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Testing a model of CO_2, water and energy exchange in Great Plains tallgrass prairie and wheat ecosystems

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Abstract

A land surface model (a modified version of the Simple Biosphere Model, Version 2; SiB2) was parameterized and tested against two years of eddy covariance flux measurements made over un-grazed tallgrass prairie and a winter wheat field in Oklahoma, USA. The land surface model computed 30-min estimates of sensible and latent heat flux and carbon dioxide flux that agree well with the patterns observed in the field, simulating in particular the contrasting seasonal timing of fluxes in the wheat, where leaf area and physiological activity peak in the spring, and prairie, where leaf area and physiological activity peak in summer. However, systematic errors in flux estimates were also identified for particular times of day and season. These systematic errors are sometimes related to difficulty in correct definition of vegetation structure (LAI) and physiological activity. This was observed particularly in the wheat site towards the end of the growing season when senescence, which reduces both the amount and the physiological activity of leaves, is difficult to parameterize. Simulation errors are also attributed to problems in the mathematical description of water stress, soil respiration, and the leaf-to-canopy scaling methodology. SiB2 tends to predict too much photosynthetic activity at low solar angles, while developing soil moisture stress before it is seen in the field. Systematic errors in energy balance terms (heat and water fluxes) occur for bare soil and dormant vegetation, related to simulation of soil heat flux. Daytime errors in sensible and latent heat fluxes average 20 W m^{-2}, and can be more than 100 W m^{-2} at certain times. In regional and global climate models, the effect of land surface sub-model errors on atmospheric dynamics will depend in part on the magnitude of the systematic error, but also on the spatial extent and temporal duration over which the systematic error persists.

Keywords: Carbon balance; Eddy correlation; Energy balance; Land surface model; Latent heat flux; Sensible heat flux

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1. Introduction

In mid-continental regions the dynamics of the lower atmosphere are closely coupled to the dynamics of the land surface, which provides heat and moisture to the boundary layer and thereby contributes to convective processes, cloud formation and convergence patterns (Yan and Anthes, 1988; Raupach, 1991; Pielke and Vidale, 1995; Wigmosta et al., 1995). Land use changes that alter the timing or magnitude of heating and moistening of the atmosphere can, therefore, affect air temperature, vapor pressure, atmospheric stability and rainfall in the vicinity of the change. The land surface and changes in land use may also impact weather conditions through changes in circulation patterns over much larger regions, extending to continental scales (Charney, 1975; Nobre et al., 1991; Bonan et al., 1992; Polcher and Laval, 1994; Claussen, 1997; Taylor et al., 1997; Stohlgren et al., 1998; Zeng et al., 1999; Wang and Eltahir, 2000; Clark et al., 2001). Mesoscale climate models (operating at grid length scales in the range 10^2–10^5 m) are particularly suited to the study of the effect of land use on regional climate because the land surface can be represented at resolutions appropriate to the landscape. Furthermore, changes in local circulation patterns related to land use can be mechanistically simulated using, in the high resolution case, large eddy simulations to resolve localized flows (e.g. 'lake breeze' effects) caused by adjacent surfaces with differing energy and mass exchange characteristics (Pielke et al., 1992).

Terrestrial vegetation is also a central player in the carbon cycle, from the dynamics of seasonal uptake and release, to long-term source-sink relationships in plant biomass and soil carbon (Moore and Braswell, 1994; Schimel, 1995; Schlesinger and Andrews, 2000; Cramer et al., 2001). Biogeochemical models parameterized at daily or coarser time-steps can successfully simulate seasonal and inter-annual carbon uptake and release (Raich et al., 1991; Parton et al., 1993; VEMAP-Members, 1995), so one could argue that CO_2 uptake and release need not be simulated at the short time-steps (<1 h) required in climate system models for water and heat. Further, short time-scale feedbacks between carbon dioxide exchange and atmospheric dynamics (through radiative heating, for example) are much smaller than the immediate interactions between surface water and energy balance and boundary layer temperature and humidity. On the other hand, the processes that determine CO_2 exchange, particularly photosynthetic uptake, respond directly to high frequency processes (e.g. changes in insolation related to diurnal cycles and cloud passage). Boundary layer humidity, temperature and CO_2 concentration also directly affect photosynthetic and stomatal physiology, and changes in these variables occur at the higher frequency time-scales characteristic of the atmosphere (seconds to minutes). We contend, therefore, that it is desirable to consider the high frequency dynamics of carbon, even if some carbon-related processes, such as plant growth, can be adequately simulated at coarser time-steps. An equally important argument for inclusion of carbon exchange in land surface schemes is that the physiological linkage between photosynthesis and transpiration means that inclusion of 'biology' in land surface models should improve their ability to simulate transpiration and energy partitioning (Randall et al., 1996; Sellers et al., 1996a; Berry et al., 1998), which is still, after all, their primary role. Thus many global and regional atmosphere models now couple water and energy balance with CO_2 exchange, resulting in both better simulation of atmospheric dynamics and contributions to our understanding of the global carbon cycle.

Land use across much of North America has changed dramatically during the last century, with intensification and expansion of agricultural activities in many central and western states contrasting widespread agricultural abandonment and forest regrowth along the eastern seaboard (Turner et al., 1990). In the Great Plains region, agricultural expansion into native grasslands has been extensive, particularly to dryland crops such as wheat and sorghum (Riebsame, 1990). The objective of this study was to test the ability of a land surface model, the simple biosphere model (SiB2; Sellers et al., 1996c), to accurately simulate the fluxes of carbon, water and energy from a native tallgrass prairie and a dryland wheat system. The model used (SiB2) has been incorporated as the land surface scheme in a general circulation model (Randall et al., 1996) and a regional climate model (the mesoscale model RAMS, Denning et al., 2003). Detailed testing of SiB2 in contrasting vegetation types will facilitate assessment of uncertainty when climate system models are