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Water and energy budgets simulation over the AMMA-Niger super-site spatially constrained with remote sensing data

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SUMMARY

The *SEtHyS_Savannah* model [Saux-Picart et al., submitted for publication. *SEtHyS_Savannah*: a multiple source land surface model applied to sahelian landscapes. Agricultural and Forest Meteorology] was developed as an extension of the SEtHyS land surface model to simulate the water and energy fluxes over dry savannah landscapes. The vegetation cover is represented by a two layer model and a mulch approach is used for the soil description. The *SEtHyS_Savannah* model was regionalized over the AMMA-Niger super-site (about 50 km by 40 km), with the help of remote sensing data. The model uses a regular 1km grid and each cell is divided in sub-grid patches in order to represent land cover and soil heterogeneities (tile approach). The vegetation cover parameters were prescribed according to the land cover map and the seasonal evolution of the Leaf Area Index (LAI), both derived from SPOT-HRV (Satellite Pour l'Observation de la Terre – High Resolution Visible) data imagery. The atmospheric forcing was assumed homogeneous over the area and provided by a meteorological station installed at the Fakara experimental site. The surface water and energy budgets were simulated over a one-year period (2005) at a 5-min time step and validated against MSG-SEVIRI (Meteosat Second Generation – Spinning Enhanced Visible and Infra-red Imager) land surface temperature and ENVISAT-ASAR (ENVIronnement SATellite – Advanced Synthetic Aperture Radar) soil humidity products. The results show realistic surface fluxes and good agreement with the MSG-SEVIRI temperature observations. The soil moisture comparison presents significant correlation but large root mean square errors. These discrepancies are the consequence of both the use of a non-spatialized atmospheric forcing and to residual vegetation effects on the radar signal. Despite these uncertainties, the results increase confidence in the model representation of Sahelian soil–vegetation processes and open new perspectives to quantify the effects of vegetation changes on evapotranspiration and runoff over the region.

Introduction

Numerous studies have shown the impacts of land surface processes on the lower atmosphere dynamics in the Sahel region (Koster et al., 2004; Taylor et al., 2007). Among all these processes, evapotranspiration is one of the key variables linking energy and hydrological surface budgets but it is often difficult to represent in land surface models. It is well known that the role of vegetation is determinant for the energy and fluxes partitioning. Indeed, a vegetated surface has generally a lower albedo and absorbs more solar energy than a bare soil. It is then likely to maintain transpiration for longer time periods when soil water is available. Moreover, by its impact on surface hydrology, vegetation limits runoff and favours infiltration.

In the Sahel region, rainfall is characterized by an extreme spatial and temporal variability which affects water and energy exchanges between vegetation and atmosphere. In order to understand the role of the vegetation on the surface processes and on the West African Monsoon (WAM) dynamics, regionalized land surface models are interesting tools to quantify water and energy fluxes transferred to the lower atmosphere and to conduct sensitivity studies or impact studies.

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In the framework of the African Monsoon Multidisciplinary Analysis (AMMA) program (Redelsperger et al., 2006; http://www.amma-international.org/), a particular emphasis is set on the study of land–atmosphere feedbacks. For this purpose, the AMMA-Catch experiment was conducted and various instruments were installed to document the surface mass and energy fluxes (Lebel et al., 2009). These datasets acquired at different temporal and spatial scales, provide all the materials to develop and validate land surface models. Such models will be used to improve predictions of the water cycle and resources over West Africa.

The purpose of this paper is to present the latest developments of a regionalized land surface model over the Fakara area situated in the south-western part of Niger (Cappelaere et al., 2009). The approach is based on the implementation of the one-dimensional *SEtHyS_Savannah* model (Saux-Picart et al., submitted for publication) on a regular grid covering the approximately 50 km by 40 km region. Each 1 km grid cell is divided in homogeneous sub-grid tiles according to a land cover map derived from high resolution satellite data. The surface model is forced with local meteorological measurements and the validation is performed against *in situ* and remote sensing data. The next section presents the *SEtHyS_Savannah* model, the study area and the available data. The regionalization methodology and the model simulations are then described in "Spatialization approach" section. The results are presented in "Results" section with the model validation against remote sensing data. Finally, the conclusion draws the main perspectives of this simulation tool in terms of impact studies of land use changes on the hydrology of South-West Niger. A detailed description of the main characteristics of the study area can be found in Cappelaere et al. (2009).

Model and data description

SEtHyS_Savannah *model*

The *SEtHyS_Savannah* model (Saux-Picart et al., 2009) is a new version of the *SEtHyS* (Coudert et al., 2006) one-dimensional Soil–Vegetation–Atmosphere-Transfer (SVAT) model, dedicated to the modeling of dry savannah landscapes. Such landscapes are characterized by heterogeneous ecosystems presenting various components of distinct properties. Two vegetation layers can be differentiated: the upper layer generally composed of crops, bushes and trees, and the understorey displaying grasses and bare soils. Indeed, in the study area, weeding between millet pockets is only very partial, both in time and space, leading to the presence of grass most of the time during the growing season. In order to represent such heterogeneous ecosystems, it is important to adopt three-source formalism as shown by Verhoef and Allen (2000). Hence, the vegetation is represented by two layers in *SEtHyS_Savannah* assuming that there is always a grass layer under a higher vegetation layer which can be crops like millet or fallow bushes. The soil is divided into two layers: the root zone for the grass which is about 60 cm deep, and a deep layer that is reached only by the roots of the top vegetation (crops and/or trees). A mulch layer can form within the top soil layer and the soil resistance to water vapour diffusivity is directly proportional to the thickness of this mulch. After a rainy event, soil evaporation can lead to a second mulch layer. Then the thickness of two mulch layers separated by a wet layer can be simulated (see Saux-Picart et al., submitted for publication for a more detailed description of the mulch). The infiltration rate is computed as the difference between the surface runoff and the through-fall rate, which is the sum of the rainfall not intercepted by the canopy and the dripping from the interception reservoir occurring when the water at the leaves surface (rain intercepted or dew) exceeds a maximum limit. The surface runoff follows the infiltration-excess mechanism (Horton runoff) following Decharme and Douville (2006). This process takes into account a soil surface crusting saturated hydraulic conductivity which was provided by *in situ* observations over the studied area (Peugeot et al., 2003). In addition, surface runoff can occur when the soil is completely saturated. Although vegetation can strongly affect runoff, only the impact of soil texture on hydraulic soil parameters is modeled. In the studied area, the vegetation is so scarce that it has almost no impact on hydrology.

The energy budget is solved separately for the three components of the model: bare soil, grass and trees. For each of them, net radiation is calculated following the same formalism as in *SetHyS* (Coudert et al., 2006). Thus, a shielding factor (Deardorff, 1978) is used to partition incoming downward shortwave and longwave radiations assuming a spherical distribution of the leaves for the two vegetation layers. The resistance scheme is presented in Fig. 1. For sensible and latent heat fluxes, aerodynamic resistances are computed between the surface, the displacement heights inside the vegetation layers and the reference level (r_{as}, r_{ag}, r_{at}: 's', 'g' and '*t*' subscripts stand for surface, low and high vegetation layers, respectively). The wind profile is assumed to be logarithmic-shaped above the canopy and exponential within the canopy. Leaf boundary layer resistances (r_{bg}, r_{bt}) are also taken into account. For the latent heat flux, two resistances are added for each component: the stomatal resistances (r_{sto_g}, r_{sto_t}) based on Ball (1988) and Collatz et al. (1991, 1992), and the soil mulch resistance (r_s) depending on the mulch thickness prognostic variable. All the parameterizations used are presented in Saux-Picart et al. (submitted for publication). This model requires the prescription of 28 parameters and eight initial values. The parameter list is summarized in Table 1. As input data, *SetHyS_Savannah* model requires the Leaf Area Index (LAI) and height (H) of the two vegetation layers, and the meteorological forcing which consists in long and short wave incoming radiations, atmospheric variables (temperature, relative humidity and wind speed) and rainfall.

The model calibration is achieved using the MCIP multiobjective calibration iterative process (Demarty et al., 2005; Coudert et al., 2006, 2008; Coudert and Ottlé, 2007) when observations regarding surface fluxes or variables are available. The approach

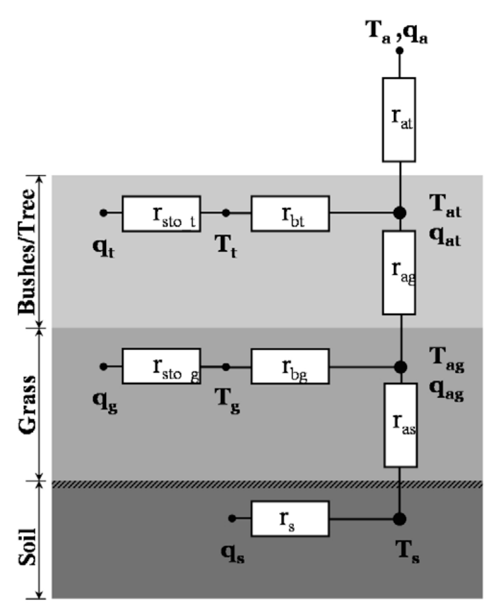

Fig. 1. Representation of the surface resistance network in the *SEtHyS_Savannah* model: at the soil surface (mulch resistance), in the grass and bushes layers and above the vegetation (aerodynamic resistances).