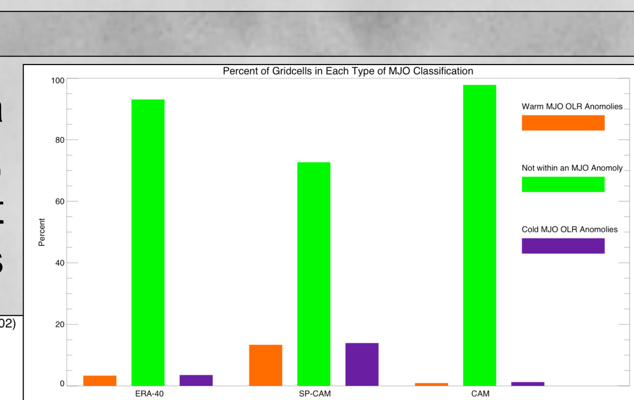


Frequency of Occurrence

The histogram of OLR below shows that all three data sources have the largest numbers of pixels in clear sky, with higher values of OLR. The SP-CAM has the most variability in its OLR distribution, with some locations showing values as low as 70 W/m^2. In this case, the distribution of OLR for the CAM is the closest to observations.

Most of the bins have thousands of data points available to average. Only the extreme ends are suspect.

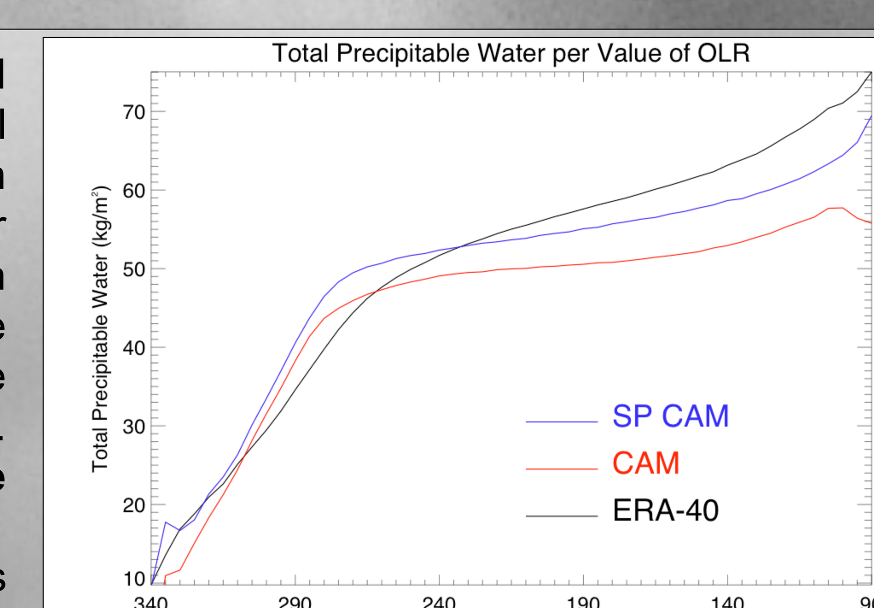




Above: Warm (dry) and cold (wet) categories have similar numbers of data points. The SP-CAM has more points classified as within MJOs and the CAM has fewest.

TPW per Value of OLR

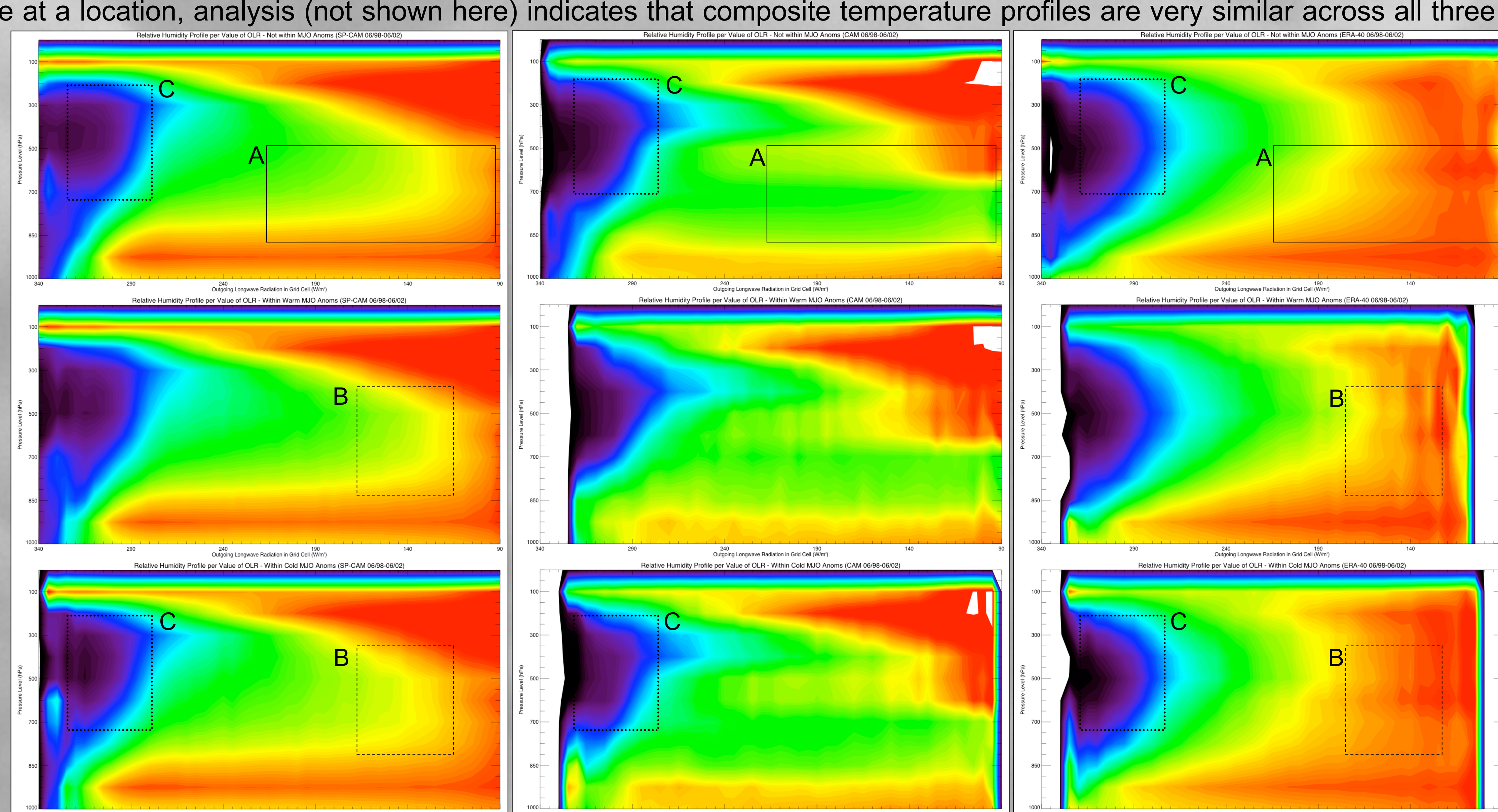
Once all of the data is binned and categorized, a simple plot of OLR vs Total Precipitable Water (TPW) shows both models have too much water vapor in clearer skies, where the amount of water vapor in the column should be lower. Also, they have too little vapor in cloudy skies, where the amount of vapor should be much higher. **Through all values, the SP-CAM is more moist than the CAM.**



Values of TPW in each of the MJO phases are not significantly different from each other, so the mean of all three are plotted here. The total vapor may not change through MJO phases, but its vertical distribution could change.

RH Profiles per Value of OLR

These plots show a profile of relative humidity (RH) per value of OLR. The left plots are the SP-CAM run, the middle are the CAM run and the right plots are ERA-40 reanalysis. The top row is a composite of points outside of the MJO disturbance, the middle row composites points in a warm MJO anomaly and the bottom row is the cold anomaly composite. While RH is a function of both the vapor and the temperature at a location, analysis (not shown here) indicates that composite temperature profiles are very similar across all three data sets. However, the high RH near the top of the SP-CAM plots is a result of the much colder tropopause in this model.



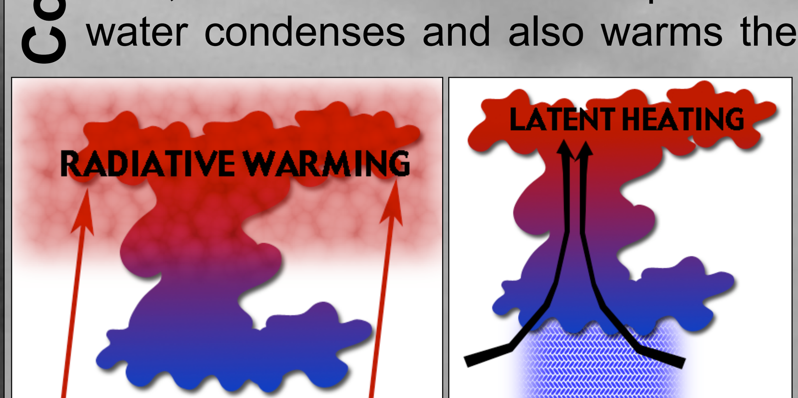
A - *The most obvious difference between the three plots is the RH of the middle troposphere in regions of lower OLR. The much dryer air in the CAM explains the lower TPW seen above, and could indicate that convective processes are not effectively moistening the full column in this model. The composite profiles in the SP-CAM are much closer to the observations, but are still too dry. Again, this explains the lower TPW values for low OLR seen above. This, plus the wide range of nearly saturated air near the surface of the SP-CAM could indicate* ***more effective and realistic convective processes for moisture transport.***

B - *The differences between the MJO phases are small, but observational data indicate a* ***middle troposphere drying in the warm phase, and a moistening in the cold phase****. The SP-CAM composites also show the same change (but to a smaller degree), however the CAM composite shows no real difference.*

C - *Both the observational data and the SP-CAM data indicate a small drying of mid-level clear skies during cold anomalies. This could indicate that the convection within the wave is* ***more efficiently removing moisture from air as it rises****, producing dryer surrounding air. The composites from the CAM show no such effect. In fact, this region of the plot almost appears to be more moist during the cold anomaly in the traditional CAM data.*

Conclusions

While the results presented here are still in their preliminary stages, they do begin to outline an interesting story. The increased amount of vapor within the SP-CAM as compared to the CAM can have many profound effects. As Bony and Emanuel describe in their 2005 paper, increased moisture in all levels of a model can increase the effects of stabilizing feedbacks. As water vapor increases through the column, the amount of atmospheric radiative cooling decreases, the upper levels become warmer relative to a dryer column, and stability increases. It is interesting to note that this feedback can be present in both clear and cloudy phases of the MJO. Also, an increase in water vapor can increase the precipitation efficiency of a cloud, which will increase the latent heating as more water condenses and also warms the upper levels of the atmosphere. Both of these feedbacks act to slightly suppress convection, keeping any locally built up energy from immediately dissipating and encouraging a slow propagation of the wave.



As shown in this study, the more realistic distribution and amount of water vapor in the SP-CAM could be the key to understanding why the simple act of adding a CRM suddenly produces such a large MJO. Much more work is needed, especially in examining precipitation formation in clouds, evaporation feedbacks in the CRM, and how the increased variability of OLR and tropospheric temperatures could be amplifying the strength of the MJO signal.

References

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[2] R. A. Madden and P. R. Julian, "Observations of the 40--50-Day Tropical Oscillation -- A Review", Monthly Weather Review, **122**, 814, (1994).

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