The Effect of Soil Moisture Initialization on Seasonal Predictions Simulated by the NCEP GCM

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1. Introduction

A large number of observational and numerical studies have shown that soil moisture field has a significant impact on model simulated climate and atmospheric variability (e.g., Shukla and Mintz, 1982). Due to the lack of long-term consistent soil moisture analysis, numerical studies of the impact of soil moisture on medium-to-seasonal range forecasts are often based on extreme or idealized conditions. Realistic initialization of soil wetness fields, however, has been recognized as a chanllenging task (Sellers et al., 1986; Sato et al., 1989). An alternative to idealized soil wetness field is model generated soil moisture fields. Such applications, however, are often subject to errors in model atmospheric forcing, particularly precipitation, evaporation, and radiation.

Modeling studies by Wang and Kumar (1998), Fennessy and Shukla (1999), and Koster et al. (2002) indicated that correctly observed or assimilated initial soil moisture states could, under certain circumstances, contribute significantly to the seasonal-to-interannual atmospheric predictability. Recently, efforts to use 'realistic' soil moisture (instead of idealized or model-generated fields) in seasonal predictions are attempted by Fennessy et al. (2002), Couville and Chauvin (2000), and Kanamitsu et al. (2002).

In the present paper, we examine the atmospheric predictability at seasonal scale using non-idealized and model-consistent initial conditions for soil moisture. This is accomplished using a state-of-the-art general circulation model, NCEP Global Forecast System (GFS), and soil moisture field from Air Force Weather Agency (ALWA) Agriculture Meteorology Modeling Systems (AGRMET) land surface analysis. Ensemble of GFS simulations are performed and the effect of initial soil moisture on seasonal predictions are assessed. A brief outline of this paper is as follows. Sections 2 and 3 describe the NCEP GFS and the AGRMET land surface analysis, respectively. Section 4 presents the experiment design. Experiment results and discussions are presented at Section 5, followed by the section of conclusions.

2. Model used

The model used for this study is a global spectral model with T42 resolution (about 300km) in the horizontal and 28 levels in the vertical. It is a slightly modified version of the GFS used for medium range weather forecasting at the NCEP. Key model physical parameterizations include the Relaxed Arakawa Schubert convection, long wave and short wave radiation, cloud-radiation interaction, non-local vertical diffusion, gravity wave drag, and mean orography.

The operational version of GFS utilizes the Oregon State University land surface model (Pan and Mahrt, 1987). As part of the efforts to unify land model in all NCEP global and regional models, NCEP community Noah LSM (Mitchell et al., 2002) has been implemented into GFS in late 2002 and this modified version of GFS is currently under evaluation. The GFS used here is the modified version that uses Noah LSM, and the GFS using OSU LSM is referred to as 'the operational GFS'.

3. Land surface analysis

AFWA AGRMET is an uncoupled land-only data assimilation system. It provides global database of land surface states and energy/water fluxes. Soil hydrology physics are forced with analyses of shelter height temperature, relative humidity, and wind speed, short and long wave radiation, and precipitation. There are 16 soil types (based on hybrid STATGSO/FAO database), which define soil moisture limits, e.g., wilting points and porosity. There are 24 vegetation types (based on NCAR/USGS database), which defines roughness length, LAI, and canopy resistance.

AFWA incorporated the Noah LSM into AGRMET in late 1999. Since AGRMET land states have spun up using the same land physics that the GFS executes, they provide ideal source of initial land states that are strictly self consistent with GFS land physics.

4. Experiment Design

Summer-time ensemble integrations initialized in mid-May, 2002 are conducted. Three realizations for atmospheric initial conditions are taken directly from the NCEP GDAS (with 24 hour apart). Observed daily SST are used during the integration. Two set of soil wetness initial states are used in the present analysis; one is based on the soil wetness analysis from NCEP GDAS and the other from the AGRMET soil wetness analysis.

Although AGRMET and GFS utilize the same vertical configuration (at depth of -0.1, -0.4, -1.0, -2.0 m), they use different specification of surface characteristics. The GFS initialization is performed in the following manner. AGRMET relative soil moisture ($Wrel$) is converted to volumentric soil moisture ($Wvol$) using wilting point ($Wwlt$) and porosity ($Wmax$) on GFS grid as follow:

$$Wvol = Wrel \times (Wmax - Wwlt) + Wwlt$$

Figure 1 shows the initial soil moisture (in mm) from GDAS and AGRMET soil wetness analysis on May 16, 2002 for the top 0-10 cm layer (left panels) and the 10-200 cm layer (right panels). For reference, the corresponding monthly average from NCEP/DOE Reanalysis 2 (R2) is also shown here. In general, ARGMET land surface analysis is dryer than GDAS field for the top 10 cm layer and become wetter for the 10-200 cm layer. Note that there are two soil layers in GDAS and R2 analysis, an upper 10 cm and a lower 190 cm thickness, while there are 4 soil layers in the ARGMET analysis, with 10, 30, 60, 100 cm thickness. Therefore, AGRMET soil moisture for the 10-200 cm layer is a summation of soil moisture from the lower three soil layers.

5. Results and Discussions

As noted earlier, two sets of initial soil wetness states (GDAS versus AGRMET) and two versions of models (GFS that uses Noah LSM versus the operational GFS that uses OSU LSM) are used in this study. A combination of soil wetness initialization and GFS runs are conducted, including Ctr_OSU (operational GFS runs initialized with GDAS soil wetness), Ctr_Noah (GFS runs initialized with GDAS soil wetness), and SoilInit (GFS runs initialized with AGRMET soil wetness). Not only the impact of soil wetness initialization on the seasonal predictions can be assessed, the differences due to the application of different LSM can also be evaluated.

Figure 2 shows the August soil wetness (monthly average) at the10-200 cm layer from the Ctr_OSU, Ctr_Noah, and SoilInit experiments. For reference, the corresponding R2 soil wetness is also shown here. In general, the use of AGRMET soil wetness field leads to a better agreement with the R2 soil wetness analysis (SoilInit versus Ctr_Noah). The impact of soil moisture initialization on atmospheric fields is less evident, such as 850 mb height field (Figure 3).

Since the Noah LSM implementation is still under evaluation, it is institutional to assess the effect of land physics on the model predictions. Figures 4 and 5 shows the August soil wetness at the 10-200 cm layer and 0-10 cm layer, respectively, over the US. Considering Ctr_Noah as the reference (bottom panel), the difference between Ctr_Noah and Ctr_OSU indicate the impact of land physics (middle panel) and the differences between SoilInit and Ctr_Noah indicate the effect of soil moisture initilization (top panel). It is shown that the effect due to initialization and the impact of land physics are comparable for the fields considered. Such argument may not hold for other field and thus further investigation is needed.

6. Conclusions

On the basis of global model studies, the impacts of soil moisture initialization on seasonal predictions are assessed. In specific, summer-time ensemble integration initialized with two sets of soil wetness fields (GDAS versus AGRMET) are performed and their results are compared and analyzed. Preliminary results indicate that seasonal predictions could be enhanced by using AGRMET land surface analysis.

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Figures:

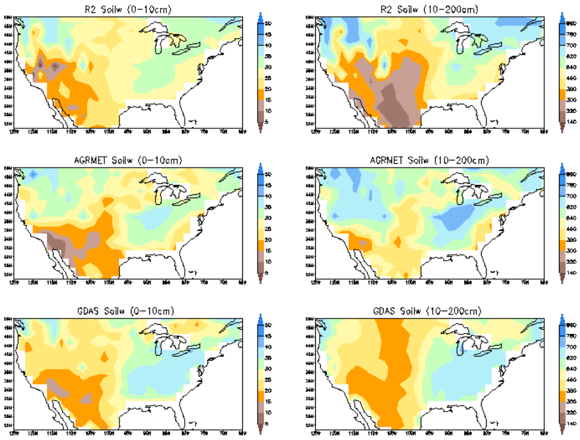

Figure 1. Soil wetness (in mm) from Reanalysis 2 (top), AGRMET (middle), and GDAS (bottom) on May 16, 2002. The 0-10 cm soil wetness fields are presented at left panels and the 10-200 cm fields are presented at right panels.

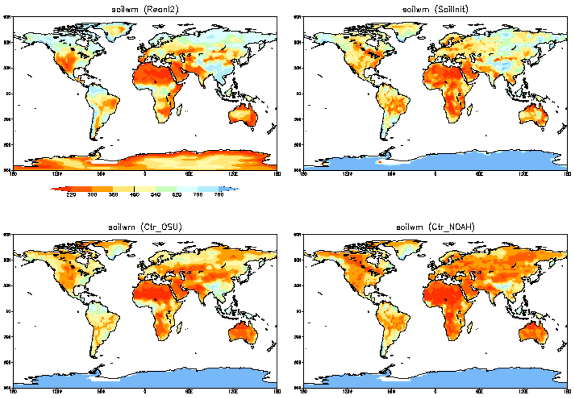

Figure 2. August soil moisture (mm) at 10-200 cm layer from R2 (left-top), Ctr_OSU (left-bottom), Ctr_Noah (right-bottom), and SoilInit (right-top).

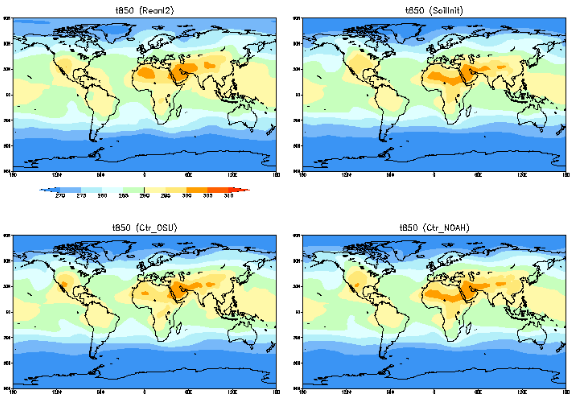

Figure 3. Same as Figure 2, except for 850 mb height field.

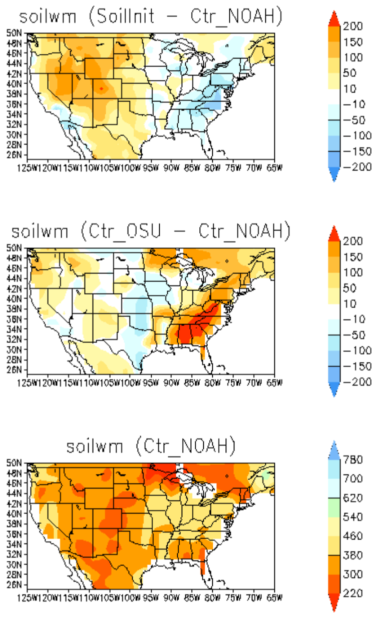

Figure 4. August soil wetness at 10-200 cm layer from Ctr_Noah experiment (bottom) and the differences between SoilInit versus Ctr_Noah (top) and between Ctr_OSU versus Ctr_Noah (middle).

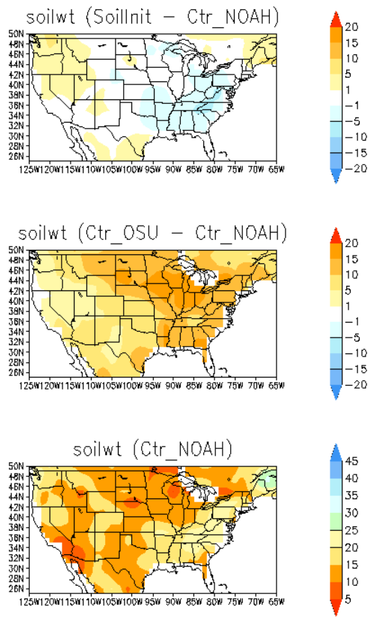

Figure 5. Same as Figure 4, except for soil wetness at 0-10 cm layer.