HTSVS - A new land-surface scheme for MM5

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1. Introduction

Land surface schemes (LSM), among others, describe the climatologically and hydrologically important interactions between the biosphere and the atmosphere, especially, the fluxes of radiation, momentum, heat and matter. Modern state-of-the-art land-surface schemes should consider both the thermal and hydrologic effects within the soil to calculate soil surface temperature and the water cycle appropriately. Thus, in the present study, a hydro-thermodynamic soil vegetation scheme (HTSVS; Kramm et al. 1996, Mölders et al. 1999) is introduced into the 3D Penn State University (PSU)/National Center for Atmospheric Research (NCAR) mesoscale meteorological model MM5 (e.g., Dudhia 1993). The results provided by MM5 using HTSVS are compared with those delivered by MM5 applying the Oregon State University land surface model (OSULSM; e.g., Chen et al. 1996, Chen and Dudhia 2000) and they are evaluated with data obtained during the intensive observation period 5 (IOP5) of the Cooperative Atmosphere Surface Exchange Study 1997 (CASES97) that took place in the Walnut River watershed east of Wichita, Kansas from 21 April to 17 June 1997 (e.g., LeMone et al. 2000).

2. Brief description of MM5

a. Physics

The RRTM longwave radiation scheme (Mlaver et al. 1997), the Grell-scheme (1993), the atmospheric boundary layer scheme by Hong and Pan (1996) and the Goddard explicit bulk-parameterization of cloud mircophysics (Lin et al. 1983) are applied in this study.

b. Model domain and resolution

Both LSMs are executed with 4 soil layers where the deepest layer is stretched to a depth of 3 m. In the horizontal, an interacting nested grid is applied with a grid cell spacing of 10 km. The coarse grid has a horizontal resolution of 30 km. There are 23 layers at σ= 0.025, 0.075, 0.175, 0.225, 0.275, 0.325, 0.375, 0.425, 0.475, 0.525, 0.575, 0.625, 0.675, 0.725, 0.775, 0.825, 0.87, 0.91, 0.945, 0.97, 0.985, 0.995 reaching to 100 hPa.

c. Vegetation fraction, soil and land-use data

The vegetation fraction, soil and land use data, field capacity as well as permanent wilting point are assigned as described by Chen and Dudhia (2000).

d. Initialization and boundary conditions

MM5 is run for 20 May 1997 0000 UT to 22 May 1997 1200 UT. During that time the synoptic situation was governed by a low over the Rocky Mountains at the border to Canada that moved slowly eastwards and a low over the East Coast that moved slowly northeast-wards. Thus, the Mid-United States were under high pressure with low to moderate near-surface winds.

Soil moisture and soil temperatures were initialized by interpolating the data of the Eta-model as described in Chen and Dudhia (2000). At the bottom, soil temperature is held constant at the weighted long-year mean soil temperature at that depth. Soil moisture is hold constant at the values initialized.

3. Short description of HTSVS

HTSVS consists of a mixture approach (Deardorff 1978) for the energy and water budgets, a multi-layer soil model, a simple canopy model (Kramm et al. 1996), and a root model (Mölders et al. 1999).

Prior to its implementation in MM5, several off-line evaluation studies were performed with HTSVS over various vegetation types using data from GREIV-74, SANA, and Jülich-experiment (Kramm et al. 1996). Moreover, a long-term evaluation was carried out using the lysimeter data gained at Brandis, Germany during 1992 to 1997 (Mölders et al. 1999). HTSVS demonstrated its ability to reasonably simulate the diurnal variation of soil temperatures, surface latent and sensible heat fluxes as well as the seasonal evolution of the latent heat fluxes and groundwater recharge.

4. Common and different aspects of the land-surface schemes

Here, the common and different aspects of OSULSM and HTSVS are elucidated. The major differences are the treatment of the vegetation effects as well as the transport of heat and moisture within the soil.

- Both LSM include Richard’s equation. The sources and sinks namely infiltration, evapotranspiration, and surface runoff are considered.
- Soil temperature prediction uses a fully implicit Crank-Nicholson-scheme.
- Hydraulic and thermal conductivity, water tension (or metric potential), and the relative humidity within the soil depend on the volumetric water content.
- The hydraulic conductivity and water tension (or metric water potential) depend on volumetric water content. In the calculation of thermal conductivity, however, other coefficients are used.
- Volumetric heat capacity of moist soils depends on the maximal volumetric water content, the density of dry soil, water, and air, the specific heat capacity of soil, water, and air, respectively. In HTSVS, the effect of air on soil volumetric heat capacity is neglected. Here, however, soil specific heat capacity depends on soil type, while in OSULSM it is assumed to be equal to $1.26 \cdot 10^6$ $Wm^{-3}K^{-1}s^{-1}$.
- Both land surface schemes use 4 layers increasing with depth. They can be chosen arbitrarily in OSULSM. In HTSVS, these layers are to be chosen according to $\Delta\xi = \ln(z_{i+1}/z_i)$ = constant where z_{i+1} and z_i are neighbored soil layers with $z_{i+1} > z_i$.
- Vegetation is represented by a single canopy layer.
- Both schemes apply a resistance network approach, but of different design.
- In the calculation of the bulk-stomatal resistance, both LSMs consider the effects of several stress factors by correction functions (Fig. 1) that are, however, formulated differently.

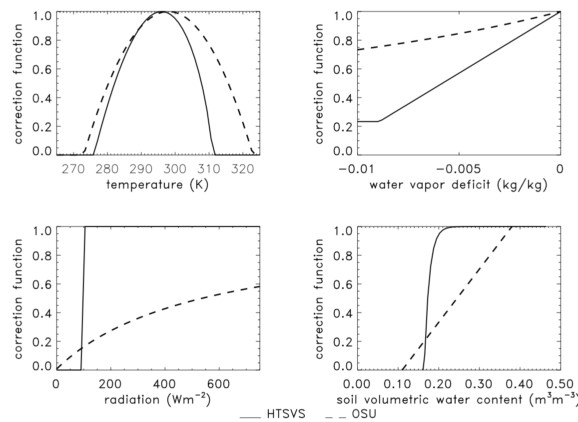

Fig. 1. Comparison of correction functions as used for the effects of temperature, water vapor deficit, radiation and soil volumetric water content.

a. Roots

In OSULSM, a thin 0.05 m top layer is followed by another two root-zone layers. Their depth depends on vegetation type. The fourth layer depth encompasses the rest of the total active layer below the root-zone. In HTSVS, the water extraction by roots is determined by a modified Cowan’s (1965) model. Depending on vegetation type roots may reach into all soil layers and there may be a different amount of roots in the upper 0.3 m than in the soil below (see Mölders et al. 1999).

b. Skin, foliage and surface temperature

In OSULSM, surface skin-temperature is calculated by use of a single linearized surface energy balance equation that represents the combined soil/vegetation surface. In HTSVS, coupled energy- and water-budget equations are simultaneously solved for the surfaces of foliage and soil to calculate the corresponding surface values of temperatures and moisture (e.g., Kramm et al. 1996). Skin temperature is determined by area-weighting bare soil and foliage surface temperatures.

c. Soil moisture and heat fluxes

In OSULSM, the budget equations for the heat and water transport within the soil are decoupled and solved separately. Thus, the soil heat flux is determined by a diffusion equation for soil temperature. At the top, the soil heat flux is determined using the surface skin-temperature. The volumetric water content is given by the diffusive form of Richard's equation derived from Darcy's law under the assumption of rigid, homogeneous, isotropic vertical flow conditions. Infiltration follows Schaake et al. (1996).

In HTSVS, coupled budget equations for the heat and water transport within the soil are simultaneously solved, i.e., the Ludwig-Soret-effect and Dufor-effect are considered. The treatment of the (vertical) heat- and water-transfer processes is based on the principles of the linear thermodynamics of irreversible processes allowing long-term integration. The water and heat fluxes of the upper most soil layer are determined by assuming height-invariant fluxes. Infiltration follows Schmidt (1990).

d. Albedo and emissivity

In OSULSM, albedo and emissivity are hold constant throughout the entire simulation time. A common albedo/emissivity is assumed for the system vegetation-soil represented using the value for vegetation. In regions covered by snow, ground albedo and emissivity are modified according to Chen et al. (1997). In HTSVS, the albedo and emissivity of soils may differ form those of vegetation. Soil albedo depends on the volumetric water content of the uppermost shallow soil layer.

e. Prognostic equations

HTSVS has 9 prognostic variables namely volumetric water content and soil temperature in four layers and the water stored on the surface. OSULSM has one prognostic variable more because it distinguishes between water stored on canopy and ground, respectively.

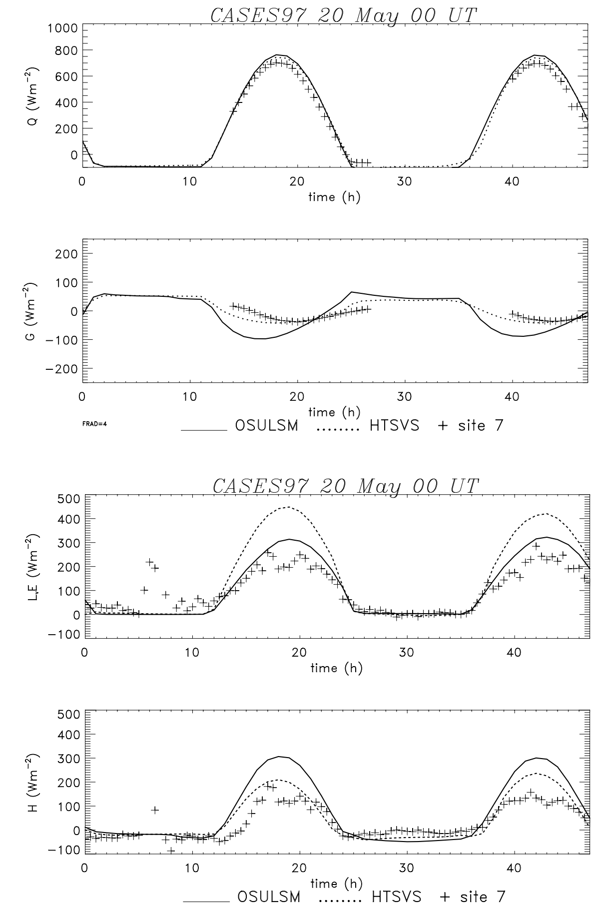

Fig. 2. Comparison of simulated and observed temporal evolution of near surface fluxes.

4. Preliminary results

Figure 2 exemplary shows the observed an simulated surface fluxes. MM5 slightly overestimates net radiation. Therefore, more energy is available to be distributed between the fluxes of sensible and latent heat. HTSVS tends to overestimate the latent heat fluxes. This overestimation, among others, may also be due to the fact that up to now leaf area index is not set according to the vegetation types. Some parameters still have to be set more appropriate for mesoscale modeling purposes. Sensible heat fluxes are modeled better than latent heat fluxes. Comparing the profiles of near surface temperatures illustrates that, on average, HTSVS provides about 4 K and OSULSM delivers about 3 K too high near surface air temperatures at night. For near surface humidity HTSVS is closer to the observed values than OSULSM that underestimates them. On average, HTSVS slightly overestimates during daytime and slightly underestimates at nighttime.

5. Conclusions and outlook

The preliminary results show that HTSVS is able to provide the energy and water fluxes at the boundary earth-atmosphere required by MM5. The parameters used were taken as usually done for micrometeorological modeling. Thus, some of them have still to be set more appropriately for the mesoscale modeling purposes of MM5. Since up to now only one synoptic situation was simulated no recommendation which scheme is to be favored for which cases can be given. Further simulations including evaluations are needed for other synoptic conditions. Moreover, tests applying other physics of MM5 are to be done. Up to now HTSVS is tested with the schemes denoted above and the Reisner-graupel scheme and the cloud radiation scheme. Coupling with other atmospheric boundary layer schemes is planed.

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