P2.29 DIFFERENCES IN THE RESPONSE OF SATELLITE PRECIPITATION ESTIMATES TO ENSO

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1. INTRODUCTION

With the launch of the Tropical Rainfall Measuring Mission (TRMM) in November of 1997 and associated advances in techniques for the retrieval of tropical rainfall from the passive microwave and precipitation radar sensors on board TRMM, substantial progress has been made towards reconciling differences in zonal mean precipitation over the tropics. A number of significant issues remain, however, with regard to the effect of regional and temporal variability on the monitoring of climate variability in tropical precipitation. For example, regional changes in precipitation systems associated with El Niño-Southern Oscillation (ENSO) appear to result in sensor dependent biases in interannual tropical rainfall variability.

Current observations show that warming of tropical Sea Surface Temperatures (SSTs) associated with ENSO leads to a more vigorous hydrologic cycle (Soden, 2000). The magnitude of this increase is somewhat less certain, however. Soden (2000) investigated this issue by performing a comparison of tropical-mean oceanic rainfall derived from the Microwave Sounding Unit (Spencer, 1993) with that predicted by a number of global atmospheric climate models. The results of this comparison show that the magnitude of model predicted change in tropical-mean precipitation is roughly one quarter of that observed by the MSU observations. This discrepancy led Soden to conclude that "either (i) the sensitivity of the tropical hydrologic cycle to ENSO-driven changes in SST is substantially underpredicted in existing climate models or (ii) that current satellite observations are inadequate to accurately monitor ENSO-related changes in the tropical-mean precipitation.

2. TRMM OBSERVED ENSO VARIABILITY

Although the MSU precipitation product does not represent the state-of-the-art in satellite rainfall estimation techniques, recent observations from TRMM of variability in tropical-mean precipitation associated with the 1997/98 El Niño, shown in Figure 1, do nothing to resolve this issue. In fact, these results suggest that Soden's conclusion that current satellite observations may be inadequate to monitor ENSO-related changes in tropical rainfall is likely correct. As the figure shows, passive microwave rainfall estimates from the TRMM Microwave Imager (TMI) are in sharp disagreement with results from the TRMM Precipitation Radar with regard to the response of tropical-mean oceanic rainfall to the ENSO event. The TMI (2A12) results show a marked increase in tropical-mean precipitation associated with ENSO while the PR (2A25) results show no such increase.

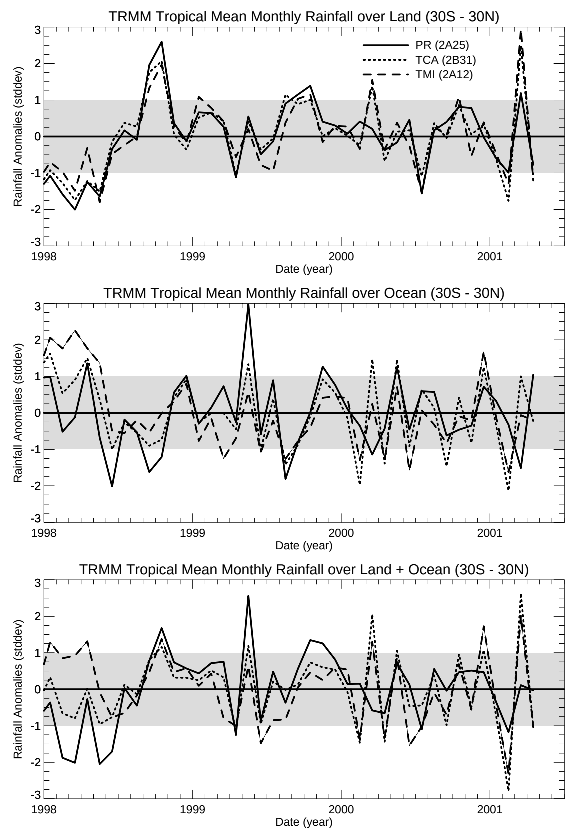

Figure 1: A comparison of the time series of monthly TRMM rainfall anomalies over a) land, b) ocean, and c) combined land+ocean. The algorithms shown include retrievals from TMI only (2A12), PR only (2A25), and combined TMI/PR (2B31) algorithms.

It is interesting to note that the satellite estimates agree very well over land, where passive microwave retrievals rely on more indirect methods relating scattering by ice particles to the surface rainfall rate. In contrast, emission-based techniques used over ocean depend on the more physically based relationship between liquid water content and surface rainfall rate. This suggests that the mechanisms producing rainfall over tropical land regions are relatively unaffected by changes due to ENSO, at least in the sense that there is little change in the resulting structure of rain systems. Over ocean, however, large-scale dynamics such as the Walker circulation appear to play a more significant role in determining the structure of rainfall systems.

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An EOF analysis of the difference between the TMI and PR rainfall estimates, shown in Figure 2, indicates that this disagreement is primarily due to differences in the response of the algorithms to changes over the tropical Pacific. As shown in this figure, the second EOF appears to capture most of the interannual variability of this difference, which is primarily located along the region of increased SSTs in the central and eastern Pacific. This indicates that ENSO induced changes in tropical Pacific rainfall are the key to understanding the differences in the interannual variability of TMI versus PR rainfall in the tropics.

3. EAST PACIFIC BIASES

As shown in Figure 3, rain systems in general are shallower and therefore have warmer cloud tops in the east Pacific, however, there is a prevalence of small shallow rain systems over the east Pacific ITCZ. Infrared-based rain retrieval techniques such as the Global Precipitation Index (Arkin and Meisner, 1987), relate the cloud-top temperature to rainfall. Such techniques will severely underestimate rainfall in the east Pacific, which has a larger proportion of shallow rain systems with warm cloud tops. During El Niño, however, warmer SSTs in the east Pacific lead to higher clouds. This reduces or even eliminates this east-west bias. As a result, IR techniques such as GPI will tend to overestimate the change in east Pacific rainfall associated with ENSO and thus overestimate interannual variability in tropical rainfall as well.

Conversely, precipitation estimates from the Microwave Sounding Unit (MSU) (Spencer, 1993) used in Soden's comparison (2000) will tend to overestimate rainfall in the east due to the fact that this algorithm neglects the effects of scattering by ice aloft. The brightness temperature/rain rate relationship of the 50.3 GHz channel used by the MSU algorithm is shown with and without the effects of ice scattering in Figure 4. The corresponding relationship for the 19.35 GHz channel used for emission-based rainfall retrievals from SSM/I and TMI is also shown in this figure. Because there is more ice in the taller west Pacific rain systems, and the MSU algorithm is calibrated there, the brightness temperature increase due to emission by liquid rain drops will dominate the decrease caused by ice scattering. This will result in an overestimate of rain in the east Pacific. During ENSO, conditions in the east Pacific are more like the west resulting in a reduction in this bias and a lower overall estimate of interannual variability in tropical rainfall. This suggests that the difference found by Soden (2000) should be even larger, however, other factors influencing the MSU estimates such as poor spatial resolution make it a poor choice for comparison with the models.

Although they suffer from a significantly shorter data record, the retrievals from TRMM, shown in Figure 1, provide much more physically direct measurements of rainfall over the ocean than IR or MSU techniques. An issue with emission-based passive microwave rainfall retrievals over the ocean such as the TMI 2A12

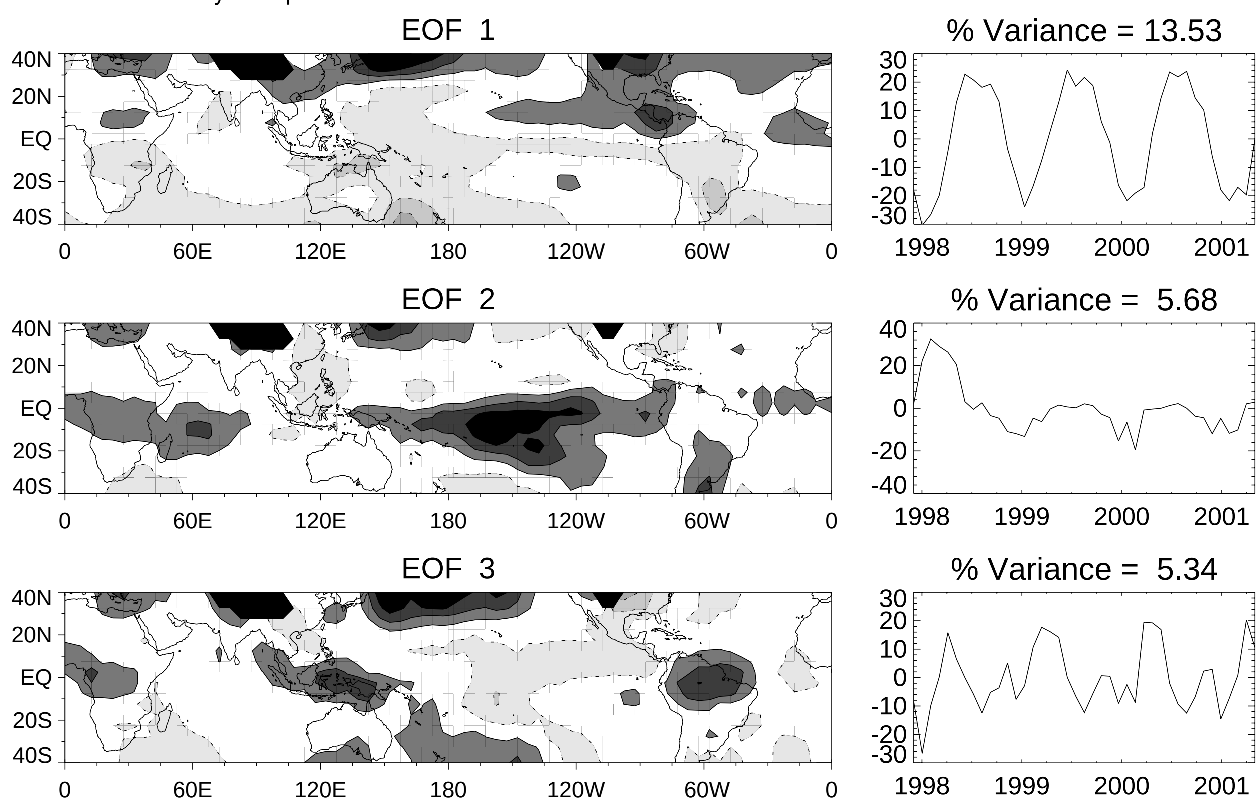

Figure 2: The first 3 EOFS and the corresponding time series of the difference between the monthly TRMM TMI (2A12) and the PR (2A25) rainfall retrievals.

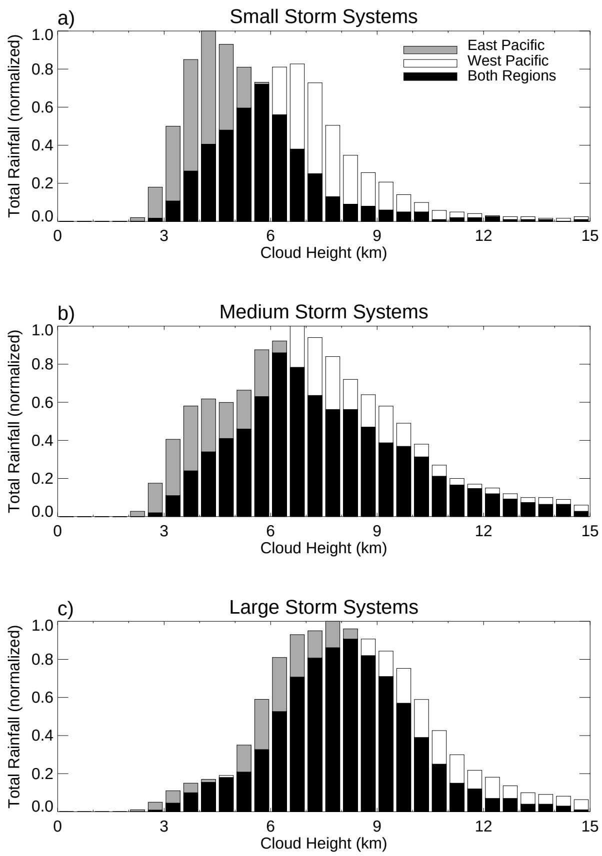

Figure 3: A comparison of cloud height versus total rainfall between the selected east and west Pacific regions for DJF 1999/2000. The results are broken into separate categories for a) small, b) medium, and c) large storms. Total rainfall within each 0.5 km cloud height category has been normalized so that the area under the curve is the same for both regions and the maximum is one.

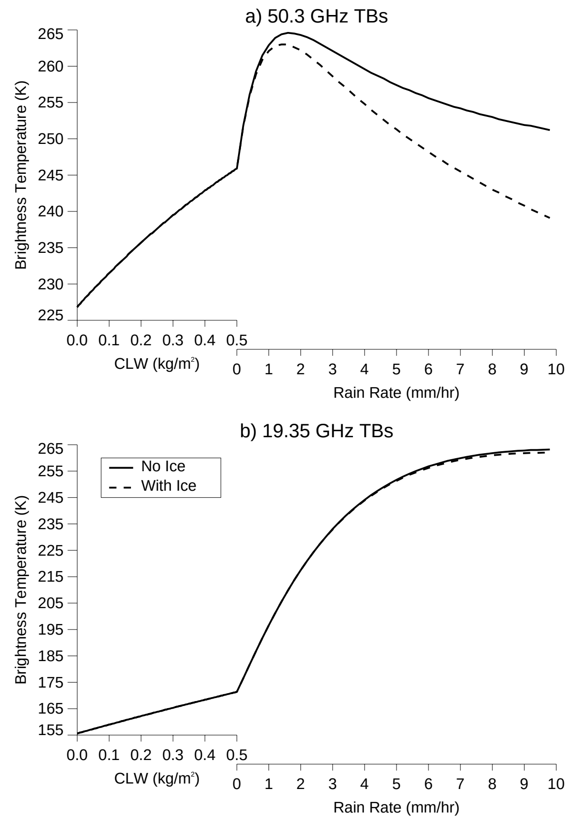

Figure 4: Simulated brightness temperatures vs. cloud liquid water and rainfall computed using an Eddington radiative transfer model (Kummerow, 1993) and a simple 6-layer cloud in the tropics. Results are shown for a) the 50.3 GHz MSU channel used for the MSU precipitation retrievals (Spencer, 1993) and b) the 19.35 GHz channel, which is the primary emission channel used for many SSM/I and TMI retrievals. The dashed line shows the scattering effect of adding ice to the cloud above the freezing level.

algorithm, however, is that the emission signal is related to the total amount of liquid water in the atmospheric column. In order to estimate the surface rain rate, therefore, it is necessary to estimate of the height of the column. This is generally based on the freezing level, which is a rough estimate of the height of the liquid water column. More accurate, however, is to use the mean height of the radar bright band, which is also a measure of the mean melting layer or the mean location of the top of the liquid water column.

Figure 5 shows a comparison of the freezing level height from several sources with the mean bright band height from the TRMM PR. Although there are significant differences in the freezing height estimates, all three sources indicate that the distance of the bright band below the freezing level is much larger in the east Pacific than in the west. Depending on the method used to estimate the freezing height or height of the water column, this difference can lead to a relative bias in the passive microwave retrievals by underestimating rainfall in the east Pacific and leading to an overestimate of the interannual variability associated with ENSO.

4. CONCLUSIONS

We have shown that rainfall estimates from GPI, MSU, and many SSM/I and TMI-based passive microwave retrieval techniques produce biased estimates of rainfall over the east Pacific ITCZ, which impact the magnitude of the observed interannual variability of tropical rainfall. Preliminary results comparing differences in drop-size distributions from the TRMM PR indicate that the PR retrievals may also suffer from biases in east Pacific rainfall. Clearly, a significant amount of work remains to be done in order to quantify and correct for these regional climate biases. This is especially difficult due to a lack of in-situ observations over regions such as the east Pacific. Until we manage to do this, however, Soden's conclusion that "current satellite observations are inadequate to accurately monitor ENSO-related changes in the tropical-mean precipitation" appears to

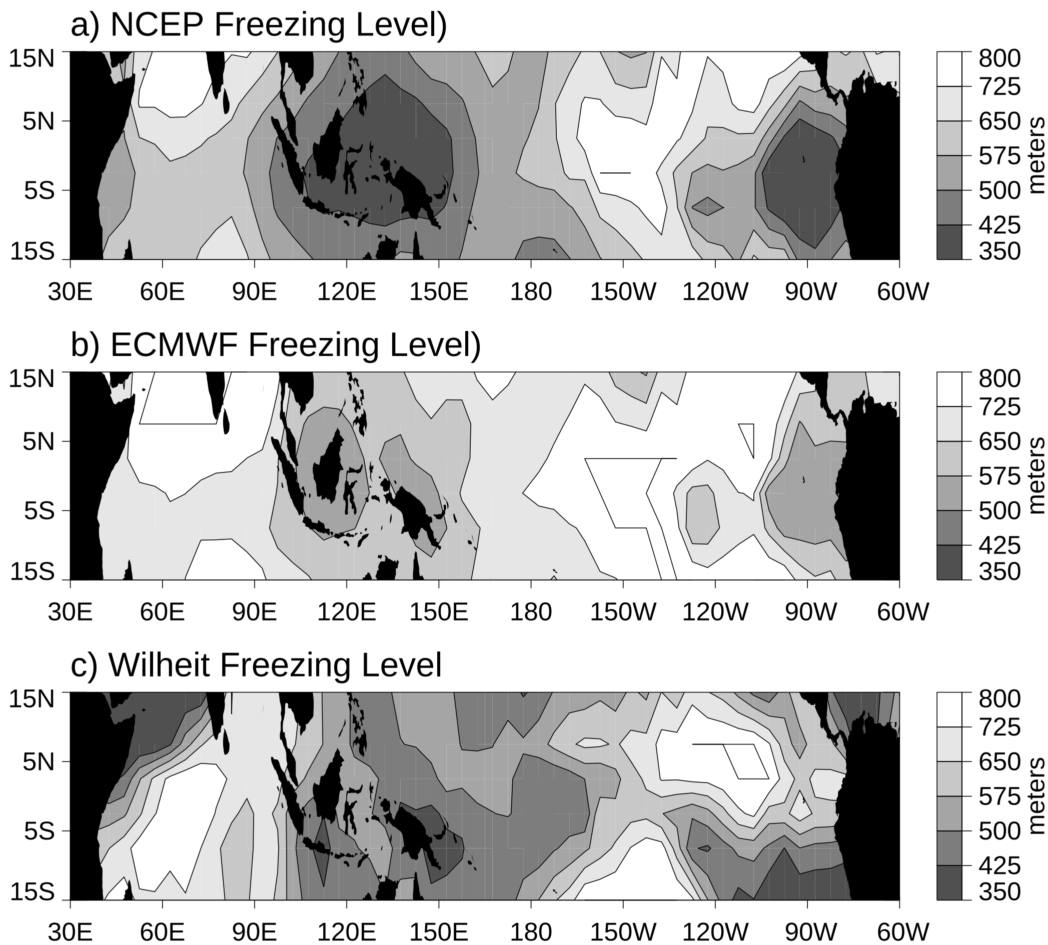

Figure 5: A comparison of the mean DJF 1999/2000 height of the freezing level, or zero degree isotherm minus the height of the bright band or melting layer height from the TRMM PR. The freezing level height is obtained from a) NCEP reanalysis, b) ECMWF analysis, and c) a retrieval from TRMM TMI using the technique by Wilheit et al. (1991).

be accurate even with respect to the latest retrievals being produced from TRMM.

5. REFERENCES

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