Impact of the FSU/COAPS Soil Moisture Initialization to Subseasonal Forecast Skill

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Introduction

Although soil moisture amount seems to be insignificant when compared to the total amount of water on the global-scale, this variable is today widely recognized to be crucial for climate studies. Soil moisture is a key variable because: 1) it has a long memory (anomaly persistence), and 2) it controls the repartition between latent and sensible heat fluxes, which in turn regulate the interactions between the land surface and the atmosphere. Many numerical studies "extreme" soil moisture values have shown that an accurate soil moisture initialization could lead to improved seasonal forecasts of near-surface climatological variables [*Shukla and Mintz 1982*, *Rind et al. 1982*, *Yeh et al. 1984*, *Sud and Fenessy 1984*, *Koster et al. 2000*, *Hong and Kalnay 2000*, among other]. However, the question whether a realistic soil moisture initialization increases the subseasonal forecast skill of near surface variables is still an open issue. This is a challenging issue since there is no global observational datasets of soil moisture to initialize climate models.

Soil Moisture Initializations

The second phase of Global Land-Atmosphere Coupling Experiment (GLACE-2) is an ongoing model intercomparison project aimed at answering the above issue. Florida State University/Center for Ocean-Atmosphere Predictions Studies (FSU/COAPS) recently joined this research group. To generate a realistic soil moisture initialization, all the participants but the FSU/COAPS model drive their land surface model (LSM) off-line with GSWP-2 observation-based atmospheric forcing data. The land surface state variables derived from the off-line simulations are then used to initialize their coupled land-atmosphere model. With such a direct assimilation into the off-line LSM, the state of near surface variables may undergo an adjustment (or spinup problem) once run online. This spinup problem can decrease the short-term to subseasonal forecast skill of near surface variables. A land data assimilation system conducted in two-ways coupled mode is expected to solve this spinup problem.

Using a coupled land data assimilation system, the reanalysis products provided by operational centers have attempted to produce realistic soil moisture state to improve the forecast of near surface variables. For instance, the National Center for Environmental Prediction (NCEP)/Department Of Energy (DOE) reanalysis 2 (R-2) adjusts the top 10 cm soil moisture using the difference between model and 5-day observed precipitation mean [*Kanamitsu 2002*]. However, this land data assimilation may reduce the soil moisture predictability when the soil moisture analysis is not in conjunction with atmospheric physics of the model. Indeed, given a soil moisture analysis affected by a heavy observed rain event, the atmospheric state of the model meanwhile can simulate a clear sky producing strong radiative and surface fluxes. Those strong surface fluxes can in turn have a negative impact on this given soil moisture analysis.

In this study, we produce a realistic soil moisture analysis that remains physically consistent with the atmospheric processes of the model by assimilating precipitation into the atmospheric component of the model. This technique is named the Precipitation Assimilation Reanalysis (PAR, *Nunes and Cocke, 2004*). It assimilates an observation-based precipitation dataset by adjusting the vertical profile of the atmospheric humidity using the difference between the model-derived and the observed precipitation. This assimilation is performed throughout an integration of the two-way coupled land-atmosphere FSU/COAPS model. Hence, the adjustment of the atmospheric humidity vertical profile not only helps to bring the model precipitation close to observation but also helps to redistribute the heat and moisture in the atmosphere, which in turn affect the adiabatic heating and hence the cloudiness. The radiative and surface fluxes that are directly affected by the cloudiness are therefore in conjunction with the soil moisture analysis.

Objective

1. Generate realistic soil moisture initial conditions using a consistent coupled land data assimilation system.
2. Understand the impact of realistic soil moisture initialization on short-term to subseasonal forecasting skill of near-surface variables (precipitation, air-temperature).

Differences Between FSU/COAPS and GLACE-2

We have recently joined the GLACE-2 team and we are the only participant using a different soil moisture initialization approach based on a coupled land surface data assimilation system.

GLACE-2 approach:

- Offline initialization
- Forcing data: the 3-hourly, 1° Global Soil Wetness Project (GSWP-2) observation-based data.
- Requires an adjustment before being used in the forecasts

COAPS/FSU approach:

- Coupled initialization
- Assimilated data: the 3-hourly 1° Global Meteorological Forcing Dataset for land surface modeling [*Sheffield et al. 2006*]
- No adjustment is required

Model and Datasets

CLIMATE MODEL

Florida State University (FSU) model coupled to the National Center for Atmospheric Research (NCAR) Community Land Model (CLM2) [*Shin et al., 2005*] with a T63 (1.875) horizontal resolution.

PRECIPITATION OBSERVATION:

- **For assimilation:** 3-hr, 1° precipitation observation-based data provided by Sheffield (2006)
- **For forecast validation**: daily, 0.25° precipitation data over the continental United States defined by interpolating quality-controlled gauge observations at over 8000 stations collected from multiple sources [*Higgins et al. 2000*].

2-m AIR TEMPERATURE OBSERVATION:

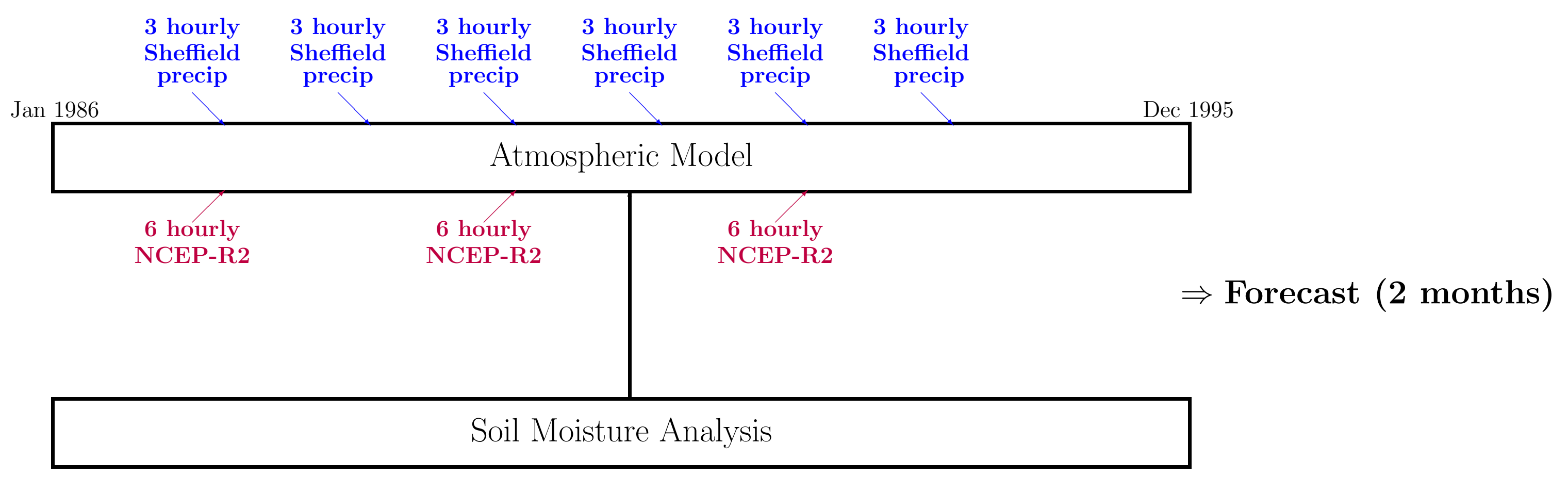
- 3-hr 1° precipitation observation-based dataset provided by *Sheffield et al. (2006)*

Initialization Method

The Precipitation Assimilation Reanalysis (PAR) method consists in two steps [*Nunes and Cocke, 2004*]:

- Precipitation nudging: Reconstruction of the vertical humidity profile based on the difference between the model-derived precipitation and the observation-based dataset from *Sheffield et al. (2006)*.
- Dynamical nudging: Dynamical variables (divergence, vorticity, potential and virtual temperature and the surface pressure) are nudged toward the NCEP-R2 reanalysis using a Newtonian relaxation technique, in order to minimize any model drift from observed large-scale circulation.

PAR-initialization (10 years)



3 hourly Sheffield precip

3 hourly Sheffield precip

3 hourly Sheffield precip

3 hourly Sheffield precip

3 hourly Sheffield precip

3 hourly Sheffield precip

Jan 1986

Dec 1995

Atmospheric Model

6 hourly NCEP-R2

6 hourly NCEP-R2

6 hourly NCEP-R2

⇒ **Forecast (2 months)**

Soil Moisture Analysis

Forecast Experimental Set Up

To investigate the impact of the realistic soil moisture initialization on subseasonal forecasts, we follow the same experimental set up as in the GLACE-2.

- Two series of forecasts:
  - For **SERIES-1**, each forecast is initialized with realistic soil moisture conditions
  - For **SERIES-2**, each forecast is initialized with a random background distribution.
  - For both SERIES, the same sea surface temperature boundary conditions (Reynolds et al. 1980) and atmospheric initial conditions (NCEP-R2) are used.
- Forecast starting dates:
  - 1st and 15th of each month between July and August and each year (1986-1995) ⇒ **60 forecasts**
  - For each forecast, 10 ensemble members are generated.
- Skill Metrics:
  - At each grid cell, we calculate the time anomaly correlation against observations using the 60 consecutive forecasts .

Results

1. Forecast Skill

Anomaly correlation coefficients under 0.2 are not statistically significant at 95% confidence level. The right hand side of the Fig1 represents the effect of the realistic soil moisture initialization by taking the difference between the anomaly correlation of the series-1 and the series-2. The correlation difference is not displayed when the correlation of series-2 is not statistically significant.

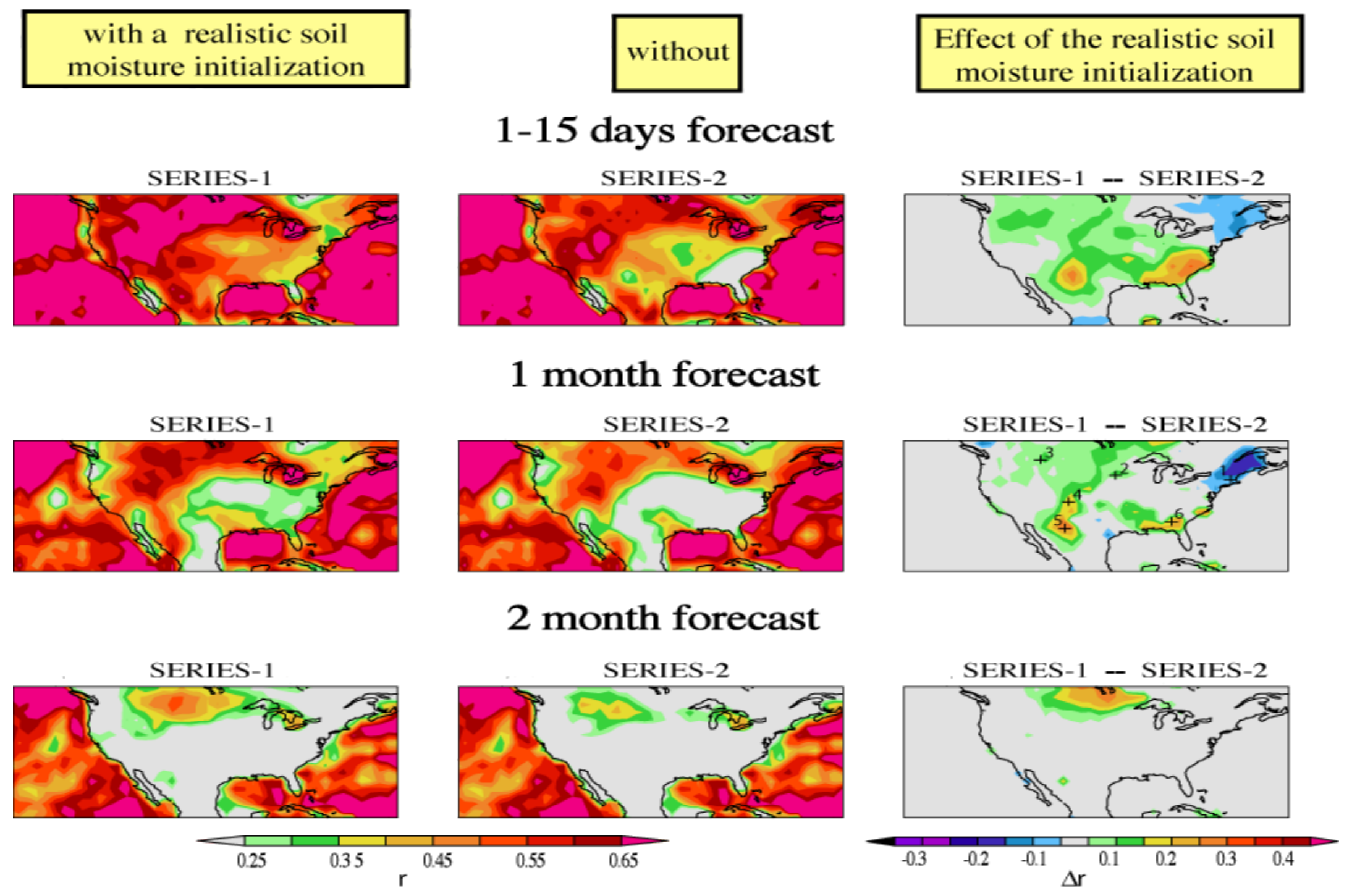


Fig1. 2-m air temperature anomaly correlation between the forecasted value and observations

As expected, for both series of forecast, the skill decreases as the forecast length increases from 15 days to 2 months. It is clear that, for all forecast lengths, the realistic soil moisture initialization increases the 2-m air temperature forecasts across much of the continental U.S.A.

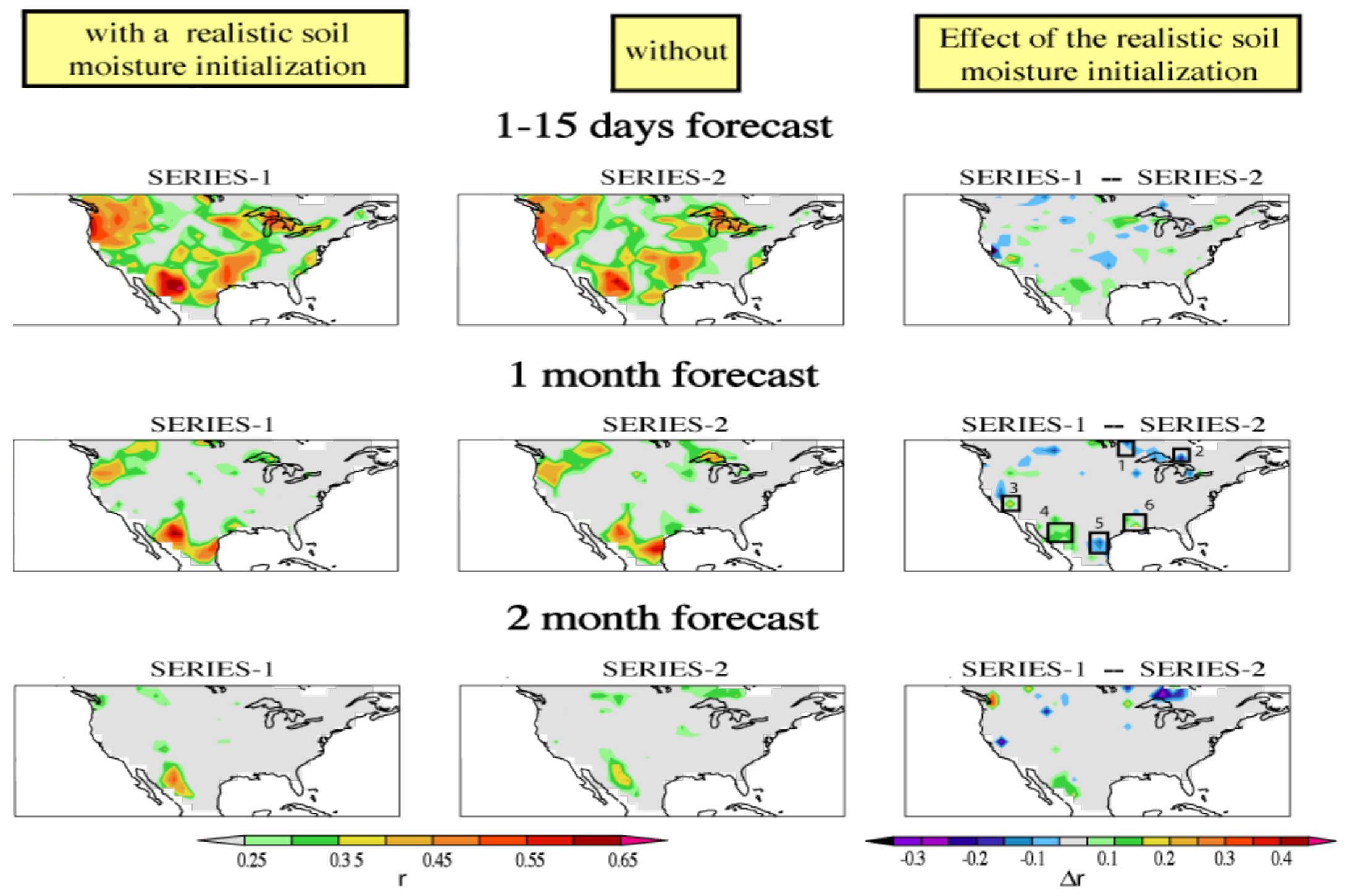


Fig2. Precipitation anomaly correlation between the forecasted value and observations.

The results for the precipitation forecasts are not as encouraging as for the 2-m air temperature forecasts. For all forecast lengths, the effect of the realistic soil moisture initialization is very locally-based and does not lead to a significant increase or decrease of precipitation forecast skill. This failure could be due to: 1) too coarse spatial resolution used in this study (T63 200km); or 2) a weak precipitation response to soil moisture conditions in the FSU/COAPS model.

2. Model Response

In this section, we concentrate on the 1-month air temperature and precipitation forecast response to a change in soil moisture levels at different locations indicated in Fig1 and Fig2 (rigth panels). The yellow zones indicate a positive model's response or a positive soil moisture-precipitation feedback. The black, red and blue dots represent the forecast months of June, July and August respectively. The change is defined as follows: $delta(x) = 100 \times \frac{x(series-1)-x(series-2)}{x(series-2)}$

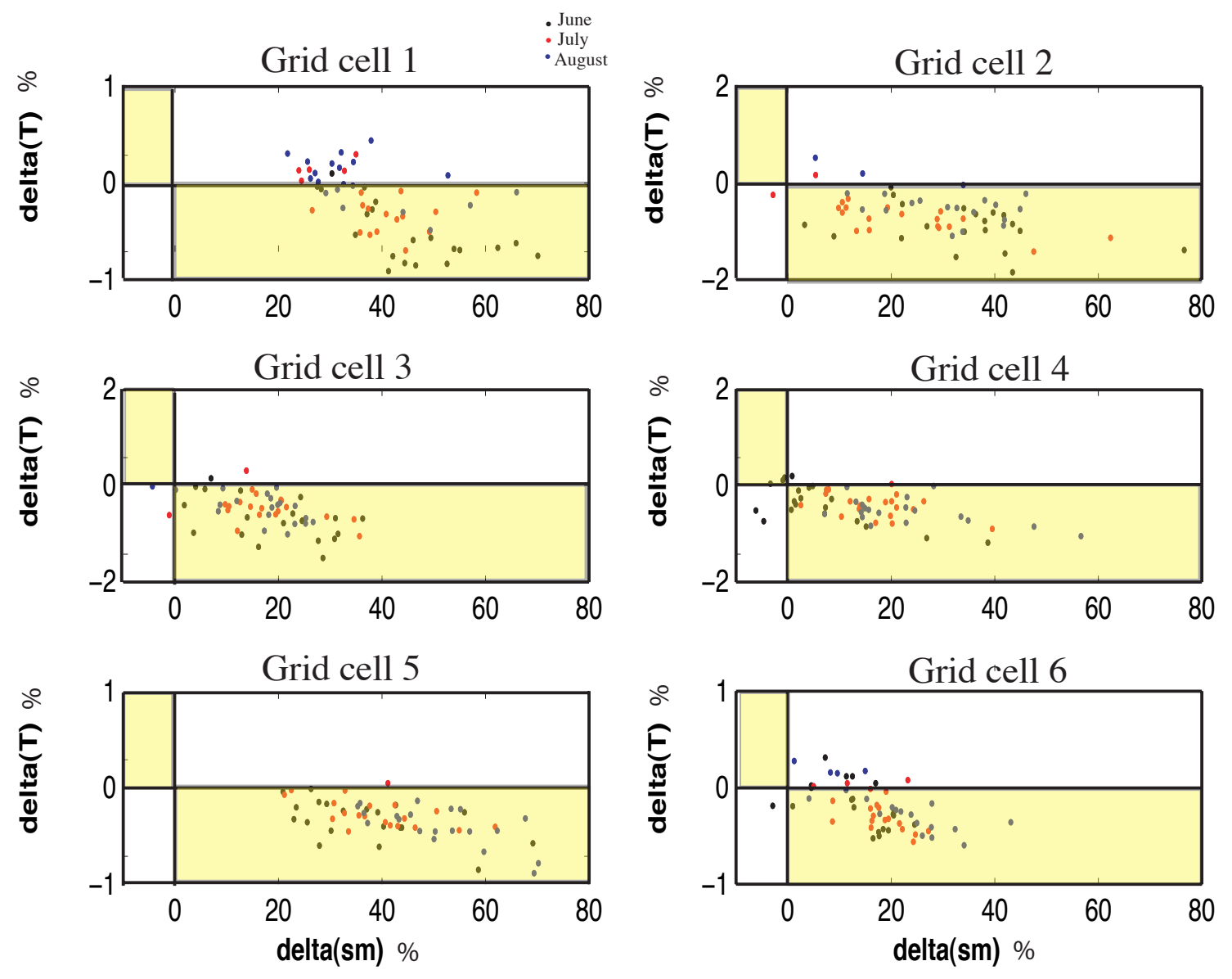


Fig3. Air temperature response to soil moisture change.

At all grid cells, the Fig3 shows a positive response of the 1-month air temperature forecasts to the 1-month soil moisture forecast. Indeed, a soil moisture increase (decrease) seems to produce an air-temperature decrease (increase). Therefore, the realistic soil moisture initialization is most likely to be responsible for the 1-month air-temperature forecast skill increase seen across most of the U.S.A in Fig1.

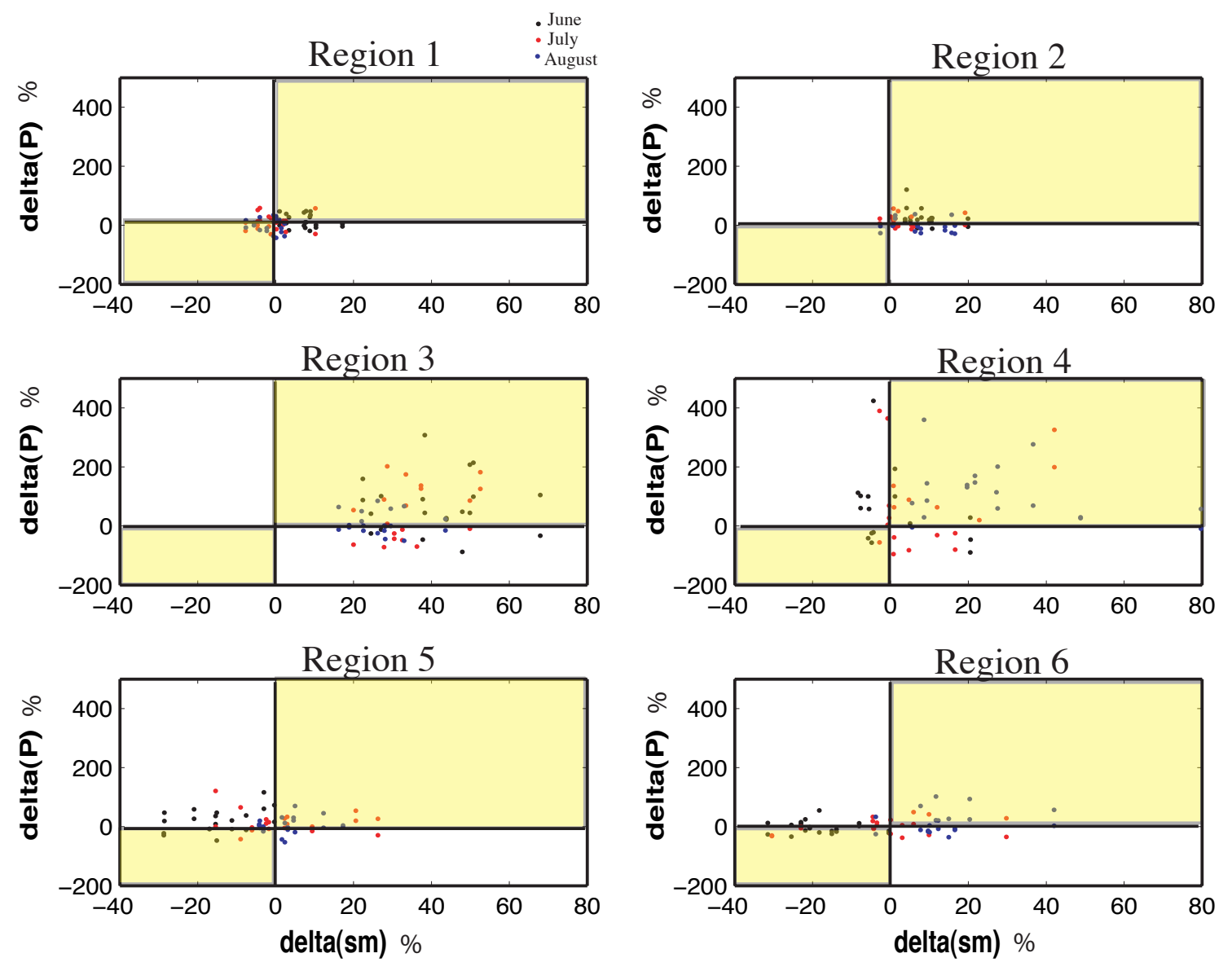


Fig4. Precipitation response to soil moisture change.

It is evident that precipitation affects soil moisture conditions. The question of whether soil moisture conditions affect precipitation is less evident. To answer this question, the Fig4 shows the relationship between the forecasted precipitation change and the soil moisture change at the time lag of -1 month (soil moisture preceding precipitation). The results are not as encouraging as for the air temperature forecasts. In regions 1 and 2, the forecasted precipitation values do not show much response to a soil moisture change, while in regions 3, 4 and 6, most of the forecasted precipitation values show a positive response. Therefore, the increase in the 1-month precipitation forecast skill seen in regions 3, 4 and 6 could be attributed to the realistic soil moisture initialization.

Conclusion

We find that our realistic soil moisture initialization has a positive impact on the 2-m air temperature forecasts of the FSU/COAPS model and leads to a increase in the short term and the subseasonal forecast skill across most of the U.S.A. However, the identification of positive soil moisture-precipitation feedbacks, which can eventually lead to an increase in subseasonal forecasting skill is less apparent. This is expected since accurate boreal summer precipitation forecasts are very challenging to obtain in weather and climate predictions. In addition, the soil moisture conditions, modifying the surface energy balance, impact directly on 2-m air temperature, while several intermediate physical processes occur before soil moisture conditions can affect the generation of precipitation.

Acknowledgements

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