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Covariabilities between Warm-season Rainfall and Pre-season Soil Moisture over the United States

Wanru Wu* **and Robert E. Dickinson**

School of Earth and Atmospheric Sciences, Georgia Tech, Atlanta, GA 30332-0340

1. Motivation & Objective

The influence of soil moisture on near-surface atmosphere and climate via land-atmosphere interaction has been recognized as important for decades (e.g., Manabe 1969; Walker and Rowntree 1977; Rind 1982; Mintz 1984; Dickinson and Henderson-Sellers 1988; Avissar and Verstraete 1990; Chahine 1992; Betts *et al*. 1996; Koster *et al*. 2003). Soil moisture variations affect subsequent precipitation through the feedbacks between the land and the atmosphere, and hence provide land surface memory (e.g., Delworth and Manabe 1988, 1989; Dirmeyer and Shukla 1993; Koster and Suarez 1995; Schär *et al*. 1999; Pal and Eltahir 2001; Koster *et al*. 2003). The typical timescale of soil moisture variability is about 2 – 3 months in mid-latitudes from both observations and model simulations (e.g., Delworth and Manabe 1988, 1989; Vinnikov *et al*. 1996; Liu and Avissar 1999; Entin *et al*. 2000; Wu *et al*. 2002), suggesting that the impact of such land surface memory on precipitation could last up to seasonal time scales.

The continental United States is selected for the present study as an ideal mid-latitude example with typical soil memory of roughly 2 – 3 months to clarify the relationship between soil moisture and precipitation. The relative importance of the land and ocean impacts on U.S. precipitation changes with seasons and the influence of the land surface is the strongest during the warm season. The variability of U.S. summer average precipitation displays strong geographical dependence with large variability in the southeastern United States. While the warm season precipitation variability in U.S. is mainly influenced by the North American Monsoon System through large-scale atmospheric circulation (e.g., Higgins *et al.* 1997; Higgins *et al.* 2003), the land surface may contribute to the precipitation distribution and variability via regional hydrological cycle. Thus, it could be a pathway to improve the predictability of summer precipitation through clarifying its relationship with pre-summer soil moisture variation.

To establish that soil moisture affects precipitation is difficult even using observations because the other direction of causality is much stronger – precipitation has a first-order impact on soil moisture. This study examines the associations between springtime soil moisture and summertime precipitation. Its primary focus is to identify the correlations between spring soil moisture variations and summer precipitation anomalies.

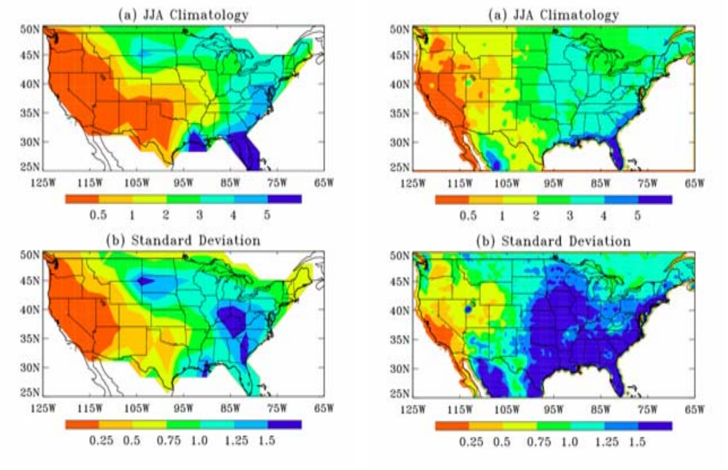
2. Methodology

Due to the shortage of large-scale long-term soil moisture observations, the data used in this study are simulated from the Common Land Model (CLM) (Dai et al. 2003) coupled with the National Center for Atmospheric Research Community Climate Model Version 3 (NCAR CCM3) (Kiehl et al. 1998). The coupling of CLM-CCM3 is detailed in Zeng et al. (2002). The sea surface temperature and sea ice are prescribed based upon observed monthly mean fields as atmospheric forcing in the model.

The data consist of monthly mean precipitation and top 1 m average soil moisture in the United States covering 1950-2000. The data quality is described in Wu and Dickinson (2004). Summer and pre-summer seasonal means are obtained by averaging together the monthly means of June-July-August and March-April-May, respectively. An anomaly is defined as the deviation of the seasonal mean from its long-term average.

The major statistical method used in the study is the singular value decomposition (SVD) (Wallace et al. 1992; Bretherton et al. 1992; Wang and Ting 2000; Liu 2003). Bootstrapping Monte Carlo estimation is used for the significance level tests.

3. Precipitation Climatology

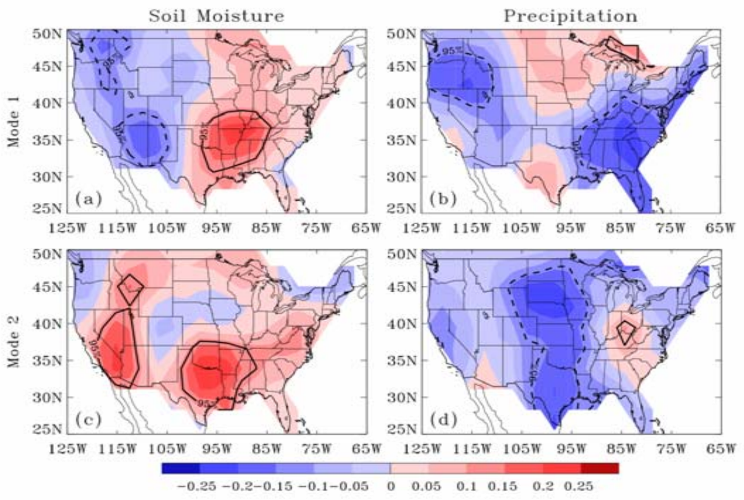


Simulation (CLM-CCM3)

Observation (Willmott-Matsurra)

4. Space-Time Coupling of Soil Moisture and P

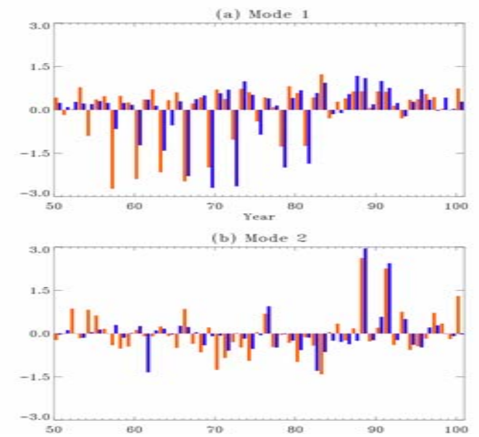
Spatial Patterns of Heterogeneous Correlations for Two Leading SVD Modes



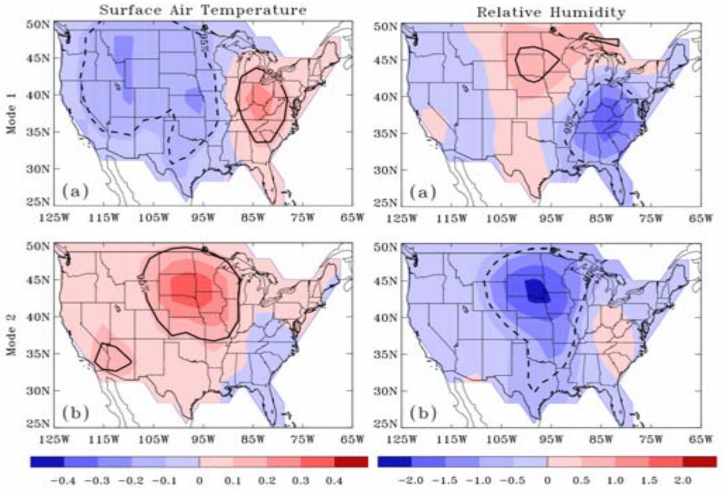
Corresponding Statistics

Leading Mode	Squared Covariance (%)	Temporal Correlation	Soil Moisture Variance (%)	Precipitation Variance (%)
1	27	0.83	9	10
2	16	0.88	5	9

Corresponding Time Series of SVD Expansion Coefficients



5. Corresponding Atmospheric Regression Pattern



6. Concluding Remarks

There are close spatial-temporal associations between springtime soil moisture and summertime precipitation over the Continental United States. Summer atmospheric fields such as surface relative humidity and air temperature also correlate significantly with the spring soil moisture SVD series. These relationships suggest that springtime soil moisture has impacts on summer atmosphere variability, although not necessarily of a single sign. The 50-year CLM-CCM3 climate simulation shows an in-phase correlation between spring soil moisture and summer precipitation over the Midwestern US and an out-of-phase relation over the Southeastern US. The SSTs in the eastern tropical Pacific and in the western tropical Pacific and Indian oceans appear to contribute to the asymmetric features of the expansion coefficient time series (Hoerling and Kumar, 2003). The overwhelming contribution of deep convection to precipitation and consequent local hydrological recycling may enhance the out-of-phase relation between the two fields. The sign of the correlation could change with different time lags or leads. Evidently, there are multiple mechanisms combined to affect such spatial-temporal covariabilities.

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* *Corresponding author email: wwu@eas.gatech.edu*