Explicit Representation of Sub-grid Scale Surface Variability in a General Circulation Model

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Introduction

Over the past decade, research on the interaction of the land surface and the atmosphere (Avissar and Pielke 1989; Koster and Suarez 1992; Seth et al. 1994; to name a few) has demonstrated that sub-grid scale spatial heterogeneities in surface parameters (including soil moisture, precipitation, and vegetation cover) have substantial effects in determining surface evapotranspiration, runoff, and other surface properties when coupled to atmospheric climate. Many of these processes occur on spatial scales too fine to be resolved by most current general circulation models (GCMs). Therefore, our current focus is to increase the horizontal resolution of these models, especially with regards to surface processes.

Several approaches have been used in the past. The most direct method is to run the atmospheric GCM at high resolution (i.e., 1° or finer). However, this still requires too much computer time for anything more than experimental runs. A second approach is to "nest" a limited-area climate model into the global domain. This solution requires the region of interest to be selected ahead of time, and if several continental domains are chosen, the simulations will be as expensive as the global high-resolution simulation is. In addition, limited-area climate models must use care with the location of their boundaries (see Seth and Giorgi 1998). A third approach is to use physical-statistical relationships to down-scale GCM results. This approach requires large amounts of data to construct such relationships, which are not always available globally. Moreover, even if these relationships can be determined, they will not always be applicable to climate change scenarios. The approach adopted in the model developed here is to "adapt" different components of the climate model, in this particular case the parameterization of land surface processes, to the required or desired resolution. This paper presents the development and preliminary results of a high-resolution, land global model that explicitly represents the spatial heterogeneities in the land surface. This work was developed under the U.S. Department of Energy (DOE)/Computer Hardware, Advanced Mathematics, and Model Physics (CHAMMP) Program.

Model Description

The interaction between the atmospheric model grid (hereafter called CCM grid) and the fine-mesh model grid (hereafter called HR grid) occurs in two stages: a disaggregation stage, where the CCM near-surface state and downward radiative fluxes are "supplied" to the HR grid, and an aggregation stage, where surface fluxes are returned back to the atmospheric model. In the disaggregation stage, energy, through downward radiative fluxes, and water, through precipitation rates, has to be exactly conserved. Simple linear interpolation (i.e., distance-dependent) from CCM grid values to HR grid values does not have this property. Several schemes have been tested. For the results presented here, values for an HR grid square entirely contained within the CCM grid box are the values of the CCM grid itself. If the HR grid box is shared between two or more adjacent CCM grid boxes, its values are determined by an area-weighted average of the CCM grid values. The aggregation stage consists of two phases. First, HR grid fluxes are averaged for each of their CCM grids. For CCM grid boxes located along the coastline, the CCM fluxes are a linear combination of the land aggregated fluxes and the ocean fluxes according to the fractional areas of land and sea.

The simulations described here use the National Center for Atmospheric Research (NCAR) Community Climate Model Version 3.2 (CCM3) model coupled to the Biosphere-Atmosphere Transfer Scheme (BATS; Dickinson et al. 1993). All simulations were done using optimal topography, observed climatological sea-surface temperatures, and initialized land surface fields, including soil moisture and temperatures in all soil layers. Two simulations have been performed: a 10-year control run (CCM3/BATS) with T42 resolution in both the atmosphere and land, and a fine-mesh run (CCM3/HRBATS) with T42 resolution in the atmospheric model and 0.5° resolution in the land. In CCM3/HRBATS only vegetation types are specified at 0.5°.

Results

Figures 1 and 2 show examples of the results obtained by CCM3/HRBATS as compared to the control simulation. The three panels on each figure show the control latent heat flux (top), the fine-mesh latent heat flux on the fine-mesh (center), and the aggregated fine-mesh latent heat fluxes to the T42 grid (bottom).

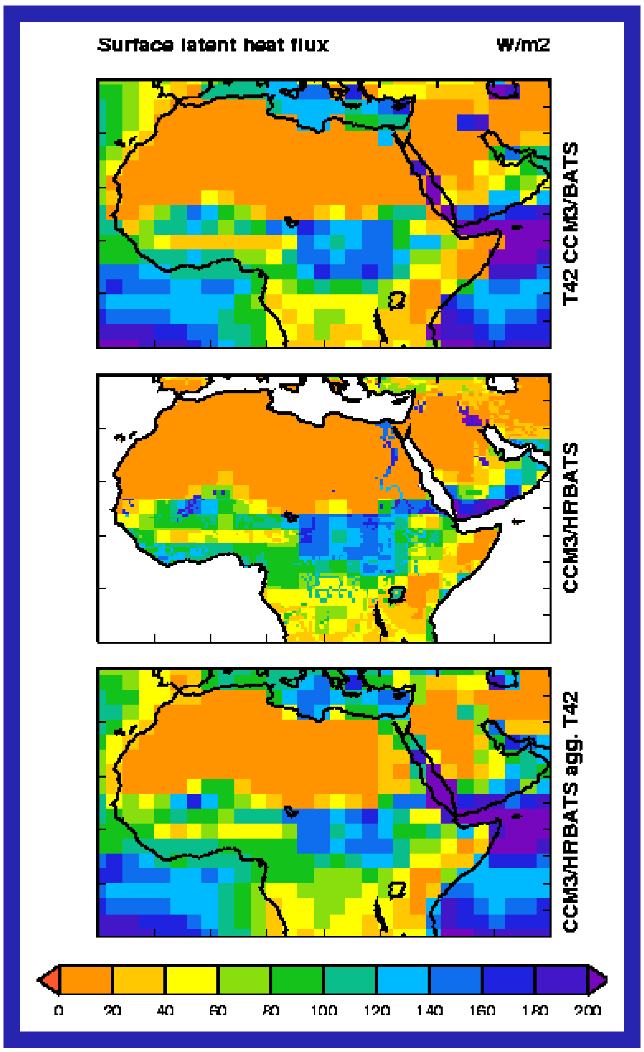

Figure 1. Over Africa. Control latent heat flux (top), the fine-mesh latent heat flux on the fine-mesh (center), and the aggregated fine-mesh latent heat fluxes to the T42 grid (bottom). (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/hahmann-98.pdf*.)

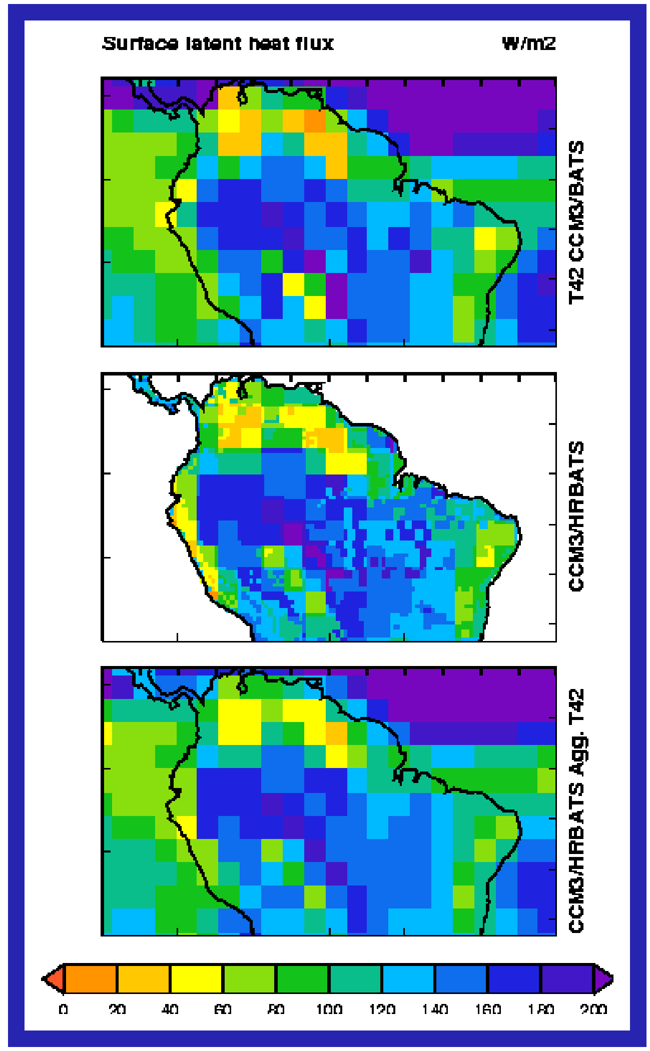

Figure 2. Over South America. Control latent heat flux (top), the fine-mesh latent heat flux on the fine-mesh (center), and the aggregated fine-mesh latent heat fluxes to the T42 grid (bottom). (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/hahmann-98.pdf*.)

Over Africa (Figure 1), the fine-mesh model clearly shows the agricultural area following the Nile and several lakes in the sub-Saharan region. These areas show more enhanced evaporation than the surrounding desert. Over South America (Figure 2), the center panel shows, through changes in latent heat flux, the fine structure of the transition zone between tropical forest and grassland over Southern Amazonia.

A further example of the possible uses of the CCM3/HRBATS model is for the simulation of snow over complex terrain (Figure 3). This figure illustrates the distribution of equivalent snow depth for the western United States during February. The three panels on this figure showing control snow depth (top), the fine-mesh snow depth on the fine-mesh (center), and the aggregated fine-mesh snow depth to the T42 grid (bottom). Although disaggregation of

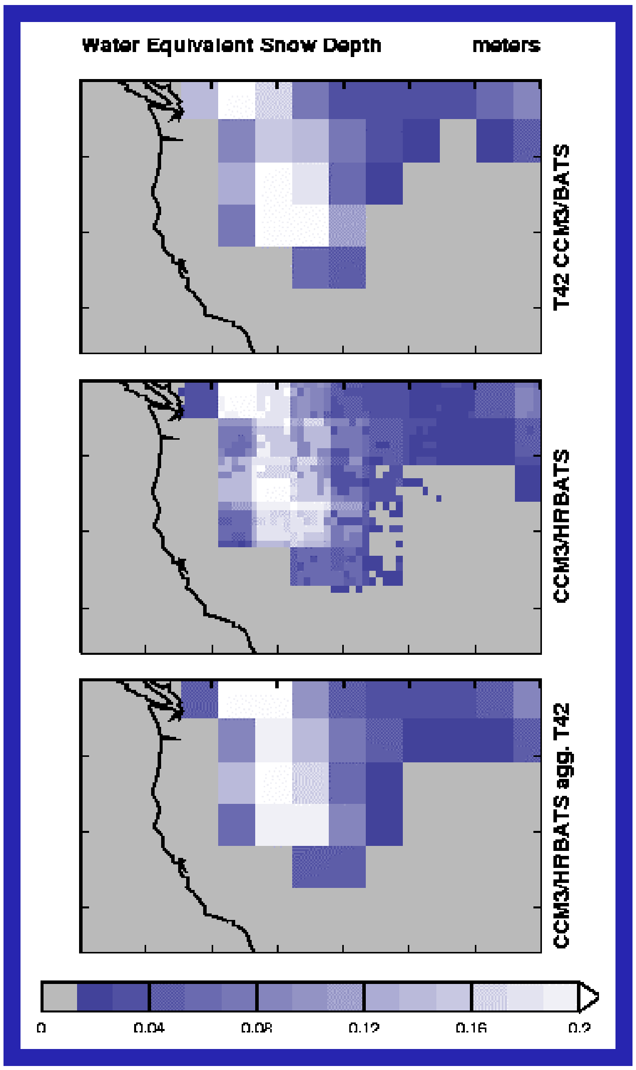

Figure 3. Distribution of equivalent snow depth for the western U.S. during February showing control snow depth (top), the fine-mesh snow depth on the fine-mesh (center), and the aggregated fine-mesh snow depth to the T42 grid (bottom). (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/hahmann-98.pdf*.)

precipitation is uniform on the HR grid and topographic effects are not included, the middle panel displays considerable horizontal variability because of the response of snow cover to the different vegetation types.

Finally, the image on Figure 4 shows the first step in validating global fields simulated by the CCM3/HRBATS model against observations. This image shows June-July-August differences in Surface Air Temperature (simulated - Legates and Willmott climatology) for CCM3/BATS (top) and CCM3/HR-BATS (bottom). A few areas of the globe are of particular interest. Around the area of the Great Lakes (USA) CCM3/HRBATS seems to reduce the surface air temperature differences from the observed values from 3 to 6 degrees to 0 to 3 degrees. Over Australia, surface air temperatures have warmed up in the CCM3/HRBATS simulation to closer to those observed.

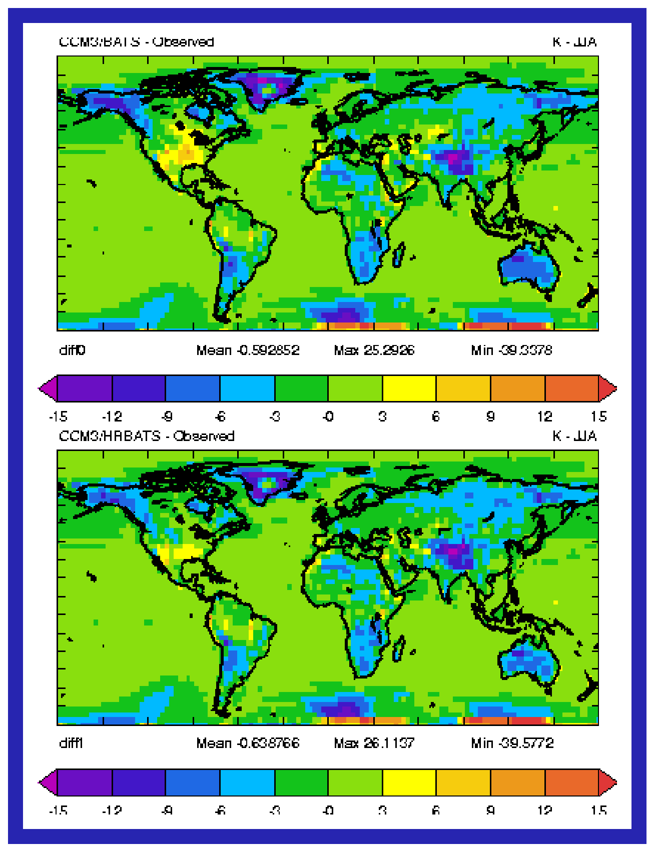

Figure 4. June-July-August differences in Surface Air Temperature (simulated - Legates and Willmott climatology) for CCM3/BATS (top) and CCM3/HR-BATS (bottom). (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/hahmann-98.pdf*.)

Summary of Results and Future Work

The results above show that the effects of sub-grid scale land variability can be studied economically and efficiently in the context of a climate model through the computation of surface fluxes and surface diagnostic quantities at higher spatial resolution than that of the host atmospheric model. This approach facilitates the testing of a variety of sub-grid scale approaches in a relatively simple way. The prototype simulation shows substantial changes in surface climate, which are consistent with changed land prescription.

Work in the near future includes

1. search for an optimal interpolation/aggregation scheme that guarantees conservation of water and energy without adding excess computational costs

2. inclusion of the effects of fine-mesh variations in topographic elevation, including slope and azimuth, atmospheric forcing, and precipitation

3. inclusion of non-uniform spatial disaggregation of precipitation and radiation (cloud) fields to the fine-mesh.

References

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