**16.6** THE RESPONSE OF TROPICAL PRECIPITATION TO ENSO

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## 1. INTRODUCTION

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. RESULTS FROM MERGED RAIN PRODUCTS

Soden's suggestion that current satellite observations may be inadequate is supported by a number of serious concerns with the use of MSU precipitation estimate to investigate climate signals in tropical rainfall. Issues such as a high bias after 1991 [Soden, 2000], poor spatial resolution, and insensitivity to changes in ice content [Berg and Kummerow, 2001] make this dataset less than ideal for looking at ENSO related tropical rainfall variability. More recently, however, several tropical rainfall datasets merging in-situ and various satellite retrievals have been developed. A comparison of the time series of mean global tropical rainfall between the Climate Prediction Center's Merged Analysis of Precipitation (CMAP) [Xie and Arkin, 1997], and the Global Precipitation Climatology Project's (GPCP) combined precipitation dataset [Huffman et al., 1997] is shown in Figure 1. For purposes of comparison, the anomalies shown have been scaled by the standard deviation and smoothed using a 25-month running mean. The two datasets were both composited from available satellite and in-situ observations over the period from 1979 to the present.

It is apparent from this plot that these two datasets show a completely different response, or lack of response, to ENSO as well as very different climate trends. The GPCP data indicates a slight increase or no trend, while the CMAP data clearly shows a strong negative trend.

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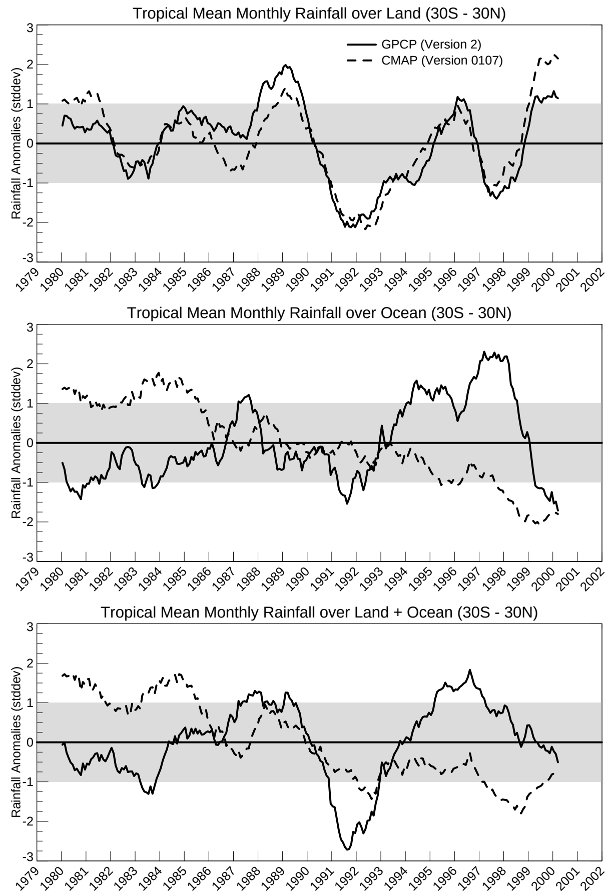


**Figure 1:** A comparison of the time series of monthly mean rainfall anomalies over a) land, b) ocean, and c) combined land+ocean from long-term composite data sets with a 25 month running mean applied. The products shown include the CMAP [Xie and Arkin, 1997] and the GPCP [Huffman et al., 1997], which are both composite data sets using satellite infrared and passive microwave retrievals as well as ground-based rain gauge data.

Neither dataset appears to indicate much of a response to the 1982/83, 1986/87, or 1997/98 El Niños, although that may be due in part to the smoothing applied to the monthly time series. The surprising part is that these two long-term global rainfall datasets utilize similar and in some cases identical component estimates from state-of-the-art satellite retrievals along with rain gauge and other long-term satellite rainfall retrievals. Based on the striking differences, it is clear that these current long-term global rainfall datasets are inadequate for monitoring variability associated with the El Niño-Southern Oscillation (ENSO) or for detecting trends associated with increases in global mean temperatures.

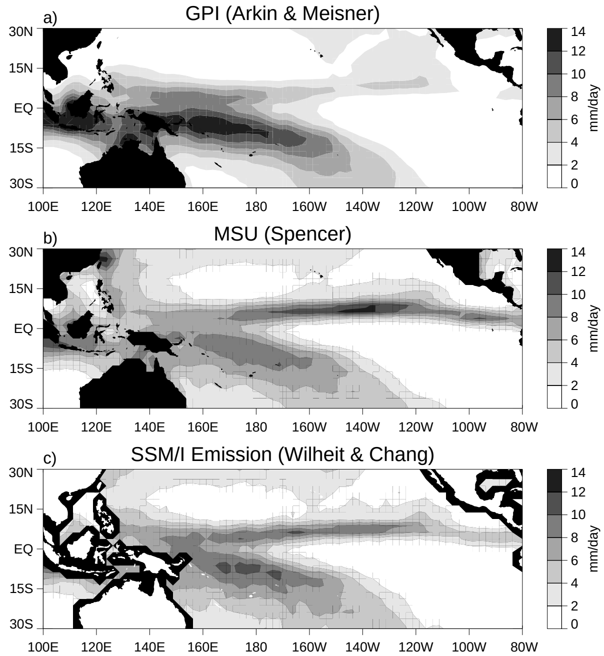


**Figure 2:** Mean Dec-Jan-Feb rainfall for the 10-year period from 1987-1996 from available long-term satellite-based rain estimation techniques. The retrievals shown include the Global Precipitation Index (GPI) based on the technique by Arkin and Meisner [1987] and Arkin et al. [1994], Spenser's [1993] estimates from the Microwave Sounding Unit, and SSM/I emission-based retrievals from Wilheit et al. [1991].

Both of these merged datasets utilize GPI [Arkin and Meisner, 1987] estimates from infrared geostationary sensors, MSU [Spencer, 1993] estimates from the NOAA polar orbiting satellite series, and SSM/I emission-based retrievals [Wilheit et al., 1991]. Figure 2 shows a comparison of 10-year mean rainfall for the 3-month period from December through February from these three different satellite rainfall sensors. The northern hemisphere winter season is chosen for this comparison because this is the season during which the differences in the infrared and passive microwave retrievals are at a maximum. As shown in the figure there are large discrepancies in east Pacific ITCZ rainfall, with the passive microwave MSU showing three to four times the amount of rainfall as the infrared-based GPI estimates. Although the merged CMAP and GPCP products employ methods to attempt to reduce or eliminate these large and obvious biases, it appears very likely that these efforts are inadequate given the large discrepancies shown in Figure 1.

Because the GPI technique is calibrated to rain gauge measurements based on the fraction of clouds colder than 235K [Arkin and Meisner, 1987], as shown in Figure 2 this technique will severely underestimate rainfall in the east Pacific, which has a larger proportion of shallow rain systems with warm cloud tops [Berg and Kummerow, 2001]. In addition, the CMAP merging algorithm [Xie and Arkin, 1997] defines error structures for the individual satellite estimates using the atoll rain gauge data [Morrissey and Greene, 1991] over the west Pacific. This error structure is then used to determine the weight used for the various satellite estimates in the final merged product. As demonstrated from the third algorithm intercomparison project of the GPCP [Ebert, 1996], due to the high sampling rate of the GPI-type infrared algorithms, they performed very well over the west Pacific for monthly accumulations. We believe that the strong correlation between cloud-top temperature and surface rain rate in the west Pacific, however, may result in over weighting the GPI estimates globally, which could lead to significant errors in interannual variability due to the strong bias in the east Pacific.

On the other hand, the MSU precipitation estimates [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 effect of scattering by ice aloft. Because there is more ice in the taller west Pacific rain systems [Berg and Kummerow, 2001] where the MSU algorithm is calibrated, scattering by ice aloft will reduce the brightness temperature increase due to emission by liquid raindrops. Over the east Pacific this reduction will be smaller due to less ice aloft resulting 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, although other factors influencing the MSU estimates make it a poor choice for comparison with the models.

Finally, while observations from SSM/I provide the most physically direct measure of cloud liquid water and therefore rain rate, several potential biases have been identified with respect to climate regime variations of the horizontal and vertical structure of rain systems [Berg and Kummerow, 2001]. Some of the regime dependent factors currently being investigated include the effect of differences in horizontal rainfall inhomogeneity in the satellite field-of-view, variations in ice content, and changes in the height of the rain column.

## 3. TRMM OBSERVED ENSO VARIABILITY

Although state-of-the-art rainfall retrievals from the Tropical Rainfall Measuring Mission (TRMM) are limited to the 4-year period of available data, information on the vertical structure of rain systems from the TRMM PR is extremely valuable for investigating biases associated with long-term satellite retrievals. In addition, the strong 1997/98 El Nino at the beginning of the mission provides the ability to monitor ENSO related changes in this short data record. Figure 3 shows a comparison of the time-series anomalies between the TRMM passive microwave (TMI), precipitation radar (PR), and combined sensor retrievals. As the figure shows, passive microwave rainfall estimates from the TRMM Microwave Imager (TMI) disagree with results from the

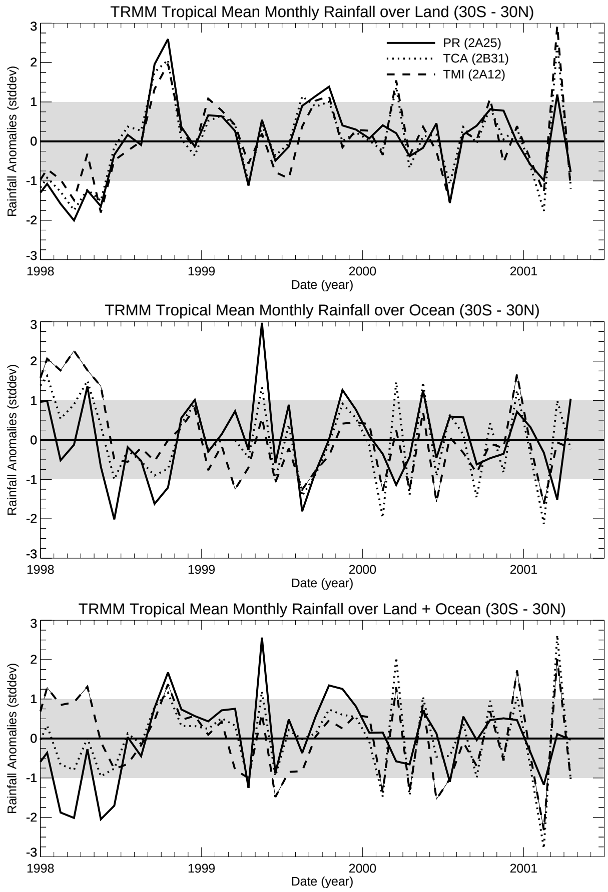


**Figure 3:** A comparison of time series of monthly TRMM rainfall anomalies over a) land, b) ocean, and c) land+ocean. The algorithms include the TMI (2A12), PR (2A25), and combined TMI/PR (2B31) algorithms.

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) line indicates at most a minimal increase.

It is interesting to note that the satellite estimates agree very well over land, where passive microwave retrievals rely on less direct 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 either relatively unaffected by changes due to ENSO, or that any changes balance out in the tropical mean. Over ocean large-scale dynamics such as the Walker circulation appear to play a bigger role in determining the structure of rainfall systems.

## 4. SUMMARY

We have shown that both recently developed long-term tropical rainfall datasets and current state-of-the-art retrievals from TRMM have significant disagreements regarding the response of tropical mean rainfall to ENSO. There is good agreement over land regions indicating a decrease in the mean rainfall associated with ENSO, but the magnitude of the ocean response to increases in SST associated with ENSO is much more ambiguous. It is clear, however, that differences in the structure of rain systems between the east and west Pacific have significant impacts on rainfall retrievals from MSU, as well as infrared and many SSM/I and TMI-based passive microwave retrieval techniques. 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. 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 be on target even with respect to the latest retrievals being produced from TRMM.

## 5. REFERENCES

Arkin, P.A., and B. N. Meisner, 1987: The relationship between large-scale convective rainfall and cold cloud over the western hemisphere during 1982-84, *Mon. Wea. Rev.*, **115**, 297-316.

Berg, W. and C. Kummerow, 2001: Differences in the response of satellite precipitation estimates to ENSO, presented at the *11th Conference on Satellite Meteorology and Oceanography*, October 15-18, Madison, Wisconson.

Ebert, E. E., 1996: Results of the 3rd algorithm intercomparison project (AIP-3) of the Global Precipitation Climatology Project (GPCP), BMRC Research Report No. 55, 199 pages.

Huffman, G. J., R. F. Adler, P. Arkin, A. Chang, R. Ferraro, A. Gruber, J. Janowiak, A. McNab, B. Rudolf, and U. Schneider, 1997: The Global Precipitation Climatology Project (GPCP) combined precipitation dataset, *Bull. Amer. Meteor. Soc.*, **78**, 5-20.

Morrissey, M. L. and J. S. Greene, 1991: The Pacific atoll raingage data set, Tech. Rep., Univ. Hawaii, Manoa, Honolulu, Hawaii.

Soden, B. J., 2000: The sensitivity of the tropical hydrologic cycle to ENSO, *J. Climate*, **13**, 538-549.

Spencer, R. W., 1993: Global oceanic precipitation from the MSU during 1979-91 and comparisons to other climatologies, *J. Climate*, **6**, 1301-1326.

Wilheit, T., A. Chang, and L. Chiu, 1991: Retrieval of monthly rainfall indices from microwave radiometric measurements using a probability distribution function, *J. Atmos. Ocean. Tech.*, **8**, 118-136.

Xie, P. and P. A. Arkin, 1997: Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs, *Bull. Amer. Meteor. Soc.*, **78**, 2539-2558.