Interpretation of glacier variations in Iceland 1930-1995

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Abstract - Glacier variations in Iceland since 1930 show a clear response to variations in climate during this period. Most non-surgeing glaciers retreated strongly during the early half of the monitoring period, following the warm climate between 1930 and 1940. A cooling climate after 1940 led to a slowing of the retreat and many glaciers started to advance around 1970. A warming of the climate since about 1985 has led to an increased number of retreating glaciers in recent years. The variations of non-surgeing glaciers in Iceland since 1930 appear to be caused primarily by variations in temperature as there are no long term variations in precipitation over this period. Variations of surge-type glaciers are dominated by the surge events. Climate variations do, nevertheless, seem to play a role in observed long term variations of some surge-type glaciers although they are more difficult to interpret than for the non-surgeing glaciers.

INTRODUCTION

On the basis of the original sources, observations of glacier variations in Iceland from 1930 to 1995 have been checked, corrected and computerised by Sigurđsson (this volume). In addition to measurements of the advance and retreat of the monitored glacier tongues, this compilation includes descriptions and location maps of the glaciers and graphs of the variations at the individual measurement locations. The present paper presents selected records from this new data set and summarises the advance/retreat records from non-surgeing glaciers in light of measured variations in the climate of Iceland since 1930.

Ice caps and glaciers cover more than 10% of the area of Iceland and they receive on the order of 20% of the total precipitation that falls on Iceland. When the glaciers are close to a steady state, they thus contribute on the order of 20% to river runoff and infiltration to groundwater aquifers in Iceland. The relative importance of glacier runoff is greater in highland areas. Glacier runoff is, therefore, particularly important for hydropower purposes, which are of great economic value for Iceland.

It is estimated that during the next decades the mean surface air temperature of the Earth will rise at a rate between 0.1 and 0.35 °C per decade due to increasing concentration of CO2 and other trace gases in the atmosphere (Houghton and others, 1996). If realised, this warming will have pronounced effects on glaciers and ice caps and lead to large runoff changes in glaciated areas. Climatic warming on the order of 0.3 °C per decade can temporarily increase glacier runoff from some Icelandic ice caps and glaciers by more than 50% and lead to a decrease in volume by approximately 40% of some glaciers over the next century (Jóhannesson and others, 1995; Jóhannesson, 1997; Saolthun and others, in press).

The advance and retreat of glaciers is an indicator of climate changes and reconstructions of past variations of glaciers from geological evidence or historical observations are an important tool for deductions about past climate. Information about many past climate changes has in part been deduced from records of...
glacier variations. Future climate changes will be monitored instrumentally and this will of course give much more quantitative information about the changes than is available about past climate changes. Nevertheless, it is important to monitor glacier variations associated with future climate changes (Haeberli, 1995). The climatic signal contained in records of glacier variations has a large area coverage whereas most meteorological data consist of point measurements. Moreover, the glacier records document climate changes that occur in relatively high mountain areas which are often poorly represented in the meteorological data. Finally, it is important for the interpretation of past records of glacier variations to obtain good data on glacier variations associated with climate changes which are well defined by measurements.

The interpretation of climate from records of glacier variations is problematic in a number of ways. The advance and retreat of surge-type glaciers is unrelated to climate and records from such glaciers must be eliminated from a data set that is to be used for deductions about climate. The response of non-surging glaciers to climate changes is influenced by the response time of the glaciers, which leads to a delay between a climate change and the associated response of the glacier terminus (cf. Johannesson and others, 1989).

Glacier variations are not only important because of local hydrological effects or as indications of climate changes. Increased runoff from glaciated areas is important for future global sea level rise that may occur as a consequence of future climate warming.
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(Warrick and others, 1996). Recent worldwide compi-
lations of glacier mass balance (Dyurgerov and Meier, 1997a,b) indicate that melting of small glaciers on Earth (excluding the ice sheets of Greenland and Antarctica) contributed 0.25 ± 0.1 mm a⁻¹ to global sea level rise in the period 1961 to 1990.

GLACIER VARIATIONS IN ICELAND SINCE 1930

Records of glacier variations in Iceland show a clear relationship with climate and such records have been used as an indicator of historical climatic variations, before regular weather monitoring was started in Iceland around the middle of the nineteenth century (Pórarinsson, 1974). Many glaciers in Iceland started retreating from their Little Ice Age maximum between 1850 and 1900 and the rate of retreat became quite rapid after 1930. As the climate gradually cooled after 1940, the retreat of the glaciers slowed down and many glaciers started advancing after 1970 (Pórarinsson, 1974; Björnsson, 1979). After about 1985 the climate has become warmer and many glaciers have started retreating again.

Figure 1 shows a photograph of the outlet glacier Sólheimajökull, which flows to the south from the ice cap Mýrdalsjökull, S-Iceland (Fig. 2), and Figure 3a shows the advance and retreat of Sólheimajökull from 1930/31 to 1994/95. Figure 3a shows a rapid retreat of Sólheimajökull between 1930 and 1960 followed by an advance which has slowed down markedly in recent years.

Sólheimajökull is a non-surging glacier which is directly affected by climate changes (Sigurðsson and
Jónsson, 1995). Variations of surge-type glaciers are not directly induced by climate changes in the same way as for non-surgeing glaciers. Surge-type glaciers may, however, be expected to reflect climate changes on time-scales longer than the interval between surges. Since accumulated mass balance changes over longer time intervals do affect the total size of the glaciers significantly. Figure 3b shows the advance and retreat of Múlajökull (cover photograph), which is a surge-type outlet glacier from the ice cap Hofsjökull, central Iceland (Fig. 2). Múlajökull has in recent decades surged with irregular 7 to 18 year intervals. The surge events in 1954, 1972, 1986 and 1992-1993 are, of course, the most prominent features of the record from Múlajökull, but the longer term variations on a time-scale of several decades are qualitatively similar to the variations of Sólheimajökull in Figure 3a.

Figure 4 shows the relative number of advancing and retreatting non-surgeing glacier termini in Iceland from 1930/31 to 1994/95. The figure is based on measurements at 19 locations at the following 18 glaciers (Fig. 3 shows the location of the main ice caps; Sigurðsson, this volume, includes location maps of the individual glacier tongues):

- Outlet glaciers from Óraefajökull, SE-Iceland: Svínafellssjökull, Virkisjökull, Fjalljökull, Kviárjökull, Hrutárjökull, Fjallsjökull.
- Outlet glaciers from Vatnajökull, SE-Iceland: Morsárjökull, Skaftafellsjökull, Brókarjökull, Skálafellsjökull, Heinabergsjökull, Fláajökull (two locations), Svínafellssjökull in Hornafjörður.
- Other glaciers: Gígjökull in Eyjafjallajökull (S-Iceland), Gljúfurárjökull (N-Iceland), Hyrningsjökull in Snæfellsjökull (W-Iceland), Nauthagajökull in Hofsjökull (central Iceland), Sólheimajökull in Mýrdalsjökull (S-Iceland).

Only termini which have been measured for several decades are included in the figure. Monitoring did not start until 1932 or 1933 at many locations and the figure is therefore based on somewhat fewer data series before 1935 (8 to 14 series) than after this time (15 to 19 series). The measurement periods for the individual glaciers are given in Table 1 in Sigurðsson (this volume). Measurements from glaciers which are known to surge are not included because terminus variations of surging glaciers are typically not controlled by climate changes. Data from mixed type glaciers, which are affected by surge events, but also seem to react to decadal variations in climate, are not included either due to difficulties in the interpretation of such records. Data from Skeiðarárjökull and Breiðamerkurjökull in Vatnajökull are not included for this reason.

The glaciers represented in Figure 4 have lengths varying from 2 to 29 km and vertical elevation ranges from 740 to over 2000 m. They fall in categories 2 and 3 as defined by Haebelri (1995):

1. “The smallest, somewhat static, low-shear-
stress glaciers (cirque glaciers, glaciers réservoirs) reflect yearly changes in climate and mass balance almost without any delay.

2. "Larger, dynamic, high-stress glaciers (mountain glaciers, glaciers évacuateurs), react dynamically to decadal variations in climatic and mass balance forcing with an enhanced amplitude after a delay of several years."

3. "The largest valley glaciers give strong and most efficiently smoothed signals of secular trends with a delay of several decades."

The figure, therefore, mixes category 2 and category 3 glaciers to some extent, which is unfortunate, because terminus fluctuations from mixed type events, but also fluctuations in climate, are not efficiently smoothed. The interpretation of the Þórsmörk glaciers, which are not included in the figure, therefore, is not possible.

Figure 4 shows that between 1980 and 90% of the termini were retreating in the time period 1931 to 1994. Although between 20% and 10% of the glacier termini were typically advancing each year during this period, all the termini, without exception, had retreated from their 1930 positions by 1960. After 1960, the fraction of advancing termini started to rise, but after 1980 more glaciers have started retreating again. The fluctuations of the Icelandic glaciers are similar to glacier fluctuations in the Alps (Haeberli and others, 1989; Haeberli, 1995), but glacier fluctuations from other parts of the world can be quite different. For example, the retreat rate of glaciers in the Tianshan Mountains in China did not slow down or re-

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**Fig. 4.** Percentage of advancing (dense shading) and retreating (less dense shading) termini of non-surge glaciers in Iceland as a function of time from 1930/31 to 1994/95. No shading indicates stationary termini. Over most of the time period shown, the figure is based on measurements at 15 to 19 locations at 18 termini (somewhat fewer termini in the years 1931 to 1935). The figure is based on the measurements of glacier variations in Iceland tabulated in Table 2 in Sigurðsson (this volume). The glaciers represented in the figure are listed in the text.

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**Fig. 5.** Summer temperature (average of May to September) and annual precipitation (sum from October of previous year to September) at Kirkjubæjarklaustur (a) and Reykjavík (b) from 1931 to 1995 (solid curves). Dashed curves are weighted, running 5 year means using the weights (1/9,2/9,3/9,2/9,1/9) centered about each year.

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verse around 1960 as was the case in Iceland and in the Alps (Choalai, 1992).

The response of the termini varies between the monitored glacier tongues as can be seen from graphs of the individual data series in Sigurðsson (this volume). Due to the small number of glaciers in the data set, we are, however, unable to draw any conclusions regarding regional differences of glacier variations in Iceland during the monitoring period.

Figure 5 shows summer temperature (May to September) and yearly precipitation (October previous year to September) in Kirkjubæjarklaustur S-Iceland (a) and Reykjavik SW-Iceland (b) from 1931 to 1995. Variations in glacier ablation are primarily related to variations in the summer temperature, whereas changes in the accumulation may be expected to correlate with variations in the precipitation record. There is a good correlation between the temperature records from Kirkjubæjarklaustur and Reykjavik, as is expected, since there is in general a good correlation between temperature measurements from different meteorological stations in Iceland (Einarsson, 1991). It can, therefore, be assumed that the temperature records from Kirkjubæjarklaustur and Reykjavik give an estimate of temperature variations that occurred on Icelandic glaciers in this time period. The figure shows that the temperature was relatively high from 1931 to 1960, especially in the years 1931 to 1940. After about 1960 the climate cooled markedly, the temperature reached a minimum between 1980 and 1985 and the climate has been slowly warming since then. There are no similar systematic trends in the precipitation records in spite of large short term fluctuations (note the shifted precipitation scale in Figure 5a,b).

The temperature and precipitation records in Figure 5 indicate that glacier fluctuations in Iceland (cf. Figure 4) were primarily controlled by variations in the summer temperature. The rapid glacier retreat from 1931 to 1960 is related to high summer temperatures in the decades after 1920. The retreat slowed down and turned to advance in the period 1965 to 1970 when the climate had become cooler and the fraction of advancing glaciers reached its maximum in the period 1975 to 1990 after the summer temperature had reached its minimum around 1980.

In spite of the strong correlation between glacier variations and summer temperature, which is apparent from figures 4 and 5, the figures show that the relationship between glaciers and climate is not simple. The decade from 1931 to 1940 is the warmest decade in the instrumental record in Iceland. In spite of this, between 10 and 20% of the glacier termini were advancing in this period, and more than 40% of the termini were still retreating during most of the very cold summers from 1970 to 1980.

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Túlkun á jöklabreyingum á Íslandi 1930-1995

Jöklabreyingar á Íslandi síðan 1930 sína skýr viðbrögð jökla við loftslagsbreytingum á þessu tíma-

bili. Flestir jöklar, sem ekki eru framhlaupsjökullar, hopuðu hratt á fyrsta helmingi tímasins, í kjölfar

hýindanna á fórða áratagi aldarian. Eftir 1940 dró ûr jökulhófurinni samfara kölnandi veðurfari og

margir jöklar fór að ganga fram um 1970. Hlíðandi

veðurfar eftir niðran niður áratagnin hefur leitt til

þess að margir jökullar hafa farið að hopa að nýja á síðu-

ustu árum. Þvo virðist sem jöklabreyingar á Íslandi

síðan 1930 séu fyrst og fremst afleiðing af breytingum í hitafari á þessu tímaði. Langtímbreyingar í

í úrkomu eru ekki miklar á tímasínu. Breytingar á

stöðu framhlaupsjökullar ráðast fyrst og fremst af því

hværner gangur er í jökulnum. Loftslagsbreytingar

víðar þó hafa nokkur áhrif á langtímbreyingum

sumra framhlaupsjökull eina og þær bírtast í me­

ingum á stöðu jökulsárfíð. Breytingar á framhlaup­

jökullum er þó mun erfiðara að túlka á grundvelli loftslagsþögu en breytingar á þörum jökulum.
Úr myndasafni Ingólfs Ísólfssonar

Úr Órefum. Morsárjökull, Skardatindur (1385 m) til hegri. Myndina tók ensk kona 1925.

Örafaferð III 1938 (sjá grein: Ferðir um Vatnajökul). Oddur (t.v.) í Skjaftaríi að kveðja Guðmund Sigurðsson á Skeiðarársand, Morsárdalur í baksýn.