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The Cryosphere Discussions

Interactive comment on "The fate of lake ice in the North American Arctic" *by* L. C. Brown and C. R. Duguay

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We would like to thank both reviewers for their helpful comments. All typographical changes and text clarifications have been made as recommended (Reviewer #1: comments 8, 9, 13, 14; Reviewer #2: comment 5). Responses to the remaining comments are as follows:

Comments: 1. Abstract: The first half of the abstract is spent presenting background information. I suggest you trim this back and focus more on presenting the significant results of the study e.g. Fig. 12.

More detailed results have now been added to the abstract.

2. p. 1777 line 25 to p. 1778 line 5: The references you cite all relate to changes in the

extent or duration of snow cover and not to changes in the depth or mass of snow on the ground. This is inconsistent with the arguments presented in the beginning of the paragraph. Future projections for changes in snow water equivalent (Räisänen, 2007; Brown and Mote, 2009) suggest a gradient over the Arctic with increases at higher latitudes and decreases along the southern boundary (can also see this in your Fig. 9b). It would be interesting to explore the implications of this gradient in more detail given the sensitivity of the lake ice climate to snow cover.

Sentences added about increasing SWE in the north, and additional references made to the suggested papers.

3. p. 1779 para starting line 9: The terminology here is a bit confusing. The act of gridding climate data does not solve data gaps. I think you need to replace "gridded climate data" with more specific terms like "reanalyses" and "climate model output". I suggest you cut most of the material in this para and just cite examples of other studies that have applied reanalyses and climate models to simulate lake ice.

The term 'gridded climate data' has been removed through the manuscript and replaced by more specific terms as suggested.

4. Section 2.2: There is no mention in the model description how snow is treated. I assume it is a single layer and eqn (1) is applied for the snow layer and for various depth increments (not stated) into the ice. Given the sensitivity of the lake ice processes to the snow layer, there should be some discussion of how well CLIMo represents on-ice snowpack properties such as albedo, density and thermal conductivity. Is melt ponding parameterized in some way? There are some recent papers looking at single layer versus multiple layer treatments of snow cover over ice that would be relevant to this discussion (e.g. Chung et al., 2010).

Melt ponding is not parameterized in CLIMo at this time. A succinct sentence about the snow layer and albedo parameterization has been added. Density is determined from the input climate data, and how well CLIMo simulates the on-ice snow pack depends

on the quality of the input data. A mention of multi-layer snow models is also added, as well as a statement about the ability of CLIMo to simulate on-ice snow packs.

5. Section 2.2: CLIMo includes a mixed layer so water temperatures should be different between the current and future climate simulations. The water column would rapidly stratify in the fall and cut-off this heat source but warmer water temperatures may play a role in delaying the onset of ice cover (e.g. Arp et al., 2010; Kvambekk and Melvold, 2010). There was no mention of this aspect of the model in the paper.

A comment about the ability of using Flake to provide mixed layer changes to CLIMo in the face of changing mixed layers has been added and the text clarified that an assumption was made for constant mixed layers in the future simulations.

6. Section 2.3: the material on the bias correction needs condensing.

This section has been condensed slightly, however as many papers do not provide explanation of how or why a bias correction was done, we feel it important to leave some of the details included.

7. Section 2.4: will snow density values from terrestrial snow courses be applicable to snow on lake ice? I think Chris Derksen has data traversing land and lakes in the Daring Lake area that could answer this question.

While density values from snow on lake ice would be ideal there is not enough of this data available to use on a continent wide basis, so terrestrial snow course densities are used instead. Based on Sturm and Liston (2003) snow on lakes is typically denser than land (e.g. 0.344 g/cm3 on lake ice vs 0.285 g/cm3 on land) which could affect the simulated ice thickness. However, due to the lack of data and varying terrain across the continent no attempt was made to adjust the terrestrial snow densities.

10. Section3.2.1: Since break-up is largely insensitive to snow depth is there a need to show Fig. 4?

Break-up quite sensitive to snow depth, removal of the snow cover in the simulations

delays the average predicted break-up dates by a week. The differences are partially masked by the size of the figure, however when zoomed in, the differences in the northern areas become more evident. Particularly in the perennial ice covered areas, which are much larger in the no snow cover scenarios.

11. Ice cover change figures: the differences due to lake depth seem subtle for the most part (unless these are being masked by the legend used). Do you really need to show all three depth results for all figures? Figure 12 is an exception as there are clear differences between the depths.

Figure 4, 10 (break-up) and 7 (mean maximum thickness) do appear fairly similar at the three depths, however the subtle differences could be of importance to the reader so we feel they should all be included.

12. It was not clear what fraction of the CRCM snow depths you applied to the lakes. The observations in Table 3 show a wide range of values for the ratio SnoLake/SnoLand including zero values. I assume that you used some typical or average value of this ratio to apply to the CRCM output but I could not find this mentioned in the text. In general I found the documentation of the methodology used for handling snow to be rather confusing. I recommend you have a separate section in the methods section summarizing how snow cover is treated in the simulations.

The ratio of snow on ice to snow on land was $\sim$0.6 for the sites where data was available, however the main simulations were run with full snow cover and no snow cover to account for possible variations. A separate section has been added in the methods (section 2.5) to outline clearly how the snow cover is treated in the validation simulations as well as the main pan arctic simulations.

15. In the Summary and Abstract the projected rates of ice cover change for 2050 seem rather modest in comparison to some of the recent observed trends. Is spatially averaging the results over the entire Arctic domain partially responsible for this? I would present the range in projected change as well as the average . . .

Ranges have been added for the thickness (in addition to the break-up, freeze-up and ice cover duration), and also now included in the abstract.

16. It would be useful to mention in the paper how CGCM3 projected changes in Arctic air temperature and precipitation compare to other CMIP3 GCMs. I think there is material on the IPCC website to address this.

A small paragraph has been added outlining how CGCM3 predictions compare to other CMIP3 GCMS, based on information in the IPCC report as well as a figured provided in the supplementary material on the IPCC website:

http://www.ipcc.ch/publications_and_data/ar4/wg1/en/en/chapter10/indiv_maps/html/CGCM
T47_10.8.html

REVIEWER #2

1. From the text it is not clear: Does CLIMo use the lake mask (or land sea mask) of CRCM? 2. 15-40% of the Canadian land area is covered by lakes. Are there lakes in each of the CRCM?

CLIMo is run for hypothetical lakes which may, or may not, be present within a CRCM tile. The varying depths of the simulations are to account for various sizes of lakes that might be present. This has been clarified in the text in a new section (2.5).

3. How does CRCM account for lakes? If there is no lake model included in CRCM, what temperature does it uses for the lake surface temperature? Does CRCM account for fraction of lakes in a grid cell, i.e. tile approach?

CRCM includes a lake model for the large great lakes only. CRCM 4.2 uses the land surface scheme from CLASS which does incorporate a mosaic option for lakes (versus land), however there is no full lake model incorporated as of yet.

4. Maybe a figure showing the lake fraction of the grid cells could be informative?

While the lake fraction would give the reader an idea of the distribution of lakes through-

out the area, there is currently no data set of this nature. The Canadian Centre for Remote Sensing produced a 'Water Fraction of Canada' map, which include wetlands and lakes, however the distribution of lakes within the CRCM tiles is not available.

Interactive comment on The Cryosphere Discuss., 5, 1775, 2011.