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Invited review

Glacial geological studies of surge-type glaciers in Iceland — Research status and future challenges

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ABSTRACT

Surging glaciers are potential analogues for land-terminating palaeo-ice streams and surging ice sheet lobes, and research on surge-type glaciers is important for understanding the causal mechanisms of modern and past ice sheet instabilities. The geomorphic signatures left by the Icelandic surge-type glaciers vary and range from glaciotectonic end moraines formed by folding and thrusting, crevasse-squeeze ridges, concertina eskers, drumlins and fluted forefields, to extensive dead-ice fields and even drift sheets where fast ice-flow indicators are largely missing. We outline some outstanding research questions and review case studies from the surge-type outlets of Brúarjökull, Eyjabakkajökull and Tungnaárjökull (Vatnajökull ice cap), Múlajökull and Sátujökull (Hofsjökull ice cap), Hagafellsjökull and Suðurjökull (Langjökull ice cap), Kaldalónsjökull, Leirufjarðarjökull and Reykjarfjarðarjökull (Drangajökull ice cap), as well as the surge-type cirque glaciers in northern Iceland. We review the current understanding of how rapid ice flow is sustained throughout the surge, the processes that control the development of the surge-type glacier landsystem and the geological evidence of surges found in sediments and landforms. We also examine if it is possible to reconstruct past surge flow rates from glacial landforms and sediments and scale-up present-day surge processes, landforms and landsystems as modern analogues to past ice streams. Finally, we also examine if there is a climate/mass-balance control on surge initiation, duration and frequency.

Contents

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1. Introduction

A basic definition of a surge-type glacier identifies it as an outlet glacier that periodically has major fluctuations in velocity over timescales that range from a few years to several decades or centuries (Benn and Evans, 2010). Surge-type glaciers experience distinctive changes in geometry and activity over a surge cycle, where the phase of rapid motion lasting a few months to several years and typically results in rapid frontal advance is described as the surge or active phase, and the period of slow flow and/or stagnation for tens to hundreds of years between surges is described as the quiescent phase (Kamb et al., 1985; Raymond, 1987; Harrison and Post, 2003). It has been estimated that less than 1% of Earth's glaciers surge (Jiskoot et al., 1998), and they have been shown to be unevenly distributed around the world's glacierized regions and cluster in certain areas, notably Alaska (Kamb et al., 1985), Arctic Canada (Copland et al., 2003), Greenland (Murray et al., 2002), Iceland (Björnsson et al., 2003), Svalbard (Dowdeswell et al., 1991; Hagen et al., 1993), Novaya Zemlya (Grant et al., 2009), as well as in the Caucasus, Karakoram, Pamir and Tien Shan mountain ranges (Hewitt, 2007; Benn and Evans, 2010; Quincey et al., 2011). This clustering implies that certain environmental factors control the location of surge-type glaciers, but despite a number of studies that have investigated the possible constraints at a regional scale the reasons for this remain poorly understood (Meier and Post, 1969; Clarke et al., 1986; Clarke, 1991; Hamilton and Dowdeswell, 1996; Jiskoot et al., 1998, 2000; Murray et al., 2003) and as yet no unifying theory to explain the surge mechanism exists (Rea and Evans, 2011). While both temperate and polythermal glaciers exhibit surging behaviour, it has been suggested the highest densities of surge-type glaciers occur in a relatively narrow climatic band bounded by mean annual temperatures of ca. 0 to −10 °C and mean annual precipitation of ca. 200–2000 mm (Sevestre and Benn, 2015). With its maritime cold-temperate to low-arctic climate and numerous temperate glaciers, Iceland largely lies within this climatic band.

All major ice caps in Iceland have surge-type outlet glaciers, and glaciological studies and historical records have revealed at least 26 surge-type outlet glaciers in Iceland (Figs. 1 and 2) (Björnsson, 1998; Björnsson et al., 2003; Björnsson and Pálsson, 2008; Thorarinsson, 1964a, 1969). Glacial geological studies have confirmed at least 2 additional surge-type glaciers (Evans, 2011; Larsen et al., 2015). Over 80 surge advances have been recorded, ranging from tens of metres up to 10 km, and systematic observations over the last several decades have allowed for a detailed description of several surges (Björnsson, 1998, 2009; Björnsson et al., 2003).

Combining the historical records of ice-front variations and glaciological field research, Björnsson et al. (2003) and Björnsson and Pálsson (2008) summarized the geographic distribution of surge-type glaciers, their subglacial topography, the frequency and duration of surges, changes in glacier surface geometry during the surge cycle, and measured velocity changes compared to calculated balance velocities. They also recorded the indicators of surge onset and described changes in ice, meltwater and suspended sediment fluxes during a surge. They show that surge-type glaciers in Iceland are characterized by gently sloping surfaces and that they move too slowly to remain in balance given their accumulation rate, and that surge frequency was neither regular nor clearly related to glacier size or mass balance. Aðalgeirsdóttir et al. (2005) found that the mass transport during surges of Vatnajökull outlets could be up to 25% of the total ice flux of individual glaciers, and that this could affect the location of the ice divides, the flow field and the size and shape of the ice cap. Fischer et al. (2003) suggested that a surge cycle on Sylgjujökull and Dyngjujökull, outlets of the Vatnajökull ice cap (Fig. 1), spans several years, characterized by a progressive acceleration in motion over an extended area in the beginning, and more pronounced velocity changes during the active surge phase lasting 1–2 years. They further suggested that the most active surge phase lasted for about one year for these glaciers.

Surge-type glaciers are of great interest in glaciology because they can shed light on dynamic instabilities and threshold behaviour in glacier systems. Glaciological research in Iceland in general has focused on glacier distribution as an effect of climatic and topographical conditions, glacio-meteorology, glacier geometry (including extensive mapping of subglacial topography), as well as glacier mass balance, glacio-hydrology, jökulhlaups and modelling glacier responses to climate change, whereas research on surge-type glaciers has focused on dynamic behaviour of the glacier during their most active surge phase, surge periodicity and meltwater production associated with surges (Aðalgeirsdóttir et al., 2005, 2006, 2011; Björnsson, 1982, 1998, 2009; Björnsson and Pálsson, 2008; Björnsson et al., 2003; Flowers et al., 2003; Guðmundsson et al., 2011; Magnússon et al., 2005; Marshall et al., 2005; Pálsson et al., 1991, 2012).

Glacial geological studies of surge-type glaciers in Iceland have typically had a different focus from the glaciological research (e.g. Sharp,

Fig. 1. Surge-type glaciers in Iceland. Glaciers marked with * are discussed in the text, and poorly known surges are indicated by grey arrows. Modified after Björnsson et al. (2003) and Björnsson and Pálsson (2008), and updated according to literature discussed in the text.