# 4.4 RESPONSE OF PRECIPITATION TO SOIL MOISTURE CONSTRAINTS IN THE NCEP GLOBAL MODEL SIMULATIONS FOR GLACE

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## 1. INTRODUCTION

Atmospheric General Circulation Models (AGCMs) have been widely used to investigate the interaction between land and atmosphere (e.g., Shukla and Mintz, 1982). A systematic response of atmosphere to slow varying state of the land surface has profound implications for seasonal prediction. Recent modeling studies have indeed found an impact from soil moisture on potential predictability at seasonal time scales (Dirmeyer, 2000; Koster et al., 2000; Kanamitsu et al., 2003). The efforts to understand the complex land-atmosphere interaction, however, are compound by the fact that the numerical results are often model-dependent. Koster et al. (2002) examined the response of the atmosphere to land surface states (referred to as land-atmopshere coupling strength) among four AGCMs and found a wide disparity in the inherent coupling strength.

Recently, the land-atmosphere coupling issue is investigated in the Global Land-Atmosphere Coupling Experiment (GLACE). GLACE is a coordinated AGCM inter comparison project in which each AGCM group performs the same highly controlled numerical experiments. Regions of strong coupling between soil moisture and precipitation have been identified from the multi-model average (Koster et al., 2004).

The NCEP EMC is among a dozen modeling groups contributing to the GLACE project. Here, we present the GLACE results using the NCEP Global Forecast System (GFS). We describe the GLACE experiment design and the NCEP GFS in Section 2 and Section 3, respectively. We then present the model results in Section 4, followed by the conclusion section.

## 2. EXPERIMENT DESIGN

GLACE is an AGCM inter comparison study aimed to examine the atmospheric response to anomalies in land surface states. It is a joint project sponsored by the Global Energy Water Cycle Experiment (GEWEX) Global Land Atmosphere System Study (GLASS) and the Climate Variability Experiment (CLIVAR). Details regarding GLACE can be found at its website: http://glace.gsfc.nasa.gov.

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For each participating AGCM, a total of three ensembles of AGCM simulations are conducted for the 1994 boreal summer period. The first set is typical AMIP runs (referred to as *W-ensemble*). For the second set, each member is forced to maintain the same time series of surface prognostic variables (referred to as *R-ensemble*). The third set is same as the second set except the surface variables are allowed to evolve freely, as only root zone soil moisture is forced to be identical among the member simulations (referred to as *S-ensemble*). Each ensemble contains 16 members and the integration covers from June 1, 1994 to August 31, 1994.

## 3. MODEL USED

The model used for this study is the global spectral forecast model of the NCEP GFS, configured with T62 horizontal resolution (~ 200km) and 64 levels in the vertical, matching that of NCEP's current seasonal forecast system. Aside from resolution, it is a slightly modified version of the model presently used for operational medium range weather forecasting at NCEP. Key model physical parameterizations include the simplified Arakawa Schubert convection, longwave and short- wave radiation, explicit cloud microphysics, non-local vertical diffusion, and gravity wave drag.

Two versions of GFS are used in this study: one is the operational version employing the OSU LSM (Pan and Mahrt, 1987) and the other is an experimental version coupled with the Noah LSM (Ek et al., 2003). Overall, we conducted three sets of GLACE runs (Table 1), as each run contains 3 ensembles with 16 members each ensemble. For R-ensemble, all members are forced to maintain the same time series of soil moisture, soil temperature, canopy water content, and snow depth. For S-ensemble, only the evolution of deeper (root zone and below) soil moisture states are constrained.

For all three runs, the ocean surface boundary fields are taken from observed 1-deg NCEP Reyolds/Stokes SST and initial atmospheric conditions are taken from the NCEP Climate Prediction Center (CPC) AMIP runs. The initial land states for the OSU and Noah runs are taken from the CPC AMIP runs while those for the NoahX run are taken from Noah cycled Global Data Assimilation System (GDAS).

**Table 1.** Three sets of GLACE runs conducted in this study.

| Exp ID | OSU | Noah | NoahX |
|---|---|---|---|
| LSM | OSU | Noah | Noah |
| Atm IC | CPC AMIP | CPC AMIP | CPC AMIP |
| Lnd IC | CPC AMIP | CPC AMIP | GDAS |

## 4. RESULTS

Figure 1 shows the time series of daily total evaporation (in mm) for the W-, R-, and S-ensemble over three regions (Eastern US, Southeast China and Central Europe) for the OSU run. Figures 2 and 3 show the corresponding time series for daily average air temperature (in K) and daily total precipitation (in mm). The Noah and NoahX runs show similar results (not shown here). Note the results presented here are model-specific (GFS only).

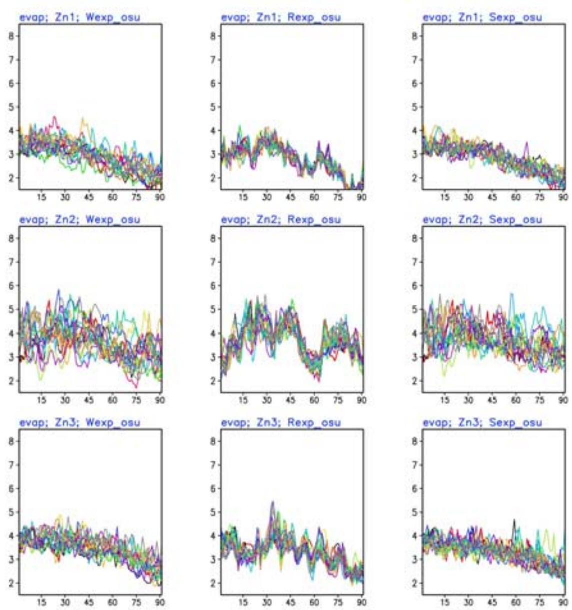


Figure 1. Time series of daily total evaporation (in mm) for the W-ensemble (left), R-ensemble (middle), and S-ensemble (right) over 3 regions (from top to bottom: Eastern US, Southeast China and Central Europe).

The impact of constrained surface prognostic states on near surface fields is evident, e.g., time series of latent heat flux and near-surface temperature show great coherence among the members of R-ensemble. However, the evolution of precipitation shows a broad disparity across the R-ensemble members. Simulations in S-ensemble have no coherent response to the deeper soil moisture states (a slowly varying field). The lack of atmospheric response to soil moisture states seen in this study has profound implications for seasonal predictions embedded in the GFS modeling system.

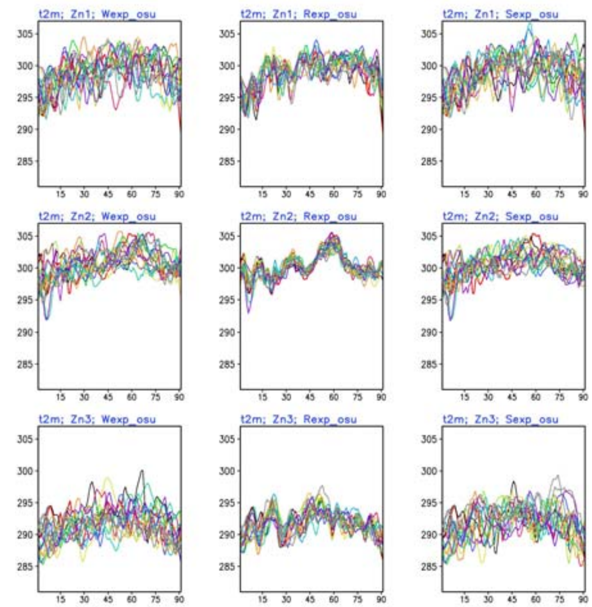


Figure 2. Same as Figure 1, except for daily average air temperature (K).

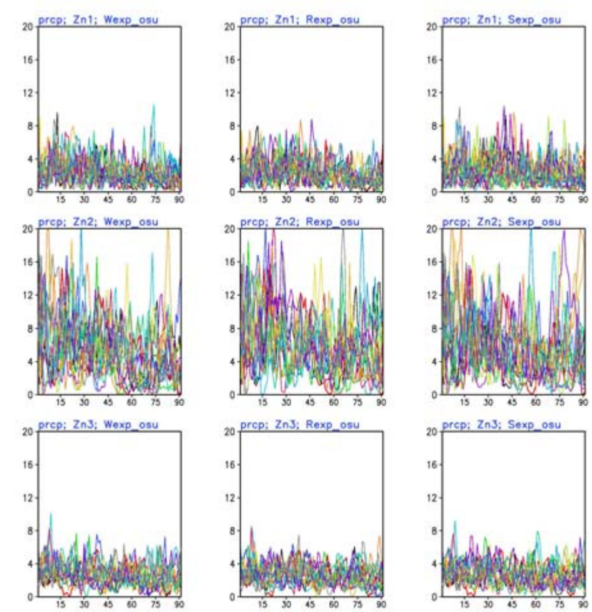


Figure 3. Same as Figure 1, except for daily total precipitation (mm).

Large intra-ensemble variance shown in Figure 3 indicates that the impact of the surface boundary conditions on the generation of precipitation is weak in GFS simulations. In fact, among the 12 AGCMs participating in GLACE, the NCEP GFS falls within the group that shows weak land-atmosphere coupling. Figure 4 shows the land-atmosphere coupling strength diagnostic, $\Omega$, for boreal summer across a dozen AGCM runs. The diagnostic variable $\Omega$, derived from intra-ensemble variance and variance of the ensemble-mean of rainfall, describes the impact of surface boundary conditions on precipitation. In principal, this $\Omega$

difference approximates the fraction of the precipitation variance explained by variations in land surface states. It was first introduced in Koster et al. (2002) and is later used in Koster et al. (2004).

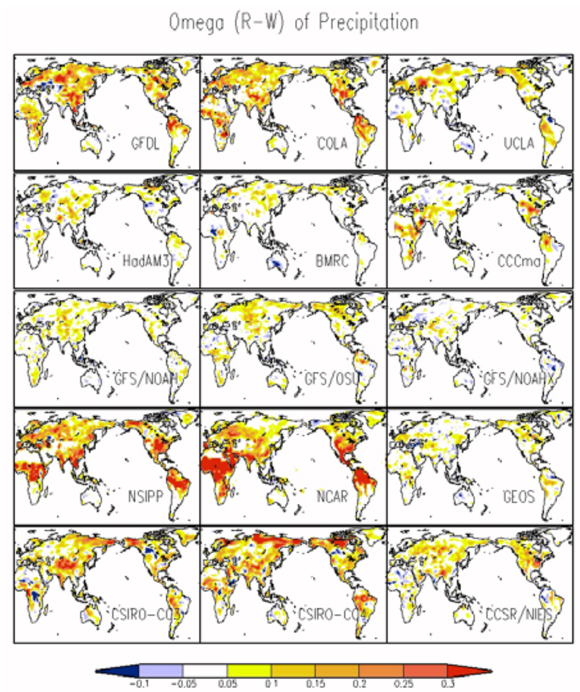


Figure 4. The Ω difference of precipitation between R- and W-ensemble from 15 AGCM runs, including three GFS runs in the 3rd row (left: Noah, middle: OSU, right: NoahX).

Figure 5 shows time series of daily average column soil moisture (in fraction) and daily total precipitation smoothed by 7-day running mean (in mm) from one member from W-ensemble (a typical AMIP run). All three runs (OSU, Noah, and NoahX) show that the impact of soil moisture on rainfall is inconclusive while the opposite direction (a first order impact) is very robust. For GFS, internal variability in the atmosphere greatly damps the impact of soil moisture anomalies and such decoupling is likely to pose great limitation on the role of soil moisture in seasonal predictability.

## 5. CONCLUSIONS

This study presents the simulation results of the NCEP Global Forecast System (GFS). The experiment design is based on the Global Land-Atmosphere Coupling Experiment (GLACE) in which participating AGCM group performed several ensembles of boreal summer simulations. Note the results shown here are model-specific (for GFS only), as the estimates from multi-model are discussed elsewhere (Koster et al., 2004).

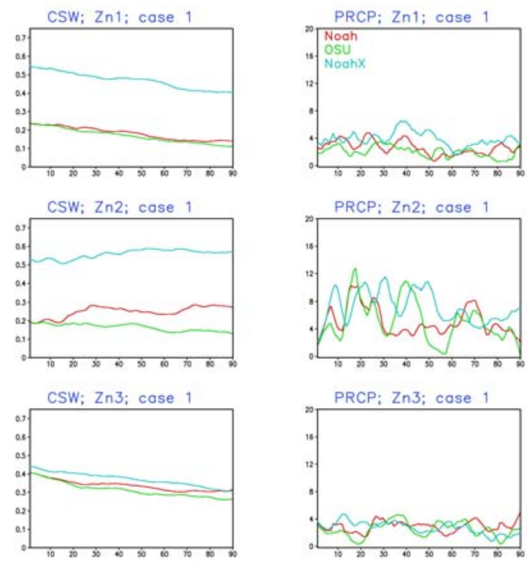


Figure 5. Results from single member from W-ensemble: time series of daily average column soil moisture in fraction (left) and daily total precipitation, smoothed by 7-day running mean, in mm (right) for three GFS runs (red for Noah; cyan for NoahX; green for OSU) over three regions (from top to bottom: Eastern US, Southeast China, and Central Europe).

The impact of prescribed land states on near surface fields is evident, as time series of latent heat flux and near-surface temperature show great coherence among the members. However, the evolution of precipitation shows a broad disparity among the members and only a small fraction of the precipitation variance can be explained by soil moisture anomalies. In fact, the NCEP GFS is among these AGCMs that show weak response of precipitation to prescribed land states. Such weak coupling implies that the initialization and monitoring of soil moisture may have limited improvement of seasonal precipitation forecasts in the GFS modeling system.

The lack of sensitivity of precipitation to soil moisture constraints is likely due to the inherent characteristics of the land surface scheme and how the moisture convection is formulated in the GFS. Future studies are needed to determine the apparently weak interaction between land and atmosphere in the NCEP GFS.

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