Investigation of summer land-atmosphere feedback over the U.S. with observations, reanalysis data and models

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1. Abstract
The first part of this study examines the impact of sea surface temperature (SST) and soil moisture on summer precipitation over two regions of the U.S. (the Upper Mississippi River Basin and the Great Plains) using data from observational SST and precipitation, and VIC-simulated soil moisture. Based on conditioned soil moisture-precipitation correlation analysis, soil moisture-precipitation feedback is more likely to be positive and significant during the warm season when the soil temperature prediction based on SST alone is low, and in the years of large precipitation anomalies, which underlines the complementary roles both SST and soil moisture play in determining precipitation and the importance of considering soil moisture in predicting climate extremes. The second part compares land atmosphere coupling strength over the U.S. between observational data analysis and model output, with as a coupling strength indicator the probability density functions of conditioned correlation over the years of large precipitation anomalies. Among the eight different regions classified by land cover types, our results identify the Great Plains as a hot spot for strong land-atmosphere coupling; results of comparison between soil moisture-precipitation coupling, our results suggest that the coupling strength is stronger in observational data than in the CAM-CLM models. The part of the result is due to the strong decrease of coupling strength from CAM3-CLM to CAM4-CLM, which is further supported by GLACE1 experiments and attributed to changes in CAM.

2. Background and Motivation
The potential positive feedback (i.e., dominant view) between soil moisture and precipitation, which tends to perpetuate and sustain anomalous hydrological conditions such as floods or droughts, promotes a long land memory and improves predictability of the land-atmosphere system (Koster et al. 2004, Dirmeyer et al. 2009). Soil moisture therefore may serve as a potential indicator for precipitation over large regions with a long land memory and therefore strong land-atmosphere coupling.

Numerical modeling studies have demonstrated the prevailing view of the positive soil moisture precipitation feedback observed over various regions in the United States (e.g., the Great Plains, including the Midwest and the Southwest), from observations studies (Sanz and Wang 2007). However, long-term observational studies on this idea are still inconclusive (Fedin and Eltahir 1997, Salvucci et al. 2002, O’Dorico and Porporato 2004; Ruiz-Barradas and Nigam 2005). A fundamental issue related to the model-observation contrast is the comparability of results from numerical modeling studies and observational analysis. Specifically, most numerical modeling studies examining the impact of soil moisture on precipitation were based on an ensemble approach. However, short observational record technically represents one member of a potential ensemble simulation.

On the other hand, numerous studies also suggest that sea surface temperature (SST) can play a important role affecting precipitation over the continental U.S. (e.g., Trenberth and Guillemot 1996; Schubert et al. 2009).

3. Objective
To understand and quantify the signficance of land surface feedback in the context of large scale SST forcing, and facilitating the application of land surface conditions in operational prediction at sub-seasonal and seasonal timescales. The specific research questions are:

• How does the impact of local soil moisture on subsequent precipitation depend on the impact of SST and on specific precipitation regimes based on observations?
• How does land-atmosphere coupling strength in models compare with observations and reanalysis data?

4. Data and Model
• Climate Prediction Center (CPC) U.S. UNIFIED daily precipitation; Variable Infiltration Capacity (VIC) modeled daily soil moisture (1950-1997)
• North American Regional Reanalysis (NARR) daily and Climate Forecast System Analysis (CFSR) 6-hourly data (1979-2012)
• Hadley Centre, Meteorological Office HadISST 1.1 Global monthly sea surface temperature (1950-2008)
• National Center for Atmospheric Research (NCAR) CAM3-CLM (Community Atmosphere Model 3;Community Land Surface Model 3) and its improved version CAM4-CLM4 (driven by observed HadISST) daily output (1950-2007)

5. Method and Results
5.1 Conditioned soil moisture-precipitation correlation

Regions:
- GP: 37.5N-45N, 105W-95W; Upper Mississippi River Basin (UM)
- UM: 36N-44N, 92W-85W

HadiSS: CPC precipitation, VIC soil moisture (1950-1997)

Two approaches to derive the SST predictors:
• Use SST averaged over identified Oceanic Areas: correlate summer precipitation averaged for a specific region (e.g., Great Plains) with summer SST of the globe, produce a global correlation map, and identify oceanic areas that present significant correlation.
• Use leading EOFs derived from Empirical Orthogonal Functions analysis: isolate the leading patterns (EOFs) of summer SST using EOF/REOF analysis under different domains (Pacific, Atlantic, and global), and identify the EOFs with significant correlations to summer precipitation of the two regions.

Fig.2: Probability distribution function of correlation between 1 day soil moisture and subsequent 21 day precipitation amount over the plains regions

6. Summary and Conclusion

For the first part:
• With the help of both GP and UM, regardless of whether precipitation amount or frequency is considered, the conditioned soil moisture-precipitation correlation is stronger during the years with large summer precipitation anomalies, and is stronger during years when SST presents high skill in summer precipitation prediction than during those years when SST exhibits high skill, which highlights the critical effects of including soil moisture in predicting extremes.

For the second part:
• Among the eight classified regions, the correlation analysis from both observations and models identify the Great Plains, i.e., NPG and SGP, as hot spots for strong land-atmosphere coupling, which is consistent with previous studies using different methodologies (Koster et al. 2004, Dirmeyer et al. 2009). Ruiz-Barradas and Nigam also identify the Plains region as having strong land-atmosphere coupling, which is consistent with previous studies using different methodologies.

Table 2: Values of PC and SI (in parenthesis) for each of correlation between 1 day soil moisture and 21 day precipitation for different datasets over the eight regions in outer quartile values: values with SI less than 0.1 are in bold and italic; values in bold and italic; values in bold and italic are significant. Table 3: Same as table 1 but for evaporative fraction

Fig.5: Distribution of dAJ (land atmosphere coupling strength for precipitation) and dAE (land atmosphere coupling strength for evaporation) over the studied region of each drought in the years 1950-1997 (its standard deviation) for the CAM-CLM models, derived from GLACE1-type experiments, indicates that significant decrease of dAJ and dAE values for pc of correlation between 1 day soil moisture and 21 day precipitation for CAM-CLM models during 1950-1997 for outer quarters are presented in the right column. (See Koster et al. 2006 for GLACE1 approach.)

Table 3: Same as table 1 but for evaporative fraction

Related papers

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