P3.17   DEVELOPMENT OF THE SECOND-GENERATION HYDROSPHERE-ATMOSPHERE
RESEARCH MODEL (CHARM) FOR THE LAURENTIAN GREAT LAKES REGION

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1. INTRODUCTION[*]

The question of what effect global warming might have on the amount of water available within the Laurentian Great Lakes basin has gained some controversy. Even the author of this extended abstract has gone on record with predictions in various directions.

Several studies during the 1990s used the results of general circulation models (GCMs) to derive a suite of meteorological variables as drivers for offline hydrologic models designed specifically for the Great Lakes basin. That is, the GCMs drove the hydrologic models, but the GCM simulations were already complete, so the GCMs were not aware of what was happening in these hydrologic models. Notably, most of the GCMs altogether ignored the presence of the Great Lakes in their simulations. These simulations consistently show that, while GCMs generally show increased precipitation over the basin, increased evapotranspiration from the basins, associated with increased temperature and available energy at the surface took the upper hand, leading to decreased net basin water supply and lowered lake levels.

More recently, Lofgren et al. (2002) carried out a similar procedure using output from two GCMs with transient CO_2 concentration scenarios. In this study, one of the two GCMs showed increased net basin supply and a rise in lake levels. Nevertheless, the prevailing wisdom remained that global warming leads to dropping lake levels. This prevailing wisdom was again supported by Croley (2003) for Lake Ontario only, in which he used updated versions of the same two GCMs to show a decrease in net basin supply in both models.

In order to help rectify the lack of two-way coupling between the atmospheric and hydrologic components of the model system in these studies, the Coupled Hydrosphere-Atmosphere Research System (CHARM) was developed (Lofgren 2004). CHARM has a regional domain and full two-way interaction between the atmosphere and both land and lake surfaces. It was applied to greenhouse warming scenarios, which results in a general increase in net basin supply for the Great Lakes (Lofgren 2005, submitted). However, significant problems remain with CHARM, and may help to explain the discrepancy between its simulation of greenhouse warming scenarios and the common wisdom that preceded its use. A particular issue is the focus of this extended abstract, the excessive amount of cloudiness that is associated with a warm bias during the winter, both in the present and future scenarios of climate. One hydrologic effect of this bias is that there is very little ice formed on the Great Lakes even in the present or recent past model simulation. This absence removes one of the mechanisms that would be expected to lead to increased lake evaporation under a greenhouse-warmed environment—because ice suppresses evaporation, a trend toward less ice in the future would lead to greater evaporation.

One of the reasons that is expected to yield high temperatures and excessive cloud cover during the winter is that water surface temperatures, other than those directly over the Great Lakes, were prescribed by spatial interpolation of the climatological ocean surface temperatures of Reynolds (1988). This usage is unrealistic and leads to anomalously high lake surface temperatures for at least three reasons: 1) the lakes are generally shallower than the oceans, and thus respond more readily to seasonal temperature fluctuations, thus cooling and freezing more during the winter; 2) the lakes other than the Great Lakes are quite small in area and are situated within a continental region that cools much more readily than the oceans; and 3) the lakes are situated at higher altitudes than the ocean, leading to adiabatic cooling effects.

2. EXPERIMENTAL DESIGN

The simulations carried out in this study used RAMS version 4.4 as a basis, in contrast to Lofgren (2004), which used RAMS 3a. It was configured to use full microphysics for clouds, rain, and snow, as well as incorporating a convective precipitation parameterization. Lateral boundary conditions were provided by the NCEP/NCAR Reanalysis Data (Kalnay et al. 1996).

In the model simulation referred to here as the base case, all lake surface temperatures (including the Great Lakes) were prescribed by spatial

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interpolation of the climatological ocean surface values of Reynolds (1988). In the interactive SST case, the water surface temperatures, including the Great Lakes and the piece of the Atlantic Ocean that is located in the southeastern corner of the domain, were simulated as interactive components of the system. A simple mixed layer of 5 m depth was used for this simulation.

The results shown here correspond to snapshots at the end of one month of simulation (January 1993).

3.   RESULTS

These model runs show the anticipated results to a modest degree. The near-surface air temperature after one month (January) of simulation is lower over the Great Lakes in the interactive lake surface temperature than in the one with specified lake surface temperature, by as much as about 4° C (Fig. 1). However, outside of the Great Lakes themselves, the temperatures were nearly identical between the two runs.

The interactive lake surface temperature case showed less cloud cover and greater solar radiation near the Great Lakes than did the prescribed lake surface temperature case (Fig. 2), apparently resulting from reduced evaporation from the lakes. Again, little effect was evident outside the immediate vicinity of the Great Lakes. One region in which a more significant effect was anticipated was to the west of Lake Superior, along the border
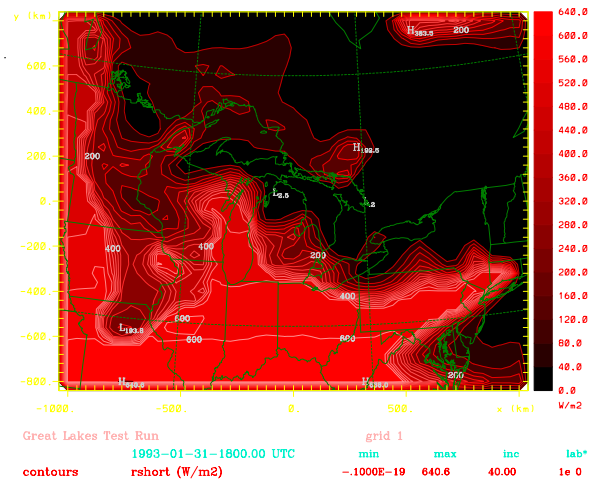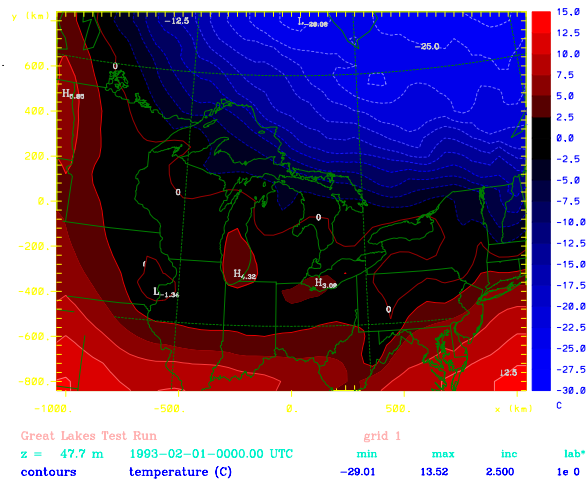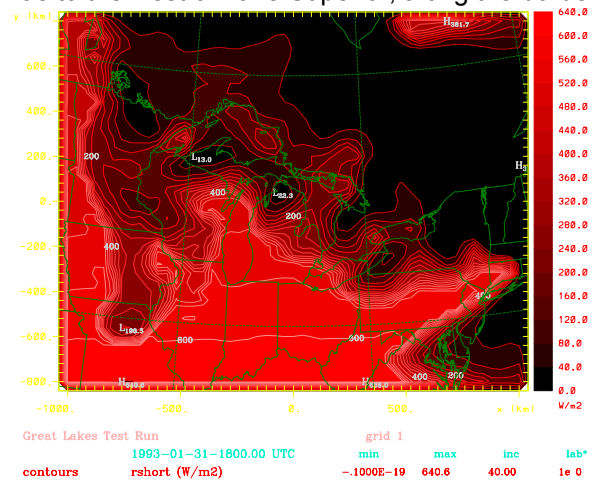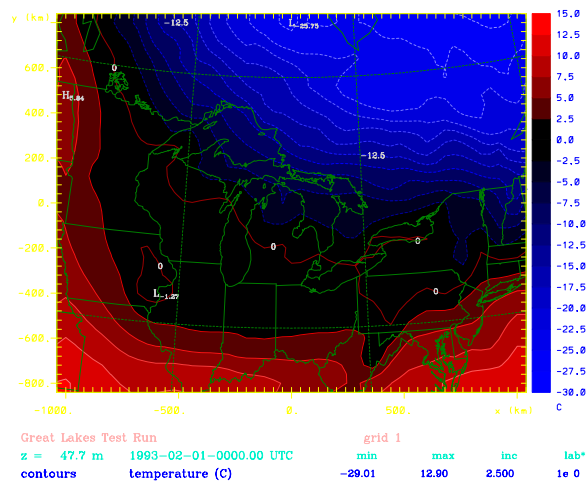

Figure 1. Near-surface air temperature ($^{\circ}$ C) at 00 UTC 1 February 1993 as simulated in (top) the interactive lake surface temperature case and (bottom) the prescribed lake surface temperature case.

between the State of Minnesota and the Province of Ontario, a region that has a rather dense array of inland lakes. However, in both model cases, the sun is nearly blocked out of this region, indicating the presence of dense clouds and little net loss of longwave radiation. This was a condition that was intended to be corrected by the inclusion of interactive lake surface temperatures, but this does not appear to be an entirely effective solution.

4. FUTURE PLANS

One feature that is conspicuously missing from the simple interactive lake surface temperature scheme used here is ice. When ice forms, it is very effective at reducing loss of heat energy through several mechanisms: 1) it causes the water vapor pressure immediately at the surface to be that corresponding to ice at the given temperature, which is lower than that corresponding to liquid water at the same temperature, 2) it inhibits the eddy mixing of heat up from deeper layers of water, 3) it is a poor conductor of heat from the underlying water to the air interface, and 4) it permits the presence of a surface colder (perhaps much colder) than 0° C, stably located over warmer water. It is anticipated that the inclusion of ice will further diminish winter evaporation both from the Great Lakes and from the smaller lakes, thus reducing the cloud cover.

Additionally, more elaborate schemes for vertical distribution of temperature will be invoked, especially for the Great Lakes themselves. The lumped temperature scheme for the Great Lakes, used in Lofgren (2004), can be implemented again. Also likely is use of the scheme of Hostetler and Bartlein (1990), with introduction of artificial flux adjustments to bring the surface temperatures into agreement with observations.

5. ACKNOWLEDGMENTS

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