The Impact of Prescribed, Model-diagnosed Soil Moisture on Interannual Variability of AGCM-simulated Precipitation Over the USA

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INTRODUCTION:

The present study was motivated by results from attribution studies that have assessed the relative impacts of SST vs. land surface boundary conditions on inter-annual variability of precipitation in the tropics and extratropics. An important result is that soil moisture memory potentially influences the interannual variability of precipitation in summertime, mid-latitude transition zones. The impact of prescribed, quasi-realistic, model diagnosing soil moisture on summertime interannual variability of precipitation over the USA is described. The focus is on two extreme events that occurred over the central USA, i.e., the summer drought of 1988 and the summer floods of 1993.

MODELS

AM2p11: AGCM 2.1x2.1° horizontal grid, 12 vertical levels, Mixed-Layer PBL turbulence and PMS convection

AM2p12: Same model as AM2p11 except 24 vertical levels, UKMO PBL turbulence, some or reference of TKE and radiation cloud scheme.

AMQp12: Similar to AM2p11 except 24 vertical levels, UKMO PBL turbulence, some or reference of TKE and radiation cloud scheme.

EXPERIMENTAL SETUP

Each experiment consists of an ensemble of 6 AM2p12 23 year integrations with prescribed, interannually varying HUM and momentum of soil moisture as described below, starting from different perturbed initial conditions.

THE EXPERIMENTS

CNTRL: The control experiment with a fully interactive land surface, including prescribed soil moisture.

OBS.SM: Same as CNTRL except soil moisture is prescribed by forcing the land model (AMQp12) with daily Shuttle Radar Topography Mission (SRTM) observed precipitation data and a monthly ECMWF-IFS 40-surface data. Interannually varying monthly means are interpolated in each model physics time step.

OBS.SM-1 SM Same as OBS.SM except that annually varying, monthly mean soil moisture is prescribed from observed ensemble mean from CNTRL.

The coupling strength, L2 (Glace et al., 2004) is applied to JJA seasonal means of precipitation and other variables. Δ2 is basically the ratio of the model’s temporal variance of ensemble seasonal means (the signal) to the total variance signal plus inter-ensemble noise) over the 21 year period (1980-2000). The differential coupling strength, Δ2, for precipitation (Fig. 7) is positive over much of the central USA, in both AM2p12 experiments, consistent with the hot spots found by Glace et al. (2004) on shorter time scales. Despite its noticeably weaker Δ2 amplitude, OBS.SM could have greater impact than CNTRL.1 SM on simulated precipitation anomalies even during extreme events, by virtue of its quasi-realistic soil moisture. Note that the differential coupling is model-dependent. Δ2, the differential coupling response for 2 meter reference temperature (Fig. 2, top panel) is generally stronger than Δ2. The 850 hPa divergence (Fig. 2, bottom panel) exhibits a detectable differential coupling response, in contrast to the regional 2 m circulation (not shown).

Coupling Strength for Precipitation: Δ2 = (σS - σ) / (σS + σ)

where S is the temporal variance of ensemble seasonal mean precipitation, (σS)2 is the temporal variance of seasonal means from all ensemble members, and σ2 is 1/3 total variance.

Differential Coupling Strength: Δ2 = (σS, CNTRL) - (σS, OBS.SM) = (σS, OBS.SM) / σS (CNTRL)

Δ2 is a measure of land-atmosphere coupling, or more specifically, of the fraction of precipitation variance attributable to interannual variations of seasonal mean soil moisture.

AM2p11 CNTRL and OBS.SM JJA assemble seasonal mean precipitation anomalies (i.e., the departures from their respective 23-year averages) are verified against SSMI observed data for two extreme summers, i.e., 1988 and 1993. Clearly, the OBS.SM simulation with prescribed, quasi-realistic soil moisture best captures the observed precipitation anomaly pattern over much of the USA (Fig. 3) in both summers. But the AM2p12 OBS.SM simulation (Fig. 4) is inferior to its AM2p11 counterpart. The AM2p12 PBL parametrization may affect the land-atmosphere coupling and the regional circulation, and in turn, precipitation.

None of the AM2p11 OBS.SM precipitation anomaly patterns are correlated with the prescribed soil moisture anomalies (Fig. 5). Also, the near-surface 2 m temperature anomalies (Fig. 6) are more realistic, overall, in OBS.SM than in CNTRL. However, in 1988, the OBS.SM maximum is shifted too far south and east.

AMQp12 CNTRL and OBS.SM simulated seasonal mean precipitation anomalies have been correlated with seasonal observations over the USA region (170°W–70°W, 25°N–50°N). The time series of OBS.SM observed domain averaged anomaly correlations (blue curve) (Fig. 7) exhibits somewhat higher values, overall, especially during late spring and/or summer. But both curves tend to differ less during winter, when soil moisture should have much less influence. Also, during strong El Nino events such as 1988 and 1993, tropical SSTs may exercise more control over the mid-latitude westerly circulation.

As for summer precipitation climate, CNTRL suffers a greater deficit than OBS.SM (Fig. 8) over the central USA, the lower Gulf States and part of the North American monsoon region. Nonetheless, OBS.SM is substantial, suggesting that soil moisture–memory accounts for only part of the precipitation deficit.

REFERENCES


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Fig. 1. Canonical correlation analysis between model simulated and observed precipitation. Model: AM2p12, AMQp12; station: 294 stations. AM2p11 results are not shown.

Summary:

1. In multi-year AM2p11 simulations, the JJA summer signal to total variance ratio for precipitation and 2 m temperature is enhanced over the USA by prescribing model simulated or quasi-realistic model-diagnosed soil moisture instead of predicting it.

2. Summertime precipitation and 2 m temperature over the USA anomalies associated with extreme events are simulated somewhat more realistically, when quasi-realistic model-diagnosed soil moisture is prescribed.

3. The summer seasonal precipitation bias found in the control simulation is reduced when quasi-realistic, model-diagnosed soil moisture is prescribed.

4. The results are affected but not overwhelmed by model-dependence.

Fig. 2. JJA seasonal mean differential coupling strength for OBS.SM vs. CNTRL. Bottom: OBS.SM simulation with prescribed model-diagnosed soil moisture.

Fig. 3. JJA seasonal mean differential coupling strength for OBS.SM vs. CNTRL. Top: Model diagnosed soil moisture. Bottom: OBS.SM simulation with prescribed model-diagnosed soil moisture.