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Process-based modeling of coupled energy and water cycle under dry tropical conditions: an experiment at local scale in the cultivated Sahel (South-West Niger)

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In the dry tropics in general and, particularly in the African Sahel, agro-ecosystems and hydrosystems are very sensitive to climate variability and land management. In turn, it has been shown that soil moisture, vegetation and surface fluxes produce substantial feedback effects on rainfall-producing atmospheric convection. Therefore, it is of prime importance to understand and to model the dynamics of the soil-plant-atmosphere continuum in response to contrasted meteorological and terrestrial conditions for this area.

The objective of this study is to produce a process-based model of water and energy transfers in the soil and land-atmosphere interface over an entire 5-year period, at local scale, for the two main land cover types of South-West Niger: millet-crop and fallow savannah. A comprehensive dataset is available over that whole period in two such fields of the Wankama catchment, making it a rather unique asset for West Africa. This area is typical of the central Sahel conditions, with ∼400-600 mm annual rainfall concentrated in the 4-5 months wet season, followed by the 7-8 months dry season. Soils are essentially sandy and prone to surface crusting, which induces a strong vertical contrast in hydrodynamic properties. The dataset used here includes 5 years of atmospheric forcing (rainfall, wind speed, sun and atmosphere radiation, air temperature and moisture) and validation variables (net radiation, turbulent fluxes and soil temperature and moisture profiles), recorded every 30 min. The seasonal course of vegetation phenology (LAI, height, biomass) and soil characteristics (particle size and density profiles) are also available. The SiSPAT (Simple Soil-Plant-Atmosphere Transfer, Braud et al., 1995) physically-based model is used for this study. It solves the mass and heat transfer system of equations in the soil, with vapour phase, coupled with a two-component (bare soil and one vegetation layer) water and energy budget at the surface-atmosphere interface. Main questions raised in this modeling exercise were, whether such a model could be adequately calibrated and validated for the two studied sites, using realistic parameter values and, what uncertainty would result for model outputs (surface fluxes and soil heat/water profiles).

The model was calibrated over a 2-year period and then validated over the other three years, for both sites. In both cases, observations are reproduced about as well for the two periods. The variations in water and energy variables, over the five contrasting years and between land covers, are highlighted. Multi-year, field-based estimations of land surface water and energy budgets are hence produced, for the first time in this area to our knowledge. Given model performances, it is felt that it can be applied with reasonable confidence to much longer periods, reflecting the strong variability that characterizes the Sahel climate.

This modeling experiment takes part in the ALMIP (AMMA Land Model Intercomparison) project, which aims at comparing land surface models at local and meso scales over a north-south eco-climate gradient represented by three West-African sites of the AMMA-CATCH observatory (RBV network).

Reference:

Braud et al., 1995. A Simple Soil-Plant-Atmosphere Transfer model (SiSPAT) development and field verification. Journal of Hydrology 166(3-4), 213–250.