

**Hydrographic conditions in North Icelandic waters
and
annual air temperature in Iceland**

by

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Abstract

Iceland is situated at fronts, i.e. at the meeting place of warm (Irminger current) and cold (East Greenland and East Icelandic Current) ocean currents. These different hydrographic conditions in Icelandic waters are reflected in the atmospheric or climatic conditions in and over the country and the surrounding seas, mainly through the Iceland Low and Greenland High. The paper deals with hydrographic conditions in North Icelandic waters - Siglunes section - in comparison to annual air temperature in Akureyri - North Iceland - and Reykjavík - Southwest Iceland - since 1950. The results show the hydrographic conditions in North Icelandic waters are coherent with air temperature both in North and South Iceland. The forcing of the atmospheric pressure systems involved ("North Atlantic Oscillation") is also considered.

Keywords: hydrographic conditions, air temperatures, annual and decadal variations; NAO.

Introduction

Iceland is situated at the meeting place of warm and cold sea and air flows (Fig.1). To the south is the Irminger Current with temperature of 4-8°C and a transport of about 2 Sv or at this outpost of the North Atlantic Current only 2% of the volume of the "birth" of the North Atlantic current system in the south and west. To the north, the sea is cold, the East Greenland Current with temperature of 0°C or less and a transport of 1-2 Sv, and the East Icelandic Current with temperatures of 0-2°C and still an unknown transport. These different hydrographic conditions in Icelandic waters are reflected in the atmosphere or climatic conditions in the country itself and its surrounding waters, than mainly through the Iceland Low and Greenland High.

The warm Irminger Current flows from the south northwards along the west coast of Iceland and from there with one branch westwards to Greenland and another branch eastwards into North Icelandic waters. The latter branch is sometimes called the North Icelandic Irminger Current. This branch has a distinct seasonal variability, it is in general strengthening in spring and summer (Stefánsson 1962, Kristmannsson 1998). Since the sixties the inflow into North Icelandic waters also had a strong annual variability when the cold currents from the north took over at least in the upper layers (Malmberg and Kristmannsson 1992, Malmberg and Blindheim 1994, Malmberg et al. 1996, Malmberg and Jónsson 1997; Fig.2b).

The Siglunes section

As described in Malmberg et al. -paper L:13 in this Session on Nordic Seas Exchanges - a selected station in North Icelandic waters (S/3 - Siglunes section -50m as well as the whole section S/1-5/0-200m, Fig.1) has been used to show interannual variability in spring in the area during the period 1952-1999 (Figs.2b and 10). Most outstanding are the changes in hydrographic conditions in the latter part of the sixties (upstream years of the "Great Salinity Anomaly" (GSA) in the seventies; Dickson et al. 1988). At this time the hydrographic conditions in North Icelandic waters changed from being Atlantic ($t > 4^\circ\text{C}$; $S > 35.0$) to Polar conditions ($t \sim 0^\circ\text{C}$; S as low as 34.0) after decades of Atlantic conditions even since the twenties (Stefánsson 1969). After the sixties the conditions have shifted between Atlantic and Polar conditions and furthermore even with one more characteristic of Arctic water with moderate cold temperatures of 1-3°C and salinities around 34.8 (downstream "tail" of the GSA's) in the seventies (Dickson et al. 1988) and eighties (Belkin et al. 1998). Besides, the salinity of the inflowing Atlantic waters since the eighties up to 1998 never reached the high values prior to the mid sixties (Fig.3). This low salinity may even in general reveal a tendency to arctic conditions during this period, which came to an abrupt end in 1999. At last the relation between temperature and salinity for all data in spring 1952-1999 at 50 m depth at the selected station in question (Fig.4) indicates the different water masses in question - Atlantic, Polar and Arctic water - the last mentioned is very close to be even North Icelandic Winter water (Stefánsson 1962), formed in winter by cooling and mixing in the North Icelandic shelf area.

Summarized, the extreme variations in temperature and salinity between years in the surface layers of the Siglunes section 1952-1999 were as large as 7-8°C in temperature and one SU in salinity (Figs.2 and 4).

Sea surface temperature at Grímsey

Grímsey is a small island in the neighbourhood of station S-3 in North Icelandic waters (Fig.1). Since 1987 sea surface temperature readings are available throughout the years to present time (1998/99), though with a few interruptions (Fig.5). Three months means for the seasons (jan.-march, april-june, july-sept., oct.-dec.; Fig.6) show the annual variations being largest in spring. Thus the cold periods of Polar conditions (1988) and Arctic conditions (1989-1990, 1995) are outlined in the recordings (Fig.7a). Comparison between the Grímsey spring data and those from the nearby S-3 station -50m (Fig.7b) gives a satisfying result supporting the overall data set used. Further the positive relationship between the Grímsey temperature and the salinity maximum in the upper 300m at S-3 (Fig.8) supports a view that the continuous Grímsey data may be used to indicate conditions at S-3 and even in the whole Siglunes section throughout the years, than referring to the close relationship between the hydrographic conditions at S/3/50m and S/1-5/0-200m (Anon.1999, Fig.11a,b). Furthermore, not only annual air temperatures in Reykjavík and Akureyri and hydrographic conditions in spring in the waters north of Iceland should be studied, but seasonal conditions in both cases as well to obtain more detailed results.

The NAO index and the hydrographic variability in North Icelandic waters

The normalized atmospheric difference between the Azores High and the Iceland Low is known as the North Atlantic Oscillation (NAO; Hurrell 1995; Fig.9). The variable forcing of these atmospheric conditions on the westerlies has an impact on the oceanic circulation through variable wind forcing and heat and vapour exchange between atmosphere and ocean. Positive NAO indices are thus in general followed by relatively strong, warm and humid westerlies in the eastern North Atlantic, but with cold and dry winds in the western North Atlantic. Negative NAO indices are on the other hand followed by cold and dry northerly winds in the eastern part and warm and humid southerly winds in the western part of the North Atlantic (McCartney 1996). As seen in figure 10a,b the 5 years running means of both NAO and salinity and temperature in surface layers (S-3/50m) in North Icelandic waters as well as integrated over the whole Siglunes section (S/1-5/0-200m; Anon.1999 see Fig.11) agree fairly well with each other as regards timing of periods, especially in the late sixties and the seventies as well as in the nineties, but not so in the eighties. This disagreement in the eighties coincide with the GSA's arrivals into the waters north of Iceland (Iceland Sea) in 1982-1983 (Dickson et al. 1988) and in 1989-1990 (Belkin et al. 1996) contributing to Arctic conditions in North Icelandic waters (a.o. Malmberg et al. 1998). Curry and McCartney (1996) have as well related irregularities between thickness of the Labrador water in the Labrador Sea and a positive NAO to impact of the GSA's in the western part of the North Atlantic in the early seventies and eighties (during the years 1970-1972 and 1982-1984).

Annual air temperature in Reykjavík and Akureyri

Comparing the variations in annual air temperature in Akureyri, North Iceland, and Reykjavík, Southwest Iceland, 1952-1998 (Fig.2) with the annual spring temperature and salinity in the sea north of Iceland (Siglunes 3 /50 m), the coherence between these time series is obvious. Cold and low saline respectively warm and high saline conditions in North Icelandic waters generally coincide with "low" and respectively "high" annual air temperature both in Reykjavík and Akureyri. The positive temperature relationship between Reykjavík and

Akureyri (Fig.12) as well as temperature and salinity relationships are further demonstrated in x-y plots (Fig.13). The poor relationship of the time series may though indicate a positive relationship of climate both in North as well as South Iceland with hydrographic conditions in North Icelandic waters. Also noteworthy is the variability in the air temperature difference between Reykjavík and Akureyri (Fig.14), being around 1°C prior to the cold ice-years in the sixties, than increasing up to 2°C during the ice-years and decreasing again after that to values frequently below 1°C, some years even to almost no difference. Further, the annual air temperature in Akureyri reached the same level after the ice-years in the sixties as before (3-4°C; Fig.2), but in Reykjavík less so where the late seventies and early eighties with 3-4°C were even colder than the sixties with 4°C compared to 5°C before. This is even also true for many of the cold years early in the century (1900-1920; Fig.15). These low temperatures in Reykjavík in the seventies-eighties and occasionally later may seem to coincide with the observed hydrographic arctic conditions in North Icelandic waters which again were related to the GSA's in the northern North Atlantic and Nordic Seas (Dickson et al. 1988, Belkin et al. 1998). It may also be noted that a general cooling and "freshening" found place during the same period in the Norwegian Sea and the eastern part of the Nordic Seas (Blindheim et al. 1999), a "freshening" related to the conditions in the East Icelandic Current in the Iceland Sea.

Summarized (Fig.2), the annual air temperature in Reykjavík respectively Akureyri was around 5°C respectively 3-4°C prior to 1965, but decreased after that to 4°C respectively almost 2°C during the extreme ice-years when also the difference between Reykjavík and Akureyri was up to 2°C (Fig.14). After the ice-years 1965-1971 the temperatures in Akureyri rose again to the former values of 3-4°C but in Reykjavík it was frequently even lower than during the cold ice-years. Noteworthy is the extreme cold year 1979 in Reykjavík respectively Akureyri with annual air temperatures of 3°C respectively 1.5°C. This year was indeed the coldest one in the 20th century (see Einarsson 1989; Fig.15), both in Reykjavík and Akureyri.

Sea and air temperatures

As the annual variations in temperature in North Icelandic waters in spring more or less coincide with the annual air temperatures in Reykjavík and Akureyri, the difference between temperatures in the sea and in the air must as well coincide in time (showing up with a few years periodicity of ~4 years) (Fig.16). This difference might from first sight due to different distances and locations generally be larger for Reykjavík than the corresponding Akureyri difference. This is in general true, especially for the cold ice-years 1965-1971, but after that the differences are only slightly larger (negative) for Reykjavík than Akureyri. Also during the period 1973-1998 the differences had an indication of a negative trend and smaller annual amplitudes, it is a relative cooling in Reykjavík and Akureyri compared with the sea temperatures.

Summarized, during the warm period prior to the ice-years in the late sixties the air temperatures in Reykjavík were near-by to those of the sea north of Iceland but relatively colder (2°C) in Akureyri (Fig.16). During the cold ice-years Reykjavík air temperatures on the other hand did not cool as much down (1°C) as those in Akureyri (2°C) and in the sea (5°C); and after that the differences were similar or slightly negative. These three different periods may refer to the three different hydrographic conditions in Icelandic waters during

the time - Atlantic, Polar and Arctic conditions - which than are reflected in the climatic conditions in Iceland.

Discussion and conclusions

The different locations of Reykjavík and Akureyri on each side of the Icelandic highlands may account for the different response to "warm" and "cold" periods. Akureyri in the north is located at the bottom of a fjord - Eyjafjörður - intruding far into the country (50 km) whereas Reykjavík in the southwest is much more open to the open ocean. "Warm" periods with southerly winds - low pressure in the Iceland Low and positive NAO - and "warm" inflow into North Icelandic waters give Reykjavík and Akureyri as well heat input, for Akureyri also including the effect of föhn-winds (Einarsson 1984). On the other hand "cold" periods with northerly winds (high pressure over Greenland and Iceland, ice-years and negative NAO) and less inflow of warm water into North Icelandic waters have a direct cooling effect in Akureyri and also in Reykjavík but less so than in Akureyri due to the southerly location with additional effect of northerly dry and bright weather.

The connection between the annual air temperatures both in North as well as in South Iceland with hydrographic conditions in North Icelandic waters reveal the fight between the Iceland Low and the Greenland High. The former is in simplest terms related to "warm" air and sea flows northwards but the latter to "cold" southwards flows. It should though be born in mind that the different tracks of the Iceland Low from the northern North Atlantic into the Nordic Seas complicate this simple sceme. The northerlies in Iceland are not only due to the Greenland High but also due to the track of the Iceland Low east and northeast of Iceland into the Norwegian Sea. These different tracks of the Low pressure include than also different weather types in Iceland (Einarsson 1984). These ocean/atmospheric conditions are steering the climate or air temperatures in Iceland, both in the south and north, conditions which than are intensified or modified by the föhn-winds of the mountainous inland of Iceland. During "warm" periods the annual air temperature in Reykjavík is closer to the spring temperature in North Icelandic waters than that in Akureyri, but during "cold" periods it is the opposite, the annual air temperature in Akureyri being closer to sea temperature than in Reykjavík. Variability in annual air temperature both in Akureyri in the North and in Reykjavík in the Southwest is thus after all related to the hydrographic variability in North Icelandic waters and all three to the principal atmospheric circulation.

At last, the most extreme variations for the period studied were observed during the so-called ice-years in the late sixties. During those years exceptional atmospheric conditions seem to have been observed (Figs.9 and 17), the atmospheric pressure being higher along the East coast of Greenland than at all other times in the 20th century along with the strong negative NAO indices observed (Fig.9). The pressure was continously increasing since around 1920 when the well-known mild period in the Northern North Atlantic and in nearby countries started (Rodewald 1967, Strübing 1968, Smed 1975; Einarsson 1989; Fig.15). Thus the cold period during the ice-years in North Icelandic waters in the late sixties may not have been quite of the same character in the atmosphere as that prior to 1920 as frequently directly or indirectly stated (a.o. Dickson et al. 1988). The exceptional high pressure over Greenland which gave rise to the extreme negative NAO and ice-years in North Icelandic waters in the late sixties and far reaching effect in wide areas in the northern North Atlantic (GSA of the seventies, Dickson et al. 1988) as well as on the living conditions in the sea (Jakobsson 1992) seemed to come to an abrupt end in the early seventies (c.f. Climatic reversale in the North

Atlantic; Dickson et al. 1975). But new decadal periods of high pressure in the north occurred into the nineties along with variable NAO indices. To close this discussion a diagram of the NAO (Fig.9) and a reversed pressure over East (Fig.17)Greenland could be shown to demonstrate the outstanding conditions observed in the sixties which gave rise to exceptional response in the northern North Atlantic including Icelandic waters and climate in Iceland.

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FIGURE CAPTIONS

- Fig. 1 Topography, nomenclature and locations referred to.
- Fig. 2 a) Mean annual air temperature in Reykjavík, SW Iceland and Akureyri, N Iceland 1950-1998.
b) Temperature and salinity at 50m in spring at station S-3 in North Icelandic waters 1950-1999.
For location see Fig.1
- Fig. 3 Maximum salinity in the upper 300m at station S-3 in North Icelandic waters in spring 1950-1999.
For location see Fig.1

- Fig. 4 Temperature-salinity relationship at station S-3/50m in North Icelandic waters in spring 1950-1999 and main water masses.
 AW: warm and saline Atlantic water ($S > 34.8$)
 PW: cold and low-saline Polar water ($S < 34.5$)
 AIW: medium warm and saline Arctic water ($34.5 < S < 34.8$)
- Fig. 5 Monthly average of continuous recording of sea surface temperature (SST) at Grímsey, North Icelandic waters 1987-1999.
 For location see Fig.1
- Fig. 6 Seasonal three months averages of SST at Grímsey 1987-1999.
 For location see Fig.1
- Fig. 7 a) Spring SST at Grímsey and station S-3/50m 1987-1999 and b) their relationship.
- Fig. 8 The relation between spring SST at Grímsey and salinity maximum at station S-3/0-300m 1987-1999.
- Fig. 9 The annual and 5 years running means of the winter NAO index a) 1870-1999 and b) 1950-1999 using normalized sea level pressure differences between Lisbon, Portugal, and Stykkishólmur, Iceland (Hurrell 1995 and pers. comm.).
- Fig. 10 Five years running means of the winter NAO and temperature and salinity in spring 1950-1999 at a) station S-3/50m and b) five stations on the Siglunes section integrated over 0-200m.
- Fig. 11 Temperature and salinity relationships in spring 1950-1999 at a) station S-3/50m and b) stations S/1-5/0-200m.
- Fig. 12 Relationship between mean annual temperature in Reykjavík and Akureyri 1950-1998.
- Fig. 13 Relationship between temperature and salinity at S-3/50m and annual air temperatures in a) Reykjavík and b) Akureyri 1950-1998.
- Fig. 14 Difference between mean annual air temperature in Reykjavík and Akureyri 1950-1998.

Fig. 15 Annual mean air temperature in Reykjavík and Akureyri 1900-1988 (Einarsson 1989).

Fig. 16 Differences between sea-temperature at S-3/50m and annual air temperatures in Reykjavík and Akureyri 1952-1998.

Fig. 17 Winter mean sea level pressure, Dec-Mar 5 years running means, hPa 10, ~1900-1990 (Blindheim, pers. comm.).

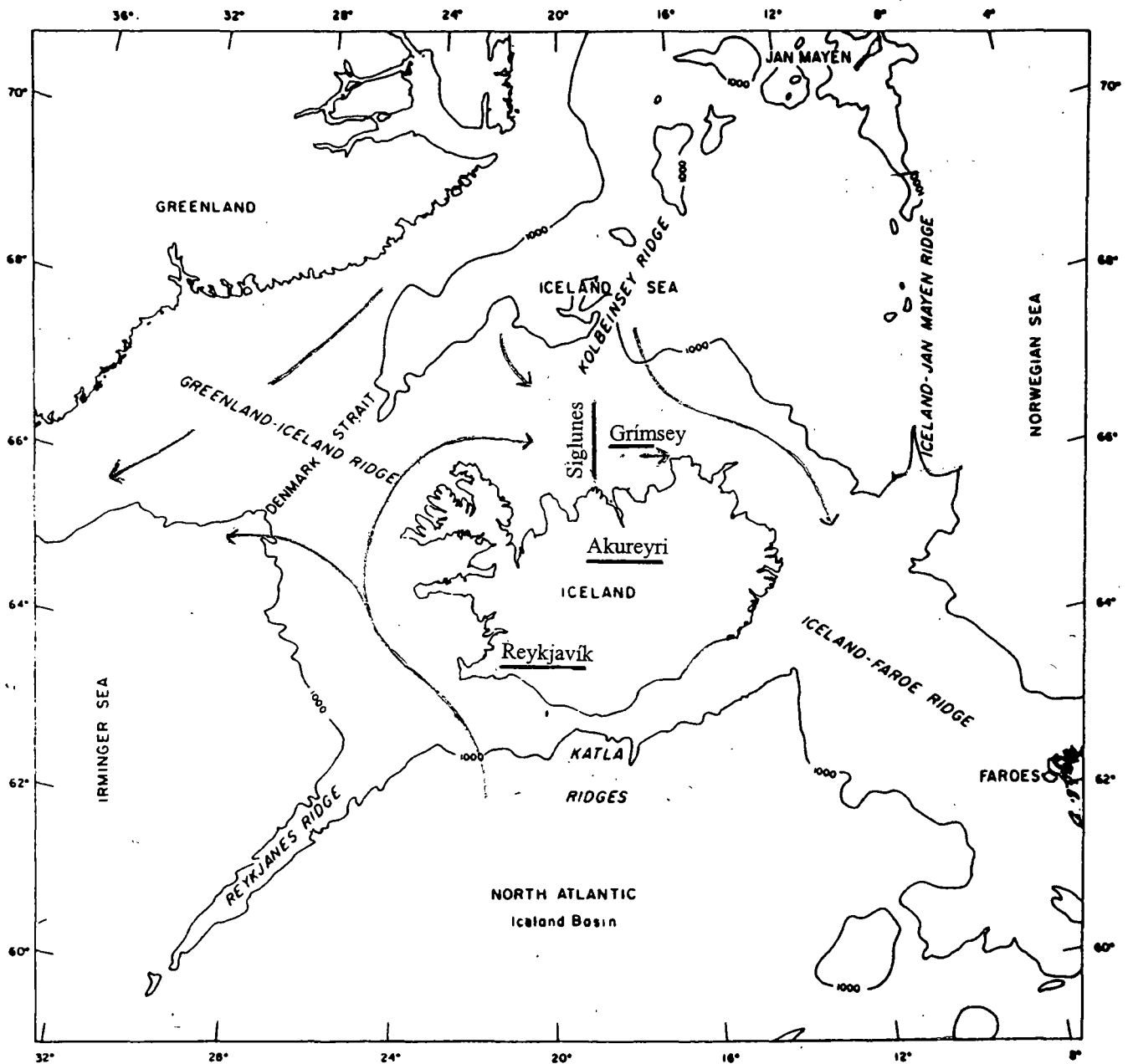


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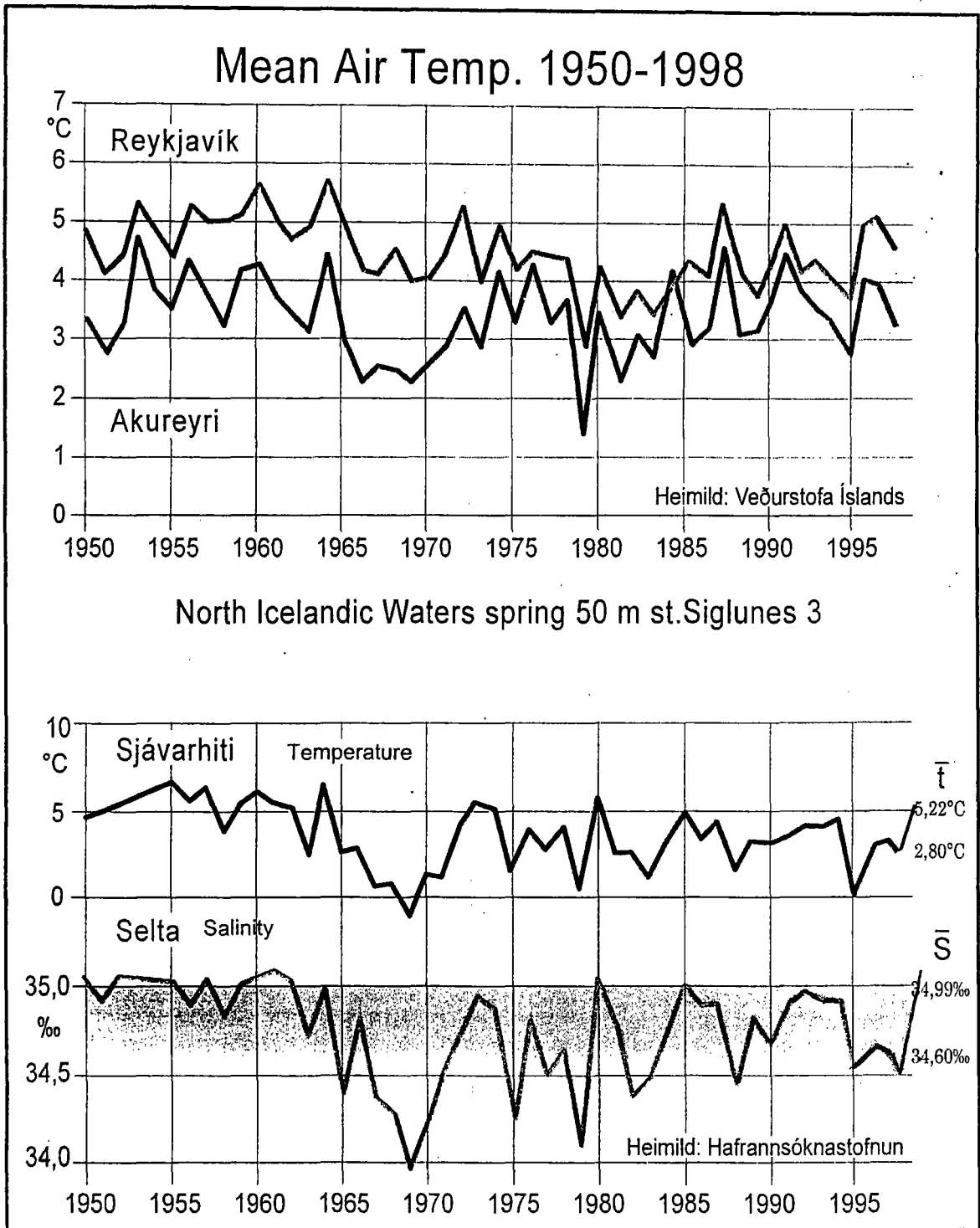


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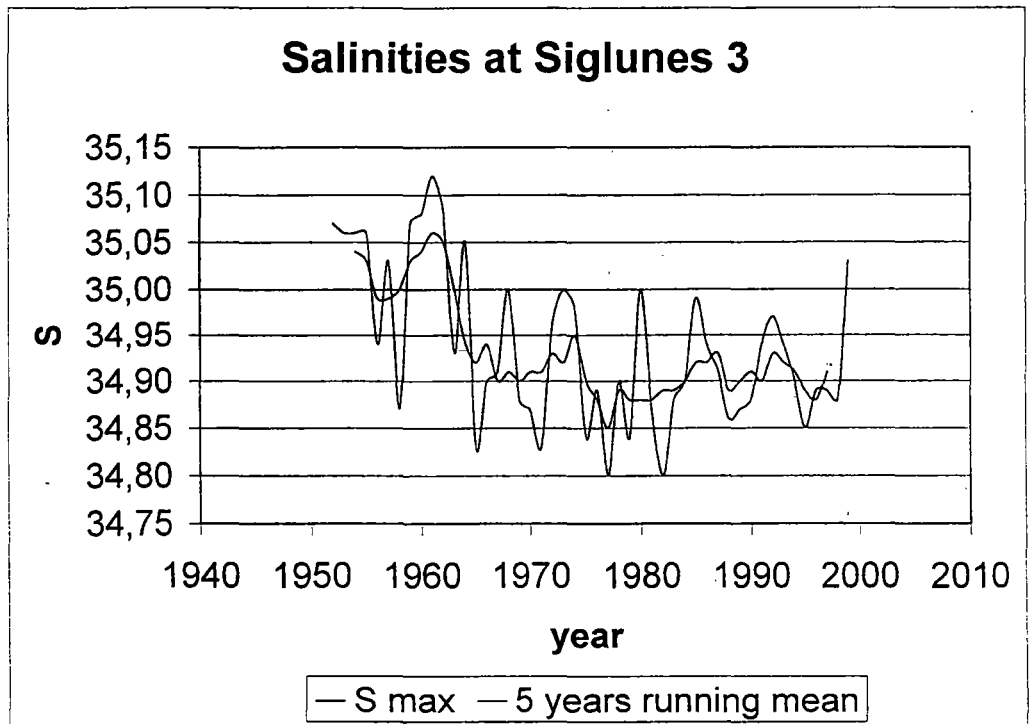


Fig. 3 Maximum salinity in the upper 300m at station S-3 in North Icelandic waters in spring 1950-1999.
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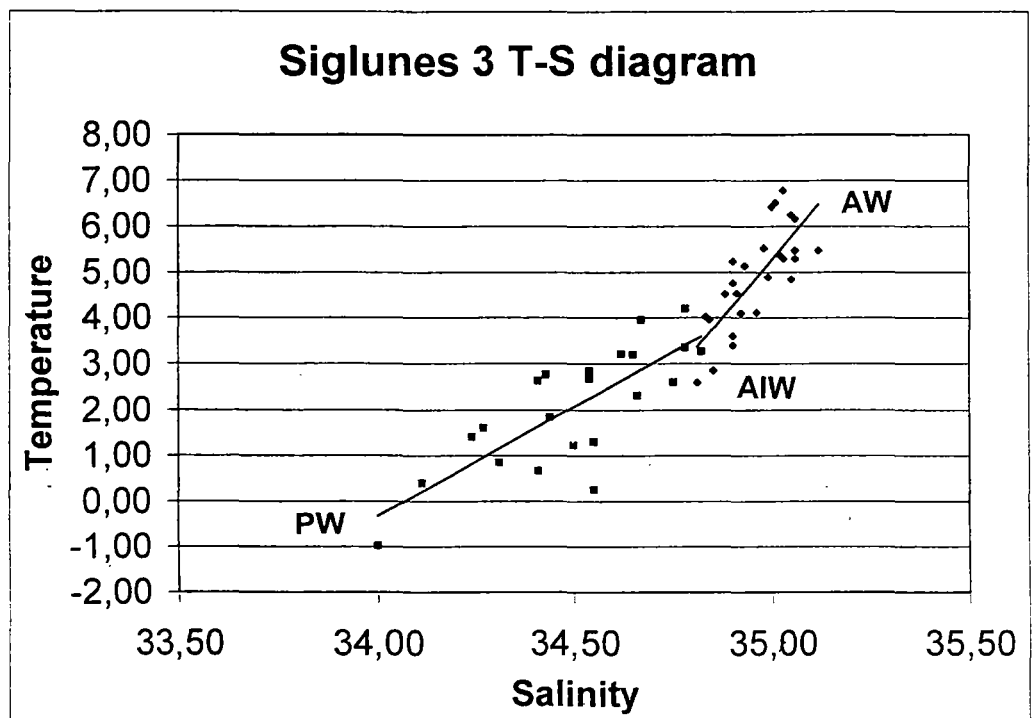


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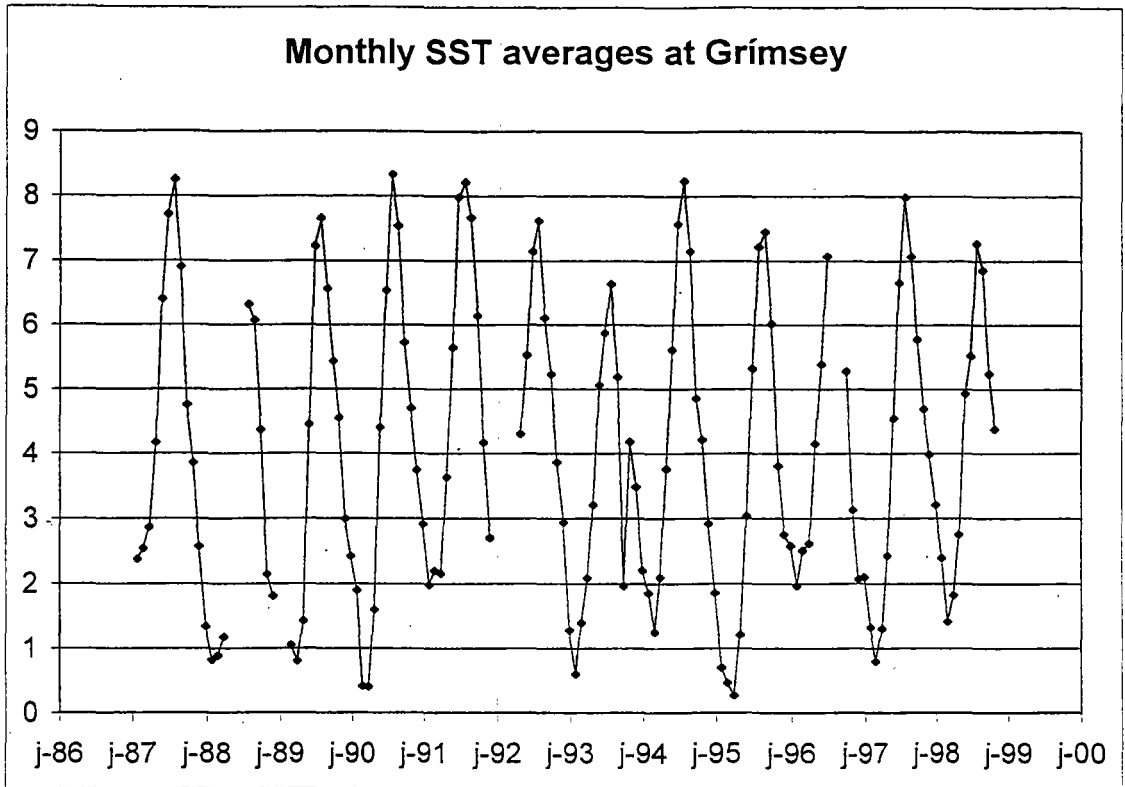


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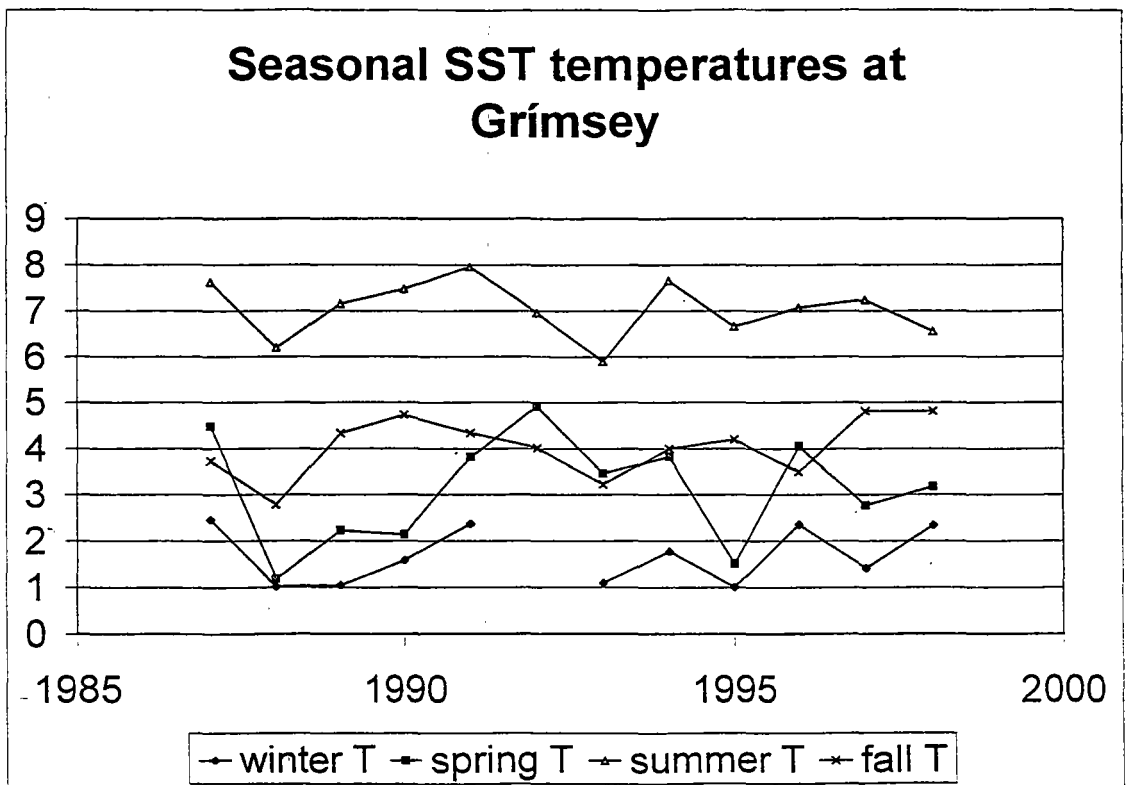


Fig. 6 Seasonal three months averages of SST at Grímsey 1987-1999. For location see Fig.1

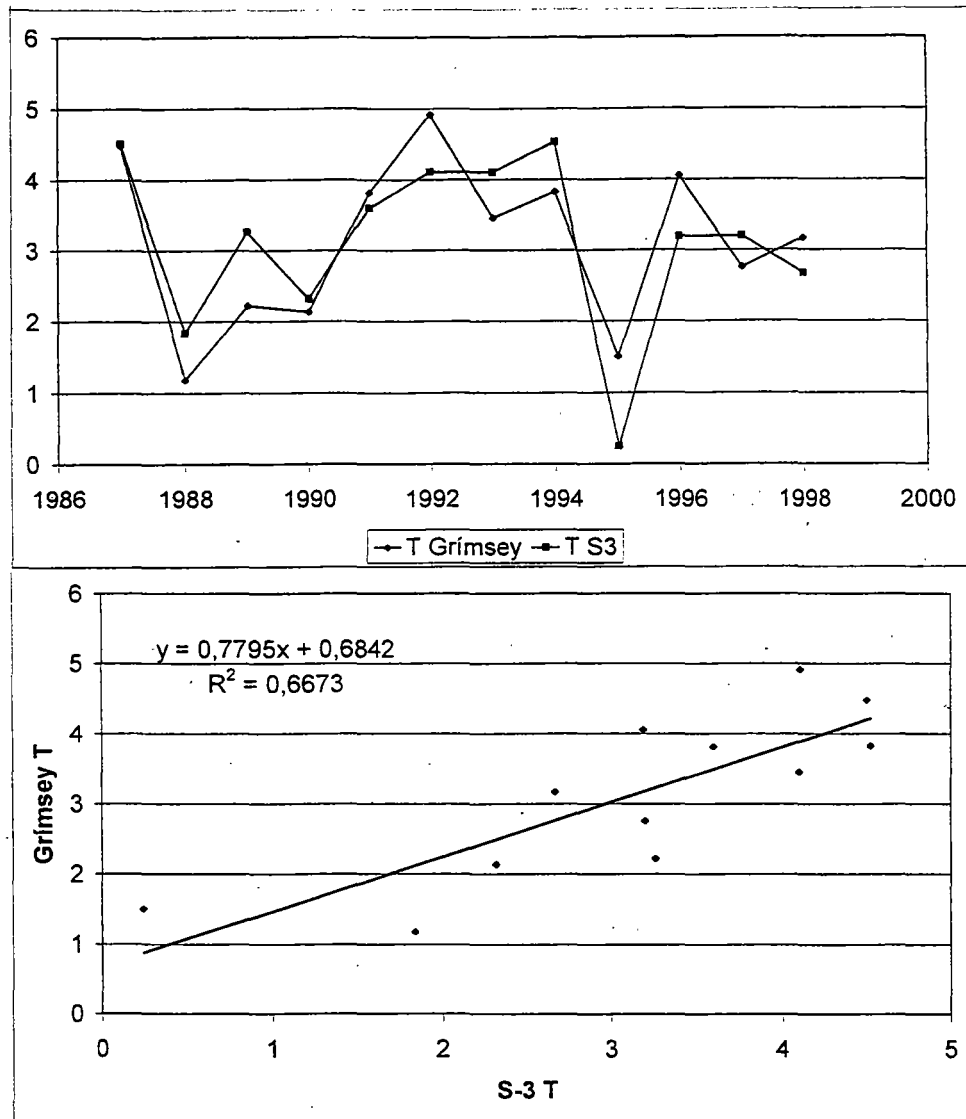


Fig. 7 a) Spring SST at Grimsey and station S-3/50m 1987-1998 and b) their relationship.

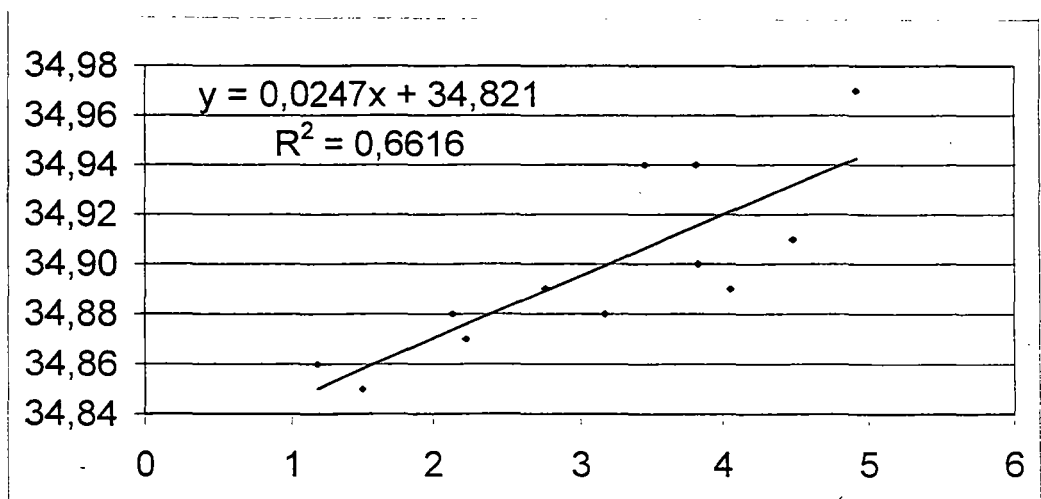


Fig. 8 The relation between spring SST at Grimsey and salinity maximum at station S-3/0-300m 1987-1998.

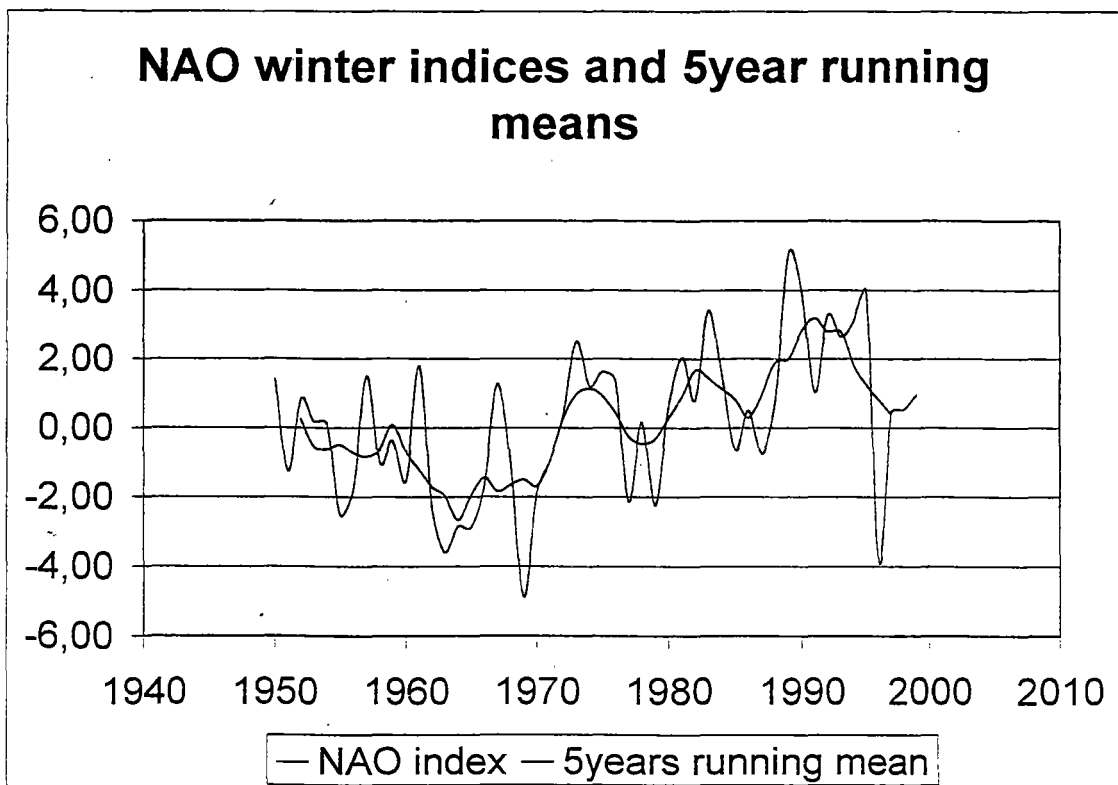
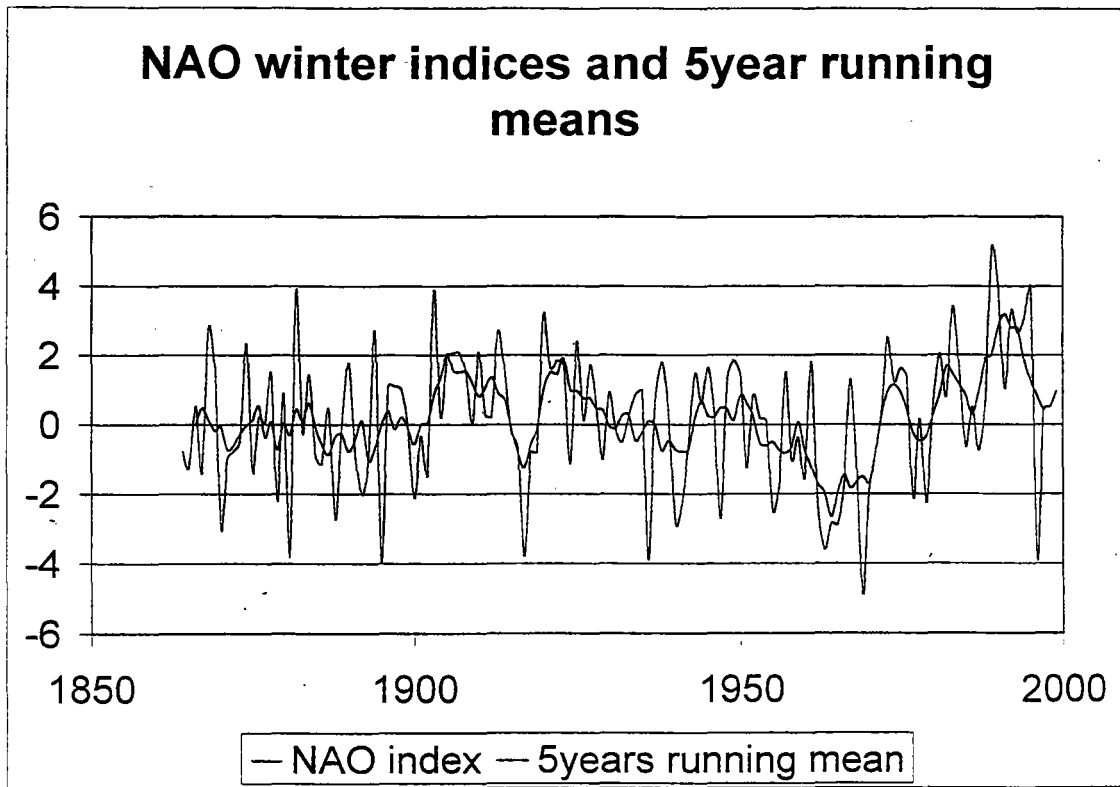


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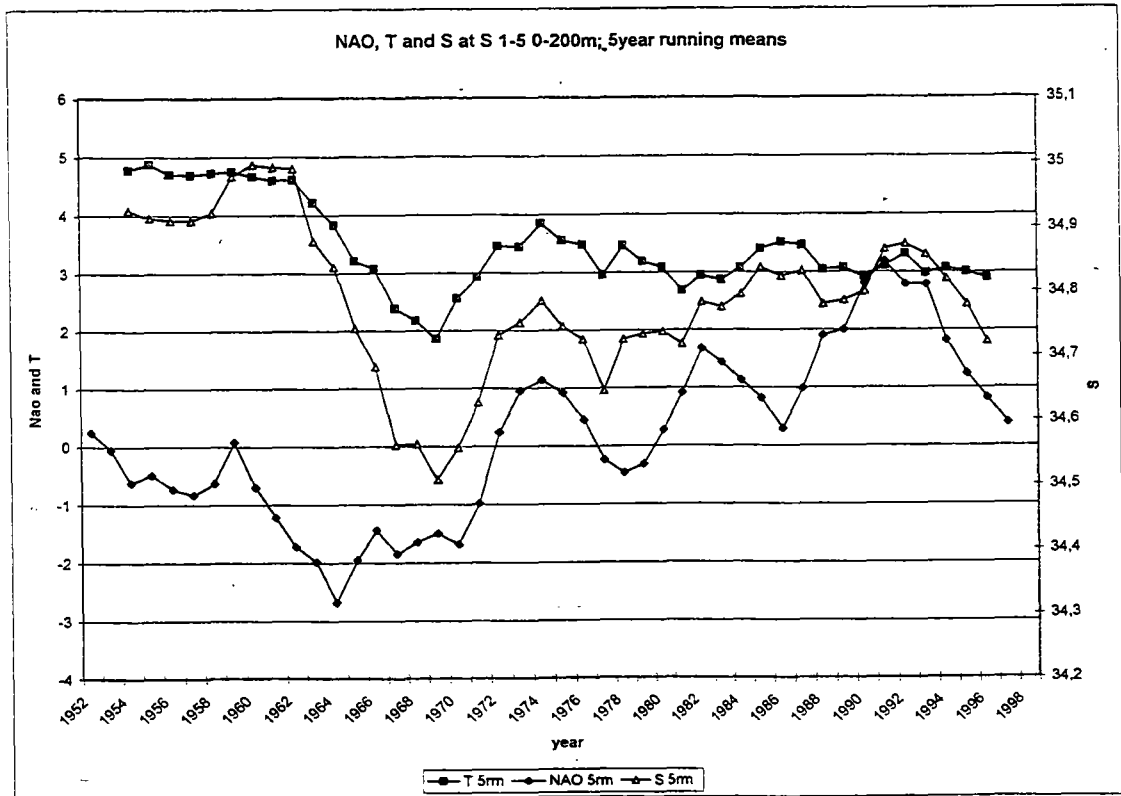
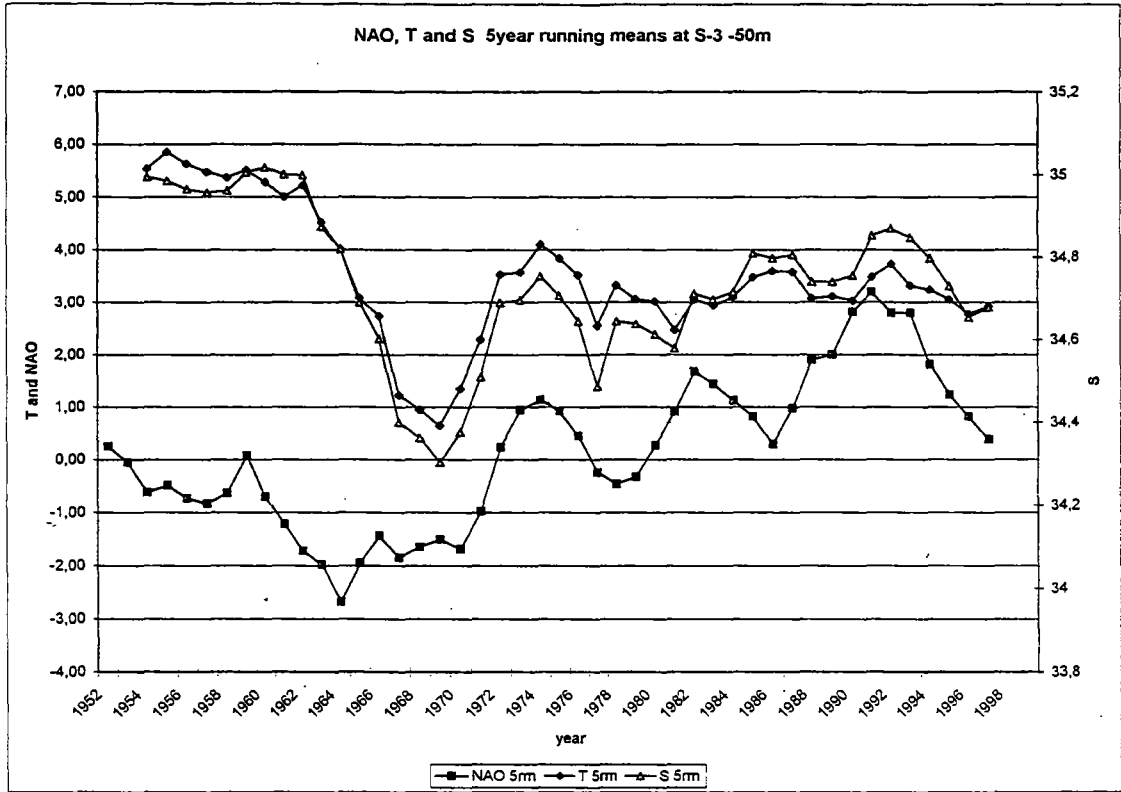


Fig. 10 Five years running means of the winter NAO and temperature and salinity in spring 1950-1999 at a) station S-3/50m and b) five stations on the Siglunes section integrated over 0-200m.

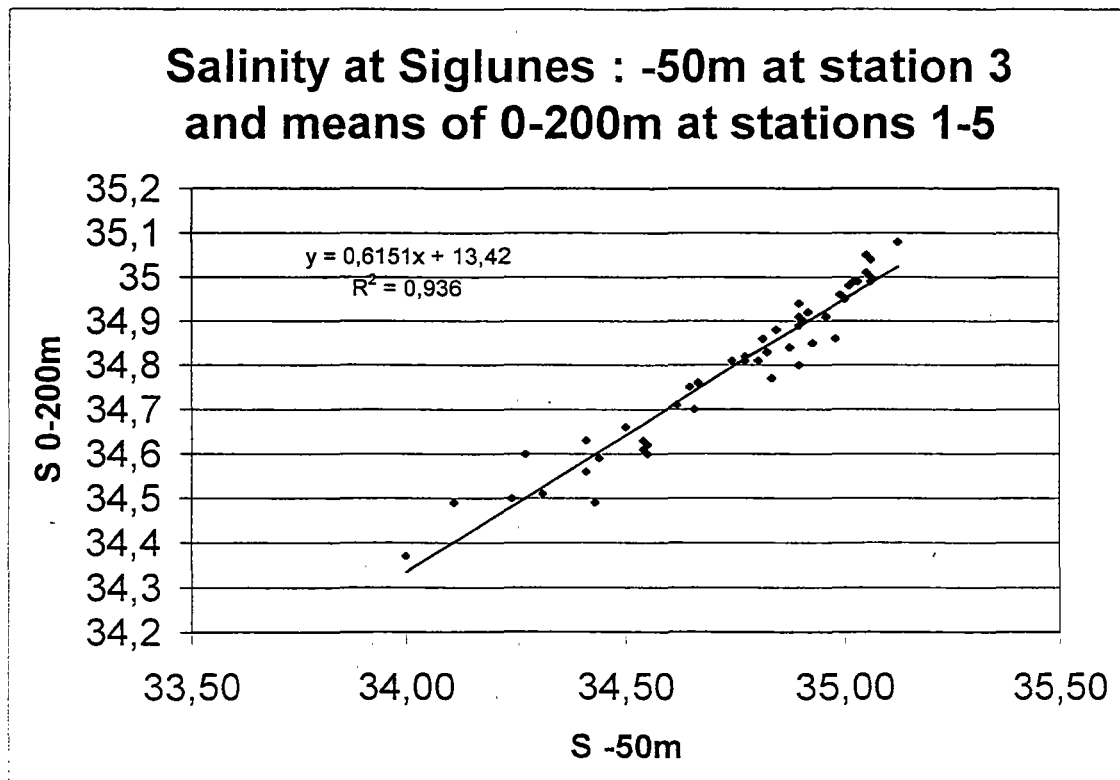
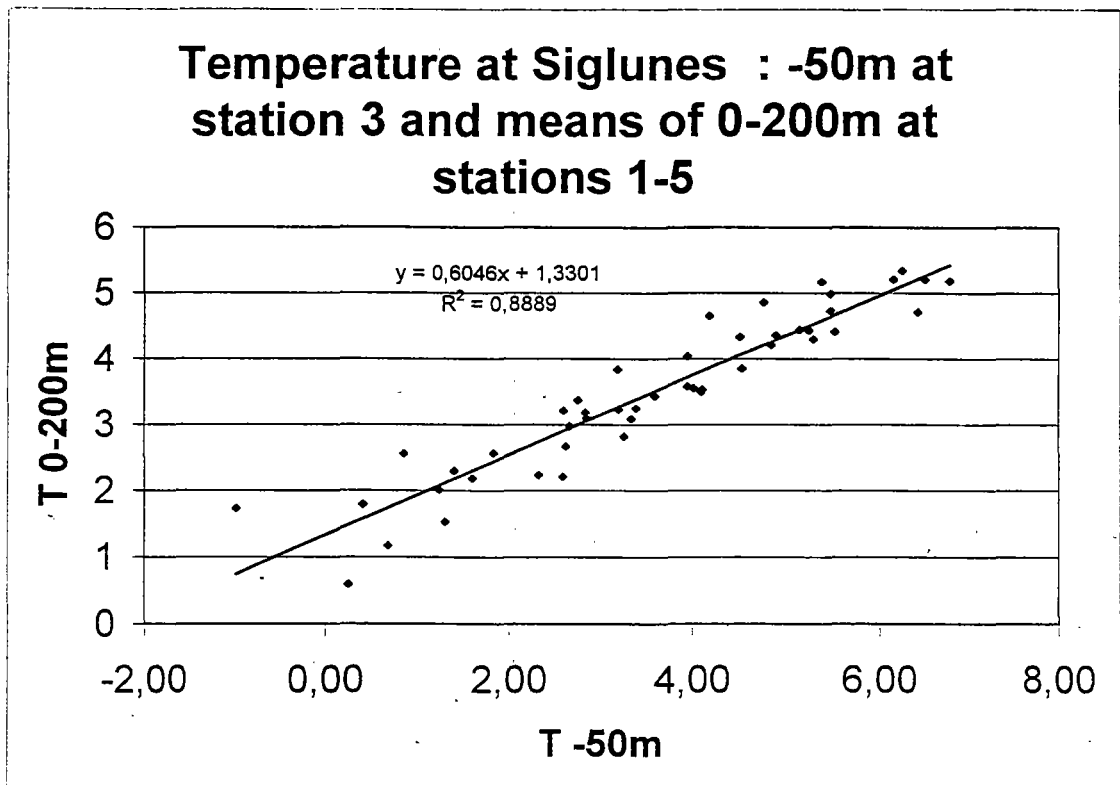


Fig. 11 Temperature and salinity relationships in spring 1950-1999 at a) station S-3/50m and b) stations S/1-5/0-200m.

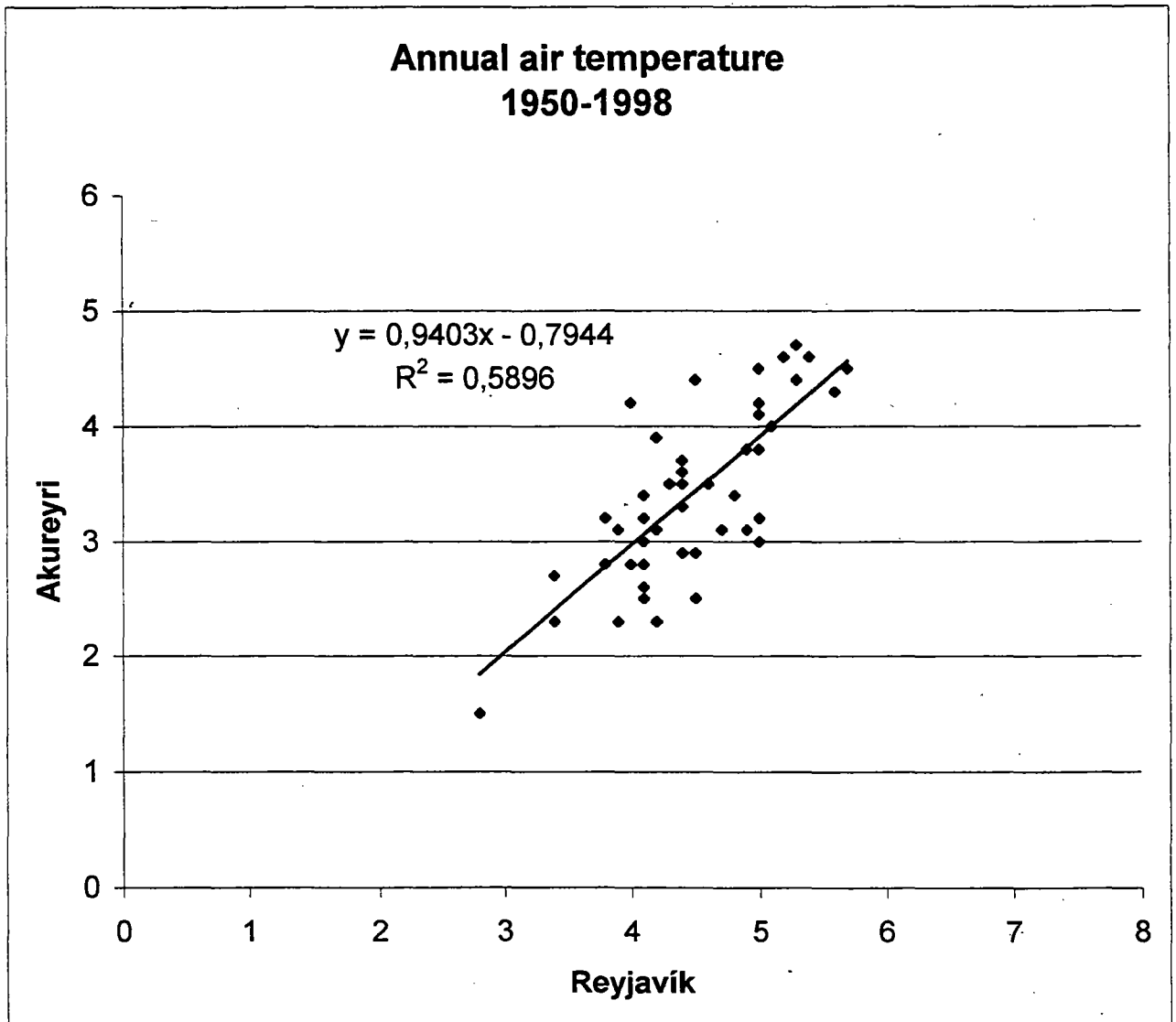


Fig. 12 Relationship between mean annual temperature in Reykjavik and Akureyri 1950-1998.

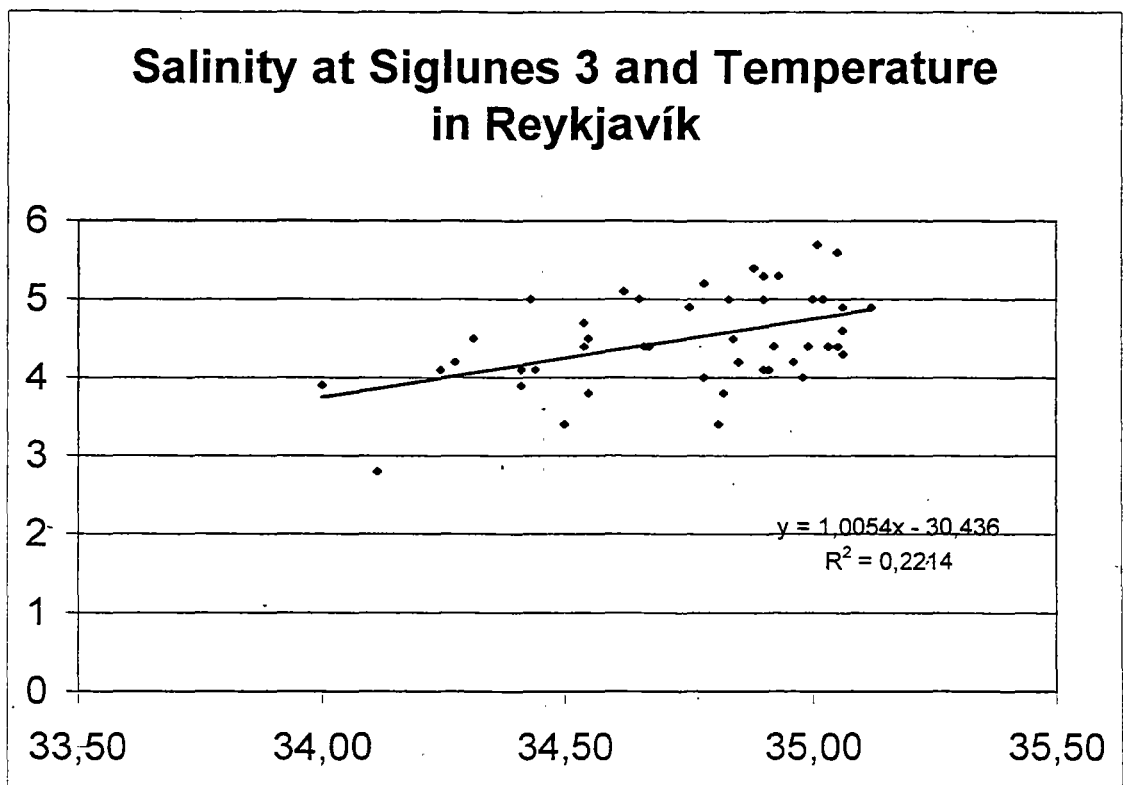
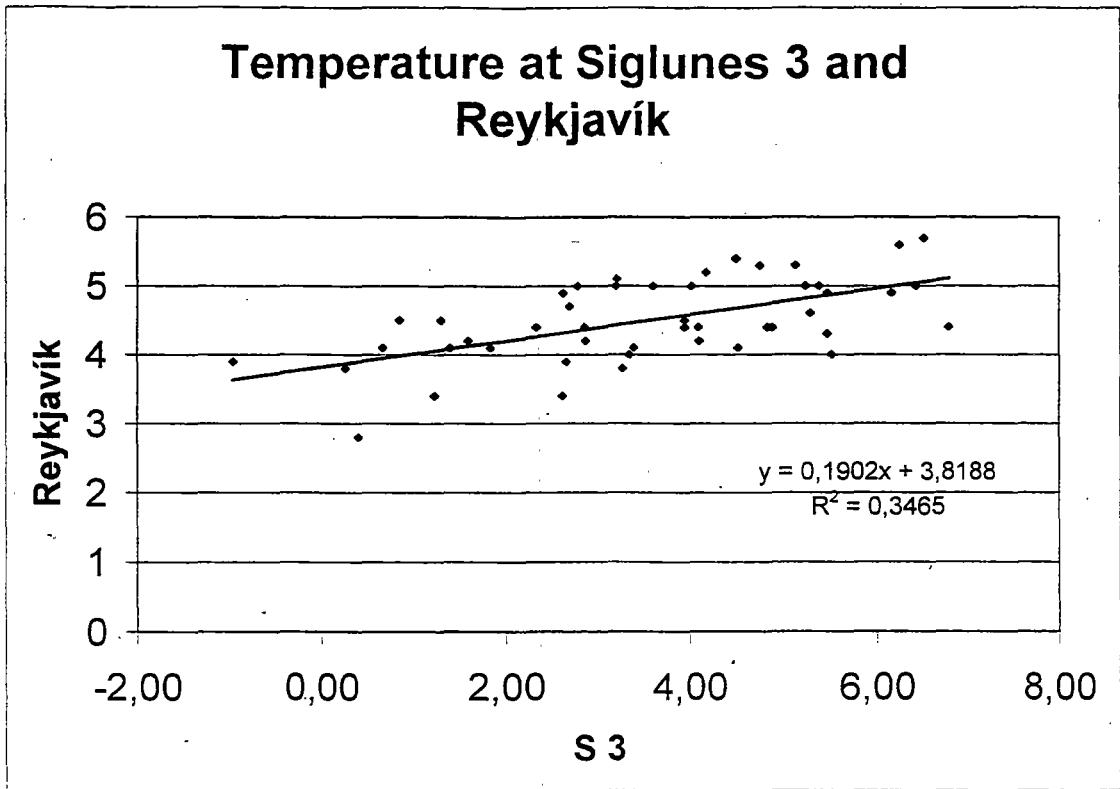


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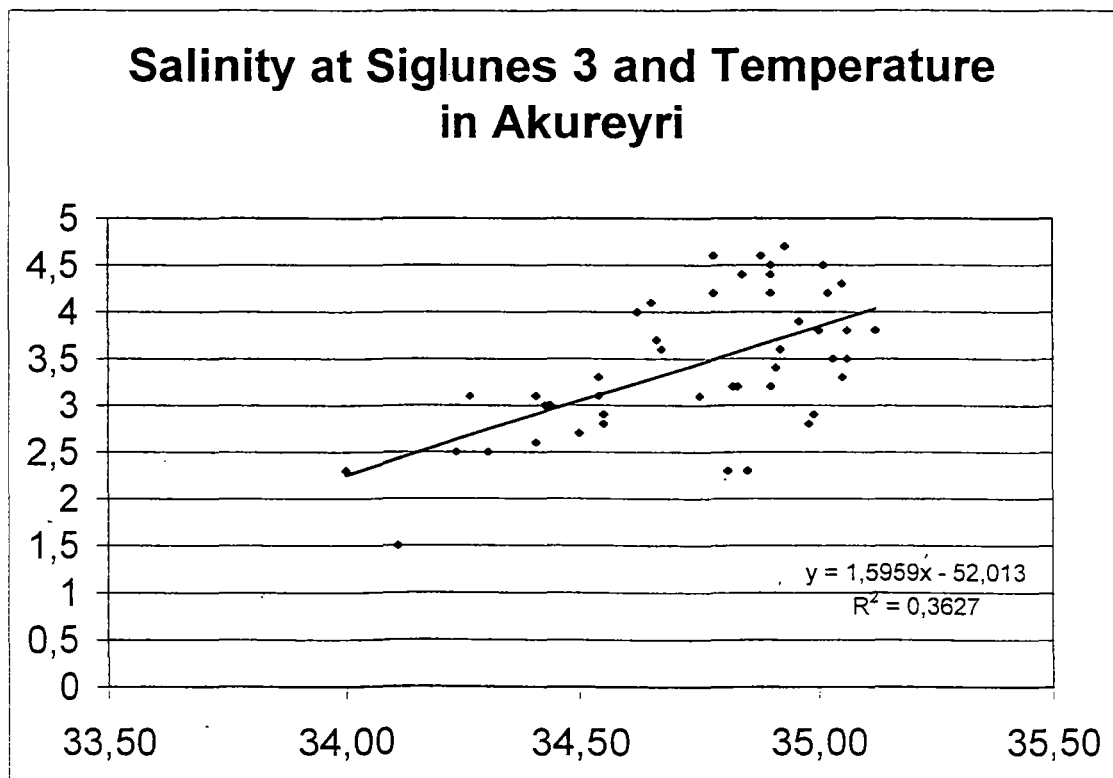
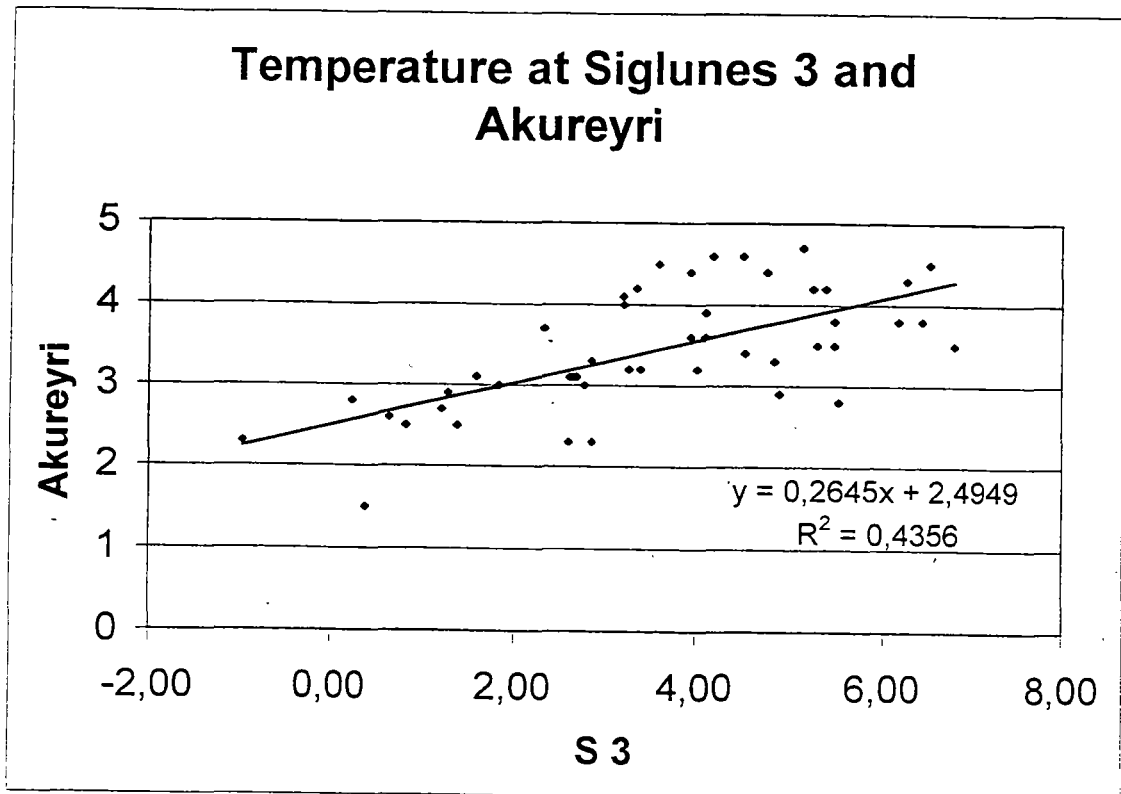


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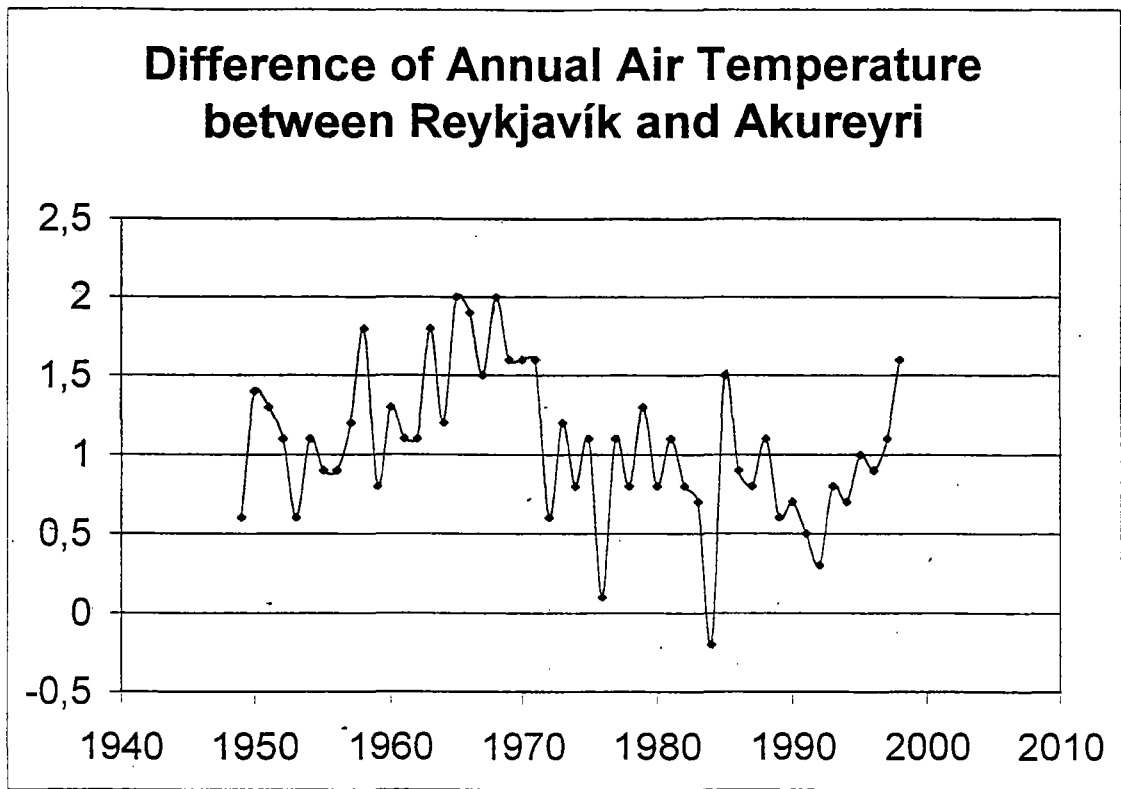


Fig. 14 Difference between mean annual air temperature in Reykjavík and Akureyri 1950-1998.

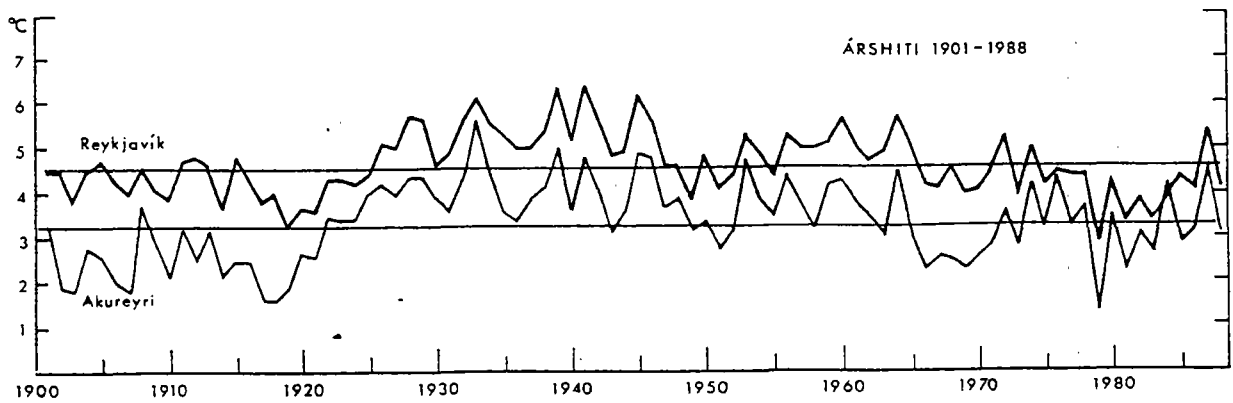


Fig. 15 Annual mean air temperature in Reykjavík and Akureyri 1900-1988 (Einarsson 1989).

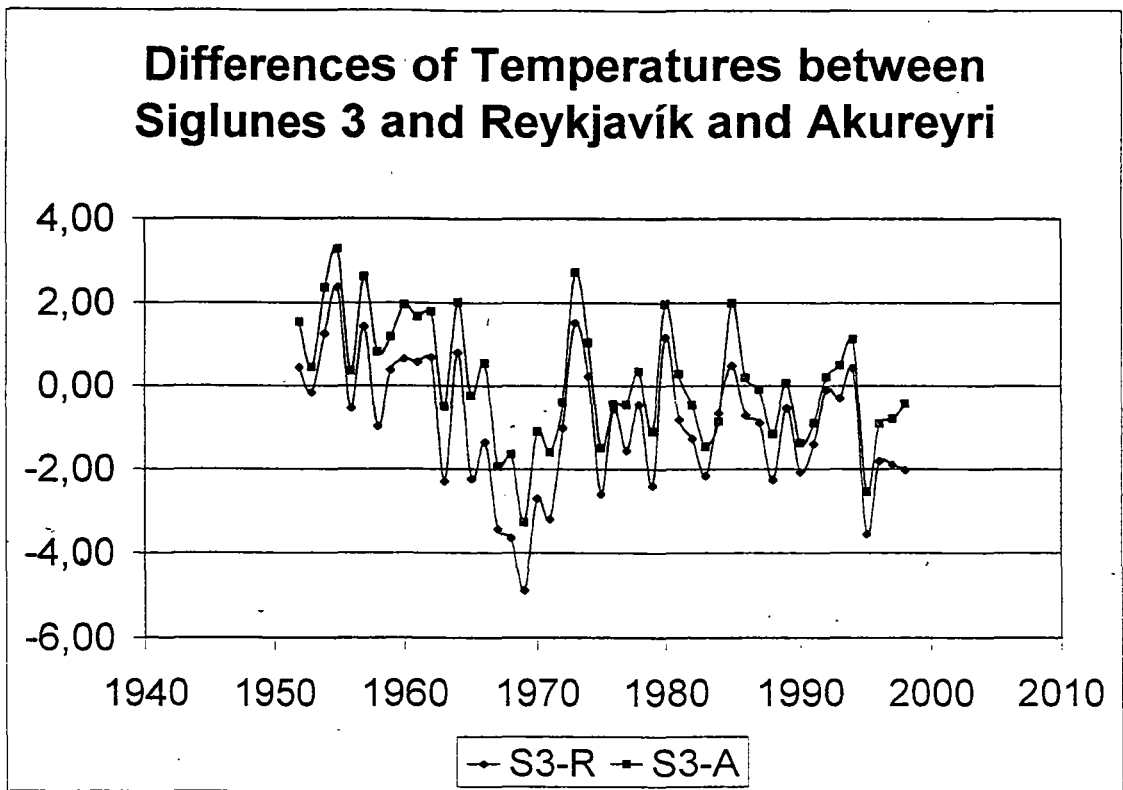


Fig. 16 Differences between sea-temperature at S-3/50m and annual air temperatures in Reykjavík and Akureyri 1952-1998.

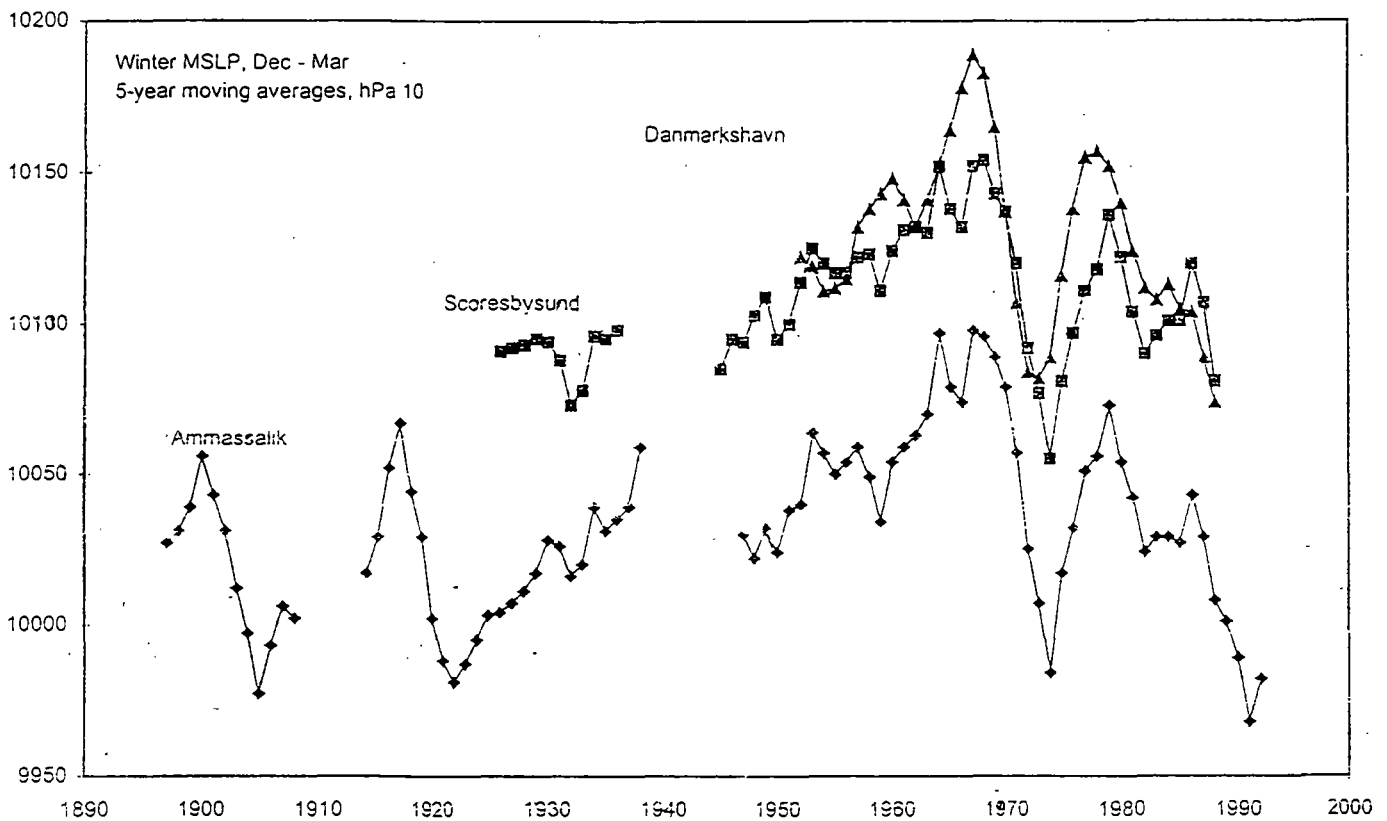


Fig. 17 Winter mean sea level pressure, Dec-Mar 5 years running means, hPa 10, ~1900-1990 (Blindheim, pers. comm.).

