Final Progress Report

Title: "Testing Climate Model Simulations of Tropical Cirrus Lifecycles: A Lagrangian Analysis Using ARM Data"

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This project integrates ARM data sets with satellite observations and model simulations to improve the representation of tropical cloud systems in climate models. We focus on describing and understanding relevant features of the lifecycle of tropical cirrus cloud systems using an innovative method which combines the Eulerian-based ARM measurements with Lagrangian information from geostationary satellites.

In the first year of this proposal, we developed and applied a (near) real-time Lagrangian cloud product for the ARM TWP and SGP sites which will supplement the existing ARM measurements by providing both forward- and back-trajectories, and related diagnostics for cloud systems passing over the ARM sites. The software for creating the Lagrangian diagnostics is currently being prepared for implementation at the ARM XDC.

During the past year, the Lagrangian cloud products have been analyzed to better characterize the life cycle of tropical cloud systems. The first study focused on two key topics: (i) the importance of cirrus anvil sublimation on tropical upper-tropospheric

humidity, and (ii) the dependence of convective cloud properties on sea surface temperature.

A controversial result of this work that, despite their strong spatial correlations, a Lagrangian analysis of the relationship between the detrained amount of cloud ice and the upper tropospheric humidity indicates no causal link between these quantities.

Furthermore, a tendency analysis reveals that cirrus decay and growth — in terms of both cloud cover and integrated ice content — is accompanied by drying and moistening of the upper troposphere, respectively, a result opposite that expected if cirrus ice were a primary water vapor source.

It was also found that a $\sim 2^\circ\text{C}$ rise in sea surface temperature results in a measurable increase in the frequency, spatial extent, and water content of deep convective cores. The larger storms over warmer oceans, however, are associated with anvils whose maximum extent and ice water content are smaller than their counterparts over colder oceans, suggesting a decrease in cirrus detrainment efficiency with increasing sea surface temperature. The results of this work have been submitted for publication in the *Journal of Climate* (Horvath and Soden, 2006).

In a second study, ARM millimeter cloud radar measurements were combined with geostationary satellite data to study the properties of tropical cirrus over the western Pacific. The cloud radar observations from Manus and Nauru reveal differences in cirrus properties: over Manus, the cirrus are more frequent, thicker, and warmer on average than

over Nauru. To explain the differences in cloud properties, the relationship between tropical cirrus and deep convection were examined by combining the radar observations with GMS satellite-derived back trajectories. It was found that 47% of the cirrus observed over Manus can be traced to a deep convective source within the past 12 hr while just 16% of the cirrus observed over Nauru appear to have a convective source within the previous 12 hr. Of the cirrus that can be traced to deep convection, the radar Doppler moments and ice water path of the observed cirrus at both sites generally decrease as the cirrus age increase. At Manus, it is found that cirrus during boreal winter typically advect over the site from the southeast from convection associated with the winter monsoon, while during boreal summer, the trajectories are mainly from the northeast. The results of this work have appeared in J. Atmos. Sci. (Mace et al., 2006).

In addition to the work on Lagrangian cloud trajectories, we have also recently completed a study on the sensitivity of water vapor feedback to refinements in continuum absorption. Using the Geophysical Fluid Dynamics Laboratory (GFDL)'s line-by-line (LBL) radiative transfer model as well as the GFDL climate model's longwave radiation parameterization, we demonstrated that the strength of water vapor feedback in GCMs is not sensitive to either the details of the longwave band approximation, nor to different formulations of water vapor continuum absorption. The results of this work have been accepted for publication in J. Geophys. Res. (Yang et al., 2005).

Publications:

Horvath, A. and B.J. Soden, 2006: Lagrangian diagnostics of tropical deep convection and its effect upon upper-tropospheric humidity, in press *J. Climate*.

Mace, G. G., M. Deng, B. J. Soden, and E. Zipser, 2006: Association of tropical cirrus in the 10-15-km layer with deep convective sources: An Observational study combining millimeter radar data and satellite-derived trajectories, *J. Atmos. Sci.*, **63**, 480-503

Yang, H, V. Ramaswamy and B. J. Soden, 2005: An Investigation on the Sensitivity of the Simulated Clear-sky Outgoing Longwave Radiation to Atmospheric Temperature and Water Vapor, in press *J. Geophys. Res.* **112**, D05104, doi:10.1029/2005JD006906