Impact of Vegetation Feedback on the Response of Precipitation to Antecedent Soil Moisture Over North America

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1. Introduction

Soil moisture-precipitation feedback can potentially produce long soil moisture memory in some regions of the globe, which contributes to seasonal and sub-seasonal precipitation predictability. Specifically, over regions of strong soil moisture-precipitation coupling such as the central North America, positive (negative) anomalies in soil moisture have been found to promote (suppress) subsequent precipitation in many studies (e.g., Kim & Wang, 2006a). However, vegetation feedback at seasonal and sub-seasonal time scales, an important physical process influencing soil moisture-precipitation interactions, has not been considered in most previous studies on the impact of soil moisture initialization.

Seasonal and sub-seasonal vegetation feedback can modify the impact of soil moisture on subsequent precipitation, which complicates the soil moisture-precipitation coupling and has significant implications on how to interpret and understand results from observation soil moisture-precipitation relationship. For example, in regions where vegetation growth is limited by water availability, increase in soil moisture will leads to more vegetation. The increase of vegetation has two effects:

(1) SM++ → Vegetation ++ → ET++ & Rnet ++ →Precipitation ++

(Positive feedback)

(2) SM++ → Vegetation ++ → Water Consumption ++ → SM – → Precipitation –

(Negative feedback)

The net impact on the response of precipitation depends on which of the two effects is dominant. In this study we investigate how vegetation feedback modifies the impact of initial soil moisture anomalies on subsequent precipitation over North America based on a series of ensemble simulations using the coupled CAM-CLM model.

2. Models and Methodology

The model used in this study is a modified version of the NCAR Community Atmosphere Model version 3 (CAM3) (Collins et al. 2004) coupled with the Community Land Model Version 3 (CLM3) (Oleson et al. 2004). Compared with the default CAM3-CLM3, the version we use includes a predictive phenology scheme simulating the seasonal vegetation variation in response to hydrometeorological conditions, a scheme we developed and validated against the MODIS LAI data (Kim & Wang, 2005). The oceanic boundary conditions in this coupled land-atmosphere model are prescribed with the climatological monthly-varying sea surface temperature and sea ice coverage. Among the three dynamics schemes available in CAM (Eulerian spectral, semi-Lagrangian dynamics and Finite Volume [FV] dynamics), we choose the FV dynamical core with a horizontal resolution of 2° latitude by 2.5° longitude and a total of 26 levels in the vertical direction.

First of all, a 12-year model spinning-up with climatological SST is carried out. Soil moisture climatology on the 1st day of each month is estimated based on the last 10 years of the model integration, and atmospheric conditions on the 1st day of each month in the last year of the model integration is used to provide initial conditions for subsequent experiments. These include three types of simulations, as summarized in the following. We take an ensemble modeling approach and each ensemble includes five members.

Simulation Type	Control	"SM"	"SM_Veg"
Initial Soil Moisture	Climatology	Climatology + dry/wet anomaly	
Phenology	Predicted	Prescribed according to Control	Predicted

The focus of this study is on how the impact of vegetation feedback varies with the timing and direction of initial soil moisture anomalies. Initial soil moisture anomalies are applied on the first day of different months (April1, May 1, June 1, July 1, …) and the impact of such anomalies on subsequent precipitation is examined based on the three types of simulations outlined above. A large magnitude of soil moisture anomalies (equivalent to 80% of the soil moisture anomalies at the corresponding time) is chosen to distinguish signal from noises.

In the CAM3-CLM3 model, when the vegetation feedback is not considered, precipitation response to soil moisture initialization is mostly observed over the Mississippi River Basin (Kim & Wang, 2006a). Therefore, some of the results presented in the following are spatial averages over the MRB, the shaded area in Figure 1, defined according to Bosilovich & Chern (2006)

3 Results I: Averages Over the MRB

Figure 1: Daily LAI anomalies as a response to an 80% increase (red) or an 80% decrease (blue) of soil moisture climatology applied on (a) April 1, (b) May 1, (c) June 1, (d) July 1, and (e) August 1, averaged over the Mississippi River Basin.

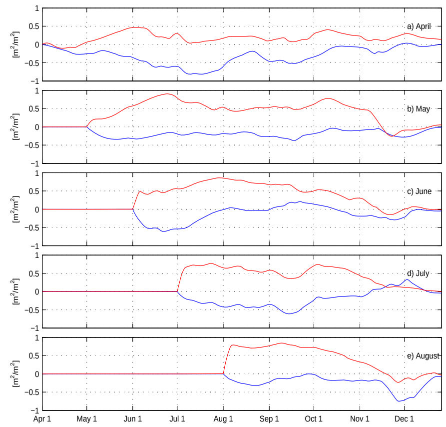
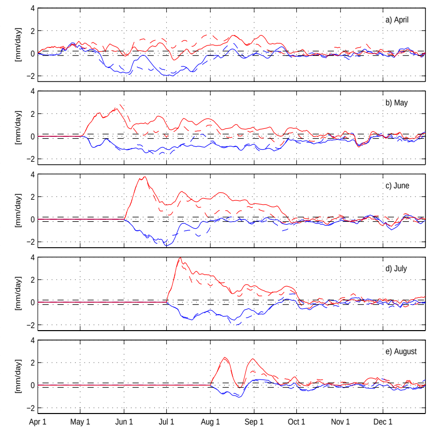


Figure 2: 10-day running mean of precipitation anomalies as a response to an 80% increase (red) or an 80% decrease (blue) of soil moisture climatology applied on (a) April 1, (b) May 1, (c) June 1, (d) July 1, and (e) August 1, averaged over the Mississippi River Basin. The dash-dot lines present the 90% confidence interval based on the t test with the last ten years of a 12-year initial integration. (Solid line: SM_Veg-Control; Dashed line: SM-Control)



4. Results II: Responses to Soil Moisture Anomalies Applied on June 1

Figure 3: (a) Precipitation in the Control ensemble, (b) precipitation differences between the SM Anomaly ensemble and the Control ensemble, and (c) precipitation differences between the SM_Veg Anomaly and the SM Anomaly ensemble in June, July, August and September. Only differences exceeding the 90% confidence level are shaded. The Anomaly ensembles are initialized with an 80% increase of soil moisture climatology on June 1.

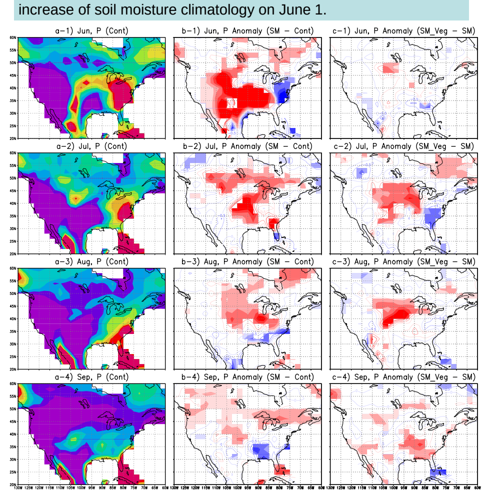
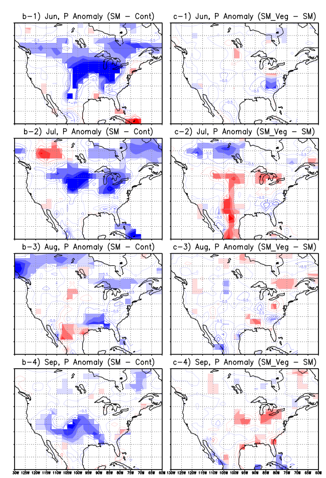
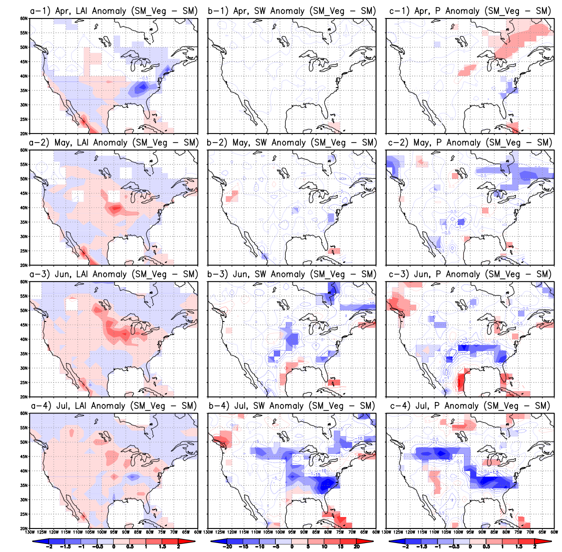


Figure 4: (b) and (c) are the same as Figures 3(b) and 3(c), but the SM and SM_Veg ensembles are initialized with a 80% decrease of soil moisture on June 1.



5. Results III: Responses to Wet SM Anomalies on April 1

Figure 5: (a) LAI differences, (b) soil water differences and (c) precipitation differences between the SM_Veg Anoamly ensemble and the SM Anomaly ensemble in April, May, June and July. Only differences exceeding the 90% confidence level are shaded. The Anomaly ensembles are initialized with an 80% increase of soil moisture climatology on April 1.



6. Summary

1. Vegetation feedback enhances the impact of wet summer soil moisture anomalies on subsequent precipitation. The soil wetness in summer promotes more vegetation growth in part of the central U.S. where plants are water-stressed. This increased vegetation leads to increased evapotranspiration and surface heating, favoring local convection. In CAM3-CLM3 during summer, this impact is dominant over the impact of faster depletion of soil moisture by increased vegetation, leading to a net positive vegetation feedback.
2. The situation reverses for wet spring soil moisture anomalies. Vegetation feedback is found to weaken the impact of wet spring soil moisture anomalies on subsequent precipitation. Precipitation in April is still in the winter regime and is not sensitive to soil wetness changes. With or without vegetation, soil moisture is going through a drying process as it moves into summer. With vegetation feedback, the increased vegetation growth speeds up this drying process, reducing soil moisture and eventually precipitation. This negative vegetation feedback would mess up the otherwise expected correlation between spring soil moisture and summer precipitation.
3. The impact of vegetation feedback is negligible in case of dry soil moisture anomalies. This may have to do with the fact that the model has a dry bias in central U.S. – plants in Control is already so water stressed that further decreae of soil moisture leads to very small decrease of vegetation.

This work has been submitted to JHM (Wang & Kim, 2006b).

References:

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