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Reconstructing hydrographic change in Petersen Bay, Ellesmere Island, Canada, inferred from SAR imagery

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ABSTRACT

Synthetic aperture radar (SAR) satellite imagery was used to reconstruct the change in limnological conditions adjacent to an Arctic ice shelf by examining the backscatter values of coastal ice in mid-winter scenes. High SAR backscatter values (>−6 dB) suggest that an ice-dammed lake was present adjacent to the south coast of Petersen Bay from 1992 until 2005. Following a large calving event of the adjacent Petersen Ice Shelf (−8.07 km^2) in August 2005, the lake drained through a region where the ice shelf had separated from the coastline. This loss of freshwater and replacement of lake ice with sea ice along the southern coast of Petersen Bay were confirmed from analyses of ice core samples and conductivity–temperature–depth (CTD) profiles. The exception to this pattern was one distinct area where terrestrial streams entered the edge of Petersen Bay and freshwater continued to collect from 2006 to 2008. However, this ephemeral area of freshwater has not reformed since 2009 due to the persistence of open water events in Petersen Bay (observed in optical satellite imagery), which likely facilitated mixing of freshwater with sea water. Based on the continued break-ups of Petersen Ice Shelf and the frequency of open water events, it is unlikely that this ice-dammed lake will reform. The results of this study underscore the utility of SAR for reconstructing past hydrographic conditions in the water column below.

1. Introduction

The Arctic is currently in a period of transformation due to climate change. Since the 1950s, annual pan-Arctic (60–90°N) surface air temperatures have increased by >2 °C, and the period 1999–2008 was the warmest over the past 2000 years (AMAP, 2011; Kaufman et al., 2009). The impacts on the cryosphere of this warming are readily monitored using remote sensing. For example, laser and radar altimetry, along with satellite-derived gravity measurements, have detected mass wasting of ice sheets, ice caps and glaciers (e.g., Gardner et al., 2011; Shepherd et al., 2012). Passive microwave and laser altimeter data have revealed declines in Arctic seasonal and multiyear sea ice (MYI) extent, with concomitant reductions in age and thickness (Comiso, Parkinson, Gersten, & Stock, 2008; Kwok & Rothrock, 2009; Maslanik, Stroeve, Fowler, & Emery, 2011; Stroeve, Holland, Meier, Scambos, & Serreze, 2007). The resulting increase in open water conditions along the northern coast of Ellesmere Island at the northern limit of North America, in combination with warmer temperatures and high winds, has been associated with the dramatic loss of ice shelves (Copland, Mueller, & Weir, 2007; White, Copland, Mueller, & Van Wychen, 2015). The ice shelves in this region comprise thick masses (>20 m) of floating landfast sea ice and glacier ice that formed up to 5500 years before present, and had an estimated area of ~9000 km^2 at the start of the 20th century (England et al., 2008; Jeffries, 1992b; Vincent, Gibson, & Jeffries, 2001). Over the last century they have lost >90% in areal extent, with an additional ~40% loss since 2005 (Mueller, Crawford, Copland, & Van Wychen, 2013; Mueller, Vincent, & Jeffries, 2006).

Studies are limited about the impacts of Arctic ice shelf losses on the surrounding environment, particularly on ice-dammed lakes, a unique type of lake that is structurally dependent on the presence of coastal ice (e.g. Mueller, Vincent, & Jeffries, 2003). An ice-dammed lake forms where a layer of relatively low density freshwater, underlain by higher density marine water, becomes impounded at the head of fiords and embayments behind an ice shelf (Fig. 1; Jungblut, Mueller, & Vincent, In press; Veillette, Mueller, Antoniades, & Vincent, 2008; Veillette et al., 2011). The freshwater that collects behind the dam typically originates from summer meltwater inflow from the surrounding catchment and will accumulate to form a layer that is as deep as the minimum draft of the ice that blocks the fiord or bay (Keys, 1977). A perennial ice cover on the lake surface prevents mixing by winds, thus allowing the freshwater layer to remain permanently stratified over the marine water below (Veillette et al., 2008). There are two types of ice-dammed lakes: shallow ice-dammed lakes that are dammed by relatively thin

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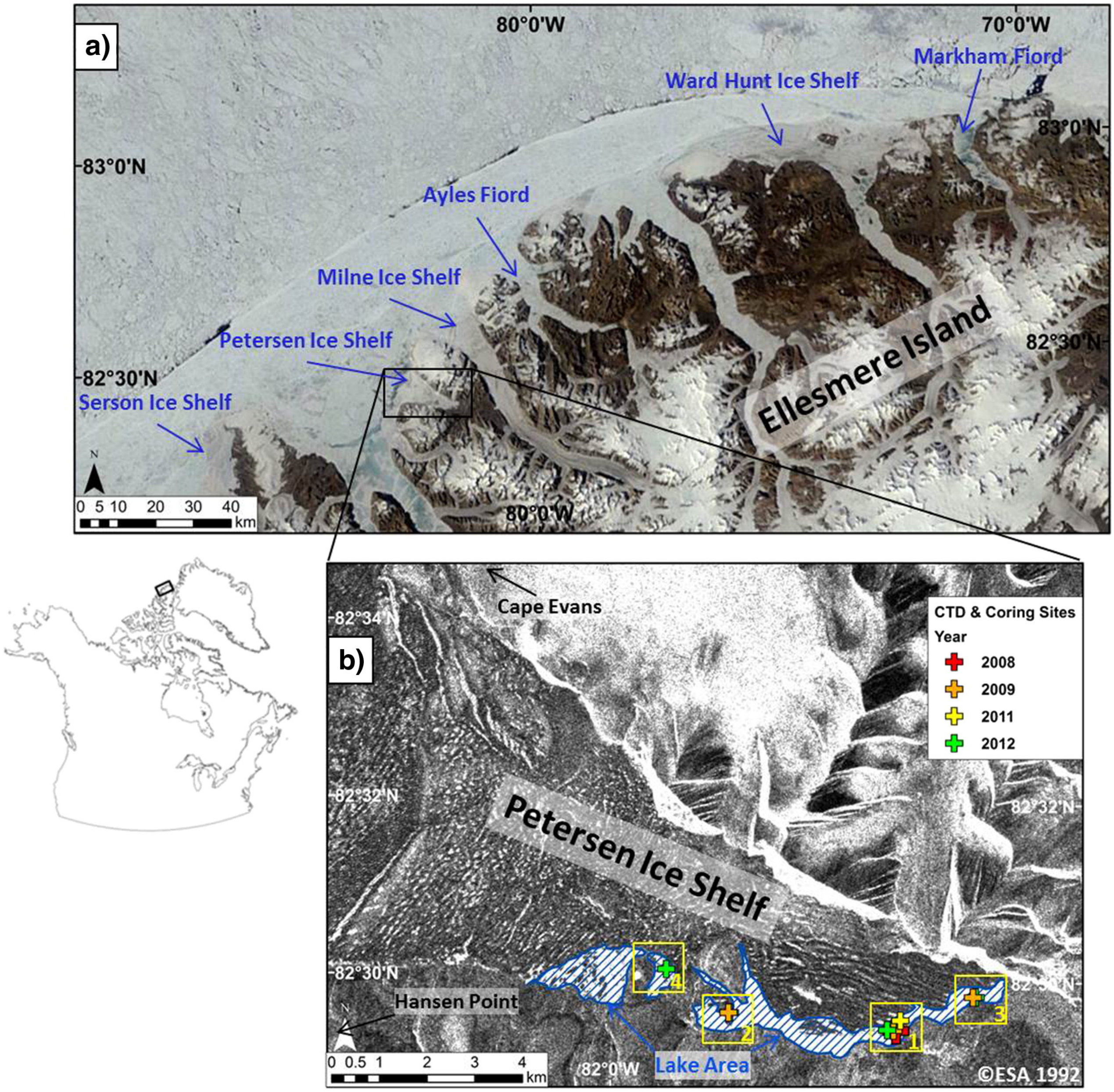

Fig. 1. (a) MODIS image (August 1, 2011) showing the location of the remaining ice shelves as of summer 2011, and inset map showing location of the northern coast of Ellesmere Island; (b) Annotated ERS-1 Standard (VV) scene from March 16, 1992, denoting the location of each CTD (Conductivity–temperature–depth) and ice coring site across the Petersen Bay study area. The striped area represents the extent of the ice-dammed lake in Petersen Bay. Yellow boxes denote the study areas for ice core and CTD measurements. No ice core was extracted in 2008. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

multiyear landfast sea ice (MLSI) and have a freshwater layer <5 m deep (Jeffries, 1992a; Jungblut et al., in press; Veillette et al., 2008), and epishelf lakes, an ice-dammed lake that is blocked by an ice shelf forming a freshwater layer that is thicker than 5 m.

The existence of an ice-dammed lake is strongly dependent upon the thickness and structure of its adjacent ice dam, meaning that changes in the dam thickness can result in a thinning of the freshwater layer. If the structural integrity of an ice dam is compromised (e.g., due to fracturing or calving), the lake can be lost entirely. For example, the epishelf lake in Disraeli Fiord drained away completely when the Ward Hunt Ice Shelf fractured in the early 2000s (Mueller et al., 2003). Leading up to this drainage event, the Ward Hunt Ice Shelf had thinned by 13 m (27%) between 1967 and 1999 (Vincent et al., 2001). Between 2000 and 2002 vertical fracturing occurred all the way through the ice shelf, providing a conduit through which the freshwater drained (Mueller et al., 2003). As a result of this drainage event, both the epishelf lake and the unique biota found within it were lost.

Recent studies have highlighted the importance of ice-dammed lakes as unique habitats for microbial ecosystems due to their vertical segregation between layers of fresh, brackish and marine water (Veillette et al., 2011). For example, the Milne Fiord epishelf lake provides a habitat for diverse microbial communities of Eukarya, Eubacteria, Archaea, and viruses, and epishelf lakes in both the Arctic and Antarctic also offer a unique habitat for fresh and brackish water species of zooplankton (Laybourne-Parry, Quayle, Henshaw, Ruddell, & Marchants, 2001; Van Hove, Swadling, Gibson, Belzile, & Vincent, 2001; Veillette et al., 2011).

Ice-dammed lakes were first characterized by measuring salinity throughout the water column to detect the marked change in water properties with depth (Crary, 1960; Heywood, 1977; Keys, 1977). Due