An Estimate of Drift Ice and Temperature in Iceland in 1000 Years

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ABSTRACT

A fairly good correlation is found between annual temperature and the incidence of drift ice in Iceland. This relation is used to estimate the temperature in Iceland in the period 1591–1846. Furthermore, the temperature and ice incidence, in the years 1591–1969 (estimated and measured) are found to be correlated with the frequency of severe years, defined in a special manner. This makes it possible to estimate the temperature and ice incidence in the period 930–1591 A. D.

The graphs of temperature and ice seem to be in good accordance with the results of analysis of O^{18} *in a glacier ice core at Camp Century, Greenland.*

INTRODUCTION

The following investigation was presented in a preliminary form at a conference on the climate of the eleventh and sixteenth centuries, held in Aspen in Colorado, June 16–24, 1962. A short review of these preliminary notes was published by *Tatsuro Asai* (1967). The procedure of investigation is here slightly modified, but the conclusions are generally the same as in the original paper.

MATERIAL USED

Fig. 1 gives a general scheme of the material used in this investigation.

The first source is temperature measurements dating back to 1846. As a temperature index the annual mean temperature of two stations, Stykkishólmur (65°05′ N 22°44′ W) and Teigarhorn (64°41′ N 14°21′ W) was used. The observations started in 1874 at Teigarhorn, and according to the experience since then the most probable mean of the two stations for the period 1846–1873 can be obtained by adding 0.1° C to the annual temperature in Stykkishólmur for that period. This mean temperature should be rather representative for the country, Stykkishólmur being affected by the mild Irminger current at the west coast, but Teigarhorn being rather under the influence of the cool East-Iceland Current. A more detailed running mean of this mean temperature is shown in Fig. 5.

The second source, shown broadly in the middle of Fig. 1, is the annual number of days affected by ice on the coast, counted in months. A more detailed running decadal mean of the annual ice incidence is shown in Fig. 5, dating back to about 1590. For the years 1781–1915 the data collected by *Thoroddsen* (1916–1917) were used, without any amendment, as read from a diagram in his book "Árferði á Íslandi í 1000 ár". For the period 1591–1780, Thoroddsen considered it impossible to draw such a diagram for every month. On the other hand, it seems possible to estimate from his book the annual ice incidence, partly based on *indirect* information regarding general weather in Iceland. In general this means that one has to increase the apparent incidence of ice. One example may serve to justify this statement. For the year 1758 the annals tell there was no drift ice at the coast, and that this had hardly occurred in memorable time. Even if no ice is mentioned in the annals for 1751, 1752 and 1753, it is therefore hardly justified to consider them to be ice-free. A word of warning must however be said here about this method of counting the days with incidence of ice. It is a matter of definition, whether we only count days with rather heavy ice, seriously affecting navigation, or whether we

count every day, when even a small amount of pack is sigthed somewhere at the coast. This makes a great difference in many years, particularly with light ice. It seems likely, that even two or three months of such light ice per year might not have been noted in the colder period of the nineteenth century. For the period 1591–1780 standardization of the ice records was aimed at as to make them comparable with Thoroddsens records for the years 1781–1915. Since the Meteorological Office of Iceland was established in 1920, the ice records have been much more detailed (Fig. 3) and in a continuous graph of the ice incidence as in Figs. 1, 5 and 6, it was therefore inevitable to reduce the observed ice amount of the last decades considerably. This has to be remembered in looking at all these diagrams, but it must also be admitted that this fact reduces considerably the confidence of these ice records.

The third type of data is shown schematically in the lowest graph of Fig. 1. This gives the number of severe years in every decade. The definition of such severe years is that there has been starvation, people dying from lack of food, or that the drift ice has reached the SW-coast of Iceland. In order to make the graph continuous the number of severe years is also defined for those decades when no such year occurs. If a severe year occurs in the next decade before or after, the period between severe years is thus considered to be 20 years, and therefore this number is ½ for the decade in consideration. The scale of the severe years is not linear in the drawing. It was considered possible to draw this graph for a much longer period than the graph for decadal incidence of ice. When historical information is scanty, one may expect unusual events such as severe starvation or drift ice surrounding the country to be recorded, even if the annual amount of ice is not mentioned. Sometimes it is also evident that the record of severe years is complete for a long period. Thus it is written that famine occurred about 976 AD, and that another famine occurred 80 years later. However, in the 15th century there is a bad gap in the written history, and therefore that part of the graph was omitted in Fig. 1.

Now we shall look for the correlation between these three factors in Fig. 1. Using this correlation we attempt to extrapolate the temperature and ice graph for most of the era of human settlement in Iceland. The result is shown in Figs. 5 and 6.

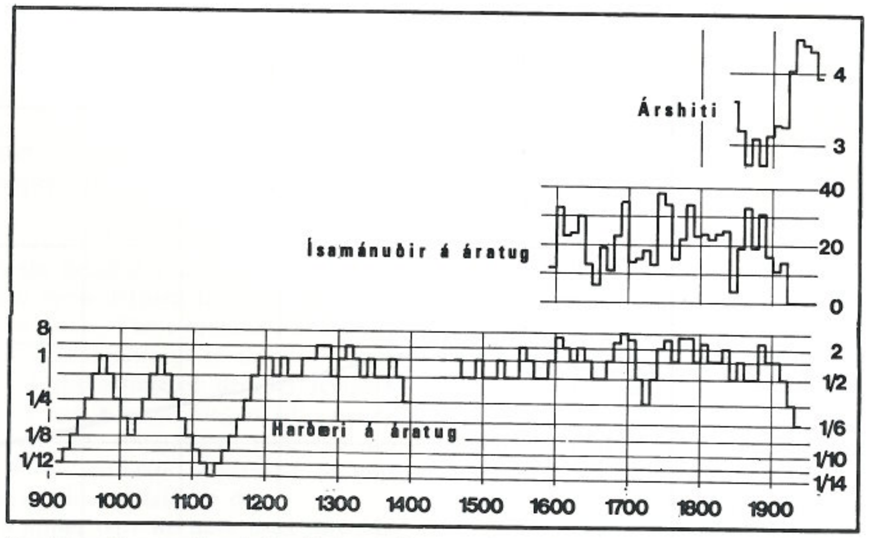

Fig. 1. A schematic graph of the information used in the paper. Top: Mean temperature of Stykkishólmur and Teigarhorn: Center: Decadal ice incidence in months. Bottom: Decadal number of severe years.

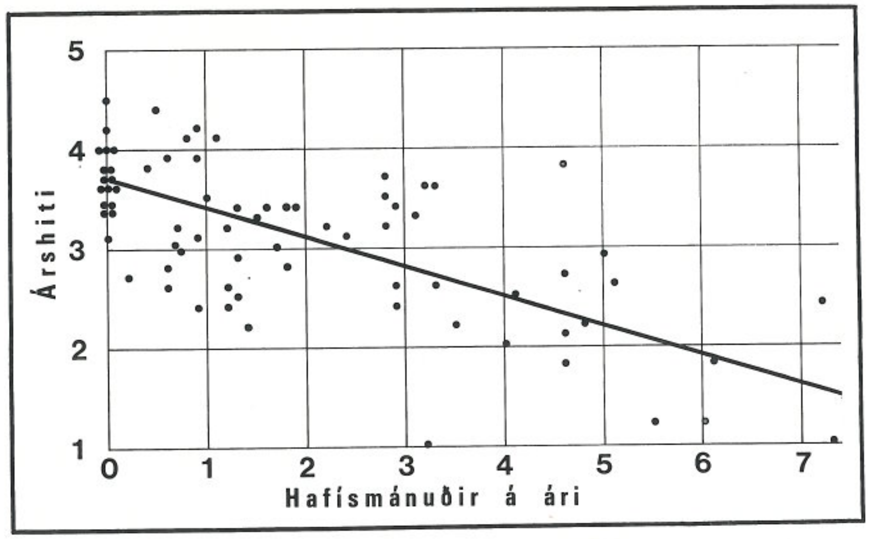

Fig. 2. Correlation of annual temperature (vertical scale) and ice incidence in months (horizontal scale) 1846–1919.

CORRELATION OF TEMPERATURE AND ICE INCIDENCE

The relation between annual temperature and annual ice incidence for the period 1846–1919 is shown in Fig. 2. The correlation coefficient is – 0.68, and it is significant to the 0.001 level. The linear regression is also shown. According to this the annual temperature may be estimated to be 3.7° C, whenever the ice duration is 0.

The error of the estimated value will be reduced approximately by a factor of 3, if we use the decadal ice and temperature. Then the error in temperature should be less than 0.3 in about 90% of all cases.

The corresponding scatter diagram for the period 1920–1969 is shown in Fig. 3. Important deviations will be noted here. The correlation coefficient is lower, – 0.39. The explanation may be that very few years of heavy ice occur in this period, but still this correlation is significant to the 0.005 level. Another point

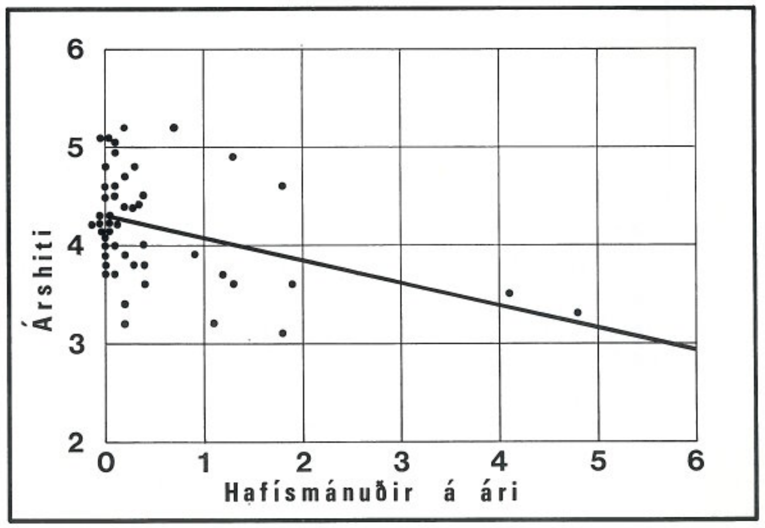

Fig. 3. Correlation of annual temperature (vertical scale) and ice incidence in months (horizontal scale) 1920–1969.

is that now the regression line is different, generally indicating higher temperature for a given ice incidence than in the period 1846–1919. The reason is probably much more thorough observations of the ice, provided by the Icelandic Meteorological Office which was established in 1920. The graph in Fig. 3 will give at least 0.6° C higher temperature than the graph in Fig. 2, if used to estimate the temperature of the period 1591–1846. There is however no reason to think that the ice records before 1846 are more complete than in the period 1846–1919. On the contrary, as mentioned before, some increase of the apparent incidence of ice in the period 1591–1846 is probably necessary in order to make that observation series comparable with the period 1846–1919. Having estimated the annual ice incidence as explained before the graph in Fig. 2 is used to estimate the temperature 1591–1846. The result is given in Fig. 5, showing by the dotted line the estimated decadal running mean of the temperature. The full line after ca. 1850 gives the observed temperature.

CORRELATION OF TEMPERATURE AND SEVERE YEARS

Having now estimated the temperature of every decade from 1591 up to date, we can compare it with the decadal number of severe years in this period.

A scatter diagram indicated that there was approximately a linear relation between the decadal temperature and the expression

$$1 / \sqrt{H},$$

where H is the decadal number of severe years, as they have been defined here. In Fig. 4 we see this correlation. The correlation coefficient is 0.76, and it is significant to the 0.001 level. The error of the estimated decadal temperature is 0.3 or less in some 84% of all cases. It must however be emphasized that the uncertainty of this estimate is greatest in mild periods, partly due to lack of data.

In Fig. 6 upper part we have used this relationship to estimate the temperature in the centuries before 1591. The graph has though been smoothed so as to give the running mean

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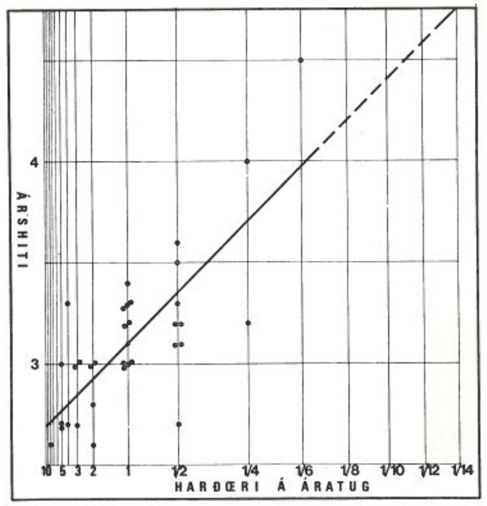

Fig. 4. Correlation of temperature and frequency of severe years (horizontal scale).

temperature of 30 years, one value plotted for every decade, except for a period in the 15th century when information is considered to be too meager. This graph only gives the broad lines of the history of temperature climate and weeps out all the shorter fluctuations. For comparison the temperature graph after 1600 AD is smoothed in the same way.

CORRELATION OF SEVERE YEARS AND ICE INCIDENCE

In order to estimate the ice incidence in the years before 1591 we use the correlation between severe years and ice incidence in the period 1591 to 1940. The regression equation turns out to be:

$$\text{Ice incidence pr. decade} = -1.4 / \sqrt{H} + 3.4$$

The correlation coefficient is 0.69, significant to the 0.001 level. In Fig. 6 lower part we have used this relationship to estimate the ice incidence in the period before 1591. The values have been smoothed so as to give the 30 year running mean, one value plotted for every decade. As in the case of the temperature the values after 1591 have also been smoothed in order to give 30 year running means.

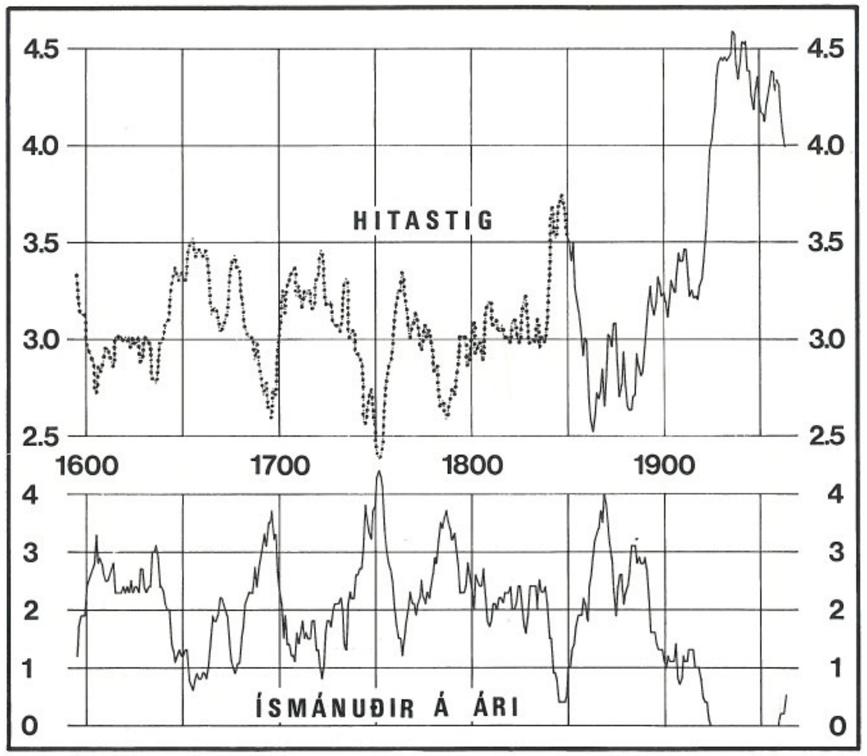

Fig. 5. Decadal running means of temperature (top) and ice incidence in months per year (below). Estimated values: dotted line.

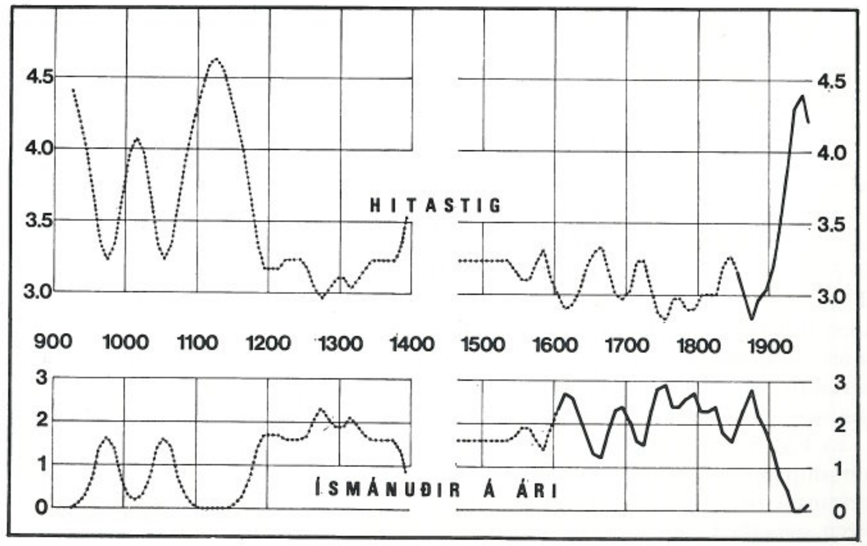

Fig. 6. Running 30-year means of temperature (top) and ice incidence in months per year (below). Estimated values: dotted line.

DISCUSSION

It must be emphasized that the temperature and ice graphs in Figs. 5 and 6 are only based on a limited type of data. Although this data is the most important, there are various possibilities to check the conclusions with the aid of historical documents and geological data. A few possibilities will be mentioned here.

The most important check available for the time being is the oxygen isotope analysis of glacier ice core in Camp Century, Greenland (*Dansgaard* et al. 1969). Fig. 7 gives the variation of the O^{18}/O^{16} ratio during the last 1000 years. In general, the correlation with the temperature in Fig. 6 is remarkable, high ratio of O^{18} being associated with high temperature, as would be expected. The strong cooling in the 12th century is very marked in both cases, and it is in fact the main characteristic of the climate during the last 1000 years. Shorter climatic fluctuations cannot be expected to be similar in Iceland and this remote place in Greenland, some 2000 km away, and therefore one should only compare the broad lines in these graphs. For example, the very warm period in Iceland in the years 1920 to 1964 seems to have been quite different at the west coast of Greenland where the 1920's and 1930's were particularly warm, but a cooling set in before 1950.

The graphs in Figs. 6 and 7 seem to throw a new light on the socalled "little ice age" which is maintained to have begun in the 16th century and lasted until about 1900. It is true that in both graphs this period is a little colder than any other during the last 1000 years. But it is not nearly as marked as one might have expected. It must though be remembered that a certain cooling may have more serious economic consequences in a cold period than in relatively mild climate. For example the number of famine years then rises much more rapidly for every degree of cooling.

The most important check of the temperature graph during the last 250 years is the temperature record of Central-England, published by professor *Gordon Manley* (1959). A 30-year running mean of the Central-England temperature is shown in Fig. 8, together with the corresponding part of the Icelandic estimat-

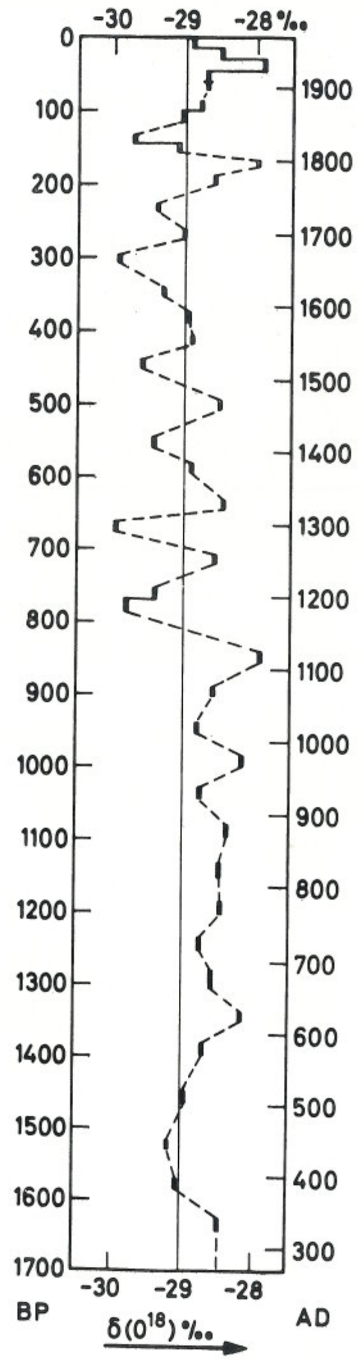

Fig. 7. Variation of the O^{18}/O^{16} ratio in Camp Century, Greenland. After *Dansgaard et al.* (1969).

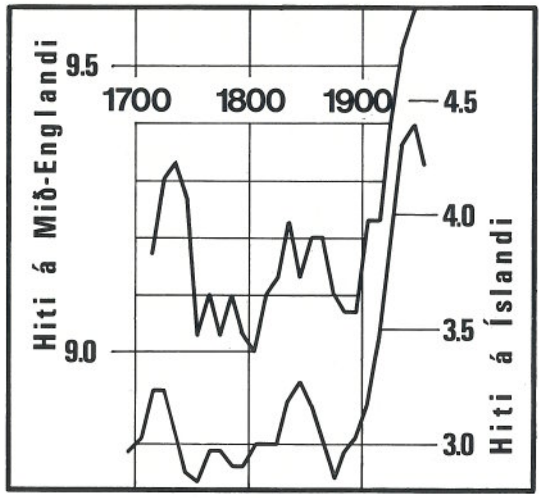

Fig. 8. A 30 year running mean temperature of Central England (*Manley* 1959) (top) and Iceland (below).

ed temperature. The correlation is remarkably good.

Some information regarding Icelandic glaciers during the last centuries is represented in Fig. 9, by *Thorarinsson* (1956). Even if the graph is not fairly accurate before regular measurements begin about 1930, it indicates strongly a climatic improvement in this century but very little general variations from 1700 to 1900, in good accordance with the temperature graph.

The number of famine years is an important basis of the temperature and ice graphs in Fig. 6. *Steffensen* (1958) and *Thorarinsson* (1956) have pointed out that the stature of Icelanders, as indicated by bone measurements, is highly correlated with the economic conditions of the nation in the past centuries. The curve of the male stature, obtained in this manner, is very much parallel to the curve of severe years.

Earlier estimates of the drift ice incidence at Iceland are generally quite different from the graph in Fig. 6. According to *Koch* (1945), the average ice incidence in the 13th century was 2–5 weeks in every 20 years, i.e. 0.2–0.6 months per year, whereas in my graph the corresponding annual ice incidence is 1½ to 2½ months. This great difference is in the author's opinion due to the fact that in his graph Koch only counts the ice directly mentioned in historical documents. In these times only heavy ice years are mentioned, the contribution of light and moderate ice years being mainly omitted.

The mild period before 1200 indicated by the graphs presented is confirmed by many historical data. After the settlement about 870 grain was grown in most parts of the country, but in the fourteenth century it was only grown in a few places in South-Iceland and then only barley. In the sixteenth century grain growing had been completely abolished. *Thorarinsson* (1956) has pointed out that glaciers must have been much less extensive at the time of settlement than later on.

The most remarkable possibility of testing the temperature and ice graphs in Figs. 5 and 6 lies probably in core drilling in the Icelandic glaciers and analyses of heavy oxygen or hydrogen. This work has now just begun, and promising results have already been obtained (*Árnason* 1969). A short ice core from Bárdarbunga has been analysed and it shows a remarkable correlation with temperature variations since about 1918. A very interesting feature is that tephra layers in the glacier ice give a fairly reliable dating of the ice, possibly during the last 1000 years.

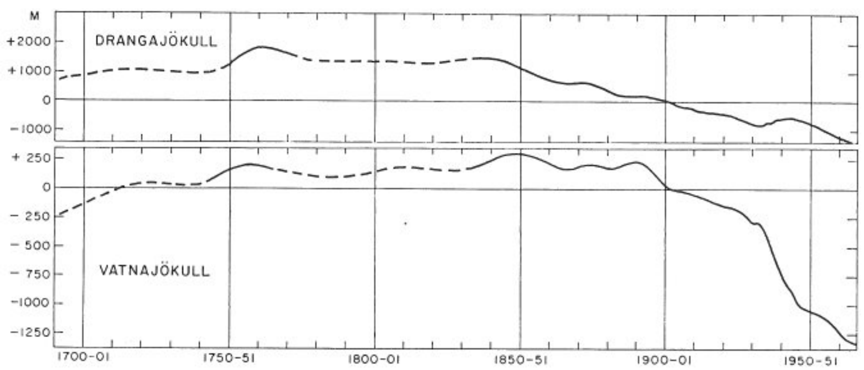

Fig. 9. Length variations of Icelandic glaciers. (After *Thorarinsson*, 1969).

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