One Dimensional Analytical Land-Vegetation-Atmosphere coupled model to investigate soil moisture bimodality.

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1. INTRODUCTION

Surface vegetation through transpiration influences the exchange of moisture and energy between the land surface and atmosphere[1]. Transpiration through stomatal opening is greatly controlled by soil water potential, i.e., soil moisture[2]. The Global Land-Atmosphere coupling Experiment (GLACE) identified regions with strong land-atmosphere interaction to be located in transition and irrigated regions where evapotranspiration is strongly influenced by soil moisture[3]. The strength of land-atmosphere coupling can be largely impacted by irrigation activities[4]. For Illinois, the United States, the region with strong land-atmosphere interaction, D'Odorico and Porporato, 2004 found the probability distribution of twenty years of summer soil moisture displayed two distinct peaks and termed this distribution as soil moisture bimodality. The Analysis of AMSRE satellite soil moisture data showed global soil moisture bimodality, which coincided with transition region[6]. D'Andrea et al. 2006, through a one-dimensional continental-scale idealized coupled land-atmosphere model, highlighted the importance of spring soil moisture for causing soil moisture bimodality. In the present study, we developed a simple box model for soil-vegetation-atmosphere dynamics for the mid-latitude region. Our objective is to examine the robustness of the multiple equilibria in the soil-vegetation-atmosphere system with the inclusion of the dynamic response of vegetation.

2. METHODOLOGY

The figure (1) shows the schematic of the land-vegetation-atmosphere coupled model. The equations (1)-(4) gives the temporal dynamics of four prognostic variables, i.e., average Potential temperature (θ_a) and average relative humidity (q_a) of the PBL, average temperature (T_s) and average relative humidity of the soil layer. The study employs two different model. First, without explicit vegetation model (Control Model, CM). The second model considers vegetation module which includes two different LAI schemes. i.e., static (representing broadleaf evergreen forest and bare soil) based on Koster and Suarez 1996 and dynamic LAI representing cropland.

$$\frac{\partial\theta_a}{\partial t} = \frac{Q_s}{\rho c_p h_a} + \frac{\epsilon_a \epsilon_s \sigma T_s^4}{\rho c_p h_a} - \frac{\partial \Delta\widetilde{\theta_a}}{\partial t} + \frac{\theta_a^* - \theta_a}{\tau} \qquad (1)$$

$$\rho h_a \frac{\partial q_a}{\partial t} = E - \rho h_a \frac{\partial \Delta\widetilde{q_a}}{\partial t} + F_q \qquad (2)$$

$$\rho_s c_{ps} h_s \frac{\partial T_s}{\partial t} = (1 - A_s) F_{rad} - Q_s - L_e(E) - \epsilon_s \sigma T_s^4 \qquad (3)$$

$$w_o h_s \frac{\partial q_s}{\partial t} = P - E - L(q_s) \qquad (4)$$

The equation (5) represents dynamics LAI scheme is based on Törnros and Menzel 2014, where LAI is a function of accumulated precipitation over the last five months (p_{acc}).

$$\Lambda dynamic = \beta o + \beta 1 pacc \qquad (5)$$

$$b = 0.45 LAI^{0.36} \qquad (6)$$

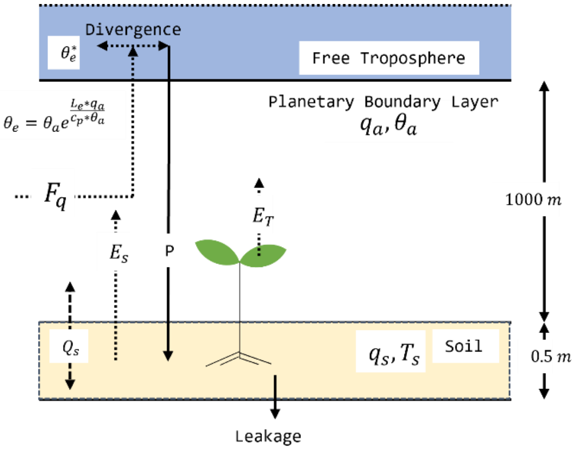

Figure 1: Schematic of land-vegetation-atmosphere coupled model.

Evapotranspiration (ET) is partitioned into soil evaporation (E_s) and plant transpiration (T). The equation (6), based on Wei et al. 2018 describes the ratio of transpiration to evapotranspiration (b) for cropland.

3. RESULTS

The CM without the explicit vegetation gave two stable equilibria, i.e., dry, steady-state, and wet steady-state (fig. 2A), depending on early summer soil moisture. For the fixed incoming lateral moisture flux, summer with low early summer soil moisture will end up in a dry and hot state compared to those starting with the high summer soil moisture. The dynamic crop vegetation maintains the two stable equilibria, ‘dry/hot’ and ‘wet/cool’ as CM but requires higher initial soil moisture to showcase a wet/cool state. On the other hand, fig 2B shows that both forest land and barren land have only one stable equilibrium, i.e., wet, and dry respectively.

We also simulated the synoptic flow variability by stochastically varying the lateral moisture convergence flux (Fq). Figure (2) shows the soil moisture histogram for the three different vegetation cover obtained from the time series of the data. The cropland with dynamic LAI and shows a stronger bimodal mode compared to the CM. For static LAI, the soil moisture histogram for both the constant forcing is unimodal but with peaks at different soil moisture values. The high LAI region has a greater probability of always remaining in the wet stable state, whereas the bare soil has peaked at dry soil moisture value.

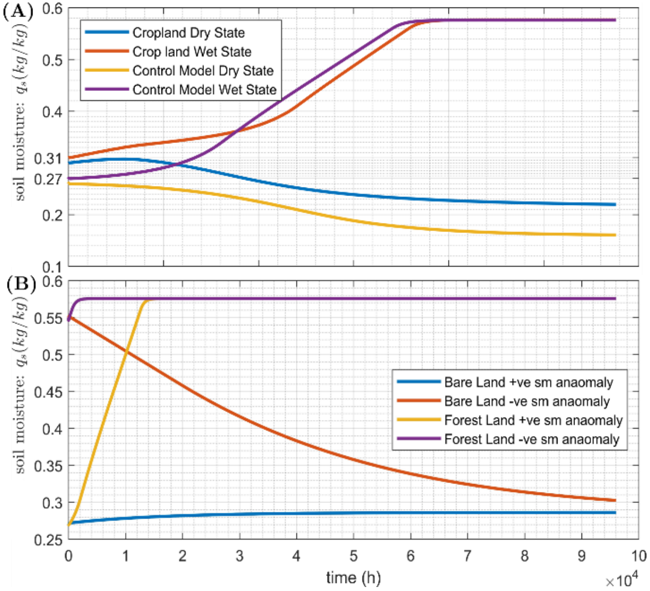

Figure 2: Preferential equilibrium states for different vegetation cover for initial soil moisture.

4. DISCUSSION

It also concludes the importance of landscape vegetation type, in addition to early summer moisture, in increasing the seasonal forecast of the mid-latitude summer season. Change from natural vegetation to cultivated vegetation increases the probability of a dry/hot state. The model, although simple, provides valuable insights into the soil-vegetation-atmosphere interaction process and leads to realistic values for the temperature and humidity.

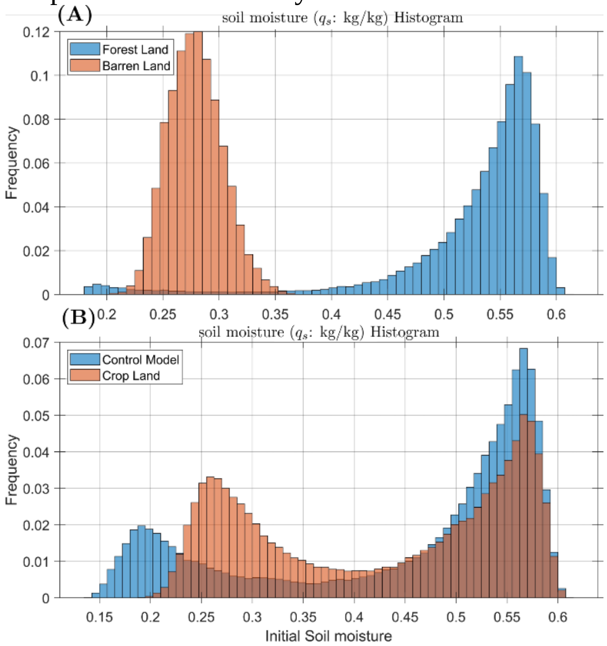

Figure 3: Time evolution of soil moisture in case of synoptic forcing for different vegetation cover.

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