An Investigation of long-term Drought over the Great Plains of the United States

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Introduction

The Great Plains of the United States experienced a number of multiyear droughts during the twentieth century, notably the droughts of the 1930s and 1950s. These droughts were characterized by decades of rainfall deficits that destroyed much of the land surface of the Great Plains. The drought of the 1930s was also associated with severe dust storms that led to its characterization as the “Dust Bowl.” Previous studies have indicated that both time-varying anomalous Sea Surface Temperature (SST) forcing from the Pacific Ocean and local soil moisture feedbacks influence the decadal fluctuations of precipitation over the Great Plains. The focus of this research to determine if the IPCC AR4 coupled climate models are capable of simulating drought in the Great Plains with the same frequency and intensity as the observations. This research will also investigate the role that precipitation, evapotranspiration, and soil moisture play in influencing long-term drought.

Data

This research uses data from the Climate of the Twentieth Century integrations of the AR4 IPCC coupled climate models. These integrations were initialized from preindustrial conditions and the only external forcing applied were historical time series of atmospheric greenhouse gases, sulfate aerosol direct effects and volcanic eruptions. The three models chosen for this research are shown in Table 1. Each modeling group produced multiple integrations of the twentieth century and results will be shown from individual model integrations as well as the “ensemble” mean results from each model.

A gridded monthly mean precipitation dataset from the Climate Research Unit is used for comparison with the models. The dataset has resolution of 0.5° x 0.5° and is available for the period 1901-1998 (New et al., 2000).

Model Name	Center/Country	Resolution lat x lon
NCAR CCSM3	National Center for Atmospheric Research/USA	~ 1.4°x1.4°
GFDL CM 2.0	US Dept. of Commers/NOAA/ Geophysical Fluid Dynamics Laboratory/ USA	2.0°x2.5°
UKMO HadCM3	Hadley Centre for Climate Prediction and Research/UK Met Office	~2.75°x3.75°

Table 1. Model Information

Domain

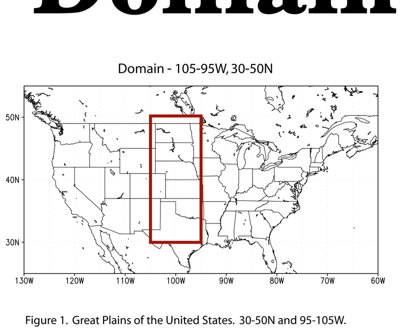

Figure 1. The Great Plains region is defined as the area between 30°-50°N and 95°-105°W. Time series of precipitation, evaporation and soil water used on this poster were calculated by averaging over this domain.

Climatology

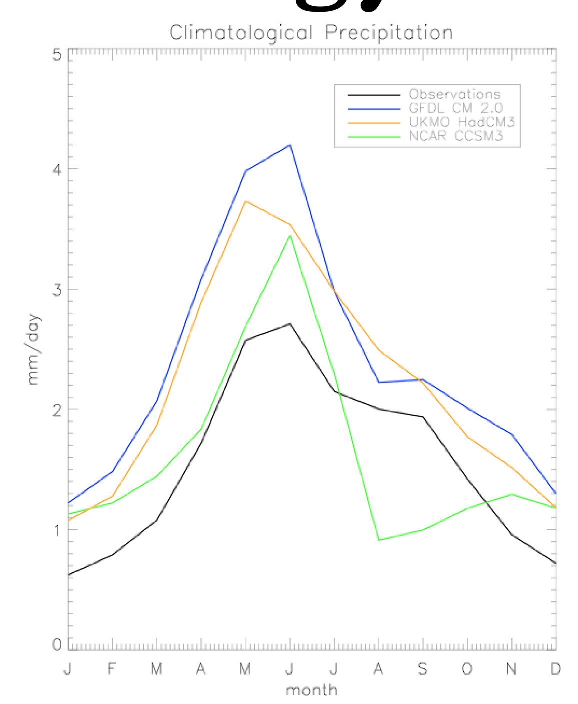

Figure 2. Monthly-mean Climatological Precipitation rates were calculated over the Great Plains for the observations as well as for each model's ensemble mean precipitation time series. The wet season for the Great Plains is defined from April-September.

Droughts?

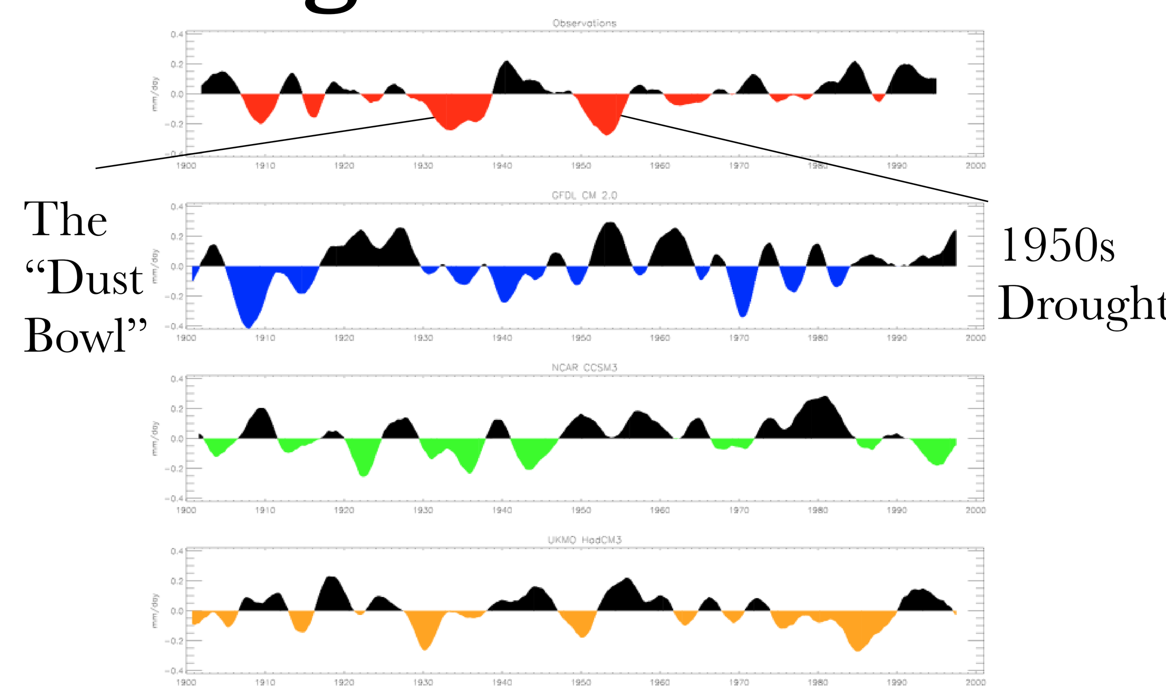

Figure 3. A time-averaging filter was applied to each precipitation time series in order to pull out the low-frequency fluctuations of precipitation over the Great Plains. (Model results are from individual model integrations, not the ensemble means)

Precipitation Characteristics

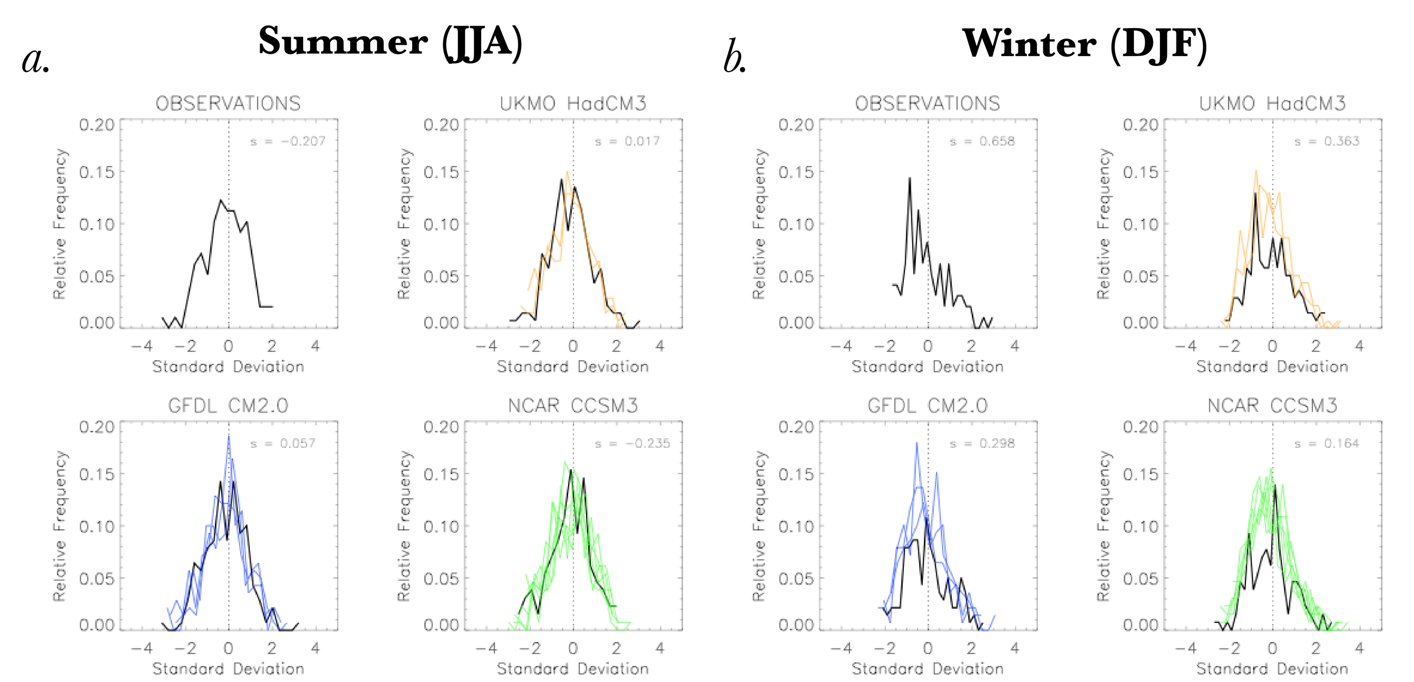

Figure 4. Relative-Frequency Density Functions of JJA (a) and DJF (b) precipitation anomalies over the Great Plains are shown. The y-axis has been normalized such that the area under each curve is one. Thick black curves represent the ensemble mean model values, while the colored curves represent the individual model integrations. The average skewness (s) is also shown on each figure. If the longer tail occurs to the right, the curve is positively skewed and if the longer tail occurs to the left it is negatively skewed.

We use Relative-Frequency Density Functions (RDFs) to look at the tendency for dry periods to occur over the Great Plains, in both the observations and the models. In Figure 4, the RDFs of precipitation anomalies for the summer and winter seasons are compared. The RDFs of summer precipitation anomalies tend to be negatively skewed, indicating an increased likelihood for extreme dry events to occur in the summer. The RDFs of winter precipitation anomalies are all negatively skewed indicating a tendency for more extreme wet periods during the winter months. Figure 5 then shows the distribution for the length (in months) of each dry and wet event. It appears as though, during the 20th Century, an even number of dry events and wet events occurred over the Great Plains. Interestingly, as Figure 5a shows, while 60% of all wet events lasted 1 month in duration, only 50% of all dry events lasted 1 month. This indicates that while an even number of wet and dry events did occur, dry events tended to persist for many months, while wet events typically only last a month or two. Model results are similar to the observations.

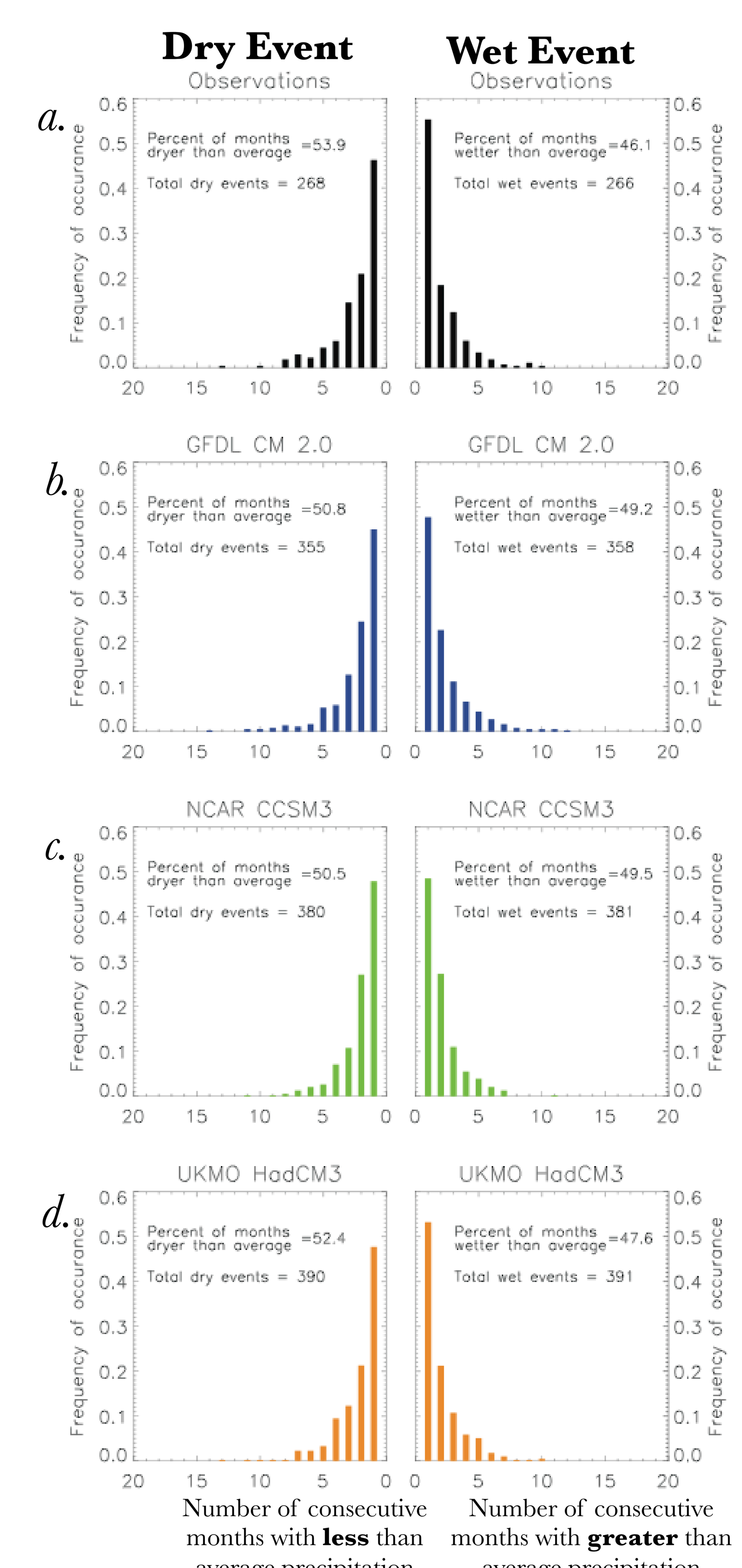

Figure 5. Relative-Frequency Density Functions for the length of dry and wet events are shown. A dry event is defined as the number of consecutive months with less than average precipitation while a wet event is defined as the number of consecutive months with greater than average precipitation.

Land-Atmo Coupling

Coupling between soil moisture conditions at the surface and the atmosphere above plays an important role in influencing wet-season (April-September) precipitation rates over the Great Plains. Soil moisture conditions at the surface impact the moist static energy content of the planetary boundary layer, thus influencing the occurrence of deep convective storms in the summer. Figure 6 shows the relationship between Precipitation, Evaporation, and Soil Moisture content in each of the three models.

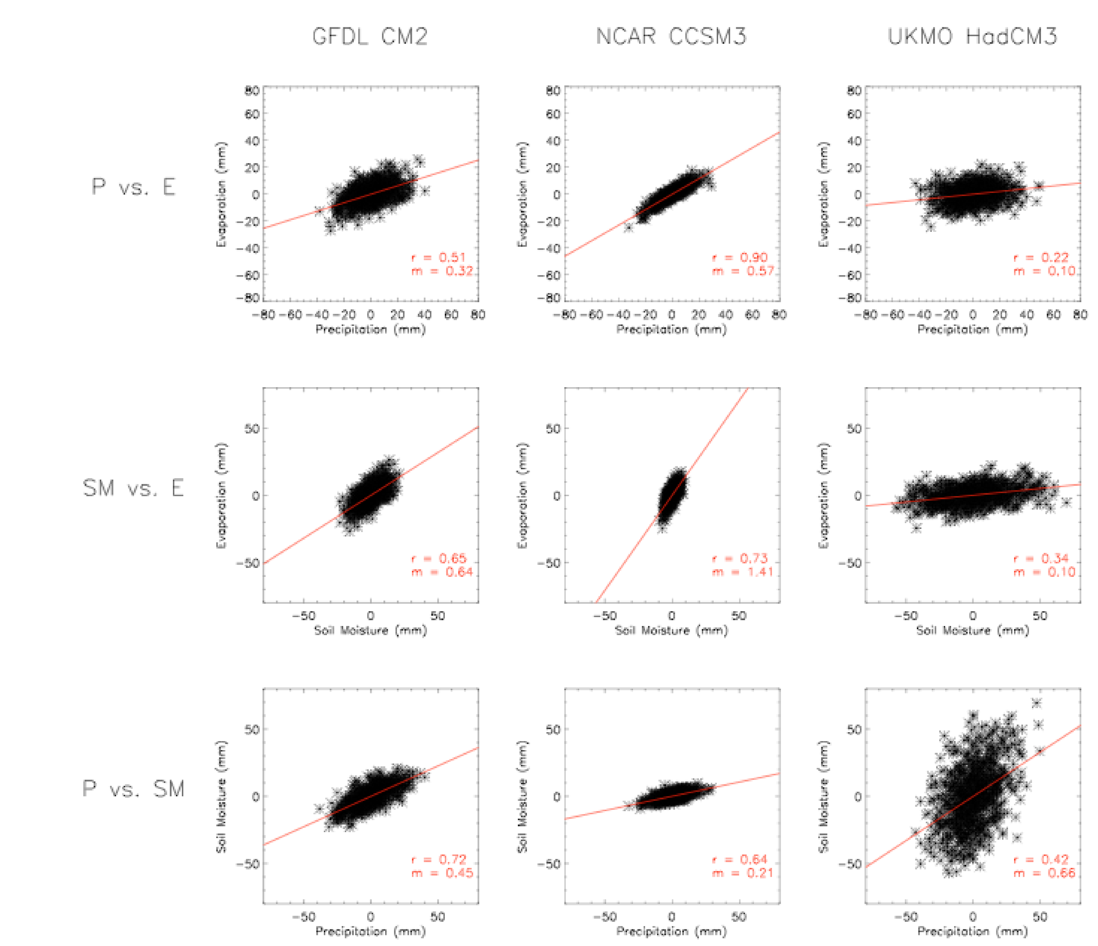

Figure 6. Scatter plots of Precipitation vs. Evaporation (top panel), Soil Moisture vs. Evaporation (middle panel) and Precipitation vs. Soil Moisture (bottom panel) are shown for each model. These scatter plots are of the “wet season” months only (April-September). Also shown are the correlation(r) and regression(m) coefficients for each relationship (red) Results in the figures are from the ensemble mean values of each model. All correlations are significant at the 99% confidence level.

Model	Integration	Precipitation vs Evaporation		Evaporation vs Soil Water		Precipitation vs Soil Water	
		Correlation	Regression	Correlation	Regression	Correlation	Regression
GFDL CM 2.0	ensemble	0.51	0.32	0.65	0.64	0.72	0.45
	run1	0.55	0.33	0.66	0.63	0.74	0.47
	run2	0.53	0.33	0.66	0.66	0.74	0.47
	run3	0.52	0.33	0.64	0.65	0.73	0.46
NCAR CCSM 3.0	ensemble	0.90	0.58	0.73	1.41	0.64	0.21
	run1	0.92	0.60	0.76	1.54	0.68	0.22
	run3	0.91	0.58	0.74	1.47	0.65	0.21
	run5	0.91	0.60	0.75	1.52	0.66	0.21
	run6	0.89	0.59	0.73	1.56	0.63	0.19
	run7	0.90	0.60	0.75	1.43	0.68	0.23
UKMO HadCM 3.0	ensemble	0.22	0.10	0.34	0.10	0.42	0.66
	run1	0.22	0.10	0.34	0.10	0.43	0.66
	run2	0.28	0.14	0.33	0.11	0.40	0.58

Table 2. Correlation and regression coefficients for each of the individual ensemble members (see figure 6)

Conclusions

Using three coupled climate models from the IPCC AR4 we have investigated the nature of long-term drought over the Great Plains. Preliminary results suggest that each model experiences a number of multi-year droughts over the Great Plains during their 20th century climate simulations. Our results also suggest that persistent and extreme dry periods are favored over the Great Plains, especially during the summer. It has also been shown that the coupling strength between the land surface and the atmosphere varies greatly between the three models. It will be interesting to see how the differences between the models influence long-term drought trends.