Glaciers in Iceland

Review by Kristinn Arnar Guðjónsson

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1. Introduction.

The first part of this paper involves a general discussion of glaciers and glaciology. It is based on the author's collective knowledge and the writings of leading specialist in the field of glaciology. The most important of those are Björnsson, H. (2009 & 2004), Paterson, W.S.B. (1999), Hambrey, M. (1994), Sugden & Brian (1976) and Eyles, N. (1984). The second part describes glaciers in Iceland and is for most parts base on Björnsson´s (2009) excellent book *Jöklar á Íslandi* (Glaciers in Iceland). No additional reference is made to the source of information in this text (except for graphs, tables and figures).

2. The formation of a glacier.

In areas where winter snow accumulation is greater than summer snow melt **perennial snow banks** form. If this is a prevailing condition the banks become increasingly thicker. Once the thickness exceeds 20 meters the snow at the base will start to re-crystallise (due to pressure) and eventually develop into ice (when the density surpasses 900 kg/m^3). This is still considered a snow bank. The process occurs in cold areas very often on mountain tops. The line that separates areas where the **mass balance** is positive (where more snow falls in the winter then melts in summer) and lower areas where the mass balance is negative (where all the winter snow melts) is called a **snow line** (in glaciology an **equilibrium line**)

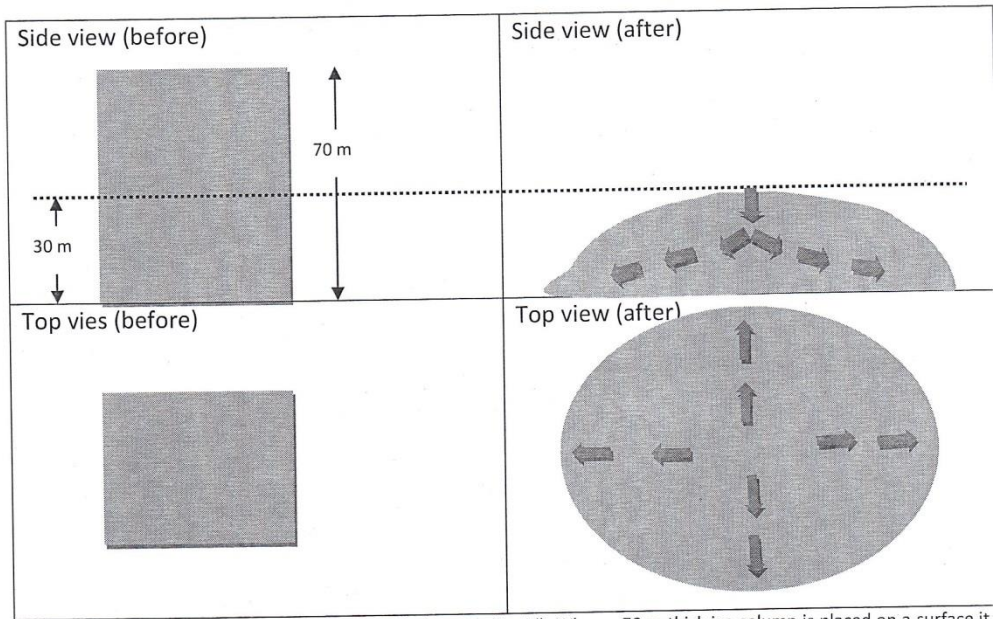


Figure 2.1: Ice is plastic and flows like a viscous substance (liquid). When a 70 m thick ice column is placed on a surface it starts flowing under its own weight to the sides eventually becoming a circular dome. The critical thickness for flow is 30 m. This explains why very large glaciers and glaciers that sit on relatively flat surfaces are dome shaped. The red arrows show the direction of flow. Figure by Kristinn Arnar Guðjónsson.

In our mind we think of ice as a solid material but in reality it is plastic meaning that it car deform under pressure. Ice in other words **flows** like syrup or a liquid – but much slower Accordingly once the thickness of the ice at the base of the bank becomes greater than 30 m it starts to flow under its own weight (figure 2.1).

When flow has stared two of the three major components of a glacier, ice and flow are present. The third component is the subdivision into an **accumulation** and **ablation zone** This division occurs when the ice flows below the snow line. The area above the line is the accumulation zone, there the glacier gains mass. The area below the line is the ablatior zone, there the glacier looses mass (figure 2.2).

Two factors are of the greatest importance for the formation of glaciers: temperature anc precipitation. Great winter precipitation (as snow) and cool and short summers are the idea conditions facilitating high accumulation and low ablation for the year. Glaciers are no found in many cold areas due to lack of winter snow (i.e. areas in a precipitation shadow). I is in fact the combination of mean summer temperature and snow accumulation tha determine the elevation of the snow line (equilibrium line in a given area)

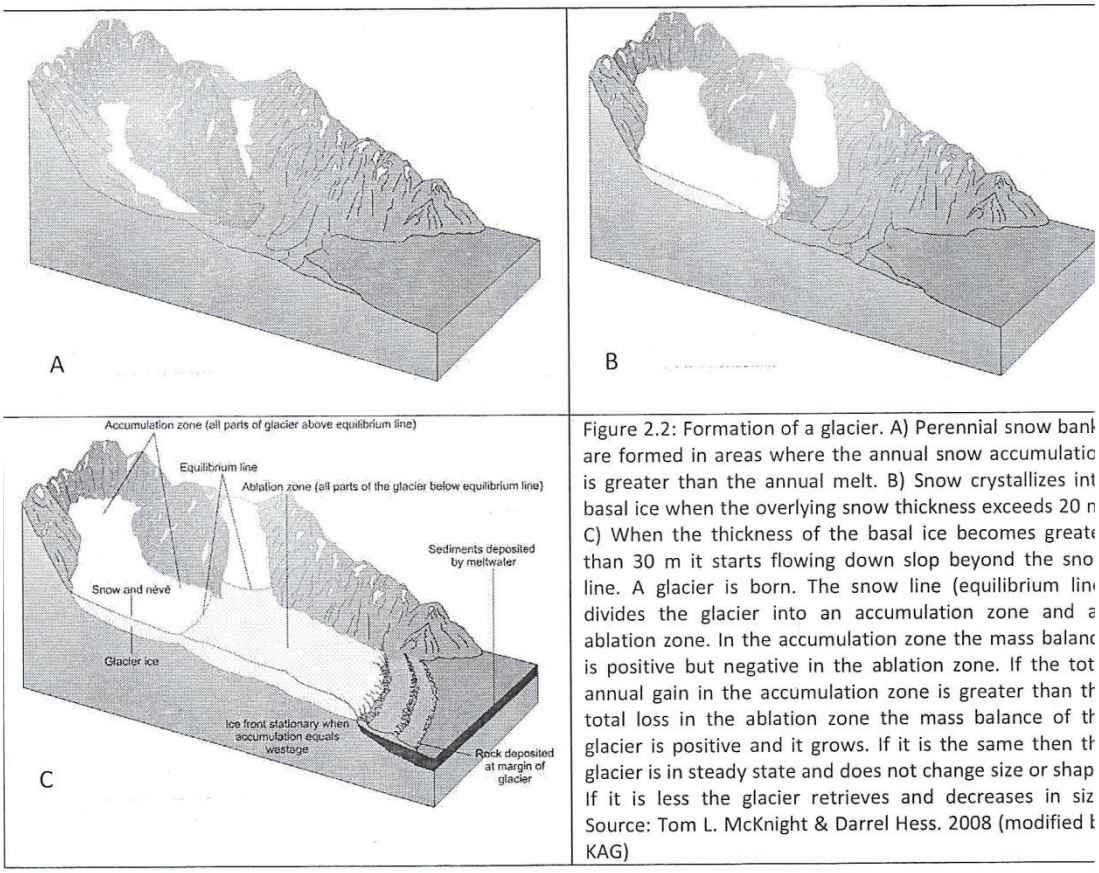


Figure 2.2: Formation of a glacier. A) Perennial snow bank are formed in areas where the annual snow accumulatic is greater than the annual melt. B) Snow crystallizes int basal ice when the overlying snow thickness exceeds 20 n C) When the thickness of the basal ice becomes greate than 30 m it starts flowing down slop beyond the sno line. A glacier is born. The snow line (equilibrium lin divides the glacier into an accumulation zone and a ablation zone. In the accumulation zone the mass balanc is positive but negative in the ablation zone. If the tot annual gain in the accumulation zone is greater than th total loss in the ablation zone the mass balance of th glacier is positive and it grows. If it is the same then th glacier is in steady state and does not change size or shap If it is less the glacier retrieves and decreases in siz Source: Tom L. McKnight & Darrel Hess. 2008 (modified b KAG)

Let us assume that in a particle ice free area with an elevation of 1100 m the snow line is at 1150 m. Climate deteriorates and mean annual temperature goes down 2°C causing the snow line to lower to 1050 m. The area is now above the snow line. A glacier starts building up and increasing the thickness. Eventually the dome of the glacier builds up to an altitude of 1250 m. The temperature returns to the original average and the snow line goes back to 1150 m. The glaciers can maintain itself since its dome exceeds the snow line by 100 m. This example shows that glaciers control their microclimate to some extent and that glaciers can prevail at much milder temperatures than those that were needed to initiate their development.

3. The physics of glaciers.

It is necessary to take a closer look at the special features of glaciers. How do they move and what factors control the rate of movement? How do glaciers grow and how do they subside?

3.1 Mass balance.

The mass balance of a glacier is the difference between total mass added and total mass lost. If the difference is a negative value the glacier is losing mass and is therefore thinning and decreasing in size. If it is a positive the glacier is growing and thickening. In some cases the value is zero, in which case the size and shape of the glacier remains the same. Such glaciers are called steady state glaciers.

Annual mass balance is calculated by measuring total accumulation in the accumulation zone at the end of summer and compares it with total melt in the ablation zone for the same time period.

The glacier strives to maintain its profile so it needs continuously to compensate for the mass added in the accumulation zone and lost in the ablation zone. This is achieved by moving the mass between the two zones. The ice is in other words continuously flowing down hill even though the glacier´s margin is retrieving. Under such circumstances more ice melts in the ablation zone than moves down from the accumulation zone. The reverse is true in an advancing glacier.

3.2 Warm and cold based glaciers.

Some glaciers are frozen to their base while others are not. Those that are frozen to their base are called **cold base glaciers** and the others **warm based glaciers** (some times called **temperate glaciers**).

The snow that falls on glaciers in extremely cold areas is way below 0°C and maintains that temperature as it is buried in the glacier. The temperature from the base to the surface in such glaciers is well below **pressure melting point** from top to bottom. They are therefore frozen to the base. In warmer areas the snow is close to 0°C when it falls at the surface. As i

is buried the pressure increase lowering the pressure melting point. Liquid water car therefore exist anywhere in the ice columns of such glaciers. They are not frozen to the bottom and in fact a water film often exists between the base and the glaciers. This is especially true in volcanically active areas. In such areas the geothermal gradient is steep and heat is easily conveyed to the surface.

We know that glaciers flow (like a liquid) but in addition warm based glaciers **slide on the base**. Their movement is therefore much more rapid than that of cold based glaciers. Severa factors affect the speed of glaciers. The most important are listed below.

1. **Temperature of the ice**: The closer the ice is to pressure melting point – the more viscous (fluid) it is. Warm ice flows faster than cold ice.
2. **Warm or cold base glaciers**: Warm based glaciers move much more rapidly than cold based glaciers since in addition to flow (which is more rapid since they are warmer they slide.
3. **Roughness of the base**: The rougher the surface the slower the movemen (especially if the glaciers are sliding).
4. **Amount of impurities in ice**: The more rock loaded the ice, the slower is the movement.
5. **Angle of slop**: Glaciers at steep slope move faster than on gentle slopes.
6. **Presence or absence of a water film at base:** The presence of a water film at the base accelerates movement.
7. **Accumulation in accumulation zone:** Large accumulation means that more mas needs to be moved per time unit. The only way to achieve that is through faste movement.

It is important to keep in mind that fast glaciers are more responsive to environmenta changes. They for example react very rapidly when climate warms. The time differenc between the change in environmental factor and the response of the glacier is called **la time**. The lag time is long in slow moving glacier (can be up to 10 years) but very rapid in fas moving glaciers (they often react instantaneously). The size of the glacier also effects the la time. Large glaciers tend to have longer lag times than small glaciers.

Icelandic glaciers are very responsive. They are all warm based and due to a stee geothermal gradient they all have a water film at their base[1]. Most of them are found o relatively steep mountains (volcanoes) and winter accumulation is high (up to 8000 mm/yea on the southeast flank of Vatnajökull). All this results in glacier that move very rapidly thu responding almost instantaneously to changes in the environment.

[1] The presence of the water film is most common in the summer. It needs not be continuous underneath th glacier.

3.3 Surging and climate response glaciers.

Many glacial margins go through periods of very rapid forward advances. These tend to occur at fixed intervals for each margin but the length of these intervals varies from on margin to another and from one glacier to another. The Interval may be few years up to hundreds of years. These advances are called **surges** and they occur in both advancing and retrieving glaciers.

Great debate is on why these surges take place. Several reasons have been suggested most relate the surges to glacial hydrology or base morphology. It is safe to say that the process is complicated and may be due to different reasons in different glaciers. The important thing here though is that such surges mask any changes that may be due to changes in climate. Surging glaciers can therefore not be used as climate indicators (figure 3.1).

On these bases we can divide glaciers or glacial margins into two categories: **surging and non-surging (climate response) glaciers.** Surges are common in Icelandic glaciers and tend to occur at relatively short intervals. This may well be due to their relatively rapid movement. Non-surging glaciers are also found in Iceland and Sólheimajökull is an excellent example of that type. When marginal changes in surging glaciers are smoothen out for long period they do show a climate response (figure 3.1).

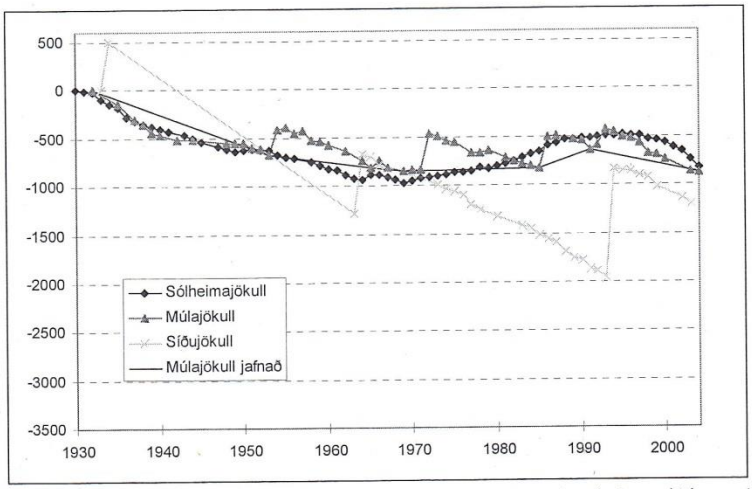


Figure 3.1: Marginal changes in three glaciers in Iceland. Sólheimajökull is a non-surging glacier and it´s marginal variations reflect temperature changes. The other two are surging glaciers. When changes in Múlajökull are rounded out they confirm a climate response similar to that of Sólheimajökull. Source: Courtesy of Oddur Sigurðsson.

3.4 Jökulhlaups.

Catastrophic floods are common in glacial rivers. During such times their flow becomes many thousand times greater than the average flow. Such floods are called **jökulhlaups** in glaciology. This is an Icelandic term that literally means river leap.

It has been calculated that flow rates from Kötlujökull during Katla eruptions may be have been as high as 800.000 m^3/s in jökulhlaups in the past. This is 8 time the flow of the Amazone the world larges river. In fact during the floods the flow constitutes 80% of all water flowing of land to the ocean on earth. Jökulhlaups in Mýrdalsjökull are caused by volcanic eruptions in Katla. The floods most often flow down Mýrdalssandur but can take different paths depending on where in the caldera the eruption occurs (figure 3.2). In the past Katla has erupted at regular intervals of 60-40 years. Its last eruption was in 1918 so it is now overdue. The eruption in Eyjafjallajökull, Katla´s next door neighbour, in 2010 may possibly trigger an eruption in Katla in the next two years. In the three eruptions in Eyjafjallajöklull during historical times (last 1100 years) Katla has been triggered shortly afterwards.

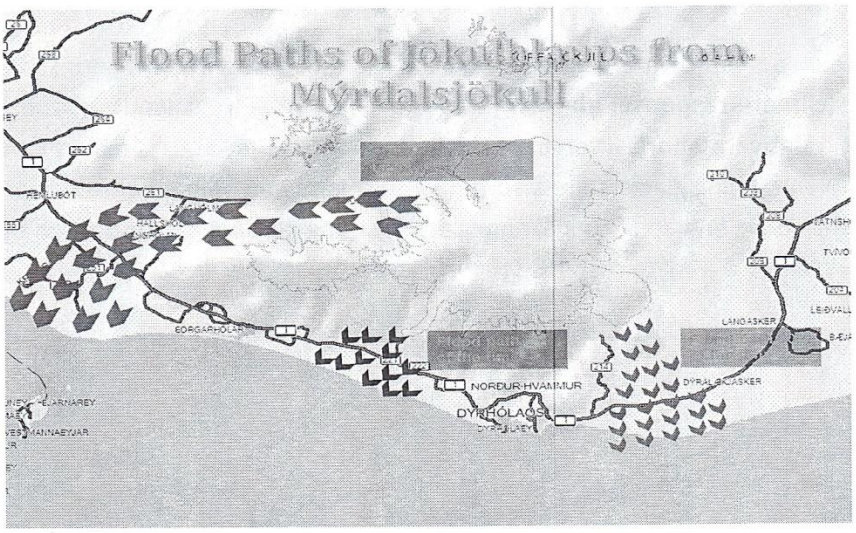


Figure 3.3: Three known paths of floods from Mýrdalsjökull (Katla). 90% of the time they go down Mýrdalssandur but 1% of the time down Sólheimasandur (come from Sólheimajökull). Once every 1000 years they go down the channel of Markarfljót. Map by Kristinn Arnar Guðjónsson.

Jökulhlaups are caused by different processes. The most powerful are associated with sub-glacial eruptions (Katla and Grímsvötn in Iceland are good examples). The following list contains the most common reasons.

1. **Jökulhlaups due to volcanic eruptions:** The eruption rapidly melts immense quantities of ice in a relatively short time. The water lifts the ice and finds its way to the glacial margin along the subsurface.
2. **Jökulhlaups due to geothermal activity:** Sub glacial lakes are formed at geothermally active areas under the glacier. As time progresses the melt water volume increases and consequently the depth of the lake. When the water level reaches 9/10 of the ice thickness it lifts the ice (since ice floats on water) and finds its way along the subsurface to the ice margin.

3. **Jökulhlaups due to emptying of marginal lakes:** Glacial outlets can dam cross-valleys which in turn fill with drainage water – a marginal lake is formed. When the level of the lake reaches 9/10 of the thickness of the ice the ice is lifted and the lake drains along the subsurface to the margin of the glacier (figure 3.4). During the late glacial period large marginal lakes were found along the great ice sheet of North America. As the ice retrieved the water found new outlets at lower altitude causing these gigantic lakes to empty partly or completely. Such jökulhlaups are credited for landforms such as the Great Canyon.
4. **Jökulhlaups associated with surging glaciers:** Jökulhlaups often follow glacial surges. These are usually small jökulhlaups.

re 3.4: Grænalón a marginal lake in South Iceland. The glacial outlet Skeiðarárjökull, which drains Vatnajökull, dams a ll valley which in turn fills with water. A marginal lake is formed. With regular intervals the lake drains as its depth omes great enough to lift the ice. The water flows along the subsurface and comes out on the outwash plain (sandur) ie south margin of the glacial outlet. Source: screen capture from Google Earth.

Classification of glaciers.

nny different classification scheme for glacier exist. The one presented here is adopted d simplified from Paterson (1999). It is based on the size and movement of the glacier and nature of the accumulation zone.

Open and closed glaciers.

iciers can be **circular (closed)** or **elongated (open)** depending on the form of the umulation and ablation area. It is important to stress that circular glaciers need not be cular in their morphology. For this reason I choose to use the terms open and closed for se two categories.

If the equilibrium line of the glacier closes in on its self the glacier is closed or circular. The ablation zone forms a rim around the accumulation zone. These glaciers are also called glacial domes (figures 2.1 and 3.5).

The glacier is open or elongated when the equilibrium line divides the glacier in two half's. The upper part is the accumulation zone and the lower is the ablation zone (figures 2.2 and 3.6).

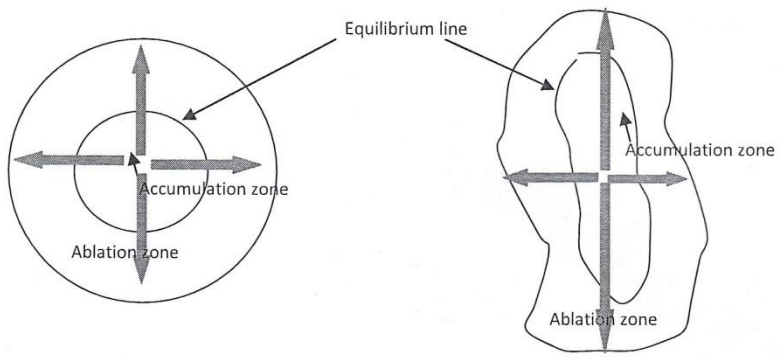


Figure 3.5: Closed glacier (circular or dome shaped). The equilibrium line closes on itself and the ablation zone forms a rim around the accumulation zone. The flow of the ice is from the centre to the margins (red line).

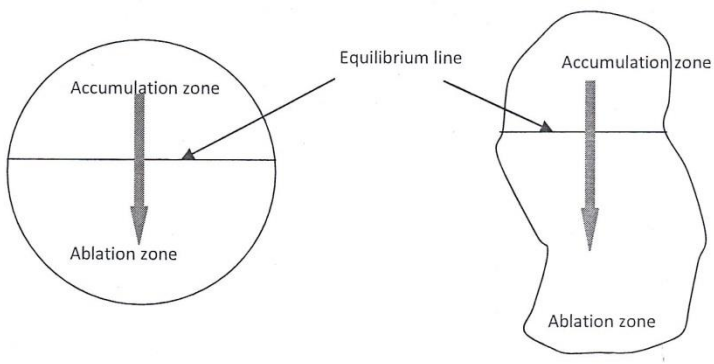


Figure 3.6: Open glacier (elongated glaciers, cirque or valley glaciers). The equilibrium line divides the glaciers in two parts an accumulation and ablation zones. The flow of ice is along the length of the glacier (red line)

It has been suggested that closed glaciers are more sensitive to temperature changes since a slight increase in the elevation of the equilibrium line can cause great changes in the area of the different zones. If the dome is flat toped a minor change may result in an equilibrium line above the dome thus the glacier loses its accumulation zone instantaneously.

4.2 Classification based on size and movement.

The following is a classification of glaciers based on morphology size and movement. It is a simplified version of a commonly used classification.

1. **Large glacier domes:** Cover several mountain peaks. They are closed and move independent or nearly independent of the underlying surface and form almos perfect domes. Only the Antarctic glacier would fall into this category today bu during the glacial period several such ice domes existed in fact one covered Iceland (figure 4.1)
2. **Small glacier domes:** Cover several mountains. They are closed but their movemen is to large extent dictated by the underlying surface. The largest glaciers in Iceland fal into this category (figure 4.2).
3. **Mountain glaciers:** Crown one mountain peak. They are closed. Snæfellsjökull i Iceland is a good example of this type (figure 4.3).
4. **Cirque glaciers:** Cover one side of a mountain (usually on the side that faces th prevailing precipitation direction). They are open. Cirque glaciers burrow bowl shap depressions in the bedrock where they sit. These are left as remnants when the melt. Several cirque glaciers are found in Iceland (figure 4.4 and 4.5).
5. **Valley glaciers:** In reality oversized cirque glaciers. Cirque glaciers start to grow whe climate deteriorates. Eventually they extend of the mountains and onto the lowe laying valleys. All valley glaciers start and end their lives as cirque glaciers. Valle glaciers are open. Valley glaciers are not found in Iceland today but many of th current cirque glaciers formed valley glaciers during the Little Ice Age maximum 15 years ago (figure 2.2 C).
6. **Glacial outlets:** These are not independent glaciers but drain outlets from dome o mountain glaciers. They behave in a similar fashion as valley glaciers. Glacial outlet are good climate indicators if they are of the non-surging type. Sólheimajökull fall into this category (figure 3.4).
7. **Rock glaciers:** These are cirque or valley glaciers that have been buried in debris c rock, sand and mud. If completely covered they can be difficult to detect.

Figure 4.1: The large glacier dome that covered Iceland during the last glacial period of the ice age. Source: unknown.

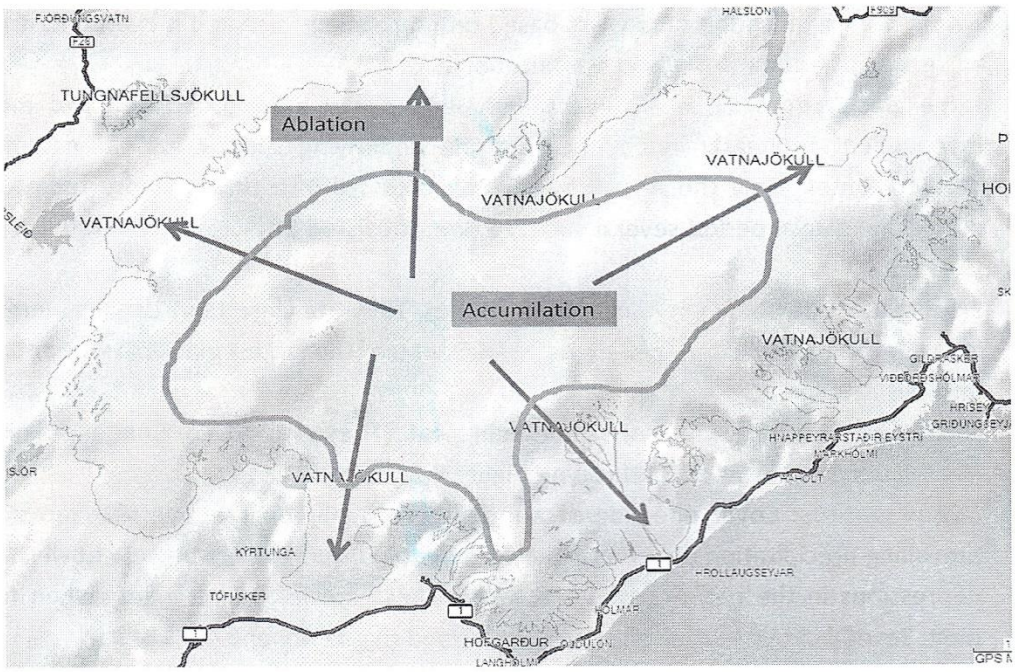


Figure 4.2: A small glacier dome – Vatnajökull in south Iceland. Picture by Kristinn Arnar Guðjónsson.

Figure 4.3: Snæfellsjökull – symmetrical mountain glacier on the Snæfellsnes peninsula in west Iceland bathe in the midnight sun. Photograph: Kristinn Arnar Guðjónsson.

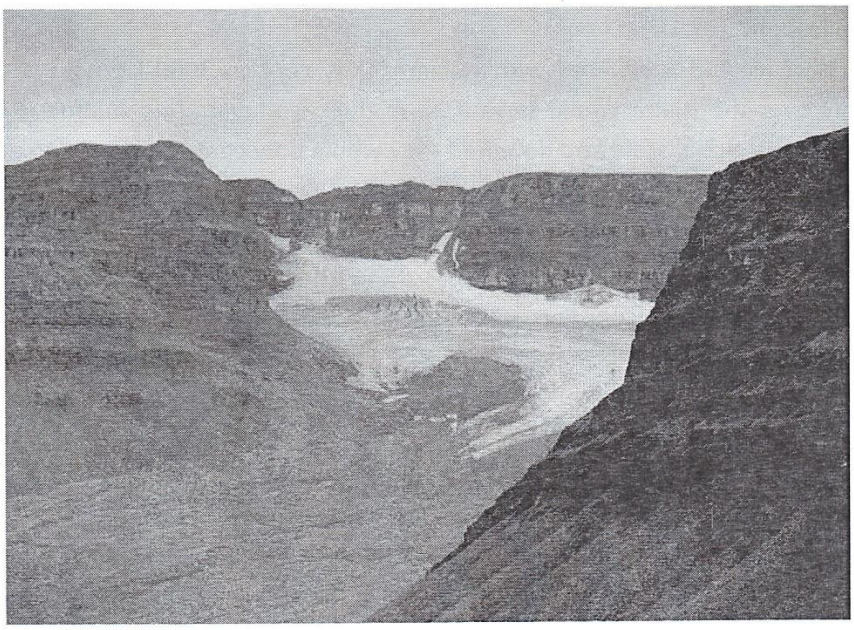


Figure 4.4: Barkaárdalsjökull – a small cirque glacier in north Iceland. The till and end moraines further down valley testify to the fact that some 150 years ago its extent was far greater and it in fact formed a valley glacier. Photograph: Kristinn Arnar Guðjónsson.

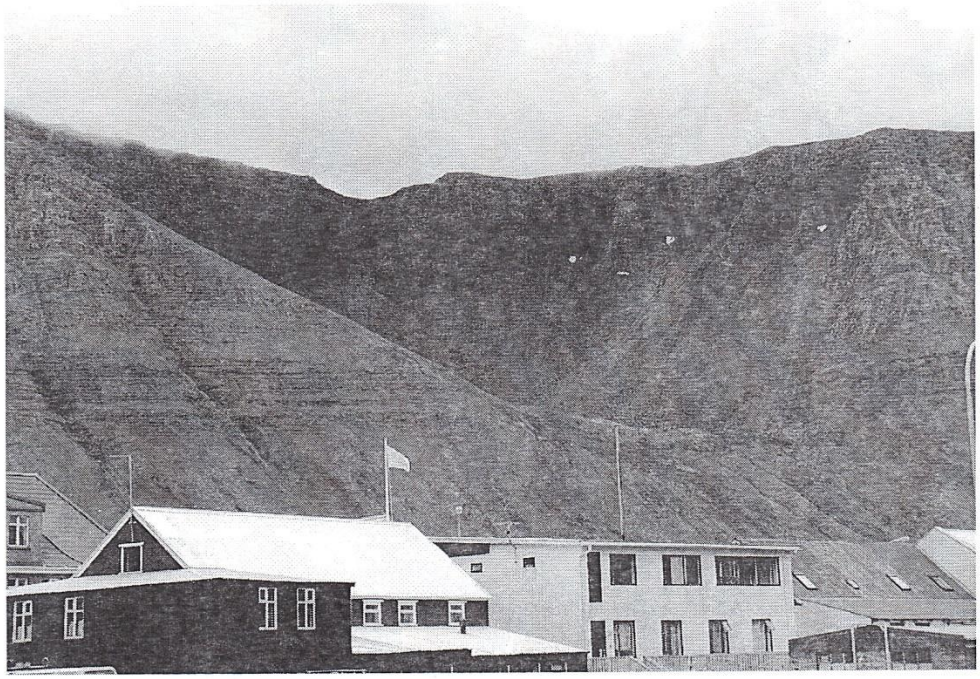


Figure 4.5: Naustahvilft a depression left by a cirque glacier in the West Fjords of Iceland. Photograph: Kristinn Arna Guðjónsson.

5. Glaciers in Iceland[2].

Currently 11% of Iceland is covered with glaciers. They contain 3600 km^3 of water and i spread evenly over the island would form a 35 m thick ice layer. This volume is howeve relatively small on a global scale and if melted they would only contribute 1 cm to global sea level rise (table 5.1 and 5.2).

Parameters for three of Iceland´s largest glaciers					
Glacier	Area km^2	Volume km^3	Greatest thickness m	% of total area	% of total volume
Vatnajökull	8100	3000	950	8%	83%
Langjökull	925	195	580	0,9%	5%
Hofsjökull	800	200	760	0,8%	5,5%
Others	1313	205	N/A	1,3%	6,5%

Table 5.1: Parameters for three of Iceland´s largest glaciers. They constitute 9,7% of the 11% of Iceland that is covered with ice. It is interesting to point out that even though Langjökull is 125 km^2 larges than Hofsjökull its volume is 5 km^2 less. Source: Björnsson, H. 2009.

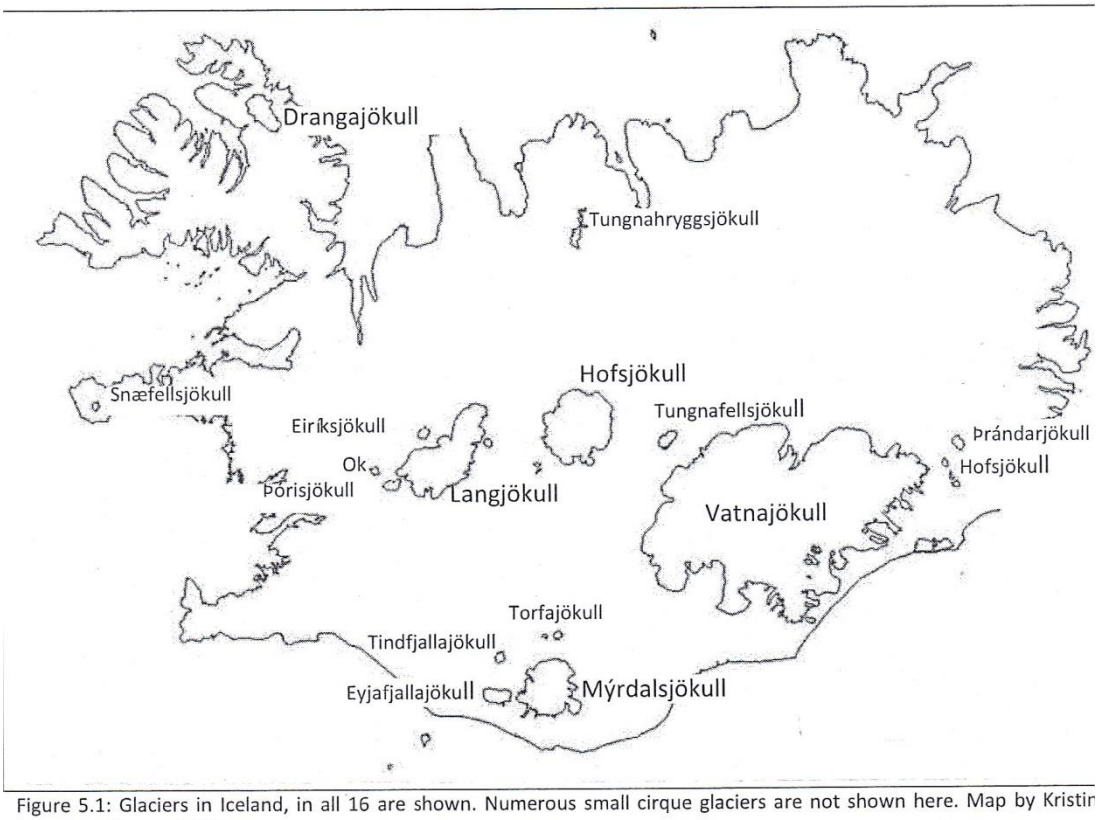


Figure 5.1: Glaciers in Iceland, in all 16 are shown. Numerous small cirque glaciers are not shown here. Map by Kristin Arnar Guðjónsson 2011.

Most of this ice is contained in three glaciers but in addition numerous smaller cirqu glaciers are found in north and northeast Iceland (see figure 5.1 and table 5.1). Of the thre

[2] This chapter is based to large extent on Björnsson, H. 2009. This holds true for most values quoted here.

Vatnajökull is by far the largest and holds the title of Europe's largest glacier. Second largest is Langjökull followed closely by Hofsjökull. Other large glaciers are Mýrdalsjökull, Drangajökull and Eyjafjallajökull (figure 5.1).

Glacier	Area km^2
Vatnajökull	8100
Langjökull	925
Hofsjökull	800
Mýrdalsjökull	596
Drangajökull	160
Eyjafjallajökull	78
Tungnafellsjökull	48
Þórisjökull	32
Eiríksjökull	22
Þrándarjökull	22
Tindfjallajökull	19
Torfajökull	15
Snæfellsjökull	11

Table 5.2: Area of the 13 largest glaciers in Iceland Source: Icelandic Geodetic Survey and Björnsson, H. 2009.

During Pleistocene and post glacial times, the island has been drastically shaped by glacial erosion and glacial or fluvioglacial deposits. The glaciers have carved alpine landscape which is characterised by cirques, fiords, U-shaped valleys and sharp mountain peaks.

The impact of glacial rivers is evident by deeply eroded canyons and deposition on sandur deltas. It is also worth mentioning that the Palagonite formation of Iceland (see the paper on the Geology of Iceland) is the product of sub-glacial volcanic activity.

Detailed and long term meteorological observations on glaciers in Iceland have provided an important understanding of the nature and character of temperate glaciers – knowledge base that will prove valuable in predicting the future of current cold based glaciers as they transfer into warm based glacier with warming climate. This will be of special importance in the study of the mountain glaciers in the Himalayan Mountains which provide 1/3 of humanity with drinking water.

The overall glaciological data now allow for modelling of mass balance and ice dynamics and for using coupled models to predict the response of glaciers to past and future climate change.

5.1 Distribution, climate and topographical conditions.

The regional distribution of Iceland´s glaciers (see figure 5.1) reflects precipitation and the fact that it occurs in a prevailing southerly winds. On the highest southern slopes of Vatnajökull and Mýrdalsjökull (1300 m.a.s.l.) annual precipitation exceeds 4000-5000 mm, peaking at 8000 mm, while it reaches 3500 mm on Hofsjökull and Langjökull.

The largest glaciers are, therefore, located in the southern and central highlands. On top of the biggest icecaps average temperature are below or close to freezing throughout the year thus most of the precipitation falls as snow. Icelandic high-altitude summers are chilly so only 10-20% of the year experiences melting. At lower levels the ablation season lasts 3-4 months (figure 5.2 and 5.3).

As state earlier the snow line at a given location depends on the combination between temperature and snow accumulation in the winter time figures 5.2 and 5.3 reflect that.

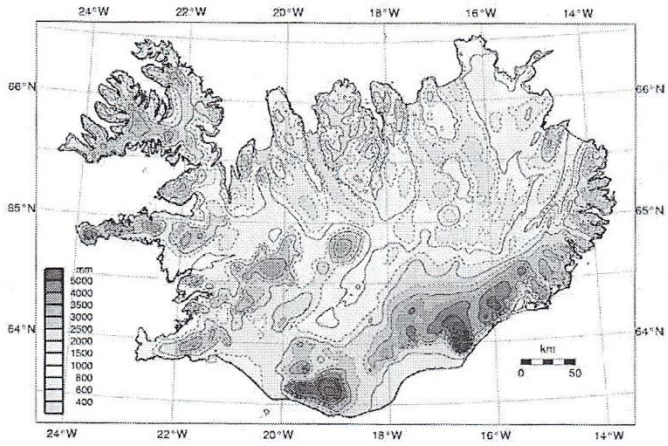


Figure 5.2: Mean annual precipitation in Iceland during the period 1971-2000. On average the annual precipitation in Iceland is 2000 mm. On the south parts of Vatnajökull and Mýrdalsjökull it exceeds 4000 mm and reaches 6000 mm on the highest points on these glaciers (the highest ever measured is 8000 mm). On the highest part of the main glaciers snow prevails in all months (above the snow line see figure 5.3). Source: Björnsson, H. 2009.

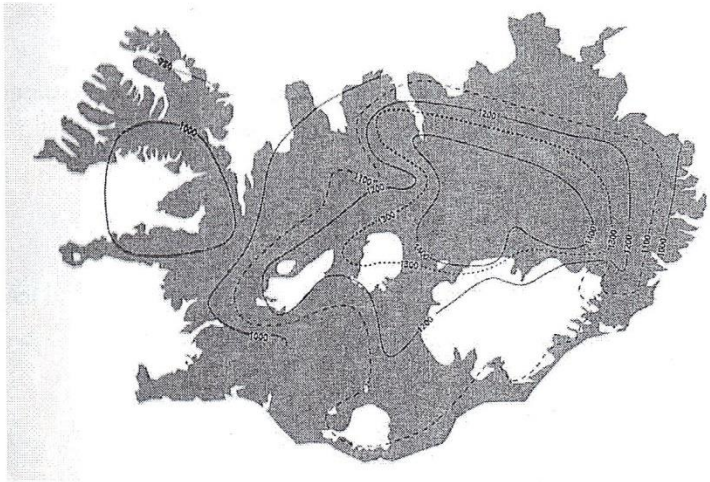


Figure 5.3: Average height of the snow line at end of summer in Iceland. Above this line snow does not melt during winter time that is to say if we have mountain peaks in a given area high enough to accumulate the snow. The line is the lowest in the southern part of Vatnajökull and Mýrdalsjökull (1100 m). The precipitation in these areas is around 4000 mm/year. As we go further away from the south coast the precipitation decreases and the elevation of the snow line increases. It is 1200 m in the southern parts of Langjökull and Mýrdalsjökull in central Iceland and as high as 1400 m in the precipitation shadow north of Vatnajökull. The figure illustrates well the combined importance of temperature and snow accumulation in deciding the elevation of the snow line. Source: Björnsson, H. 2009.

The southernmost outlets of Vatnajökull and Mýrdalsjökull (e.i. Sólheimajökull) descend to 100 m elevation or less (lowest 20 m). In these areas even the winter balance is slightly negative even though total precipitation exceeds 1500 mm in many of these areas. Most of that falls as rain. Summertime losses in these areas measure 9 m (water equivalents). For glacier outlets in central Iceland (which terminate at elevations of 600-800 m) the summer balance ranges from -4 to -6m.

Central Iceland has several steep mountains reaching over 1400 m and maintaining smal glaciers. In northern coastal areas the snow line goes below 1000 m evidenced by over 10(small cirque glaciers in the region.

In the West Fjord (northwest Iceland) annual precipitation reaches 3000 mm and the glaciations limit registers the lowest in Iceland 600-700 m. The mountain plateau in the area is between 700-900 m. It is a home to 10 small cirque glaciers and the ice cap Drangajökull Iceland's northern most glaciers.

As stated earlier glaciers can prevail at much milder temperatures than those that were needed to initiate their development since they add to the elevation of the area. Detailed ice thickness measurements carried out by Björnsson and others on Iceland´s glaciers in the pas decades has provided us with detailed maps of the sub-glacial surface. These maps show that only 10-20% of a glacier´s bad lies above today´s glaciations limit. Thus Iceland´s bigges icecaps exist thanks mainly to their own thickness. This is best seen at Langjökull where a mere 5% of the underling surface is above the snow line.

5.2 Past changes in Icelandic glaciers.

During the Climate Optimum 7000 years ago, the Pleistocene ice still remaining over Icelanc disappeared. From this time until 3000 years ago Iceland´s climate was warmer and drie than at present. The island was glacier free during this period (with small mountain glacier possibly existing on the country's highest peaks).

3000 years ago the climate condition deteriorated resulting in cooler and wetter weather During this period glaciers reappeared in Iceland. Two outstanding periods of glacier growtl have been identified during this time. The first is the climate deterioration around 500 B.C. which was the onset of the Subatlantic time. The climate was colder and precipitatior increase causing glaciers to edge downward to lower lying areas. The outermost moraines o Kvíárjökull and Svínafellsjökull probably stem from this period. In other areas the glacier grew to their present day size and in some case exceeded their current size.

During the period from 700-1300 A.D. the climate improved and glaciers in Iceland receded Manny of the areas that are currently glaciated were prosperous farmlands at the beginnin of settlement around 800 A.D.

The second period of glacial growth was between 1300- 1900 A.D. This period is called th Litle Ice Age . During this period some glacial outlets advanced around 10-15 km reclaimin farmlands and built up areas. The snow line crept down from 1200 m to 700 m in som areas. For steeper outlets the advance culminated in the 1750s but for broader lobes of th larger ice caps the maximum was reached between 1850 and 1890.

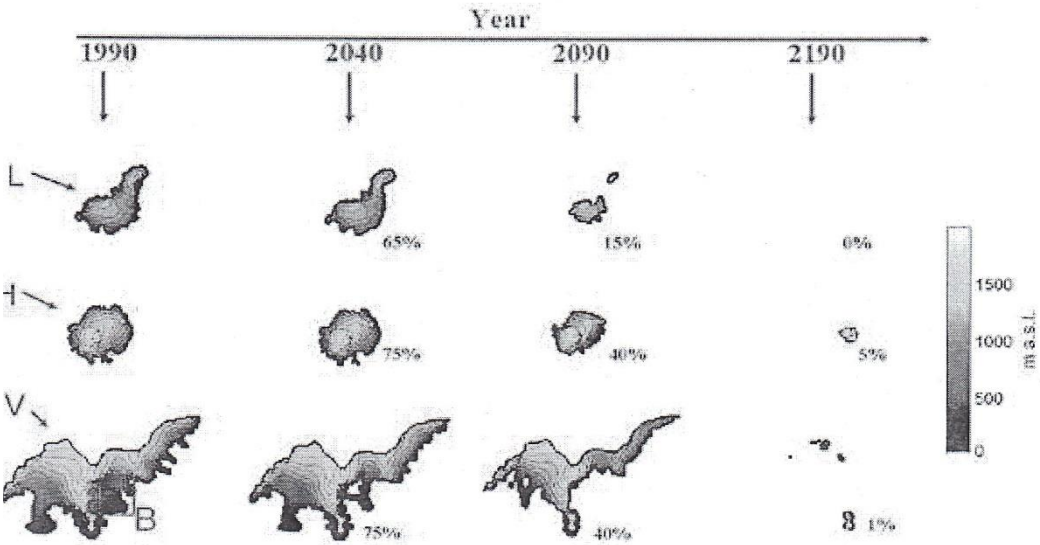
During the 1890s a general recession began in Iceland´s glaciers and became very rapid afte 1930. However after 1940 summers became coolers so glaciers retreated more slowly anc some outlets started advancing around 1970. Since 1985 warmer climate has prevailec resulting in an increased rate of retreat of the glaciers. The important factor in this is ar increase in summer temperature that has resulted in higher summer melt. Now long-terr change in precipitation has been observed. Since 1890 the leading outlets of Vatnajökul have drawn back 2-5 km and the ice cap volume has decrease 300 km^3. Currently the southern margin of Vatnajökull is retreating on average 100 m/year.

5.3 Future changes.

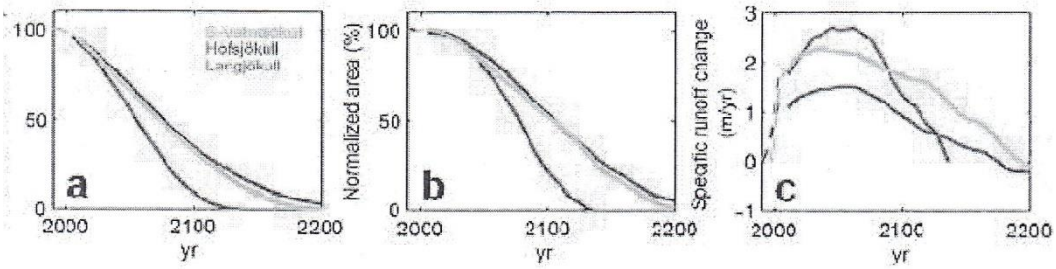
Future changes were explored in the paper on Iceland´s climate. The fallowing i summarized there:

- Sea temperature will increase around the island. The magnitude of this increase i uncertain and depends to a large extent on vertical mixing of the ocean water.
- Sea ice from Greenland will disappear completely from Icelandic waters in lat summer. The amount of Icebergs may however increase.
- The size and volume of glaciers will decrease drastically (most glaciers almost gone i 2100) (figure 5-1 and 5-2). Low rising flat domes (e.g. Langjökull) will decrease in siz more rapidly than other glaciers.
- The number of marginal glacial lakes will increase and spring floods from glaciers wi be bigger and more catastrophic. To begin with the bed load of glacial rivers wi increase but as their flow decreases with smaller glaciers so will the bed loa decrease.
- Geographical location of glacial river channels will changes
- Isostatic re-bounce will cause land lift in certain areas but may in more distal area cause the lowering of land.
- The reduction of ice mass will cause increased production of magma at the boundar of the mantel and the crust which in turn will increase volcanic activity and possibl induce long-lasting flood eruptions (shield volcanoes)
- The sporadic permafrost found within the interior of Iceland will disappear.
- Very large changes in Iceland's flora and fauna both on land and in the ocean ar predicted. Species that currently identify milder climates will become permaner inhabitants. At the same time species that prefer colder climates disappear. Thi trend has already been observed in vegetation, insect fauna and birdlife and i expected to be accelerated in the coming decade. The overall impact is not sure bu some important species will be lost at same time new beneficial species will b introduced. The greatest worry concerns the interdiction of parasitic spices to th

environment (many of which could not thrive in the colder climate of the 20th century[3].



re 5-1: Predicted changes in the three largest glaciers in Iceland based on estimated warming and calculated changes inter accumulation during the 21st century. On top Langjögull, middle Hofsjökull and at bottom the southern margin atnajökull. The figures shows that given a relatively mild warming during the 21st century. Langjökull (which is a flat d glacial dome) will almost disappear (Source: Halldór Björnsson et. al. 2009).



re 5-2: Predicted changes in volume (a), area (b) and runoff in the next 200 years for Iceland's three largest glaciers. If the most conservative forecast for warming are realised all Icelandic glaciers will disappear during these 200 years.

Jökull	Flatarmál (km2)	Rúmmál (km3)	Mesta þykkt (m)	Hæðarbil (m a.s.l.)
Langjökull	925	195	580	390-1290
Hofsjökull	880	200	760	600-1790
Vatnajökull	8100	3000	950	0-2100
Suðurhluti Vatnajökuls	3170	1279	900	0-2100

e 5-1: Presentday parameters for the three largest glaciers in Iceland (the lowest line is for the south margins of ajökull). First column gives name of glacier, second gives area, third gives volume, forth gives greatst ice thickness the final gives elevation ranges of the glaciers in question (Source: Halldór Björnsson et. al., 2009).

s important to note that only the most important changes are listed here.

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