EVALUATING SUB-GRID VARIABILITY OF SURFACE FLUXES WITH A CELLULAR AUTOMATA VERSION OF THE WET-DRY DAISYWORLD MODEL

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Dennis Baldocchi[1], James Dorsey and Monique Leclerc
University of California, Berkeley, CA and University of Georgia, Griffin, GA

1. INTRODUCTION

Landscapes, whose horizontal dimensions correspond with the grid size of a land-atmosphere model or pixel resolution of satellite sensors like MODIS, are rarely uniform. Typical grid or pixel regions are comprised of a mosaic of land patches, each with a different potential to control or influence momentum, mass and energy transfer. Of prime concern is how the spatial variability of surface fluxes, within and among constituent patches of a landscape, are integrated and averaged at the scale of the model grid or pixel.

We simulated spatial patterns of vegetation with models employed by landscape ecologists and coupled them with biophysical algorithms used by micrometeorologists to compute surface temperature and sensible and latent heat fluxes of the constituent patches. With explicit and high spatial resolution fields of energy exchange in hand we were able to investigate scaling issues related to sub-grid variability. Here, we examine: 1) how differences in biophysical properties (e.g. surface albedo and surface conductance) affect the composition and spatial heterogeneity of a landscape and its energy exchange; 2) bias errors and scaling rules associated with the sub-grid averaging of the non-linear functions used to compute surface energy balance and 3) issues related with measuring energy balance closure over heterogeneous landscapes by overlaying a flux footprint probability distribution over this virtual world.

2. METHOD

We modified the 'Daisyworld' model of Watson and Lovelock (1983) to consider the energy balance of vegetation with differing potential to evaporate water vapor which we denote 'Wet/Dry Daisyworld' (Baldocchi et al., 2005). We then extended this theory across a two-dimensional landscape, at high resolution, using cellular automata (CA) (von Bloh et al., 1999). Energy exchange from 'wet' and 'dry' daisies were computed by varying their albedoes and surface conductances. Virtual landscapes of wet and dry daisies were computed with the CA algorithm by considering competition between actively transpiring 'wet-daisies' and 'dry-daisies' for bare ground through temperature-dependent birth and death probabilities and by rules associated with crowding. Computations were made for a domain with 512 cells on each axis.

To study energy balance closure of the virtual landscape, flux footprint probability distributions were superimposed over the energy flux fields Flux footprints were computed by using the Lagrangian theory of Thomson (1987). We consider the effects of heterogeneous turbulence within a plant canopy (Baldocchi, 1997) and account for veering of wind direction in the plant canopy. Turbulence statistics for the three dimensional flux footprint model were derived from a higher order closure model (Meyers and Paw U, 1987).

3. RESULTS

The spatial coefficient of variation (cv) of land class, latent heat exchange, net radiation and surface temperature scale with the exponential power of the size of the averaging window. Though conceptual in nature, the two-dimensional 'Wet/Dry Daisyworld' model produces a virtual landscape whose power law scaling exponent resembles the one derived for a heterogeneous savanna ecosystem.

We compared expected values of energy exchange with functional computations based on mean conditions for the virtual landscape. Bias errors

[1]Department of Environmental Science Policy and Management, 137 Mulford Hall, Berkeley, CA, 94720;
email: baldocchi@nature.berkeley.edu

associated with the non-linear averaging of the surface energy balance equation increase as the coefficient of variation of the surface properties increases. Ignoring sub-grid variability of latent heat exchange produces especially large bias errors (up to 300%) for heterogeneous landscapes.

Spatial variations in latent heat exchange, surface temperature and net radiation, derived from our ‘Daisyworld' model, scale with the spatial variation in surface properties. These results suggest that we may be able to infer spatial patterns of surface energy fluxes from remote sensing data of surface features. ‘Wet-dry' Daisyworld, therefore, has the potential to provide a link between observations of landscape heterogeneity, deduced from satellites, and their interpretation into spatial fields of latent and sensible heat exchange and surface temperature.

Superimposing a flux footprint probability density function over the virtual landscape, reveals that deficient spatial sampling occurs and the energy balance is routinely underestimated.

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