HYDROLOGICAL FORECAST SKILL ASSOCIATED WITH LAND SURFACE INITIALIZATIONS

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Knowledge of sub-surface soil moisture conditions at the start of a seasonal or sub-seasonal forecast can potentially increase the skill of the forecast through the impact of soil moisture on the surface energy budget and associated evolution of meteorological quantities. This study is aimed at quantifying, across a broad range of state-of-art forecast simulations, the contribution of realistic soil moisture initialization to sub-seasonal hydrological forecast skill. Soil moisture initialization is based on offline land surface model simulations with realistic (Global Soil Wetness Project 2) atmospheric forcing. In this presentation, we report on the current status of the forecast experiment and discuss the sub-seasonal forecast results found so far with the MIROC AGCM in boreal summer.

Key Words : *soil moisture, predictability, forecast skill, AGCM, land and atmosphere interaction*

1. INTRODUCTION

Numerical weather forecasts rely on atmospheric initialization - the accurate specification of atmospheric prognostic variables at the beginning of the forecast. Such initialization may contribute to forecast skill at leads of up to about ten days[1)].

Forecasts at longer leads, however, require a different strategy. Operational centers now supply seasonal atmospheric forecasts based largely on forecasts of ocean behavior. The idea is simple - if sea surface temperatures (SSTs) can be predicted months in advance, and if the atmosphere responds in predictable ways to the predicted SSTs, then aspects of the atmosphere behavior can be predicted months in advance.

Soil moisture, another slow variable of the climate system, is beginning to garner attention in the forecast community[2)]. The timescales of soil moisture memory are typically 1 or 2 months[3)], sigficantly less than those of the ocean. Nevertheless, soil moisture has a special importance. Some atmospheric general circulation model (AGCM) studies note a strong tropical -extratropical contrast in the ocean impact on climate, with the ocean showing a relatively small impact during summer in midlatitudes[4)]. For the prediction of summer midlatitude precipitation over continents at sub-seasonal and longer leads, land surface initialization may be more important than ocean initialization[5)]. Note that for land surface initialization to affect a forecast, two things must happen: (i) the initialized soil moisture anomaly must be remembered into the forecast period, and (ii) the atmosphere must respond in a predictable way to the soil moisture anomaly. Global Land-Atmosphere Coupling Experiment-1 (GLACE-1) is, in essence, a thorough analysis of the second aspect, the response of a modeled atmosphere to soil moisture anomalies[6)] by a similarity diagnostic[7)]. GLACE-1 thereby filled a critical void, since abroad, multi-model analysis of this important element of the climate system had never before been performed. The first aspect, associated with soil moisture memory, is addressed only indirectly in GLACE-1 through a side analysis , this study

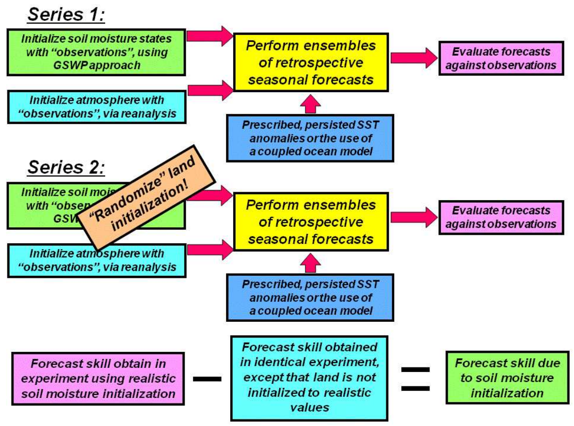

Fig-1 Schematic diagrams of Series-1 and 2. Scaled values are used to initialize land surface states in Series 1 and 2. In Series 2, however the values are randomly chozed from the target 10 years (1986 to 1995), but same dates.

examines the joint impact of memory and atmospheric response in the context of initialization and forecast skill.

2. EXPERIMENTAL DESIGN

(1) Model

The model used in this study is the Model for Interdisciplinary Research Climate (MIROC) AGCM[8] (T42 horizontal resolution), which has been developed and improved by the Center for Climate System Research, the University of Tokyo, the National Institute of Environmental Studies, and the Frontier Research Center for Global Change. For the land-surface scheme, we adopted the Minimal Advanced Treatment of the Surface Interaction and RunOff (MATSIRO) model[9], designed to represent biospheric processes such as photosynthesis.

(2) Ensemble Simulations

There are two types of ensemble simulation (Series-1 and 2).

Series 1:Forecast simulations using realistic land surface state initialization. Length of each forecast: 2 months (more precisely, 60 days); Start dates: July 1, July 15, and August 1 in each of the years 1986-1995. Total number of start dates: 30; Number of ensemble members per forecast: 10; Equivalent number of simulation months: 300 (=25 years) The 10 ensemble initial states are generated by adding small perturbations (3-hour scale) on atmospheric variables.

Series 2: Forecast simulations not using realistic land surface state initialization. Length of forecasts, start date, total number of start dates, number of ensemble members per forecast, number of simulation months are the same as in for Series 1. For Series 2, the initial land states for a given forecast ensemble are not identical ; rather, they are drawn from a distribution of potential states, the distribution determined from long term simulations with the model. Series-2 is identical to Series-1 in every way except for the fact that it does not benefit from realistic land state initialization.

(3) Land surface initialization

Optimally, initial land surface states for Series-1 are established through participation in the Global Soil Wetness Project - Phase 2 (GSWP-2)[10]. Through GSWP-2, modelers produce global fields of land surface fluxes, state variables, and related hydrologic quantities by driving their models offline with global arrays of observations-based meteorological forcing. This forcing spans the period 1986-1995 at a resolution of 1 degree. GSWP-2 model states at the forecast start times can be used to initialize the 2-month forecasts.

Adjustment of the initialized fields is necessary because of climate bias in the forecast system relative to observations. As pointed out in Koster and Suarez (2003), use of unmodified fields could lead to suboptimal forecasts-the unmodified fields would lead to a transitional climate "drift" during the forecast period, and the interpretation of the forecast could be affected by the drift[11]. To avoid this drift, land initial states are scaled to adjust the model climate, i.e., the offline based land surface anomalies are added to the AGCM's climate we use.

This study is based on an implicitly assumption that the model-generated land surface fields are accurate, to the first order. Data assimilation techniques through the satellite-derived soil moisture data have recently been developed, and the more accurate land surface fields will be used in the future.

(4) Anomaly persisted sea surface temperature

This study is designed to isolate the impacts of land initialization on sub-seasonal predictability and forecast skill. Thus, model-to-model variations in predictability associated with ocean processes should be avoided if possible. The SSTs to be prescribed during each forecast period have been provided by the authors ; the time series of SST fields were constructed by applying a simple persistence measure to the SST anomalies present on the forecast start date. The SST prescription is deemed acceptable because of the short length of the forecast simulations (2months) relative to the long timescales of ocean variability.

3. POTENTIAL PREDICTABILITY

(1) Quantification of potential predictability

First we discuss the potential predictability (hereafter; PP) for soil moisture (5-25cm depth from the land surface). PP is the maximum predictability possible in the forecast system - a measure of the degree to which atmospheric chaos will limit forecast certainty even under the assumption of a perfect model, perfect initialization, and perfect validation. To isolate land impacts on PP, we compare the values generated in Series-1 and 2; to generate the values for a given series, we essentially quantify the ability of one ensemble member to "predict" the mean of the remaining ensemble members in a given forecast. The details of the approach are as follows: 1) For a given ensemble forecast, assume that the first ensemble member represents nature. Assume that the remaining ensemble members represents the forecast. 3) Determine the degree to which the forecast agrees with the assumed nature. 4) Repeat multiple times, with each ensemble member in turn taken as "nature". The resulting skill diagnostics are then averaged. The PP is an underlying characteristic of a modeling system that underlies its ability to generate true skill in any forecast exercise.

(2) Soil moisture

Figure 2 shows the PP for soil moisture associated with land surface initialization for days 1-15 (Fig.2 a-c) and days 16-30 (Fig.2 d-f). The forecast simulations start on July 1, July 15, and August 1st from 1986 to 1995. PP for soil moisture shows the maximum limitation of PP for atmospheric variables (e.g., near surface temperature, precipitation). Fig.2-b and e were obtained from Series-2; they show the PP that stems from knowledge of the atmospheric initial and SST boundary conditions. Those on Fig.2-a and d show results from Series-1, that is, the PP stemming from knowledge of land surface initial conditions in addition to the atmospheric initial and SST boundary conditions. Therefore the PP due to land surface initial conditions is shown in Fig.2-c and f for days 1-15 and 16-30.

Figure 2-c shows that the land surface initialization leads to a significant increase in PP, particularly in the center of the Eurasian continent such as Siberia, Asia, the Sahel Africa, and the eastern region of North America. Some desert regions (e.g., Sahara in Africa) does not have strong PP associated with the land surface initialization because there is no enough room in Series-2 (Fig.2-b) neverthless the simulated soil wetness is really realistic or not.

Many regions still have strong PP in days 16-30 (Fig.2-f) even though atmospheric memory is already dissipated[7]. This would suggest the importance of land surface initilization at least for the hydrological forecast in sub-seasonal scale. The strong PP is particularly distributed over North America and Siberia where this climate model has strong land-atmosphere coupling strength for atmospherere in boreal summer[12]. Therefore the land surface initialization has strong potential to contribute to atmosphere by land and atmosphere interactions.

In this forecast system, knowledge of the land state at the start of the forecast can potentially lead to important increases in forecast skill as well as atmospheric initial and SSTs alone.

4. FORECAST SKILL

(1) Quantification of forecast skill

This section discusses the forecast skill (compared to actual observations) associated with land surface initialization at days 1-15 and days 16-30. The forecast skill is calculated by first averaging the simulated anomaly over the 10 ensemble members in a given forecast and then paring that averaged anomaly with the observed anomaly for that time period. We then compare the resulting r^2 values at each grid cell using 30 (10 ensemble members times 3 starting dates) forecast / observed pairs. The computed r^2 is our measure of the forecast skill.

(2) Soil moisture

We first focus on the computed forecast skill for soil moisture (Fig.3 a-c). The observation was obtained from the GSWP-2 project which we used for the land surface initialization. Series-1 (Fig.3-a) shows strong forecast skill of soil moisture all over the world on the contrary that only some regions have significant

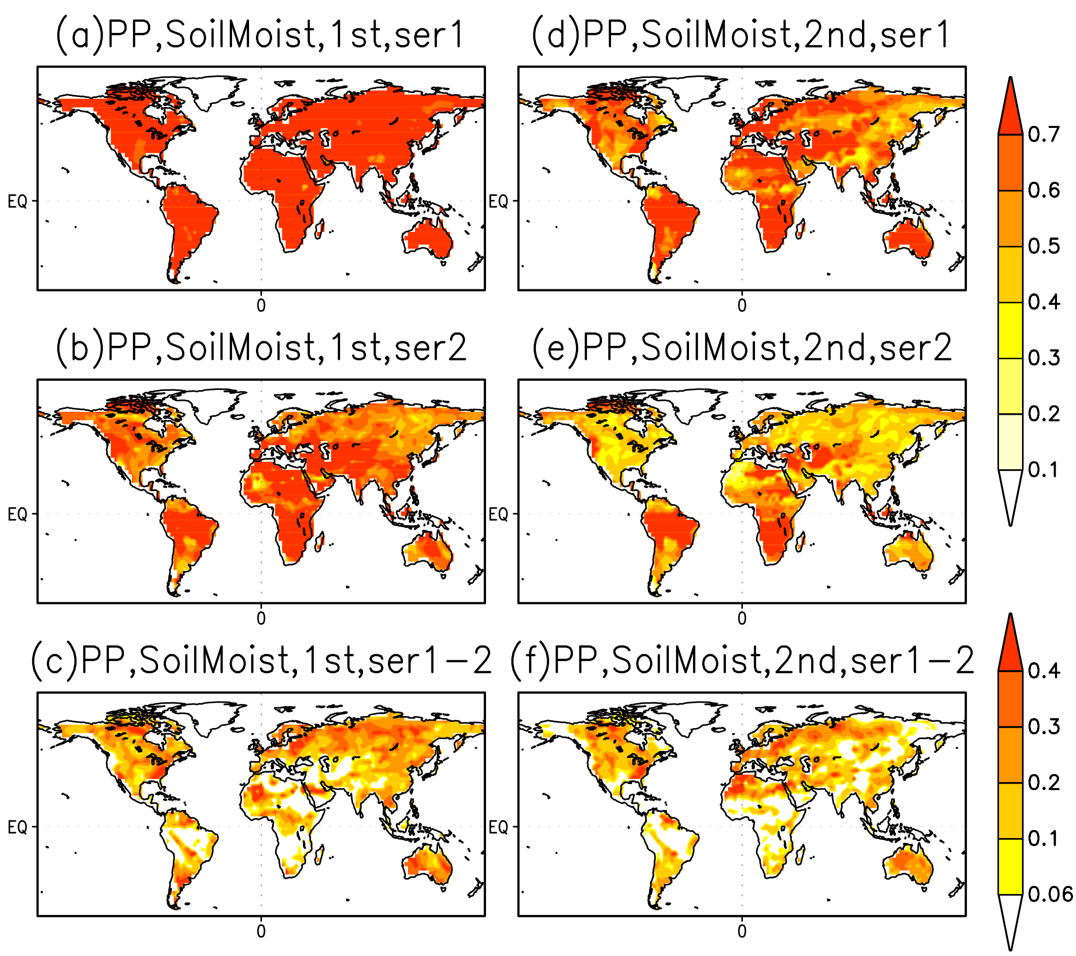

Fig-2 Potential predictability (r^2) of 15 days soil moisture averages for July 1, July 15, and August 1 ensemble simulations. (a)-(c) indicates for the first 15 days (days 1-15) and (d)-(f) for the second 15 days (days 16-30) respectively. (a) and (d): PP due to land surface initialization in addition to atmospheric initial and SST boundary. (b) and (e): Same as (a) and (d) but land surface state are not initialized. (c) and (f): PP due to land surface initialization.

forecast skill in Series-2 (Fig.3-b) by atmospheric initial and SST boundary conditions. The Sahel Africa and the Indian sub-continent have large forecast skills in Fig.2-b but the values are largely decreased at days 16-30 in Fig.2-e. Thus soil moistures are sensitive to atmospheric noise over these regions by strong land-atmosphere interactions.

We can quantify the geographical distribution of forecast skill associated with land initilization (Fig.3-c) by subtracting the values between Series-1 and 2. Figure 3-f shows many regions still have strong forecast skill (more than 0.4) during days 16-30, and the large forecast skill of soil moisture could be benefitable for many aspects of water resources assessment to predict the hydrological / drought risk in advance.

(3) 2-meter height temperature

Figure 4 shows the forecast skill of 2-meter height temperature (hereafter; T2m) for days 1-15 (Fig.4 a-c) and 16-30 (Fig.4 d-f). T2m has a large forecast skill in Fig.4-a and b during days 1-15. As plotted in Fig.4-c, land initialization contribute to T2m forecast skill mainly over East Asia, the equatorial Africa, Amazon, and North America despite of small values comparing to Fig.3-c for soil moisture. As shown in Fig.4-b and f, those regions do not have strong forecast skill only by atmospheric initialization and SST forcing. Therefore the results suggest that land surface initialization would be an important contributor to improve T2m forecast skill in summer season.

(4) Extreme event

Finally we discuss the forecast skill of T2m for the 1988 US drought which is one of the worst extreme drought events in the world. Figure 5 shows T2m anomaly of observation (Fig.5-b and e), Series-1 (Fig.5-a and d) and 2 (Fig.5-c and f) respectively against climatology (mean state between 1986 and 1995) of each dataset. The panels of Series-1 and 2 are the results of days 16-30 which start on on July 1 (Fig.5-a and c) and 15 (Fig.5-d and f), and therefore the impact of atmospheric initialization cannot

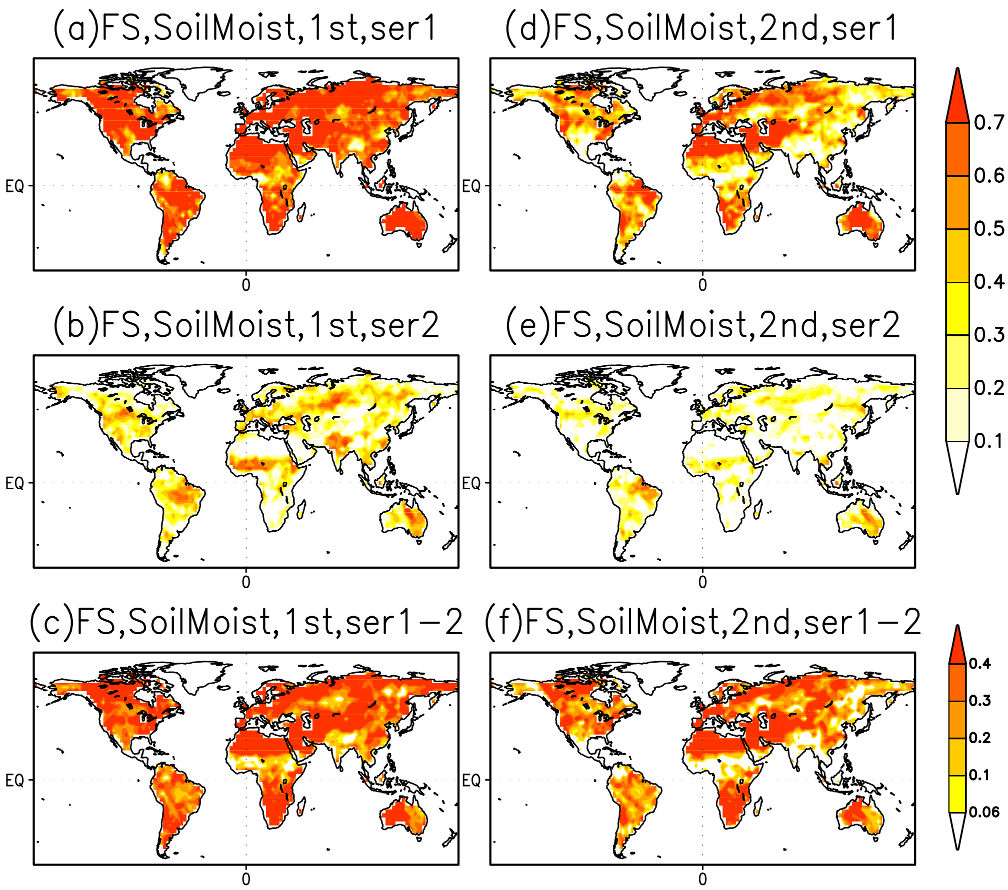

Fig-3 Forecast skill (measured as the correlation coefficient between model forecasts and observations) of soil moisture in Series-1 and 2. Left panels show for days 1-15 and right panels for days 16-30. Forecast skill associated with land surface initialization is quantified in (c) and (f).

be expected. Palmer and Brankovic (1989) suggests that the US drought was linked to anomalous oceanic conditions in the tropical Pacific[13]. In our forecast simulations however, Series-2 does not simulate positive anomalies of T2m (more than 1 degree) in July 16-30 on the contrary that Series-1 successfully has positive anomalies to some extent. In August 1-15, both Series-1 and 2 have positive anomalies of T2m, however the values are more realistic in Series-1 where initial state of soil moisture is dry against climatology (not shown). In addition to the anomalous SSTS in the tropical Pacific, realistic initial land surface state could be another necessaly condition to predict the 1988 US drought from perspective of the geographical distribution and the values.

5. SUMMARY AND DISCUSSION

The forecasts examined herein allow a first assessment of the contribution of land surface initialization on 1-month forecast skill. The results suggested some interesting aspects of hydrological forecast skills. The better hydrological forecast skill would be utilized to water resources assessment to prevent hydrological risks (e.g., water scarecity, agricultural drought, fire danger). Particularily, river discharge will partly be predicted in advance based on land surface initialization.

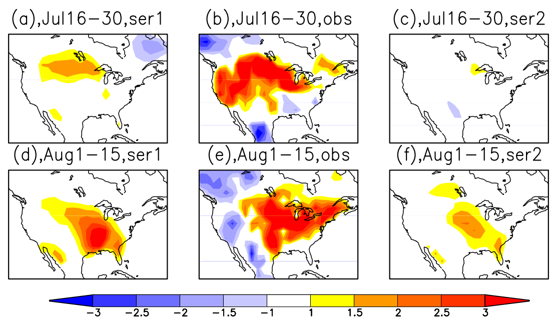

Fig-5 Anomaly of T2m temperature in 1988 against climatology. Left panels: Series-1; Middle panels: Observation (GSWP-2); Right panels: Series-2. All the forecast simulations are obtained from July 1 (upper panels) and July 15 (lower panles) simulations.

Finally, this paper introduced a hint of an improvement in the sub-seasonal hydrological forecasts by land surface initialization. We will invesigate the physical mechanism of hydrological extreme events

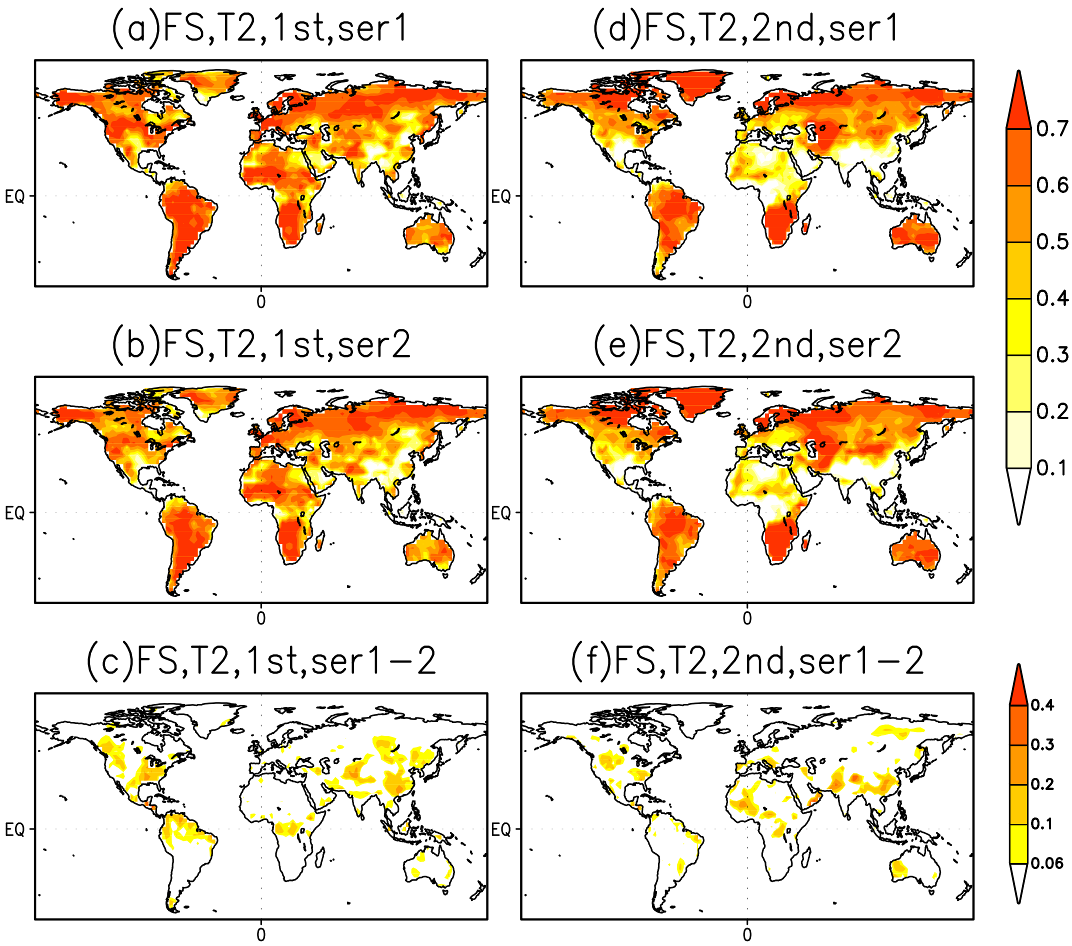

Fig-4 Same as Fig.3 but for 2-meter height temperature.

from the viewpoint of land-atmosphere interactions.

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