Mechanisms of 21^{st} Century Changes in Sahel Precipitation in the CMIP3 Climate Models

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Project Summary

The CMIP3 models simulate contradictory projections for changes in rainfall over the African Sahel over the 21^{st} century. In some models, enhanced precipitation is predicted as a consequence of enhanced land/sea temperature contrast and monsoon circulation (Haarsma et al.; 2005). In others, the Sahel dries in response to the warming of tropical oceans, in analogy to the response to a warm ENSO (Held and Lu; 2007). We propose to investigate these two mechanisms in the pre-industrial, 20^{th} century and A1B 21^{st} century scenario integrations of all CMIP3 models.

The first mechanism requires that a hotter Sahara produce a stronger heat low, thus driving a stronger monsoon circulation and heavier rainfall. Unfortunately, things need not be so simple. For example, a hotter Sahara and a stronger circulation might at the same time bring dryer air to overlay the monsoon layer over the Sahel and might cap convection, thus reducing rainfall. Or the direction of influence between the Sahara low and Sahel rainfall might be opposite to what hypothesized, with anomalies in Sahel rainfall causing a wave response that affects the strength and the spatial extent of the Sahara low. We will use statistical analysis to diagnose, in each model, the relationship between the strength of the Sahara low and other relevant quantities (for example, surface temperature, energy fluxes at the surface, vertical structure of the boundary layer, strength and vertical structure of subsidence, strength of convection in the Sahel and in Asia, local circulation). Similarly, we will check how robust across models is the hypothesized link between the land-sea temperature contrast and the strength of moisture convergence by the monsoon circulation. More refined theories of the monsoon hold that surface temperature is not the relevant quantity, but that one should look at the boundary layer moist static energy and surface enthalpy fluxes. We plan to investigate these relationships as well.

The second mechanism for Sahel rainfall change holds that tropical SST warming leads to a dryer Sahel. The hypothesis is that the main convective regions in the warming tropical oceans set the tropospheric temperature of the entire tropics to a warmer moist adiabat profile. Regions where moisture availability is limited might not reach the new threshold in boundary layer moist static energy that would be necessary for deep convection to develop in this stabilized environment, and might consequently become dryer. We will investigate whether long-term drying can be achieved by the tropospheric stabilization mechanism, in particular whether and to what extent a differential rise in moist static energy of land and ocean occurs on the long time scales of global warming. If this is the case, then we can ask whether different model treatments of vegetation and land surface processes can influence the time lag between land and ocean and, ultimately, the Sahel response to a generalized warming.

This study will be diagnostic in nature, and will complement other theoretical and modeling work on the mechanisms controlling mean tropical rainfall in GCMs that the investigators are pursuing under different sources of support. We also anticipate that our ongoing collaboration with Dr. Isaac Held (GFDL) will carry on in the proposed project, so that the results of our diagnostics on several models and Held's insights from more detailed analysis and experimentation with a single GCM will feed back on each other.