Remote Sensing of Environment 113 (2009) 816–834

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

# Variability in ice phenology on Great Bear Lake and Great Slave Lake, Northwest Territories, Canada, from SeaWinds/QuikSCAT: 2000–2006

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ARTICLE INFO

*Article history:*
Received 8 October 2008
Received in revised form 18 December 2008
Accepted 19 December 2008

*Keywords:*
Lake ice
Great Bear Lake
Great Slave Lake
QuikSCAT
Phenology

ABSTRACT

The temporal evolution of the backscatter coefficient, sigma-nought ($\sigma°$) from QuikSCAT was evaluated for monitoring ice phenology on Great Bear Lake (66°N, 121°W) and Great Slave Lake (61°40′N, 114°W), Northwest Territories, Canada. Results indicated that $\sigma°$ from QuikSCAT can be used to detect melt onset, water clear of ice and freeze onset dates on both lakes. An ice phenology algorithm was then developed to assess the spatiotemporal variability on both lakes from QuikSCAT for the period 2000–2006. Results showed that for Great Slave Lake, the average melt onset date occurred on year day (YD) 123, the average water clear of ice date was on YD164, and the average freeze onset date was on YD330. On Great Bear Lake, the average melt onset date occurred on YD139, the average water clear of ice date was YD191, and the average freeze onset date was YD321. Ice cover remained present for at least five weeks longer on Great Bear Lake than on Great Slave Lake and most of the difference can be explained by earlier ice melt on Great Slave Lake. Spatially, on Great Bear Lake, melt onset took place first in the eastern arm, water clear of ice occurred first in southeastern and western arms, and freeze onset appeared first in the northern arm and along the shorelines. On Great Slave Lake, melt onset began first in the central basin and then progressed to the northern and eastern arms later in the season. The central basin of Great Slave Lake cleared earlier than the periphery due to the discharge from the Slave River. Freeze onset on Great Slave Lake occurred first within the east arm, closely followed by the north and west arms, and then finally in the centre of the main basin.


## 1. Introduction

Lake ice phenological events such as the timing of freeze-up and break-up events, and ice cover duration, have been shown to be sensitive indicators of climate variability and change (e.g. Schindler et al., 1990; Robertson et al., 1992; Walsh et al., 1998; Magnuson et al., 2000; Assel et al., 2003; Duguay et al., 2006; Austin & Colman, 2007; Kouraev et al., 2007). It is important to note, however, that there are inter-country and even inter-agency differences in ground-based freeze-up and break-up records. For example, some document the initiation of break-up, while others register the date when the water body becomes completely ice-free. This is an important distinction when examining variability and trends in ice records from different sources, given that the entire break-up process can last for up to four weeks at a single site (Prowse et al., 2007). Freeze-up and break-up are more clearly defined in terms of processes with specific dates identifying key events. Freeze-up defines the period between initial ice formation (i.e. freeze onset) and the establishment of a complete ice cover (i.e. complete freeze over), while break-up defines the period between the onset of snowmelt (i.e. melt onset) and the complete disappearance of the ice (i.e. water clear of ice). These are the definitions and terminology adopted in this paper.

In Canada, over the period 1951 to 2000, trends towards earlier water clear of ice dates have been observed for many lakes during the latter part of the 20th century, but complete freeze over dates have shown few significant trends over the same period (Duguay et al., 2006). The observed changes in Canada's lake ice cover have also been found to be influenced by large-scale atmospheric forcing (Bonsal et al., 2006). Over the last two decades, however, the Canadian ground-based lake ice-observing network has almost totally disappeared. Moreover, one limitation with reported changes in water clear of ice and complete freeze over dates is that they have been based on local observations, generally made along shores and in bays, and are therefore not representative of the entire lake surface. Remote sensing has the potential to re-build part of the lost network in addition to providing more spatially representative phenology information for future studies on the impacts of climate on lakes.

The historical satellite archive from the Advanced Very High Resolution Radiometer (AVHRR) optical sensor has recently been used to assess trends in lake ice phenology over Canadian lakes from 1984 to 2004 (Latifovic & Pouliot, 2007). The problem with optical data is that it suffers from atmospheric interference (e.g. clouds) and polar darkness, which limits ice phenology parameter retrievals during

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doi:10.1016/j.rse.2008.12.007

crucial times (i.e. freeze onset). The microwave region of the electromagnetic spectrum is perhaps more useful for the monitoring and study of lake ice phenological processes because of its all weather/polar darkness imaging capability. Numerous researchers have used ERS-1/2 synthetic aperture radar (SAR) imagery for monitoring ice formation, the thickening of ice cover, and freezing to the bottom, of shallow Arctic and sub-Arctic lakes in Alaska (Jeffries et al., 1994; Morris et al., 1995) and northern Manitoba, Canada (Duguay et al., 1999; Duguay & Lafleur, 2003). Duguay et al. (2002) utilized RADARSAT-1 SAR imagery for monitoring ice growth and decay and related processes of shallow sub-Arctic (tundra and forest) lakes in northern Manitoba, Canada. One of the major limitations of these previous studies is the limited temporal resolution of ERS-1/2 and RADARSAT-1 SAR imagery, thus establishing and subsequently mapping the precise dates of ice phenological changes is difficult. Passive microwave data from the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I) 85 GHz brightness temperature channel has been used to detect spatial phenology changes over Great Slave Lake (GSL), Northwest Territories, Canada (Schertzer et al., 2003). However, the 85 GHz channel is susceptible to considerable atmospheric interference and its spatial resolution is still relatively coarse which can lead to large brightness temperature differences between water and land (Cavalieri et al., 1999).

The SeaWinds scatterometer on board the NASA's QuikSCAT satellite, provides twice-daily observations at moderate spatial resolution (~8–10 km) and previous studies have demonstrated its utility for monitoring phenological processes over various components of the cryosphere (e.g. sea ice, snow, seasonally frozen ground, ice sheets and ice caps) (Howell et al., 2005, 2006, 2008; Wang et al., 2005, 2007, 2008). QuikSCAT observations have yet to be utilized over the northern Canadian large deep lakes (e.g. Great Bear Lake (GBL) and GSL) and could be used as a baseline for long term spatiotemporal phenology estimates to better understand change and variability. There are very few studies on GBL and GSL both of which primarily contribute to the hydrological processes operating in the Mackenzie Basin and we know little about their respective ice phenology spatial distribution.

The goal of this study was to utilize QuikSCAT observations to improve our understanding of phenological processes over GBL and GSL. Three objectives were pursued: i) evaluate the utility of QuikSCAT data for estimating ice phenology parameters over the two northern great lakes; ii) develop an algorithm to map the spatial distribution of ice phenology parameters; and iii) analyze the temporal and spatial variability in ice phenology from 2000 to 2006 over both lakes.

## 2. Study area description

GBL (66°N, 121°W) and GSL (61°40′N, 114°W) are two large northern lakes, with surface areas of $31.3\times10^3$ km$^2$ and $28.6\times10^3$ km$^2$ respectively, located within the Mackenzie River Basin in the Northwest Territories, Canada (Fig. 1). GSL has a mean depth in the main basin of 41 m (maximum depth of 163 m) and receives inflow from several rivers including the Hay and Slave. The eastern arm of GSL is much deeper with a mean depth of 249 m and a maximum depth of 614 m. GBL has a mean depth of 76 m and a maximum depth of 446 m, and flows into the Mackenzie River via the Great Bear River.

The lakes are situated across two physiographic regions, the Interior Plains and the Precambrian Shield (French & Slaymaker, 1993). The western half of GSL and the majority of GBL are situated in the flat-lying Interior Plains which is underlain by thick glacial, fluvial and lacustrine deposits, and is occupied by many wetlands and lakes in parts (Woo et al., 2007a). The eastern portions of both lakes are located in the Precambrian Shield region. This region is comprised of undulating topography with bedrock outcrops forming hills and valleys that contain wetlands and lakes, whereas to the west lies the Western Cordillera which influences the climate of the region (Woo et al., 2007a).

Both GBL and GSL lie within the high latitude continental Mackenzie River Basin. Over the annual cycle, temperatures within the Mackenzie River Basin can range between −50 °C to 30 °C but the mean monthly temperature during the winter typically ranges from

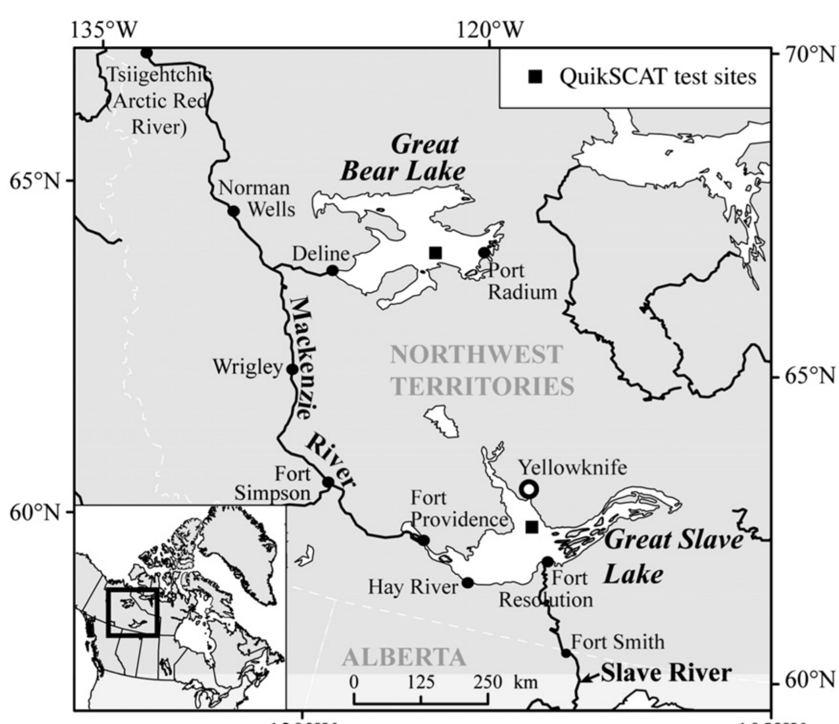


**Fig. 1.** Location of Great Bear Lake and Great Slave Lake within the Mackenzie River Basin in the Northwest Territories, Canada.