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Ecological Modelling 188 (2005) 174–216

ECOLOGICAL MODELLING

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Comparison of surface energy exchange models with eddy flux data in forest and grassland ecosystems of Germany

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Received 15 April 2004; received in revised form 27 January 2005; accepted 31 January 2005
Available online 23 March 2005

Abstract

Latent heat, which plays a major role in the energy balance of ecosystems, is usually calculated in different types of models, e.g., water balance approaches, aggregated “big-leaf” models, multi-layer ecosystem process models, that can be generally catalogued as Soil–Vegetation–Atmosphere–Transport models (SVATs) in a broader sense, etc. In this study, four (multi-) layered models (PLant-ATmosphere INteraction model (PLATIN), MixFor-SVAT, SVAT-CN, PnET-N-DNDC) and an atmospheric boundary layer model including vegetation (HIgh Resolution Vegetation Atmosphere Coupler (HIRVAC)) were used to predict latent heat (LE) and sensible heat (*H*) exchange in the target area of VERTIKO, a research project on vertical transports of energy and trace gases and their spatial/temporal extrapolation under complex natural conditions. Investigated vegetation types were a Norway spruce forest, and two grassland sites in Brandenburg and Saxony (Germany) during field campaigns in 2001 and 2002. Four models had half-hourly to hourly time steps, but PnET-N-DNDC had a daily time step. All models used meteorological conditions above the canopy as input, and computed LE and *H* independently, or *H* as the residual of the energy balance. Intercomparisons

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Abbreviations: *b*, offset of linear regression; [CO_2], CO_2 concentration; DoY, day of year; EC, eddy covariance; ET, evapotranspiration; E_0, potential evaporation; FB, fractional bias; IA, index of agreement; LW, longwave radiation; *m*, slope of linear regression; MAE, mean absolute error; NIR, near infrared radiation; *P*, air pressure; PAR, photosynthetic active radiation; PPT, precipitation; R.H., relative humidity; R_g, global radiation, incoming shortwave radiation; RMSE, root mean square error; R_n, net radiation; S.E. of *y*, standard error for the *y* estimate; S.E., standard error of parameter; T_a, air temperature; *u*, wind speed

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doi:10.1016/j.ecolmodel.2005.01.057

and discussions of model parameters focussed on vegetation type (or species), and LAI. Model predictions were compared to half-hourly and daily eddy covariance measurements of ecosystem LE and *H* during two periods (cold and wet fall 2001, warm and dry summer 2002) to include contrasting weather conditions in the model evaluation.

The agreement between modeled and measured fluxes was reasonable for most models. Yet, as the models were principally based on energy balance, the lack of energy balance closure as found in the data made it difficult to evaluate models against data, indicating a need for more attention to measurement accuracy in future studies. Systematic differences between the models were obvious. In general, HIRVAC model predictions of LE were routinely the lowest, and PnET-N-DNDC the highest. The tendency of under- or overestimating LE fluxes was comparable in PLATIN, SVAT-CN and MixFor-SVAT. SVAT-CN especially underestimated LE and overestimated *H* of the forest site. Under- or overestimation by the models could not be attributed to vegetation type. Both, MixFor-SVAT and SVAT-CN underestimated LE of one of the grassland sites, and overestimated the other. When averaging all model outputs, daily fall fluxes reached between 75 and 115% of the data for the three sites (76–83% for the summer period), and between 65 and 90% for half-hourly fluxes (73–97% for summer).

Sensitivity analysis for an important model parameter, LAI, revealed only small effects on modeled LE in most models, probably due to compensation in the relative amounts of evapotranspiration and soil evaporation, at least for the limited range of LAI we analyzed (mean $\pm 1\,\mathrm{m}^2\,\mathrm{m}^{-2}$). The sensitivity to LAI was smaller for forest simulations than for grasslands. For a given site PLATIN and MixFor-SVAT showed lowest, SVAT-CN intermediate, and HIRVAC largest sensitivity to changes in LAI. For latent heat simulations of forests, the sensitivity of LE to changes in LAI was smaller than the differences in the LE predicted by the five models. Further, it is much more important to determine vegetation type and accurate leaf physiology than the LAI of the system.

The models differed widely in their approach for canopy radiation, leaf physiology, energy balance, atmospheric transport or soil water modeling, yet the treatment of evaporative losses from soil and interception pools seemed to cause the larger differences between the models after rain events.

Keywords: Multi-layer models; Latent heat; Model sensitivity; SVAT schemes; Grassland; Forest ecosystems

1. Introduction

Latent and sensible heat are important variables in meteorology, hydrology and ecology, as they affect climate, which in turn determines environmental parameters, that alter mass and energy exchange between the ground and the atmosphere. To reduce uncertainty in predictions of surface energy exchange, or to fill data gaps a better understanding of ecosystem processes controlling surface energy exchange is required. A series of Soil–Vegetation–Atmosphere–Transport models (SVATs) have been developed, that estimate surface energy exchange, or components of evapotranspiration (transpiration, soil evaporation and interception). The models differ in scope, temporal and spatial scale, complexity or model approach. Apart from purely empirical or statistical methods, most of the models are explicitly based on the principle of energy (or water) balance. Examples of such model types include: SVATs of the pure ‘big-leaf’ type (e.g., zero-dimensional models based on Monteith, 1965; Priestley and Taylor, 1972; Shuttleworth and Wallace, 1985); intermediate ‘big-leaf’s (Raupach and Finnigan, 1986) with one vegetation layer that has already some vertical dimension, implicit in parameterization of solar radiation transfer, turbulent exchange, bulk stomatal conductance (Dickinson et al., 1993; Sellers et al., 1996; Kellomäki and Wang, 1999; Martin, 1999; Verhoef and Allen, 2000; Zhan et al., 2003; Wang et al., 2004; Zavala, 2004); or multi-layer ecosystem process models (e.g., Baldocchi and Harley, 1995; Williams et al., 1996; Wohlfahrt et al., 2000; Baldocchi and Wilson, 2001; Tanaka, 2002). Mass and energy flux models are also commonly used in biogeochemical or growth and ecosystem dynamic models such as HYBRID (Friend et al., 1997), hydrological applications (e.g., Engel et al., 2002) or land surface schemes of climate models (e.g., Wang et al., 2001; Zhang et al., 2005). ‘Big-leaf’ type models rely more on lumped or ‘effective’ model parameters than the latter. They are the method of choice for long-term or large-scale application, when computation time is an issue, or when estimates of energy exchange are a second-order problem, as in growth or biogeochemical models. Multi-layer ecosystem process models put the main focus on extensive process understanding, and require a larger number of a priori model parameters.