

Surface fluxes of water vapour, heat, momentum and CO₂ over a savannah in Niger: A contribution to HAPEX-SAHEL.

A. Verhoef, H.A.R. de Bruin and R. Krikke

Wageningen Agricultural University, Department of Meteorology, Duivendaal 2,
6701 AP Wageningen, The Netherlands

ABSTRACT

This study concerns a Soil-Vegetation-Atmosphere Transfer (SVAT) model, which consisted of the "best" parts of the SVAT's as developed by Choudhury and Monteith (1988) and Deardorff (1978). Model simulations are compared with data collected in the context of the HAPEX-SAHEL project (Gourtorbe et al., 1994) for day 273, which is about 9 days after the last rainfall in 1992.

1. INTRODUCTION

For large scale models such as Global Circulation Models (GCM's) the lower boundary condition is often provided by a Soil-Vegetation-Atmosphere-Transfer (SVAT) model. A wide range of SVAT's is in use nowadays, varying from models based on the simple big-leaf concept by Monteith (1965) to complicated multiple source models. Obviously, a SVAT intended to provide the lower boundary condition in GCM's needs to be able to describe a wide range of surface types, varying from completely vegetated to sparsely vegetated or completely bare surfaces. Especially sparse canopy surface types exhibit rather demanding features with respect to the exchange of momentum, water vapour, CO₂ and heat between the surface and the atmosphere.

In this paper attention will be focused a sparse canopy. We will compare SVAT model simulations with data collected in 1992 at a savannah site, in the framework of the HAPEX-SAHEL project. Two existing SVAT models are considered, notably the model by Choudhury and Monteith (1988) and by Deardorff (1978). In a separate study these models have been tested. Using the results of the latter, we constructed a combined model, consisting of the "best" parts of the original SVAT's. Some preliminary results will be presented.

2. EXPERIMENTAL SETUP

The HAPEX-SAHEL experiment was executed in Niger during 1991-1992 with an intensive observation period in August-October 1992. The measurements of the Department of Meteorology of the Wageningen Agricultural University were carried out at the West-Central super site, about 50 (km) east of Niamey. The vegetation consisted of a ground layer of annual herbs and grasses with scattered multi-stemmed shrubs (*Guiera senegalensis*). The sensible and latent heat fluxes were determined by Eddy correlation (EC) methods. The momentum flux by EC and profile methods. CO₂-fluxes were obtained by the EC technique. The EC setup consisted of a Solent 3-D sonic anemometer, a Lyman-alpha humidity meter, a fast response thermocouple and the LICOR CO₂/H₂O gas analyzer. Cup anemometers and psychrometers provided the data for the P method. All instruments were mounted on three masts of 5 (EC equipment), 6 (psychrometers) and 10 (anemometers + thermocouples) metres height. The slow data were processed with Campbell 21-X dataloggers, the fast were processed by p.c.'s. All raw and calculated data were stored on tapes.

3. MODEL DESCRIPTION

In this section we will describe briefly the various SVAT models used in this study. For more detailed information the reader is referred to the cited papers as well as to Van den Hurk et al. (1994).

3.1. THE MODEL OF CHOUDHURY-MONTEITH

The model of Choudhury and Monteith (1988) (CM88), can be regarded as an extension of the model by Shuttleworth and Wallace (1985). Two components are distinguished: a canopy layer and the underlying bare soil. In CM88 soil heat flux density and the resistance regulating soil evaporation are explicitly parameterized. The radiant energy available to the canopy is parameterized as total net radiation minus soil heat flux density and minus the net radiation reaching the bare soil. Measured values of total net radiation are needed as forcing. The partition of available energy over sensible and latent heat flux is solved using the Penman-Monteith equation.

In the soil two layers are present, of which the lowest is assumed to be saturated with water. Soil evaporation takes place at the intersection of the two layers (depth z). The transfer of water vapour through the upper soil layer is regulated by a resistance, proportional to depth z and water diffusivity. The soil heat flux density is parameterized using the temperature difference at the surface and depth z and a resistance, which is a function of the soil heat conductivity and depth z . The depth z increases at a rate proportional to the soil evaporation rate, in order to simulate the retreat of the saturated zone as soil water is evaporated into the air. The Penman-Monteith equation is used to

solve simultaneously for the surface temperature, temperature at depth z , the soil heat flux and soil evaporation. The soil layers have no heat capacity.

It is assumed that momentum and scalars are transferred by the same mechanism. An aerodynamic resistance between the canopy air and the substrate is introduced, which depends on the roughness length of the bare soil surface, and which is parameterized assuming an exponential decay of the eddy diffusivity within the canopy layer. The level between the canopy and the soil sources is regarded to be the effective level of the momentum sink. This level varies with LAI and canopy height (Shaw and Perreira, 1982). A boundary layer resistance between the leaf surface and the canopy air is also introduced, reflecting the absence of bluff body forces for heat and water vapour exchange. No equivalent resistance is present in the pathway between the canopy air and the soil surface.

3.2. THE MODEL OF DEARDORFF

In modified form the scheme of Deardorff (1978) (D78) is in use in various GCM's (Dickinson et al., 1986; Noilhan and Planton, 1989). As in CM88, a dual-source surface is postulated in D78: a canopy layer and the underlying soil. The net radiation is computed, whereas in CM88 the measured value is taken. Separate energy balances are drawn up for the canopy and the substrate, and the incoming radiant energy is distributed over the two components using the fraction of vegetation cover. The canopy temperature T_g is evaluated iteratively, while the soil temperature T_g is predicted from the previous time step, where a rate of change of T_g is computed. A weighting procedure is used to obtain the temperature and humidity deficit within the canopy layer, and use is made of the explicit values of the temperature and humidity at the soil surface, the canopy surface and the reference level. This weighting is included in the iterative solution of the radiation balance.

The boundary layer resistance for heat and water vapour exchange between the canopy air and the canopy surface is treated somewhat more rigorously than in CM88. The aerodynamic exchange within the canopy is parameterized as a weighted average for the exchange of a completely bare soil and for a dense canopy using u_* as the characteristic wind speed within the canopy. The analytic stability correction of Louis (1979) is used for the aerodynamic resistance above the canopy.

Soil evaporation is treated as function of the relative humidity in the top soil layer. Both the soil heat and soil moisture transport are described with the force-restore method by Bhumralkar (1975). A forcing of the sensible heat and moisture transport at the surface is modified by a restoring term depending on the temperature and soil moisture deeper in the soil. Both the forcing and restoring term are functions of coefficients which depend on the soil type and moisture content (Noilhan and Planton, 1989)

3.3. THE COMBINED MODEL

A comparison with our data collected at the savannah site in the framework of HAPEX-SAHEL revealed that CM88 underestimates the soil heat flux, while this important term of the surface energy balance is described satisfactorily by D78. On the other hand the description of the various resistances by CM88 appears to be better than that used in D78. On the basis of these results we constructed a combined model consisting of the best parts of D78 and CM88 (Annex I). In this paper some results of the combined model are presented.

4. RESULTS AND DISCUSSION

In Figures 1 to 4 a comparison for net radiation, latent, sensible and soil heat flux density is made between model simulations and observations. Also, in figure 4 the simulated soil heat flux in CM88 is depicted.

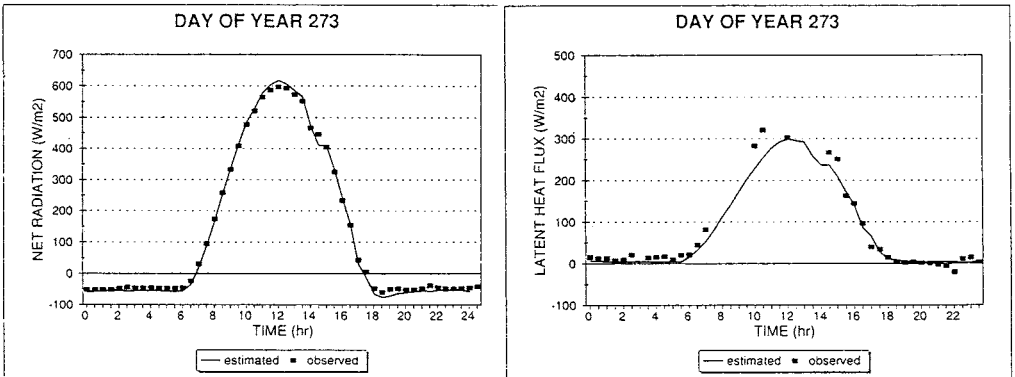


Fig.(1); Estimated net radiation by the combined model compared to observed values.

Fig.(2); Estimated latent heat flux by the combined model compared to observed values.

These results refer to 9 days after the last rainfall. It is seen that the combined model describes net radiation and latent heat flux fairly well. The results for sensible heat are less satisfactory. The combined model, which is using (as D78) the force-restore method by Bhumralkar (1975), describes soil heat flux considerably better than CM88. It should be noted that in our case of a sparse savannah vegetation, soil heat flux is an important term of the surface energy balance.

At present, the flux of CO₂ is not described in the combined model. In the near future we will include this very important feature, making use of the results by Verhoef et al. (1994), Moncrieff et al. (1994) and Jacobs (1994).

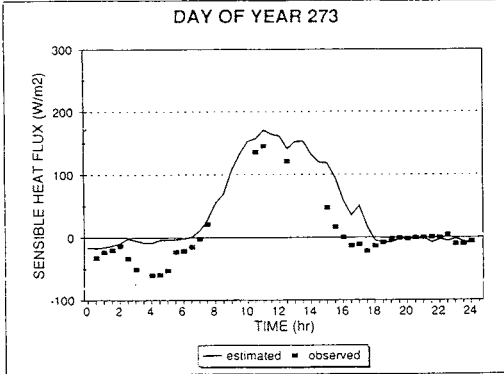


Fig.(3); Estimated sensible heat flux by the combined model compared to observed values.

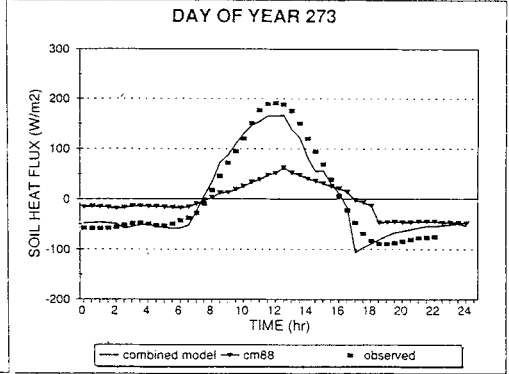


Fig.(4); Estimated soil heat flux by the combined model and CM88 compared to observed values.

ACKNOWLEDGEMENTS

We thank Ad van den Berg for his assistance. We are grateful to everybody involved in the 1992 HAPEX-SAHEL field campaign. The first author received a grant of NWO/MFO (NWO 750.650.37). The EU (former CEC) supported a part of this research (EPOC-0024-C(CD) and EV5V-CT91-0033). Also, the Dutch National Research Programme on Global Air Pollution and Climate change financed part of this project.

REFERENCES

- Bhumralkar, C.M.** (1975): Numerical experiments on the computation of ground surface temperature in an atmospheric general circulation model; *J. Appl. Meteorol.* **14**, 1246-1258.
- Choudhury, B.J. and Monteith, J.L.** (1988): A four-layer model for the heat budget of homogeneous land surfaces; *Q.J.R. Meteorol. Soc.* **114**, 373-398.
- Deardorff, J.W.** (1978): Efficient prediction of ground surface temperature and moisture, with inclusion of a layer of vegetation; *J. Geophys. Res.* **83**, 1889-1903.
- Dickinson, R.E., et al.**, (1986): Biosphere-Atmosphere Transfer Scheme (BATS) for the NCAR Community Climate Model; NCAR Technical Note NCAR/TN-275+STR, 69 pp.
- Gourtope, J-P, et al.**, (1994): HAPEX-Sahel: a large scale study of land atmosphere interactions in the semi-arid tropics; *Annales Geophysicae* **12**, 53-64.
- Jacobs, C.M.J.** (1994): Direct impact of atmospheric CO₂ enrichment on regional transpiration; Wageningen Agric. Univ., The Netherlands; 179 pp.

Louis, J.-F. (1979): A parametric model of vertical eddy fluxes in the atmosphere; *Boundary-Layer Meteorol.* **17**, 187-202.

Moncrieff, J.B., et al. (1994); Submitted for publication to Special Issues (HAPEX-SAHEL), *J. of Hydrol.*

Monteith, J.L. (1965): Evaporation and the environment; *Symp. Soc. Exp. Biol.* **19**, 205-234.

Noilhan, J. and Planton, S. (1989): A simple parameterization of land surface processes for meteorological models; *Monthly Weather Rev.* **117**, 536-549.

Shaw, R.H. and Pereira, A.R. (1982): Aerodynamic roughness of a plant canopy: a numerical experiment; *Agric. Meteorol.* **26**, 51-65.

Shuttleworth, W.J. and Wallace, J.S. (1985): Evaporation from sparse crops - an energy combination theory; *Q.J.R. Meteorol. Soc.* **111**, 839-855.

Van den Hurk, B.J.M. et al., (1994): An intercomparison of 3 vegetation/soil model for a sparse vineyard canopy; Submitted for publication to *Q.J.R. Meteorol. Soc.*

Verhoef, A. et al., (1994); Submitted for publication to *Agric. Meteorol.*

ANNEX I

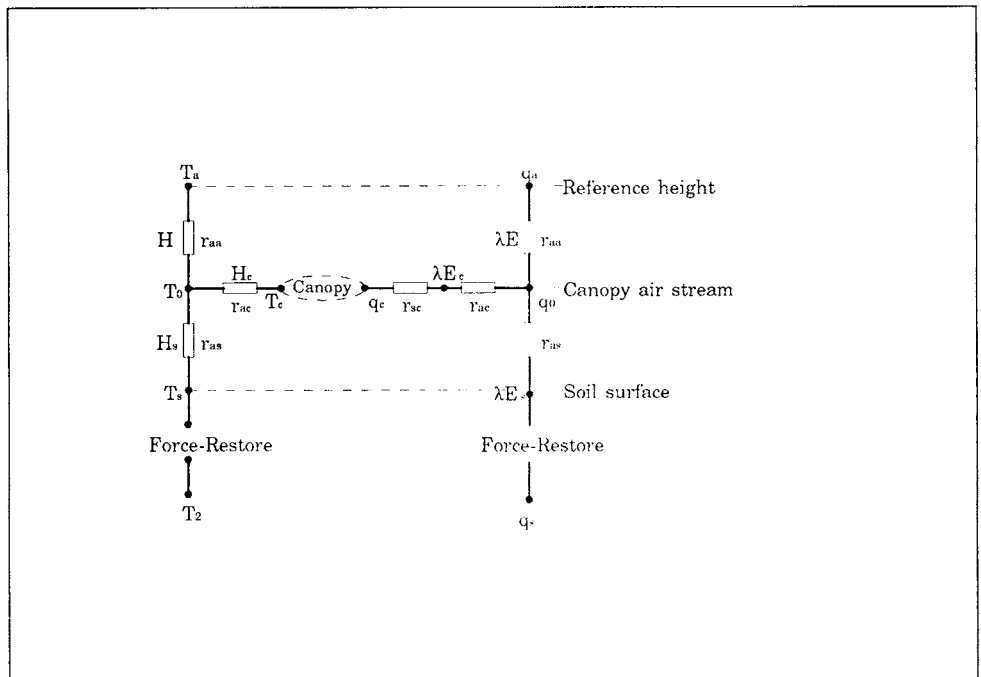


Fig.(5); Schematic diagram of the Combined Model.