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Connections between oceanic conditions off N-Iceland, Lake Mývatn temperature, regional wind direction variability and the North Atlantic Oscillation

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ABSTRACT

The oceanic conditions off northern Iceland are governed by the relative strengths of northern and southern influences. The interannual hydrographic variations are described by data collected in spring from the Siglunes section off central N-Iceland. About 55% of the hydrographic variability there can be explained by local variations in wind frequency differences during January to May, namely (S+SE)-(N+NW). The mid-latitude meridional atmospheric pressure gradient variations, described by the North Atlantic Ocillation index, do not explain observed hydrographic variations off N-Iceland. Aquatic climate variations in Lake Mývatn, NE-Iceland, are most pronounced in the spring. These variations are connected to processes that affect the air temperature at Lake Mývatn in spring, which includes the oceanic temperature conditions off N-Iceland. The strongest connection is with regional (S+SW)-(N+NE) wind frequencies during the preceeding three months.

Keywords: Iceland Sea, Lake Mývatn, North Atlantic Oscillation, wind direction, hydrography, time series.

INTRODUCTION

Fronts between temperate and arctic influences, both in the atmosphere and the ocean, lie in the vicinity of Iceland. The Irminger Current branch of the North Atlantic Current carries relatively warm Atlantic Water and conditions there are relatively stable from year to year. The Irminger Current flows northward west of Iceland and splits in two at the Greenland-Iceland Ridge, where one branch swings west and south to form a cyclonic circulation in the Irminger Sea, but the other branch, generally smaller, rounds the northwest peninsula of Iceland and flows eastward on the shelf as the North Icelandic Irminger Current (Figs. 1 and 2). The hydrographic conditions on the shelf north of Iceland are characterized in terms of water masses of different origins; relatively warm and saline Atlantic Water, S>35, t>4 ˚C, cold low salinity Polar Water, S<34.4, North Icelandic Winter Water, S: 34.85-34.90, t: 1-2˚C, Arctic Intermediate Water, S: 34.8-35, t: 0-2˚C (Stefánsson 1962; Stefánsson and Guðmundsson 1969). The interannual hydrographic variability is much greater north of Iceland than off the south This arises chiefly from the different proportions there of Atlantic Water on one hand and Polar or Arctic Water on the other hand.

Dedicated to Professor Unnsteinn Stefánsson in honour of his contributions to oceonography and education.

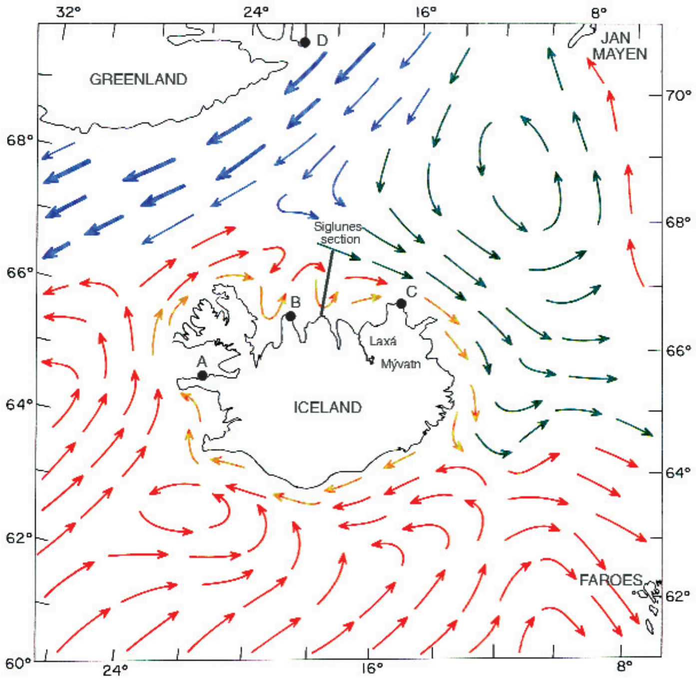


Figure 1. Surface currents in the vicinity of Iceland. Red: Relatively warm and saline Atlantic Water; Blue: Cold, low salinity Polar Water; Green: Arctic Water; Yellow: Coastal Water. From Stefánsson and Ólafsson 1991. The figure shows the Siglunes section and the site of the recording thermograph at the outflow from Lake Mývatn to River Laxá. Also indicated are the meteorological observation stations at Hraun á Skaga (B), Cape Tobin (D), Raufarhöfn (C) and at Stykkishólmur (A) which has been used as the northern end of the North Atlantic Oscillation dipole.

In the late sixties, sea ice extended in spring time over the northern coastal area, even up to the shore, hindered shipping and induced cold air temperature. The Atlantic Water inflow to the N-Iceland shelf has ecological consequences. It not only transports heat into the region, but also supplies it with essential nutrients for primary production and in the Atlantic Water stratification is moderate and permits sufficient mixing to replenish nutrients in the euphotic layer (Stefánsson and Ólafsson 1991). On the northern shelf region are nursing and fishing grounds for several commercially important species.

The Iceland Sea is a region of water (Swift and Aagaard 1981) mass transformation producing Arctic Intermediate Water which overflows the Greenland-Iceland and the Iceland-Faroe Ridges and contributes to the North Atlantic Deep Water (Swift and Aagaard 1981).

Advection and mixing on the N-Iceland shelf and in the Iceland Sea was the subject of Unnsteinn Stefánsson´s 1962 monograph, North Icelandic Waters. There he pointed out, after examining the atmospheric pressure difference between Cape Tobin on E-Greenland and Raufarhöfn on NE-Iceland, that the inflow of Atlantic Water to the Iceland Sea was influenced by north-south winds (Figs. 1 and 2). Later, Stefánsson and Guðmundsson (1969) elaborated on this and concluded that the conditions off NE-Iceland were predictable from the north-south wind field and air temperature, three to four months earlier. More recently, Stefánsson (1999) has revisited the question of influences on the advection of Atlantic Water and shown that the difference in the frequency of south+southwest and north+northeast winds at Hraun á Skaga in N-Iceland, during January-May, correlated with the hydrographic conditions off Siglunes N-Iceland in May-June. There he uses the mean wind frequencies as a proxy for the wind stress acting on the ocean surface. The data Stefánsson examined from Hraun á Skaga were limited, and this issue will here be explored further using similar methods.

Lake Mývatn is located in the interior NE-Iceland at an elevation of 277 m. The climate of Iceland is in general maritime, where the coastal air temperature is lower than the sea surface temperature except for the summer months. For the northeast interior of Iceland, Markús Einarsson (1979) mentioned, that one might even talk about "continentality" in the climatic character of that region. Mývatn is 37 km^2 in area, with a mean depth of only 2 m and it is divided into two main basins. Mývatn is primarily ground

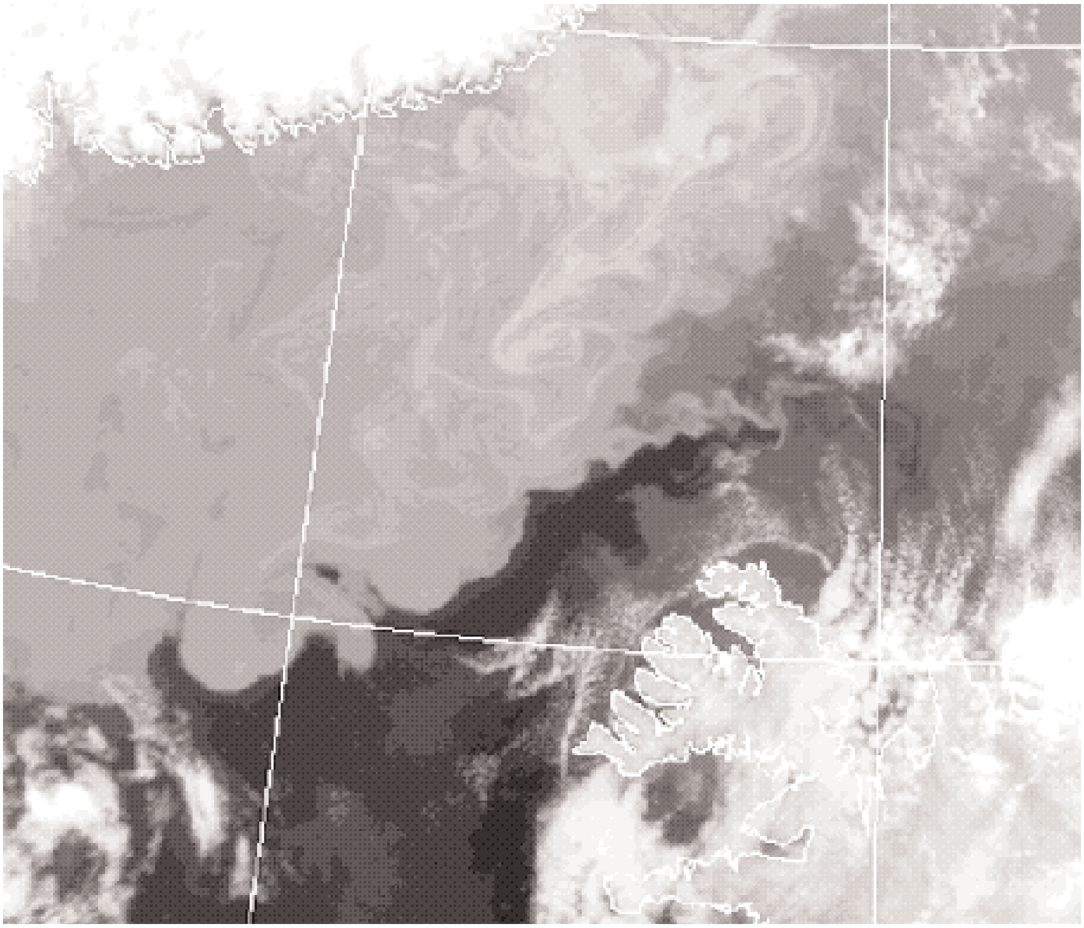


Figure 2. Infrared satellite image of the Greenland Strait from 6 November 1996. The southward flowing East Greenland Current with ice and cold Polar Water is light in shade and extends over a large proportion of the strait. It meets the relatively warm water, dark shade, of the northward flowing North Icelandic Irminger Current off the northwest peninsula of Iceland.

water fed from springs, some of which discharge geothermal water with temperatures up to about 25˚C. The water renewal time for Mývatn is 27 days and the lake drains at a rate of about 33 m^3s^{-1} into River Laxá which runs northward to the sea in about 13 hrs (Fig. 1). Unnsteinn Stefánsson (1970) first described the main features of the Lake Mývatn temperature distribution and nutrient chemistry. A later study of temperature records and the heat budget of Mývatn, has revealed that the temperature of the lake, when ice free, can be modelled as a seasonal signal superimposed with the effect of the local air temperature of the previous days (Ólafsson 1979). Furthermore, the lake regulates the temperature of River Laxá as it runs to the sea. Mývatn is ice covered with a median ice duration of 189 winter days and a range of 143-244 days, but there are large ice free areas downstream from the groundwater springs and upstream from the outflow into River Laxá (Rist 1979). Lake Mývatn is on average ice free in mid-May. The Lake Mývatn-River Laxá ecosystem is productive, it supports rich benthic biota, waterfowl populations, trout and salmon stocks (Jónasson 1979, 1979a).

Climatological variability in regions around the North Atlantic has in many cases been found to be

TABLE 1

Spring time hydrographic observations on the Siglunes section.

Year	*Date*	*Mean t °C*	*Mean S PSS 78*	*Stations*	*Comments*
1952	15 June	4.209	35.004	1, 2, 3, X	X at 66° 53´N
1953	9 June	4.442	34.844	1, 2, 3, X	X at 66° 49´N
1954	11 June	5.204	34.982	1, 2, 3, 4, 5	
1955	16 June	5.190	34.987	1, 2, 3, 4, 5	
1956	22 June	4.854	34.800	1, 2, 3, X	X at 66° 48´N
1957	12 June	4.712	34.951	1, 2, 3, 4, 5	5 by interpolation
1958	4 June	3.544	34.825	1, 2, 3, 4, 5	
1959	22 June	5.170	34.990	1, 2, 3, 4, 5	
1960	11 June	5.338	35.047	1, 2, 3, 4, 5	
1961	13 June	4.986	35.072	1, 2, 3, 4, 5	
1962	3 June	4.295	35.037	1, 2, 3, 4, 5	
1963	15 June	3.207	34.806	1, 2, 3, 4, 5	
1964	8 June	5.204	34.972	1, 2, 3, 4, 5	
1965	6 June	3.372	34.490	1, 2, 3, 4, 5	
1966	5 June	3.093	34.872	1, 2, 3, 4, 5	
1967	1 June	1.166	34.554	1, 2, 3, 4	Sea ice at 5
1968	18 June	2.558	34.504	1, 2, 3, 4	Sea ice at 5
1969	6 June	1.730	34.371	1, 2, 3, 4	Sea ice at 5
1970	10 June	2.296	34.495	1, 2, 3, 4, 5	
1971	25 May	1.531	34.594	1, 2, 3, 4, 5	
1972	5 June	3.971	34.804	1, 2, 3, 4, 5	
1973	10 June	4.412	34.861	1, 2, 3, 4, 5	
1974	29 May	4.425	34.885	1, 2, 3, 4, 5	
1975	29 May	2.188	34.598	1, 2, 3, 4, 5	
1976	5 June	3.583	34.768	1, 2, 3, 4, 5	
1977	28 May	3.179	34.604	1, 2, 3, 4, 5	
1978	1 June	4.043	34.760	1, 2, 3, 4, 5	
1979	3 June	1.792	34.491	1, 2, 3, 4, 5	
1980	29 May	4.726	34.993	1, 2, 3, 4, 5	
1981	28 May	2.205	34.811	1, 2, 3, 4, 5	
1982	7 June	2.672	34.626	1, 2, 3, 4, 5	
1983	4 June	2.008	34.656	1, 2, 3, 4, 5	
1984	29 May	3.088	34.818	1, 2, 3, 4, 5	
1985	3 June	4.363	34.961	1, 2, 3, 4, 5	
1986	30 May	3.243	34.911	1, 2, 3, 4, 5	
1987	3 June	4.329	34.833	1, 2, 3, 4, 5	
1988	22 May	2.563	34.592	1, 2, 3, 4, 5	
1989	31 May	2.818	34.852	1, 2, 3, 4, 5	
1990	28 May	2.239	34.700	1, 2, 3, 4, 5	
1991	22 May	3.432	34.941	1, 2, 3, 4, 5	
1992	18 May	3.529	34.910	1, 2, 3, 4, 5	
1993	23 May	3.503	34.915	1, 2, 3, 4, 5	
1994	24 May	3.845	34.901	1, 2, 3, 4, 5	
1995	23 May	0.591	34.616	1, 2, 3, 4, 5	
1996	27 May	3.838	34.745	1, 2, 3, 4, 5	
1997	27 May	3.225	34.709	1, 2, 3, 4, 5	
1998	1 June	2.982	34.622	1, 2, 3, 4, 5	

related to a climatological index, the North Atlantic Oscillation index, NAO. This index describes the relative strengths of the "Icelandic low" and the "Azores high" and the strength of the westerly winds between them. The variations of the NAO indices are related to changes in winds, paths of winter storms and the flux of heat and moisture between the ocean and adjacent continents. The conditions the NAO index describes are particularly important in winter and the index has been related to wintertime warming/cooling in Europe, widespread precipitation variability and recent cooling in the Northwest Atlantic (Hurrell and van Loon 1997). It has furthermore been suggested, that the NAO coordinates the intensity of deep convection at three main Atlantic regions, the Greenland/Iceland Seas, the Labrador Sea and the Sargasso, and links thus to the global thermohaline circulation (Dickson *et al.* 1996).

The NAO index is calculated for months, seasons, winters and years based on the difference of normalized sea level pressures between Stykkishólmur, Iceland (Fig. 1) and either Lisbon, Portugal for the winter index or Azores for the monthly and seasonal indices (Hurrell 1996). Hurrell´s winter index extends back to 1865 but the alternative NAO index of Jones *et al.* (1997), based on sea level pressure difference between Gibraltar and SW-Iceland, extends further back, to 1823. The NAO index correlates positively with precipitation in Iceland (Hurrell and van Loon 1997), but although the NAO signature reflects atmospheric pressure variations near Iceland its relation to oceanic climate there has not previously been examined in detail.

DATA

Temperature and salinity variations at the Siglunes section

The longest hydrographic time series from the N-Iceland shelf is from the Siglunes section, which extends north from Siglunes and into the Iceland Sea at 18° 50´ W. Data from 50 m at the third station on this section have frequently been used to illustrate hydrographic variations in the waters north of Iceland (Malmberg and Kristmannsson 1992; Malmberg and Blindheim 1994).

The time series here presented, is based on the 5 southernmost stations on the Siglunes section, as observed in the spring from 1952 to 1998. The stations are between 66˚ 16´ N and 67˚ 00´ N. From 1952 the spring time data have been collected annually during surveys of ecological conditions. In some years sea ice has prevented the occupation of all 5 stations (Table 1), and the observation dates have a range of 35 days (Fig. 3). For each spring time occupation

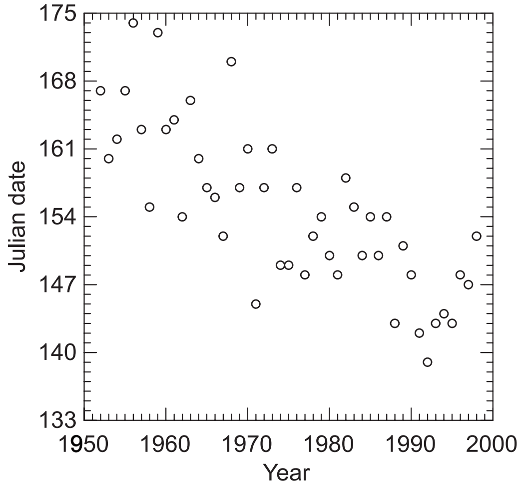


Figure 3. Timing of Siglunes section surveys 1952-1998. Julian date 152 is 1 June.

of the section, temperature and salinity at standard depths (0 m, 10 m, 20 m, 30 m, 50 m, 75 m, 100 m, 150 m and 200 m) are used to calculate section means of temperature and salinity by numerical integration. The time series therefore represent mean temperature (t) and mean salinity (S) integrated with depth from surface down to 200 m and with distance along the section, 44 nautical miles or 81 km. For each year, temperature and salinity deviations are calculated on the basis of the mean temperature (t=3.288 ˚C) and the mean salinity (S=34.727) for the period 1961-1980, Table 1, Fig. 4. The choice of reference period is related to the first use of this series (Ólafsson 1985), but the number of years with negative temperature deviations is presently 21 out of 47 and years with negative salinity deviations are 16 out of 47. The means for the 1952-1998 period are t= 3.466 ˚C and S=34.789.

The Siglunes section data have the drawback of having been collected at variable dates in the spring and that the collection dates have progressively moved forward in the latter part of the time series, Fig. 3. The series, however, represents the 81 km long section from the surface down to 200 m depth and seasonal warming is most pronounced near the surface and above thermocline, but below about 50 m depth the short term variability is more likely caused by

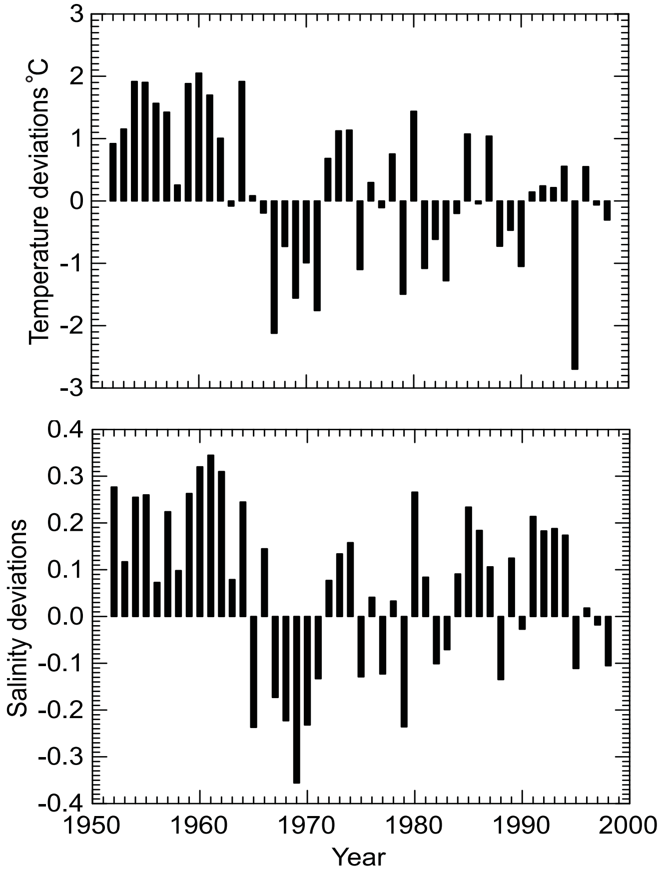


Figure 4. Siglunes section mean temperature and salinity deviations from the 1961-1980 mean.

advection. As will be shown, the variable observation dates have introduced bias at least in the temperature series. It may be feasible to decrease this bias by excluding surface layer data from the series. However, that approach is not further advanced here, but the effect of shifting observation dates will be examined.

The Siglunes section data are accessible at http://www.hafro.is/

Lake Mývatn and River Laxá temperature

A recording thermograph from Negretti and Zambra Ltd, was installed in the outflow from Lake Mývatn to River Laxá in February 1972 (Ólafsson 1979). As opportunities have provided, the precision of the thermograph has been checked against measurements with calibrated mercury thermometers. Daily mean temperatures were calculated from reading at 4 hour intervals from the weekly records. From the daily mean temperatures, mean monthly temperatures were calculated and mean temperatures for eleven otherwise defined periods (Table 2).

The Lake Mývatn temperature data are accessible at http://www.hafro.is/

Meteorological data

Hraun á Skaga is at the tip of the low relief Skagi peninsula (Fig.1). Data from this weather station, covering the period 1956-1998, were provided by the Icelandic Meteorological Office. The series covers monthly wind frequency from 8 directions. In addition to the 8 directions, monthly direction frequency differences were derived for (S-N), (S+SW)-(N+NE), (S+SE)-(N+NW) and (S+SW+SE)-(N+NE+NW). From these data, mean frequencies were calculated for different annual time periods of 1 to 8 months, and these means are used to examine climatological connections. The mean wind frequency data used here, integrate over time, by direction, wind effects on the sea surface. The wind frequency can, however, not be explicitly related to

TABLE 2

Periods for Lake Mývatn and River Laxá mean temperature calculations.

Period	*Time interval*	*Period length days*
P 1	1 May - 14 June	46
P 2	15 June — 31 July	46
P 3	1 August — 15 September	46
P 4	16 September — 31 October	46
Summer	1 June — 30 September	122
PP 1	16 April — 15 May	30
PP 2	16 May — 14 June	30
PP 3	15 June — 14 July	30
PP 4	15 July — 13 August	30
PP 5	14 August — 12 September	30
PP 6	13 September — 12 October	30

the wind stress on the ocean surface since wind strength is not taken account of.

Indices of the annual, winter (December to March) and the three month period (December to February) North Atlantic Oscillation were obtained from http://www.cgd.ucar.edu/cas/climind/nao_winter.html (Hurrell 1996).

RESULTS AND DISCUSSION

CONDITIONS ON THE SIGLUNES SECTION

Connections of Siglunes section deviations to wind frequencies

The meteorological station Hraun á Skaga lies at the tip of the Skagi peninsula which is in sight from the southern stations on the Siglunes section (Fig.1). The mean wind frequencies over January-May, 1956-1998, indicate that during these months the most frequent wind directions are SW, NE, E, N and S, and that the least frequent wind directions are NW, SE and W (Fig. 5). The coefficient of variation for the more frequent directions is 40-50 % but much higher for the less frequent directions.

Connections between the Siglunes section temperature and salinity deviations and mean wind frequencies over variable periods at Hraun á Skaga were examined using Pearson correlation coefficients. The periods ranged from one month to eight months before June. This examination revealed correlations in particular with the S-N and the (S+SE)-(N+NW) frequency differences, but lower correlations with the (S+SW)-(N+NE) and the (S+SW+SE)-(N+NE+NW) differences (Fig. 6).

The results presented in Figure 6 show that:

- i The correlation coefficients increase as more months before June are added to the wind frequency mean and reach a maximum when January is included in the mean.
- ii The temperature deviations have similar correlations with both the S-N and the (S+SE)-(N+NW) frequency differences but markedly lower correlations with the (S+SW)-(N+NE) frequency difference.
- iii The salinity deviations have in all cases lower correlations with the (S+SW)-(N+NE) frequency difference than with the S-N difference and highest correlations with the (S+SE)-(N+NW) frequency difference.
- iv The mean (S+SE)-(N+NW) wind frequency at Hraun á Skaga during January to May, explains 54 % of the temperature deviations on the Siglunes section and 57 % of the salinity deviations (Fig. 7). The mean S-N wind frequency for the same period explains 54 % the temperature deviations and 49 % of the salinity deviations. The best fit regression relationships, with standard errors of slopes and intercepts, are:

$$\Delta t = (0.119 \pm 0.017)*((S+SE)-(N+NW))-(0.018 \pm 0.122) \quad r=0.734$$

$$\Delta S = (0.019 \pm 0.003)*((S+SE)-(N+NW))-(0.035 \pm 0.018) \quad r=0.757$$

These statistical analyses indicate that the ocean temperature regime north of Iceland is connected to the relative south-north wind frequencies and that the salinity there is additionally influenced by the west-east components of the wind field. This is in general agreement with Stefánsson´s conclusion (Stefánsson 1999), except that the (S+SE)-(N+NW) wind frequency differences correlate here better with the temperature and salinity deviations, r=0.734 and 0.757 respectively, than the (S+SW)-(N+NE) differ-

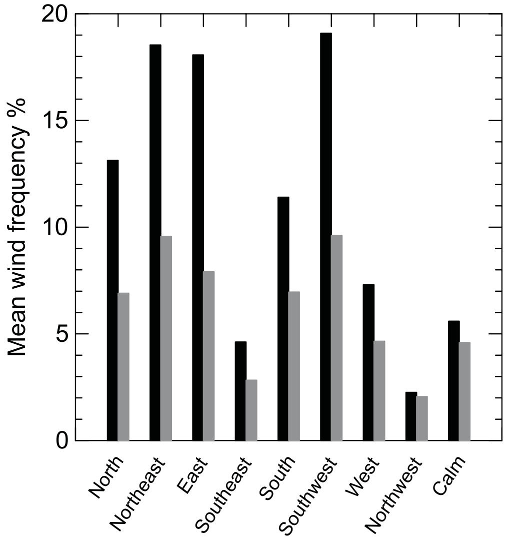


Figure 5. Mean wind frequencies at Hraun á Skaga during January-May 1956-1998 (black) and their standard deviations (grey).

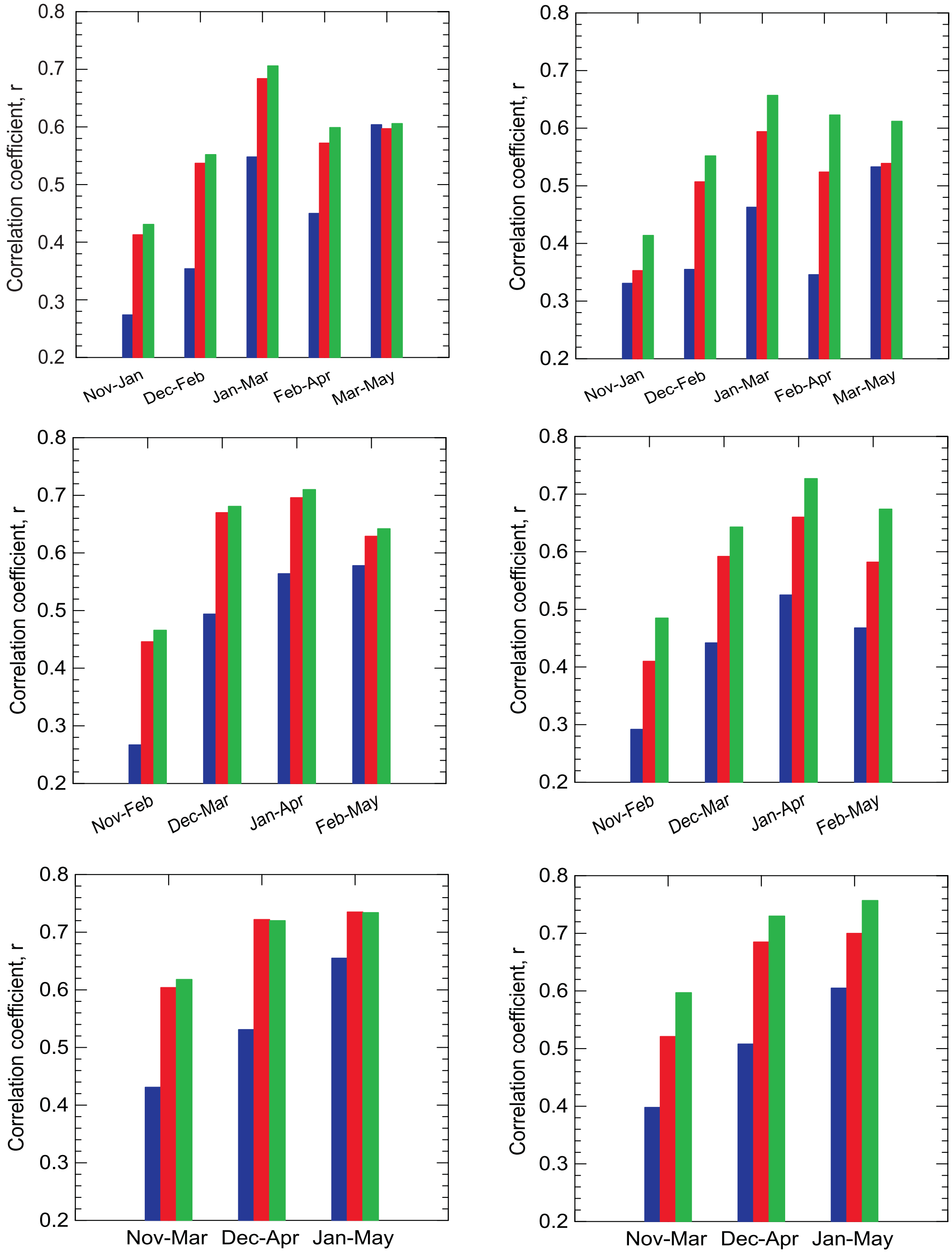


Figure 6. Changes in correlation coefficients, r, between Siglunes section temperature deviations (left) and salinity deviations (right) with mean frequencies of winds at Hraun á Skaga, as the mean winds are calculated for 3 (top), 4 (middle) and 5 (bottom) month periods preceeding June. The (S+SW)-(N+NE) frequency difference is shown in blue, the (S-N) frequency difference in red and the (S+SE)-(N+NW) frequency difference green.

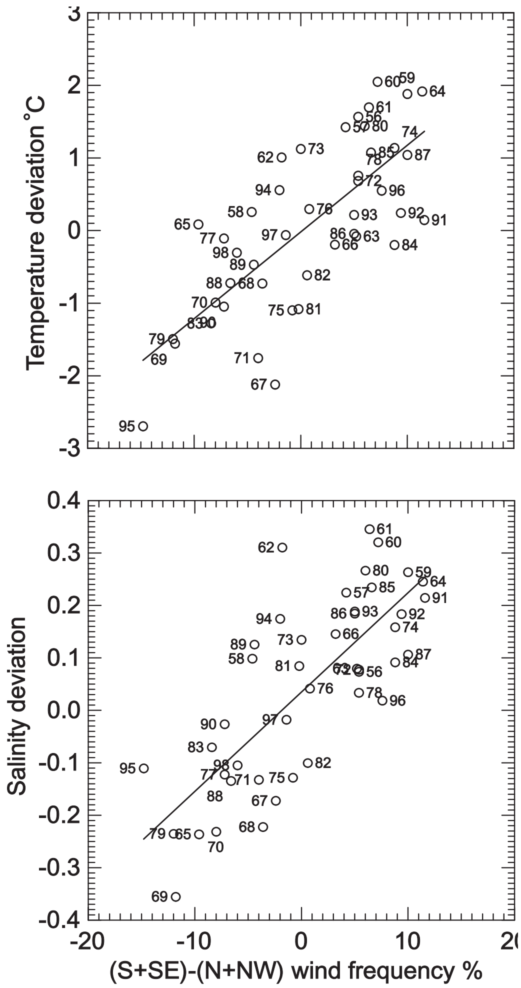


Figure 7. Connections between temperature and salinity deviations at the Siglunes section and mean (S+SE)-(N+NW) wind frequencies, January to May, at Hraun á Skaga. Numbered symbols indicate years.

ences, r=0.655 and 0.605 respectively. It is worth noting the importance, for the salinity, of the least frequent wind directions, SE and NW. The above correlations point to causal relationships but the wind frequency variations can not easily be interpreted in terms of physical processes. Further analysis using wind stress data is required to elucidate the processes at work.

The northerly winds are, as a rule, colder than the southerly winds and the sea to air heat flux is therefore greater under north wind conditions. In addition to that, there is air-sea interaction through advection and vertical mixing. Although the results above relate to meteorological conditions at one location, Hraun á Skaga, variability there reflects the whole northern Iceland although there are slight differences in the wind patterns west and east of Iceland from that at Hraun á Skaga. As can be deduced from the ocean current chart (Fig. 1), from Stefánsson (1962) and Stefánsson and Guðmundsson (1969), the variability in wind influence on advection is critical in the area to the west and northwest of Iceland. There, the North Icelandic Irminger Current flows northward with the Iceland shelf as a topograpic boundary on its right side and meets the strong East Greenland Current on its left side (Fig. 2).

The East Greenland Current is the predominant source of fresh water in the Iceland Sea and the amount of fresh water in the Iceland Sea is governed by winds (Jónsson 1992). In addition to variable advection, conditions for vertical mixing also change. When low salinity surface Polar Water extends over Atlantic or Winter Water, the halocline prevents deep vertical mixing. For the exceptionally cold conditions in the spring of 1995 (Fig. 4), the negative salinity deviation was less than might have been expected (Fig. 7). Late that winter, northeasterly winds were particularly persistent (Fig. 8). Under these conditions the flux of low salinity Polar Water from the East Greenland Current into the Iceland Sea has been restrained but the advection from the Norwegian Sea into the Iceland Sea gyre south of Jan Mayen can have been enhanced (Fig. 1). At the same time, intensive sea to air heat flux resulted in deep vertical mixing in the Iceland Sea and hence relatively high salinity (unpublished results).

Connections of Siglunes section deviations to the North Atlantic Ocillation, NAO

Having established relatively close connections between the oceanographic variability north of Siglunes and the wind frequency differences at Hraun á Skaga, a close connection to the NAO index is not expected except in the case of close links between the winds at Hraun á Skaga and the NAO index. An examination of the correlations between the temperature and salinity devi-

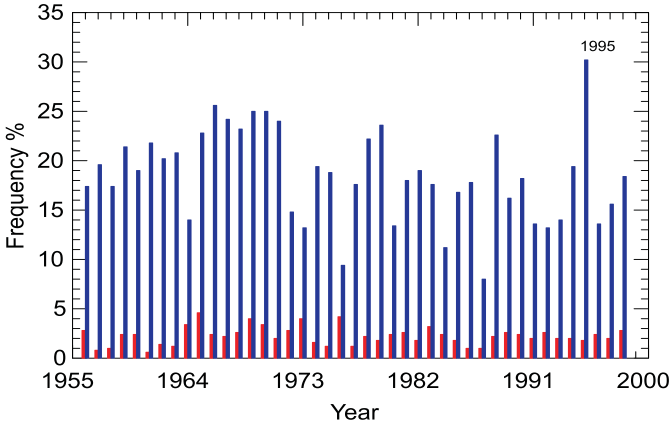


Figure 8. The mean frequency during January-May 1956-1998, of northwest (red) and northeast (blue) winds at Hraun á Skaga.

ations at the Siglunes section and the various expressions of the NAO index for the months before May, showed only weak positive correlations in the following cases: Between NAO winter (Dec–Mar) and ΔS, r=0.178 and between NAO (Dec.-Feb.) and ΔS, r=0.236 (Fig. 9). In the former case the slope of the regression line is 0.014±0.012 and in the latter case 0.022±0.013. These weak connections disappear altogether when subjected to a multiple regression analysis of connections between the Siglunes Dt and DS and Hraun á Skaga wind frequencies with NAO indices included. In other words, the NAO index has no positive relation to the residuals of the linear relationships in Figure 7.

The NAO index represents a meridional pressure gradient driving westerly winds in mid latitudes. It is quite clear, that conditions in the Iceland Sea north of Iceland largely depend on the relative influences of northerly and southerly winds. Although some periods of negative NAO have, at Hraun á Skaga, predominantly northerly winds associated with them, as 1969 and 1979 are examples of, there are other instances, like 1996, when this is not the case. To the west and north of Iceland the direction of winds associated with cyclones moving across the Atlantic, is determined by the tracks of the cyclones. Even though the tracks are different during periods of strong and weak NAO (Rogers 1990), this is clearly insufficient to exert overall control on the frequency of north/south winds in Iceland. For a given positive NAO index the storm tracks may vary considerably and even result in predominant northerly winds, as 1995 demonstrates.

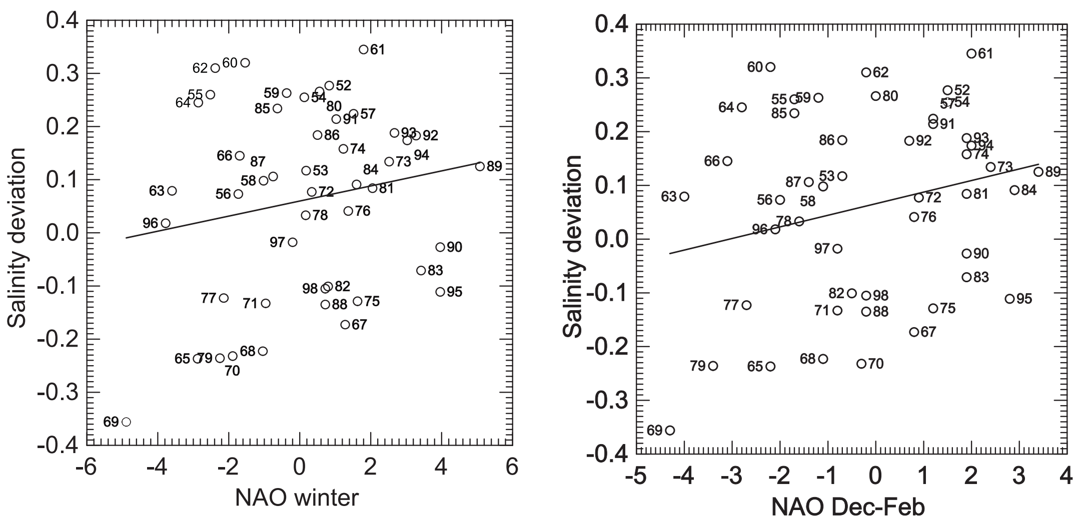


Figure 9. Connections between salinity deviations at the Siglunes section and the NAO indices for winter (Dec-Mar) and the three month period Dec-Feb. Numbered symbols indicate years.

LAKE MýVATN AND RIVER LAXÁ TEMPERATURE

The annual records.

Details of the Mývatn temperature records have been described elsewhere (Ólafsson 1979), but here the 27 year record is summarised. The calculated mean annual temperature (Fig. 10), shows a maximum of 13.1 °C in mid-July. The temperature distribution is negatively skewed. The cause of this may lie in the location of the thermograph, at the outflow to River Laxá. Upstream from this location, in winter, is an ice free area variable in extention, but as it grows in spring, it absorbs solar radiation and the water will warm to some extent whilst the main Mývatn basins are still ice covered. At that time, the temperature recorded certainly does not

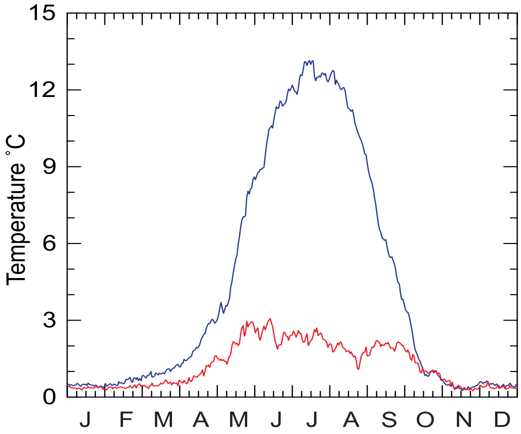


Figure 10. Mean annual temperature trace in Lake Mývatn and River Laxá (blue) and the standard deviation of the mean (red).

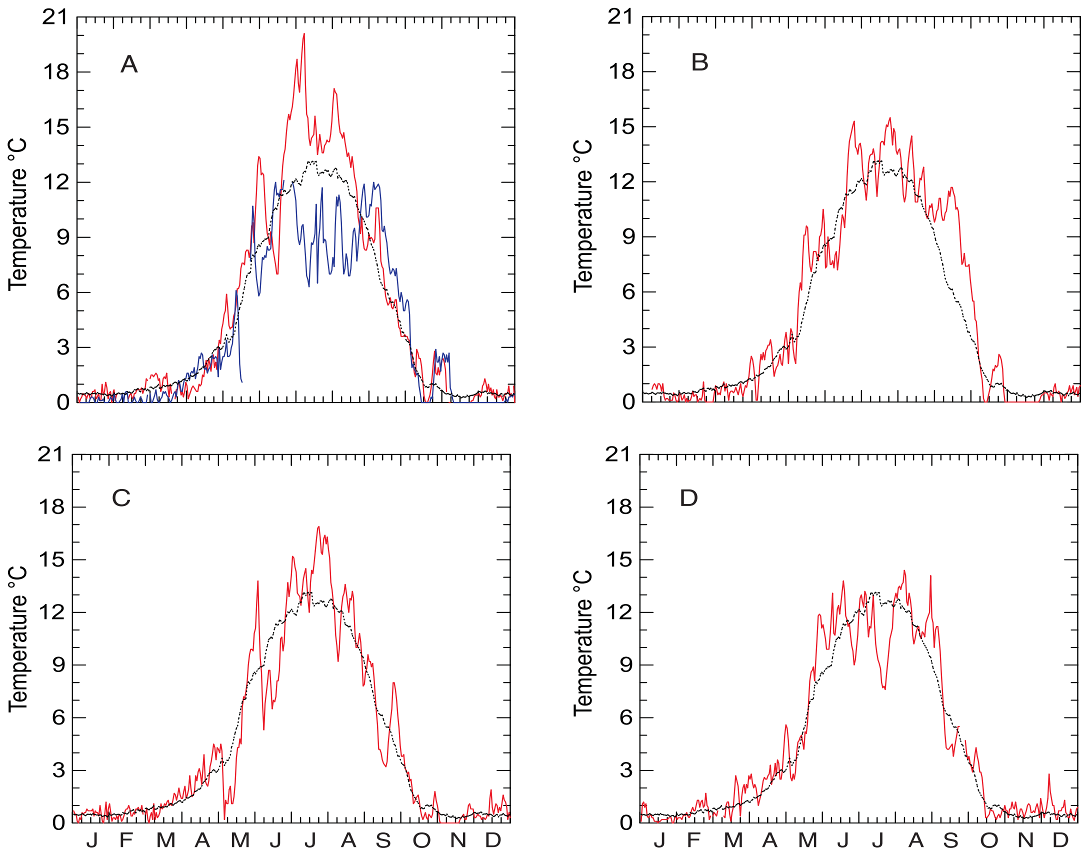


Figure 11. Lake Mývatn annual temperature traces for a) a warm year, 1991 (red) and a cold year 1993 (blue), b) 1996, c) 1997 and d) 1998. The mean annual temperature is shown in black.

TABLE 3

Mean monthly temperature of Lake Mývatn outflow 1972-1998.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1972		1.0	1.2	2.7	7.6	10.3	12.2	9.6	5.7	1.7	0.5	0.7
1973	0.6	0.6	1.6	2.6	6.0	9.2	13.5	10.4	7.8	2.3	0.3	0.8
1974	0.8	0.5	1.1	3.5	7.8	11.2	11.6	10.0	4.6	1.2	0.4	0.5
1975	0.7	0.9	1.1	2.1	5.7	8.9	12.9	12.5	4.6	2.0	0.6	0.7
1976	0.8	0.7	1.0	2.6	5.9	12.3	14.1	11.0	7.9	2.8	0.5	0.3
1977	0.8	0.9	1.4	1.4	4.9	10.9	13.0	11.4	6.0	1.8	0.4	0.5
1978	0.5	0.9	1.0	2.3	5.6	9.4	11.9	12.9	6.2	0.9	0.1	0.5
1979	0.5	0.8	1.1	1.7	2.5	7.4	11.0	9.9	3.1	1.9	0.2	0.7
1980	0.3	0.8	1.1	2.1	7.1	11.8	12.9	11.8	6.6	1.0	0.4	0.5
1981	0.6	0.7	0.9	2.3	5.5	9.5	11.4	11.6	5.9	0.6	0.8	0.7
1982	0.7	0.7	0.9	2.2	4.1	12.7	12.8	10.6	4.1	2.2	0.4	0.7
1983	0.5	0.7	1.0	1.5	3.6	7.7	11.9	9.8	5.1	0.5	0.5	0.6
1984	0.6	0.8	0.9	1.8	6.3	12.8	15.7	12.0	6.6	1.1	0.8	0.7
1985	0.4	0.8	1.1	2.5	6.4	10.9	10.9	9.9	4.9	2.8	0.2	0.5
1986	0.4	0.4	0.8	2.5	3.7	11.4	12.7	11.4	5.4	1.0	0.7	0.3
1987	0.3	0.5	1.0	2.3	6.7	12.3	13.4	12.5	5.6	1.0	0.4	0.0
1988	0.1	0.2	1.0	1.9	5.5	11.5	12.0	11.2	5.9	0.4	0.1	0.2
1989	0.1	0.1	0.7	1.6	3.6	10.2	12.9	10.5	5.9	2.5	0.3	0.6
1990	0.5	0.5	0.6	1.2	5.5	11.5	12.5	11.7	6.0	1.2	.	0.2
1991	0.4	0.6	1.0	1.6	7.2	11.8	15.6	12.6	6.5	1.8	0.5	0.6
1992	0.7	0.3	1.1	2.0	5.2	9.4	11.3	10.4	4.9	3.1	0.4	0.2
1993	0.1	0.2	0.5	2.0	4.7	9.9	8.6	9.2	8.6	1.7	0.6	0.1
1994	0.1	0.4	0.8	1.4	5.6	8.6	14.5	12.4	6.5	0.7	0.2	0.0
1995	0.0	0.4	0.4	1.3	4.3	10.2	11.4	12.7	7.1	1.0	0.2	0.2
1996	0.5	0.2	0.8	2.3	6.8	10.7	13.5	11.9	9.8	1.9	0.0	0.5
1997	0.6	0.5	0.9	2.6	4.8	9.5	14.6	11.7	6.3	1.5	0.3	0.7
1998	0.3	0.7	1.2	2.6	6.3	11.2	10.7	12.1	6.5	1.7	0.8	0.8
Mean	0.5	0.6	1.0	2.1	5.5	10.5	12.6	11.2	6.1	1.6	0.4	0.5
St. dev.	0.2	0.3	0.3	0.5	1.3	1.4	1.6	1.1	1.4	0.7	0.2	0.2

represent the whole lake, but only the upstream ice free region which may as it grows reach near equilibrium with the atmosphere.

The standard deviations of the daily means provide information on the periods when the temperature is most variable, or least predictable, from year to year (Fig. 10). The standard deviation is under 0.5 °C in mid winter, when the water temperature is controlled by freezing/thawing and slight warming by irradiation as the sun´s daily altitude increases. The standard deviations increase in spring to an annual maximum of about 3 °C in late May-early June, remain quite high in July, the warmest month, reach a minimum on 24 August and have a second but lower maximum in September. The standard deviations arise from variations in weather patterns, the coming of summer in May/June and the onset of autumn in September. The variability described by the standard deviations also relates to conditions for the aquatic biota in general and for biological processes which are sensitive to environmental conditions. The periods in Table 2, and the mean temperature data in Tables 3 and 4, provide material for investigations into relations between variations in the biota and temperature conditions. A relationship between springtime temperature variations in River Laxá and salmon catches has been observed (Þorvaldsson 1991).

The annual temperature records differ substantially between individual years (Fig. 11). In 1991 there was an exceptionally warm period, with a record daily mean temperature of 20.1 °C and a daily maximum of 21.0 °C on 8 July, the year 1989 was unusually cold, whilst the years 1995-1998 serve to illustrate recent variability.

TABLE 4

Mean period temperature of Lake Mývatn outflow 1972-1998. (For period definitions, see Table 2).

Year	*PP1*	*PP2*	*PP3*	*PP4*	*PP5*	*PP6*	*P1*	*P2*	*P3*	*P4*	*Summer*
1972	5.1	9.6	10.6	11.5	7.9	4.8	8.6	11.4	8.1	3.2	10.7
1973	3.2	7.8	11.4	13.1	9.2	6.6	6.3	12.8	9.7	3.9	11.0
1974	5.7	9.4	11.6	11.9	8.4	2.1	8.5	11.9	9.1	1.4	10.9
1975	2.5	8.3	11.5	12.6	10.4	2.3	6.4	12.0	10.7	2.1	11.5
1976	3.4	10.4	13.5	12.6	9.7	6.2	8.0	13.5	10.0	4.4	12.5
1977	2.5	7.8	12.1	12.5	9.5	4.6	6.4	12.8	9.5	3.3	11.8
1978	3.8	7.6	10.8	13.3	10.2	3.6	6.6	11.3	11.3	2.1	11.4
1979	1.9	4.3	9.8	11.0	7.5	2.7	3.5	10.4	8.0	1.9	9.4
1980	3.4	10.8	12.7	12.7	9.6	3.9	8.8	12.3	10.5	2.3	12.1
1981	3.1	7.7	10.8	12.3	9.3	3.3	6.3	11.4	10.0	2.0	10.9
1982	2.4	8.0	13.7	12.9	7.3	3.2	6.3	13.3	8.8	2.4	12.0
1983	2.2	4.6	11.3	10.8	8.2	2.9	4.1	11.4	8.6	1.6	9.8
1984	3.8	10.1	14.2	14.3	10.3	4.0	8.5	14.7	10.8	2.3	13.5
1985	4.0	8.1	12.7	10.3	7.3	3.8	7.1	11.6	8.3	3.4	10.5
1986	2.8	6.8	13.2	12.3	8.9	3.6	5.4	13.0	9.7	2.2	11.8
1987	3.1	11.0	13.5	13.9	10.2	3.2	8.1	13.6	10.9	1.9	12.7
1988	3.7	10.0	11.4	12.0	9.6	2.7	8.1	11.5	10.2	1.5	11.6
1989	2.9	6.3	11.5	12.8	8.8	4.6	5.5	12.2	9.5	3.2	11.2
1990	2.4	9.7	9.9	14.2	9.4	3.5	8.3	11.7	10.3	1.8	11.9
1991	3.7	9.6	15.1	14.7	10.0	4.0	8.0	15.0	11.2	2.8	13.3
1992	2.6	8.6	10.1	11.6	7.3	5.4	6.1	10.5	8.5	4.0	10.5
1993	2.8	7.8	9.8	8.8	10.1	5.4	6.3	9.3	9.7	3.3	9.2
1994	3.2	6.4	12.5	14.0	10.4	3.4	5.9	13.2	11.0	2.0	11.8
1995	2.7	6.4	11.7	12.4	10.9	4.3	5.7	11.5	11.7	2.2	11.5
1996	3.7	8.3	12.9	13.7	10.9	6.8	7.2	13.5	11.5	4.2	12.0
1997	2.7	8.1	11.7	13.9	9.9	4.2	6.1	13.1	10.2	2.8	11.9
1998	3.6	9.7	11.7	11.2	10.3	4.0	7.9	10.9	10.8	2.4	11.3
Mean	3.2	8.3	11.9	12.5	9.3	4.0	6.8	2.2	9.9	2.6	11.4
St. dev	0.8	1.7	1.4	1.4	1.1	1.2	1.4	1.3	1.1	0.8	1.0

Connections of Lake Mývatn temperature to oceanic and atmospheric variations

Lake Mývatn is a small body of water with a relatively large surface area to interact with the atmosphere. Such interactions are limited by ice for a substantial part of the year, but the response time of the ice free lake is short, less than a week (Ólafsson 1979). The Lake Mývatn temperature patterns, which are related to climatic variations, emerge as periods of high standard deviations of the daily means. Interannual variance, in the mean temperatures of various periods, listed in Tables 3 and 4, is highest in the period from 16 May to 14 June (PP2). The mean temperatures for the PP2 period range from 4.3 °C in 1979 to 11.0 °C in 1987 (Fig. 12).

Examinations of Lake Mývatn temperature connections to oceanic or atmospheric variations are limited by the length of the time series (1972-1998), which is 20 years shorter than the oceanic Siglunes series. Correlations with the Siglunes section temperature deviations are moderately

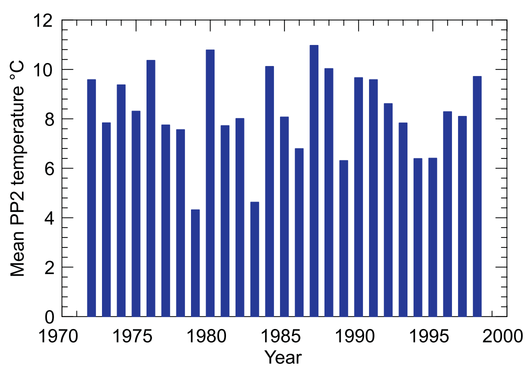


Figure 12. Interannual variations in Lake Mývatn mean temperature in the period 16 May to 14 June.

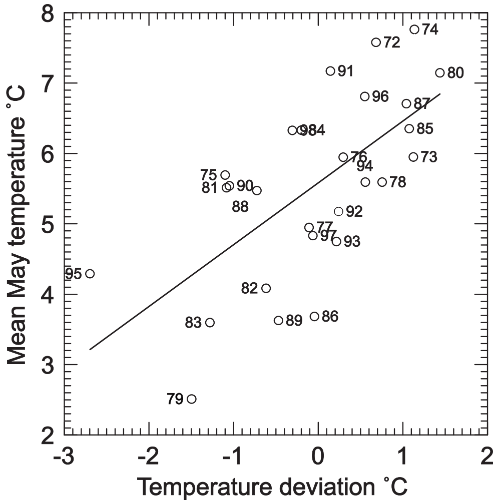


Figure 13. Connection between temperature deviations at Siglunes and Mývatn mean temperature in May. Numbered symbols indicate years.

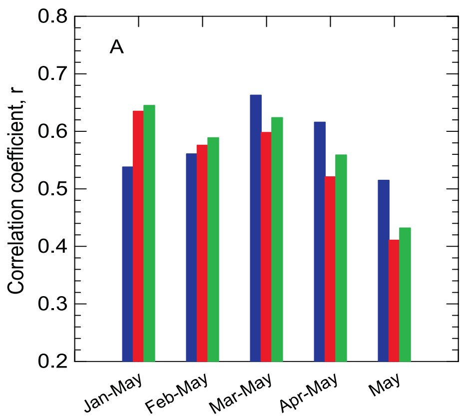
TABLE 5

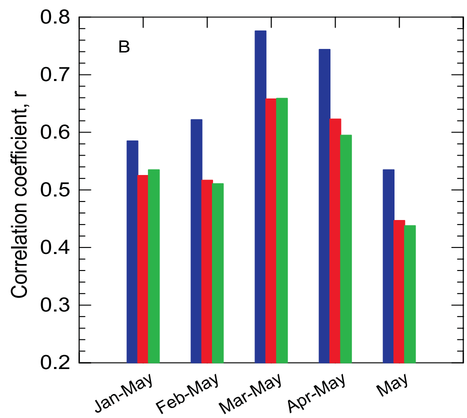
Correlation coefficients between mean temperatures of Mývatn and temperature deviations at Siglunes Section in May-June. For period definitions, see Table 2.

Mývatn period	*r*
May	0.648
June	0.273
P 1	0.503
PP 1	0.581
PP 2	0.482

strong, but strongest in early spring periods (Table 5, Fig. 13). A connection is therefore also expected between the Lake Mývatn temperature conditions and wind frequencies at Hraun á Skaga, although the interaction mechanism differs from that between the ocean north of Iceland and the winds.

The connections of Lake Mývatn mean temperatures with mean wind frequencies, over variable number of months preceeding June, at





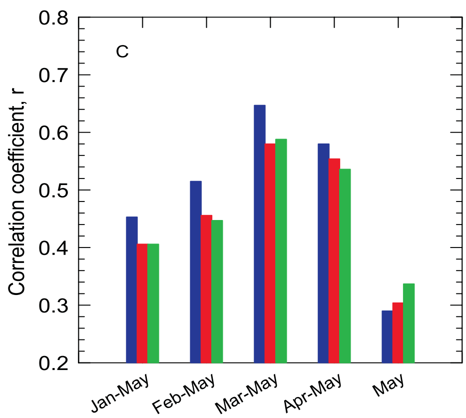


Figure 14. Changes in correlation coefficients, r, between mean Mývatn temperature and mean frequency of winds at Hraun á Skaga for different time periods: May (A), PP2 period,16 May-14 June (B) and June (C). The (S+SW)-(N+NE) frequency difference is shown in blue, the (S-N) frequency difference in red and the (S+SE)-(N+NW) frequency difference in green.

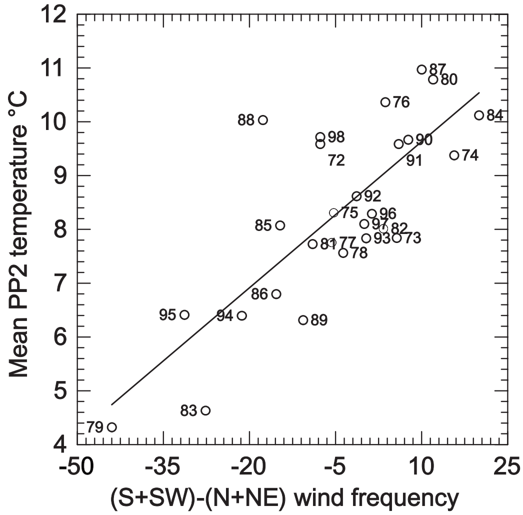


Figure 15. Connection between mean wind frequency at Hraun á Skaga, March to May, and in Lake Mývatn mean temperature in the period 16 May to 14 June. Numbered symbols indicate years.

Hraun á Skaga, were examined using Pearson correlation coefficients. This revealed general positive correlations with southerly winds. These correlations are high with the (S+SW)-(N+NE), (S-N) and the (S+SE)-(N+NW) frequency differences, highest though, r=0.776, in the first mentioned case (Fig. 14). The correlations increase as the number of months before June in the frequency mean is increased to include March (Figs. 14 and 15). These correlations reflect, in summary, processes which have direct or indirect effects on the air temperature at Lake Mývatn in the spring period. This includes warm southerly winds, sea to air heat flux north of Iceland, as well as advection of warm water onto the N-Iceland shelf. It is also possible, that northwesterly winds bring generally colder air than northeasterly winds, but no data on that aspect are presently under evaluation. The conditions at Lake Mývatn in spring are clearly related to weather patterns during the preceeding winter months, in other words to the severity of winter.

Connections of Lake Mývatn mean temperatures to the North Atlantic Ocillation, NAO

The mean temperatures for the periods May,

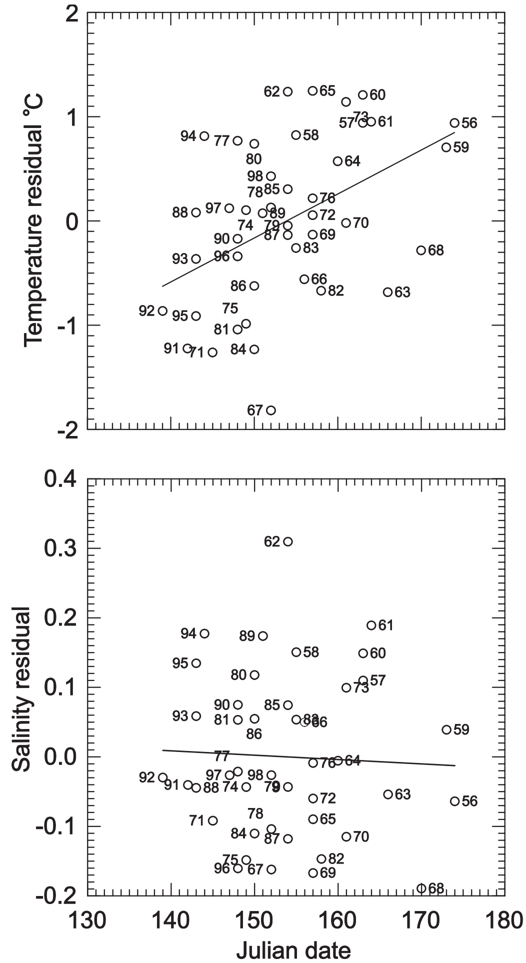


Figure 16. Relationships between Julian dates of Siglunes section observations and temperature and salinity regression residuals. Numbered symbols indicate years.

June, Sep, P1 and PP2 were examined for correlations with expressions of the NAO, covering winter and three-month seasonal indices from the months preceeding the Mývatn mean periods. The results of this analysis revealed no positive correlations of any significance.

BIAS IN DATA

Long temperature and salinity data time series are invaluable to monitor interannual and long term hydrographic variations, but the value rests heavily on the criteria that the data are collected in a standardized fashion, *e.g.* at the same time and same locations annually, to avoid bias arising from seasonal processes. This relates particularly to surface waters where changes may be rapid.

As shown in Figure 3, the observation date for the Siglunes section extends over 35 days in the 47 year record. There is a possible influence of the observation date on the relationships observed between the Siglunes section deviations and parameters from Hraun á Skaga and Lake Mývatn (Figs. 7 and 13). Examination of the regression residuals from the temperature- and salinity-wind frequency connections (Fig. 7) in relation to the observation dates, reveals that the temperature deviations are related to the observation date, whereas the salinity deviations seem independent of date (Fig. 16). The regressions are:

$$t_{resid} = (0.042 \pm 0.013) * \text{Julian date} - 6.48 \quad r=0.441$$

and

$$s_{resid} = (-0.001 \pm 0.002) * \text{Julian date} + 0.096 \quad r=0.044.$$

It can not be resolved wheater the residual temperature trend arises from the relative timing of observations and seasonal changes or from interannual variations in heating and advection. The years 1952-1955, when the hydrographic observations were made near mid-June (Table 1), are not included in this analysis, since the Hraun á Skaga meteorological data presently extend back to 1956.

The Siglunes section observation dates have a smaller range, but nevertheless 23 days, during the period of the Lake Mývatn temperature series, 1972-1998. The temperature residuals from the regression shown in Figure 13, are not statistically correlated with the timing of the Siglunes section observations.

CONCLUSIONS

On the basis of the results described the following conclusions are drawn:

1. Unnsteins Stefánsson´s earlier findings, that the advection of Atlantic Water, through the Greenland Strait into the Iceland Sea, is connected to the regional meteorological conditions, are confirmed.
2. The north-south wind regime northwest and west of Iceland, in January-May, has a strong influence on the Atlantic Water advection and conditions north of Iceland in late May/early June. The east-west leaning of the wind additionally relates to the salinity variations, probably by affecting the amount of Polar Water that is advected eastward from the East Greenland Current. The ocean response time to local wind direction variations is short, *i.e.* a few months.
3. The mid-latitude meridional atmospheric pressure gradient variations, described by the NAO index, do not explain observed hydrographic variations off N-Iceland.
4. Aquatic climate variations of Lake Mývatn and River Laxá are most pronounced in the period from mid-May to mid-June. These variations are connected to processes that affect the air temperature at Lake Mývatn in spring, including the oceanic temperature conditions off N-Iceland. The strongest connection is with regional (S+SW)-(N+NE) wind frequencies in the preceeding three months.
5. The 47-year Siglunes section spring-time hydrographic time series is weakened by the fact that the data have been collected over 35 calendar days. This emphasizes the importance of standardized procedures and quality control when time series of environmental data are acquired.

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