1.4 SIMULATING THE SYNOPTIC CLIMATOLOGY OF EXTREME PRECIPITATION EVENTS UNDER GLOBAL WARMING.

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1. INTRODUCTION

An important factor in global warming is the change in extreme precipitation, which can have strong impact on a variety of human and natural systems. Climate models indicate that extreme precipitation will increase in intensity under greenhouse-warming scenarios. Knowing a clear physical basis for such increases can provide confidence in such projections. Here, we assess model simulations of extreme cold season precipitation linked to synoptic weather patterns.

Specifically, we examine extreme daily precipitation events that cover several observation sites or several grid points in a regional climate model (RCM), which we term widespread extreme events. By restricting our analysis to such widespread events, we are assuming that the hydroclimate dynamics producing the events are resolvable by the RCM, so that the model should replicate observed behavior. Thus, as part of our effort, we compare simulations of contemporary climate with observations. The comparison assesses whether or not the simulated extreme, widespread events have the same physical basis as observed events. We also examine similar events in a future scenario, assessing the physical basis for changes between contemporary and projected climates.

2. OBSERVATIONS AND SIMULATIONS

2.1 Observations

Observed daily precipitation comes from cooperative climate-observing-network data archived by the U.S. National Climatic Data Center. Eischeid et al. (2000) and Clark and Hay (2004) extracted the observations used here and provided quality control assessments. We use data for the 1980s, but to mesh with other analyses we are performing, we required all stations used here to report for the period 1950-1999 with no more than 7.5% missing or question-

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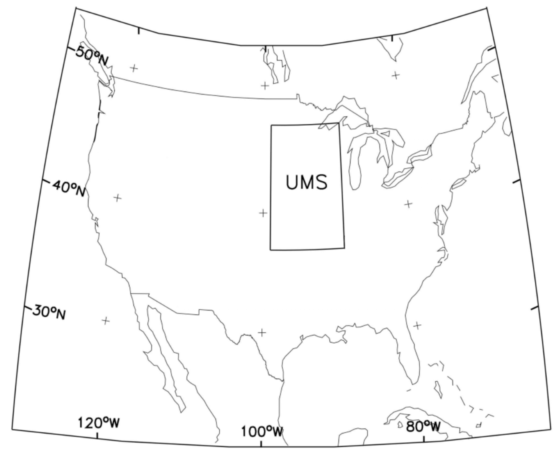

Figure 1 - Simulation domain and the location of the Upper Mississippi analysis box.

able data. We assumed that continuity of record over a 50-year period implied reliability and thus an acceptable quality level in the data. Our analysis focused on an Upper Mississippi basin (UMS) region (Fig. 1), for which 476 stations met our reliability criterion.

For evaluation of the synoptic circulation associated with observed extreme precipitation, we used 500 hPa geopotential heights from the reanalysis (Kalnay et al. 1996) produced by the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR).

2.2 Simulations

Model output used here came from contemporary and future-scenario periods simulated by the Second-Generation Regional Climate Model (RegCM2; Giorgi et al. 1993a,b). Simulations used the continental U.S. domain shown in Figure 1, with 50-km grid spacing. Reanalysis or global climate model (GCM) output provided initial and lateral boundary conditions.

The reanalysis simulation used the NCEP/NCAR reanalysis (Kalnay et al. 1996), supplemented by observations of surface temperatures in the Gulf of California and the

North American Great Lakes. The simulations spanned October 1978 to December 1988 with the first three months considered a spin-up period, ignored by the analysis. GCM-driven simulations used output from the Hadley Centre Climate Model, Version 2 (HadCM2; Johns et al. 1997). The HadCM2 contemporary-climate simulation had effective greenhouse gases corresponding roughly to the 1990s. The HadCM2 scenario-climate simulation assumed a 1% per year increase of effective greenhouse-gas concentrations after 1990. The 10-year window used from the scenario-climate was the decade 2040–2049 (Pan et al. 2001). Here, we refer to the contemporary and future RCM climates driven by HadCM2 as the control and scenario simulations, respectively, and the climate change is the scenario minus control difference.

RCM simulations were continuous for each of the ten-year driving periods. However, partly to reduce influences of spin-up and partly due to storage problems, we used only the final 8 years of the NCEP-driven simulation and the final 9 years of the GCM-driven runs. Analysis of observations covered the same 8-year period as the NCEP-driven run, 1981-1988. Pan et al. (2001) give further details of the models and simulations and discuss general features of the precipitation output and its change under enhanced greenhouse warming.

3. EXTREME PRECIPITATION

We focus on the cold half of the year, October-March, under the assumption that synoptic dynamics are more likely to play a role in extreme widespread events, compared to the warm half. We diagnose extreme daily precipitation for observations by examining all daily precipitation events among the observation stations in our Upper Mississippi River box and defining the most intense 0.05% as extreme. We perform similar analysis for each simulation, treating each grid point in the same way as our observing stations.

The resulting 0.05% threshold for UMS observations is 120 mm/day. In contrast, the NCEP-driven, control, and scenario simulations have thresholds of only 42.2 mm/day, 43.2 mm/day, and 50.3 mm/day, respectively. The difference is due to difficulties climate models have in simulating the intensity of extreme events as strongly as observed (e.g., Gutowski et al. 2003, 2006), which is at least partly a consequence of relatively coarse resolution versus to the dynamics directly producing intense condensation. The corresponding average UMS precipitation in the simulations is.1.66 mm/day, 1.82 mm/day and 2.14 mm/day. The scenario-simulation threshold increases by about the same amount (17%) over the control simulation as the climate change for average precipitation. However, the scenario run shows a longer "tail" in its frequency versus intensity distribution (not shown), so the average extreme precipitation in the scenario run is 26% greater than the average control-simulation extreme precipitation.

Extreme precipitation sometimes occurs simultaneously at several UMS observing stations or several model grid points (e.g., Fig. 2). We extract for further analysis days for which at least 10 model grid points or observation sites have extreme precipitation, defining these to be widespread extreme events. For the simulations, these events involve 50-70% of all grid points that have extreme daily precipitation, by our definition. There are 6 days with such widespread events in the observed UMS precipitation, whereas the simulations have 7 (NCEP-driven), 8 (control) and 5 (scenario) days with widespread events.

4. SYNOPTIC CONDITIONS

We diagnose synoptic conditions associated with these events by examining 500 hPa geopotential heights for the day of the event as well as the day before and the day after. The 500 hPa circulation for nearly all of these extreme widespread events has a cut-off low or deep trough over the center of the United States (e.g., Figs. 3 and 4). Typically the cut-off low or deep trough is present at about the same location the day before, so that it is slow moving or even stationary. These features suggest that the flow is equivalent barotropic, so that during this period the

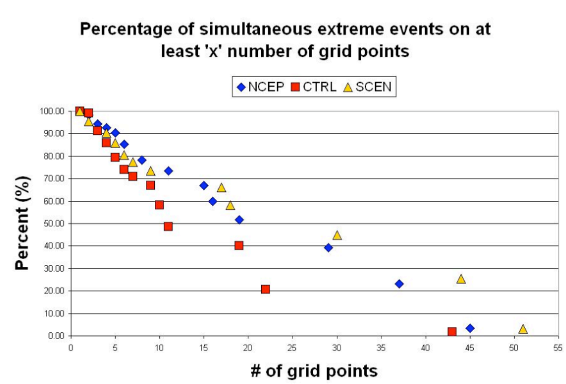

Figure 2 - The percentage of extreme events occurring simultaneously on at least 'x' grid points.

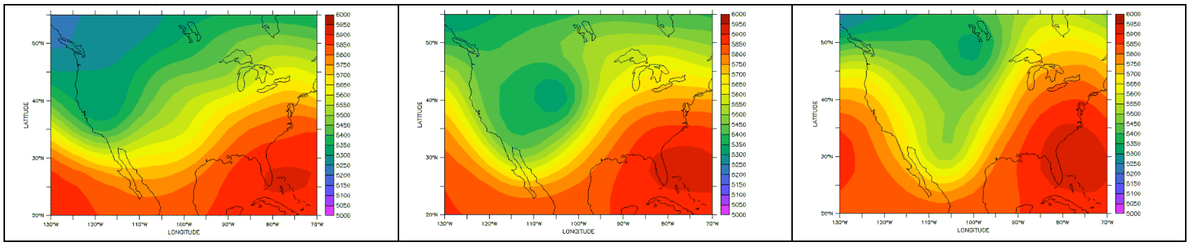

Figure 3 - Example of 500 hPa geopotential heights during an observed extreme widespread precipitation event in the Upper Mississippi region, for 1 day before the event (1 Dec 1982, left panel), the day of the event (2 Dec 1982, center panel) and 1 day after the event (3 Dec 1982, right panel). The contours are every 50 m from 5000 m – 6000 m.

lower level circulation is transporting substantial moisture from the Gulf of Mexico into the center of the U.S. The Upper Mississippi River Basin thus imports moisture persistently during this period. The circulation pattern often continues the day after the extreme, widespread precipitation event, but only about two-thirds of the time. The key synoptic transport process to the event appears to be persistent flow from the Gulf of Mexico that lasts long enough to bring moisture to the Upper Mississippi River Basin for its extreme event.

An important feature of the results in Figs. 3 and 4 is that the observed and simulated events all have the same synoptic behavior. Thus, even though the model has deficiency in simulating the intensity of extreme precipitation, it reproduces the observed 500 hPa circulation associated with the observed extreme widespread events. This suggests that the model can still be used to assess the processes producing extreme precipitation, even if the precipitation amount itself is less extreme than observed. In other words, we can place more confidence in the quality of the circulation simulation associated with extreme behavior than on the resulting precipitation.

Figure 4 also shows that the 500 hPa circulation associated with these extreme events is essentially the same in the NCEP-driven, control and scenario simulations. According to this model, the circulation conditions for extreme, widespread daily precipitation in the UMS cold season do not change with climate change. Instead, the warmer climate can contain more moisture in the atmosphere, which can and, in these cases, does lead to more precipitation.

5. CONCLUSIONS

The regional climate model examined here, RegCM2, reproduces the observed synoptic conditions associated with extreme, widespread daily precipitation during the cold half of the year for our Upper Mississippi River Basin box. This circulation behavior occurs even though the simulated extreme precipitation amount is low compared to the observed precipitation for the same percentile range.

The result suggests that circulation analyses may give more robust indication of occurrence and change in extreme events. It also suggests that regional climate models are useful tools for diagnosing the physical processes leading to extreme events.

The model's scenario climate has the same synoptic conditions for extreme widespread precipitation as the contemporary-climate simulations. This suggests that there are no shifts in circulation regime for the extremes examined here. Rather a more important factor is the amount of moisture the atmosphere can contain, which is larger in a warmer climate.

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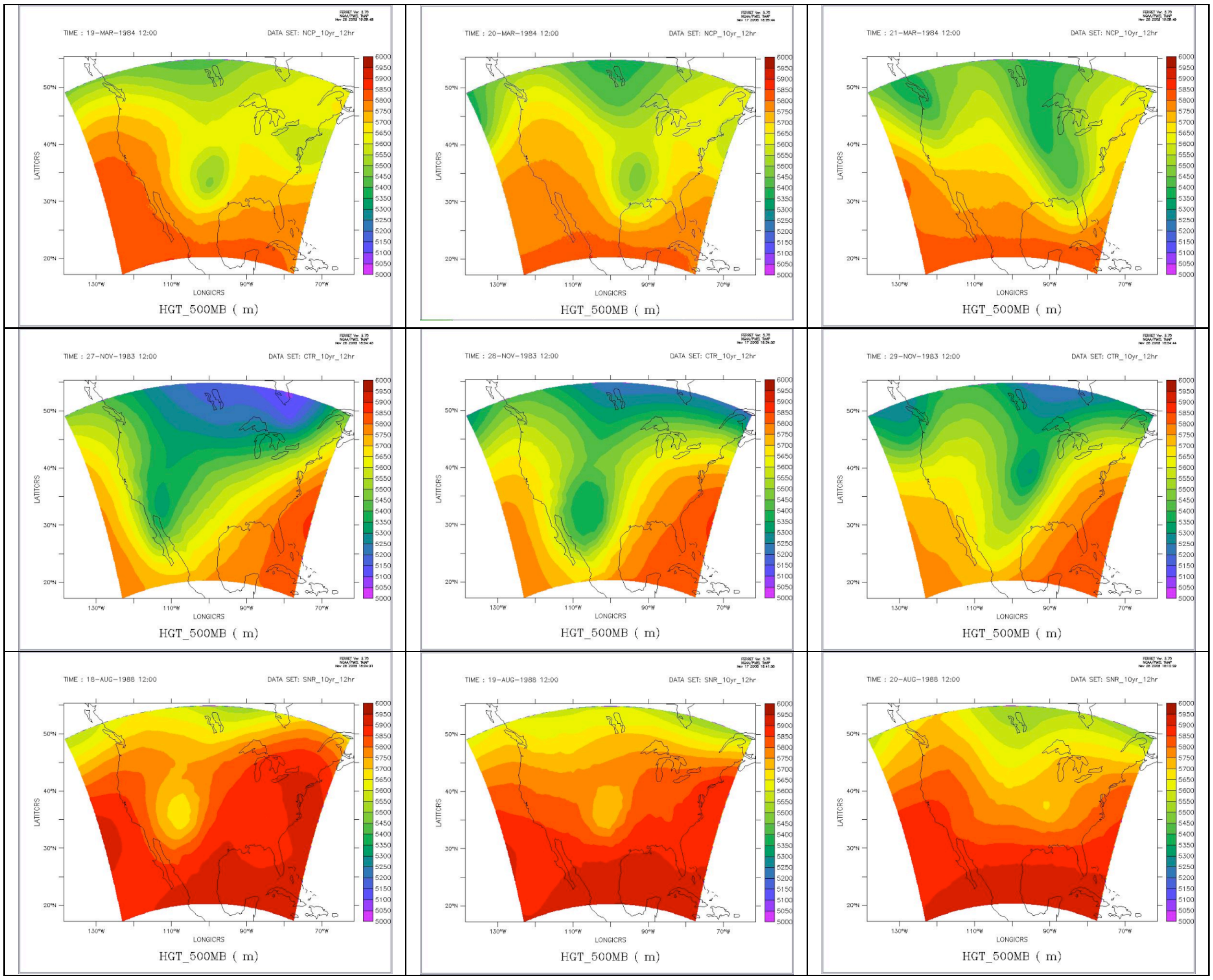

Figure 4 – Examples of 500 hPa geopotential heights during simulated extreme widespread precipitation events in the Upper Mississippi region, for 1 day before the event (column A), the day of the event (column B) and 1 day after the event (column C). Examples are from the NCEP-driven run (top row), the GCM-driven contemporary-climate run (middle row) and the GCM-driven scenario run (bottom row). The contours are every 50 m from 5000 m – 6000 m.

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