THE TROPICAL RAINFALL MEASURING MISSION (TRMM): CONVERGENCE OF THE RAINFALL PRODUCTS FROM THE RADAR AND RADIOMETER

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ABSTRACT

Rainfall products from different sensors on the Tropical Rainfall Measuring Mission satellite are converging in a monthly, zonal mean sense. There is, however, still some discrepancy in the product's interannual variability, with the greatest differences between radar and radiometer estimates occurring during the 1997/1998 ENSO event. While the discrepancy cannot be accounted for at this time, a new validation paradigm is proposed that could be used to understand and correct these discrepancies in the future.

INTRODUCTION

The Tropical Rainfall Measuring Mission (TRMM) was launched in November of 1997. Version 3 of the algorithms was used at launch, but was released only to algorithm developers. The first publicly available data, Version 4, was released on 1 September 1998. These data showed significant disagreement between the Precipitation Radar (PR) derived rainfall (Product 2A25 in the TRMM data system nomenclature) and the TRMM Microwave Imager (TMI) instantaneous rainfall products (2A12). The product set was updated to Version 5, which has been available since 1 October 1999. Rainfall products showed a somewhat better agreement among the sensors [1]. Fig. 1 shows zonal mean average rainfall for PR and TMI for February 1998. As can be seen, there are still significant disagreements in the tropical mean rainfall, particularly in the Inter-Tropical Convergence Zone. Version 6 of the algorithms is due in November of 2002, and early comparisons among the products reveal that the discrepancies are further decreasing.

Despite progress towards reconciling differences in zonal mean precipitation over the tropics, a number of significant issues remain with regard to the effect of regional and temporal variability on the monitoring of climate. An important such issue was investigated by Soden [2] who compared rainfall derived from the Microwave Sounding Unit [3] 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 for the ENSO event of 1987 is roughly one quarter of that observed by the MSU. 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.

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 Fig. 2, 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.

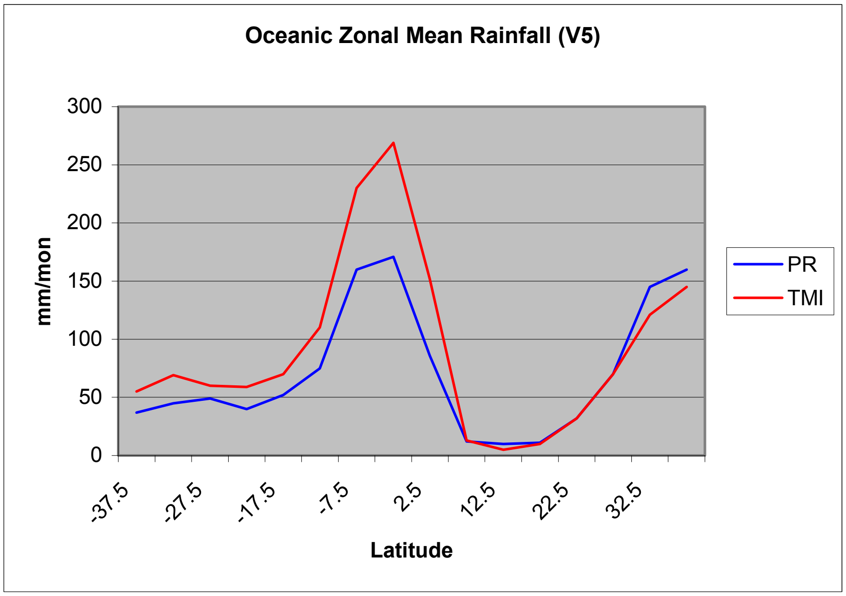

Fig. 1. Zonal mean average rainfall from TRMM Precipitation radar (PR) and Microwave Imager (TMI).

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.

An EOF analysis of the difference between the TMI and PR rainfall estimates, shown in Fig. 3, 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.

A PROPOSED VALIDATION STRATEGY

The TRMM validation effort, based upon conventional wisdom, assumed that satellite products would have a systematic and a random error component, and that accurate ground-based estimates of rainfall could be used to identify each of these. If coincident observations were made at a “validation” site over sufficient time, each component could be easily identified from a scatter of the rain estimates. Central to this notion, however, was an assumption that ground-based sensors were significantly more accurate than the satellite. While TRMM has struggled with the issue of improving the ground-based rain estimates, it is conceptually possible to cover a satellite footprint completely with gauges and this problem is thus left as an engineering exercise.

In addition to the engineering problem, however, there is also a conceptual flaw in the very premise that satellite products have bias and random errors. In reality, satellite algorithms tend to have only a small systematic error component. On a global basis, operational algorithms generally produce global rainfall averages around the 3 mm/day as dictated by radiative budget closure arguments. While this number may be uncertain to ±10% (the difference between PR and TMI in the current Version 5 products), it is not a very large number relative to biases usually found at ground validation sites. What appears as a systematic error at one location or time is in fact caused by the spatial and

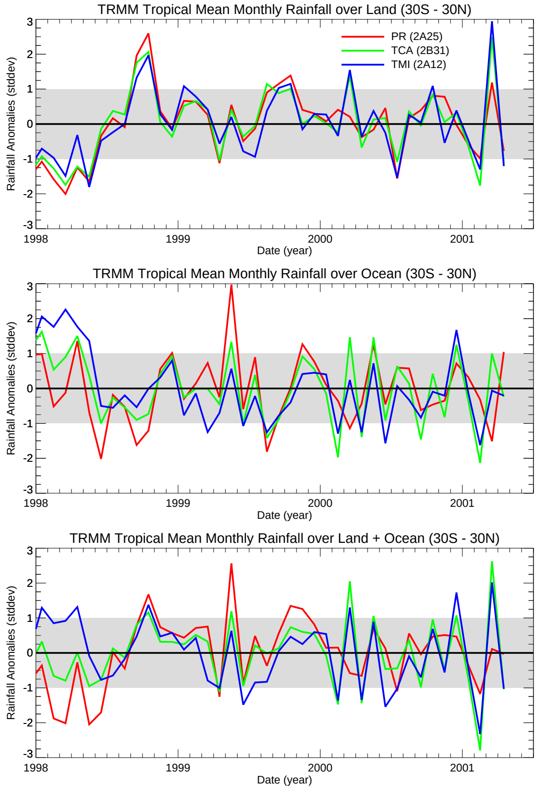

Fig. 2. A comparison of the time series of monthly TRMM rainfall anomalies over a) land, b) ocean, and c) combined land+ocean. The algorithms shown include retrievals from TMI only (2A12), PR only (2A25), and combined TMI/PR (2B31) algorithms.

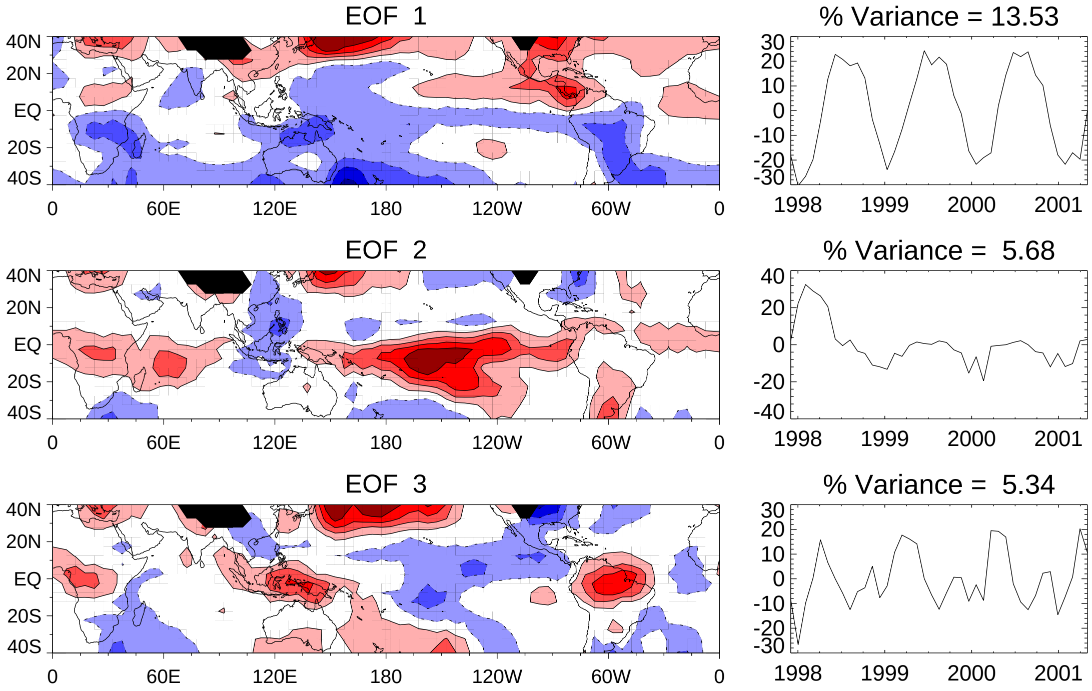

Fig. 3. The first three EOFS and the corresponding time series of the difference between the monthly TRMM TMI (2A12) and the PR (2A25) rainfall retrievals.

temporal variability of parameters that are assumed constant in the satellite algorithm. An example might be the PR algorithm in stratiform rain where the surface reference technique is generally not applicable and the DSD is assumed by the algorithm. Rain will be underestimated by PR if the drops are larger than average, and underestimated if they are smaller. Given that drop sizes appear to vary both randomly and regionally, it is perfectly consistent to have two validation sites find very different biases and random errors. What appears as a systematic bias to an observer on the ground, however, is from the satellite perspective, nothing more than the spatially random variability of the drop size distribution.

As such, it is simply not possible to detect algorithm biases from the current validation sites, no matter how accurate their rainfall estimates are, or how many additional parameters they measure. Validation sites can only detect local biases in a global pattern of over- and underestimates caused by the natural variability of assumed parameters. A straightforward manifestation of this problem has been the inability of validation sites to resolve the 20% global rainfall bias between TRMM PR and TMI, as one or the other sensor appears more or less correct depending on the individual site.

These local biases, when interpreted correctly (not as algorithm flaws that lead to systematic biases, but random errors in a global framework) are the largest source of error on small time and space scales, and the first ones to decrease when better observations become available. As such, these uncertainties are critical for products such as the area averaged instantaneous rain products needed for data assimilation, or short term/small area rainfall accumulations needed for hydrological applications. Solving the engineering issues needed to get very accurate surface rainfall estimates from ground-based sensors must therefore remain a high priority activity. Unfortunately, these same products are not appropriate for the satellite bias issues, which are related to uncertainties in global products needed for climate variability or climate trend studies. Here, the assumption that errors are purely random is inappropriate, as it would suggest that global products, due to large sampling sizes, have virtually no error. Parameters such as the drop size distribution are likely to have large-scale variability that is impossible to detect at the validation sites. These small, but systematic changes from year to year and over large areas will introduce an error of unknown magnitude into the global satellite rainfall estimates.

For the current scheme to be effective in answering systematic error questions, a fundamentally new validation strategy must emerge that goes beyond accurate measurements at a few locations. Indeed, it requires a fundamental change in philosophy. Satellite algorithms each have the ability to determine some of the rainfall profile properties but not enough to constrain the problem fully. A persistent problem is that the absolute variability of each parameter, when taken out of context, is so large as to make retrievals meaningless. If, in the stratiform rainfall example above, one allows for all stratiform drop size distributions ever measured, then the uncertainties in the derived rainfall is far greater than that derived from comparisons with in-situ measurements. Nature, it appears, constrains the variability. It is this constraint on the natural variability that is needed by retrieval algorithms – and particularly if the constraints are correlated.

In our proposed validation scheme, one assumes that there are a large, but finite number of rain structures, and that these rain structures can be observed and classified by the PR. A classification might be such that all PR profiles that have the same reflectivity profiles with height, within some maximum deviation, are considered equal. It is further assumed that climate regimes are not fundamentally different entities, but simply different statistical mixtures of these rain profiles. If this is the case, then ground-based observations can be used to obtain the variability of the parameters (DSD in this example) appropriate for each rain profile. This constraint, if smaller than the variability over all rain profiles, would then be useful for the PR when it does observe a given rain profile at a location other than the validation site. As such it begins to constrain the PR solution in a very systematic fashion, and uncertainties on a global scale, appropriate for climate variability and trending studies, may be derived.

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