CAUSES OF LONG-TERM DROUGHT IN THE UNITED STATES GREAT PLAINS

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1. Introduction

In this study, we examine the role of soil moisture in multi-year droughts in the United States Great Plains (USGP). The results are based on a number of long simulations carried out with the NASA Seasonal-to-Interannual Prediction Project (NSIPP-1) atmospheric-land general circulation model (AGCM).

Results from 70-year 9-member ensemble simulations (1930-1999) with the NSIPP AGCM forced with observed SST show that the ensemble mean low frequency (time scales longer than about 6 years) rainfall variations in the USGP are linked to a pan-Pacific pattern of SST variability (Schubert et al. 2002). The potential predictability of rainfall in the USGP associated with SSTs is rather modest, with about 1/3 of the total low frequency rainfall variance being forced by SST anomalies.

Simulations with climatological SST show that the model produces multi-year droughts in the USGPs even in the absence of SST anomalies. Here, we examine the nature of such fluctuations with a particular focus on the role of soil moisture feedbacks. We do this by comparing a 100-year control simulation forced with climatological SST with another 100 year run also forced with climatological SST but in which all feedbacks between the atmosphere and the soil wetness are turned off.

2. Results

The top panel of Fig. 1 shows the time history of the annual mean precipitation (P), evaporation (E), and deep soil wetness (w_3) in the control run. All three quantities (P, E, w_3) exhibit highly correlated long-term fluctuations. The lag-1 autocorrelation of w_3 is 0.48. The strong correlation between P and E (0.97) implies that on interannual time scales w_3 fluctuations result from a small residual in a nearly equilibrated surface water budget. The covariance of both P and E with w_3 suggests that P and E are largely determined by soil conditions.

The bottom panel of Figure 1 shows the results of the 100-year simulation in which the effect of the soil moisture feedback is turned off by fixing the evaporation efficiency or "β" (ratio of the evaporation to the potential evaporation) in the land surface model formulation to its seasonal climatology, as described in Koster et al. (2000). In this case the evaporation and more importantly the precipitation variations over the USGP are considerably reduced compared with the control run. The reduction in variance is qualitatively consistent with the results of Koster et al. (2000). Fig. 2 provides another view of the differences in the USGP precipitation in the fixed β and control runs. By normalizing the precipitation to have unit variance and zero mean, we see more clearly that, in addition to impacting the amplitude of the rainfall variations, the lack of interaction with soil moisture appears to reduce the year-to-year memory in the precipitation variations (lag-1 autocorrelation in precipitation is 0.29 in the control run and 0.04 in the fixed β run). Further results are presented in Schubert et al. (2002).

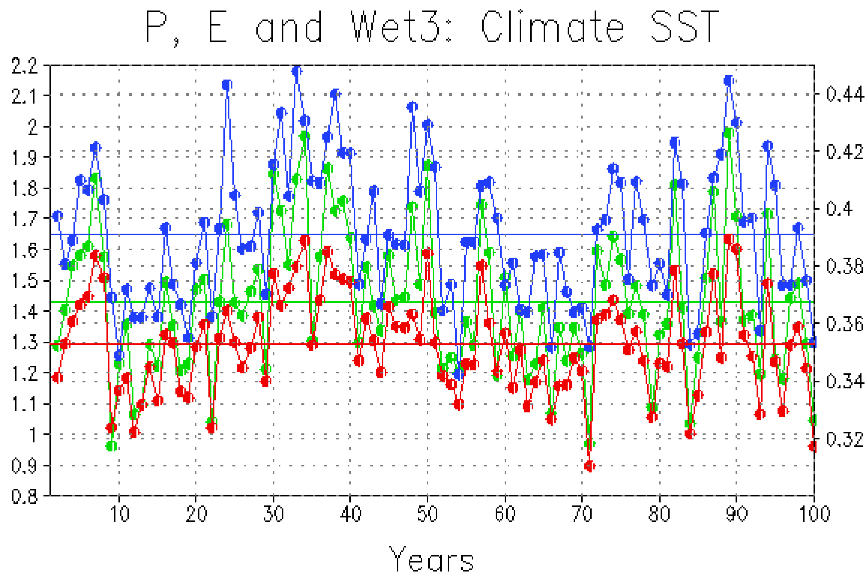
3. Conclusions

The results of this study show that interactions with the soil increase the variance and introduce year-to-year memory in the hydrological cycle of the USGP. The year-to-year soil moisture variations are consistent with a red noise process, in which the deep soil is forced by white noise and damped with a time scale of about 2 years. As such, the role of low frequency SST variability is to introduce a bias to the net forcing on the soil moisture that drives the random process preferentially to either wet or dry conditions.

References

Koster R.D., M.J. Suarez, M. Heiser, 2000: Variance and predictability of precipitation at seasonal-to-interannual timescales. J. Hydrometeor., 1, 26-46.

Schubert, S.D., M.J. Suarez, P.J. Pegion, M.A. Kistler, and A. Kumar, 2002: Causes of long term drought in the United States Great Plains. Submitted to J. Climate.



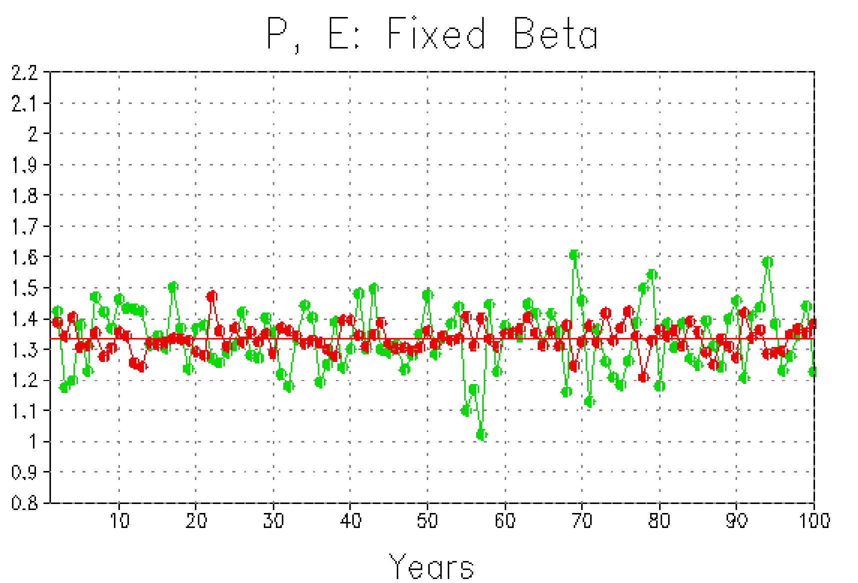


Figure 1: Top panel: Time series of the annual mean precipitation (green curve), evaporation (red curve) and w_3 (deep soil moisture, blue curve) over the USGP (30°-50°N, 95°-105°W), from the control run with climatological SSTs. Bottom panel: same as top panel, except for the run with climatological SST and fixed β. Note that the soil moisture (w_3) plays no role in the fixed β run. The units for precipitation and evaporation are mm/day (left ordinate), and they are dimensionless (values range from 0-1) for w_3 (right ordinate).

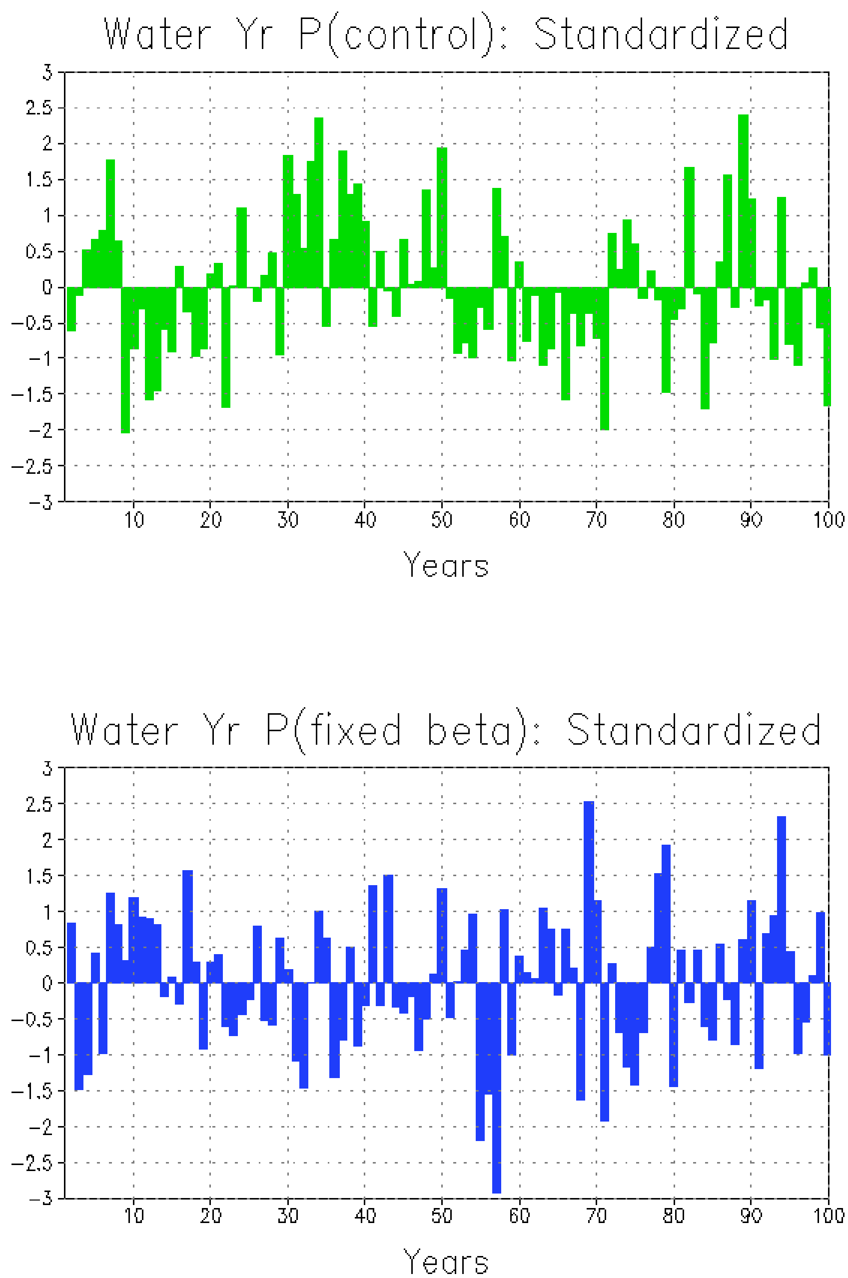


Figure 2: The top panel shows the annual mean (water year) precipitation from the control run standardized to have zero mean and unit variance. The bottom panel is the same as the middle panel except for the fixed beta run.