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

C. T. Gordon[1] and Sergey Malyshev[2]

[1]Geophysical Fluid Dynamics Laboratory, [2]Princeton University

INTRODUCTION:

The present work 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-diagnosed 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: 2.5°x2.0° horizontal grid; 18 vertical levels; Mellor-Yamada PBL turbulence and RAS convection. Land Model: LM2p5 water bucket (Milly and Shmakin, 2002). AM2p11 participated in Glace (2004).*

AM2p12b *AGCM: Similar to AM2p11, except 24 vertical levels; UKMO PBL turbulence; some re-tuning of RAS and stratiform cloud scheme. Land Model: LM2p6 (minor upgrade to LM2p5). For model details, see GAMD (2004).*

EXPERIMENTAL SETUP

Each experiment consists of an ensemble of 6 AMIP-like 22-year integrations with prescribed, interannually-varying Hurrell SSTs and treatment 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 predicted soil moisture.*

OBS.SM *Same as CNTRL, except model-diagnosed soil moisture is prescribed by forcing the land model, offline, with daily Schnur (Nijssen, Schnur and Lettenmaier, 2001), observed precipitation data and 6-hourly ECMWF ERA-40 surface data. Interannually varying monthly mean values are interpolated to each model physics time step.*

CNTRL.1.SM *Same as OBS.SM, except that interannually-varying, monthly mean soil moisture is prescribed from ensemble member 1 of CNTRL.*

The coupling strength, Ω, (GLACE,2004) is applied to JJA seasonal means of precipitation and other variables. Ω is basically the ratio of the model's temporal variance of ensemble-seasonal means (the signal) to the total variance (signal plus intra-ensemble noise) over the 21 year period (1980-2000). The differential coupling strength, $\Delta\Omega_p$ for precipitation, (*Fig. 1*) is positive over much of the central USA, in both AM2p11 experiments, consistent with the hot spots found by GLACE (2004) on shorter time scales. Despite its noticeably weaker $\Delta\Omega_p$ amplitude, OBS.SM could have greater impact than CNTRL.1.SM on simulated precipitation anomaly errors during extreme events, by virtue of its quasi-realistic soil moisture. Note that the $\Delta\Omega_p$ response is model-dependent. $\Delta\Omega_T$, the differential coupling response for 2 meter reference temperature, (*Fig. 2, top panel*) is generally stronger than $\Delta\Omega_p$. The 850 hPa divergence (*Fig. 2, bottom panel*) exhibits a detectable differential coupling response, in contrast to the regional Z_{700} circulation (not shown).

Coupling Strength for Precipitation: $\Omega_p = \frac{(N\sigma^2_{p(EM)} - \sigma^2_p)}{(N-1)\sigma^2_p} \approx \frac{\sigma^2_{p(EM)}}{\sigma^2_p}$ *as* $N \to \infty$

$\sigma^2_{p(EM)}$ = *the temporal variance of ensemble seasonal mean precipitation,* σ^2_p = *the temporal variance of seasonal means from all* N *ensemble members, and approximately,* $0 \le \Omega_p \le 1$.

Ω_p is a measure of the fraction of precipitation variance attributable to interannual variations of all surface boundary conditions, e.g., SSTs as well as soil moisture. Ω_p is related to the signal-to-noise ratio: $SNR_p \approx \Omega_p/(1-\Omega_p)$.

Differential Coupling Strength: $\Delta\Omega_p\,(OBS.SM, CNTRL) = \Omega_p\,(OBS.SM) - \Omega_p\,(CNTRL)$

$\Delta\Omega_p$ 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.

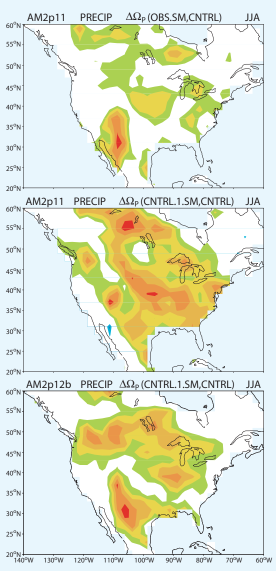

Fig 1. JJA seasonal mean differential coupling strengths for precipitation. Top: AM2p11 OBS.SM vs. CNTRL. Middle: AM2p11 CNTRL.1.SM vs. CNTRL. Bottom: AM2p12b CNTRL.1.SM vs. CNTRL.

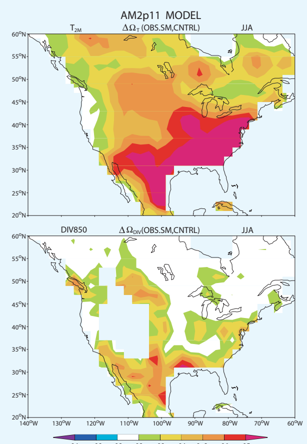

Fig 2. JJA seasonal mean differential coupling strength for OBS.SM vs. CNTRL. Top: near-surface 2m temperature. Bottom: divergence at 850 hPa.

AM2p11 CNTRL and OBS.SM JJA ensemble-seasonal mean precipitation anomalies (i.e., the departures from their respective 21-year averages) are verified against Schnur 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 patterns over much of the USA (*Fig. 3*) in both summers. But the AM2p12b OBS.SM simulation (*Fig. 4*) is inferior to its AM2p11 counterpart. The AM2p12b PBL parameterization may affect the land-atmosphere coupling and/or the regional circulation, and in turn, precipitation.

Note how well the AM2p11 OBS.SM precipitation anomaly patterns are correlated with the prescribed soil moisture anomalies (*Fig. 5*). Also, the near-surface 2m 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.

CNTRL and OBS.SM-simulated ensemble-monthly mean precipitation anomalies have been correlated with Schnur observations over the USA region (170W- 70W, 25N-50N). The time series of OBS.SM vs. 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 Niño events such as 1983 and 1998, tropical SSTs may exercise more control over the mid-latitude winter circulation.

As for summer precipitation climatology, 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, the OBS.SM bias is substantial, suggesting that soil moisture memory accounts for only part of the precipitation deficit.

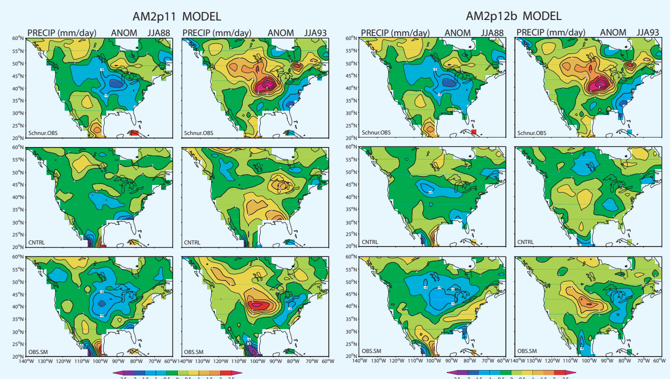

Fig 3 and 4. JJA ensemble-seasonal mean precipitation anomalies for the summers of 1988 (left) and 1993 (right). Top: Schnur OBS. Middle: CNTRL control simulation. Bottom: OBS.SM simulation with prescribed model-diagnosed soil moisture.

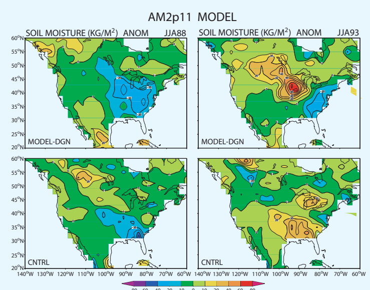

Fig 5. JJA ensemble-seasonal mean active soil moisture anomalies for the summers of 1988 (left) and 1993 (right). Top: Model-diagnosed soil moisture. Bottom: AM2p11 CNTRL control simulation.

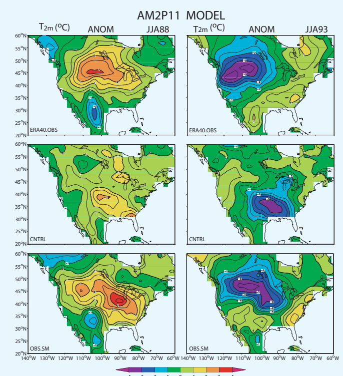

Fig 6. JJA ensemble-seasonal mean near-surface 2m temperature anomalies for the summers of 1988 (left) and 1993 (right). Top: ERA40 OBS. Middle: CNTRL control simulation. Bottom: OBS.SM simulation with prescribed, model-diagnosed soil moisture.

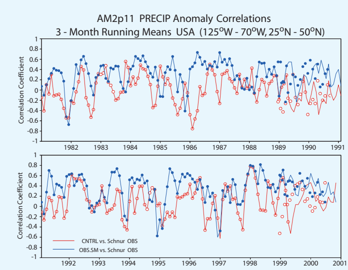

Fig 7. Monthly mean anomaly correlations between model simulated and Schnur "observed" ensemble-monthly mean precipitation anomalies vs. time. Three-month running mean time series are plotted. Red curve: AM2p11 CNTRL. Blue curve: AM2p11 OBS.SM.

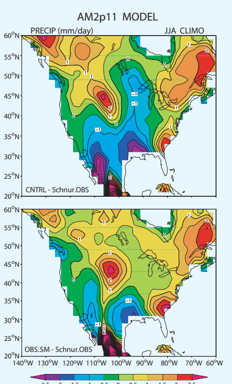

Fig 8. Climate bias of simulated JJA summer ensemble-seasonal mean precipitation relative to Schnur OBS. Top: AM2p11 CNTRL control simulation. Bottom: OBS.SM simulation with prescribed, model diagnosed soil moisture.

Summary:

1. In multi-year AMIP-like simulations, the JJA summer signal to total variance ratio for precipitation and 2m 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 2m 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.

References:

*GAMD Team - Anderson, J. L., et. Al. (2004): The New GFDL Global Atmosphere and Land Model AM2-LM2: Evaluation with Prescribed SST Simulations. J. of Climate, **17**, 4641-4673.*

*GLACE Team - Randal D. Koster, Paul A. Dirmeyer, et. al., (2004): Regions of Strong Coupling Between Soil Moisture and Precipitation. Science, **305,** 1138-1140.*

*Milly, P. C. D, Shmakin, A. B. (2002): Global modeling of land water and enegry balances. Part I: The land dynamics (LaD) model. J. of Hydrometeorology, **3**, 283-289.*

*Nijssen B., Schnur R., Lettenmaier D. P. (2001): Global retrospective estimation of soil moisture using the Variable Infiltration Capacity land surface model, 1980-1993. J. of Climate, **14**, 1790-1808.*

Acknowledgements:

The ERA-40 reanalysis data used in this study were obtained from the ECMWF. The authors also wish to thank Eric Wood for providing the Schnur precipitation data.

Tony.Gordon@noaa.gov