An estimation of future temperatures in small lakes of the Labrador-Ungava Peninsula

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Introduction

Climate change is a great threat to lakes, especially for the many lakes that are small and shallow. Even small changes in lake temperature can profoundly affect key physical and biological processes through nonlinear dynamics. Estimating the future trajectories of temperature change in lakes appears a necessary step to prepare for the diverse changes to come. We selected a small lake and estimated the future annual cycle of water temperature at the horizons 2041-2070 and 2071-2100 using a lake model and output from a regional climate model. The lake model was run at many locations across the Labrador-Ungava Peninsula in order to provide a 2D view of the changes to come. The lake we used is Lake Simoncouche (48.233 °N, 71.251 °W), a small lake with a surface area of 0.83 km^2, a maximum depth of 8.7 m and a mean depth of 2.2 m.

Data and methodology

Past and future annual cycles of water temperature at all depths were estimated using a 1-D process-based lake model (MyLake, version 1.2; Saloranta and Andersen, 2007), meteorological data from the North American Regional Reanalysis (NARR), and projected meteorological changes from a regional climate model (CRCM5). The lake model has a 1-day time step and is forced with seven meteorological variables. The Lake Simoncouche model was prepared using bathymetric data. The selected vertical resolution is 1 m. The model was calibrated using meteorological data at nearby stations and observed water temperature 3.5-year time series (Figure 1). Once the model satisfactorily reproduced the observations, Lake Simoncouche was conceptually placed at 1156 positions between 45.25 and 62.25 °N and 56.25 and 79.25 °W (resolution of 0.5° in latitude and longitude) and past and future annual cycles were derived at each of these pixels. The annual cycles were derived from 30-year simulations using NARR time series for the reference period (1981-2010) and the same time series modified with the projected differences (the delta method) for the futures periods (2041-2070 and 2071-2100). For the results presented here, the deltas we used were from a single CRCM5 simulation using the greenhouse gas concentration scenario RCP 8.5, i.e. concentration continuing to increase throughout the 21st century. We used monthly deltas derived over the simulation periods (Figure 2). Each 30-year simulation was run twice, an average of the last ten years of the first simulation being used as initial conditions of water temperature and ice thickness for the second simulation.

Diverse maps were produced from the simulated annual cycles. They show either past or future conditions, or projected changes. Some of these maps were designed to provide an indication of the intensity and duration of the thermic stress for salmonids populations, and temperature conditions favorable to growth and productivity (not shown).

Selected results

The projected increases in maximum heat content (relative to 0 °C) between 1981-2010 and 2071-2100 (90 years) are presented in Figure 3. For the latitude zones 45-50 °N, 50-55 °N and 55-60 °N, the average increases are 24.6, 32.2 and 36.3 %, respectively.

The projected increases in volume-weighted temperature in summer for the depth range 0-5 m between 1981-2010 and 2071-2100 are presented in Figure 4. Since the volume between 0 and 5 m is a very large part of the total volume for Lake Simoncouche (~96 %), the horizontal variations of Figure 4 resemble those of Figure 3. For the latitude zones 45-50 °N, 50-55 °N and 55-60 °N, the average increases are 4.8, 5.7 and 6.6 °C, respectively. When expressed in temperature change per decade, these average increases are 0.54, 0.63 and 0.73 °C decade^{-1}. These are large values by comparison with the global mean observed increase in summer surface temperature reported by O'Reilly et al. (2015), i.e. 0.34 °C decade^{-1} between 1985 and 2009. We used the same summer period, i.e. June-July-August.

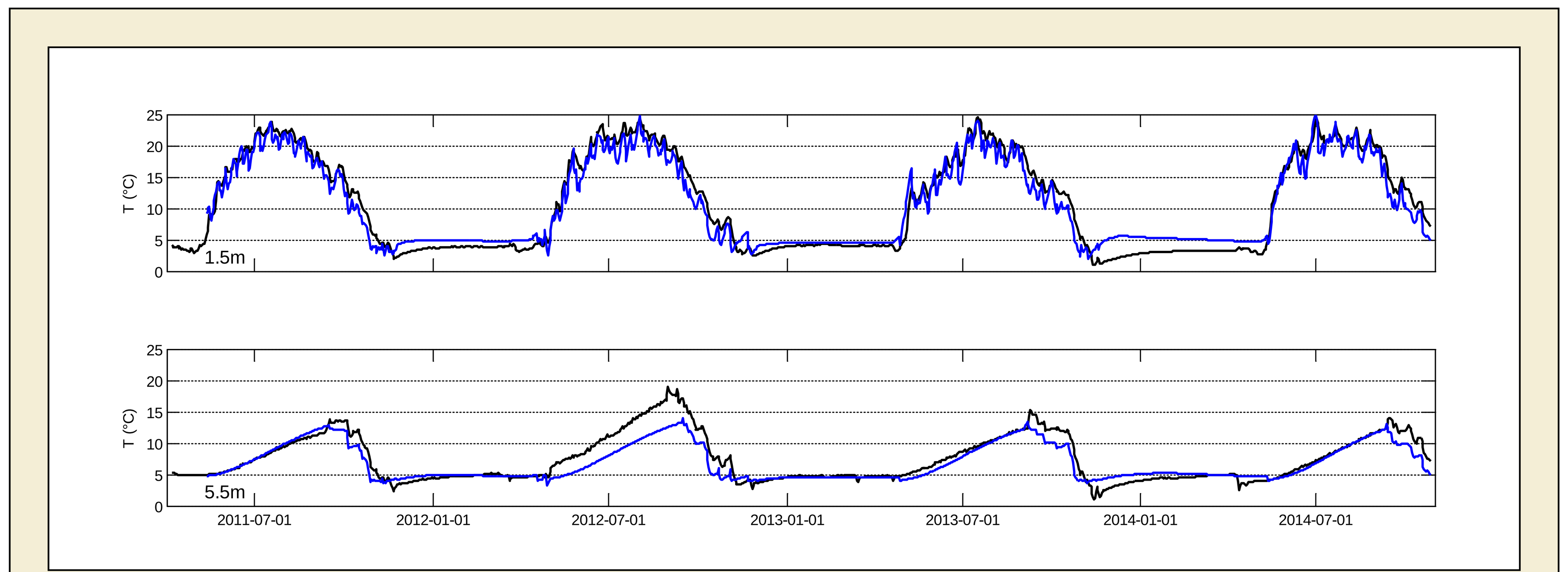

Figure 1. Comparison between observed (black) and modelled (blue) temperatures at 1.5 m and 5.5 m for Lake Simoncouche. The ~3.5-year simulation started on 12 May 2011 using an observed temperature profile for initial conditions. All meteorological time series used to force the model were observations except cloud cover which was reanalysis data. The larger difference at 5.5 m during the second summer can be attributed to the instrument being slightly higher in the water column, the observed time series being a composite of data from three moorings.

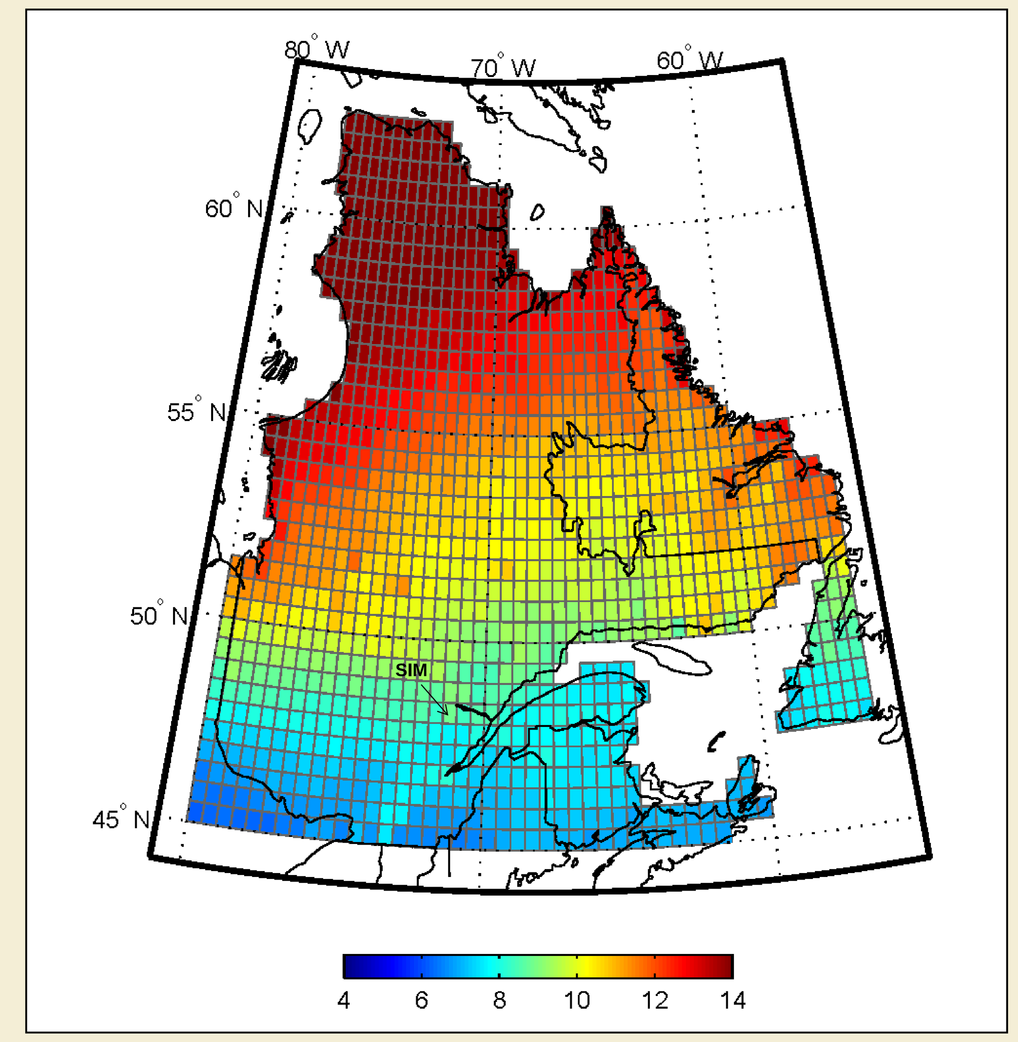

Figure 2. An example of monthly deltas used to derive future 30-year meteorological time series: projected change in air temperature for February between 1981-2010 and 2071-2100 (°C) (scenario RCP 8.5). Deltas were derived for air temperature, atmospheric pressure, global radiation, cloud cover, precipitations and wind speed.

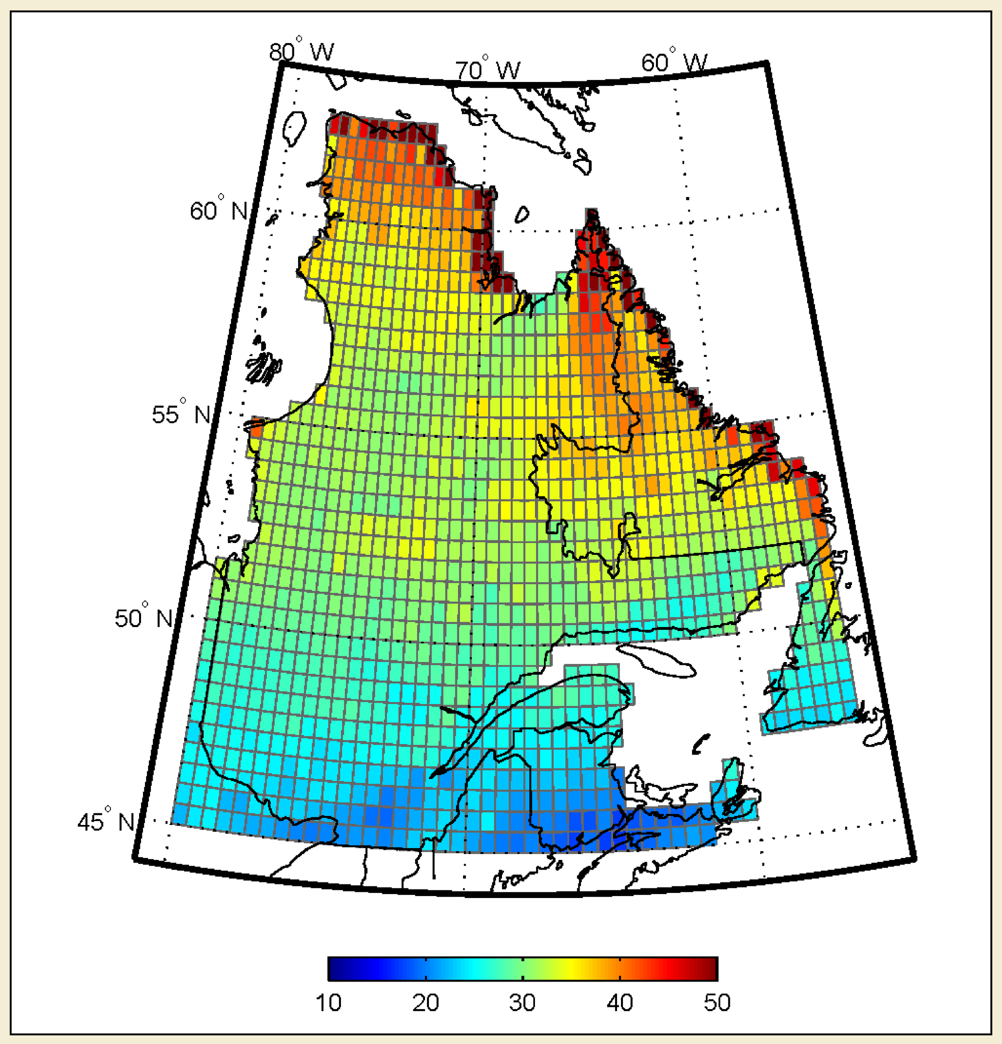

Figure 3. Lake Simoncouche, increase in maximum heat content between 1981-2010 and 2071-2100 (%) (RCP 8.5). The change in heat content gives an indication of the change in temperature integrated over the entire water column.

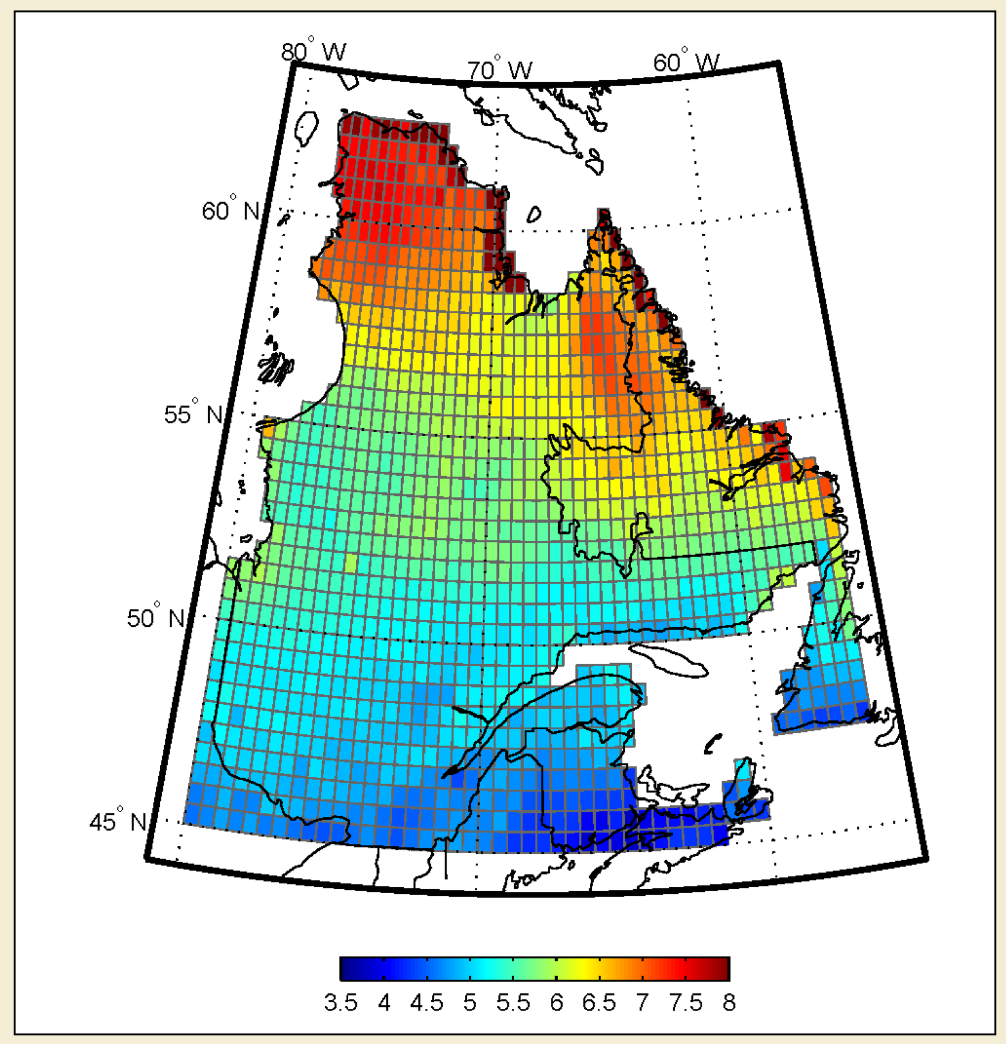

Figure 4. Lake Simoncouche, increase in volume-weighted average temperature (°C) for the depth range 0-5 m in summer (June-July-August) between 1981-2010 and 2071-2100 (scenario RCP 8.5).

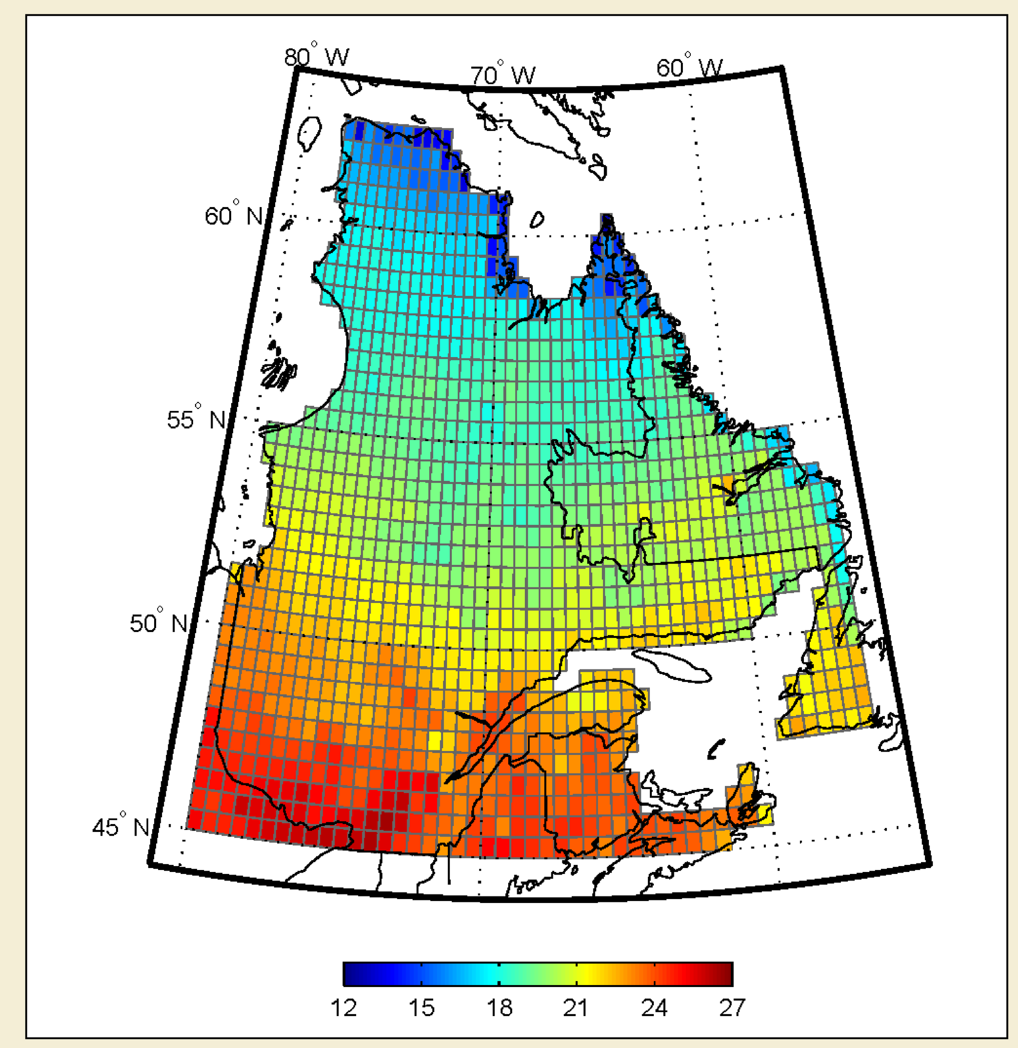

Figure 5. Lake Simoncouche, volume-weighted average projected temperature (°C) for the depth range 0-5 m in summer (June-July-August) for the period 2071-2100 (scenario RCP 8.5).

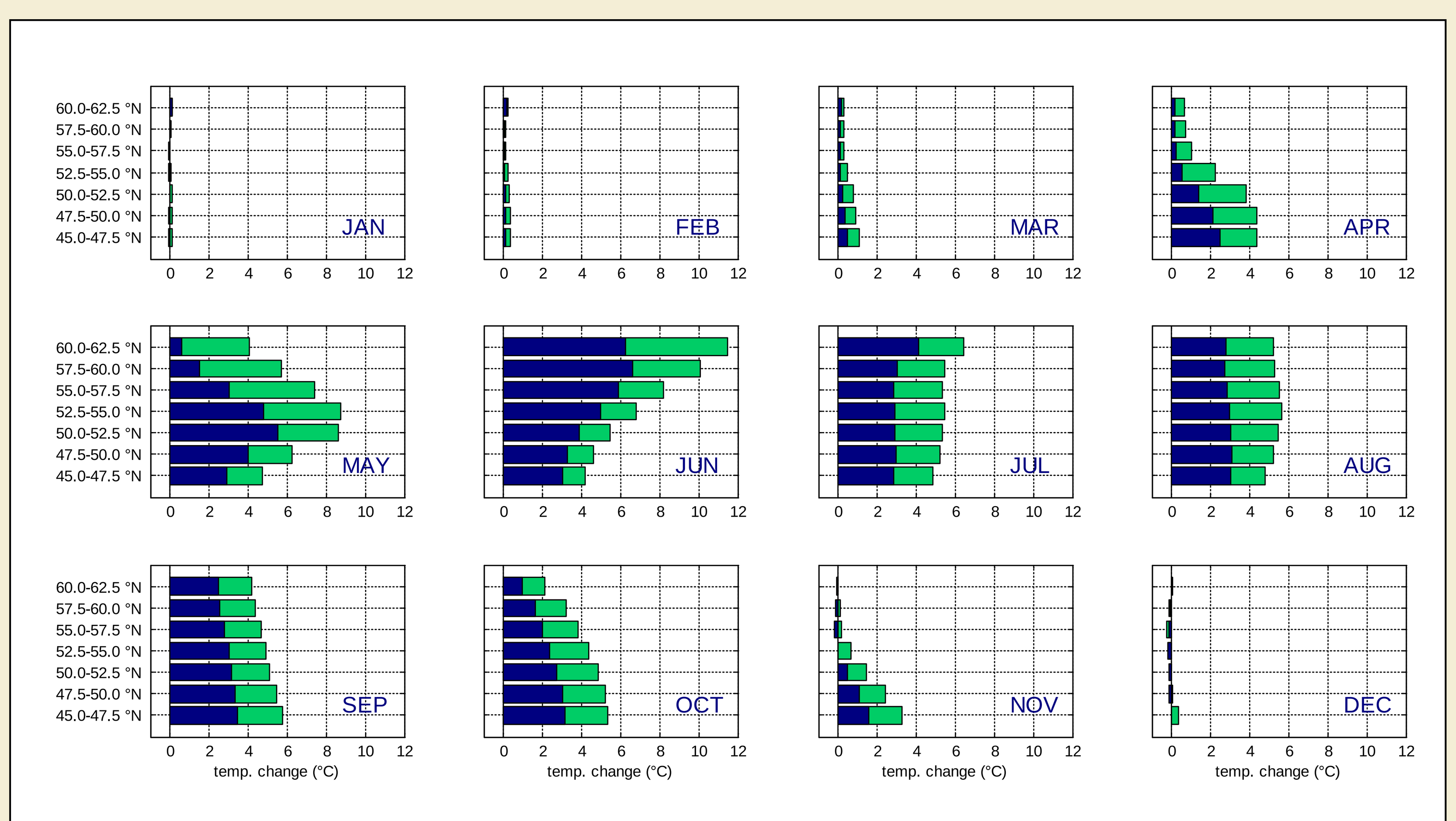

Figure 6. Lake Simoncouche, average projected temperature change (°C) for the depth range 0-5 m between 1981-2010 and 2041-2070 (blue) and between 2041-2070 and 2071-2100 (green) per month and per latitude zone (scenario RCP 8.5). The sum of both periods gives the projected change over 90 years.

Selected results (continued)

The projected volume-weighted average temperatures in summer for the depth range 0-5 m at the horizon 2071-2100 are presented in Figure 5. Although the projected increases in temperature for southern Québec are smaller than those for further north (Figure 3), the results for this sub-region indicate very high summer temperatures, in some cases in excess of 26 °C.

The projected temperature changes for the depth range 0-5 m between 1981-2010 and 2041-2070 and between 2041-2070 and 2071-2100 are presented per month and per latitude zone in Figure 6. The largest increases are at northern latitudes in early summer. At southern latitudes, the larger increases tend to occur later in early autumn.

The MyLake model also simulates the evolution of ice and snow covers and has been used for that purpose in some studies (e.g. Dibike et al., 2011). The projected diminutions in number of days with ice cover and in maximum ice thickness between 1981-2010 and 2041-2070 and 2071-2100 are presented in Figure 7, averaged over latitude zones. The projected tendency is for more important diminutions north of 50 °N. Considering that the first period is 60-year long and the second period is 30-year longs, the results appear to suggest in some cases an acceleration of the diminution throughout the 21st century, e.g. at southern latitudes for both duration of the period with ice cover and maximum ice thickness, and at northern latitudes for maximum ice thickness.

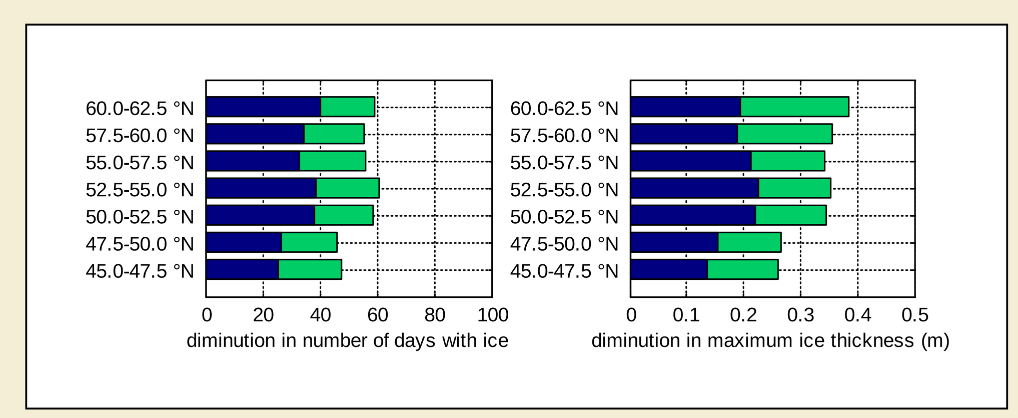

Figure 7. Lake Simoncouche, average projected diminution in number of days with ice cover and in maximum ice thickness (m) between 1981-2010 and 2041-2070 (blue) and between 2041-2100 (green) per latitude zone (scenario RCP 8.5). The sum of both periods gives the projected diminution over 90 years.

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