Glaciology

Glacial Surges

Group 7
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Loretta Visintin, Maud Laurin, Monika Dragosics, Sam Tizzard, Thaddäus Tiedje

Figure 1: Svalbard surging glacier (D. Benn)

1. Overview

1.1 What is a surge?

Glacier surges are cyclic phenomena which are not directly triggered by external events, but instead are caused by repetitive variations that occur at the bed of the glacier (Sharp 1988). A surging glacier can be defined as a glacier that periodically has a much faster flow rate than normal (Benn and Evans 2010).

1.2 Surge cycles

Surge cycles are periods of time in which a glacier goes through a phase of slow flowing ice and a phase of rapid flowing ice. Active phase is much shorter than quiescent phase.
Quiescent phase: longer duration, slower ice flow, build up of ice at reservoir near top of the glacier

SURGE IS TRIGGERED...

Active Phase: much faster duration, much more rapid ice flow, ice from reservoir moved down glacier often causing the snout of the glacier to advance

2. Distribution of surging glaciers

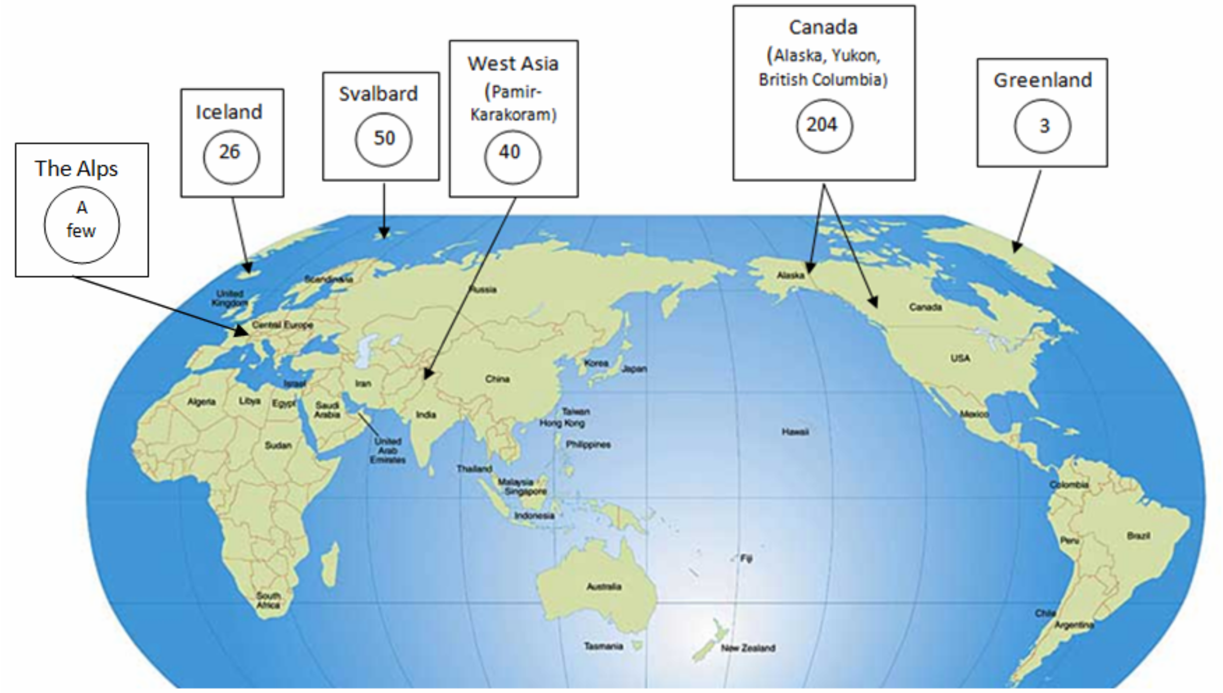

Figure 2: Distribution of surging glaciers (Cuffey and Patterson 2010).

This summary suggests that surging glaciers are present in tectonically active mountain ranges and/or geological provinces with weak bedrock (Cuffey and Patterson 2010).

3. Temperate Glacier Surges

Temperate glaciers are mainly at a constant melting point except from the top few metres of ice, which are subject to seasonal changes. Temperate glacial surges are surges that occur quickly with a short duration (compared to polythermal). This means lots of melt water which could explain the triggering and propulsion of the surge (Benn and Evans 2010).

4. Polythermal Glacier Surges

Surges occur in a very similar way to temperate glaciers when there is a temperate bed with only parts near the surface of the ice around freezing point.

Surges occur quite slowly with a longer duration than temperate glaciers when there is a frozen bed. The difference in-front of the surge (frozen bed) and behind the surge (temperate bed) causes the warm ice to force the colder ice forward (Benn and Evans 2010).

5. Surge mechanism

5.1 Hydrological switch model

The hydrological switch model attributes temperate glacier surge to change in basal hydrology.

This model was developed to explain the related change in sliding speed and basal hydrology observed during the 1982-83 surge of Variegated glacier. Surge initiation and termination occur in response to a switch in basal drainage configuration from an efficient conduit system to an inefficient linked cavity system, and back again (Benn and Evans, 2010).

The efficient conduit system corresponds to a subglacial drainage system where water is conducted through tunnels that have been incised upward into the ice, forming a river-like system of widely spaced tributary branches. These join down glacier to form a relatively small number of outlet rivers, which emerge from the glacier snout. This channeled water system underlies the glacier during the quiescent phase (Björnson, 1998).

The inefficient conduit system corresponds to a subglacial drainage system where water is dispersed across the bed through a distributed network of water filled cavities interconnected by narrow passages called orifices. The water filled cavities form at the lee side of bedrock bumps where the ice pressure normal to the bed is at a minimum. Discharge through the system is controlled by the throttling action of the orifices. Thus, high pressure is required to drive water through such a drainage system, lubricating the bed and facilitating sliding over a large area. This linked cavity system underlies a glacier over a surge episode (Björnson, 1998).

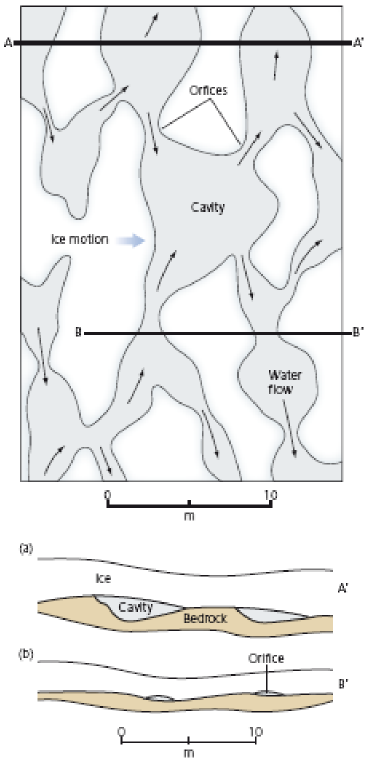

Figure 3: linked cavity network (Benn and Evans 2010).

5.2 The thermal switch model

The thermal switch model was intruduced by Murray et al. (2000) and observed on Bakaninbreen in Svalbard. The thermal switch model explains surges of polythermal glaciers in terms of changes in basal thermal regime.

The idea of a thermal switch mechanism for glacier surging has recently been developed by Murray et al. (2000) and Fowler et al. (2001). This model suggests that surge cycles on polythermal glaciers occur in response to switches between frozen and unfrozen conditions at the bed. During the quiescent period, the glacier is cold-based and slow moving.

Because of the build-up of ice in the reservoir area, the driving stress is increased, which leads to higher ice creep rates. This generates heat and initiates a positive feedback between accelerated ice motion and strain heating. Parts of the bed can be raised up to the pressure melting point, and energy of glacier motion is used to produce meltwater. Cold ice and permafrost located downglacier may prevent this water from escaping. Therefore the basal water pressure is rising and leads to reduced basal drag and faster sliding. Surge propagation occurs because of stress transfer from the surging area (where basal drag is small) to the surrounding ice (where basal drag is high). Surge termination occurs when subglacial water is able to dissipate. This can happen either through the bed or via thrust faults extending from the bed to the surface. (Benn and Evans 2010)

6. How to measure a surge?

Measuring the surge of the Variegated Glacier, Alaska, 1982-83.

One of the most intensely studied glaciers in the world; the Variegated Glacier, was the site of a field study that spanned from 1971 to 1986 inclusively. An array of techniques were employed to measure changes in ice velocity, elevation, basal water pressure and hydrology among others. Ice velocity during a surge can be measured by such means as stakes in the ice relative to fixed bedrock positions and GPS. Aerial photographs and more recently, satellite imagery, have also been employed to plot the movement and varying elevation levels of surging glaciers (Eisen et al. 2001, 2005; Kamb et al. 1985).

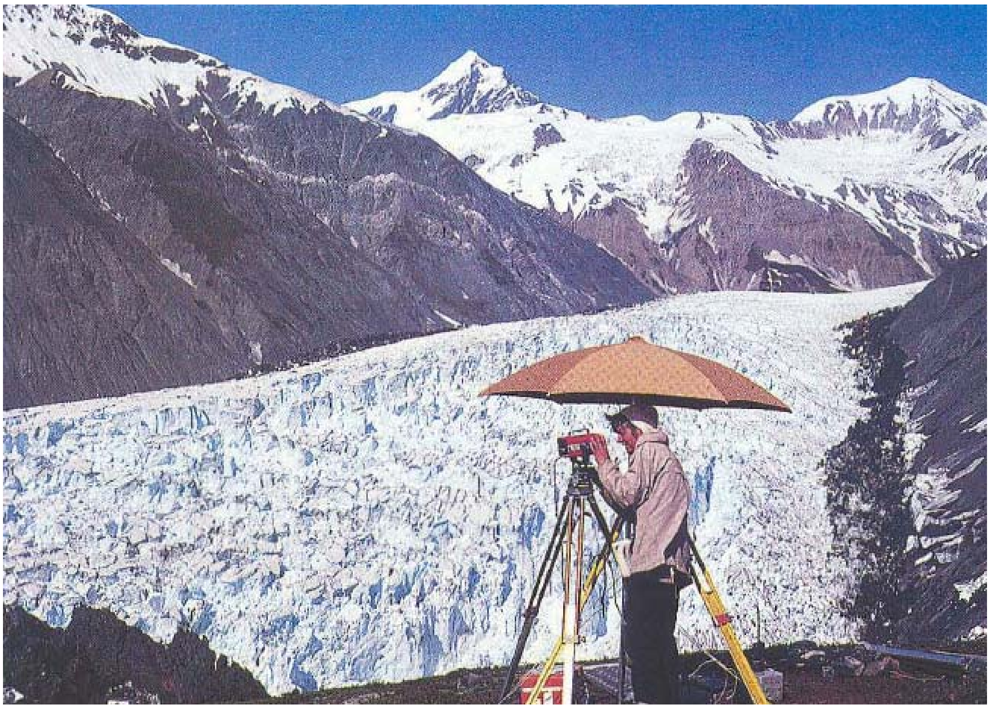

Figure 4: Field measurements at Variegated Glacier, Alaska, 1983. Dietrich (1984)

During the 1982-83 surge at Variegated Glacier, techniques such as using borehole inclinometry (to assess the spatial configuration of the drill hole) were pioneered to measure the rate of basal sliding in comparison to internal deformation. This method revealed the important role that basal sliding plays in glacial surges, as data revealed basal sliding accounted for approximately 95% of movement during surges (Kamb et al. 1985).

Another method pioneered at the Variegated Glacier used boreholes and pressure transducers to track the flucuations in basal water pressure. These measurements revealed that water pressure was unusually high during a surge and dropped dramatically at surge termination, indicating that basal hydrology and water pressure levels are linked to surges, and supported the theory that high water pressure allows glaciers to "float" over its bed during a surge (Kamb et al. 1985).

7. Key studies

7.1 Iceland

Iceland is a glaciated country. Approximately 11 % of Iceland's total land area is covered by glaciers taking up roughly 100.000 km2. The major glaciers are Hofsjökull, Langjökull, Mýrdalsjökull, Drangajökull and the largest ice cap is Vatnajökull. Altogether 26 surge-type glaciers ranging in size from 0.5 to 1500 km2 have been identified in Iceland. Study of geographic distribution shows the special environment where glaciers are located, which does not affect the glacial surges. Surge intervals vary between glaciers from several years up to a century. Several glaciers demonstrate a regular surge periodicity, but most of them do not. In the example provided we will see that surges have a marked impact on the geometry of the ice cap and they also play an important role in the mass flux through the outlet glaciers. Moreover, measurements of glacier surface velocity emphasize the development and propagation of a surface. Another important consequence of a surge is that surges have an impact on the dynamics and hydrology of

Figure 5: Brúarjökull surge 1964 (S. Thorarinsson, 1964)

Iceland's temperate ice caps. This causes an alteration of the overall geometry of the ice caps and perturbs ice and water divides. (Björnsson 2003)

7.2 Alaska

The Alaskan type surges have a rather sudden onset, extremely high maximum ice flow rate (tens of meters per day) and a sudden termination often with a discharge of stored water. These surges are thought to be controlled by the hydrological switch model.

1982-83 surge of Variegated glacier, on the coastal side of the St Elias Mountains is the benchmark against which all other temperate surging glacier are compared.

The glacier surged in two phases, the first beginning early in 1982 and terminating in July of that year, and the second beginning in the winter of 1982-83 and lasting until early summer. Each phase took the form of a wave of enhanced velocities propagating downglacier, the leading edge of which was a dramatic ice bulge (Benn and Evans, 2010).

Dye tracing gave evidence for the nature of the basal water drainage system revealing the existence of a hydrological switch model. The surge termination occurred rapidly over a few hours on 4th July 1983 and was marked by an outburst flood of turbid water, an abrupt drop in the pressure in the basal water system and a drop in the glacier surface thought to be the result of the collapse of basal cavities and the formation of an efficient tunnel drainage system (Benn and Evans, 2010).

Similar surges termination and the pattern of cold season initiation and summer termination applies to most other Alaskan surging glaciers. For instance the 1987-88 surge of West Fork Glacier began in late August (after the melt season in Alaska) and terminated the following July. The Bering Glacier surge event in 1993-95 showed this pattern too and its termination coincided also with a massive outburst flood (Benn and Evans, 2010).

7.3 Svalbard

Svalbard is one cluster where surging glaciers occur. It is estimated that the percentage of surge-type glaciers are 13%, while others estimate the percentage to be 90%. Both estimates are markedly higher than the global average of <1%. In Svalbard, bedrock geology has been shown to be one important control as well. Most of Svalbards glaciers are polythermal (Benn and Evans 2010).

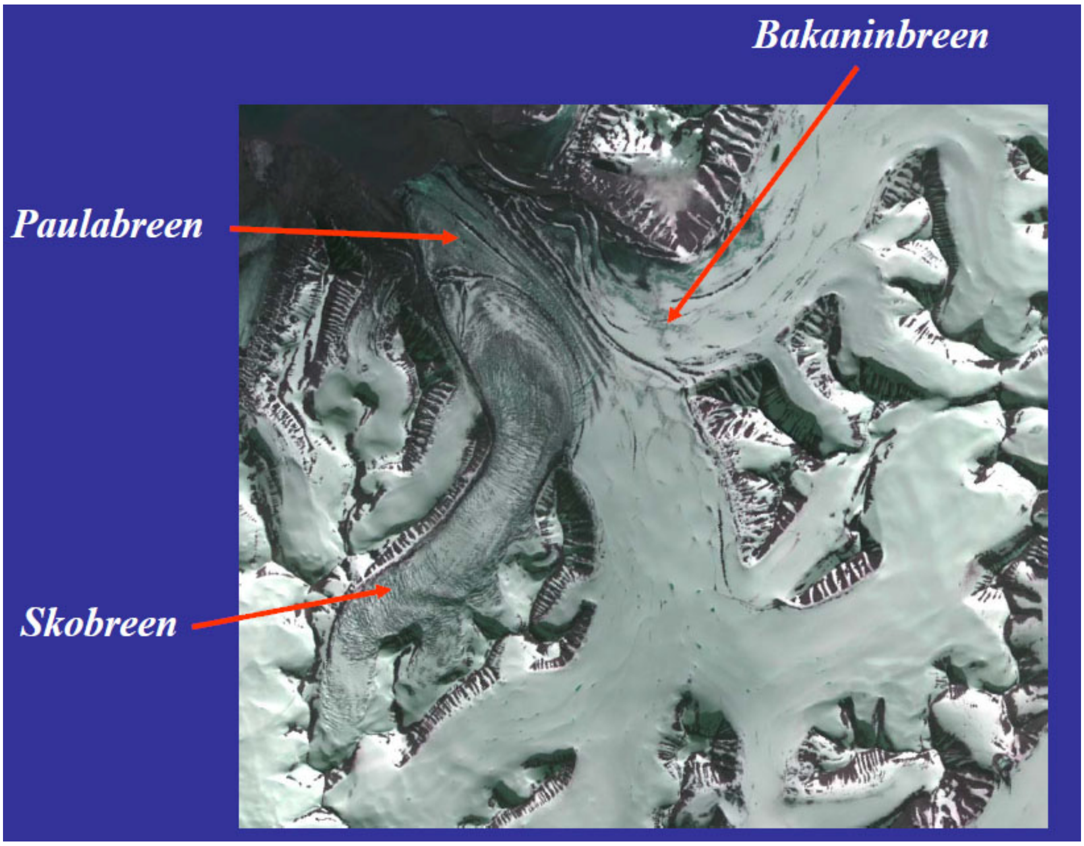

Figure 6: Bakaninbreen, Paulabreen and Skobreen (D. Benn)

Bakaninbreen is a 17 km long valley glacier in central Spitsbergen, Svalbard. The last surge of Bakaninbreen was between 1985 and 1995. About 7 km away from its terminus, Bakaninbreen is confluent with Paulabreen. The lower ablation zone of the two glaciers is separated by a prominent medial moraine, as you can see in figure 6. In 1985, a steep ramp developed at the downglacier boundary of faster flowing icea few kilometers from the terminus of Bakaninbreen (Dowdeswell et al., 1991). The ramp grew during the surge from 25 to 60m. Between 1985 and 1989, the rate of surge front propagation varied between app. 1 and 1.8km per year. After 1989, the rate progressively declined, and by 1994–95 it was only 1.8–3.0m per year (Murray et al., 1998).
(Benn and Evans 2010)

7.4 Alps

In the Alps there are no glaciers surging at present, although there have been a few surging in the past (Hoinkes 1969). As an example we are pointing out Vernagtferner in Austria and Ghiacciaio del Belvedere in Italy.

7.4.1 Vernagtferner

Since 1600 Vergagtferner in the Ötztal Alps (Tirol, Austria) was surging four times.

Meltwaters of Hochjochferner, Hintereisferner and Kesselwandferner (Ferner means glacier) were dammed up to a lake which was a constant menace to the Ötztal for as long as it existed.
The lake caused floods with heavy damage on the Ötztal every time when it was emptying.
A heavy flood was carrying blocks of ice and could even cause a rise in the level of the River Inn of about 0,6m even at Innsbruck, after traveling a distance of 102km in nine hours.
Advance periods occured between 1678 and 1929 in an interval of about 809 years.
The flow mode of this glacier is characterized by short periods of rapid advance, followed by much longer periods of quiet retreat. During retreat the average surface velocity is less than 0,05m/day, during advances it becomes more than 0,5m/day. Max speed 12,5m/day in 1845.
Surges of Vernagtferner are clearly connected to variations of climatic conditions, and because of the warm climate in the last decades the glacier could not rill the reservoir area anymore to start surging. (Hoinkes 1969)

7.4.2 Ghiacciaio del Belvedere

Ghiacciaio del Belvedere is near Macugnaga, Valle Anzasca, in the Italian Alps.
Ghiacciaio del Belvedere is a temperate, heavily debris-covered glacier fed by steep glaciers (especially Ghiacciaio del Monte Rosa as the main tributary), ice and snow avalanches as well as rock falls from the large east face of Monte Rosa.
The glacier developed an extraordinary change in flow, geometry and surface appearance between the summer 2000 and summer 2001. In June 2001, the Club Alpino Italiano observed heavily crevassed and almost debris-free ice towering above the orographic right lateral moraine, which was last reached by the glacier during the 19th century (= maximum stage of the Little Ice Age).
As a consequence of the flow acceleration, the surface at the glacier foot became dramatically compressed and deformed. The high water pressure was indicated by dirty ice-marginal pools, and the large ice volume displaced within a short time. This surge was an exceptional phenomenon. (Haeberli et al. 2002)

Figure 7: Ghiacciaio del Belvedere surging, 2001 (Haeberli et al. 2002)

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