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MODELING SURFACE FLUXES OVER A SPARSE VEGETATION

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Abstract - In this paper some of aspects in modeling over sparse vegetation using the Land-Air Parameterization Scheme (LAPS), including an approach in calculating the turbulent transfer coefficient using "K-theory" inside a sparse vegetation canopy, were considered. For this purpose, the scheme was run for different sparse agricultural cultivars, i.e., apple orchard, winter wheat and soybean crops, at different sites. The modeled values for surface fluxes, canopy temperature and soil moisture content, were compared with observations.

Keywords: Turbulence, orchard, surface scheme, sparse vegetation, transpiration

INTRODUCTION

In cases when a homogenous but sparse vegetation canopy covers the land, fluxes from the soil surface and vegetation occur. The interaction between soil surface and vegetation canopy fluxes are proven experimentally and numerically. For example, there exists considerable evidence for sparse vegetation that: (i) the sensible heat flux generated at the soil surface accounts for one third of the energy available for transpiration, and that (ii) stomatal resistance exerts a significant influence on soil evaporation in a sparse vegetation canopy due to internal feedbacks in the soil-vegetation canopy system. Therefore, modeling the surface fluxes inside and over a sparse vegetation canopy is of great importance. Bauerle and Bowden (2011) used a spatially explicit mechanistic model to separate key parameters affecting transpiration to provide insights into the most influential parameters for accurate predictions of within-crown transpiration, particularly for sparse vegetation. Additionally, they tried to assess the vertical profile of leaf-to-atmosphere sensitivity of transpiration to independent variations in leaf morphology and physiology parameters among genotypes of a forest tree species with known differences in leaf morphology and physiology in an attempt to better understand key parameters for larger scale transpiration models.

Use of the sophisticated new-generation soil-vegetation-atmosphere transfer (SVAT) schemes (see, for example, Friedl, 2002) gives us many opportunities in modeling surface fluxes inside and over vegetation, in particular for sparsely distributed vegetation. In their study, Dirmeyer et al. (2011) tried to determine to what accuracy soil moisture must be known in order to simulate surface energy fluxes within this observational uncertainty, and whether there is a firm relationship between the variabilities of soil moisture and surface energy fluxes. Such a relationship would provide information for planning the future measurement of soil moisture, the design of field experiments, and points of focus for soil model development. They looked for relationships in three different land surface schemes and found that the evaporative fraction (EF; the ratio of latent heat flux to the sum of the latent plus sensible heat fluxes) can be measured in the field to an accuracy of about 10%. Further, it was found that where vegetation is sparser, there exists a more gradual decrease of EF sensitivity with a decrease in soil moisture. Bare soil desert areas behave similarly to sparsely vegetated areas but with lower peak EF. Tundra regions have a unique behavior, probably because evaporation is limited more by a lack of radiant energy at high latitudes. The results suggest that accuracy in the measurement or model simulation of soil moisture is most critical within the drier portion of the range of variability of soil moisture. It is also more important over sparsely vegetated areas, for which evapotranspiration is dependent on moisture in a shallower column of soil.

While significant progress has been made in the parameterization of land surface processes within the SVAT schemes, remote sensing-based methods for initializing, updating, and validating land surface-state variables within these models remain inadequate. In particular, virtually all of the dynamic components of land surfaces that influence and interact with the atmosphere are treated as prognostic variables within SVAT models (e.g., soil moisture and surface temperature). Therefore, a need exists for operational methods to monitor key variables such as vegetation density, soil moisture status, surface temperature, and energy fluxes at spatial and temporal scales that are commensurate with the needs of large-scale hydrologic and atmospheric circulation models. In a paper by Friedl (2002), a two-layer energy balance model designed for use with thermal remote sensing is described. Using this model it was found that second-order effects related to feedbacks between the surface radiation and energy balance can be dramatic for sparse vegetation canopies, even when the vegetation is only moderately stressed.

Considerable research in the last decade addresses various aspects of modeling many complex land-atmosphere processes on small, medium, or large scales, using new methodologies and approaches, numerical methods and software techniques (Walko, 2000; Xiu and Pleim, 2001; Mihailović et al., 2004). In many of these models, calculating the turbulent fluxes inside and over a vegetation canopy requires the specification of turbulent transfer coefficients for momentum, heat, and water vapor inside the canopy. In the last two decades, their parameterization has been considered by many authors (Lalić et al., 2003; Mihailović et al., 2004, among others). These works have remarkably improved the parameterization of energy, mass, and momentum exchange inside different plant communities in land surface schemes, making them more relevant 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 (Lalić and Mihailović, 2004; Pingtong and Hidenori, 2000; Pinard and Wilson, 2001). Many current vegetation-atmosphere and environmental models, however, require a more reliable approach for modeling turbulent fluxes inside vegetation canopies, particularly in the case of sparse vegetation canopies i.e., those in which the plant spacing is on the order of the canopy height or larger.

The objective of this work was to consider the use of the land surface scheme in modeling surface fluxes and temperatures inside and over a sparse vegetation canopy with a sophisticated approach for calculating the turbulent transfer coefficient inside a vegetation canopy since it remarkably determines the calculation of surface fluxes. This subject was elaborated through the following steps: (i) description of the method used for calculation of the turbulent transfer coefficient inside a vegetation canopy; (ii) description of the test sites, (iii) evaluation of the method used by the Land-Air Parameterization Scheme (LAPS), and (iv) discussion and comments on the obtained results.

MATERIALS AND METHODS

In this section, the method for calculating the turbulent transfer coefficient inside the sparse vegetation canopy used in this paper in terms of its ability to realistically and accurately simulate biophysical processes over a number of test sites for which data were available for validation, is considered. First, the method of calculation the turbulent transfer coefficient inside a sparse vegetation canopy is shortly described. Second, the LAPS surface scheme (Mihailović et al., 2000; Pielke Sr., 2002) used in numerical tests is reviewed in the main features.

It was started with the equation for calculating the turbulent transfer coefficient inside a sparse vegetation canopy in land-atmosphere schemes (Mihailović et al., 2004).

$$\frac{d}{dz}\left(K_s \frac{du}{dz}\right) = \sigma_f \frac{C_d \bar{L}_d (H-h)}{H} u^2 \tag{1}$$

where: z is the vertical coordinate, K_s the turbulent transfer coefficient inside the canopy, u the wind speed inside the canopy, σ_f the fractional vegetation cover (a measure of how sparse the tall grass is), C_d the leaf drag coefficient, L_d the area-averaged stem and leaf area density (also called canopy density), H the canopy height and h the canopy bottom height (the height of the base of the canopy, see Fig. 1). Equation (1) is solved to obtain u. However, the inadequacy of these approaches lies in the fact that the behavior of K_s must be given *a priori*, i.e. presupposed by experience. In contrast to that it is changed the order of steps in calculation of the turbulent transfer coefficient inside a sparse vegetation, i.e. it is solved Eq. (1) for K_s after assuming a functional form of solution for wind speed inside a vegetation canopy that will be obtained iteratively (Mihailović et al., 2006). The final equation has the form:

$$\frac{dK_s}{dz} + a(z)K_s = b(z) \tag{2}$$

where $a(z)$ and $b(z)$ are coefficients that depend on plant morphology (Mihailović et al., 2006).
For the fixed attenuation factor, Eq. (2) can be solved using the finite-difference scheme:

$$K_s^{n-1} = K_s^n - \Delta z\left\{b^n(z) - a^n(z)K_s^n\right\} \tag{3}$$

where n is the number of the spatial step in the numerical calculating on the interval $[H,h]$ while Δz is the grid size defined as $\Delta z = (H-h)/N$, where N is a number indicating an upper limit in the number of grid sizes used. The turbulent transfer coefficient calculation starts from the canopy top then goes backward to the canopy bottom height, h, that is defined according to Mihailović et al. (2004). To obtain parameter of attenuation an iterative procedure for this parameter is used that is not finished until the condition

$$\left|\sum_{k=1}^{K} u_i^{k+1} - \sum_{k=1}^{K} u_i^{k}\right| < \mu \tag{4}$$

is reached, where K is number of iteration, while μ is less than 0.001. With this parameter, the wind profile, on the interval $[H,h]$, is calculated according to the expression (21) in Mihailović et al. (2006).

The fluxes and other meteorological and soil moisture quantities are calculated numerically using the LAPS scheme that calculates energy fluxes. This scheme is designed as a software package that can be run as part of an environmental model or as a stand-alone one. It includes modeling the interaction of the land surface and the atmosphere under processes divided into three sections: subsurface thermal and hydraulic processes, bare soil transfer processes and canopy transfer processes. The scheme has seven prognostic variables: three temperature variables (canopy, soil surface and deep soil), one interception storage variable, and three soil moisture storage variables. For the upper boundary conditions, seven meteorological variables are used at a reference level within the atmospheric boundary layer. The structure of the LAPS scheme is shown schematically in Fig. 1. Basically, the upper-story canopy and ground surface are considered to interact with conditions in the canopy air space via aerodynamic resistances: the bulk boundary layer resistance for the canopy leaves, r_b the aerodynamic resistance between the soil surface and the canopy source height, r_d surface resistances, r_c and r_{surf} which relate to the upper-story canopy and bare soil, respectively, while the soil and plant resistances are r_{surf} and plant r_{plant} . (The over bars in r_b and r_c mean that these terms are area-averages). Finally, the canopy is considered to interact with the conditions in the atmosphere via the aerodynamic resistance r_a , i.e., resistance between canopy air space and reference height and e_r . When the foliage is dry, the canopy resistances r_b and r_c are calculated assuming that all the individual stomatal and boundary layer leaf resistances act in parallel. The fluxes' sensible and latent heat from canopy and soil are represented by an electrical analog model in which the fluxes are proportional to potential differences (in temperature or water vapor pressure) and inversely proportional to resistances, which are equivalent to the inverse integrals of conductance over a specified length scale. In this figure the symbols introduced are: $e_*(T_f)$ the saturation water vapor pressure at the canopy temperature T_f , e_a the water vapor pressure of the air in the canopy, σ_s the factor to correct soil dryness, $e_*(T_g)$ the saturation water vapor pressure at the soil surface temperature T_g , while T_a is the canopy air temperature. Finally, T_r and e_r are the air temperature and the water vapor pressure at reference height, z_r . The parameterization of fluxes: (i) sensible heat fluxes (H_g , H_f , $H_g + H_f$), (ii) latent heat fluxes (λE_g , λE_f , $\lambda E_g + \lambda E_f$), (iii) resistances and (iv) the hydrological part of the LAPS scheme, that is not described here, can be found in Mihailović et al. (2004).

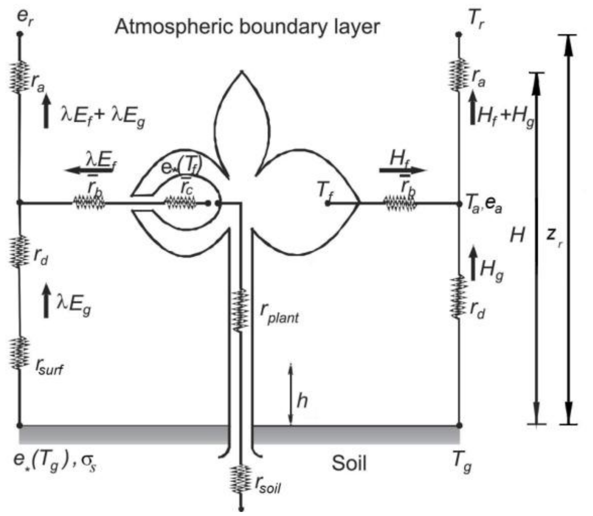

Fig. 1. Schematic diagram of the Land-Air Parameterization Scheme (LAPS). The transfer pathways for latent sensible heat fluxes are shown on the left - and right-hand sides of the diagram, respectively.

RESULTS AND DISCUSSION

This part comprises the following steps: (i) information about the experimental sites and the types of data that were available for each one; (ii) results of simulation runs conducted for each of the test sites, and (iii) comparison results obtained and observations with the accompanying discussion.

Data for the evaluation of the fluxes calculated using the aforementioned method for the turbulent transfer coefficient, as well as meteorological quantities important for the process of the transpiration from a sparse vegetation (canopy temperature, soil surface temperature and soil moisture), were available from the following sites: (i) the maize from De Sinderhoeve, The Netherlands (surface fluxes, canopy temperature), (ii) the apple orchard, rapeseed and spring wheat from Chlewiska, Poland (surface fluxes) and (iii) soybean from Caumont, France (soil moisture content).

The first set for comparisons was a data set that is part of a larger measurement program that examined the exchange processes of heat, mass and momentum just above and inside a maize canopy during its growing season in De Sinderhoeve (The Netherlands). In this measurement program, the canopy temperature was measured by an infrared thermometer. The experimental site was in the centre of the Netherlands (51° 59' N, 5° 45' E). The site was 250 m x 300 m, surrounded by other agricultural fields where maize is dominant. The maize was planted in north-northeast/south-southwest rows with row spacing of 0.75 m and with 0.11 m spacing in the row (12 plants per m²). October 4, 1988 (MO in the further text) was selected, representing the maize in growth stage with the fractional cover of 0.50 (σ_f =0.50). This parameter was measured together with the maize height, roughness length and

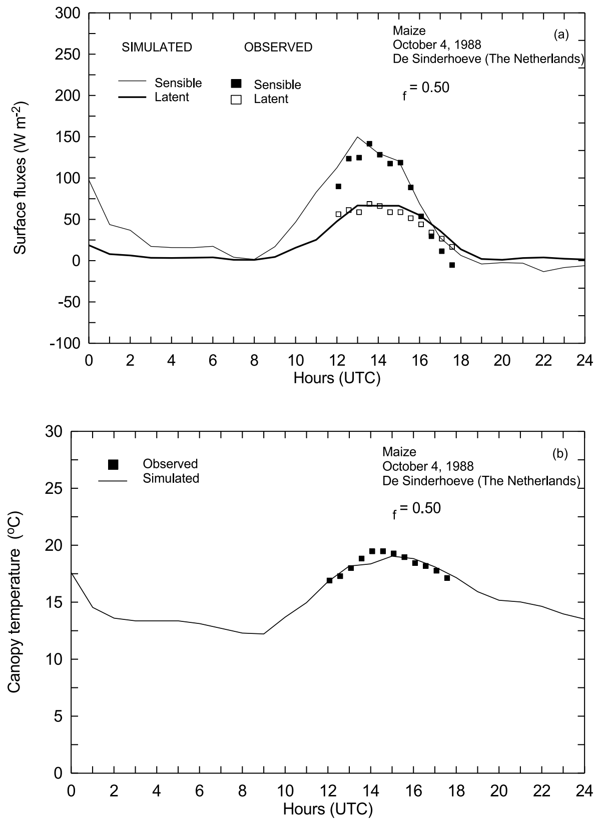

Fig. 2. Diurnal variations of latent and sensible heat fluxes (a) and canopy temperature (b) over maize field in De Sinderhoeve (The Netherlands) for October 4, 1988.

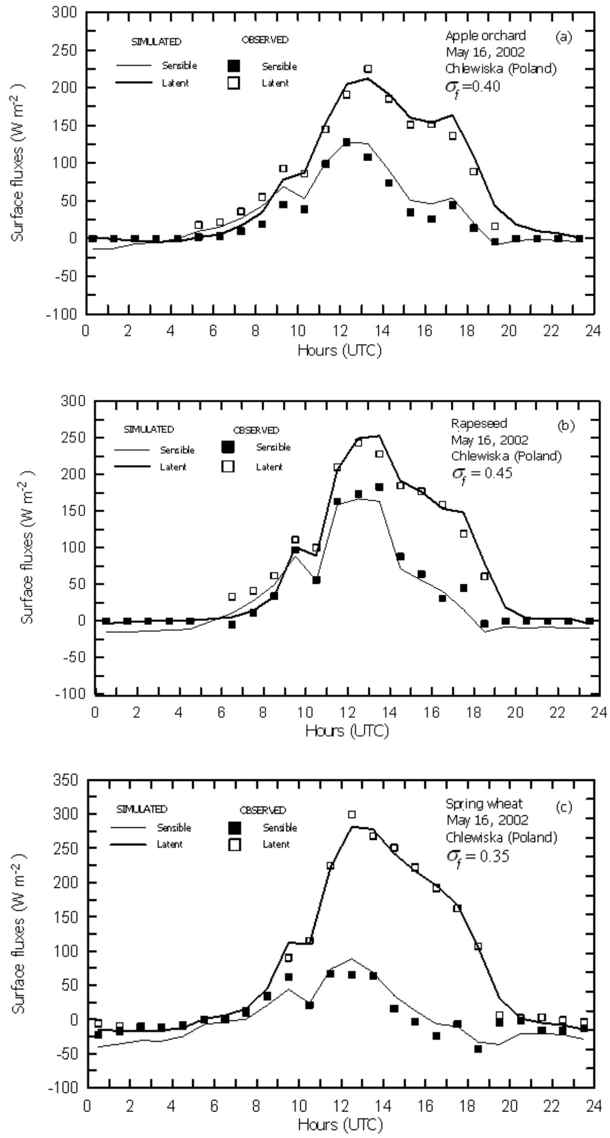

Fig. 3. Diurnal variations of latent and sensible heat fluxes over (a) apple orchard, (b) rapeseed field and (c) spring wheat field in Chlewiska (Poland) for May 16, 2002.

displacement height. The minimum stomatal resistance was not measured and was assumed to be equal to 200 s m^{-1}. The texture of the soil at the experimental site was very similar to the soil texture indicated in Mihailović et al. (2000). The maize and soil parameters used in the runs are also in Mihailović et al. (2000). The incoming shortwave radiation was considerably reduced so that the maximum reached just 409 W m^{-2}. The atmospheric boundary conditions at the reference level, z_r =4.5 m, were derived from measurements of global radiation, cloudiness, precipitation, specific humidity, temperature and average wind speed for 24 h from 00 UTC at 15-min intervals. These values were interpolated to the beginning of each time step of 600 s. All time integrations were started at 00 UTC with the initial values of atmospheric pressure of 1016 hPa.

The second test was done with apple orchard, rapeseed and spring wheat data sets, used from a measurement program that examined the heat balance structure for these plant fields. These fields were located in Chlewiska in the Wielkopolska Region, the best developed agricultural region in Poland close to the Ukraine and Belarus borders (51° 28' 60" N/22° 37' 60" E at 151 m of altitude). The apple orchard was

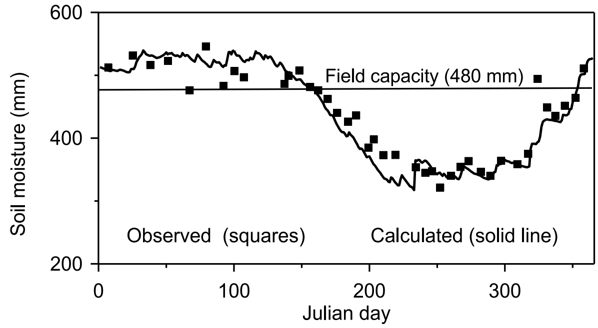

Fig. 4. Daily averages of the total soil water content (mm) over a depth of 1.6 m simulated by LAPS compared with weekly measurements under a soybean field at the Caumont site during its growing season in 1986.

grown at an experimental site on a 500 x 300 m plot with rows oriented from north to south, while trees were planted with a 5 m row spacing and 4 m spacing in the row. The soil of the rapeseed and the apple orchard was loamy sand, while that of spring wheat was sandy loam (in deeper layers it was sandy clay). Rapeseed was grown in an experimental site on a 800 x 500 m plot with rows oriented from north to south where the plant population was sown with a 0.25 m row spacing with about 100 plants per m² (σ_f = 0.45). Spring wheat was grown at an experimental site on a 750 x 500 m plot with rows oriented from east to west. The plant population was sown with a 0.10 m row spacing and about 500 plants per m² (σ_f = 0.35) The apple orchard was grown at an experimental site on a 500 x 300 m plot with rows oriented from north to south while the trees were planted with a 5 m row spacing and 4 m spacing in the row. In the Chlewiska data set (Poland) for May 16, 2002 the atmospheric boundary conditions at z_r = 3.5 m, the apple orchard was derived from measurements of global radiation, precipitation, water vapor pressure and wind for 24 h from 00 UTC at 60-min intervals. The methodology and measurement equipment used are described in detail in Leśny et al. (2001). The time step had a value of 3600 s while values of the atmospheric pressure used in numerical integrations had the value of 103.6 kPa. Morphological and aerodynamic characteristics of orchard can be summarized as follows: leaf area index (*LAI*) - 0.8 m²m⁻², canopy height 3.5 m, fractional cover (σ_f) 0.40, canopy bottom height 0.40 m, effective roughness length 0.005, displacement height 2.49 m, and roughness length. In runs, the soil had the following physical and water characteristics: volumetric soil water at field capacity 0.19 $m^3 m^{-3}$, volumetric soil water content at saturation 0.41 m^3m^{-3}, wilting point soil water content 0.047 $m^3 m^{-3}$, Clapp-Hornberger constant 4.90, heat capacity of solid soil fraction 840 J kg^{-1} K^{-1}, saturated hydraulic conductivity $35 \cdot 10^{-6}$ m s^{-1}, soil density 1250 kg m^{-3}, soil water potential at saturation -0.22 m and ground emissivity 0.97 (Komisarek, 2000). The soil layer thicknesses were defined as D_1=0-0.05 m, D_2=0.05-0.5 m and D_3=0.5-1.5 m. Initial values of the volumetric soil water content in these three layers were 0.196 $m^3 m^{-3}$, 0.167 $m^3 m^{-3}$ and 0.173 $m^3 m^{-3}$, respectively. Initial values for the soil temperature at the surface layer (15.0^{0}C) and deep soil layers (15.8^{0}C) were according to Mihailović (2004). The net radiation was measured by net radiometers (net radiometer transmitter) while for measurements of the soil heat flux soil plates were used (Hukseflux) – 5 pcs. Vertical gradients of temperature and water vapor pressure were calculated by derivate functions of the vertical profile of these two values. Functions were approximated by values measured on five levels over the active surface. Methodology and measurement equipment are described in detail in papers by Olejnik et al. (2001), Eulenstein et al. (2002) and Leśny et al. (2001).

Finally, the HAPEX-MOBILHY data set was used for comparison. The data were obtained from HAPEX-MOBILHY experiment at Caumont (SAMER No. 3). The chosen location was a soybean crop field. Soybean plants start to grow in May and are harvested at the end of September. The soil type at Caumont is loam. This data set was used because it includes a full year of atmospheric forcing and weekly soil moisture measurements up to 1.6 m depth with 0.1 m interval. Details about the forcing data used for Caumont run can be found in Mihailović et al. (2006). The morphological and aerodynamic characteristics of soybean can be summarized as follows: leaf area index (*LAI*) 2.9 m^2m^{-2}, canopy height 0.6 m, fractional cover (σ_f) 0.60, canopy bottom height 0.03 m, effective roughness length 0.003, extinction parameter 2.775, displacement height 0.37 m, roughness length 0.05 m and canopy source height 0.25 m. The soil of the soybean had the following soil and water characteristics: volumetric soil water at field capacity 0.24 m^3 m^{-3}, volumetric soil water content at saturation 0.49 m^3m^{-3}, wilting point soil water content 0.160 m^3 m^{-3}, Clapp-Hornberger constant 5.30, heat capacity of solid soil fraction 796 J kg^{-1} K^{-1}, saturated hydraulic conductivity $7.20 \cdot 10^{-6}$ m s^{-1}, soil density 1400 kg m^{-3}, soil water potential at saturation -0.79 m and ground emissivity 0.92. The soil layer thicknesses were defined as D_1= 0-0.1 m, D_2= 0.1-0.4 m and D_3= 0.4-1.5 m. Initial values of the volumetric soil water content in these three layers were 0.200 m^3 m^{-3}, 0.190 m^3 m^{-3} and 0.185 m^3 m^{-3}, respectively. Initial values for the soil temperature at the surface layer (18.1^{0}C) and deep soil layers (18.8^{0}C) are calculated according to Mihailović (2006).

Here we will discuss and examine the success of the aforementioned method for calculating the turbulent transfer coefficient inside a vegetation canopy supports, calculation of (i) heat and water fluxes above a sparse vegetation canopy, (ii) canopy temperature and (iii) soil moisture content beneath a sparse vegetation canopy. The used method was tested using mostly used surface observations from the forest that were well documented in Mihailović et al. (2006). However, here will be performed tests with the LAPS scheme that is run over the different a sparse vegetation communities.

The comparison will start by analyzing the one-day time integration of surface flux outputs above the maize field in De Sinderhoeve (The Netherlands). Fig. 2 shows the diurnal variations of the computed surface fluxes (Fig. 2a) and canopy temperature (Fig. 2b) for the MO case (October 4, 1988). The observed values of the sensible and latent heat fluxes are indicated by black and white squares, respectively. These values were obtained from van Pul (1992). Figure 2a shows surface flux outputs for all schemes obtained by running them using the MO data set. In this case, the fractional vegetation cover as well as the density of the maize canopy was significantly reduced (σ_f = 0.50 and LAI = 2.0) at the end of growing season, so the rate of evaporation was sharply decreased. This situation was characterized by larger amounts of sensible heat fluxes (vs. latent) because of the significant contributions from the bare soil fraction. The LAPS scheme showed a good agreement in reproducing the latent heat course. Similar results were obtained for the simulation of the sensible heat fluxes. Apparently, these results could be addressed to the method for calculating the turbulent transfer coefficient inside a vegetation canopy that is elaborated in Mihailović et al. (2004). Namely, in this approach it was assumed that in a sparse vegetation canopy this coefficient is strongly affected by processes in the environmental space, including the plants and the space above the bare soil fraction. Therefore, K_s inside a sparse vegetation canopy can be represented by some combination of turbulent transfer coefficients in that space, i.e., for example, as a linear combination weighted by the fractional vegetation cover. Fig. 2b shows the observed values of the canopy temperature and its modeled diurnal variations. The LAPS scheme gave good simulations of the canopy temperature.

Now we will analyze the one-day time integration of surface fluxes above the apple orchard, rapeseed and spring wheat and rapeseed fields in Chlewiska (Poland). Fig. 3 shows the diurnal variations of the computed surface fluxes for May 16, 2002. The observed values of sensible and latent heat fluxes are indicated by white and black squares, respectively. These values were taken from the report of the research project "Agricultural landscape structure impact on the heat balance structure of active surface" financed by the State Committee for Scientific Research (Poland). Three sets of equipment were simultaneously used for measurements of the Bowen ratio method (values of net radiation, soil heat flux and vertical gradients of temperature and water vapor pressure are needed for calculations by the Bowen method).

Looking at the panels in Fig. 3 it can be seen that a high level of agreement with the observations, for both the latent and sensible heat fluxes, is achieved by the LAPS. There are no significant differences between the computed and observed values of the latent heat fluxes for all considered plant communities, after 10 UTC and before 18 UTC (Figs. 3a-3c). This trend was slightly different over the apple orchard and rapeseed for the period between 06 UTC and 10 UTC, when the LAPS underestimated the observations, reaching a maximum difference of 25 W m^{-2}. During the nighttime period, there are practically no differences between simulations and observed values. The sensible heat flux simulations were close to the observations. The differences occurred over the apple orchard and rapeseed for the period between 06 UTC and 10 UTC when the LAPS overestimated the observations.

Model outputs for the total water content (TWC) in mm beneath the soybean canopy for Julian day 120-273 during 1986 were compared with measurements in a soybean field at Caumont (France) where plants start to grow in May and are harvested at the end of September. For comparison of the predicted TWC with the observations, weekly TWC measurements through the year based on neutron sounding probes for the top 1.6-m soil layer at 0.1-m intervals were available. A comparison of the predicted TWC with the measurements is plotted in Fig. 4. The curve, representing the values of the TWC over 1.6-m depth, was obtained by simulation using the described method for calculating the turbulent transfer coefficient over sparse vegetation. It is seen that the modeled values are close to observation also when the soybean canopy is sparsely distributed.

CONCLUSIONS

In this work the modeling of surface fluxes over sparse vegetation, using an approach for the turbulent transfer coefficients inside a vegetation canopy, were considered and discussed. This quantity is of crucial importance for modeling the soil evaporation in a sparse vegetation canopy due to internal feedbacks in the soil-vegetation canopy system. In this paper, some of the aspects in that modeling using the Land-Air Parameterization Scheme (LAPS) including an approach to calculating the turbulent transfer coefficient inside a sparse vegetation, were considered. For this purpose, this scheme was run for different sparse agricultural cultivars, i.e., apple orchard, winter wheat, rapeseed and soybean crops, at different sites, and then comparisons were done between the modeled values for surface fluxes, canopy temperature and soil moisture content, and observations.

The method for calculating the turbulent transfer coefficient inside a sparse vegetation canopy in terms of its ability to realistically and accurately simulate biophysical processes over a number of test sites for which data were available for validation, was shortly considered. Usually, the turbulent transfer coefficient inside a sparse vegetation is given *a priori*, i.e. presupposed by experience. In contrast to that, the order of procedural steps is changed, i.e. Eq. (1) was solved after assuming a functional form of solution for wind speed inside the vegetation canopy that was obtained iteratively.

The LAPS surface scheme used in numerical tests was reviewed. Then, information was given about the experimental sites, with sparsely distributed canopies, and corresponding data. They were: (i) the maize from De Sinderhoeve (October 4, 1988), The Netherlands (surface fluxes, canopy temperature); (ii) the apple orchard, rapeseed and spring wheat from Chlewiska (May 16, 2002), Poland (surface fluxes) and (iii) soybean from Caumont (May – September 2006), France (soil moisture content).

To demonstrate how a proper calculation of the turbulent transfer coefficient inside sparse vegetation affects the simulation of surface fluxes, canopy temperature and soil moisture content, and thus evapotranspiration, we performed experiments using LAPS over the aforementioned communities. The results obtained depicted the following facts.

The LAPS scheme shows a good agreement in reproducing the latent heat course over the maize field (October 4, 1988). Similar results were obtained for the simulation of the sensible heat fluxes. Apparently, these results could be addressed to the method for calculating the turbulent transfer coefficient inside a vegetation canopy. Namely, in this approach it was assumed that in a sparse vegetation canopy this coefficient is strongly affected by processes in the environmental space, including the plants and the space above the bare soil fraction. Therefore, inside a sparse vegetation canopy, it can be represented by some combination of turbulent transfer coefficients in that space, i.e., for example, as a linear combination weighted by the fractional vegetation cover. The LAPS scheme gave good simulations of the canopy temperature.

A high level of agreement, for both the latent and sensible heat fluxes was achieved by the LAPS, with the observations for data set May 16, 2002. There were no significant differences between the computed and observed values of the latent heat fluxes for all considered plant communities (apple orchard, winter wheat and rapeseed) after 10 UTC and before 18 UTC. This trend was slightly different over the apple orchard and rapeseed for the period between 06 UTC and 10 UTC, when the LAPS underestimated the observations, reaching a maximum difference of 25 W m^{-2}. During the nighttime period there were practically no differences between simulations and observed values. The sensible heat flux simulations were close to the observations. The differences occurred over the apple orchard and rapeseed for the period between 06 UTC and 10 UTC when the LAPS overestimated the observations.

The LAPS model outputs for the total water content in mm beneath the soybean canopy (during the growing season of 1986), compared with measurements in a soybean field (based on neutron sounding probes for the top 1.6-m soil layer at 0.1-m intervals), showed good agreement with observations. This was also evident for period of the growing season, when the soybean canopy was sparsely distributed.

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