9A.3 A COUPLED CANOPY-SOIL MODEL FOR THE SIMULATION OF ATMOSPHERIC TURBULENCE MODIFIED BY TALL VEGETATION

Edward G. Patton[1,*], Jeffrey C. Weil[2,1], and Peter P. Sullivan[1]

[1]National Center for Atmospheric Research, Boulder, CO
[2]University of Colorado, Boulder, CO

1. MOTIVATION

The immediate goal of this work is to develop a new numerical model capable of predicting the influence of plant biophysics and soil properties on atmospheric turbulent exchange at scales ranging from the leaf level (centimeter to meter scale for a leaf or clumps of leaves) to the planetary boundary layer (kilometer scale). The near term scientific objectives are to use this model to provide a time-dependent, spatially varying canopy-induced source/sink distribution for large-eddy simulation (LES) which will potentially offer the ability to generate intermittency in simulations of very stable boundary layers due to the rapid response of leaves to local variations in atmospheric temperature. This source/sink distribution will also be very useful in canopy-chemistry-turbulence studies because many of the biogenic emissions are tied with leaf temperature and available sunlight. Upon coupling with a parameterization that accounts for the canopy influence on the turbulence (*e.g.,* Harman and Finnigan, 2007), this model can ultimately be incorporated into weather and climate models which cannot resolve the canopy as a means to account for within-canopy processes on the total flux of constituents into or out of the canopy layer.

1.1 The Land-Surface Model

Although simplified, the NOAH (National Center for Environmental Prediction / Oregon State University / Air Force / Office of Hydrology) land-surface model (Chang et al., 1999) describes the fairly complete physics of the soil-water-vegetation system. In addition to the sensible and radiative heat fluxes, this model accounts for the moisture/vapor flux from the vegetation and a soil and hydraulic model for moisture supply to the plant roots. In its current form, the canopy in NOAH exchanges heat and moisture as a single "big leaf" and assumes that emitted scalars are vented immediately from the canopy space. Sensible and latent heat fluxes are determined through a coupling between radiation and photosynthesis models and the solution of a leaf energy balance; the Monteith (1973) resistance method is adopted. In the soil, the NOAH model predicts vertical profiles of temperature and moisture using a one-dimensional model with specified lower boundary conditions. One advantage of the NOAH model is that it was previously coupled with the NCAR LES to simulate the effects of a horizontally-varying soil moisture content on the mean and turbulence structure of the PBL (Patton et al., 2005), and therefore the interface between the two is already established.

2. The multi-layer canopy model

The key aspect that has been added to NOAH is that the canopy is now vertically distributed; meaning, the canopy is multi-level. NOAH remains as a 1-D column model (which will be implemented at ever horizontal location), but the canopy extends vertically into the flow domain. Therefore, the vertical distribution of the light environment, atmospheric temperature, moisture and wind fields drive the system. We accomplished this by merging a number of already developed models in to NOAH's more simple canopy system.

Much of the canopy light environment model stems from MEGAN (Guenther et al., 1995), which uses specified leaf scattering and reflection coefficients combined with the assumption of a spherical leaf angle distribution to calculate the absorption and scattering of direct/diffuse radiation by both sunlit and shaded leaves (Goudriaan and van Laar, 1994; Leuning et al., 1995). The emission algorithm for reactive species also comes from the MEGAN model (Guenther et al., 1995).

Stomatal conductance is calculated using a photosynthesis-based formulation following GEM (Niyogi et al., 2008), where a photosynthesis - carbon assimilation - transpiration model (Collatz et al., 1991, 1992) is coupled with the Ball-Berry model (Ball et al., 1987; Leuning, 1990). Applying the biophysical components of GEM at the meter scale should be reasonable since the functions determining these components were largely derived from leaf level measurements (Bonan,

[*]*Corresponding address:* Edward G. Patton, National Center for Atmospheric Research, P. O. Box 3000, Boulder, CO, 80307-3000. E-mail: patton@ucar.edu

1996), however for the implementation presented here, the exchange is scaled to the percent of the grid volume occupied by the leaf matter.

Solving the leaf energy balance for leaf temperature follows the quartic solution presented by Nikolov et al. (1995) and and estimating the boundary layer conductance is also based upon Nikolov et al. (1995) which uses an assumed leaf size and shape and a function of leaf Reynold's number.

Vertically varying sensible and latent heat fluxes from leaves to the atmosphere are then calculated based upon the local gradient between the leaves and the atmosphere and the appropriate combination of leaf boundary layer resistance and stomatal resistance (the reciprocal of conductance).

To establish whether the model is working appropriately, it will first be tested by driving the model with measured atmospheric conditions taken during the CHATS campaign (Patton et al., 2008). Coupling with the LES code will follow.

3. Expected Impacts

During the day time, canopies intercept incoming solar radiation at elevated heights. This intercepted radiation warms the upper layers of the plants which in turn warm the atmosphere in contact with them. Deeper within the canopy, the leaves are typically more shaded and therefore warm these layers of the atmosphere less. This differential radiation absorption creates a thermodynamically stable region within the canopy isolating surface and canopy emitted/absorbed species from the overlying atmosphere. These species are typically trapped until the passing of intermittently occurring organized turbulent motions (Gao et al., 1989). The tool is expected to properly capture these relatively infrequent but organized events and should therefore accurately predict canopy/soil exchange and the total flux to the overlying atmosphere.

We expect that this numerical tool will impact a broad range of previously unaddressable problems. Previous observational and numerical research has hinted at the benefits of shelterbelts for farmers, but the results of these studies offer conflicting views as to their benefit or detriment (Cleugh, 1998). The tool we propose which includes dynamically solved photosynthesis and leaf energy budgets in combination with the traditional physical implementation of the plants, will couple the necessary components to complete the picture and for the first time give scientists the ability to tell farmers how to implement windbreaks to increase their water-use efficiency and how the shelter will affect their crop.

The 400 meter AmeriFlux WLEF Tall Tower site has continuously sampled profiles of numerous atmospheric variables and chemical constituents such as velocity, water vapor, and CO_2 for the last eight years or so. While measurements such as these have proven themselves extremely valuable in quantifying the diurnal, seasonal, and yearly contribution of the North American continent to the global carbon budget, interpretation of the measurements remains uncertain. The unprecedented measurement heights are fantastic on one hand since they represent such an immense upstream fetch ($\sim$ 10km). However, this vast fetch also implies that these measurements include fluxes coming from many different plant-canopy and land-surface types that emit, store, and therefore exchange scalars very differently. These measurements of net ecosystem exchange may therefore be unrepresentative of the average across the fetch if one particular stand is dominating the measurement. Our simulation system will naturally incorporate heterogeneity and time-dependent forcing and will resolve the canopy-turbulence responsible for bringing momentum and constituents to and from the canopy air-space and the boundary layer motions that bring these quantities to the measurement location.

Similarly, questions persist regarding the influence of boundary-layer processes on ozone production, biogenic hydrocarbon oxidation rates and the distribution of isoprene and its oxidation by-products. Although isoprene has a short lifetime and hence a short transport distance, its reaction by-products can influence ozone photochemistry over a much larger area than the isoprene itself. Through a simple formulation, Patton et al. (2001) showed that biogenic hydrocarbon reaction rates are modulated by the canopy's influence on the atmospheric turbulence. These simulations relied on fixed emission rates distributed through the canopy. In contrast, this model will predict the spatial and temporal variability of available radiation and therefore leaf temperatures providing for realistic canopy hydrocarbon emissions, thereby eliminating the confusion of fixed emission rates on the predicted distributions of these compounds. Through these studies, we expect to be able to accurately show the the influence of intermittent canopy venting and spatially and temporally varying sources on measured isoprene profiles.

One of the major shortcomings of current large-scale simulations is the inability to generate the effects of intermittent turbulence near the ground surface (Van de Weil et al., 2002). Because of their low heat capacity, plant canopies complicate surface exchange by isolating surface and canopy sources from the overlying atmosphere by creating a layer in the sub-canopy air space that is thermodynamically stable. This numerical tool will allow for thorough examination of the processes determining land-surface fluxes and the atmospheric response. The incorporation of NOAH will also provide naturally for simulation of the diurnal cycle of the PBL. Improved PBL/land-surface interaction parameterizations will result from this coupled numerical system and will improve surface exchange estimates in larger-scale models (meso, regional and climate scales).

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