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A PHOTOSYNTHESIS-BASED GAS-EXCHANGE EVAPOTRANSPIRATION MODEL (GEM) COUPLED WITH A LAND SURFACE SCHEME FOR MESOSCALE APPLICATIONS

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1 INTRODUCTION

Accurate representation of land surface processes (LSPs) is a pivotal component of mesoscale models. LSPs affect not only the surface energy balance but also the entire boundary layer structure, mesoscale circulations, cloud formation, and precipitation patterns. In the majority of mesoscale models a diagnostic Jarvis-type LSP scheme is employed. However, there are compelling reasons to adopt photosynthesis based land surface approaches: First, the Jarvis approach relies heavily on the prescription of so-called minimum stomatal resistance (Rs_{min}). As shown in studies such as Niyogi and Raman (1997), and Alapaty et al. (1997), the errors in prescribing Rs_{min} can have a profound impact on the entire boundary layer simulations. Hence, there is a need to adopt biophysical schemes that do not rely on the Rs_{min} specification and have a more mechanistic approach.

Second, the photosynthesis-based relations, though not causal, are based on gas exchange parameters that can be measured in the laboratory or field studies. Further, these parameters seem to be robust and show remarkable similarity for different phenological or landscape types, without any significant seasonal or other environmental modulation in the basal values (Collatz et al. 1991).

Third, with the advances in the remote sensing technology a number of high resolution (order of a kilometer and even smaller scales) land use - land cover (LULC) and ecological data sets such as GAP (Gap Analysis Program*, www.gap.uidaho.edu)* are now becoming nationally available. Without an ecological or photosynthesis based biophysical module the atmospheric models cannot extract the benefits of such detailed, high-resolution datasets.

Additionally, studies such as Niyogi and Raman (1997), and Niyogi et al. (1998) show that the photosynthesis-based schemes are more interactive and hence better able to replicate the stomatal resistance variations with environmental changes.

2 MODEL

Accordingly, we developed, coupled, and validated a gas – exchange - based surface evapotranspiration model (GEM) as a land surface/soil-vegetation-atmosphere transfer (SVAT) scheme for mesoscale models. The vegetation module is based on the Ball-Woodrow-Berry stomatal model (Ball et al., 1987) and the Collatz et al. (1991, 1992) photosynthesis scheme. Photosynthesis or carbon assimilation is taken as the residue of gross carbon assimilation and loss due to respiration. The respiration loss is estimated following Calvet et al. (1998), using maximum assimilation rates (Schulze et al., 1994) as limited by mesophyllic conductance estimates. The mesophyllic conductance is coupled to soil moisture and evapotranspiration. To achieve a fully coupled two-way interaction between the surface and the atmosphere, the GEM-based physiological resistance module is linked to a detailed PBL and land surface process (LSP) model (Noilhan and Planton, 1989; Alapaty et al., 1997). At the core of the model, five equations are solved prognostically for topsoil and deep-soil temperature and moisture and rainfall interception, to yield evapotranspiration estimates. This is also provided as a surface boundary condition for the atmospheric model. In the atmospheric model, net radiation at the surface is the sum of incoming solar radiation (a function of solar zenith angle, surface albedo, and atmospheric turbidity), atmospheric longwave back-scattering radiation, and outgoing longwave surface radiation. Upward and downward longwave radiation are calculated as functions of soil emissivity, ground temperature, atmospheric longwave emissivity, and atmospheric temperatures. Additionally, the PBL model uses surface layer similarity relationships with a turbulent kinetic energy (TKE) approach for the mixed-layer parameterization.

3 VALIDATION

The coupled system was validated over various natural surfaces: a C4 grass prairie, a C4 corn field, a C3 soybean field, a C3 fallow site, a C3 hardwood forest site, and a tropical field site. For each of the surfaces, except the fallow site, two case studies were performed under contrasting surface conditions (such as different soil moisture or leaf area index). In all, 11 case studies were conducted and the model simulations were compared with actual field measurements of surface sensible and latent heat fluxes. For some of the observations, measurements of vertical boundary layer profiles or direct measurements of stomatal resistance and photosynthesis rates were available and were compared with the GEM-based coupled SVAT model output. Results indicate that the model is able to simulate the various surface and boundary layer characteristics quite successfully. Generally the surface energy fluxes, particularly the latent heat flux, were within 10%-20% of the observations without any tuning of the biophysical-vegetation characteristics.

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The model also satisfactorily simulated the day-to-day variations in the heat fluxes. The model response to the changes in the surface characteristics has been consistent with observations and theory.

4 CONCLUSIONS

Photosynthesis based coupled models can be efficiently applied for a range of environmental applications at different scales. We conclude that the photosynthesis-based SVAT approaches are superior to Jarvis-based approaches and can be applied for mesoscale environmental and weather models at various scales, because of the inherent feedback the vegetation models can provide on the atmosphere factors, which is critical in developing a realistic simulation environment.

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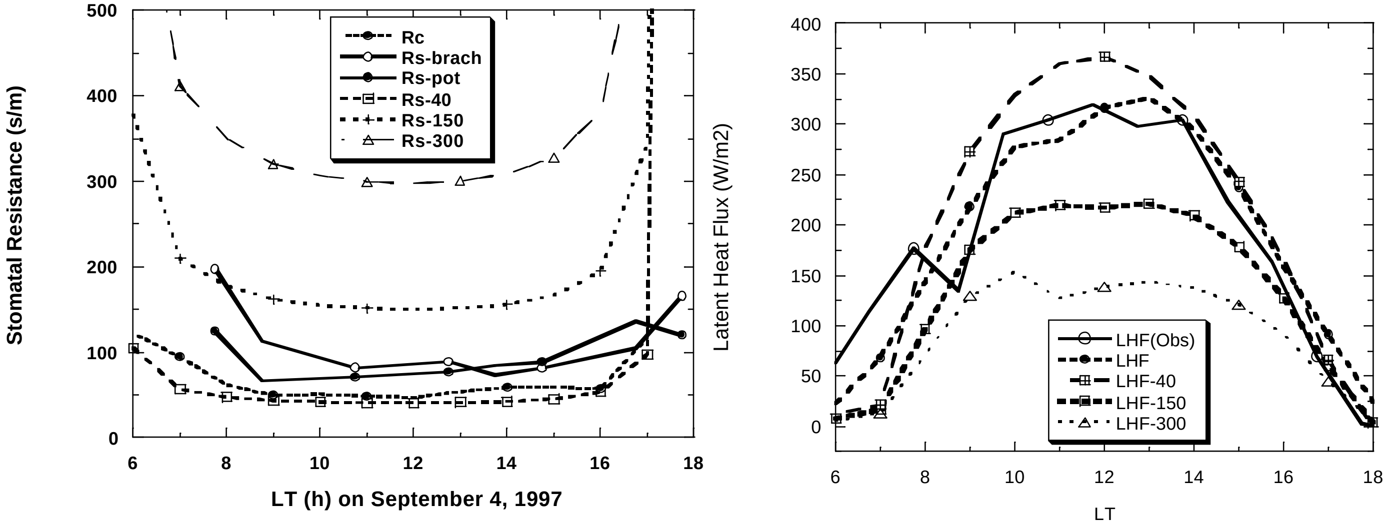

Figure 1a-b *Stomatal resistance and latent heat flux variations for the C3 fallow case, comparing the observations (Rs-brach and Rs-pot) with GEM predictions (Rc), and Jarvis-type predictions for 40 sm^{-1} (Rs-40), 150 sm^{-1} (Rs-150), and 300 sm^{-1} (Rs-300) as possible minimum stomatal resistance assignments for the fallow landscape.*