Title of Abstract: Evaluating the Importance of Land-Surface processes for seasonal predictions of regional climate in the United States (NA16GP1671)

Project Duration: 10/1/01 – 9/30/04

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Introduction:

Observations show a strong tendency for wet (dry) southwest U.S. summer monsoons to follow dry (wet) winters there. The strength of the monsoon has, in turn, been linked to summer rainfall in other parts of the country, especially the central Great Plains and Mississippi Valley, where dry (wet) conditions in these regions accompany wet (dry) summers in the southwest U.S. Our working hypotheses focus on the role of land surface processes in this variability. The hypotheses are: 1) that the observed link between winter precipitation and summer monsoon strength is established through land-surface processes (principally snow cover, vegetation and soil moisture content), and 2) that regional hydrologic processes, which are a consequence of local modifications of the large-scale circulation through regional-scale atmosphere-land surface interactions, are crucial in shaping land-surface conditions in the western and southwestern U.S. during winter and spring. Hence, accurate long-lead forecasts of summer rainfall in the U.S. may require accurate forecasts of the regional hydrologic cycle in the southwest, especially the precipitation and surface water budget during the preceding winter and spring.

Project Goals:

The primary objectives of this project are to critically examine the hypotheses stated above and explore the limits of the predictability of summer precipitation given current skill in forecasting tropical SSTs. We will also undertake a detailed investigation of the effects of uncertainties in land-surface conditions on such predictions. We expect that the understanding gained through this research will benefit community-wide efforts aimed at extending the period over which numerical models can maintain predictability associated with a given initial condition. The proposed work will also result in quantitative estimates of the impact of uncertainties in land-surface conditions on seasonal predictions. In addition, the use of the NOAH land-surface scheme and the development of methods to incorporate the newly available satellite products using this scheme will contribute to the expansion of the long-term prediction capability at the National Centers for Environmental Prediction, which currently use NOAH in their operational models.

Method:

For this investigation, we are utilizing models of the atmospheric circulation on global (the UCLA atmospheric general circulation model, AGCM) and regional (the Mesoscale Atmospheric Simulation, MAS, model) scales. Both models are interactively coupled to the

physically-based NOAH land-surface scheme to investigate the role of land-surface processes in variations of the hydrologic cycle. The AGCM is being used to study the effects of land-surface processes and SST anomalies in shaping the global circulation and the MAS model will be one-way nested within the AGCM to study how regional-scale atmosphere-land surface processes modify the hydrologic cycle.

Results and Accomplishments:

Second Year Report

Second Year Plan: Couple the AGCM code with the NOAH land surface model and perform two 20-year long integrations, one with climatological SSTs and the other with observed SSTs for the period 1979-1998. Analyze simulations to assess the impact of realistic land-atmosphere interactions on the simulated interannual variability. Perform and analyze additional sensitivity runs with the MAS/NOAH model to quantify the positive feedback mechanism involving soil moisture and summer monsoon rainfall and to investigate the sensitivity of monsoon rainfall to Gulf of California SSTs.

Our previous work with the global model on the sensitivity of the North American monsoon to sea surface temperatures came to the following conclusions: 1) that internal atmospheric variations are capable of producing interannual variations in the southwest United States monsoon that are comparable to those observed, and 2) that these variations could thermodynamically force the SST anomalies in the adjacent Pacific Ocean and Gulf of Mexico that are observed to accompany these variations. We noted that the implications of these results for seasonal forecasting were rather pessimistic since variations associated with internal atmospheric processes cannot be predicted on seasonal timescales. We have extended this work in the past year to assess the impact of regional-scale SST anomalies on the monsoon using the MAS regional atmospheric model as described next.

The regional modeling work has been focused on investigating the effects of the sea surface temperature (SST) at the northern Gulf of California (GOC) on the warm season rainfall in the Arizona-New Mexico (AZ-NM) region and northern Mexico. For this investigation, we performed two sets of seasonal simulations over a domain including the continental US and Mexico with a spatial resolution of 60km. At this resolution, about 40 grid points are located within the GOC, with 10 grid points for the northern GOC. In the first set of simulations (CNTL), the GOC SSTs were prescribed from the surface temperature in NCEP Reanalysis-2 (R2 hereafter). As the GOC is not resolved by the global model used for R2, the SST values immediately west of the GCM coastline were extrapolated for the GOC SST. The GOC SST obtained in this way remains below 25 C throughout the warm season (June-July-August-September), much lower than the values available from limited observations (e.g., Mitchell et al. 2002). In the second set (SENS), the GOC SSTs were increased from the CNTL by 1 C, 1.5 C and 3 C in the entrance, central, and northern part of GOC, respectively. The simulations were performed for the 4-month period from June to September for the six years of 1980, 1984, 1988, 1990, 1991, and 1993, which contain three wet summers (1984, 1988, 1990), two dry summers (1980, 1993) and one normal summer (1991). This experiment was designed to examine the hypothesis that the GOC SSTs play a crucial role in determining the timing of

the onset and the amount of warm season monsoon rainfall in AZ-NM, perhaps through evaporation over the GOC that tends to increase as SST increases. This hypothesis is inferred by Mitchell et al. (2002) in their observational study on the relationship between summer monsoon rainfall in AZ-NM and the GOC SST, especially in the northern part of GOC.

Results of this experiment do not appear to support the hypothesis that the GOC SST determine the timing of the onset of warm season monsoon rainfall in AZ-NM. Figure 1 presents the time series of the daily rainfall averaged over the AZ-NM region (bottom) and the Great Plains (GP) region (top) in the CNTL (red) and SENS (blue) runs. The arrows indicate the monsoon onset date determined by Higgins et al. (1998). Rainfall in AZ-NM shows some differences between CNTL and SENS, especially after the onsets. For the period immediately before and after onsets, however, notable differences between the daily rainfall between CNTL and SENS are not found except for 1991 (normal year case) in which rainfall in AZ-NM show a large increases, and perhaps earlier onset, with higher SSTs in GOC. Note that the monsoon onset dates calculated from the simulated rainfall using the method of Higgins et al. (1998) are different from the ones computed from observed data shown in Fig. 1. The effects of increased GOC evaporation associated with higher SSTs in SENS runs appear to increase rainfall in northern Mexico along the coast of GOC most notably. The AZ-NM rainfall is larger in SENS than in CNTL for the July-August period as well, but the differences are much smaller than in the regions that are in the immediate vicinity of GOC (not shown).

This experiments performed thus far are not completely conclusive. Most importantly, the GOC SST in the SENS runs may be colder than the reality. Despite the 3 C increases over the CNTL runs, the SST in the northern GOC remains below 30 C in the SENS runs while observations (Mitchell et al. 2002) show that the SST in the northern GOC becomes warmer than 30 C in mid-July. Another uncertainty is the role of land surface forcing. A recently completed regional climate simulation for East Asia shows that soil moisture and temperature plays a crucial role in warm-season water cycle, and it may take several years to spin up these variables in coupled atmosphere-land simulations. Hence, the effects of land surface forcing may have not been correctly represented in these seasonal simulations. Analysis of the model data from this experiment is underway. An experiment to examine long-term evolution of land-surface variables and their impacts on simulating warm season water cycle is being designed.

As a part of this study, we have examined the performance of our regional climate model, the coupled MAS-SPS model, in a multi-year hindcast for the western U.S. A paper was prepared based on the results of this study, and is in press.

In addition, we have finally successfully coupled version 3.04 of the NOAH land surface model to the UCLA AGCM. NOAH is a physically based LSM that predicts soil moisture content and soil temperature in multiple soil layers. NOAH predicts snow water equivalence (SWE) and canopy moisture content. The temperature and water vapor mixing ratio at the atmosphere-land interface is computed by solving the surface energy balance (SEB) equation. It includes formulations for frozen soil, hydraulic characteristics for various soil types, and the effects of atmospheric and soil conditions on transpiration. NOAH is currently coupled with NCEP operational NWP models (Global Spectral Model, Eta regional model, Regional Spectral Model) as well as their climate simulation versions. It is also coupled with

regional climate models based on PSU/NCAR MM5 and WRF. The co-I is involved in the collaborative efforts for improving NOAH LSM as well as its application to NWP and climate models. The most recent UCLA work on NOAH includes the nonlinear form of SEB equation and incorporation of vertically varying soil characteristics. NOAH provided fluxes of momentum, sensible and latent heat and surface albedo link the model to the AGCM. Preliminary test runs show reduced evaporation and precipitation over land that bring the results more in line with those observed.

Future Work:

With the AGCM/NOAH we will perform two 20-year long integrations, one with climatological SSTs and the other with observed SSTs (1979-1998). We will analyze these simulations to assess the impact of realistic land-atmosphere interactions on the simulated interannual variability in the North American monsoon. We will pay special attention to the tendency in the simulations for wet (dry) summer monsoons to follow dry (wet) winters in AZ-NM, a tendency noted in observations, at least for the most recent 40 years.

We will also perform and analyze RCM simulations forced by AGCM/NOAH output aimed at understanding the role of soil moisture and snow cover anomalies on the interannual variability of the monsoon. In particular, these simulations will be used to assess the impact of *regional scale* land-atmosphere interactions on the simulated interannual variability.

We have also been investigating the rainfall variability in the SWUS associated with interannual variability in the North American monsoon on very long time scales (Kim 2002). Concerning the relationship between winter and summer rainfall in the SWUS, it was found that this relationship appears strongly only during the most recent 40 years or so (after 1962). For the earlier periods, the relationship is weak or even reversed. For example, during the period 1901-1931, the winters preceding wet summers were very slightly drier than normal, but winters preceding dry summers were also drier than normal. During the period 1932-1962, winters preceding wet (dry) summers were wetter (drier) than normal, the opposite of what is observed during the most recent period. The reasons for these changes are not clear and their investigation is hampered by a lack of observations of the atmospheric circulation prior to 1950. We will investigate whether this sort of decadal variability can be reproduced in a 100-yr simulation using the AGCM/NOAH and SSTs prescribed from the GISST observations for 1901-2000.

Publications/presentations from this project:

Farrara, J. D. and J.-Y. Yu, 2003: Interannual variability in the southwest United States monsoon and sea surface temperatures: A general circulation model study. *J. Climate*, **16**, 1703-1720.

Kim, J. and J.-E. Lee, 2003: A multi-year regional climate hindcast for the western U.S. using the Mesoscale Atmospheric Simulation (MAS) model. *J. Hydrometeor.*, in press.

Kim, J., 2003: A projection of the effects of the climate change induced by increased CO_2 on extreme hydrologic events in the western U.S. *Climatic Change*, submitted.
Farrara, J. D. and J.-Y. Yu, 2003: Interannual variability in the North American monsoon: A general circulation model study. 14th Symposium on Global Change and Climate Variations, 3.1, Long Beach, CA, 9-13 February 2003.
Kim, J., 2002: Precipitation variability associated with the North American Monsoon in the 20th century. *Geophys. Res. Lett.*, **29**, 10.1029/2001GL014316.

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FIGURES

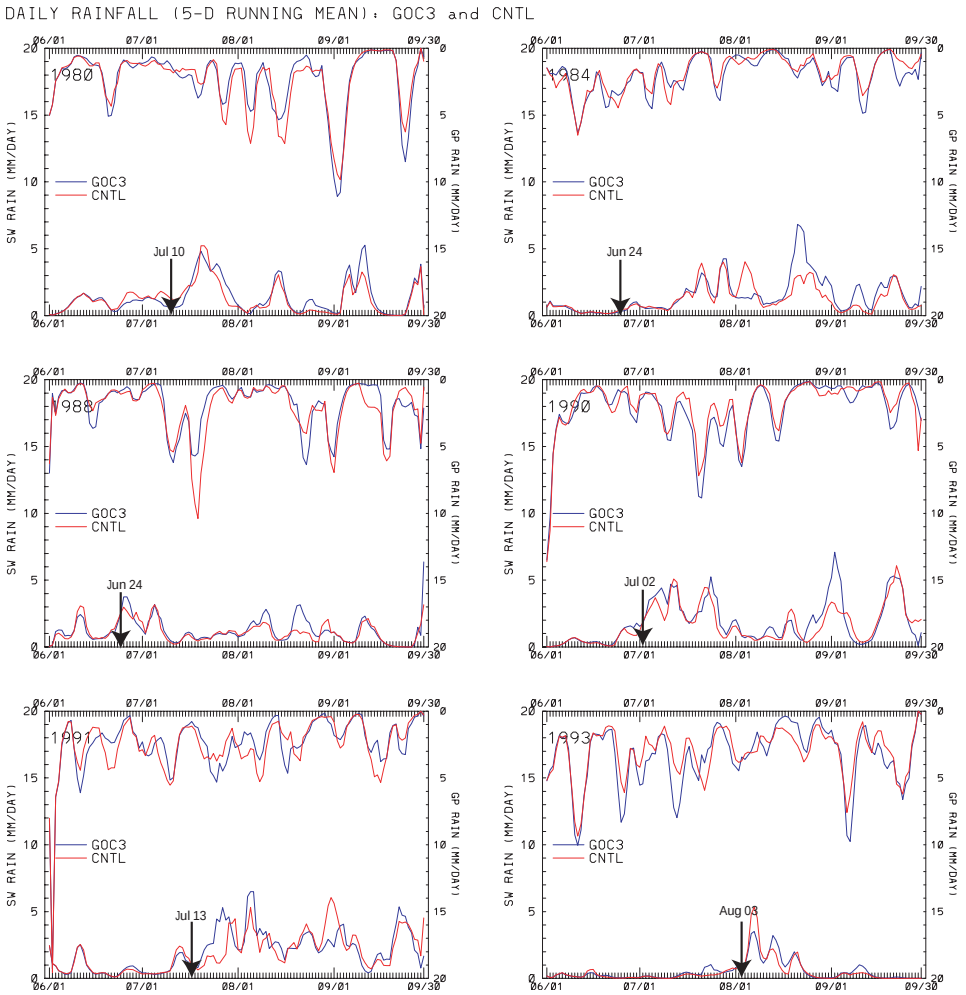

Fig. 1 The time series of the daily rainfall averaged over AZ-NM and the Great Plains.