VARIABILITY OF RAINFALL OVER TROPICAL OCEANS: SCIENTIFIC BASIS AND JUSTIFICATION FOR TRMM

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ABSTRACT

We have investigated the following questions in this paper:

1. How good are the existing observed rainfall climatologies over the tropical oceans?

2. What are the similarities and differences between the rainfall climatologies produced by different global general circulation models (GCM)?

3. What is the magnitude and structure of the interannual variability of monthly mean rainfall over the tropical oceans as simulated by GCMs, and how does it compare with the interannual variability of the outgoing long wave radiation (OLR) anomalies?

4. What is the magnitude and structure of rainfall anomalies associated with the warm episodes of the El Nino-Southern Oscillation (ENSO) phenomenon?

We hope that an investigation of these questions will help establish the need and scientific justification for TRMM, and interalia, will help evaluate whether the expected accuracy of the proposed measurement mission is adequate.

1. INTRODUCTION

Interannual changes of monthly and seasonal mean rainfall in the tropics, and the associated changes in the tropical and the extratropical atmospheric and oceanic circulations represent one of the most important components of the global climate variability. These changes can occur either due to interactions between the atmosphere, ocean and biosphere or due to the internal dynamical processes in the atmosphere itself. In either case an uncertainty in the estimate of rainfall over the tropical oceans has remained a stumbling block in our understanding of the global hydrological cycle and in verifying global dynamical models for which changes in rainfall represent changes in the vertically integrated diabatic forcing due to latent heat of condensation.

Recognizing the need for more reliable measurements of tropical rainfall, an earth-observing system, known as the Tropical Rain Measurement Mission (TRMM), has been proposed.

TROPICAL RAINFALL MEASUREMENTS
John S. Theon and Nobuyoshi Fugono (Eds.)

ISBN 0-937194-14-4

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The main scientific goals of this mission are:

1. To advance the earth system science objective of understanding the global energy and water cycle by means of providing distributions of rainfall and heating over the global tropics.
2. To understand the mechanisms through which changes in tropical rainfall influence global circulation, and to improve our ability to model these processes in order to predict global circulation and rainfall variability at monthly and longer time scales.

It is hoped that TRMM will help answer the following important questions:

1. What is the 4-dimensional structure of latent heating in the tropical atmosphere? How does it vary diurnally, intraseasonally, seasonally and annually?
2. What is the role of latent heat released in the tropics in both tropical and extra-tropical circulations?
3. What is the monthly average rainfall over tropical ocean areas of about 10^5 km^2 and how does this rain and its variability affect the structure and circulation of the tropical oceans?
4. What is the relationship between precipitation and changes in the boundary conditions at the earth's surface (e.g., sea surface temperatures, soil properties, vegetation)?
5. What is the diurnal cycle of tropical rainfall and how does it vary in space?
6. What is the relative contribution of convective and stratiform precipitation and how does the ratio vary in different parts of the tropics and in different seasons?
7. How can improved documentation of rainfall improve understanding of the hydrological cycle in the tropics?

In the present paper we have described the seasonal cycle of OLR and observed rainfall to determine the reliability of existing observed rainfall climatologies over the tropical oceans. We discuss the results of rainfall simulation by global general circulation models. In particular, we have examined the similarities and differences between the rainfall climatologies and their variability for two different GCMs. We also describe the magnitude and structure of rainfall anomalies associated with the warm episodes of the ENSO phenomenon.

2. SUMMARY AND CONCLUDING REMARKS

We have first examined the seasonal cycle of OLR and observed rainfall. Since we have only long-term monthly mean fields of observed rainfall (Jaeger, 1976), we have examined the departures of January and July mean rainfall from the annual mean. We find that the magnitude of the interannual variations of observed rainfall over the tropical oceans is far less than that over the tropical land masses. We have also compared the interannual changes of OLR over the tropical oceans with Jaeger's observed rainfall data and find that the magnitude of the interannual changes for OLR is considerably larger than that for the observed rainfall and also has larger spatial coherence. We also find rather unexpectedly that the structure of the interannual changes of observed rainfall and OLR are so similar over the tropical land masses that the OLR anomalies could be converted to the rainfall anomalies (5.7 watts m^{-2} = 1 mm day^{-1}; Arkin, personal communication). This leads us to suggest that the interannual changes of rainfall over the tropical oceans based on OLR changes can also be considered to be more realistic than those derived from scanty rainfall observations over the oceans.

We have compared the monthly mean rainfall fields simulated by the two different global general circulation models of GFDL (Geophysical Fluid Dynamics Laboratory) and GLA (Goddard Laboratory for Atmospheric Sciences) and it is found that the rainfall rates for the GLA model, particularly over the western Pacific, are larger than those for the GFDL model. Considering the uncertainty of rainfall data over the oceans we find it difficult to comment on the relative accuracy of the two model simulations. Since both the models have been successful in addressing various aspects of climate variability and predictability, such large differences in the rainfall rates simulated by the two GCMS point to the need for a quantitative measurement of rainfall over tropical oceans.

We have also examined the interannual variability of monthly mean rainfall simulated by the GFDL and GLA models and compared these with the interannual variability of the outgoing long wave radiation (OLR). There is a remarkable agreement between the variability of the model-simulated rainfall by both models and OLR. (See Figs. 1, 2, and 3). All three estimates of rainfall variability indicate that the western Pacific-eastern Indian Ocean is the region of highest rainfall variability over the globe. The value of the standard deviation ranges from 2-4 mm/day^{-1} over areas of several million square kilometers.

Finally, we have examined some results from previous studies on the sensitivity of GCM-simulated circulation and rainfall to observed SST anomalies in the tropical Pacific. We find that the magnitude of the monthly mean rainfall anomalies in the western Pacific that occur in association with the El Nino episodes are in the range of 4-8 mm/day for a spatial scale of 1000-2000 kilometers.

Based on these results of observed and model simulated rainfall variability we suggest that the TRMM observing system which is expected to have the required accuracy to resolve monthly mean rainfall anomalies of 1 mm/day^{-1} averaged over areas of about 500 km x 500 km, should be adequate to describe the interannual variability of monthly rainfall over the tropical oceans.

3. ACKNOWLEDGEMENTS

The author is extremely grateful to Mr. M. J. Fennessy for his help in conducting this study. Discussions with Mr. M. J. Fennessy and Dr. J. L. Kinter were quite useful in writing this paper. Thanks to Ms. Marlene Schlichtig for typing the manuscript and preparing the figures. The author would also like to thank the members of the science steering group of TRMM for the benefit of various stimulating discussions on this and related topics. This research was supported by NASA's Climate Program (NAGW-557) and NSF grant ATM-8414660.

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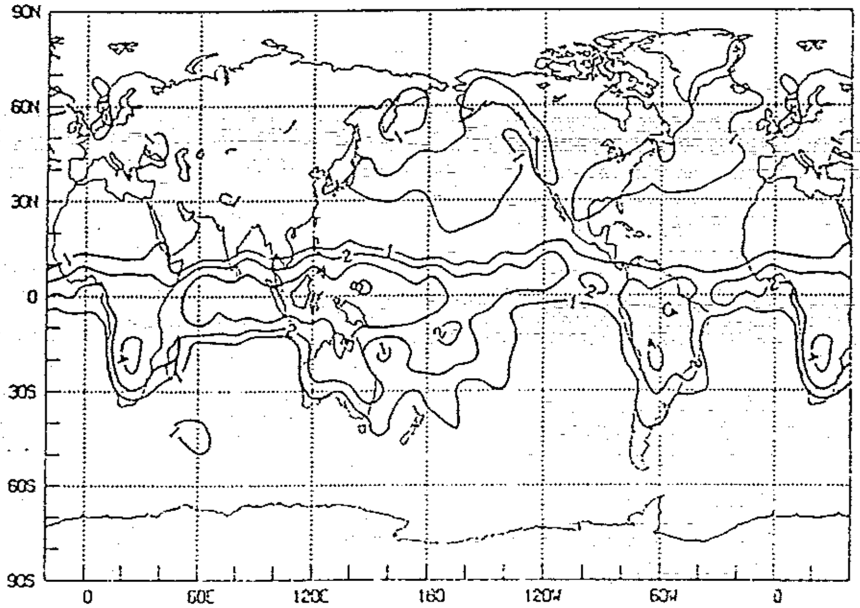

Figure 1. Standard deviation of January mean rainfall (mm/day) as simulated by the GLAS climate model.

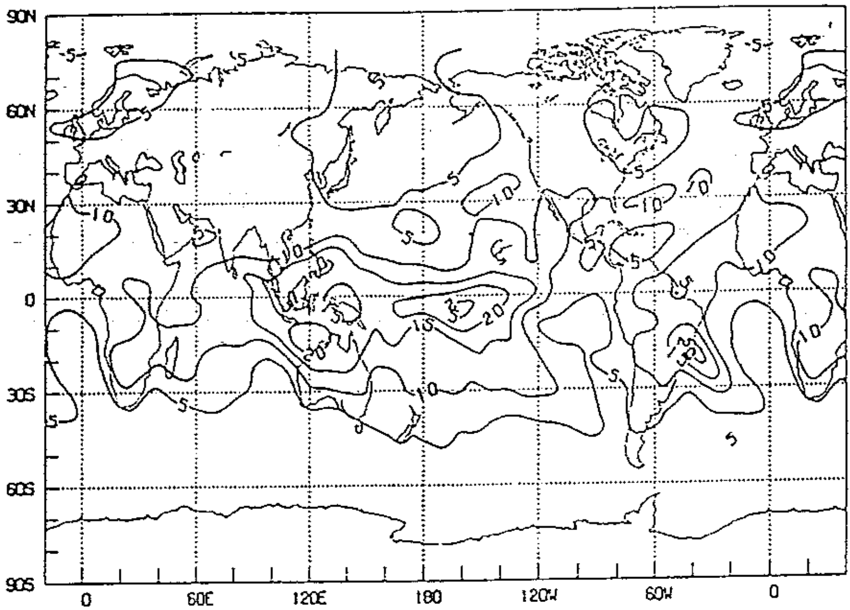

Figure 2. Standard deviation of January mean OLR (watts/m^2) based on observed data, 1974-1986.

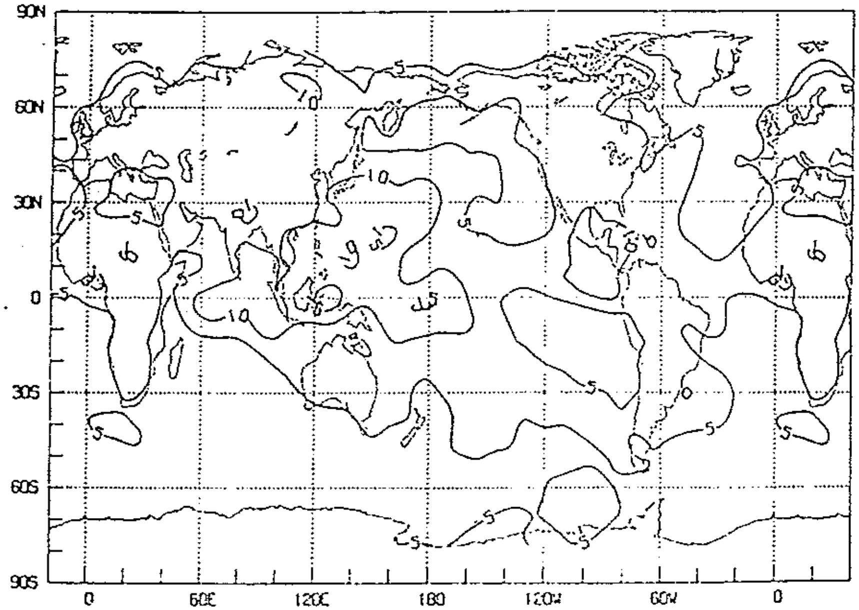

Figure 3. Standard deviation of July mean OLR (watts/m^2) based on observed data, 1974-1986.