Final report to the

National Aeronautics and Space Administration on

Analysis of the Diurnal Cycle of Precipitation and its relation to cloud radiative forcing using TRMM products

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1. Project overview

In our 1996, TRMM proposal, we outlined a research plan involving three primary objectives that would address the following three scientific questions which were among those to be addressed by TRMM:

- What is the diurnal cycle of tropical rainfall and how does it vary in space?
- What are the relative contributions of convective and stratiform precipitation, and how does the ratio vary in parts of the tropics and in different seasons?
- How can improved documentation of rainfall improve understanding of the hydrological cycle in the tropics?

The tasks we set for ourselves were these:

> *We proposed to conduct detailed comparisons of the diurnal cycle of precipitation, and related variables against observations.*
>
> *We proposed to compare the diurnal cycle of the simulated top-of-the atmosphere outgoing longwave radiation (OLR) against that measured by CERES.*
>
> *We proposed to use the Colorado State University General Circulation Model (CSU GCM) as a tool to understand how the surface radiative forcing of clouds controls the diurnal cycle of precipitation over deep convectively active regions over land.*

This Final Report will demonstrate that we have indeed carried out the research plan that we proposed, and have obtained substantive scientific results that have been published in peer-reviewed journals and presented at major scientific meetings.

2. Results

By incorporating the TRMM satellite orbital information into the geodesic version of the CSU GCM, we are able to fly a satellite in the GCM, and sample the simulated atmosphere in the same way as the TRMM sensors sample the real atmosphere. The TRMM sampling statistics of precipitation and radiative fluxes at annual, intraseasonal, monthly-mean and composited diurnal time scales are evaluated by comparing the satellite-sampled against fully-sampled simulated atmospheres. This information provides a valuable guidance for efficient usage of TRMM data and future satellite mission planning.

In a related study, we have also examined the sampling statistics associated with multiple satellites by simulating TRMM, Aqua and Terra in the GCM. A manuscript on this work has been submitted to the *Journal of Geophysical Research*. A copy is attached.

We have conducted a systematic comparison of our model results with observations. Many of these have been published by Lin et al. (2000) and Fowler et al. (1999). Some of the most

interesting results deal with convection and its diurnal variations over the tropical continents. The CSU GCM uses a prognostic kinetic energy (CKE) in place of the quasi-equilibrium closure of the Arakawa-Schubert cumulus parameterization. A parameter, alpha, is used to relate the CKE to the cumulus mass flux. This parameter is expected to vary with cloud depth, mean shear, and the level of convective activity, but up to now a single constant value for all cloud types has been used. By comparing against TRMM, ERBE, and ISCCP, we found that this approach cannot yield realistic simulations of both the diurnal cycle and the monthly mean climate states (Lin et al. 2000, JCL).

In response to these TRMM-based findings, a physically-based parameterization was developed to represent variations of alpha with cloud depth, mean shear, and the vigor of convection. We have tested it in a single-column model and a full GCM. Preliminary results indicate that the new scheme gives improved simulations over the tropical summer continents. We are also combining 2-D and 3-D cloud resolving model simulations to estimate the statistical features of these effects over different climate regimes. A paper on these results is currently in preparation.

3. Conclusions

We have used TRMM data to understand nature, and to understand our model. In the process, we have learned to make our model simulate nature more faithfully, e.g. by introducing the variable alpha discussed above.

Our continuing work with TRMM data will extend these accomplishments and prepare the way for the era of the Global Precipitation Mission.

Publications made possible by this grant

Fowler, L. D., D. A. Randall, P. T. Partain, and G. L. Stephens, 2001: Cloud radiative forcing in the Colorado State University General Circulation Model. Paper presented at the *Climate Conference 2001*, Utrecht, The Netherlands, August 20-24, 2001.

Fowler, L. D., and D. A. Randall, 1999: Simulation of upper-tropospheric clouds with the CSU general circulation model. *J. Geophys. Res.*, **104**, 6101-6121.

Fowler, L. D., B. A. Wielicki, D. A. Randall, M. D. Branson, G. G. Gibson, and F. M. Denn, 2000: Use of a GCM t o explore sampling issues in connection with satellite remote sensing of the Earth's radiation budget. *J. Geophys. Res.*, **105**, 20757-20772.

Fowler, L. D., and D. A. Randall, 2000: The second generation of cloud microphysics and fractional cloudiness in the CSU general circulation model. Paper presented at the *13th International Conference on Clouds and Precipitation*, 14-18 August 2000, Reno, Nevada.

Lin, X., D. A. Randall, and L. D. Fowler, 2000: Diurnal variability of the hydrologic cycle and

radiative fluxes: Comparison between observations and a GCM. *J. Climate*, **13**, 4159-4179.

Lin, X., L. D. Fowler, and D. A. Randall, 2001: Flying the TRMM satellite in a GCM. Submitted to *J. Geophys. Res.*

Lin, X., D. A. Randall, and L. D. Fowler, 2000: Implementing the vigor of convection and ambient wind shear into the CSU GCM. Paper presented at the *24th Conference on Hurricanes and Tropical Meteorology of the American Meteorological Society*, 29 May - 2 June 2000, Ft. Lauderdale, Florida.

Randall, D. A., 2000: Cumulus convection and climate. Paper presented at the *Fall AGU meeting*, San Francisco. (Invited paper)

Randall, D. A., 2001: What has TRMM taught us about the hydrologic cycle? Paper presented at the *European Geophysical Society Conference*, Nice, France. (Invited paper)

Attachments

Fowler, L. D., and D. A. Randall, 1999: Simulation of upper-tropospheric clouds with the CSU general circulation model. *J. Geophys. Res.*, **104**, 6101-6121.

Fowler, L. D., B. A. Wielicki, D. A. Randall, M. D. Branson, G. G. Gibson, and F. M. Denn, 2000: Use of a GCM t o explore sampling issues in connection with satellite remote sensing of the Earth's radiation budget. *J. Geophys. Res.*, **105**, 20757-20772.

Lin, X., D. A. Randall, and L. D. Fowler, 2000: Diurnal variability of the hydrologic cycle and radiative fluxes: Comparison between observations and a GCM. *J. Climate*, **13**, 4159-4179.

Lin, X., L. D. Fowler, and D. A. Randall, 2001: Flying the TRMM satellite in a GCM. Submitted to *J. Geophys. Res.*