SIMULATION OF AIR TEMPERATURE INSIDE THE SUNFLOWER CANOPY BY THE LAND-AIR PARAMETERIZATION SCHEME

Dragutin T. Mihailovic, **Branislava Lalic** and **I. Arsenic**, Faculty of Agriculture, Department of Field and Vegetable Crops, University of Novi Sad and Research Institute of Field and Vegetable Crops, Novi Sad, Serbia and Montenegro
E-mail: guto@polj.ns.ac.yu
E-mail: branka@polj.ns.ac.yu
E-mail: ilija@polj.ns.ac.yu

Abstract

The Land-Air Parameterization scheme (LAPS) describes water vapor, heat and momentum transfer between the land surface and the atmosphere. The scheme is designed as a software package that can be run as part of an atmospheric, hydrological or ecological model, or as a stand-alone model that operates with seven prognostic variables and 16 morphological and physiological input parameters. Such a large number of parameters provide a reliable simulation of diurnal courses of meteorological elements inside the crop. In this paper, the LAPS scheme has been used for simulating the diurnal course of air temperature inside a sunflower field. Model outputs of air temperature inside the canopy for 18-24 July 1998 are compared with micrometeorological measurements inside a sunflower field at the Rimski Sancevi experimental site (Serbia). The benefit of using this scheme is evident for a broad range of practical and scientific activities in environmental and closely related sciences, such as the biophysical parameterization of vegetation in atmospheric, ecological and agricultural models of all scales, the designing of biometeorological systems for giving the information regarding the occurrence of plant diseases, microclimate simulation and particle movement in the plant environment.

Introduction

Recently, highly sophisticated land surface schemes have become a powerful tool in the attempts of meteorologists, ecologists, and agronomists to: (i) improve the weather and climate simulation; (ii) design biometeorological systems for giving the information regarding the occurrence of plant diseases; (iii) explore the potential climatic impacts of vegetation change; (iv) predict the microclimate of crops in fields or inside greenhouses; and (v) parameterize spore, pollen and particle movement within and just above the canopy for the purposes of biological and ecological models (Mihailovic et al., 2002; Mihailovic et al., 2001; Pingtong and Hidenori, 2000; Szabo and Eitzinger, 1998; Zhang et al., 1997; Pielke et al., 1997; Lalic and Mihailovic, 1998; Sato et al., 1989; Sellers et al., 1989). The role of these schemes in ecology is described in a paper by Svirezhev (1998) that deals with an axiomatic system in ecological modeling based on an earlier concept of biosphere. There are a vast number of papers devoted to the sensitivity schemes to their variables. Soil-plant parameters are needed in atmospheric, hydrological, ecological, and agricultural models that require accurate description of the surface energy and water fluxes to assure the realistic simulation of partitioning the available energy into sensible and latent heat fluxes as well as the cycling of carbon through different organic and inorganic phases (Sellers and Dorman, 1987; Laval, 1988; Mihailovic et al., 1995; Henderson-Sellers, 1996; Mihailovic and Kallos, 1997; Mihailovic et al. 1999; Mihailovic et al., 2000). However, these tests all considered the sensitivity of the scheme prognostic variables rather than the diagnostic ones, which are also required for calculating the latent and sensible heat fluxes inside the plant environment. For example, there were no tests carried out indicating the reliability of air temperature inside the canopy, calculated diagnostically by some surface schemes. This would be especially important in research on crop microclimate, interactions between plants and the aerial environment (Sinoquet and Le Roux, 2000), calculating the fluxes from vegetated surfaces as well as in plant protection forecasts (Mihailovic et al., 2001).

Due to this limited knowledge our paper will be focused on the question of how well the LAPS scheme (Mihailovic et al., 2000; Mihailovic et al., 1999; Mihailovic and Kallos, 1997; Mihailovic, 1996) reproduces the diurnal temperature variations inside the sunflower canopy. The results obtained are compared with the results of micrometeorological measurements inside a sunflower crop grown at the Rimski Sancevi Experiment Field of the Institute of Field and Vegetable and Crops in Novi Sad, Serbia.

Materials and Methods

Scheme and Basic Equations. The LAPS scheme describes the interaction of the land surface with the atmosphere, as a result of the processes that can be divided into the following three sections: subsurface thermal and hydraulic processes; bare soil transfer processes; and canopy transfer processes. These processes are interaction of the vegetation with radiation, evaporation from bare soil, evapotranspiration (which includes transpiration and evaporation of intercepted precipitation and dew), conduction of soil water through the vegetation layer, vertical water movement in the soil, runoff, heat conduction in the soil, and momentum transport (Mihailovic et al., 1993; Mihailovic et al., 2000; Mihailovic and Kallos, 1997; Mihailovic, 1996). The LAPS scheme uses 16 morphological and physiological plant input parameters for deriving the coefficients and resistances governing all fluxes inside and above the plant canopy.

The prognostic equations for the canopy temperature, Tf, and the soil surface temperature, Tg and deep soil temperature Td, are

$$(C_f \, \partial T_f / \partial t = R_{netf} - H_f - \lambda E_f \quad [1]$$

$$C_g \, \partial T_g / \partial t = R_{netg} - H_g - \lambda E_g - G \quad [2]$$

$$C_g \, \partial T_d / \partial t = 2(R_{netg} - H_g - \lambda E_g - G) / (365\pi)^{1/2} \quad [3]$$

where C is the heat capacity, R_{net} the sum of short wave radiation and effective long wave radiation, H the sensible heat flux, G the soil heat flux and λE the latent heat flux. The subscript f refers to the canopy, g to the soil surface. The soil heat flux is parameterized using the force-restore method (Mihailovic et al., 1999).

The prognostic equation for the water stored on the canopy surfaces, w_f is

$$\partial w_f / \partial t = P_f - E_{wf} / \rho_w, \quad [4]$$

where ρ_w is the density of water, P_f the amount of water retained on the canopy, E_{wf} the evaporation of water from the wetted fraction of canopy. When the conditions for dew formation are satisfied, the condensed moisture is added to the interception store, w_f. The parameterisation of the soil water content is based on the concept of the three-layer model. The governing equations take the following form

$$\partial w_1 / \partial t = \{P_1 - F_{1,2} - (E_g + E_{tf,1}) / \rho_w - R_0 - R_1\}/D_1 \quad [5]$$

$$\partial w_2 / \partial t = \{ F_{1,2} - F_{2,3} - E_{tf,2} / \rho_w - R_2\}/D_2 \quad [6]$$

$$\partial w_3 / \partial t = \{ F_{1,2} - F_3 - R_3\}/D_3 \quad [7]$$

where w_1 is the volumetric soil water content in the ith layer, Pl the infiltration rate of precipitation into the upper layer of soil water store, D_i the thickness of the ith soil layer, $Fi,i+1$ the water flux between i and $i+1$ soil layer, $F3$ the gravitational drainage flux from recharged soil water store, Eg the evaporation from the soil surface, $Etf,1$ and $Etf,2$ the canopy extraction of soil water by transpiration from the first and the second soil layer, respectively, $R0$ the surface runoff and Ri the subsurface runoff from the ith soil layer. Detailed parameterization of terms in Equations 1 through 7 can be found in Mihailovic (1996). Equations 1 through 3 are solved using an implicit backward scheme while Equations 4 through 7 are solved using an explicit time scheme.

Results and Discussion

Numerical Experiments. To examine how successfully the foregoing proposed model supports simulation of the air temperature inside a tall grass canopy, a test was performed using the LAPS land surface scheme described in Mihailovic et al. (2000) and Pielke (2002). LAPS outputs of air temperatures inside the canopy for ten days (8-17 July 2002) were compared with single-point micrometeorological measurements over a sunflower field at the Rimski Sancevi experimental site in Serbia. In the numerical experiments we used a data set from a measurement program that examined the exchange processes of heat, mass, and momentum just above and inside a sunflower canopy during its growing season. The experimental site (270 m x 68 m) is located in the northern part of Serbia (45.3°N, 19.8°E) on a chernozem soil of the loess terrace of southern Backa with the following physical and water properties: Clapp-Hornberger constant, 6.50; ground emissivity: 0.97; heat capacity of the soil fraction: 780 J/ kg/C; saturated hydraulic conductivity: 32 x 10.3 m/s; soil moisture potential at saturation:0.036 m; soil density: 1,290 kg/m/cubed; ratio of saturated thermal conductivity to that of loam: 1.0; volumetric soil moisture content at saturation: 0.52; volumetric soil moisture content at field capacity: 0.36; wilting point volumetric soil moisture content: 0.17; and effective ground roughness length: 0.01 m. The experimental site was surrounded by other agricultural fields also sown with sunflowers. The sunflower rows were oriented north to south, with row spacing of 0.70 m. This data set was chosen because it was considered typical and representative of a fully developed sunflower crop.

For the 8-17 July period the mean estimated leaf area index was 3.0; the crop height, H, was around 1.99 m; and the canopy bottom height, h, was 0.100 m. The extinction factor β, the zero plane displacement and roughness length were calculated according to Mihailovic and Kallos (1997). In these calculations the area-averaged stem and leaf area density had a value of 1.59/m, while a value of 0.2 was used for the leaf drag coefficient. We calculated the following values: $\beta = 6.578$ and $d = 1.54$ m. Since the minimum stomatal resistance was not measured, we assumed it to be 40 s/m. The fractional vegetation cover was 0.90. Other parameters used in the simulation can be found in Mihailovic et al. (2000).

Temperatures were measured using platinum resistance thermometers (Pt-100) set at 0.95 and 2.1 m above the ground. The wind speed at the reference level of $zy = 2.1$ m was measured using a Vector Instruments anemometer. A Kipp Zonen CM5 solarimeter was used to measure incoming solar radiation; while relative humidity was recorded using a Greisinger sensor set at 2.1 m. Precipitation was measured by an electronic rain gauge manufactured at the Institute of Physics in Belgrade. Soil temperature was measured at 0.05, 0.1, and 0.2-m depths. In all data sets, the atmospheric boundary conditions at $zr = 2.1$ m were derived from measurements of global radiation, precipitation, relative humidity, and wind for 24 hours from 0000 LST at 30-min intervals. The longwave atmospheric counterradiation was calculated via an empirical formula described in Mihailovic et al. (1995), including a correction for the amount of cloudiness. Cloudiness data were taken at 30-min intervals from the nearest standard meteorological station, Rimski Sancevi, which is 500 m away from the experimental site. These values were interpolated to the beginning of each time step (Δt = 120 s). The thickness of soil layers was defined as $D1$ = 0-0.1 m, $D2$ = 0.1-0.5 m, and $D3$ = 0.5-1 m. The initial conditions for the volumetric soil moisture contents corresponding to these layers were $w1 = 0.16$, $w2 = 0.15$, and $w3 = 0.13$. At the initial time the ground temperature, Tg, was 292.68 K. The initial condition for atmospheric pressure was 100.53 kPa. The temperature inside the canopy air space in the scheme is determined diagnostically from the energy balance equation, representing the equality of the sensible heat flux from the canopy to some reference level in the atmosphere, and the sum of sensible heat flux from the ground and sensible heat flux from the leaves to the canopy air volume (Mihailovic, 1996). In these calculations the three aerodynamic resistances are calculated as in Mihailovic et al. (2002), Mihailovic and Kallos (1997) and Mihailovic (1996), while the canopy source height, ha (Sellers et al., 1986), has been calculated using the expression $ha = H\{1+2/\beta[1+exp\ (\beta/(H/h-1))/2]\}$, suggested by Mihailovic and Rajkovic (1993). After substituting the foregoing values of parameters in the expression for ha we found its numerical value of 1.1 m.

The validity of the LAPS-simulated air temperature inside the canopy was tested against the observations recorded by the platinum resistance thermometer located at 0.95 m at 30-min intervals during 8-17 July 2002. Figure 1 depicts the calculated and observed diurnal variations of air temperature inside the sunflower canopy at the experimental site. After midnight, the simulated values are lower than the observations, while in the early afternoon the simulated values are higher than the observed ones. This situation occurs because at night LAPS simulates less heat transfer from the ground into the canopy air space than the observations indicate. In contrast, during the afternoon the scheme calculates a lower amount of evapotranspiration, which in some days results in a higher leaf temperature and consequently a higher air temperature inside the sunflower canopy.

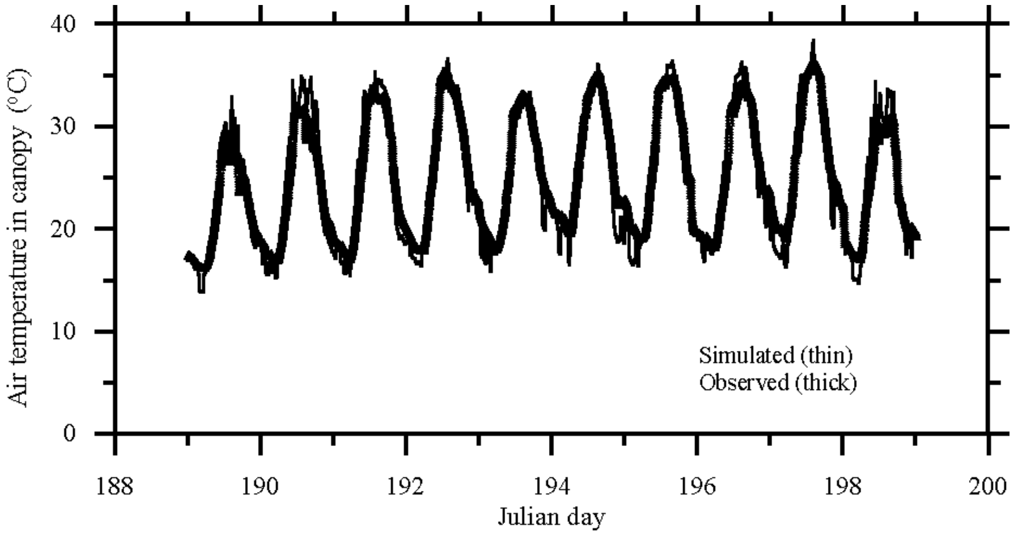

Figure 1. Ten-day variation (8-17 July 2002) of the air temperature simulated by LAPS and observed inside a sunflower canopy at the Rimski Sancevi site.

Acknowledgments

This research was supported by the New York State Energy Research and Development Authority under contractual agreement NYSERDA 4914-ERTER-ES-99. The research was also supported by the Serbian Ministry for Science and Technology under contracts BTR.S.02.0401.B and BTR.S.02.0427.B. The investigators would like to thank Dr. S.T. Rao for making valuable comments.

References

Henderson-Sellers, A. 1996. Soil moisture simulation: Achievements of the RICE and PILPS intercomparison workshop and future directions. Global and Planetary Change. 13:99-115.

Lalic, B. and D.T. Mihailovic. 1998. Derivation of aerodynamic characteristics using a new wind profile in the transition layer above the vegetation. Research Activ. in Atmos. and Oceanic Modelling, Rept. 27:4.17-4.19.

Laval, K. 1988. Land surface processes. *In*: Physically based modelling and simulation of climate and climatic change - Part 1. M.E. Schlesinger (Ed.), Kluwer Acad. Pub., Dordrecht, p. 285-306.

Mihailovic, D.T. 1996. Description of a land-air parameterization scheme (LAPS). Global and Planetary Change. 13:207-215.

Mihailovic, D.T. and G. Kallos. 1997. A sensitivity study of a coupled soil-vegetation boundary layer scheme for use in atmospheric modelling. Boundary-Layer Meteorol. 82:283-315.

Mihailovic, D.T. and B. Rajkovic. 1993. Surface vegetation parameterization in atmospheric models: A numerical study. Meteor. Z. 2:239-243.

Mihailovic, D.T., G. Kallos, I. Arsenic, B. Lalic, B. Rajkovic, and A. Papadopoulos. 1999. Sensitivity of soil surface

temperature in a force-restore equation to heat fluxes and deep soil temperature. Int. J. of Climatol. 19:1617-1632.
Mihailovic, D.T., I. Koci, B. Lalic, I. Arsenic, D. Radlovic, and J. Balaz. 2001. The main features of BAHUS - biometeorological system for messages on the occurrence of diseases in fruits and vines. Environ. Model. Software (accepted).
Mihailovic, D.T., B. Lalic, I. Arsenic, J. Eitzinger, and N. Dusanic. 2002. Simulation of air temperature inside the canopy by the LAPS surface scheme. Ecol. Modelling. 16:691-696.
Mihailovic, D.T, T.J Lee, R.A Pielke, B. Lalic, I.D. Arsenic, B. Rajkovic, and P. L. Vidale. 2000. Comparison of different boundary layer surface schemes using single point micrometeorological field data. Theor. Appl. Climatol. 3/4:135-151.
Mihailovic, D.T., R.A. Pielke, B. Rajkovic, T.J. Lee, and M. Jeftic. 1993. A resistance representation of schemes for evaporation from bare and partly plant-covered surfaces for use in atmospheric models. J. Appl. Meteor. 32:1038-1054.
Mihailovic, D.T., B. Rajkovic, B. Lalic, and Lj. Dekic. 1995. Schemes for parameterizing evaporation from a non-plant-covered surface and their impact on partitioning the surface energy in land-air exchange parameterisation. J. Appl. Meteor. 34: 2462-2475.
Pielke, R.A. 2002. Mesoscale Meteorological Modeling. Second Edition. Academic Press, New York. . 676 pp.
Pielke, R.A., T.J. Lee, J.H. Copeland, J.L. Eastman, C.L. Ziegler, and C.A. Finley. 1997. Use of USGS-provided data to improve weather and climate simulations. Ecological Appl. 7:3-21.
Pingtong, Z. and T. Hidenori. 2000. A first order closure model for the wind flow within and above vegetation canopies. Agric. For. Meteor. 103:301-313
Sato, N., P.J. Sellers, D.A. Randal, K. Schneider, J. Shukla, J.L. Kinter III, Y.-T. Hou, and E. Albertazzi. 1989. Effect of implementing the simple biosphere model in a general circulation model. J. Atmos. Sci. 46: 2757-2782.
Sellers, P.J. and J.L. Dorman, 1987. Testing the simple biosphere model (SiB) using point micrometeorological and biophysical data. J. Clim. Appl. Meteorol. 26: 622-651.
Sellers, P.J., Y. Mintz, Y.C. Sud, and A. Dalcher. 1986. A simple biosphere model (SiB) for use within general circulation models. J. Atmos. Sci. 43: 505-531.
Sellers, P.J., W.J. Shuttleworth, J.L. Dorman, A. Dalcher and J.M. Roberts. 1989. Calibrating the simple biosphere model for Amazonian tropical forest using field and remote sensing data: Part 1. Average calibration with field data. J. Appl. Meteorol. 28: 727-759.
Sinoquet, H., and X. Le Roux. 2000. Short term interactions between tree foliage and the aerial environment: An overview of modelling approaches available for tree structure-function models. Ann. For. Sci. 57:477-496 .
Svirezhev, M.Y. 1998. Globalistics: a new synthesis Philosophy of global modelling. Ecol. Model. 108:53-65.
Szabo, M. and J. Eitzinger. 1998. Evaluierung eines Simulationsmodells zur Berechnung der Klimaparameter in einem Glashaus spezifischer Ausfuehrung. Wetter und Leben. 50:53-64.
Zhang, Y., Y. Mahrer, and M. Margolin. 1997. Predicting the microclimate inside a greenhouse: an application of a one-dimensional model in an unheated greenhouse. Agric. For. Meteorol. 86:291-297.