J5.14 SIMULATION OF POSSIBLE FUTURE EFFECTS OF GREENHOUSE WARMING ON GREAT LAKES WATER SUPPLY USING A REGIONAL CLIMATE MODEL

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1. INTRODUCTION

The Laurentian Great Lakes contain about 20% of the world's surface freshwater and cover a total area of 247,000 km^2. The land portion of their drainage basin covers 534,000 km^2. Because of their large surface area, the lakes exert a strong influence on the climate of neighboring regions. They also represent a major resource for various water uses, including consumptive use, ecological habitats, shipping, hydroelectric, and recreational use.

Concern has arisen over the influence of greenhouse warming on the water resources of the Great Lakes Basin. Public attention has been focused in particular by a rapid drop in the lake levels between 1998 and 2001. Previous studies (Croley 1990, Mortsch and Quinn 1996, Chao 1999) have pointed toward lower lake levels, but Mortsch et al. (2000) and Lofgren et al. (2002) contain some evidence of the possibility of a rising trend in lake levels.[1]

2. EXPERIMENTAL DESIGN

Using the Coupled Hydrosphere–Atmosphere Research Model (CHARM, Lofgren 2003), projected climate was simulated over the Great Lakes Basin for time periods centered at 1989, 2030, and 2095. This limited-area model requires input of meteorological state variables around the edges of the domain, for which output from the Canadian Centre for Climate Modelling and Analysis Coupled General Circulation Model version 1 (CGCM1, Reader and Boer 1998) was used. Simulations spanned the years 1984-1993, 2025-2034, and 2090-2099, from which the results of the first year's simulation within each time span were discarded as spin-up times.

CHARM was run on a single 40-km grid centered at 45° N 84° W, with 53 grid points in the east-west direction and 43 in the north-south direction. There were 22 layers in the vertical, the lowest being 100 m thick, and increasing to 1900 m thick near the model top at 18.4 km above sea level.

In the 1989 case, the atmospheric CO$_2$ concentration was taken as 330 ppm; in the 2030 case, 496 ppm, and in the 2095 case, 948 ppm. Within CHARM, no account is taken of sulfate aerosols. This is not in keeping with the driving CGCM1. However, standard scenarios of evolution of sulfate aerosol concentration have little change over time over the Great Lakes region (Figs. 1 and 2 of Reader and Boer 1998).

3. RESULTS

3.1 *Surface Air Temperature*

The annual mean near-surface air temperatures increased in the 2030 and 2095 cases relative to the 1989 case by very consistent amounts (Fig. 1). In the 2030 case (not shown), temperatures are 1-2 K warmer than in the 1989 case; in the 2095 case, they are 4-5 K warmer.

Warmer temperature features over the lakes in all of the cases are due to a combination of lake effects and orographic effects. Other patterns common among the three case are locked into orographic features.

3.2 *Surface Mixing Ratio*

The near-surface water vapor mixing ratio is important in the Great Lakes' water budget. It plays an important role in regulating the evaporation of water both from the Great Lakes' surfaces and from the land, wetlands, and lakes within their drainage basin. Also, along with the water vapor at higher levels, it is a component of the precipitable water available to fall as rain or snow.

The annual mean near-surface water vapor mixing ratio rises between the 1989 and 2095 cases (Fig. 2). Increases are in the approximate range of 0.002-0.003, thus on the order of a 30% increase.

3.3 *Precipitation*

The precipitation rate is expected to increase by 2095 (Fig. 3), especially in the southern part of the domain. The increases are particularly focused on the lake effect zones at the eastern and

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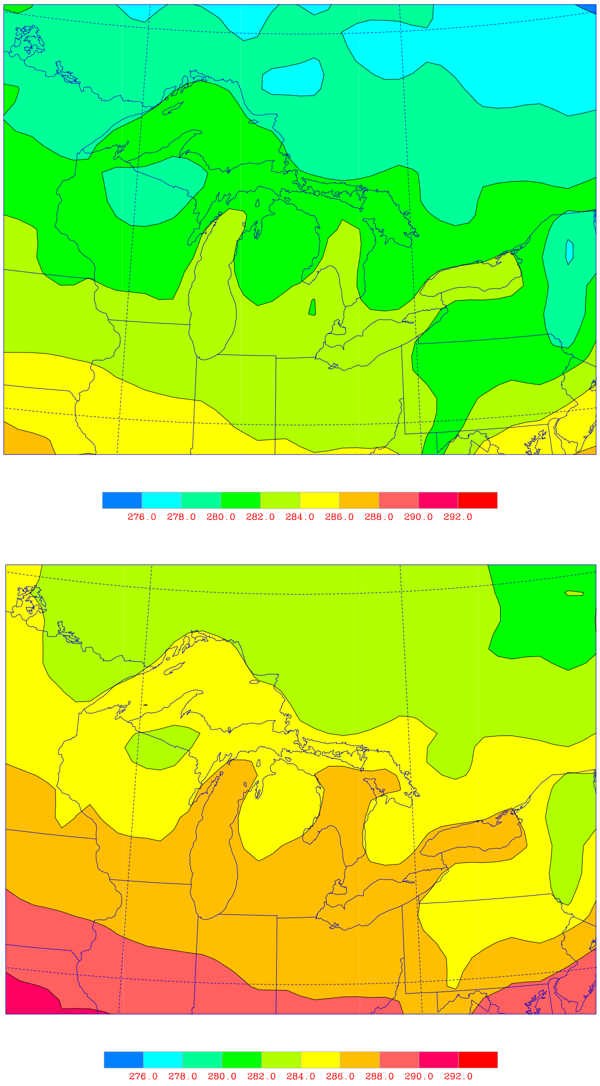

Figure 1. Annual mean near-surface air temperature (K) for (a) the 1989 case and (b) the 2095 case.

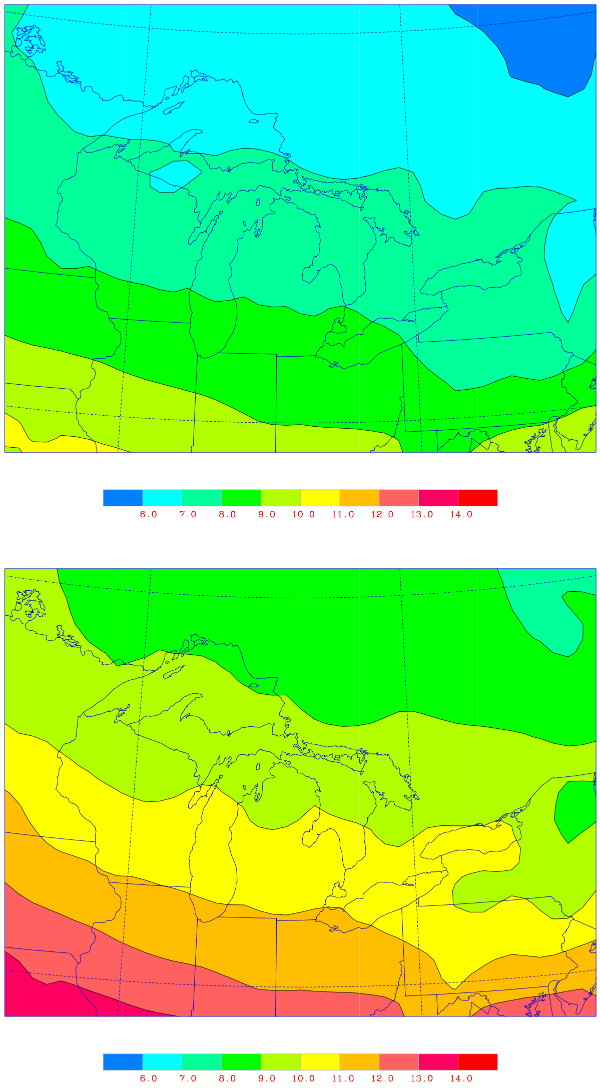

Figure 2. Annual mean near-surface water vapor mixing ratio for (a) the 1989 case and (b) the 2095 case. The values have been multiplied by 1000 in the color bars.

southeastern margins of the lakes, although the eastern end of Lake Superior appears to be an exception. Unfortunately, the concentrated region of precipitation near the southwestern corner of the domain appears to be a relic of the model.

3.4 *Hydrologic Budget*

Using the entire drainage basin of Lake Erie as an example, the runoff into the lake from its tributary rivers (Fig. 4a) is generally elevated in the future scenarios, but not exclusively for all months. There is indication of the generally-observed greenhouse warming pattern of increased winter runoff, due to increased liquid precipitation and snowmelt during the winter months. Along with this, the minimum in runoff occurs earlier in the year in the future cases than in the 1989 case.

The overlake precipitation (Fig. 4b) is generally greater in the 2095 case than in the 1989 case, especially during the winter and spring. Comparison of the 2030 case to the 1989 case does not yield such a strong change in precipitation.

The overlake evaporation was deemed in studies such as Lofgren et al. (2002), Mortsch et al. (2000), and Mortsch and Quinn (1996) to be the

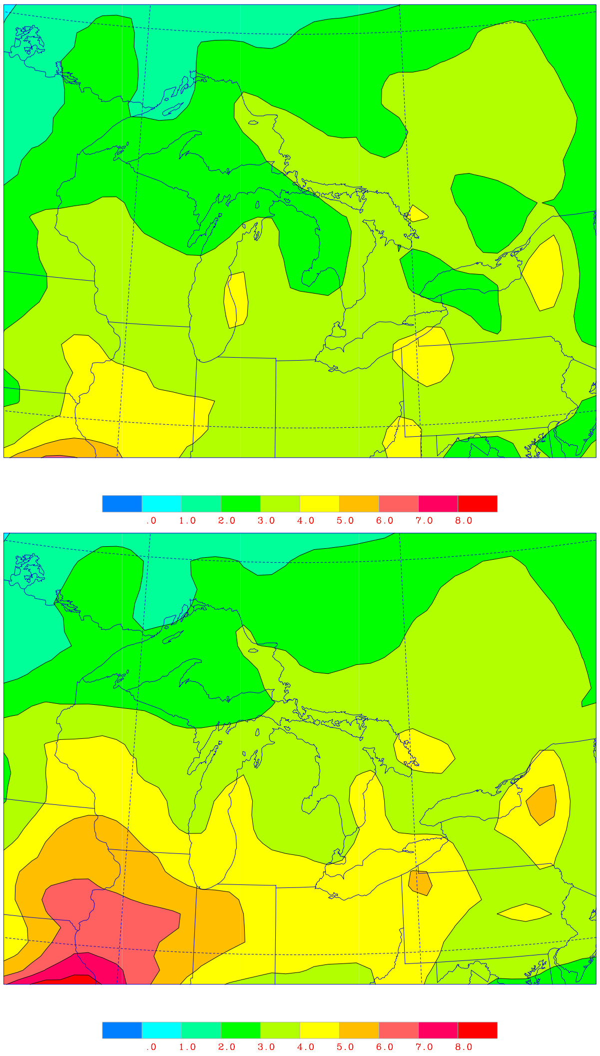

Figure 3. Annual mean precipitation (mm/day) for (a) the 1989 case and (b) the 2095 case.

primary reason for an expectation of lower lake levels in the Great Lakes. The results shown in Fig. 4c contradict this, showing almost no change in the evaporation among the three model cases.

The net basin supply is defined as *R* + *P* - *E*, where *R* is runoff into the lake, *P* is precipitation directly into the lake, and *E* is evaporation from the lake. This quantity is shown in Fig. 4d. There is an increase in the net basin supply for the Lake Erie Basin in the 2030 and 2095 cases relative to the 1989 case for most months.

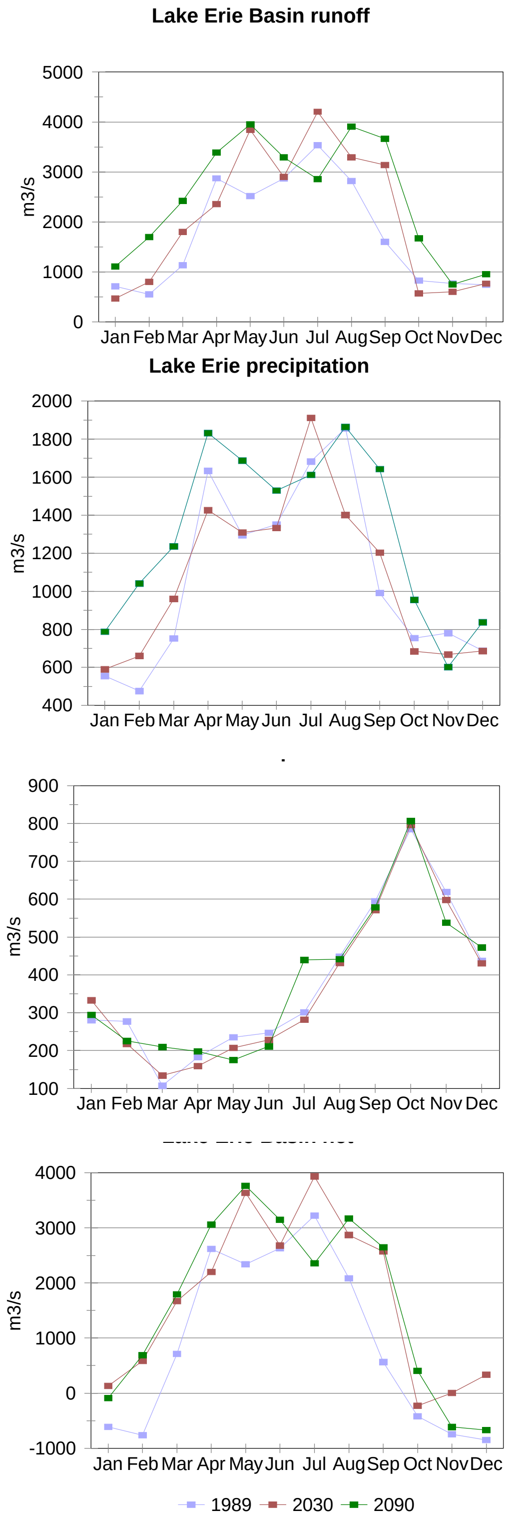

Figure 4. Components of the hydrologic budget for the Lake Erie Basin–(a) runoff, (b) precipitation, (c) evaporation, and (d) net.

4. DISCUSSION

Although the analysis of net basin supply is not shown here for the Great Lakes other than Lake Erie, they also show an increase in net basin supply. This has not yet been processed into a change in terms of lake levels, but if the increases in net basin supply turn out to be true, they are sure to result in rises in lake levels. This is in contrast to all of the results of studies of the impact of global warming on Great Lakes levels that were carried out prior to the summary given in Mortsch and Quinn (1996). It also contrasts with the results shown in Lofgren et al. (2002) for a Great Lakes hydrologic model driven in a one-way coupling scheme by the results from the CGCM1 model. However, it is in qualitative agreement with the results from the same study using the Hadley Climate Centre's Coupled Model version 2 (HadCM2).

The Hadley Centre has published (Mitchell and Johns 1997) that their parameterization of the direct effects of sulfate aerosols is "overactive" relative to detailed calculations of these effects. Partially as a result of this, they have developed a newer model version (HadCM3, Gordon et al. 2000; Pope et al. 2000), deemed to be more accurate. Driving of the Great Lakes hydrology model in the mode of Lofgren et al. (2002) but using HadCM3 has not yet been carried out. However, there is reason to suspect that part of the difference between increased lake levels or net basin supply using the HadCM2 model in the Lofgren et al. (2002) study and the CHARM model in the present study on the one hand, and the decreasing water in the CGCM1 model and all others summarized in Mortsch and Quinn (1996) on the other hand, is that the models predicting increasing lake levels or net basin supply include at least a crude representation of the presence of the Great Lakes, while all others regard this entire region as land.

One of the most striking results shown here is the very strong resemblance among the model cases of the annual cycle of evaporation from Lake Erie shown in Fig. 4c. Additional analysis is needed to elucidate the factors leading to this. One possible contributor is a moistening of the boundary layer to offset the higher ambient temperatures of the lakes. Another is greater stability of the boundary layer over the lakes, particularly during the winter season, when the greatest warming of the air takes place.

5. ACKNOWLEDGMENTS

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