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A HYBRID APPROACH TO PROJECTING FUTURE WATER BUDGET CHANGES IN THE UNITED STATES GREAT PLAINS

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1. INTRODUCTION

General circulation model sensitivity studies of increased greenhouse-gas climate states are often used to provide projections of potential future states for climate change impact assessments. Almost all of these models agree that a global scale warming is likely to occur in response to the alteration in atmospheric gas content due to human activities. Mid-continental areas in the mid-latitudes, such as the Great Plains, may experience warming above the global average. Therefore, it is important to study the ramifications for natural and agro-ecosystems of these potential climate changes. One of the most fundamental controls on vegetation is the soil water budget. Unfortunately, despite significant advances in GCMs in the last decade, there are still difficulties in using model output directly in climate change impact assessments. First, there are disagreements among the various GCMs regarding the spatial patterns of change in hydrologic system variables. Second, the models are inherently limited in spatial resolution. Third, the length of a time series representing an anomalous climate state in fine spatial resolution GCMs tends to be limited.

Alternate approaches to climate change scenario production have also been utilized. Purely empirical methods use observations from an historically warm period to provide a potential scenario for the future. This method often yields fairly brief time series that cannot be used to assess variability effects. More commonly, observational time series are utilized in scenario creation, after applying correction factors representing GCM-predicted changes in mean temperature and precipitation. This incorporates any model hydrologic cycle difficulties directly into the scenario. We have developed a hybrid approach that helps to overcome some of these problems by relying only minimally on GCM output to guide scenario development based on long time series of daily climate observations. The calendar shift method of climate change scenario creation is described below.

2. CALENDAR SHIFT CLIMATE CHANGE SCENARIOS

In the mid-latitudes, the range of the annual cycle of temperature far exceeds the anticipated extent of any future human-induced warming. Instead of choosing temperature analogs from brief periods of intense heat (e.g., the 1930s), a sufficient range of analogs for the future are found in the annual cycle itself. For most of the year, a simple calendar shift of the annual cycle will allow for the representation of a GCM-projected warmer climate using the observed temperature record. For instance, if February is projected by a GCM to change 4.5°C in the Great Plains region, then an appropriate temperature scenario may be derived by sampling the period February 27 to March 26. Only monthly temperature change projections from a GCM are needed for this resampling approach; the precipitation, and other weather variables, are simply shifted with the calendar dates. A scenario created in this manner has the advantage of maintaining dynamically consistent relationships between various climate variables, as they are all drawn from the same historical day. In addition, the observed intra- and interannual variability of the observed climate system is automatically incorporated in the scenario. "cept" solar rad

While the calendar shift approach for climate change scenario generation is fairly simple, there are significant complications that must be resolved. For instance, shifting individual months often results in overlap or gap periods, as the GCM projected temperature change is not the same for each month. In addition, there is a substantial gap in the mid-summer for which there is no calendar analog. The small discontinuities are resolved by modifying the calendar shifts at the beginning and end of months so as to create a smooth transition, skipping every other day to fill gaps and double-counting days to remove overlaps (Figure 1).

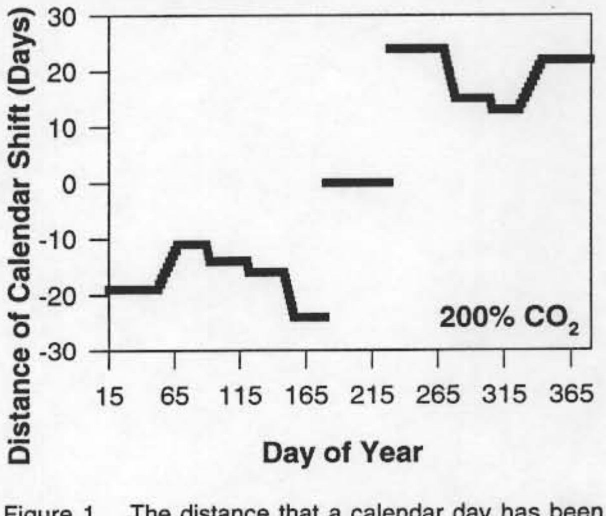

Figure 1. The distance that a calendar day has been shifted in order to reach the day of the year indicated. The climate scenario in this case is for 200% CO_2 levels at Gothenburg, Nebraska.

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1996 AMS Atlanta
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Negative shifts occur in the first half of the year, with warmer calendar days shifted to the earlier, colder portion of the year. In the second half of the year, the shifts are positive, in order to move the warmer days of the middle year towards the colder end of the year. January 15 is the nadir of the annual temperature cycle, dividing the winter season for shifting purposes. The first half of January is combined with December, and the second half is combined with February.

The summer temperature gap is filled with data that are not calendar shifted, but are instead temperature shifted by the magnitude of the modeled temperature differences. Further temperature shifts are applied to the calendar shifted days adjacent to the summer gap in order to remove any step changes at the transitions. The problem of introducing model dependent precipitation biases is avoided simply by not shifting precipitation amounts or variability during the summer gap period. Since there is no clear, systematic modeling evidence supporting a particular type of precipitation change in the Great Plains, this is a reasonable approach.

The resulting annual cycle of daily temperatures for an increased CO_2 scenario is illustrated in Figure 2.

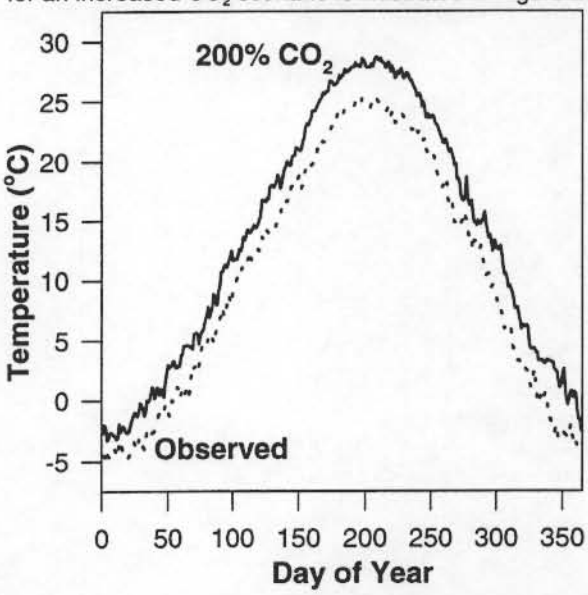

Figure 2. A comparison of the observed annual cycle of temperature and the calendar shifted climate change scenario for Gothenburg, NE.

The model guidance in this case was drawn from years 61-80 of a transient increasing greenhouse gas run produced by the Geophysical Fluid Dynamics Laboratory (Data Source: National Climatic Data Center). Because of the length of the climate record at Gothenburg, 80 years of daily scenario data are available for impact assessments of this stage of an ongoing climate transition.

With such a lengthy daily scenario, a full range of natural variability changes may be evident. For instance, as March begins to act more like April, substantial changes in the probability of frost damage to early crops may take place. Figure 3 shows the change in the probability of temperatures ≤0°C changes radically between days 50 and 100 of the annual cycle. The summer season also undergoes substantial change, with the frequency of occurrence of days with temperature ≥35°C doubling in the warm season (Figure 3). These same scenario data can also be used to examine growing season parameters such as length, degree days, and phenological timing. The temperature data can be integrated with precipitation and other observed variables to provide inputs for complex impact assessments, such as crop yield models. Some climate variables that are directly impacted by the annual cycle of solar radiation, such as snow cover, may need to be corrected when calendar shifted to account for the solar radiation differences between the shifted time and the original position of the day in the seasonal cycle.

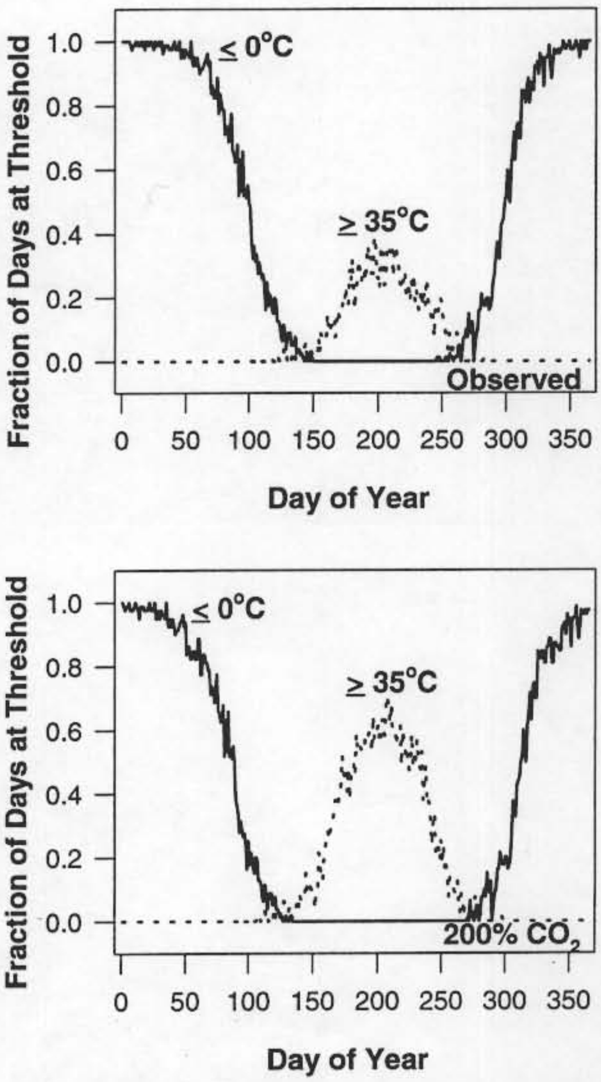

Figure 3. The probabilities of achieving ≤0°C or ≥35°C temperature thresholds in Gothenburg, Nebraska, during presently observed conditions and a 200% CO_2 scenario.

summer pcp - need to discuss pcp further

3. WATER BUDGET CHANGES IN THE GREAT PLAINS

A simple example of the utility of the calendar shifted climate change scenario data is illustrated by looking at the changes occurring in the water budget at Gothenburg, Nebraska, over the course of a climate change projected by the GFDL GCM sensitivity study. Years 21-40 of the model represent the transition through 133% CO_2 equivalent forcing, years 41-60 represent 166% CO_2 equivalent forcing, and years 61-80 represent 200% CO_2 equivalent forcing. Even though these periods last only 20 years, 80 years of scenario data were prepared for each situation. Since most agriculture in the Gothenburg area is irrigated, the deficit of soil water during the growing season is one of the most important water budget parameters, as this must be replaced by groundwater pumping. Precipitation and temperature data alone are available for the 80-year daily scenarios; therefore, a Thornthwaite-Mather water budget approach is utilized here. The water budget was calculated each month for the 80-year scenarios.

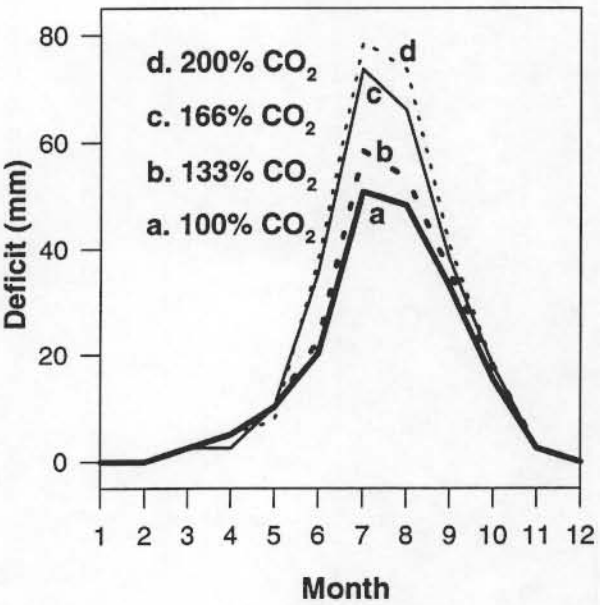

Figure 4. Projected monthly soil water deficits for Gothenburg, Nebraska, for three stages of increasing greenhouse gas climate change.

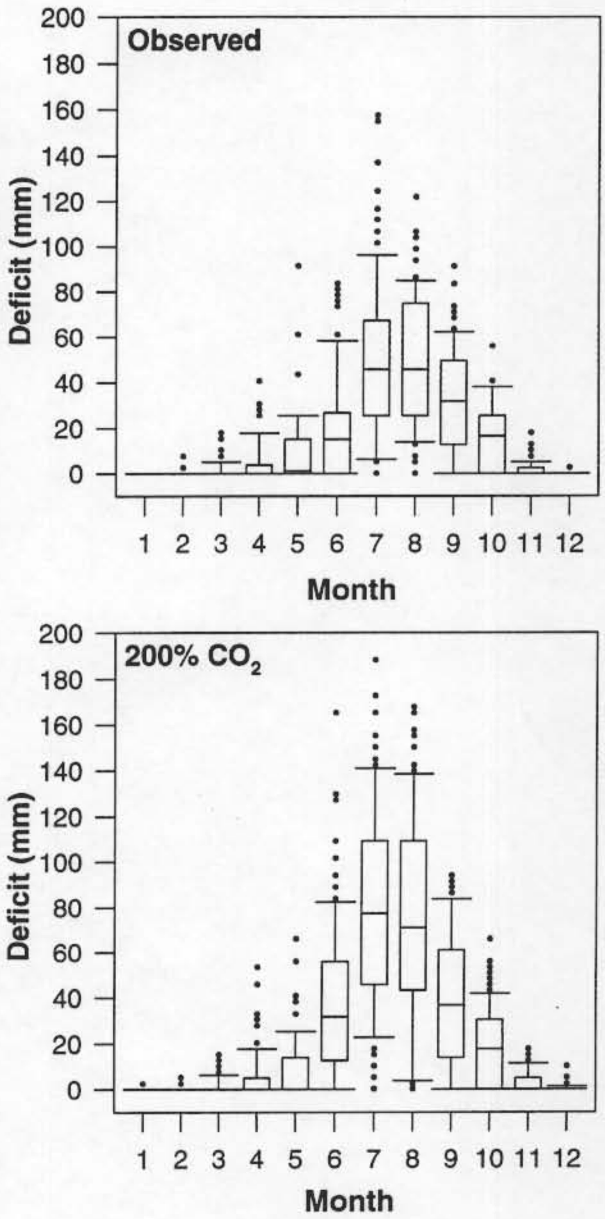

Figure 5. Box and whisker plots of monthly soil water deficits for Gothenburg, Nebraska, during observed times and a 200% CO_2 scenario. The edges of the box are set at the 30th and 70th percentile, with the whiskers at the 10th and 90th percentile.

The average water deficits are displayed in Figure 4. The amount of water deficit increases as greenhouse gas levels rise, indicating a progressive need for more irrigation in a region of declining ground water tables. The distribution of monthly soil water deficit statistics also changes, with a substantial increase in variance indicated by the vertical extent of the boxes and whiskers in Figure 5. The whiskers marking the 10th and 90th percentile during the growing season months show much greater separation for the climate change scenario, and therefore, more variance. Possessing 80 years of scenario data allows for accurate variance assessments.

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