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Seasonal evolution of supra-glacial lakes on the Greenland Ice Sheet

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Abstract

A survey of supra-glacial lakes on the western margin of the Greenland Ice Sheet reveals a seasonally-driven hydrological system, culminating in widespread lake drainage in late summer. We used satellite imagery to study the evolution of 292 lakes across two sites totalling 22 000 km^2 in area. During 2001, the lakes combined area increased to 75±5 km^2 by the beginning of July. Over the following 25 days, an area totalling 36±3.5 km^2 drained from 216 lakes. At one study site, we used meteorological data and a positive degree day model to calculate the volume of water generated by melting in the lake catchments. Based on this estimate, the mean depth of filling lakes surveyed rose from 1.5±0.7 m on 7th July to 3.9±1.1 m on 1st August, in agreement with a value for one lake of 4.4±0.9 m we have derived from airborne altimetry. During this 25 day period, we estimate that 38±18×10^7 m^3 of water drained from the surface at this site, and that there was an average water flux of 1.3±0.3 m^3 s^{-1} passing through each lake that drained completely.

Keywords: Greenland Ice Sheet; supra-glacial lakes; ice melting; remote sensing; mass balance

1. Introduction

The Greenland Ice Sheet is losing mass near its margin through a combination of increased surface melting and glacier discharge (Krabill et al., 1999; Shepherd and Wingham, 2007). With glacier discharge currently accounting for roughly two-thirds of this mass loss (Rignot and Kanagaratnam, 2006), it is essential that the mechanisms controlling fluctuations in ice flow are incorporated into models of the Greenland Ice Sheet's current and future mass balance (Alley et al., 2005a). This would help to improve the accuracy of predictions of the response of the Greenland Ice Sheet to projected changes in climate (Church and Gregory, 2001). Our present understanding is complicated by uncertainties surrounding key processes, such as the sensitivity of glaciers to changes in basal lubrication resulting from, for instance, the penetration of supra-glacial meltwater to the ice sheet bed. Observations (Zwally et al., 2002) near the equilibrium line of western Greenland (~50 km inland) have identified a correlation between surface melting and seasonal ice sheet acceleration, and it is suggested that melting induces acceleration via enhanced basal

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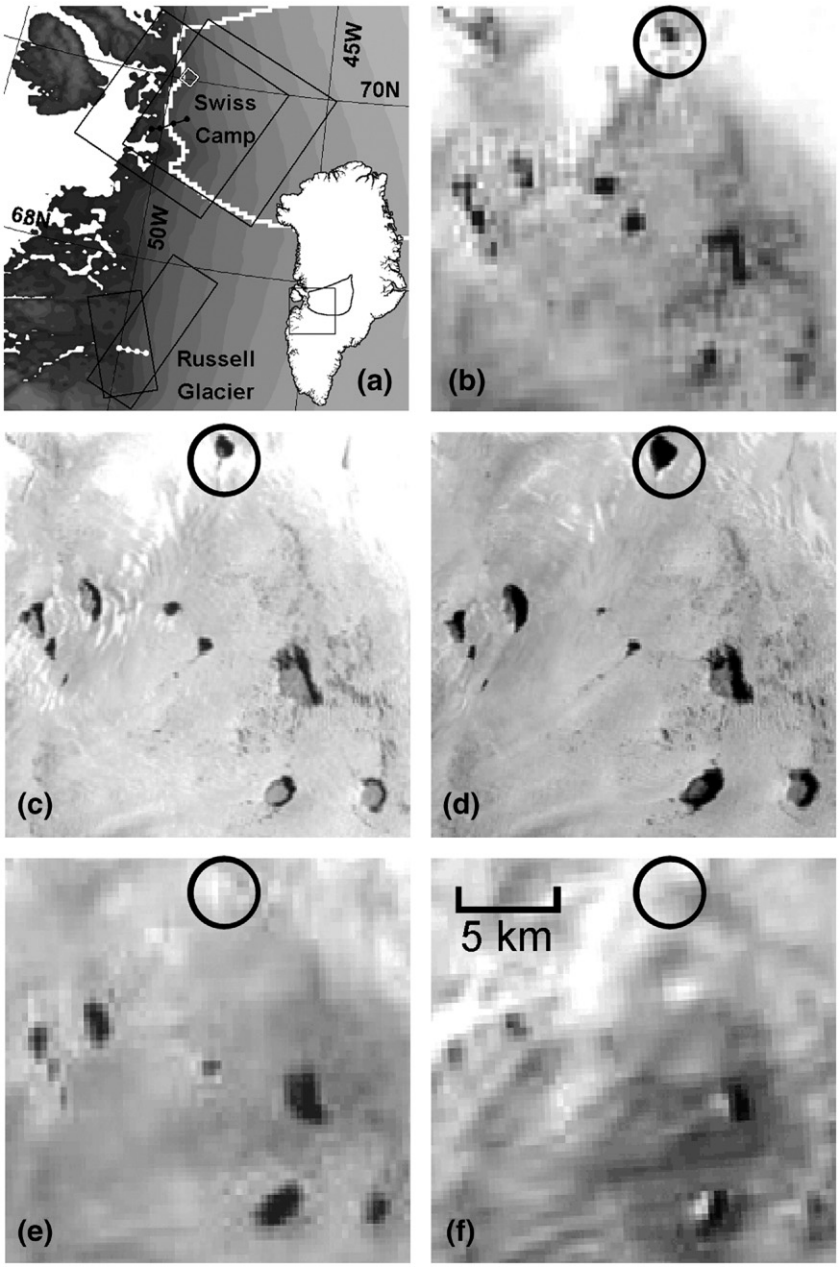

Fig. 1. Time series of lake evolution, Swiss Camp, 2001, ~1100 m. (a) Study areas; greyscale shows surface elevation contoured at 250 m intervals, with the black boxes indicating satellite image coverage and the white box denoting the lake site shown in Landsat images (b) to (f). The white boundary on the greyscale image and the black polygon on the outline map indicate the runoff catchment, and the dotted lines show the locations of ground meteorological stations used in this study; (b) 30th June; (c) 7th July; (d) 1st August; (e) 8th August; (f) 18th September. The circled lake (area of 0.69 km^2 in (d)) illustrates early season lake growth and then the subsequent drainage between 1st and 8th August.

lubrication. Were such a direct coupling to similarly affect faster ice downstream, it could provide a mechanism for the rapid dynamic response of the Greenland Ice Sheet to climate warming.

During summer, melting of snow and ice causes supra-glacial lakes up to several square kilometers in size to develop near the margin of the Greenland Ice Sheet (Echelmeyer et al., 1991; Nienow and Hubbard, 2005). During the melt-season, water has been observed to drain rapidly from similar lakes on polythermal glaciers on Ellesmere Island and Svalbard (Liestøl et al., 1980; Boon and Sharp, 2003). The downward-