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A NUMERICAL CASE STUDY OF WET VS. DRY REGIMES IN THE WEST AFRICAN SAHEL

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1. INTRODUCTION

Rainfall in West Africa is highly variable on a variety of spatial and temporal scales, particularly in the semi-arid to arid transition zone of the Sahel. Vegetation in this region often grows in dense strips interspersed with large areas of completely bare soil. This vegetation pattern is dubbed “tiger bush,” and these areas are thought to have an important influence on the hydrology of the Sahel. However, the water balance in the tiger bush is poorly understood. The goal of this study is to develop a better understanding of the interaction of surface fluxes, surface and subsurface soil moisture, and rainfall in the tiger bush environment.

2. DATA AND METHODOLOGY

Hydrometeorological modeling allows us to control inputs and measure outputs in land-atmosphere interaction quantitatively. The simulations involved the use of a two-dimensional coupled land-atmosphere numerical model with open lateral boundary conditions. The Goddard Cumulus Ensemble (GCE) is a non-hydrostatic, anelastic numerical cloud resolving model composed of prognostic equations for momentum, potential temperature, and water vapor mixing ratio (Tao and Simpson 1993). Coupled to GCE is the Parameterization for Land Atmosphere Exchange (PLACE), a surface-vegetation-atmosphere transfer model (Wetzel and Boone 1995). A transect of approximately 1000 km divided into 2048 grid points with 1990 inner points at 0.5 km spacing and a stretched grid (1:1.06) on either side was implemented. In the vertical, there were 33 grid points from 0.0 to 21.5 km altitude. This grid was also stretched with the spacing between levels ranging from 80 m at the surface to 1200 m at the top of the troposphere.

The sounding, vegetation, soil type, soil moisture, and soil temperature data used to initialize the model were derived from the Hydrologic Atmospheric Pilot Experiment in the Sahel (HAPEX-Sahel) (Goutourbe et al. 1994). The initial sounding was a modification of a sounding taken 21 August 1992 at 2230 UTC. The soil type used was a sandy loam soil. The tiger bush land cover was setup so that approximately 67% was bare crusted soil and the rest vegetation (based on aerial photographs). The soil surface was strongly crusted in bare areas but permeable under the bushes. Observations in the tiger bush environment show that the soil underneath the vegetation is wetter throughout than the bare soil. A wet regime is referred to as one in which the soils are moist and a dry regime is one in which the soils are dry.

Two numerical experiments were performed in which the only difference between the two runs was the initial soil moisture content. Volumetric soil moisture (increasing downward) in the wet regime ranged from 0.05 to 0.18 cm cm^{-3} in the bare soil areas, and underneath the vegetation ranged from 0.13 to 0.26 cm cm^{-3}. In the dry regime, soil moisture ranged from 0.02 to 0.10 cm cm^{-3} in the bare soil areas, and underneath the vegetation ranged from 0.05 to 0.21 cm cm^{-3}. Soil moisture for the dry regime was observed on 20 August 1992, and soil moisture for the wet regime was observed on 22 August 1992. These dates were chosen because of large differences in soil moisture between each sample and their close temporal proximity to the initial sounding. Both simulations began at local midnight and ran for 24 hours with a 5 s time step and GCE invoking PLACE at 3-min intervals.

3. RESULTS

Analysis began with examination of heat fluxes and their priming of the planetary boundary layer. Both regimes received approximately equal amounts of net radiation throughout the diurnal cycle (Fig. 1). The wet regime yielded a higher ground heat flux because of a higher heat capacity in the wet soils. This simulation also yielded a higher latent heat flux (nearly double that of the dry soil simulation) due to increased evapotranspiration from the surface. The dry soil simulation, because of a lower ground heat flux, had a higher fraction of radiation available to boundary layer growth through sensible heat flux. The greater latent heat flux produced in the wet regime generated a slightly moister boundary layer 1-2 g kg^{-1} (~10-20%) and a stronger θ_e gradient than produced in the dry regime. The dry regime had a faster growing boundary layer and a weaker vertical gradient of θ_e that dissipated by early evening. The wet regime was able to maintain a strong vertical gradient of θ_e through the late morning hours and well into the evening. This was evident in the evolution of CAPE in each regime. By noon, the wet regime had 3043 J kg^{-1} K^{-1} of CAPE, 16% more than the dry regime.

Around 19:00 local time, enhanced cumulus began forming in both regimes. The dry regime formed more convective cells but they were less intense than those produced in the wet regime (peak updraft speeds of 18

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m s^{-1} vs. 26 m s^{-1}). In addition, only one cell lasted longer than one hour in the dry regime. There was increased entrainment in the higher and drier boundary layer which quickly eroded its upward gradient in θ_e. The wet regime had fewer convective cells but they lasted nearly twice as long. In addition to having stronger updrafts and increased duration, convective cells in the wet regime also were more efficient in generating new cells via stronger downdrafts. These downdrafts introduced significant amounts of low θ_e air into the boundary layer forming outflow boundaries. Only in the wet regime were the outflow boundaries intense enough to boost rising parcels to their level of free convection.

Additional information will be presented at the conference including a more detailed discussion of the land-atmosphere interaction and cases where there is no observed precipitation. Surface and subsurface soil moisture will also be presented.

4. ACKNOWLEDGEMENTS

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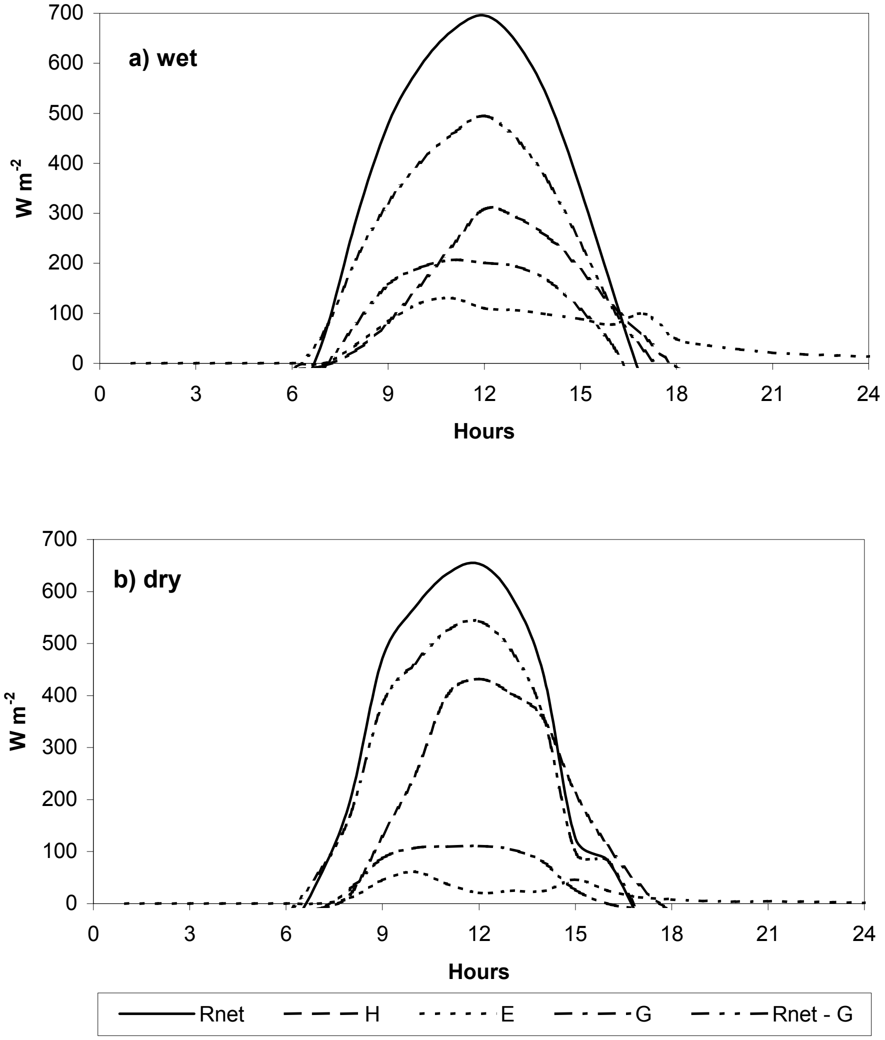

Fig. 1. Time series of domain-average surface fluxes of net radiation (Rnet), sensible heat (H), latent heat (E), ground heat (G), and available energy (Rnet – G) for the (a) wet and (b) dry regimes.