

The Relation Between Air Temperature and Freeze-Up/Break-Up Dates on Lakes Across Northern Canada

FRÉDÉRIC LENORMAND¹ AND CLAUDE R. DUGUAY²

EXTENDED ABSTRACT

Several studies have shown that long series of lake ice observations can serve as a proxy climate records, and the monitoring of freeze-up and break-up trends may provide a convenient integrated and seasonally specific index of climatic perturbations. Some authors (e.g. Livingstone, 1997) are of the opinion that historical lake ice records may be a more reliable indicator of past local and regional climatic changes than even air temperature records themselves, since the latter are frequently subject to inhomogeneities and bias resulting in station alterations and observer changes. In particular, inter-annual variations in lake ice cover duration and thickness may allow estimates of local climatic variability and long-term changes in lake ice phenology may provide a robust indication of climatic change. For these reasons, there is a growing interest in examining the utility of lake ice parameters as indicators of climate variability and change at northern latitudes. This study describes how lake ice parameters (freeze-up dates, break-up dates, and ice cover duration) can be affected by climate variability and change over a 24-year period (1963–1987) for 28 sites located near or above treeline in Canada.

A number of lake sites were selected via queries in the Canadian Ice Database (CID) using latitude above 60°N as the main search criterion (Lenormand *et al.*, 2002). The second criterion used is the number of years of ice records, in this case defined as greater than 23 years. This criterion decreased the number of lake sites from 55 to 37. Finally, the third criterion relates to the homogeneity of the data for each site. Only the lake sites with long, continuous, time series were selected. With this last criterion, the number of lake sites passed from 37 to 28 (25 different lakes) for the period ranging from 1963–1964 to 1986–1987. Due to the lack of ice data and the more southern position of treeline in northern Quebec, the selection of lakes in that region was made by choosing lakes at latitudes lower than those chosen in the western Canada.

Recent studies, conducted in Wisconsin, Finland, and for a few lake and river sites with long historical records in the northern hemisphere, have shown that the freeze-up and break-up dates are sensitive indicators of climatic variability and climate change (Palecki and Barry, 1986, Anderson *et al.*, 1996, Magnuson *et al.*, 2000). Figure 1 shows a map of the spatial variations in annual mean near-surface air temperature from 74 meteorological stations for the 24-year period. Spatial interpolation of air temperature was performed with the natural neighbor method with the more sensitive coefficient "advanced" in Vertical MapperTM. Figure 2 shows modeled and observed freeze-up and break-up dates for lake sites in four terrestrial ecozones of Canada. The modeled dates are calculated for the 24-year period with linear regression equations derived from the relation between annual, seasonal and monthly mean temperature and *in situ* freeze-up/break-up dates of the 28 sites. Finally, Figure 3 shows the variations in ice conditions together with the seasonal mean variations of near-surface air temperature over the period 1963–1987.

¹ Meteorological Service of Canada, 4905 Dufferin, Downsview, Ontario M3H 5T4, Canada

² Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska 99775-7320, USA

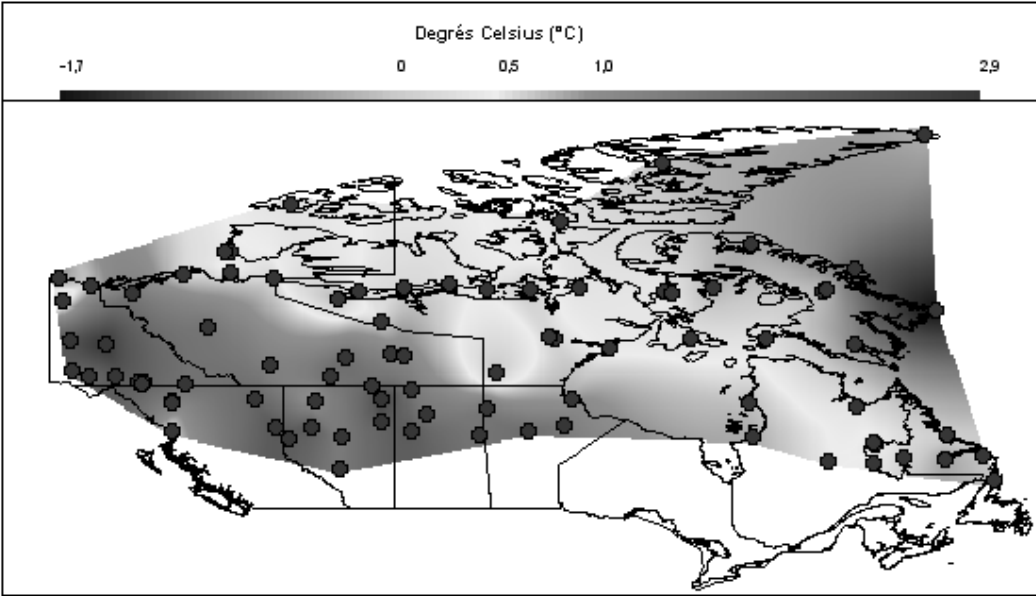


Figure 1. Variations in mean annual near-surface air temperature between 1963 and 1987.

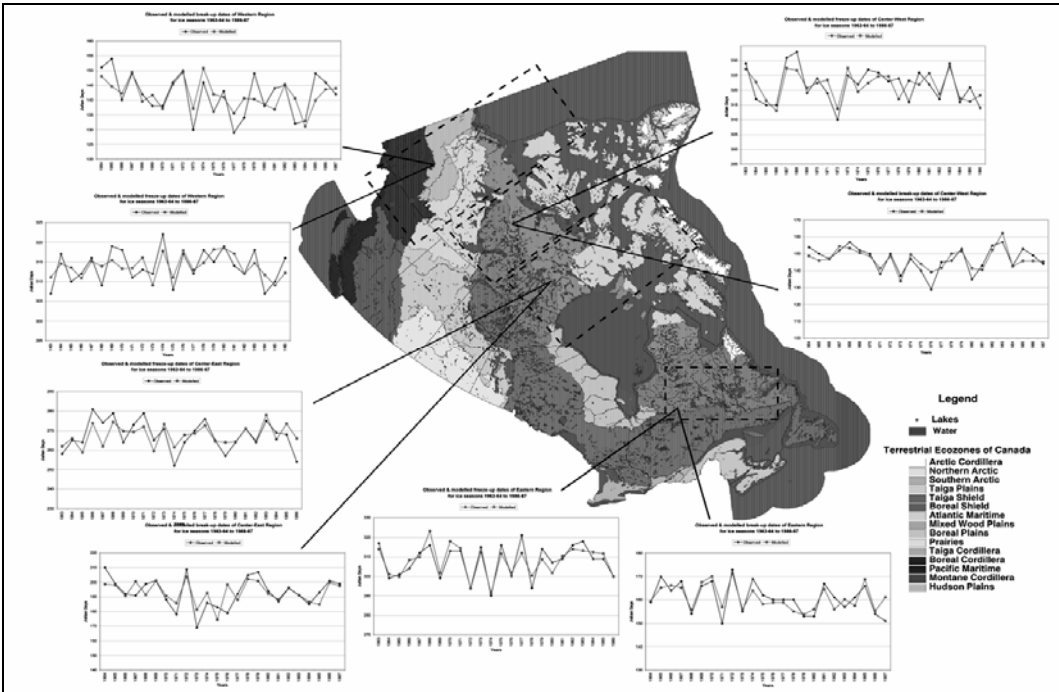


Figure 2. Lake sites, Canadian terrestrial eozones, and modeled freeze-up/break-up dates for four different regions.

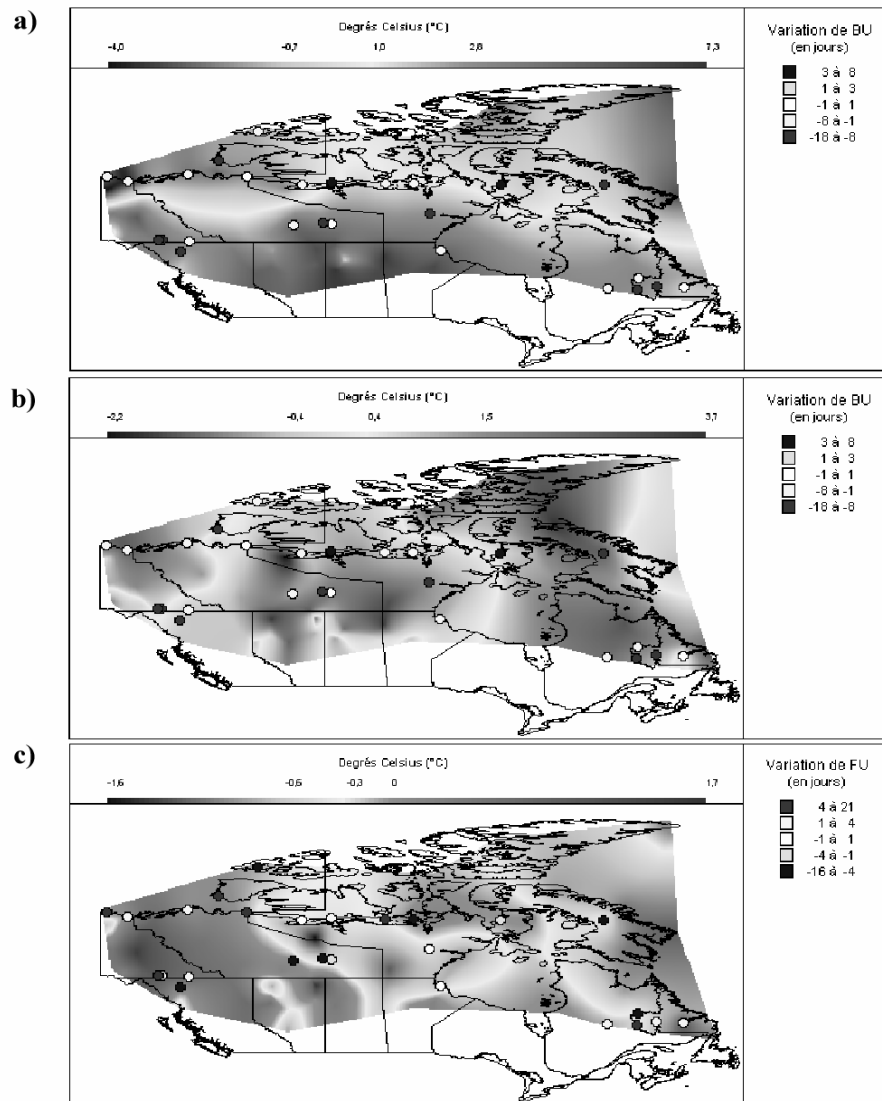


Figure 3. Comparison between variations in ice phenology and seasonal air temperature during the period 1963–1987: a) break-up/spring, b) break-up/summer, and c) freeze-up/autumn.

The main results of this study can be summarized as follow:

- 1) Sites surrounding Great Slave Lake show the same pattern of variations in ice conditions, except for McLeod Bay where no significant statistical relationship was found for break-up dates. Whereas this bay is 714 meters deep, in comparison to 145 meters for the mean depth of GSL, it shows that bathymetry is an important variable influencing ice conditions.
- 2) Modeled dates (Figure 2) are generally representative of the observed dates. One region in particular (Eastern) shows modeled dates in very close agreement with field observations.
- 3) Lake ice phenology changes show a good relation with changes in seasonal air temperature over the period 1963–1987 (Figure 3).

- 4) This research did not permit to find an east-to-west gradient in lake ice conditions as was revealed by variations in mean annual air temperature (Figure 1). However, Table 1 indicates that the Western and Eastern regions, composed mainly of continental lakes, have more significant correlation coefficients for freeze-up while the Center-West and Center-East regions show more significant correlations for break-up.
- 5) Coastal lakes react differently than continental lakes. Table 2 shows that continental lakes are more influenced by surface air temperature than coastal lakes. This difference can be due to the influence of other meteorological and morphological factors (e.g. wind, precipitation, bathymetry).

Table 1. Correlation coefficient (r) and standard error (SE) for freeze-up/break-up dates per region.

Ice Conditions	Western		Center-West		Center-East		Eastern	
	r	S _E	r	S _E	r	S _E	r	S _E
FU	0,65	6,6	0,67	7,6	0,62	7,6	0,77	5,6
BU	-0,62	7,4	-0,7	6,6	-0,67	8,6	-0,68	6

Table 2. Descriptive statistics: comparison between coastal and continental lakes.

Variables	Coastal Sites	Continental Sites
Number of sites (ratio)	13 (46%)	15 (54%)
Significant r (ratio)	21(29%)	52(71%)
Mean r	± 0,63	± 0,68
Mean S _E	8,7	6,8

Keywords: lake ice, freeze-up, break-up, northern Canada

REFERENCES

- Anderson WL, Robertson DM, Magnuson JJ. 1996. Evidence of recent warming and El Niño-related variations in ice break-up of Wisconsin lakes. *Limnology and Oceanography* **41**(5): 815–821.
- Lenormand F, Duguay CR, Gauthier R. 2002. Development of a historical ice database for the study of climate change in Canada. *Hydrological Processes* **16**: 3707–3722.
- Livingstone DM. 1997. Break-up dates of alpine lakes as proxy data for local and regional mean surface air temperatures. *Climatic Change* **37**: 407–439.
- Magnuson JJ, Robertson DM, Benson BJ, Wynne RH, Livingstone DM, Arai T, Assel RA, Barry RG, Card V, Kuusisto E, Granin NG, Prowse TD, Stewart KM, Vuglinski VS. 2000. Historical trends in lake and river ice cover in the Northern Hemisphere. *Science* **289**: 1743–1746.
- Palecki MA, Barry RG. 1986. Freeze-up and break-up of lakes as an index of temperature changes during the transition seasons: A case study for Finland. *Journal of Climate and Applied Meteorology* **25**(7): 893–902.

ACKNOWLEDGEMENTS

This research was made possible with the financial support of the Meteorological Service of Canada (MSC). We are particularly grateful to Ross Brown and Anne Walker for their assistance in obtaining the digital files and paper archives.