Development and Evaluation of a Coupled Photosynthesis-Based Gas Exchange Evapotranspiration Model (GEM) for Mesoscale Weather Forecasting Applications

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ABSTRACT

Current land surface schemes used for mesoscale weather forecast models use the Jarvis-type stomatal resistance formulations for representing the vegetation transpiration processes. The Jarvis scheme, however, despite its robustness, needs significant tuning of the hypothetical minimum-stomatal resistance term to simulate surface energy balances. In this study, the authors show that the Jarvis-type stomatal resistance/transpiration model can be efficiently replaced in a coupled land–atmosphere model with a photosynthesis-based scheme and still achieve dynamically consistent results. To demonstrate this transformative potential, the authors developed and coupled a photosynthesis, gas exchange–based surface evapotranspiration model (GEM) as a land surface scheme for mesoscale weather forecasting model applications. The GEM was dynamically coupled with a prognostic soil moisture–soil temperature model and an atmospheric boundary layer (ABL) model. This coupled system was then validated over different natural surfaces including temperate C4 vegetation (prairie grass and corn field) and C3 vegetation (soybean, fallow, and hardwood forest) under contrasting surface conditions (such as different soil moisture and leaf area index). Results indicated that the coupled model was able to realistically simulate the surface fluxes and the boundary layer characteristics over different landscapes. The surface energy fluxes, particularly for latent heat, are typically within 10%–20% of the observations without any tuning of the biophysical–vegetation characteristics, and the response to the changes in the surface characteristics is consistent with observations and theory. This result shows that photosynthesis-based transpiration/stomatal resistance models such as GEM, despite various complexities, can be applied for mesoscale weather forecasting applications. Future efforts for understanding the different scaling parameterizations and for correcting errors for low soil moisture and/or wilting vegetation conditions are necessary to improve model performance. Results from this study suggest that the GEM approach using the photosynthesis-based soil vegetation atmosphere transfer (SVAT) scheme is thus superior to the Jarvis-based approaches. Currently GEM is being implemented within the Noah land surface model for the community Weather Research and Forecasting (WRF) Advanced Research Version Modeling System (ARW) and the NCAR high-resolution land data assimilation system (HRLDAS), and validation is under way.

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