P2.6 IMPLEMENTATION OF THE NCAR COMMUNITY LAND MODEL (CLM) IN THE NASA/NCAR FINITE-VOLUME GLOBAL CLIMATE MODEL (FVGCM)

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1. INTRODUCTION

Land-surface processes are an important component of the climate system and more realistic representation of the land-surface has been critical in climate modeling. In this study, the recently developed state-of-the-art NCAR Community Land Model (CLM) version 2.0 land-surface model (Dai et al. 2002; Zeng et al. 2002) was integrated into the NASA/NCAR finite-volume Global Climate Model (fvGCM; Lin and Rood 2002). The CLM2 provides a comprehensive physical representation of soil/snow hydrology and thermal dynamics and biogeophysics. The CLM2 was developed collaboratively by an open interagency/university group of scientists, and based on well-proven physical parameterizations and numerical schemes that combine the best features of three previous land surface models: Biosphere-Atmosphere Transfer Scheme (BATS; Dickinson et al. 1993), the NCAR Land-surface Model (LSM; Bonan 1996), and the IAP94 snow model (Dai and Zeng 1996). The Data Assimilation Office (DAO) has collaborated with NCAR to produce the NASA/NCAR fvGCM, which is a unified climate, numerical weather prediction, and chemistry-transport model suitable for data assimilation, with the DAO's finite-volume dynamical core and NCAR's suite of physical parameterizations.

2. MODELS

2.1 The Community Land Model (CLM2)

The CLM2 is a one-dimensional point model that uses sub-grid scale tiles. The CLM2 has one vegetation layer with a photosynthesis-conductance model to realistically depict evapotranspiration (Bonan 1996). There are 10-uneven vertical soil layers with the bottom layer at 3.43-m and water, ice, and temperature states in each layer. The CLM2 features up to five snow layers depending on the snow depth with water flow, refreezing, compaction and aging allowed. In addition, the CLM2 utilizes two-stream canopy radiative transfer, the Bonan lake model (1996), topographic enhanced streamflow based on TOPMODEL (Beven and Kirkby 1979), and turbulence is considered above, within, and below the canopy.

2.2 The NASA/NCAR fvGCM

The DAO's finite-volume dynamical core is capable of resolving atmospheric motions from meso- to planetary-scale with a terrain-following Lagrangian control-volume vertical coordinate system (Lin 1997; Lin and Rood 1999). The fvGCM dynamical core formulation includes a genuinely conservative Flux-Form Semi-Lagrangian (FFSL) transport algorithm (Lin and Rood 1996) with Gibbs oscillation-free monotonicity constraint on sub-grid distribution. There is a consistent and conservative transport of air mass and absolute vorticity, and subsequent superior transport of potential vorticity by the FFSL algorithm (Lin and Rood 1997). In turn, the mass, momentum, and total energy are conserved when mapping from the Lagrangian control-volume to the Eulerian fixed reference coordinate. The physical parameterizations of the fvGCM are based on NCAR Community Climate Model version 3.0 (CCM3) physics. The NCAR CCM3 parameterizations are a well-balanced set of processes with a long history of development and documentation (Kiehl et al. 1998). The moist physics package includes the Zhang and McFarlane (1995) deep convective scheme, which handles updrafts and downdrafts and operates in conjunction with the Hack (1994) mid- and shallow convection scheme. For the radiation package, the longwave radiative transfer is based on an absorptivity-emissivity formulation (Ramanathan and Downey 1986) and the shortwave radiative parameterization uses the δ-Eddington method (Briegleb 1992). The boundary-layer

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mixing/turbulence parameterization utilizes the "nonlocal" formulation from Holtslag and Boville (1993). In addition, the NCAR physical parameterization package includes orographic gravity wave drag based on McFarlane (1987).

3. RESULTS

The fvGCM coupled CLM2 was run at 2 x 2.5° horizontal resolution with 55 vertical levels for a 15-year period from 1991-2006 with initial conditions based on AMIP (Atmospheric Model Intercomparison Project) and fixed sea-surface temperatures based on an annual climatology. The 10-year climate from the fvGCM CLM2 Control run was then intercompared with the climate from fvGCM LSM, the European Center for Medium-range Weather Forecasting (ECMWF) reanalysis and the National Centers for Environmental Prediction (NCEP; Kalnay 1996) reanalysis. The variables that we concentrated our analysis on included skin temperature, sea-level pressure, 2m specific humidity, precipitation, 500 mb heights, and 300 mb zonal winds. The mid- and upper-level atmospheric variables were compared using ECMWF, while NCEP was used for the surface fields. We concluded that the incorporation of CLM2 did not significantly impact the fvGCM atmospheric climate circulation from that of LSM (Figure 1). The most striking difference was the warm bias in the CLM2 surface skin temperature over desert regions, which was equal and opposite to the LSM cold bias (Figure 2). In addition, the 2m specific humidity shows that the CLM2 climate is drier than that of LSM. We determined that the warm bias can be partially attributed to the value of the drag coefficient for the soil under the canopy (csoilc), which was too small for sparsely vegetated regions resulting in a decoupling between the ground surface and the canopy. We also found that the canopy interception was high compared to observations in the Amazon region. We performed several experiments designed to improve the CLM2 representation of surface hydrologic processes and the model's computational performance.

The experiments (Table 1), each of which included only one of the modifications, were run for 5 years starting in January 2000. All of the experiments were intercompared with the Control (the initial test case) based on a 2000-2004 average. The following experiments were completed: the exponential csoilc scheme (Experiment I), the leaf heat capacity scheme (Experiment II), the implicit leaf temperature scheme (Experiment III), the revised interception scheme (Experiment IV), the revised interception with sub-surface runoff turned off (Experiment V), and an experiment including all of the modifications (Experiment VI).

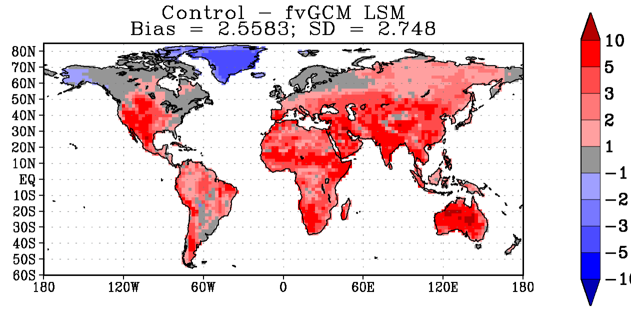

Figure 1. Surface skin temperature differences of the 10-year climate for the Control versus fvGCM LSM.

For Experiment I, csoilc (1) was considered a function of vegetation density as represented by the LAI (Leaf Area Index),

$$csoilc = 0.05 * \exp(LAI/4) \quad (1)$$

in order to correct the warm bias resulting from the decoupling. Analysis of the results revealed that there was a substantial impact, and the warm and dry bias in the fvGCM CLM2 was significantly reduced. The global annual mean bias and standard deviation for the intercomparisons of skin temperature with NCEP reanalysis presented in Figure 2, show a reduction in the standard deviation and the bias for Experiment I compared to the Control. Experiment II, the leaf heat capacity scheme, which was shown to improve the memory of skin temperature and impact its diurnal cycle, had only a marginal impact on the annual mean (Figure 2). Experiment III included changes to the numerical scheme that solves the water and energy balance of the vegetation canopy. An implicit scheme, which is scientifically accurate and computationally more efficient, replaced the explicit scheme previously used in CLM2 (Wang et al. 2002a). While the implicit scheme saves computation time, it does not cause noticeable changes in the model results (Figure 2).

For Experiment IV, the change involved incorporating precipitation sub-grid scale variability into the canopy interception scheme, which causes a decrease of interception loss and subsequent increase in the canopy throughfall (Wang et al. 2002b). This leads to more infiltration of precipitation into the soil. The current interception scheme in CLM2 allows for too much canopy interception and hence canopy evaporation, decreasing the skin temperature. The results from the 5-year run show that the new interception scheme causes about 0.5° in warming, which in turn increases the CLM2 warm bias when compared to NCEP (Figure 2). The positive impacts were an increase in the low-level moisture and a significant decrease in the interception loss ratio (canopy evaporation to precipitation). Experiment V included the modified interception scheme but with Z. -L. Yang and G. -Y. Niu's sub-surface runoff scheme turned off. This was done to correct some unrealistic overestimation of lateral sub-surface runoff, which may have resulted from not considering the impact of topography in the runoff scheme. As a result of this change, the runoff generation mechanism was altered so all of the water drains from the bottom soil layer, but the total runoff remains unchanged. This produced a realistic runoff ratio (runoff to precipitation) when using the new interception scheme. Another positive outcome based on our modifications was a realistic runoff ratio that did not require tuning, and allowing the water to drain from the bottom layer reduced the sensitivity of runoff generation to other factors in the model. Inhibiting the sub-surface runoff also reduced the warming caused by the revised interception scheme (Experiment IV) and the results from Experiment V did not deviate much from the Control (Figure 2).

In Experiment VI, all of the modifications were incorporated and the largest and most beneficial change was attributed to the exponential csoilc scheme, which considerably decreased the warm bias in the CLM2 when compared to the Control. This result was expected based on Figure 2, which shows Experiment I having the most substantial impact. In Figure 3, surface skin temperature difference plots for fvGCM LSM, the Control and Experiment VI versus NCEP are displayed. The improvements, due to the modifications in Experiment VI, are especially noticeable over Africa, Asia and the southwestern U.S. In addition, the differences in skin temperature from Experiment VI (bottom of Figure 3) more closely resemble those from the fvGCM LSM versus NCEP (top of Figure 3). Also, the standard deviation from Experiment VI does not differ greatly from that of the fvGCM LSM (Figure 2).

Table 1: Description of experiments.

Experiment	Description
Control	Initial fvGCM CLM2 run
Experiment I	Exponential csoilc
Experiment II	Leaf heat capacity
Experiment III	Implicit leaf temperature
Experiment IV	Revised interception
Experiment V	Exp. IV w/o subsurface runoff
Experiment VI	All of the modifications (I-V)

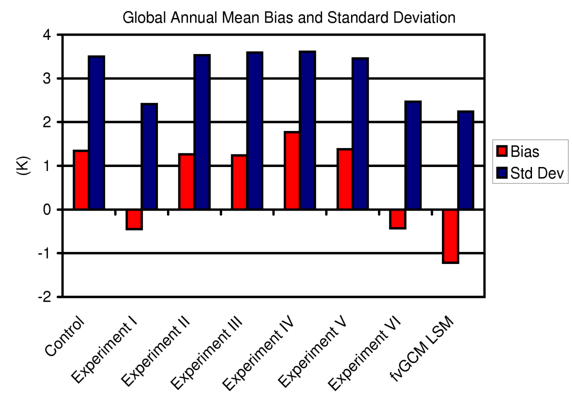

Figure 2. The global annual mean standard deviations of surface skin temperature between the Control, Experiments I-VI (Table I), and fvGCM LSM versus NCEP.

4. SUMMARY

In this study, the NCAR CLM2 land-surface model (Dai et al. 2002; Zeng et al. 2002) was coupled to the NASA/NCAR fvGCM (Lin and Rood 2002). We determined that the CLM2 did not drastically effect the climate of the fvGCM from that of LSM. The most noticeable change was a shift to a warm bias in the surface skin temperature from the cold bias in LSM. We also found that the canopy interception was high compared to observations in the Amazon. A number of experiments were executed in order to improve the representation of surface processes in the CLM2. Modifying the drag coefficient under the canopy allowed for a reduction of the warm and dry bias. Also, changes to the interception scheme and sub-surface runoff produced a more realistic interception loss ratio, and increased the canopy throughfall leading to more soil infiltration and resulting plant transpiration.

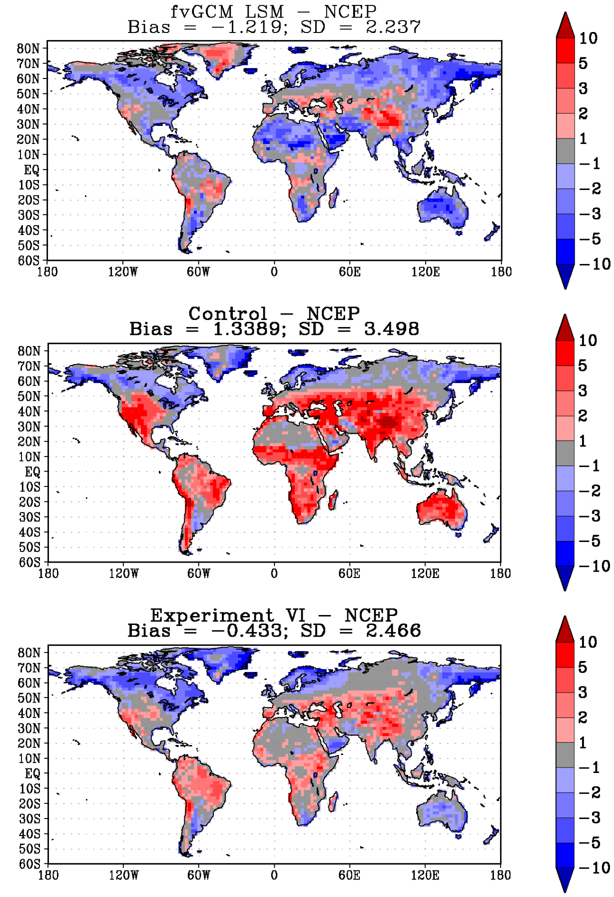

Figure 3. Surface skin temperature differences of the 5-year average for fvGCM LSM (top), the Control (middle), and Experiment (VI) (bottom) versus NCEP.

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