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LAND-ATMOSPHERE INTERACTIONS

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1. INTRODUCTION

Two coupled atmosphere-land surface models (RAMS/CENTURY and RAMS/GEMTM) have been applied to investigate the feedbacks between weather, and vegetation and soil on seasonal and longer time scales. The RAMS version used is described in Liston and Pielke (1999), and has been applied in Pielke et al. (1999). The coupled modeling systems were validated against observed atmospheric and vegetation evolution during the growing season. The coupled models were then used to investigate, for example, the relative importance of landuse change and of radiative and biological effects of current and doubled CO_2 on seasonal weather. Global model results using the NCAR CCM3 model have also been completed to explore whether these feedbacks teleconnect over long distances and can alter the global atmospheric circulation. A major conclusion of this study is that climate models must include dynamic, interactive land-surface parameterizations for the assessment of seasonal and longer-term atmospheric predictability.

2. RAMS/CENTURY COUPLING

Land-surface characteristics play a key role in partitioning energy received at the earth's surface. Vegetation, through transpiration and evaporation, modifies atmospheric and land-surface hydrological processes. Both observational and modeling studies have shown that two-way atmosphere and biosphere interactions are very important components of both atmospheric and ecosystem dynamics.

A coupled RAMS/CENTURY modeling system has been developed to study regional-scale two-way interactions between the atmosphere and biosphere (Lu 1999; Lu et al. 1999). Both atmospheric forcings and ecological parameters (LAI, etc.) are prognostic variables in the linked system. The atmospheric and ecosystem models exchange information on a weekly timestep. The ecosystem model CENTURY receives as input: air temperature, precipitation, radiation, wind speed, and relative humidity simulated by the regional atmospheric model RAMS. From CENTURY-produced outputs, variables including leaf area index (LAI), vegetation transmissivity, vegetation fractional coverage, displacement height, roughness length, rooting profile, and albedo can be computed and returned to RAMS. In this way, biogeochemical-constrained vegetation responses to weekly and seasonal atmospheric changes are simulated and fed back to the atmospheric/land-surface hydrology model.

The coupled model has been used to simulate the two-way interactive biosphere and atmosphere feedbacks from 1 January through 31 December for 1988, 1989, and 1993, which represent dry, average, and wet years, respectively, focusing on the central United States. In these experiments, the CENTURY-produced outputs of LAI and vegetation transmissivity are input into RAMS. Validation is performed for the atmospheric portion of the model by comparing with over 3,800 meteorological-station observations over the entire domain, and for the ecological component by comparison to AVHRR remote-sensing NDVI data sets.

A series of sensitivity experiments have been conducted to highlight interactions and feedbacks between atmospheric and land-surface processes. The coupled control run's atmospheric lateral boundary conditions have been perturbed to create both dry and wet springs. The model's ability to represent the interannual and seasonal variations in both climate and biomass has been examined. The results show that seasonal and interannual climate patterns are significant influences on land-water energy exchange. The coupled model captures key aspects of weekly, seasonal, and annual feedbacks between the atmosphere and ecological systems. This demonstrates the coupled model's usefulness as a research tool for studying complex interactions between the atmosphere, biosphere, and hydrosphere.

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In the modeling system, vegetation is permitted to grow in response to the simulated weather with the weather feeding back to influence subsequent plant and biogeochemical dynamics over the central Great Plains of the United States (e.g., see Lu 1999). In addition, plant development feeds back to the evolution of weather. As a result of the feedback, fine-grid domain-averaged temperatures are up to 2°C cooler with associated increases in precipitation. More details of this study are reported in Lu et al. (1999).

3. RAMS/GEMTM COUPLING

The plant model, the General Energy and Mass Transfer Model (GEMTM), was coupled to the meteorological model, the Regional Atmospheric Modeling System (RAMS) over the same domain (Eastman 1999; Eastman et al. 1999). The modeling system was then used to investigate the effects of when landcover is changed from current to potential vegetation, radiative forcing is changed from $1 \times CO_2$ to $2 \times CO_2$, and biological effects of doubled CO_2 are included.

On the domain average, both landuse change from natural to the current landscape, and the biological effect of doubled CO_2 resulted in significant cooling. Figure 1c shows the increase in vegetation cover due to the enrichment of CO_2 in the atmosphere.

The model results indicate that $2 \times CO_2$ felt by the biology, and landuse change exhibit dominant effects on meteorological and biological fields (Figure 1a-c). This was found at daily to seasonal temporal scales, and grid to regional spatial scales. The radiation impacts of $2 \times CO_2$ are found to be minimal, with interactive effects between the three areas of investigation as large as the radiational impact. More details of the study are found in Eastman et al. (1999).

4. CCM3 GLOBAL SIMULATION

Two ten-year general circulation model experiments were performed to compare a simulation where land-surface boundary conditions were represented by observed, present-day landcover with a simulation where the surface was represented by natural, potential landcover conditions assumed to be representative of the pre-settlement landcover distribution (Chase 1999; Chase et al. 1999).

As a result of these estimated changes in historical landcover, significant temperature and hydrology changes affected tropical land surfaces, where some of the largest historical disruptions in total vegetation biomass have occurred. Also of considerable interest, because of their broad scope and magnitude, were changes in high latitude Northern Hemisphere winter climate which resulted from changes in tropical convection, upper-level tropical outflow, and the generation of low-frequency tropical waves which propagated to the extratropics. These effects combined to move the Northern Hemisphere zonally-averaged westerly jet to higher latitudes, broaden it, and reduce its maximum intensity (Figure 2a and b). Low-level easterlies were also reduced over much of the tropical Pacific basin while positive anomalies in convective precipitation occurred in the central Pacific. There were large simulated ten-year average changes in near-surface temperature (Figure 3), although globally-averaged changes were small.

5. CONCLUSION

Land-atmosphere interactions clearly have importance on regional and global climate. Indeed, climate cannot be adequately understood if these interactions are not considered. Pielke (1998) and Pielke et al. (1999) discuss the implications of this conclusion in the context of climate prediction. Other researchers (e.g., Claussen 1994, 1998; Claussen et al. 1999; Foley 1994; Texier et al. 1997; Dirmeyer 1995, 1999; U.S. National Research Council 1994) provide results which support this conclusion.

6. ACKNOWLEDGMENTS

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Figure 1: RAMS/GEMTM coupled model results – the seasonal domain-averaged contributions to maximum daily temperature due to: f1 = natural vegetation, f2 = 2×CO_2 radiation, f3 = 2×CO_2 biology, f12 = interaction of natural vegetation and 2×CO_2 biology, f13 = interaction of natural vegetation and 2×CO_2 biology, f23 = interaction of 2×CO_2 for radiation and biology, f123 = the interaction of all three factors. (b) Same as (a) except for minimum daily temperature contribution. (c) Same as (a) except for LAI (from Eastman et al. 1999).

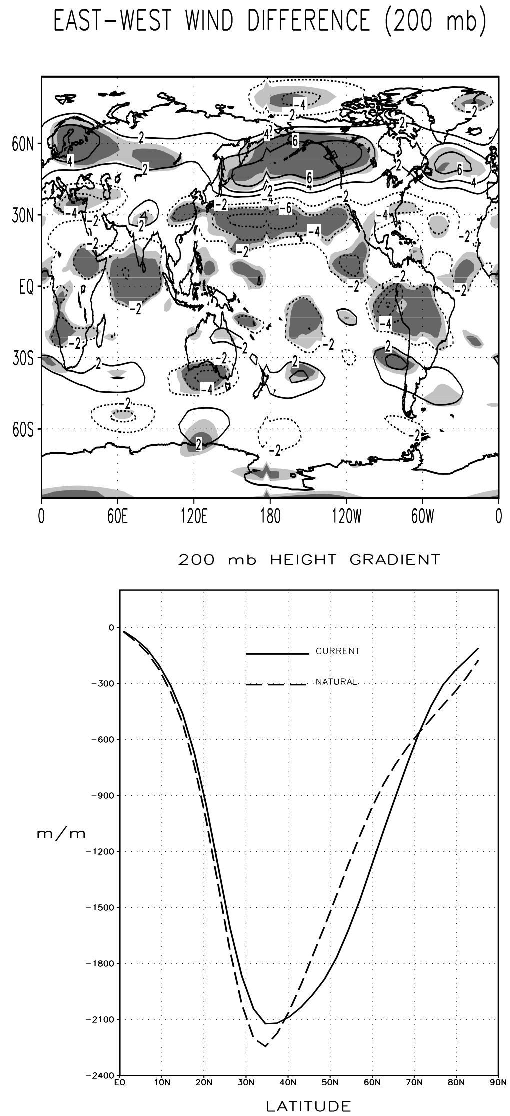

Figure 2: CCM simulations – (a) difference in 200 mb east-west wind (current-natural landcover). Contour by 2 m s^{-1}. Light shading represents the 90% significance level for a 1-sided t-test. Dark shading represents the 95% significance level. (b) Comparison of north-south derivative of zonally-averaged 200 mb heights (d(Z200)/dy) in the Northern Hemisphere (from Chase et al. 1999).

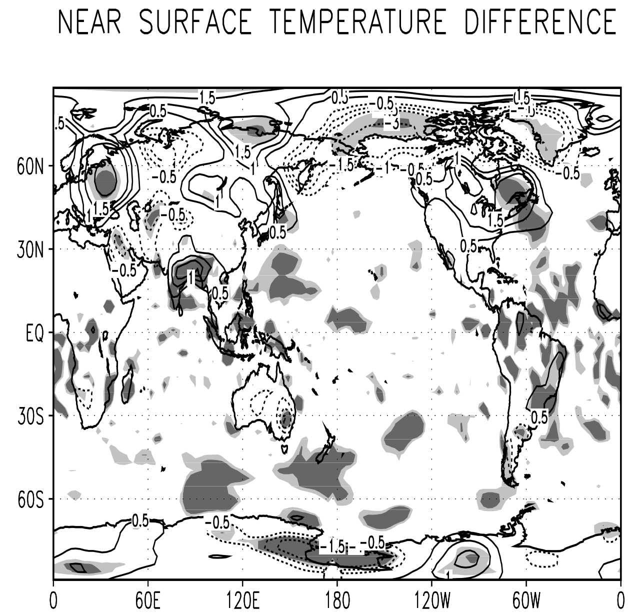

Figure 3: Difference in near-surface air temperature (current-natural) using a 9-point spatial filter for easier visibility. Contour by 0.5, 1.0, 1.5, and 3.0°C. Shaded regions as in Figure 2 (from Chase et al. 1999).

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