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Advection of Climate by Ocean Currents

The hypothesis I want to discuss is that heat fluctuations in ocean currents can be traced from year to year and even for many years. These heat fluctuations will in turn affect the air temperature anywhere on the track of the ocean current. A forecast of climate during several years should thus be possible, at least in favourable areas: Iceland seems to be one of these localities.

A classical example of climate advection by ocean currents is seen in Figure 1 from the great work of the Norwegian oceanographers B. Helland-Hansen and F. Nansen, "The Norwegian Sea" (1909).

The uppermost graph in Figure 1 illustrates the temperature fluctuations from year to year in the waters off Sognefjord in western Norway. The next graph shows the temperature fluctuations one year later at Lofoten off northern Norway. Graphs III and IIIa show on the other hand the sea temperature fluctuations one year later still in the Barents Sea, and graph IV gives the simultaneous variations of the ice-free area in the Barents Sea.

The conclusion of Helland-Hansen and Nansen (1909) is that the heat in the currents of the Atlantic water off Norway is so conservative that it can be recognized one year later at Lofoten and two years later in the Barents Sea, having travelled some 1000 nautical miles.

OCEAN CURRENTS REACHING ICELAND FROM THE NORTH

It has been shown by Malmberg (1969) and others that the temperature and salinity conditions in the waters northeast of Iceland fluctuate, and that these fluctuations are strongly correlated to the incidence of drift ice. Furthermore we know, as can be seen on Figure 2 by Professor Thórarinsson (1956), that there is a close correlation between air temperature and drift ice in Iceland, at least in the long run.

In the light of Helland-Hansen's and Nansen's observations (1909) we are now faced with an interesting problem: Can we trace the anomaly of the oceanographic conditions northeast of Iceland to previous conditions in the waters far to the north of Iceland, possibly several years ago? In other words, is it possible to forecast the ice conditions and/or the temperature climate well in advance? This will now be discussed (see Figure 3).

The velocity of climate advection by ocean currents found by Helland-Hansen and Nansen was approximately 1½ nautical miles a day. This is much less than the velocity in the strongest current along the continental shelf of Norway.

We should therefore expect the advection of heat from the north towards Iceland to be far slower than the velocity in the relatively narrow river of the East-Greenland current along the Greenland continental shelf. In the broad area between Greenland, Iceland and Spitzbergen there are even some vortices making possible a stagnation of a great mass of sea for a considerable time. As an example it takes current bottles approximately half a year to reach Iceland from the area south of Jan Mayen, and 1–4 years from the area between Jan Mayen and Spitzbergen. The cold surface currents from the Beaufort Sea flowing across the North Pole may reach the area north and northeast of Iceland (see Figure 4). It is generally thought that their velocity is some ½–1½ nautical miles a day. A journey of 5000

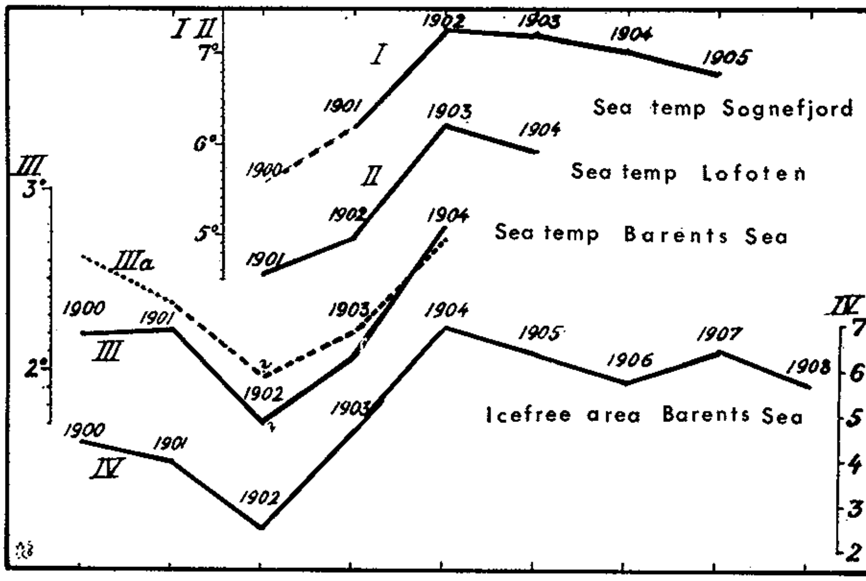

Fig. 1. A graph indicating a time lag of climatic variations in the direction of the sea current along the Norwegian coast, from Sognefjord towards the Barents Sea. (After Helland-Hansen and Nansen).

km from the Beaufort Sea to Iceland would thus take a period of 5—15 years approximately. This discussion should be kept in mind when we look for possible climatic anomalies in the north, being advected towards Iceland be means of sea currents.

ANNUAL ICE FORECASTS IN ICELAND

This spring the drift ice off Iceland has been less than in any other ice season since 1966. This was indeed forecast in the beginning of December last year. The moderate ice in 1970 and the heavy ice in 1969 was again forecast quite well.

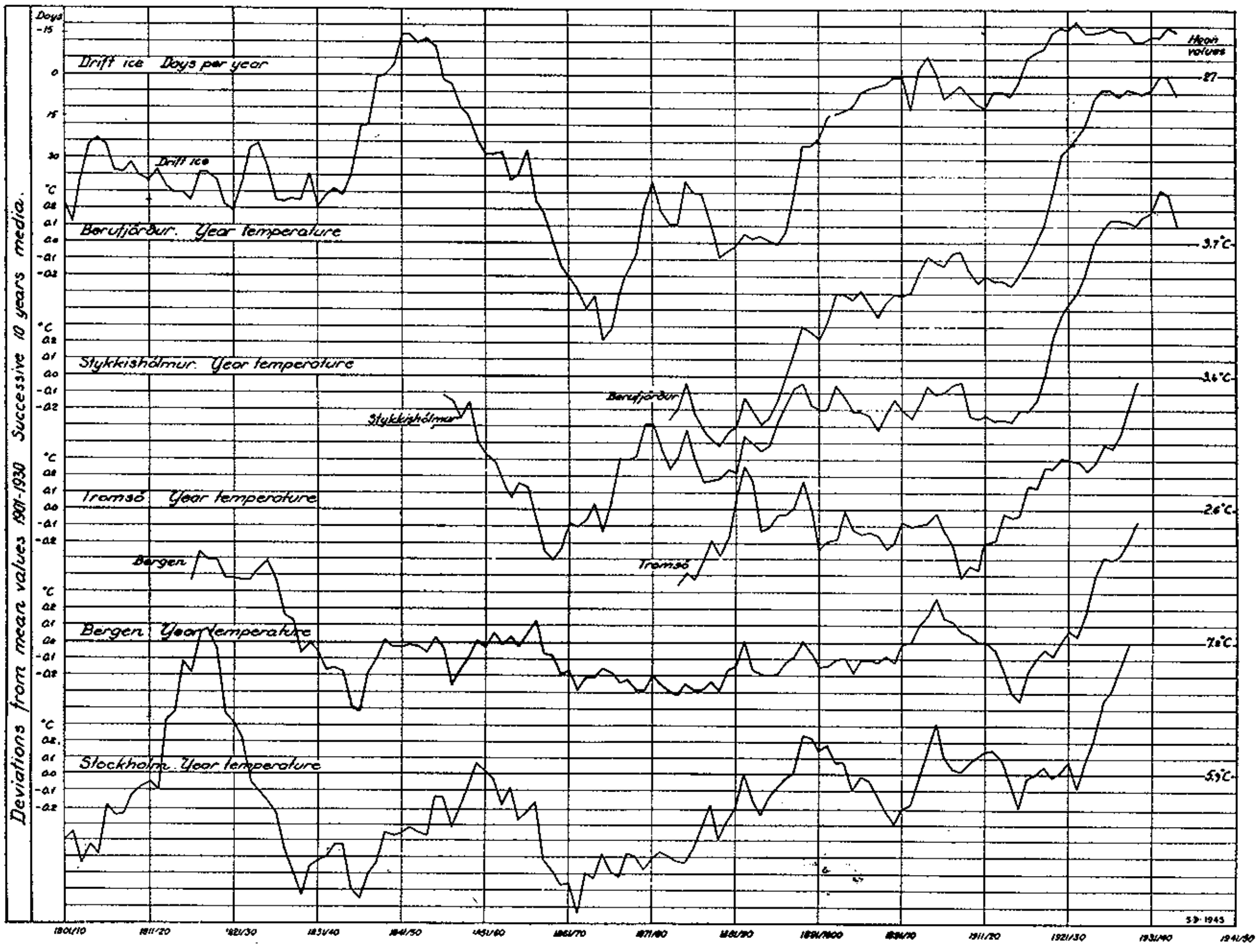

Fig. 2. Temperature graphs from some Icelandic and Scandinavian stations compared with the Iceland drift ice graph. (Thorarinsson).

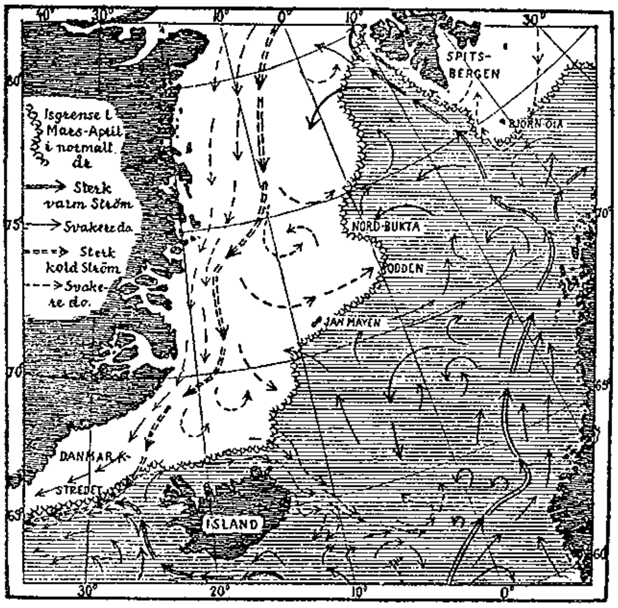

Fig. 3. Currents and ice conditions in late winter (Nansen '24).

These three seasonal forecasts were all based on the relationship between the temperature at Jan Mayen, 500 km NE of Iceland, and the sea ice at Iceland some half a year later. This oblong island of Jan Mayen with the magnificent volcano Beerenberg in one end like a huge bow of a battleship, was, according to Icelandic Annals, discovered in 1194 and given the striking name Svalbarði, which means "Chilly iron-clad". A somewhat similar name, Svalbard, was in the 20th century given to Spitzbergen by the Norwegians who probably misunderstood the Icelandic Annals. But let us now look at the forecasting relationship, Figure 5.

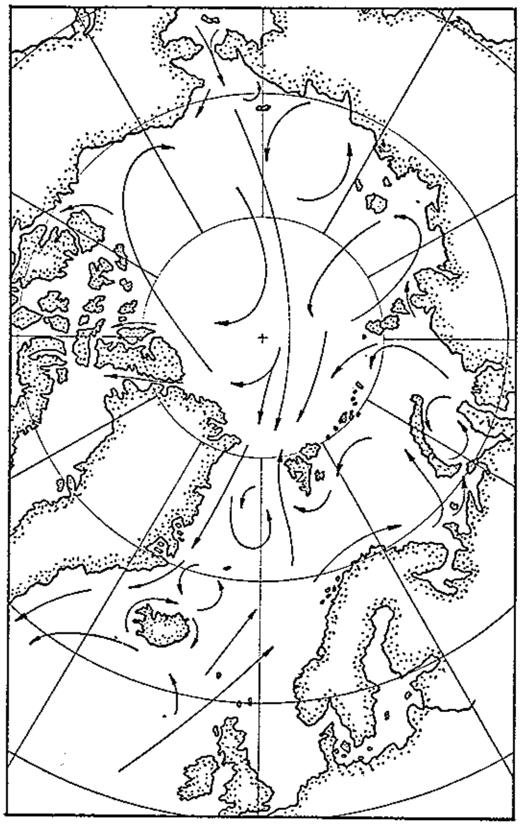

Fig. 4. Surface currents in the Arctic Ocean.

On the abscissa we have the weighted air temperature at Jan Mayen in the months June to November, September to November weighted 50% more than June to August. On the ordinate we have the annual incidence of drift ice at Iceland, counted in months. The correlation coefficient is more than 0.9 between the actual ice and the ice as estimated from the smooth curve. The physical explanation of this correlation seems to be possible in the light of the discussion of the heat advection by the ocean currents. The June to November air temperature at the island of Jan Mayen reflects to a high degree the simultaneous temperature of the surrounding sea. This correlation is demonstrated by the relationship between air and sea temperature at the weather ship M southeast of Jan Mayen, where it is possible to estimate the mean sea temperature of June to November with a root-mean-square error of ± 0.14 degrees Celsius, basing the estimate on the air temperature only. Since the sea temperature is also strongly correlated to the salinity, we can thus estimate the oceanographic conditions around Jan Mayen in the

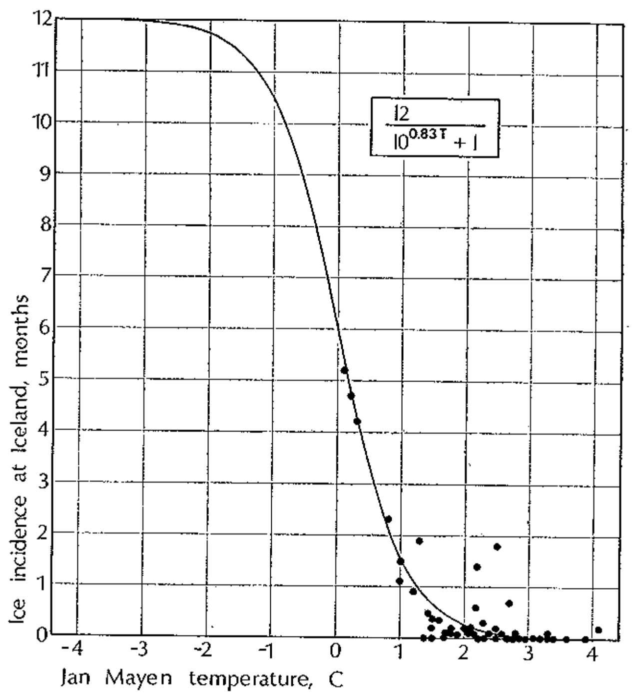

Fig. 5. Relation between the weighted June–November air temperature at Jan Mayen and the ice incidence at Iceland in the following ice season.

period June—November. And since the travel time of these Jan Mayen waters towards Iceland is of the order of half a year, a forecast for the ice season, usually having its peak in April and May, is thus possible. It needs no explanation that it would be useful to know something about the coming ice season. It seems even to be justified to forecast the air temperature anomaly on the coast af North- and Northeast-Iceland during the spring months, on the basis of the Jan Mayen temperature in the preceding summer and autumn. Furthermore, the annual temperature in SW-Iceland seems to depend somewhat on the temperature of the NE-coast in the preceding year.

MULTI-YEAR TEMPERATURE FORECASTS FOR ICELAND, BASED ON SPITZBERGEN TEMPERATURE IN PRECEDING YEARS

We have a long series of Spitzbergen temperature, starting in 1894 and only interrupted in World War II. The observations before World War II were made at many different stations, but the series was analyzed and homogenized by Birkeland and Hesselberg (Geofysiske Publikasjoner). Figure 6 gives the running ten year mean of the Spitzbergen temperature (dotted line, scale to the left), and at the same time the corresponding graph for the Iceland temperature. An inspection of the curves indicates that the Iceland graph lags some 2—3 years behind the Spitzbergen temperature. This becomes somewhat more evident in the lower part of the figure where we have displaced the Iceland temperature 3 years back in time so the graphs coincide to a higher degree.

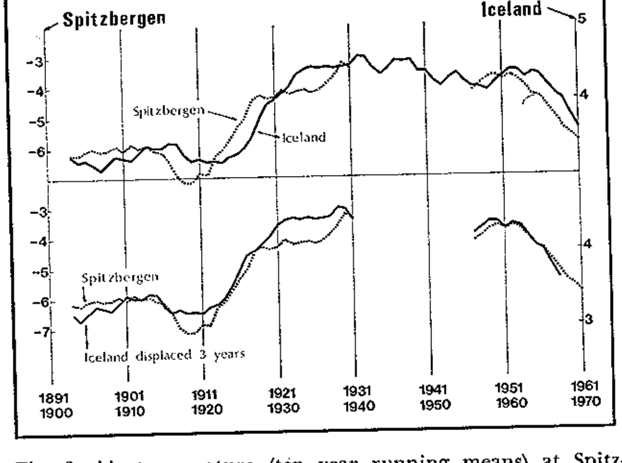

Fig. 6. Air temperature (ten year running means) at Spitzbergen and Iceland. In the lower graphs the Iceland temperature is displaced 3 years back in time. The improved correlation indicates a time lag.

This suggests that the Iceland temperature during the next years, let us say three years, may be expressed by means of a regression equation of the type:

$$I_{1-3} = aS_{-1} + bS_{-2} + cS_{-3} + dS_{-4} \text{ etc.}$$

where I_{1-3} is the mean temperature anomaly in Iceland during the next three years, S_{-1} is the anomaly of the annual temperature in Spitzbergen during the last year, S_{-2} in the second last year etc. a, b, c and d are coefficents to be determined statistically. The regression analysis gives the values:

$$a = 0.104$$
$$b = 0.117$$
$$c = 0.086$$
$$d = 0.054$$

It is interesting to note that the second last year in Spitzbergen gives a higher contribution than the last year to the future three years in Iceland. This again indicates a time lag of three years.

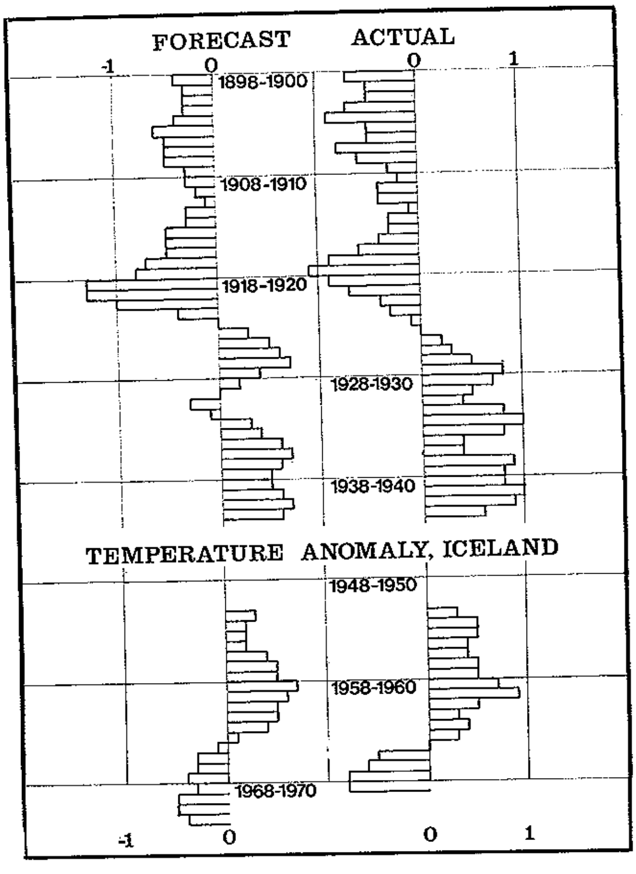

Fig. 7. Running three-year mean temperature in Iceland. Left part illustrates the *computed* values according to Spitzbergen temperatures in *previous* years. Actual values to the right.

In Figure 7 we see the comparison of forecast and actual 3-years temperature in Iceland according to the formula. The correlation coefficient is 0.85, which is a significant value to the 0.001 level. And it is noticable that this is even a *higher* value than the correlation of *contemporary* values of 3-year mean temperature in Spitzbergen and Iceland. The main importance of this formula is however that it would have provided a useful forecast even when the temperature was rapidly rising after 1920 and also when it was falling after 1960. And from the temperature forecast it would have been possible to derive also a forecast of the changing ice conditions.

The explanation of this relationship is in my opinion the gradual advection of anomalies of oceanographic conditions from the area of Spitzbergen towards Iceland. Some of the sea masses near Spitzbergen may reach Iceland in the first year if they are lucky enough to be caught by the E-Greenland current and after that by the E-Iceland current. Other masses flow gradually into the great cyclonic gyre between Jan Mayen and Spitzbergen, stagnating there for 1—4 years approximately before they affect the North-Icelandic waters.

According to this prediction formula, no substantial warming of the climate in Iceland is to be expected in the three years 1971—1973, compared with the period since 1965.

CLIMATE ADVECTION FROM NORTHWEST-GREENLAND TO ICELAND

The last example I want to discuss, possibly supporting the hypothesis of climate advection by ocean currents, is a comparison of the climate fluctuations in Northwest-Greenland and Iceland during the last 350 years shown in Figure 8. The first graph is after Dansgaard et. al. (1969) and gives the ratio of the oxygen isotope O^{18} to the normal oxygen O^{16} in glacier ice at Camp Century, 225 km E of Thule in NW Greenland. This ratio is considered to be a good indicator of the prevailing air temperature when the precipitation was condensed. The next graph is taken from my paper in Jökull (Bergthórsson, 1969) and is based on the relation between drift ice and temperature in Iceland in the last 120 years. It gives the estimated 10 year running means of the temperature in Iceland. It should be mentioned that these two graphs are independently derived.

There are of course some possible errors in these graphs. It is, however, rather encouraging to realize the general resemblance of the two curves. The wavelength of the most prominent fluctuations is very similar, some 50 years on the average. The well-known heat wave in the 20th century stands out clearly in both curves. It however occurs approximately 10 years earlier in Greenland than in Iceland. And a very similar time lag, of 10—15 years, can in fact be recognized in most of the earlier fluctuations. Superimposed on these greater waves are some variations which seem to occur almost simultaneously in both countries, in the 17th, 18th and 20th century, and possibly also in the middle of the 19th century.

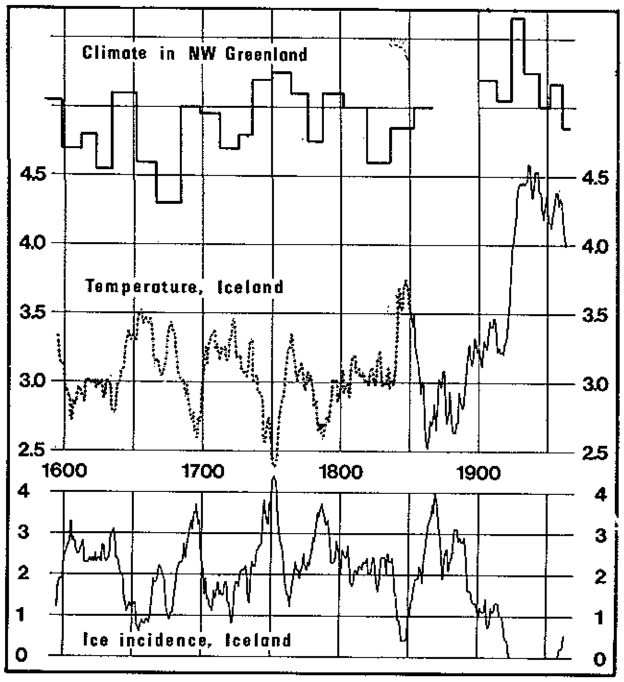

Fig. 8. Climate in NW-Greenland and Iceland. Uppermost graph: The ratio O^{18}/O^{16} at Camp Century (after Dansgaard). The lower graphs give the estimated air temperature and sea ice conditions at Iceland during the last 400 years.

To return to the hypothesis of advection by the ocean currents, this lag is of the same order as the supposed drift time of the waters from the Beaufort Sea to Iceland. The frequent occurrence of this kind of lag might indicate that the climate in Northwest-Greenland is closely correlated to the climate in the Beaufort Sea, even if simultaneous temperature anomalies seem to occur in Iceland and Greenland. It is to be hoped that further drilling in glaciers of Greenland, Iceland and other countries, e. g. Spitzbergen, can give us some valuable information concerning the history of climate in these areas.

I have in this talk been discussing the hypothesis of climate advection due to ocean currents. Because of lack of oceanographic data I have been forced to use mainly indirect methods to test this hypothesis. A more direct test would of course be a continuous analysis of oceanographic properties, both in time and space. This reminds us of the need for an international coordination of oceanographic observations. Hitherto these observations have been mainly restricted to expeditions, organized independently by single institutions. In this respect the meteorologists have gone a step further with their synoptic mapping of the global atmosphere at different levels twice a day. Such a three-dimensional analysis of the oceans, let us say four times a year, would be a great progress. But while we are waiting for such an undertaking it seems to be justified to use all available pieces of information, direct or indirect, to study the interaction of sea and atmosphere.

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DISCUSSION

Malmberg: Ladies and gentlemen. I want to add some information on the currents in the Iceland Sea with reference to the lecture of Páll Bergthórsson. Current velocities obtained by means of direct current measurements in the slope area northeast of Iceland in *June 1970* agree fairly well with previous findings from drift bottle experiments and dynamical calculations (Stefánsson 1962 – North Icelandic Waters, Rit Fiskideildar 4, 269 pp.). A residual current of about 10 cm/sec with southeasterly direction was obtained, but in *September 1970* a residual current up to 30 cm/sec was obtained at the same position with an almost easterly direction. In *March 1971* we again found currents of 30 cm/sec at the same place. These dates may be useful in spite of short measuring periods since no other data on direct current measurements are available from this area, but further studies are planned farther offshore.

Secondly I have a question about the 5 to 15 year periods or time lags of the characteristics of the water masses. I believe that the water masses must change on their way from one season to another and from year to year due to renewal and through climatical changes. Thus it seems to me to be a rather long time for the currents to maintain their characteristics. I want to ask my friend Pál Bergthórsson about this point.

Bergthórsson: Well, this is in fact the same question that I was asking myself, whether it could be that the waters can keep their characteristics for such a long time. The only answer I have is, that there are some indications in these graphs. But of course when we are considering these water masses in the Arctic it is difficult to imagine how this can occur. We know that the coverage of the ice is rather constant from year to year so it cannot be the coverage that is different originally, and the fluctuations in the coverage cannot be so important. But, on the other hand, there might be variations in the thickness of the ice. In other words, the total volume of the ice carried by the current may be different from time to time, and it is possible that this property is conserved from year to year. If it is very thick after the winter it will also be rather thick in the autumn, other things being equal. The latent heat could thus be preserved. With a greater ice volume there is also probably less salinity in the uppermost layers, so that when these waters arrive to the sea north of Iceland there will also be less salinity in it, the ocean thus being more stable and allowing ice formation without sinking of the cooler surface sea.

Sigurdur Thórarinsson: Bergthórsson mentioned in his interesting lecture the drilling up in North West Greenland and the probable time lag between the temperature fluctations as revealed by the ice core up there as shown by Dansgaard and the climate in Iceland, and he stated that we have to wait for further drillings. I just wanted to inform the audience that next summer we plan such a drilling through our largest glacier, Vatnajökull, and in that glacier we happen to have a lot of volcanic ash layers, that possibly or probably can be exactly dated. So we have a hope of getting a more exactly dated ice core than they got in North West Greenland and it shall be interesting to see, how this Icelandic core compares with the Greenland one and whether we find this time lag. And speaking of climatic fluctuations, the glaciers react to these fluctuations and fluctuations in the glacier volume cause rising or sinking of the sea level. We know the period of glacier recession from about 1920 to about 1950 clearly showed up on the mareographs as a measurable rising of the sea level. I wonder if anyone knows if there have been any measurements or any statement of a sinking of the sea level as a result of the cold years of the last decade or so.