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NORTHERN LAKE IMPACTS ON LOCAL SEASONAL CLIMATE

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1. Introduction

Great Bear Lake and Great Slave Lake are two major lakes in the Mackenzie River Basin. As large lakes, they perturb local climate through impacts on storms, fluxes of heat, moisture, and momentum and related mesoscale weather processes. Weather events can greatly influence the hydrodynamic regimes of lakes, for example by surface layer mixing and upwelling, and in turn, weather events are affected through the large differences in heat capacity, roughness length, and albedo of water compared with nearby soil and vegetation, as well as differences in the vertical transfer of heat in the water column compared with those on land.

In this study, the Princeton Ocean Model (POM) of Mellor (1998) is coupled to the Canadian Regional Climate Model (CRCM) of Caya and Laprise (1999) for Great Bear Lake and Great Slave Lake, to examine the interaction between large northern lakes and the surrounding regional atmosphere.

2. Models and experiments

The atmosphere-lake coupled model consists of two components: the atmospheric model CRCM (version 3.4) and ocean model POM (1998 version), set up for the lakes. The CRCM set-up uses 29 vertical levels and a 15-min time step. Driven by the CMC (Canadian Meteorological Centre) 6-hourly analyses, the coarse-resolution CRCM model simulations are performed at a horizontal resolution of 51 km. Clearly, the surface flux estimates from a 51-km resolution grid are too coarse to represent the forcing fields to drive the lake model, which has a 5-minute (approximately 10-km) horizontal resolution. To improve the atmospheric model's resolution, the outputs of coarse-resolution model simulations are used to nest fine-resolution simulations. This downscales the horizontal resolution to a 15-km resolution domain over the Mackenzie River Basin.

POM is implemented and customized for Great Bear Lake and Great Slave Lake with a horizontal resolution of 5 minutes and 13 σ layers. Time steps are 15 minutes. The bathymetry of Great Bear and Great Slave Lakes was digitalized from Canadian Hydrographic Service Charts #6390, #6370 and #6341. Closed lateral boundaries around each lake are used and there is no water exchange between rivers and lakes. Salinity is set to zero. The initial water temperatures are prescribed, based on available observations (MacDonald et al., 2004).

The coupled model system exchanges information between the atmosphere and the lakes at the air-water interface at every coupling time step. A typical simulation begins with the forward integration of the 15-km fine resolution CRCM simulation for 1 time step (15 minutes) with fixed lake-surface temperature. Wind stress, sensible and latent heat fluxes, radiative flux and fresh water flux, as computed from CRCM, are transferred to POM. POM is then integrated forward for 15 minutes, which constitutes one time-step of its baroclinic-mode time-step, and produces a new surface temperature field which is then passed to CRCM, which in turn is integrated forward for another 15 minutes.

In this study, coupled and uncoupled simulations consist of CRCM, with or without the POM lake model. All the simulations start on June 1 and end on October 31 for both 1998 and 1999, allowing the model system to spin-up during June in each year, and accommodating differing ice-free onset times in each year. All the analyses started from 1 July, disregard model outputs before that time. In the uncoupled experiment, the CRCM simulation does not include the feedbacks from the lakes to the atmosphere. Comparisons between the coupled and uncoupled POM-CRCM simulations enable us to study the impacts of the lakes on water and energy cycles.

3. Lake impacts on local seasonal climate

The lake-averaged energy balances over Great Slave Lake simulated by the coupled CRCM-POM model are shown in Fig. 1a. Here, total heat flux (Q_{ST}) and net radiation flux (Q^{*}) are positive when the lake gains heat, and latent heat flux (Q_{E}) and sensible heat (Q_{H}) are positive when lake releases energy.

In summer, Great Slave Lake receives heat flux from the atmosphere, whereas in the fall, this received summer heat is released back into the atmosphere. During the period from July to October, the total heat fluxes gradually decrease from about +200Wm^{-2} in early July to about -200Wm^{-2} in late October. The corresponding net radiation linearly decreases from about +200Wm^{-2} in early July to about -50Wm^{-2} in late October, which suggests that solar flux dominates the heat exchange between the atmosphere and the lake in early summer.

During mid-summer, most of the received heat fluxes are net radiation fluxes; the latent and sensible heat fluxes are small. After September, the surface latent and sensible heat fluxes dominate the heat exchange between the lake and the atmosphere. Comparison between Figs 1a and 1b suggests that the coupled model is able to give qualitatively correct estimates of the overall observed energy balance and time series variations for Q^{*}, Q_{E}, Q_{H}, and Q_{ST} for Great Slave Lake for July-October 1999. Observed data from Rouse et al. 2003) is included in the figures.

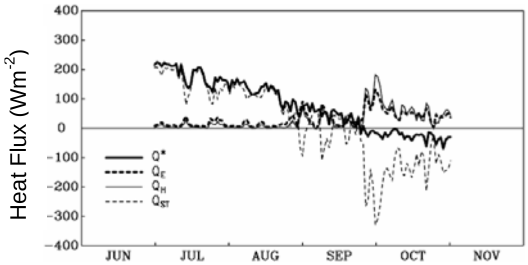


Figure 1a. Energy balance over Great Slave Lake in 1999 simulated by CRCM-POM, for time series of net radiation (Q^*), latent heat flux (Q_E), sensible heat (Q_H), and total heat flux (Q_{ST}). Units are Wm^{-2}.

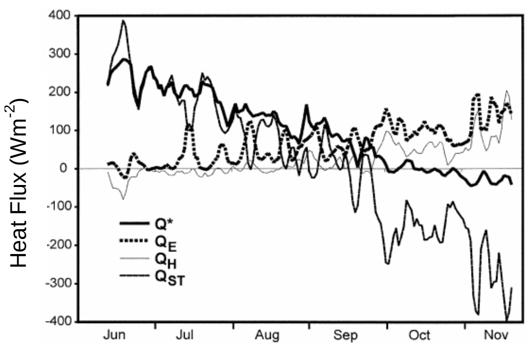


Figure 1b. As in Fig. 1a, for the observed 1999 Great Slave Lake time variations in Q^*, Q_E, Q_H, and Q_{ST} , from Rouse et al. (2003).

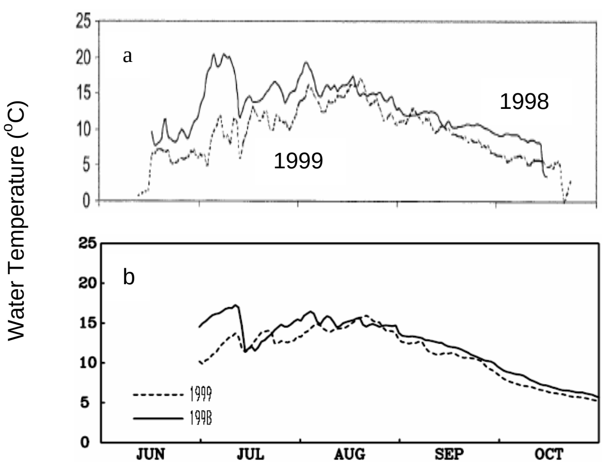


Figure 2. Surface temperature (°C) averaged over Great Slave Lake in 1998 and 1999, showing (a) observations (from Schertzer et al. 2003) for 1998 (solid), and 1999 (dashed), and (b) simulations for 1998 (solid), and 1999 (dashed).

The surface water temperatures of Great Slave Lake, corresponding to its surface fluxes, are shown in Figs. 2a-2b, averaged over the entire lake for 1998 and 1999. The surface water temperature gradually increases in early summer, and the lake becomes warmest in early August. Thereafter, particularly after late August, the water temperature steadily decreases. Both the simulation and observations show that the lake reaches about 15°C maximum temperature in early August, and this temperature persists until late August. Comparison with observations suggests that the coupled model gives a good simulation of the overall magnitude and variation of surface water temperature.

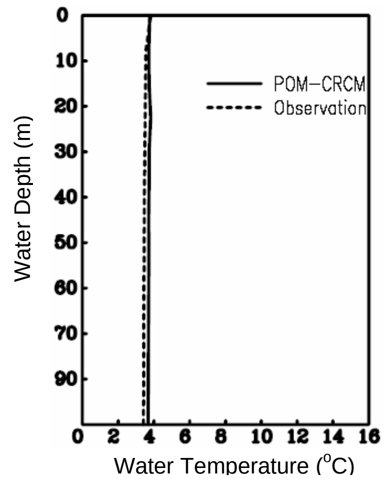


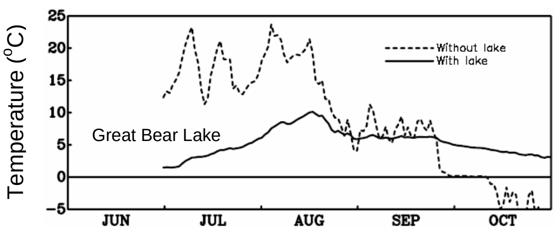
Figure 3. Vertical profiles of water temperature (°C) 10 km west of Port Radium, comparing averaged observations for August 1964 and August 1965 (dashed), and coupled model simulation for August 1999 (solid). The 1964-1965 data is from http://www.ilec.or.jp/database/nam/nam-30.html, the International Lake Environment Committee Foundation – ILEC.

Figure 3 shows the coupled model simulation of the vertical profile of water temperature in McTavish Arm at 10 km west of Port Radium (66.05°N, 117.55°W) for August 1999, and the available averaged observations. For the water temperature, only data collected from 1964 and 1965 are published (http://www.ilec.or.jp/database/nam/nam-30.html: Johnson, 1994).

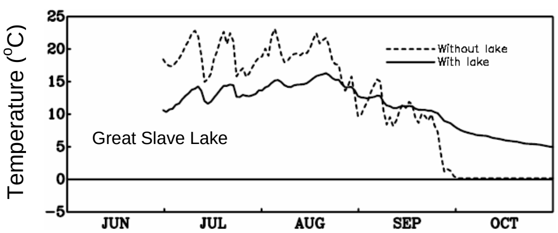
Both observations and the coupled model simulation suggest that Great Bear Lake is well mixed, because the temperatures are similar from top to bottom at about 3.5°C. Compared with observations, the modelled water temperature in 1999 is slightly warmer than the observations during 1964-1965.

The simulated lake-averaged (with and without lakes) surface temperatures in 1999 are shown in Fig. 4. In the uncoupled simulation (without lakes), the surface temperature over Great Bear Lake is about 10°C higher than in the coupled model simulation in July-August, and about 10°C lower in October. There are no significant differences from the end of August to the end of September (Fig. 4a). A similar pattern can be seen in Great Slave Lake (Fig. 4b). Comparison between Figs. 4a and 4b shows that Great Bear Lake has a notably stronger impact on the simulations of lake-surface temperature than Great Slave Lake.

Corresponding to the temperature time series patterns, uncoupled simulations (without the lake) result in overestimates in the surface sensible and latent heat fluxes in summer (July-August), and underestimates in these surface heat fluxes in October. The associated summer overestimate in the surface sensible heat fluxes is more than 50Wm^{-2} and the October underestimate, by more than 50Wm^{-2} (Figs. 5a-5b). Furthermore, uncoupled simulations result in a summer overestimate in latent heat transport from the lake surface (as estimated from surface evaporation), by about 100Wm^{-2}, and an October underestimate by about 50Wm^{-2} (Figs. 6a-6b). Therefore, the impacts of northern lakes on regional surface heat exchanges between the lake and the atmosphere are significant.

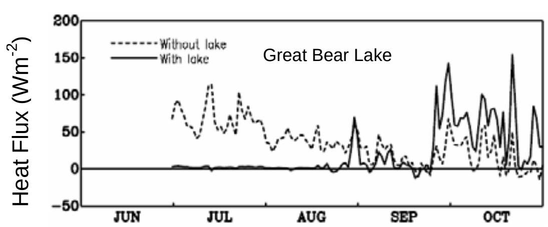


(a)



(b)

Figure 4. Lake-wide averaged surface temperature (^{o}C) in 1999, for simulations with (solid) and without (dashed) the lake for (a) Great Bear Lake (b) Great Slave Lake.



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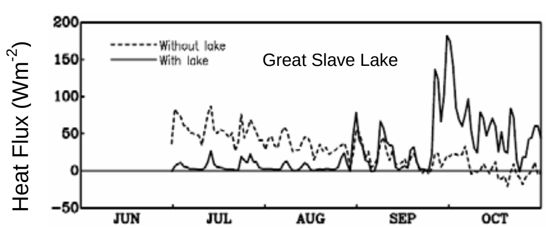
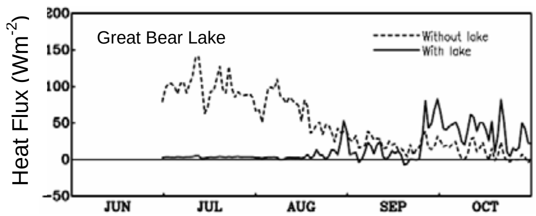
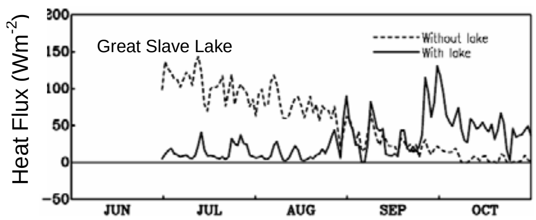


(b)

Figure 5. As in Fig. 4 showing lake-wide averaged Q_H, surface sensible heat flux (Wm^{-2}) in 1999, for simulations with (solid) and without (dashed) the lake for (a) Great Bear Lake (b) Great Slave Lake.



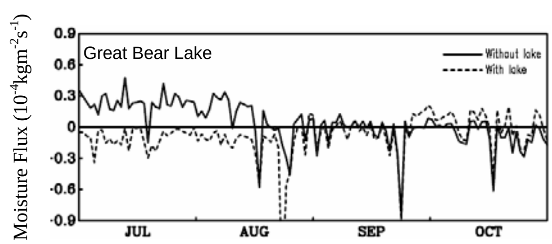
(a)



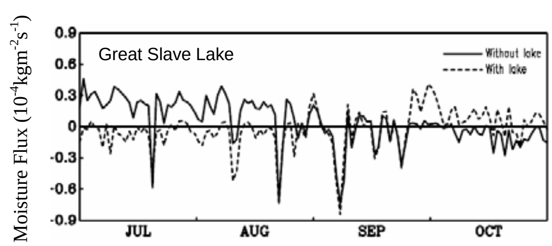
(b)

Figure 6. As in Fig. 5 showing lake-wide averaged Q_E, latent heat, transport from the lake surface (Wm^{-2}) in 1999, for simulations with (solid) and without (dashed) the lake for (a) Great Bear Lake (b) Great Slave Lake.

The associated impacts of northern lakes on surface moisture exchanges are shown in Figs. 7a-7b. As with the surface heat exchange simulations, these simulations suggest that the northern lakes have significant impacts on the surface moisture exchanges over the lakes. Compared to uncoupled simulations, the coupled simulations suggest that the lakes introduce large seasonal thermal lags due to their large heat capacities, resulting in reductions in moisture fluxes by about 3×10^{-5}kg m^{-2}s^{-1} in July-August and enhanced moisture fluxes in the fall.



(a)



(b)

Figure 7. As in Fig. 5, showing lake-wide averaged moisture flux in 1999, for simulations without (solid) and with (dashed) the lake for (a) Great Bear Lake (b) Great Slave Lake. Units are 10^{-4}kgm^{-2}s^{-1}.

4. Conclusions

The Princeton Ocean Model (POM) was implemented to simulate Great Bear Lake and Great Slave Lake, and coupled to the Canadian Regional Climate Model (CRCM) to simulate regional atmosphere-lake interactions. Our analysis includes heat fluxes and surface lake temperatures. Comparisons between our simulations and the observations suggest the coupled lake-atmospheric model can provide good representations of the lake water temperatures.

Our results show that the northern lakes have significant impacts on local water and energy balances. In summer, coupled simulations and observed surface temperatures over the lakes are colder than uncoupled simulations; the lakes tend to reduce the fluxes of surface latent and sensible heat. In the fall, surface temperatures over the lakes are warmer than the uncoupled simulations; the lakes tend to increase the latent and sensible heat fluxes.

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