INTERACTION BETWEEN THE ATMOSPHERE AND MOUNTAIN FOREST: LOCAL SCALE ASESSMENT OF ENERGY AND WATER FLUXES

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Abstract: This study presents early results from the development of a geo-referenced local biophysical model (referred to as 'Forest_SVAT_Bg'). This is 1D coupled model of canopy flows with dynamic response of leaf temperature along with the vegetation dynamics on a short-term time scale (10 days). The radiative surface properties and their seasonal impacts on local microenvironment are evaluated. The main surface fluxes and energy balance are parameterised using semi-empirical dependencies. The water and energy fluxes to/from the canopy are quantified. The biosphere feedbacks partitioning at extreme weather of 'relatively dry'/'wet' conditions are evaluated. Model derived soil moisture is validated by *in situ* measurements and a good model performance is confirmed. Simulations of surface fluxes at the root zone depth are presented. The model is driven using site-scale micrometeorological measurements (1974 - 1979) at a pure spruce forest stand (24°41´; 41°40´) in scare studied mountain region of the Balkans.

Keywords: *soil–forest–atmosphere continuum, canopy-air exchange, short-term biophysical interactions, site-scale, mountain environment, extreme weather, atmospheric and ecosystem dynamics*

1. INTRODUCTION

The interactions between meteorological, hydrological and biological components of the climate system are implemented by land–atmosphere exchanges of energy and matter, involving all three of the carbon, water and energy cycles. The vegetated land-surface is functioning through this mass- and energy- exchange with the atmosphere, consistently to the root zone soil moisture status (Landsberg, 1986). The strength of this link at any particular location depends on the three major resources for plant growth: light, water and nutrients. Land surface evaporation determines the soil moisture dynamics that in turn, influences the carbon cycle through the role of water as a plant resource. Direct energy exchanges between land surface and atmosphere influence large-scale atmospheric dynamics that also exert strong local effects on the microclimates in which ecosystems live, thus influencing long-term ecosystem evolution (Raupach, 1998).

The importance of land-surface processes for climate has been increasingly recognized by the global modelling community over the past decade (e.g. Dikinson, 1983; Minz, 1984). Including biological details of the land surface in general circulation models (GCMs) improves climate predictions (e.g. Pielke et al., 1997). As vegetation plays a significant role in determining the partition of surface fluxes, so green vegetation fraction must be represented adequately in numerical weather prediction models, seasonal climate prediction models, and in climate variability models. Efforts during the last decade have been concentrated on the improvement of atmosphere-biosphere interaction models (e.g. Running and Hunt, 1993).

Since biophysical and biogeochemical feedbacks on climate depend on the vegetation and soil properties, which in turn respond to climate, our first aim was to perform research on vegetation-atmosphere interactions for the scare studied region of Balkans to gain knowledge about local terrestrial biophysical feedbacks. The ultimate goal of this study is to develop a local scale soil-vegetation-atmosphere-transfer (SVAT) model, aimed to predict site scale water vapor- and energy- exchange at a native forest canopy and understand how mass and energy exchange vary in time with vegetation functioning at this part of the globe, where the Mediterranean influence may provoke 'dry' or 'wet' annual conditions.

2. THE FOREST SVAT MODEL

2.1 Model description

A process-based model for quantitative assessment of forested land-surface-atmosphere interactions at a site scale is developed that is referred to as 'Forest_SVAT_Bg model'. This is a simple one-dimensional (vertical), geo-referenced biophysical Soil-Vegetation-Atmosphere Transfer (SVAT) framework aimed to derive the main biometeorological processes and to gain a better understanding of the microclimate modification. The actual evapotranspiration is considered as the key parameter that controls the portioning of energy and water fluxes at vegetated land surface.

The ‘Forest_SVAT_Bg’ simulations have been run with a time step of 10 days over six years, at a fairly homogeneous closed forest cover, operating as a consecutive procedures of two related sub-models, each one consisted of several panels and sub-panels depending on the parameterisation they concern, as follows:

Vegetation sub-model. Land surface parameterisation of albedo, roughness and moisture availability is applied for description of the land-surface-atmosphere interface of the one-dimensional processes (transfer of radiation, turbulence, sensible and latent heat). The equations used to describe the energy transfer processes are covered by three panels of the ‘Vegetation sub-model’:

PANEL 1: Radiation balance of forest canopy (R_N). Combining semi-empirical dependencies (accordingly to Berlyand, 1961; Kimball, 1973; Djolov et al., 1970; Kondratyev, 1977), the net radiation of the forest surface is described by equation (1):

$$R_n = (1-\alpha)R_s + \varepsilon(R_L - \sigma T_s^4) \quad (1)$$

where R_s is global short-wave radiation downwards on the canopy; α is the surface albedo; ε is the long-wave emissivity of the surface; R_L is the downward long-wave radiation; T_s is the surface temperature and σ the Stefan Boltzmann constant. The first and the second terms on the right-hand side of (1) represent available short-wave and long-wave radiation respectively.

PANEL 2: Energy balance partition. The net energy R_n, absorbed by the vegetation-soil system, is partitioned amongst evapotranspiration LE_o, sensible heat transfer H, photosynthesis Ph as well as heat storage in the soil S, trees and air H_t. It is assumed: non-divergent vertical fluxes over the forest; homogenious soil thermo-physical properties along the soil profile; taking the fluxes towards the upper surface of the forest as positive, and those away from it as negative, neglecting the secondary energy sources/sinks; accounting the 0-20 cm soil heat storage and exchange.

PANEL 3: Potential evapotranspiration concept. The parametrization of potential evapotranspiration E_o is prescribed following Budyko (1974) and assuming as driving force the vapor pressure gradient between evaporating surface and overlying air. The E_o parametrization is given by a bulk aerodynamic relation:

$$E_o = \rho D(q_s - q) \quad (2)$$

where: ρ and q are the air density and specific humidity; D is an integral diffusion coefficient.

Water balance sub-model. A simple “bucket” water balance model over given time step is used:

$$dW/dt = P - E \quad (3)$$

where: W - available soil moisture, P - rainfall, E - actual evapotranspiration, and t - time. It is assumed no surface runoff under the closed canopy and negligible drainage to groundwater over dry periods.

Coupling between the Vegetation sub-model and Water balance sub-model. Parametrization of process includes a simple conceptual bucket model, including: coupling between the forest heat balance (PANEL 2) and the stand water balance (equation 3), adopted to describe the time variation of soil moisture in the root zone at two levels of its availability β, according to the dependence:

$$E = f(E_o, T_s, \textit{soil texture}, \beta), \text{ where } \beta = f(W, W_{max}, W_{min}, \textit{soil texture}),\ 0 < \beta < 1 \quad (4)$$

2.2 Study area and model inputs/outputs

Input data. Published data from micrometeorological observations performed at the station of the National meteorological network Ardashla in the period 1974-1979 are used for the model runs. These include: meteorological data from routine observations of standard meteorological parameters in forested environment; agrometeorological information that cover the total soil moisture (W) and soil hydro-physical properties (bulk density) along the profile. W was measured gravimetrically once per month (at the end of the first decade of each month) for the period April-October at three depths of the soil profile: 3 cm, 30 cm, and 80 cm. The forest micrometeorological station is situated in Rhodophes mountain, South Bulgaria (24°41′; 41°40′; 1680 m alt, SW facing slope with a steep inclination) in the Continental-Mediterranean climate zone. The forest cover is formed by a pure mature *Picea exelssa* L. stand with a closed (0.8) canopy and well-covered soil surface.

Outputs. The prognostic outputs of the model describe the one-dimentional transfer of energy and water through the soil-forest-atmosphere system: E_o, E, T_s, and W are obtained as 10-days averaged values and compared to available observations of W at the experimental station.

3. FOREST SVAT MODEL APPLICATIONS

3.1 Surface climate: surface fluxes and energy balance

The local scale model 'Forest_SVAT_Bg' is being utilized as a framework for identifying scale-relevant forested-land-atmosphere feedbacks of energy and water cycles that form the site microclimate. Assuming seasonal albedo variation consistent with spruce phenology, the model thermodynamics accounts for the leaf surface temperature governing energy conservation, canopy physiology and the rooth zone depth of 1 m. The canopy net radiation R_n mean annual course and its partition into main heat fluxes of: latent heat *LE*, sensible heat *H* transfer to the atmosphere, and the reradiation into the ground heat flux *S* for the whole experimental period are derived (Fig. 1a). The structure of heat balance of spruce canopy is revealed as the simulated heat fluxes (values and trends) are similar to other results reported (e.g. Rudnev 1984): mean annual *LE* accounts on average to $0.7R_n$, being maximal during vegetation, when the *H*-flux is minimal, whereas *S* approximates to 0.07 R_n; growing season *H/LE* ratio is about 0.47. All these trends in canopy energetic fluxes are consistent with the course of the soil moisture (see Fig. 1b).

(a) (b)

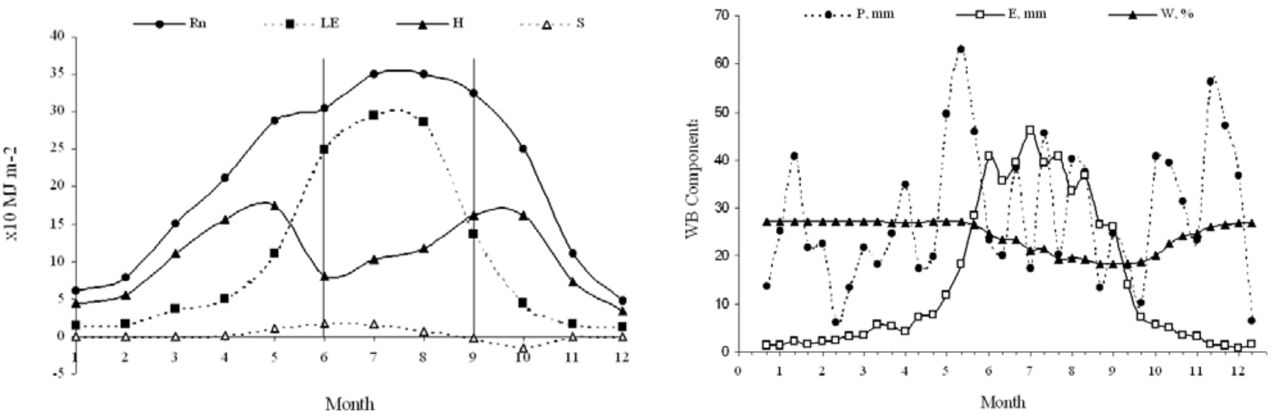

Figure 1: (a) Heat balance of a spruce canopy (24°41′; 41°40′) and its partition into energy fluxes: latent heat *LE*, sensible heat *H*, 0-20 cm soil heat flux *S*. **(b)** Water balance at root-zone depth of 1 m: soil moisture *W*, evapo-transpiration *E*, and precipitation *P*. Annual means, averaged for 1974−1978. Vertical lines delimited growing season.

3.2 Extreme events: diagnostic on land surface state for wet and dry years

Based on the experimental setup, extreme weather conditions are selected: relatively 'dry' or 'wet' periods As examples of dry/wet conditions the growing seasons of 1978/1976 are considered. For these years the annual- and growing season- precipitations are lower/higher than the six-year average precipitation. The mechanisms of atmosphere-land exchange are evaluated on inter-annual basis and the extend to which environmental self-modification occurs and the strenght that these feedback cycles can attain during the seasonal variations of the relatively dry/wet years are compared and shown in Fig. 2 (a, b, c).

(a) (b) (c)

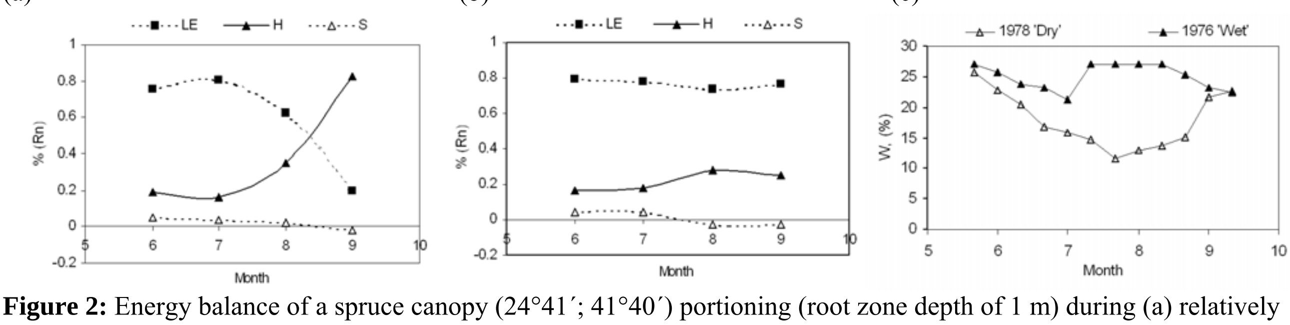

Figure 2: Energy balance of a spruce canopy (24°41′; 41°40′) portioning (root zone depth of 1 m) during (a) relatively dry (1978) and (b) relatively wet (1976) conditions of the growing season. (c) Soil moisture during the growing season for a wet (▲) and a dry (Δ) years. (*LE* –latent heat; *H* – sensible heat; *S* – soil heat flux).

Strong gradients in surface sensible and latent fluxes associated with different surface heating and moistening conditions are observed. At optimal soil moistening periods (May-June), the patterns of the forest-cover-atmosphere interactions are identical for 'Dry' and 'Wet' years, i.e. evaporative demands exceed the released sensible heat from forest canopy to atmosphere. With a soil moisture stress (after July, Fig. 1c), the evapotranspiration is reduced (Fig. 1a, b) and the sensible heat flux increased, although for the wet 1976, *LE* exceeds *H* along the whole year. For the dry 1978, after soil moisture depletion in the mid-July, *H* exceeds *LE*. Reflected by the *H/LE* structure, the Bowen ration accounts to 0.34/1.31, respectively for the wet/dry growing seasons. Knowledge about covariances among the microclimate drivers and about coupling between ecosystems functioning and meteorological processes may be critical for forecasting extreme events (*e.g.* flash-floods and droughts, fires) at mountain environment.

3.3 Surface hydrology: potential role of root-water availability feedback

The temporal structure of soil moisture is a key feature for understanding and predicting of land-atmosphere interactions. Since soil moisture exhibits a high degree of spatial and temporal variability and has an influence on surface energy fluxes, it should be possible to indirectly estimate this quantity using atmospheric measurements at screen level. Calculative procedure, following 'Forest_SVAT_Bg' model is performed and the key hydrological state variables are derived for each one of the six years of model runs. The components of the water balance (means for the dataset): precipitation, the model evapotranspiration *E*, and the model soil moisture *W* during vegetation period are derived (see Fig. 1b). Soil moisture simulations are validated by *in situ* measurements for the surface layer (0-30 cm) and in deep horizon (0-80 cm). Results confirm a good model performance (R^2 varies between 0.62 and 0.74).

Evapotranspiration is dependent on the available soil moisture in the root zone tepth. A 2-layer soil hydrology model, based on discretised dependences and utilising the soil water suction and thermo-hydric properties is applied. Evapotranspiration from the vegetated land surface (at a mean surface resistance) is obtained to be limited directly by soil moisture availability and canopy energy loading (Fig. 1b).

4. CONCLUSIONS

Applying a bottom-up integrated approach, a geo-referenced forest cover-atmosphere analysis is performed by the 'Forest_SVAT_Bg' coupled model. Reasonable simulations of the variability of land surface energy and moisture fluxes and storages at native forest cover are obtained. The canopy energy balance and its partition into latent and sensible heat as depended on soil moisture availability is depicted. This model constructed to function at a regional scale can serve to inform models at other scales, e.g. GCMs for local scale microcimate. A further refinement of the model includes a daily basis calculations and its development for larger scale applications that would serve for prediction of extreme weather (drought, flash floods etc.). It is hoped that the results of this agrometeorological model will help clarify the land surface-atmosphere dynamic interactions and their role in weather, climate and ecosystem sustainability.

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