Veðurstofa Íslands
Report

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(editors)

ACROSS - Atmospheric Circulation Related to Oscillations in Sea-ice and Salinity

ACROSS Conference, Reykjavík, Iceland, March 26-28, 1998

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ACROSS
ATMOSPHERIC CIRCULATION RELATED TO OSCILLATIONS IN SEA-ICE AND SALINITY

Seltu- og hitasveiflur í norðanverðu Atlantshafi, tengsl við hringrás andrúmsloftsins

Conference, March 26-28, 1998, Reykjavík, Iceland

PROGRAMME

Thursday, March 26

8:45 - 9:30	Registration
9:30 - 9:35	**Magnús Jónsson**, director, Icelandic Meteorological Office *OPENING ADDRESS*
9:35 - 9:40	**Trausti Jónsson**, Icelandic Meteorological Office *SOME PRACTICAL DETAILS*
9:40 - 10:10	**Povl Frich,** Danish Meteorological Institute, Denmark *ATMOSPHERIC CIRCULATION RELATED TO OSCILLATIONS IN SEA-ICE AND SALINITY (ACROSS)*

Morning Session. Chairperson: Jón Ólafsson

10:10 - 10:50	**Robert R. Dickson**, MAFF Fisheries Laboratory, UK (*Invited speaker*) *THE RESPONSE OF THE NORDIC SEAS TO LONG-TERM CHANGES IN THE NORTH ATLANTIC OSCILLATION*
10:50 - 11:10	**Coffee**
11:10 - 11:35	**Svend-Aage Malmberg**, Marine Research Institute, Iceland *DECADAL-SCALE CLIMATE VARIATIONS IN THE ICE-EXTENT AND HYDROGRAPHIC PARAMETERS IN THE WATERS AROUND ICELAND*
11:35 - 12:00	**Steingrímur Jónsson,** University of Akureyri / Marine Research Institute, Iceland *FRESH WATER IN THE NORDIC SEAS*
12:00 -13:20	**Lunch**

Afternoon Session I. Chairperson: Einar Sveinbjörnsson

13:20 - 13:45 **Sirpa Häkkinen**, GSFC, Maryland, USA
VARIABILITY OF THE NORTH ATLANTIC OVERTURNING FOR THE PERIOD 1951-1993

13:45 - 14:10 **Harald Engedahl** Norwegian Meteorological Institute (DNMI), Norway, **Gro Eriksrød,** Norwegian Polar Institute (NPI), Norway & **Bjørn Ådlandsvik,** Institute of Marine Research (IMR), Norway
A CLIMATOLOGICAL OCEANOGRAPHIC ARCHIVE COVERING THE NORDIC SEAS AND THE ARCTIC OCEAN WITH ADJACENT WATERS

14:10 - 14:35 **Carsten Hansen**, Danish Meteorological Institute, Denmark
IMPACT OF WINDSTRESS ON THE WATER MASS EXCHANGES BETWEEN LABRADOR SEA AND BAFFIN BAY

14:35 - 15:00 **Dave Thompson**, JISAO University of Washington, USA
THE ARCTIC OSCILLATION

15:00 - 15:30 **Coffee**

Afternoon Session II. Chairperson: Þóranna Pálsdóttir

15:30 - 15:55 **Roberto R. Barrera**, University of Barcelona, Spain
CONSIDERATIONS ABOUT AN OBJECTIVE SPECTRAL ANALYSIS

15:55 - 16:20 **Páll Bergþórsson**, former director, Icelandic Meteorological Office
TEMPERATURES IN SVALBARD AND GLOBAL TEMPERATURE VARIATIONS

16:20 - 16:45 **Þór Jakobsson**, Icelandic Meteorological Office
OBSERVING AND DESCRIBING SEA ICE PROCESSES IN ICELANDIC WATERS

17:00 - 17:45 Icebreaker invited by the Ministry for the Environment

Dinner on your own (you will be advised on the possibilities)

Friday, March 27

Morning Session: Chairperson: Tómas Jóhannesson

9:00 - 9:45 **Gerard C. Bond,** Lamont-Doherty Earth Observatory, USA (*Invited speaker*)
PERSISTENT MILLENNIAL-SCALE CLIMATE INSTABILITY IN THE NORTH ATLANTIC DURING THE HOLOCENE

9:45 - 10:10 **Anna María Ágústsdóttir**, Pennsylvania State University, USA, **R.B. Alley**, Pennsylvania State University, USA & **P. Fawcett**, University of New Mexico, USA
ABRUPT CLIMATE CHANGES AND THE NORTH ATLANTIC DEEPWATER FORMATION. INSIGHTS FROM THE GENESIS CLIMATE MODEL AND OBSERVED DATA

10:10 - 10:25 Coffee

10:25 - 10:50 **Jón Eiríksson**, University of Iceland, **Karen Luise Knudsen**, University of Aarhus & **Hafliði Hafliðason**, University of Bergen
HOLOCENE PALEOCEANOGRAPHIC RECORD FROM SEDIMENT CORES ON THE NORTH ICELANDIC SHELF

10:50 - 11:15 **Ólafur Eggertsson,** University of Lund, Sweden
ORIGIN OF THE ARCTIC DRIFTWOOD

11:15 - 11:40 **Ingibjörg Jónsdóttir**, Icelandic Meteorological Office & **Astrid E.J. Ogilvie**, INSTAAR, USA
HISTORY OF SEA ICE IN ICELANDIC WATERS

11:40 - 12:05 **Victor G. Savtchenko,** World Climate Research Programme, Switzerland
CURRENT PLANS FOR ORGANISATION OF WCRP RESEARCH INTO CRYOSPHERE AND CLIMATE

12:05-13:15 Lunch

Afternoon Session. Chairperson: Haraldur Ólafsson

13:15 - 13:50 **Heinz Wanner,** Institute of Geography, Climatology and Meteorology, University of Bern, Switzerland
HOW FAR DO WE UNDERSTAND DECADAL TO CENTURY SCALE CLIMATE VARIABILITY AND CHANGE IN THE EUROPEAN ALPS?

13:50 - 14:15 **Jürg Luterbacher**, Institute of Geography, Climatology and Meteorology, University of Bern, Switzerland
MONTHLY SEA LEVEL PRESSURE PATTERNS DURING THE LATE MAUNDER MINIMUM (1675-1715) COMPARED WITH 20TH CENTURY CIRCULATION

14:15 - 14:40 **Marie Ekström**, University of Lund, Sweden
COMPARISON OF WIND DIRECTIONAL DATA FROM COPENHAGEN AND LUND (1753-) WITH FOCUS ON ESTIMATION OF WATER FLUX ANOMALIES OF THE BALTIC SEA

14:40 - 15:05 **Gaston R. Demarée**, Royal Meteorolgical Institute of Belgium & **Astrid E.J. Ogilvie**, INSTAAR, USA
EARLY INSTRUMENTAL METEOROLOGICAL OBSERVATIONS IN GREENLAND AND LABRADOR

15:05 - 15:40 **Coffee**

15:40 - 17:00 **General discussion**

19:15 ***Conference Dinner at the restaurant Lækjarbrekka***

Saturday, March 28

Excursion (optional). Please contact the reception for further information.

List of participants

Name	Affiliation	Country
Þórður Arason	Icelandic Meteorological Office	Iceland
Anna María Ágústsdóttir	Pennsylvania State University	USA
Roberto R. Barrera	University of Barcelona	Spain
Páll Bergþórsson	Byggðarendi 7, Reykjavík	Iceland
Guðmundur G. Bjarnason	IRIS - Tæknigarði	Iceland
Gerard C. Bond	Lamont-Doherty Earth Obseratory	USA
Jóhannes Briem	Marine Research Institute	Iceland
Magnús Danielsen	Marine Research Institute	Iceland
Gaston Demarée	Royal Meteorological Institute	Belgium
Robert R. Dickson	MAFF Fisheries Laboratory	UK
Ólafur Eggertsson	University of Lund	Sweden
Eydís Eiríksdóttir		Iceland
Jón Eiríksson	University of Iceland	Iceland
Marie Ekström	University of Lund	Sweden
Harald Engedal	DNMI	Norway
Björn Erlingsson	Halo, haf- og lofthjúpsfræðistofa	Iceland
Avan Anwar Faraj	Marine Research Institute	Iceland
Povl Frich	Danish Meteorological Institute	Denmark
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Halldór Geirsson	University of Iceland - student	Iceland
Karl Grönvold	Nordic Volcanlogical Institute	Iceland
Sigrún Gunnarsdóttir	Icelandic Meteorological Office	Iceland
Hjörleifur Guttormsson	Alþingi	Iceland
Carsten Hansen	Danish Meteorological Institute	Denmark
Svanbjörg H. Haraldsdóttir	Icelandic Meteorological Office	Iceland
Sirpa Häkkinen	NASA Goddard Space Center	USA
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Tómas Jóhannesson	Icelandic Meteorological Office	Iceland
Kristján Jónasson	Icelandic Meteorological Office	Iceland
Ingibjörg Jónsdóttir	Icelandic Meteorological Office	Iceland
Kristín Jónsdóttir	University of Iceland - student	Iceland
Magnús Jónsson	Icelandic Meteorological Office	Iceland
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Brynhildur Magnúsdóttir	Building Research Institute	Iceland
Svend-Aage Malmberg	Marine Research Institute	Iceland
John Mortensen	Marine Research Institute	Iceland
Sólveig Ólafsdóttir	Marine Research Institute	Iceland
Haraldur Ólafsson	Icelandic Meteorological Office	Iceland

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Friðrik Pálmason	Agricultural Research Institute	Iceland
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Flosi Hrafn Sigurðsson	Icelandic Meteorological Office	Iceland
Hjalti Sigurjónsson	Icelandic Meteorological Office	Iceland
Leifur A. Símonarson	University of Iceland	Iceland
Árni Snorrason	Icelandic Energy Authority	Iceland
Árný E. Sveinbjörnsdóttir	University of Iceland	Iceland
Einar Sveinbjörnsson	Icelandic Meteorological Office	Iceland
Þorsteinn Sæmundsson	Icelandic Meteorological Office	Iceland
Dave Thompson	University of Washington	USA
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Heinz Wanner	University of Bern	Switzerland
Barði Þorkelsson	Icelandic Meteorological Office	Iceland
Egill Þórðarson		Iceland

List of speakers

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ATMOSPHERIC CIRCULATION RELATED TO OSCILLATIONS IN SEA-ICE AND SALINITY (ACROSS)

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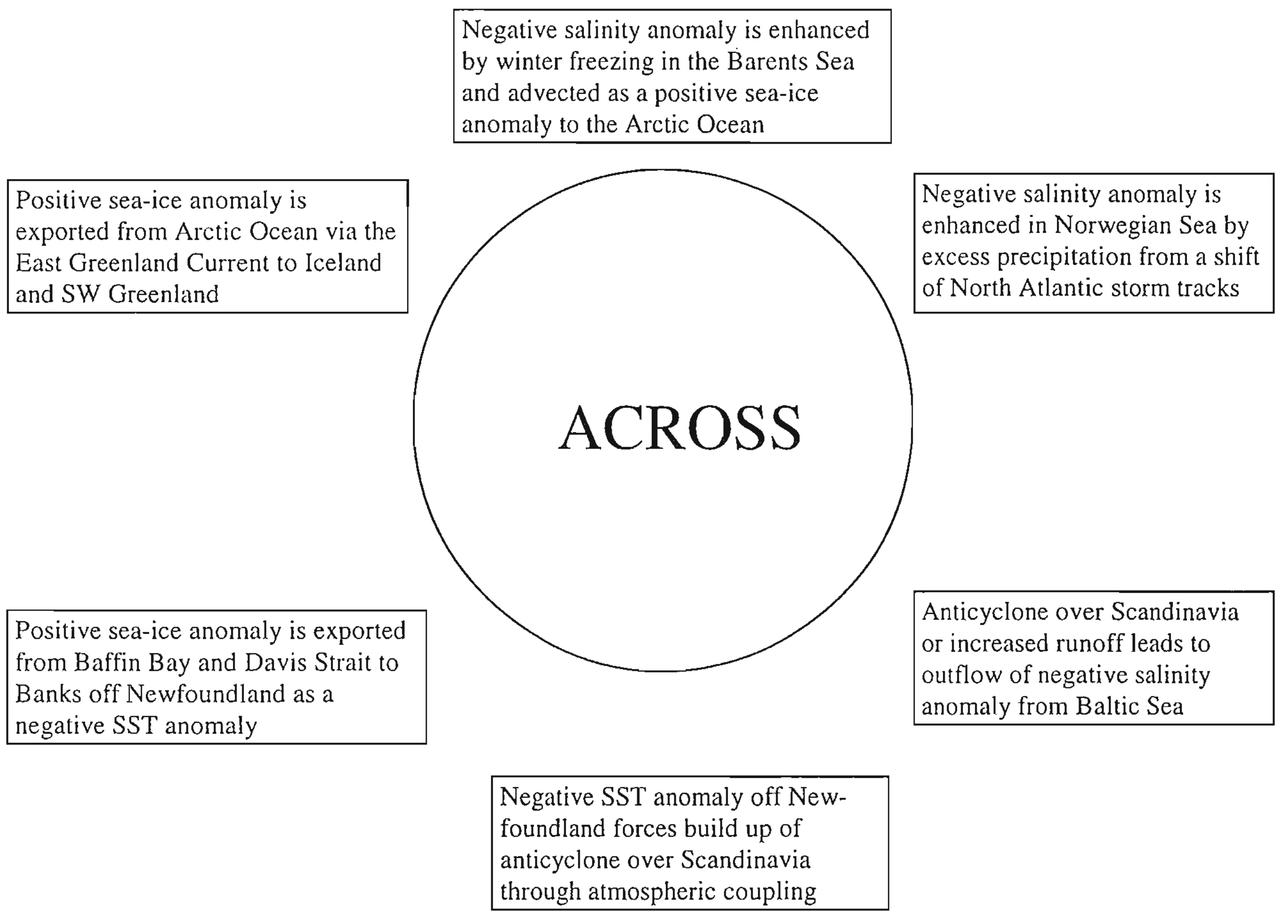
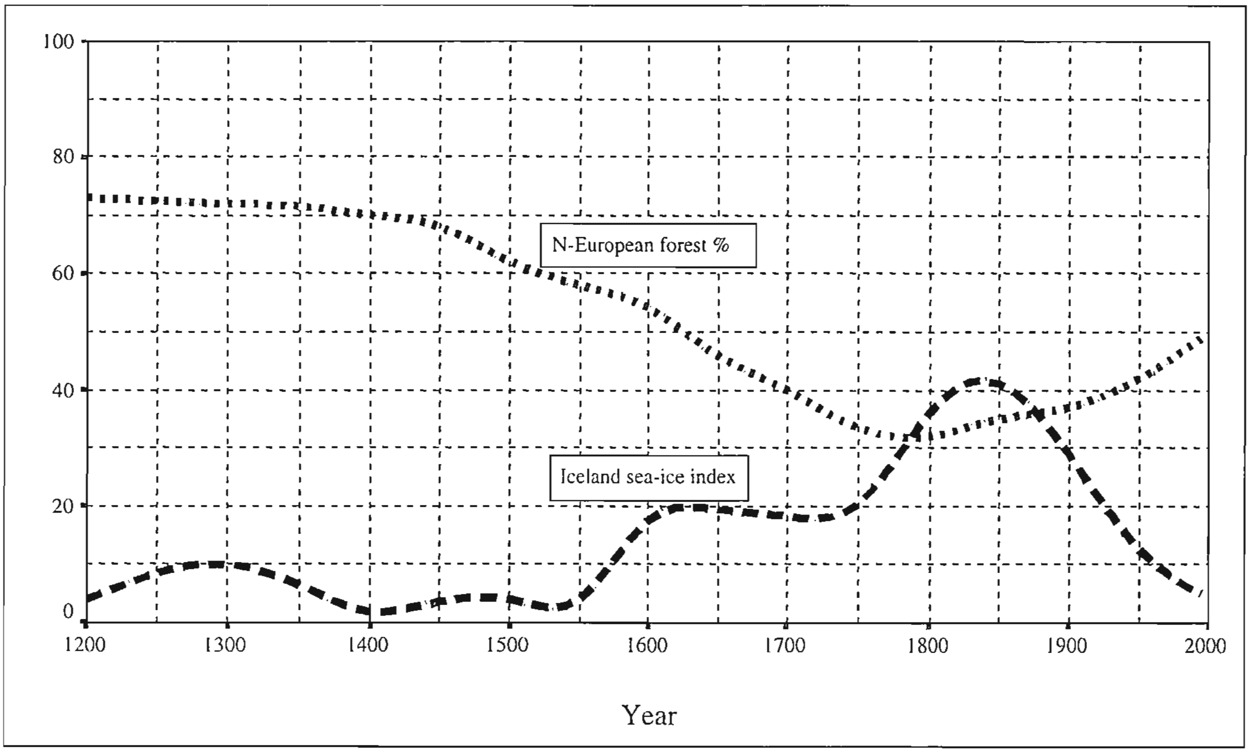
The overall aim of the ACROSS project has been to improve our understanding of ocean-atmosphere interactions in the Northern North Atlantic region. This has been accomplished through a comprehensive compilation and analysis of existing atmospheric and oceanic data. The project has especially concentrated on quasi-periodic oscillations in the ocean-atmosphere system over the past 50 years, as well as longer term variations in the climate of Northwest Europe. A conceptual model of how atmospheric circulation is related to oceanic variability has been proposed. The most persistent phenomena in the ocean system are related to anomalies of sea surface salinity and sea-ice extent. Through couplings with sea surface temperature, it is shown how atmospheric feedbacks can help to sustain a quasi-periodic oscillation. The ACROSS conceptual model is illustrated below.



A main goal of the project has been to determine the relative importance of natural climatic variability and man-induced climatic changes, and establish how much of the observed past climate variability can be attributed freshwater forcing. In order to study how sensitive the ocean circulation in the Nordic seas is to large perturbations in e.g. runoff from the Eurasian continent, both data studies and sensitivity experiments have been used. One specific aim was to study how the reduced forest cover in historic times could have affected runoff from Northwest Europe to the Nordic Seas. Tentative results may indicate, that there is a link between the large extent of sea-ice around Iceland during the Little Ice-Age and a reduced forest cover in Europe. See figure below.



Finally, the impact of catastrophic fresh-water fluxes from the drainage of the Late-glacial Baltic lake has been reviewed, in an attempt to understand the Younger Dryas climatic anomaly.

The ACROSS project is funded by the Nordic Environmental Research Programme.

THE RESPONSE OF THE NORDIC SEAS TO LONG-TERM CHANGES IN THE NORTH ATLANTIC OSCILLATION

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The North Atlantic Oscillation (NAO) is the dominant recurrent mode of atmospheric behaviour across the Nordic Seas and Arctic Ocean. The North Pacific (NP) pattern becomes dominant only south of the Bering Strait. Between low-index and high-index extreme states of the NAO, mean winter sea-level pressures decrease from a centre of maximum change (-14 to -20 mb, according to dataset) over Iceland and the Iceland Sea to a line of zero change near the Bering Strait. The NAO index exhibits a considerable decadal variability which appears to be amplifying with time. Thus in a record extending back to 1865, the NAO index evolved to its most persistent and extreme negative state in the 1960s, and thereafter to an equally extreme positive state in the late 1980s to early 1990s. This gradual evolution from low- to high-index conditions in winter brought the expected northeastward extension of the Atlantic storm track to the Greenland, Iceland, Norwegian and Barents Seas, together with an increase in the numbers of deep Atlantic storms from near-zero during low-index conditions to around 15 per winter during the high index phase.

These decadal shifts in the winter NAO and storm track are associated with major changes in the freshwater supply to high latitudes, especially in the European Arctic and subarctic. Modern datasets on moisture-flux (Serreze et al. 1995c) and precipitation (Xie and Arkin 1996) are available only from 1974 and 1979 respectively, so that low-index extrema are under-represented. Nevertheless, between composites of winter months representing "low-index" and high-index conditions, the total net moisture flux through 70°N increases from 4.4 to 7.6 x 107 kg s^{-1}, and the proportion which passes north through the Nordic Seas-Scandinavia sector (10°W to 50°E) increases from 0% to 58%. The major precipitation change also takes place in this sector, increasing by about 15 cm per winter along the length of the Norwegian Atlantic Current between "low-index" and high-index extrema.

The "Arctic warming" observed in the subsurface, Atlantic-derived layers of the Arctic Ocean during the early 1990s is largely the result of the same multi-decadal evolution in the NAO index. Specifically, direct and proxy evidence suggests that the warming is the combined result of a warmer and stronger inflow of Atlantic water along both the main inflow branches as the NAO index built to its most prolonged and extreme positive values of record. At the peak, both Atlantic inflow streams were observed to be running between 1° and 2°C warmer than normal and there is some evidence that their transports also increased. Salinities along both inflow branches appear to have declined as the NAO evolved from its low-index extreme of the 1960s to its high-index extreme of the 1990s, consistent with the increasing freshwater accession and reduction in sea-ice over this period. In the 50-500 m layer of the Sorkapp Section, the decrease was between 0.033 and 0.050, resulting in a decrease in the mean density of this layer by 0.1- 0.15 kg m^{-3}.

The increased flux of heat to the Barents Sea and adjacent Arctic was accompanied by a marked retraction of sea-ice, part of a general reduction of 647,000 km^2 in the median ice extent across both the western and eastern parts of the European Arctic between the low-index [winters (1963-69)] and high-index [winters (1989-95)] extrema of the NAO. Since this change is measured at the time of the annual sea-ice maximum (April), it would seem to indicate a decreased winter production of ice rather than (or in addition to) increased summer melt-back, with an additional but minor effect on "Arctic warming".

Though the data set is incomplete, gappy and less than reliable, the distributions of 0-200 m dynamic height throughout the Nordic Seas and Arctic Ocean appear to change in the expected sense during contrasting states of the NAO. Specifically, the "high-index" mode is associated both with a stronger northward transport of Atlantic water through the Norwegian Sea, and with a narrower but more intense Transpolar Drift Stream towards Fram Strait.

The interannual variations of the winter NAO index explain about 60% of the variance in the annual volume flux of ice through Fram Strait since 1976; a 1-sigma change in the winter NAO index is then associated with a >200 km^3 change in annual ice flux. The simulated volume flux is well-matched to the observed flux and its supposed forcing. Since there is no very-obvious time-lag between forcing and flux, these observed and simulated series appear to confirm the dominance of direct regional wind forcing over broadscale changes in the Arctic Ocean circulation in determining the year-to-year variability of ice-flux.

While the Fram Strait ice flux is thus strongly and positively corellated with the winter NAO index, the case of the "Great Salinity Anomaly" (GSA) of the 1960s demonstrates that large anomalies in the flux of ice and freshwater are not unknown during the opposite low-index phase. These low-index anomalies are likely to be event-like and conspicuous, but are not necessarily of greater amplitude than the ice flux maxima observed during the 1990s. The estimated 2000 km^3 of extra ice and freshwater brought south by the GSA in the mid-'60s (Aagaard and Carmack 1989) compares with a one-year increase of 1826 km^3 in the flux of ice alone observed in the Fram Strait between 1993-4 and 1994-5 (Vinje et al. 1997). The size of the efflux in 1994-5 suggests that a new GSA may be underway, and our first attempts to trace it in the hydrographic record are briefly described.

DECADAL-SCALE CLIMATE VARIATIONS IN THE ICE-EXTENT AND HYDROGRAPHIC PARAMETERS IN THE WATERS AROUND ICELAND

Svend-Aage Malmberg, Marine Research Institute, Reykjavík, Iceland, e-mail: svam@hafro.is

Introduction

Iceland is situated at the meeting place or fronts of warm and cold ocean currents, which meet at this point because of the geographical position and the submarine ridges (Greenland-Scotland Ridge) which form a natural barrier against the main ocean currents around the country. To the south is the warm Irminger Current which is a branch of the North Atlantic Current and to the north are the cold East Greenland and East Icelandic Currents. The different hydrographic conditions in Icelandic waters are also reflected in the atmospheric or climatic conditions in and over the country and the surroundings seas, mainly through the Iceland Low and Greenland High.

Hydrographic conditions

A selected hydrographic section in North Icelandic waters has been used to characterize the hydrographic conditions in North Icelandic waters from year to year. In these North Icelandic waters periods of Atlantic, Polar and Arctic conditions have been manifested, periods which more or less coincide with drift-ice conditions as well as the so-called NAO index in general. In the warm waters south of Iceland periods of relatively high and low salinities occur. Noteworthy were the low salinities observed in the mid-seventies (Great Salinity Anomaly) and again in the early nineties. The latter periods may also be related to far-reaching conditions in the Sub-Polar Gyre (Malmberg et al. 1996, Belkin et al. 1997). Positive vs. negative anomalous conditions in the atmosphere and hydrosphere were reported (a.o. Rodewald 1967) across the North Atlantic from the Labrador Sea to the Barents Sea. Conditions in Icelandic waters, located in between these two western and eastern seas, but also nearby the Polar and Arctic fronts, are more complex and very sensitive to the variability in sea and air. In the continuation to the Rossby waves or the NAO one must consider the advection of the GSA in the northern North Atlantic in the seventies (Dickson et al. 1988) originating in the waters north of Iceland in the sixties as well as the suggested new anomaly in the eighties (Belkin et al. 1997), possibly orginating as well in the waters west of Greenland. The response in the different oceanographic regions may also vary due to local conditions. Thus examples have been given on different timing of decrease of convection in the Iceland Sea (late sixties) and the Greenland Sea (seventies) in relation to wind stress curl over the two sea areas (Malmberg and Jónsson 1997).

References

Belkin, L.M., S. Levitus, J.I. Antonov & S.A. Malmberg 1997. "Great Salinity Anomalies" in the North Atlantic. Progress in Oceanography, submitted.

Dickson, R.R., J. Meincke, S.A. Malmberg & A.J. Lee 1988. The "Great Salinity Anomaly" in the northern North Atlantic, 1968-1982. Progress in Oceanography 20(2), 103-151.

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VARIABILITY OF THE NORTH ATLANTIC OVERTURNING FOR THE PERIOD 1951-1993

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This study has investigated a 43-year model simulation for the period, 1951 to 1993 where the forcing is provided by COADS atmospheric anomalies (from daSilva et al. 1994) added to the ECMWF climatology. The only fields that do not vary during the time period are: cloudiness, P-E (from NMC), river runoff and open boundary T and S (from Levitus) at Bering Strait and 15S. The model used is that of Häkkinen and Mellor (1992).

The goal in this study is to explore the subsurface variability such as that related to meridional overturning cell (MOC). The model simulation suggests that the MOC has entered a very intense period since the mid-1980's and this trend has continued up to the end of 1993. The source of this variability is in the subpolar gyre and its interactions with lower latitudes as the simulated NADW overflow has hardly any changes. The strengthening of MOC follows closely the North Atlantic Oscillation (NAO) -index which also reached historically (since 1870's) the highest values in the early 1990's (Hurrell 1995). The anomalous values of MOC in the early 1990's are close to two standard deviations above the average of the model simulation period. In fact, the atmospheric forcing associated with the NAO pattern is found to be the dominant forcing for the variability in MOC at interannual and longer time scales. The upper ocean effectively integrates the changes in the surface fluxes related to NAO which results in changes in meridional heat transport (MHT). The low frequency NAO influence is predominant in the Gulf Stream region as it forces the overturning cell variability which is concentrated on the western boundary current region. The MHT/MOC changes influence the heat content (and SST) in the Gulf Stream region, thus the NAO and its oceanic signal are nonlocal in nature. This was also the conclusion of Deser and Blackmon (1993) in their study of the surface climate variables for the North Atlantic.

A CLIMATOLOGICAL OCEANOGRAPHIC ARCHIVE COVERING THE NORDIC SEAS AND THE ARCTIC OCEAN WITH ADJACENT WATERS

Harald Engedahl (1), Gro Eriksrød (2,3) and Bjørn Ådlandsvik (2)
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(3) from March 24, 1997: Norwegian Polar Institute (NPI), Middeltunsgt. 29, N-0368 Oslo, Norway.

Method

Considered is the use of a numerical model to enhance the information contained in oceanographic observations. For this purpose the three-dimensional baroclinic, primitive equation ocean model ECOM3D (Blumberg & Mellor 1987, Engedahl 1995) was used to produce a climatological dynamically consistent data archive containing monthly mean fields of sea surface elevation, currents, salinity and temperature. The archive covers the Nordic Seas and the entire Arctic Ocean including adjacent areas such as the Barents Sea and the Kara Sea, with a horizontal grid size of 20 km. In the vertical the fields are stored at 31 standard oceanographic levels from 0 to 4500 meters.

First, a Hydrographical Archive was produced based on gridded climatological data from Sidney Levitus (Levitus & Boyer 1994, Levitus et al. 1994) and Peter Damm (1989), and refined with observed hydrographic data obtained from IMR, NPI and Russian institutions, mainly the Arctic and Antarctic Research Institute (AARI) in St. Petersburg. The data was checked and interpolated to the 20 km model grid at the IMR by a Cressman analysis (Engedahl et al. 1995). Then, the model was run in diagnostic mode, i.e., with the fields of salinity and temperature from the Hydrographic Archive held fixed, until a quasi stationary circulation was obtained. Volume transports at the open boundaries were described according to the results from Böning et al. (1996). No other forcing was applied. The produced dynamically adjusted fields of sea level and current constitute the Diagnostic Archive.

The production of the digitized archive is actually an extension of part of the work which was carried out during the MetOcean MOdeling Project (MOMOP). The differences between the old and new archives are listed below:

The new archive covers a much larger area including the entire Arctic Ocean (but the same horizontal resolution as in the old archive is retained).

The new archive is based on hydrography (i.e. salinity and temperature) from a new global database of Levitus and Boyer (1994) and Levitus et al. (1994).

The new archive is produced on a true polar-stereographic map projection by implementation of curvilinear coordinates in the ocean model (Blumberg and Herring 1987). This insures a correct adjustment of area/volume.

A better dynamical adjustment is applied following the same procedure as in Ezer and Mellor (1994).

More hydrographical observations are taken into account.

Results and conclusion

The model seems to reproduce most of the surface or near surface circulation commonly believed to exist in the actual area, for instance the northward flow of warm and saline water from the Atlantic along the west European Shelf from Ireland to Svalbard with a branching off into the Barents Sea. In the Barents Sea the surface current indicates an outflow through the St. Anna Trough. The most significant currents in the Arctic Ocean seems to be reproduced. In addition, the East Greenland current, the East Icelandic current and the Labrador current is clearly pronounced in the model results.

Considering the volume transports the model seems to perform satisfactorily. The calculated transport to the right across some selected sections have been compared with available estimates from the literature. All calculated transports are clearly within the same order of magnitude as the estimates which are based on observations. In general there is a fairly good agreement between the calculated and the observed transports.However, the northward flow through the sections Scotland to Shetland, Svinøy towards Northwest, Bjørnøya towards West and Sørkapp (Spitzbergen) towards West show values 1.5 to 2.0 times higher than the estimates. In addition, the northward transport through the Danish Strait is about twice the size cited in the literature. Nevertheless, for the areas covered the new archive provides useful information about the monthly mean circulation, which may be applied as boundary values for further climatological model studies.

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IMPACT OF WINDSTRESS ON THE WATER MASS EXCHANGES BETWEEN LABRADOR SEA AND BAFFIN BAY

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Fields of windstress (from ECMWF analyses), observed hydrography, and estimated freshwater fluxes are examined at the Davis Strait and Eastern Baffin Bay. It is demonstrated that the wind field over Eastern Baffin Bay may control the water exchange with the Northern Labrador Sea, due to the influence on mixing and drift in the shallow surface halocline during the ice-free season. By such mechanisms the wind normally acts to maintain an ice-free state during August to November. However, the degree of ice coverage shows a strong interannual variation, and during a few individual years (latest in 1996) the ice-free state has not developed. It is suggested that this variability is caused by variations of the cyclone activity, which is associated with the large-scale atmospheric circulation.

THE ARCTIC OSCILLATION

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The leading empirical orthogonal function of the wintertime sea-level pressure (or 1000-hPa height) field is more strongly coupled to surface air temperature fluctuations over the Eurasian continent than the more widely publicized North Atlantic Oscillation (NAO). It resembles the NAO in many respects, but its primary center of action covers more of the Arctic, giving it a more zonally symmetric appearance. Coupled to strong fluctuations at the 50-hPa level on the intraseasonal, interannual, and interdecadal time scales, this mode can be interpreted as an equivalent barotropic surface signature of modulations in the strength of the polar vortex aloft. It is proposed that the zonal asymmetric surface air temperature and mid-tropospheric circulation anomalies observed in association with this mode are secondary baroclinic features induced by the land-sea contrasts. The same modal structure is mirrored in the pronounced trends in winter and springtime surface air temperature, sea-level pressure and 50-hPa height over the past 30 years: parts of Eurasia have warmed by as much as several degrees, sea-level pressure over parts of the Arctic has fallen by 4-hPa, and the core of the lower stratospheric polar vortex has cooled by several degrees. These trends are interpreted as the development of a systematic bias in one of the atmosphere's dominant naturally occurring modes of variability.

OBSERVING AND DESCRIBING SEA ICE PROCESSES IN ICELANDIC WATERS

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The Sea Ice Research Unit of the Department of Research and Processing is in charge of sea ice services in Iceland. Sea ice in the Iceland Sea, the Denmark Strait (Greenland Sound) between Iceland and Greenland, and in Icelandic waters in general, is monitored by the assistance of the Icelandic Coast Guard, the fishing fleet, transport vessels, coastal weather stations and the oceanographic vessels of the Marine Research Institute of Iceland.

By considering Icelandic and foreign weather forecasts, a general outlook on changes in sea ice extent and movements of sea ice is offered to those who need it. Requests are mainly received from the fishing fleet, transport vessels, tourist ships, sailors and the news media.

Charts are submitted to ice services abroad. Observations and other data are preserved. An annual report on sea ice at the coasts of Iceland is published and distributed to subscribers. At the moment the writing of these reports are, however, lagging somewhat behind due to other duties. Observations are typed and stored in data banks.

The Icelandic Meteorological Office participates in international projects on sea ice and atmosphere/ocean interaction in northern latitudes. Development in the field of remote sensing and use of sea ice models is ongoing.

ABRUPT CLIMATE CHANGES AND THE NORTH ATLANTIC DEEPWATER FORMATION. INSIGHTS FROM THE GENESIS CLIMATE MODEL AND OBSERVED DATA

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Results from the GISP2 and GRIP ice cores in Greenland show occurrence of a prominent centuries-long cold climate anomaly centered on 8250 calendar years before present (abp). A shutdown and abrupt reinitiation of the North Atlantic Deep Water formation has been suggested as a most likely cause of abrupt climate events. The GENESIS climate model provides a venue for modeling the effects on climate of changes in NADW formation. Three 8K experiments with low, high and enhanced high ocean heat transport simulate the hypothesized NADW shutdown, active NADW formation comparable to the present day situation, and a more vigorous NADW formation than occurs at present day. Comparison with data from Greenland and different sites around the world where records of the 8K events are available leads us to conclude that the difference of the HOT-COLD experiment best simulates the observed climate change occurring during the brief return toward glacial conditions during the 8K event. The HOT-COLD experiments show a better fit to the data than the WARM-COLD or the HOT-WARM experiments, suggesting that this early Holocene cool climate event is caused by a shutdown of NADW formation, when ocean heat flux was enhanced during Holocene compared to present-day.

HOLOCENE PALEOCEANOGRAPHIC RECORD FROM SEDIMENT CORES ON THE NORTH ICELANDIC SHELF

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Paleoceanographic proxies from box cores and up to 4 m long gravity cores obtained on the BIOICE HM-107 cruise to North Iceland in 1995 are described. A research project (PANIS, Palaeo-environments on the North Icelandic Shelf) involving the universities in Reykjavík, Aarhus, and Bergen was formed with the aim of studying the palaeoenvironmental history of the North Icelandic shelf back to the Lateglacial.

The study area is located on both sides of the Kolbeinsey Ridge with an outer set of cores at c. 67°N and an inner set at c. 66°30'N. This is the boundary region between the warm, full salinity Irminger Current and the colder, lower salinity East Icelandic Current which branches off the East Greenland Current. The PANIS sampling covers south-north trending sedimentary basins extending from the

Tjörnes fracture zone northwards along both sides of the submarine Kolbeinsey Ridge, an actively spreading oceanic ridge that divides the North Icelandic shelf in two subregions. The basins lie on the outer North Icelandic shelf which has a fairly well defined slope northward just north of 67°N. Data were collected at water depths of c. 400 m while the depth on the intervening ridge is much shallower. The outer cores display a 14,000 yr long record (14C years with a 400 yr reservoir age correction) with relatively low sedimentation rates while the inner cores cover only c. 4,000 yr with sedimentation rates exceeding 1 m/1,000 yr, or c. 10 years per centimeter of sediment. Potentially, these records contain decadal variations in the oceanographic conditions back in time, observable in the microfossil record and sedimentological parameters.

Biogenic sediments on the North Icelandic shelf include a component of both planktonic and benthic foraminifera, molluscs, and diatoms, allowing detailed biozonation and 14C dating. Numerous tephra markers from Iceland serve to correlate marine and terrestrial records and they allow reliable correlations based on tephrochronology. Total carbon content varies from .3 - 4.2 %, while the total carbonate content typically varies between 5 - 15 %. The biological productivity is rather high and the assemblages have not been affected by deep-sea carbonate dissolution. Considerable variation with time is seen in the input of rock fragments, quartz crystals, and altered volcanic glass, indicating periods of ice rafting.

Near the shelf edge, the records show strong influence of the Irminger Current prior to c. 13,000 BP. This is followed by a marked cooling and then by slightly warmer but unstable conditions prior to another cooling event (Preboreal). Conditions warmer than present between 9,000-5,000 BP are followed by fluctuating but decreasing temperatures in the last 4,000-5000 yr of the Holocene.

High resolution cores closer to land show considerable variation in both foraminiferal assemblages and sedimentary input during the last 4,000 yr. Planktonic foraminifera show marked cooling of surface waters at 3,000 BP with some amelioration during the Medieval Warm Period, and cooling again during the Little Ice Age. The benthic fauna indicates a general cooling trend during the last 4,000 yr but a certain cyclicity is distinctly present. Two severe periods of ice rafting are indicated by quartz concentrations just after 3,000 yr BP and during the Little Ice Age after c. 1500 AD. The former ice rafting event occurred at the same time or slightly after the deposition of the tephra marker H3, the largest holocene Hekla eruption.

THE ORIGIN OF THE ARCTIC DRIFTWOOD

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Driftwood from the coast of the Arctic Islands; Baffin Island, Greenland, Svalbard and Iceland has been studied by using the method of tree-ring analyse and wood anatomical studies.

The aim of the studies has been to establish an overall picture of the origin of the wood and its transportation's routes in the Arctic and Northern Atlantic oceans.

A total of more that 1000 logs from the arctic shores have been collected and analysed during the recent years.

The driftwood occurs on most beaches in the Arctic and on nearby islands that are influenced by Arctic water. The amount of the wood varies greatly from scattered logs to beaches completely covered with wood. The driftwood presently resting on the arctic coasts originates in the circumpolar boreal forest regions. Rivers draining these regions to the north carry the wood into the Arctic Ocean.

When the wood reaches the sea it is transported by a combination of wind, ice and currents. The changes in driftwood penetration depend on the direction of the currents transporting the wood and variation in sea ice cover of the Arctic Ocean and its surroundings. Due to the seasonal changes of sea ice cover most of the driftwood entering the Arctic Ocean via rivers becomes frozen into the sea ice. As the wood has a limited ability to float on open water therefore is the sea ice that is responsible for its transport to distant beaches e.g. Iceland, Baffin Island.

HISTORY OF SEA ICE IN ICELANDIC WATERS AD 1850-1998

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An ongoing project at the Icelandic Meteorological Office describes the sea-ice history of Iceland from AD1850 onwards. The reasons for great variations on all time-scales in the amount and duration of ice off the coasts are considered, as well as the impacts the ice has had on human activities.

Sea ice is usually not formed around Iceland but is occasionally brought up towards the coasts by the East Greenland Current. Great variations in the extent of ice are believed to be due to differences in the amount of ice and Arctic Water in the East Greenland Current, atmospheric pressure fields in the North Atlantic Region, and the oceanographic conditions in the sea around Iceland.

Sea-ice information has been collected from various historical sources. These include early sea-ice charts from the Danish Meteorological Institute and the Norwegian Polar Research Institute, printed books and newspapers, as well as unpublished diaries, letters and ship's logbooks. The more recent data includes the Icelandic Coast Guard's ice charts, satellite images and ship's reports. The information is interpreted and then coded in order to produce sea-ice indices describing the severity and persistence of sea ice off the coasts of Iceland during the period. The indices will then be compared to different environmental data, such as air temperature, atmospheric pressure and sea surface temperature.

HOW FAR DO WE UNDERSTAND DECADAL TO CENTURY SCALE CLIMATE VARIABILITY AND CHANGE IN THE EUROPEAN ALPS?

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Introduction

The analysis of distinct climatological time series is a suitable method to recognize and to diagnose natural climate variability and possibly anthropogenic climate change. During the last centuries three natural factors mainly influenced the low frequency variability in the climate records: Variable solar forcing, explosive volcanism and internal oscillations in the climate system (Mann et al. 1998, Stocker 1996). Anthropogenic forcing by greenhouse gases exerts a remarkable influence on the climate system only since about 1950.

This contribution concentrates to discuss decadal to century scale climate variability and change in the European Alps by analyzing and interpreting observational data from two different time periods. By using synoptic and spectral techniques it aims to recognize and to explain as many responsible processes as possible causing climate fluctuations in the central European and Alpine area.

Data analysis and interpretation

An almost 300 years long curve of the movements of the large Swiss Aletsch glacier was reconstructed by Holzhauser and Zumbühl (1998) by analyzing morain positions, fossil soils, anchoraged trunks in the glacier forefield (dendrochronology) as well as old paintings representing the glacier stages at a defined date (Fig. 1). The curve shows surprisingly regular, almost periodical fluctuations between warm/dry and therefore glacier hostile, and cool/wet glacier friendly periods. The strongest glacier retreat within this curve was observed in the Roman age around 1900 to 2000 BP. It is comparable with the present situation or that during the Holocene climate optimum. Even during the medieval climate optimum a slight glacier advance took place. It is recommended to call these advances Little Ice Age Type Events (LIATE's) because they seem to be typical at least for the dynamics within the Alpine climate system over the last 3000 years or even further back.

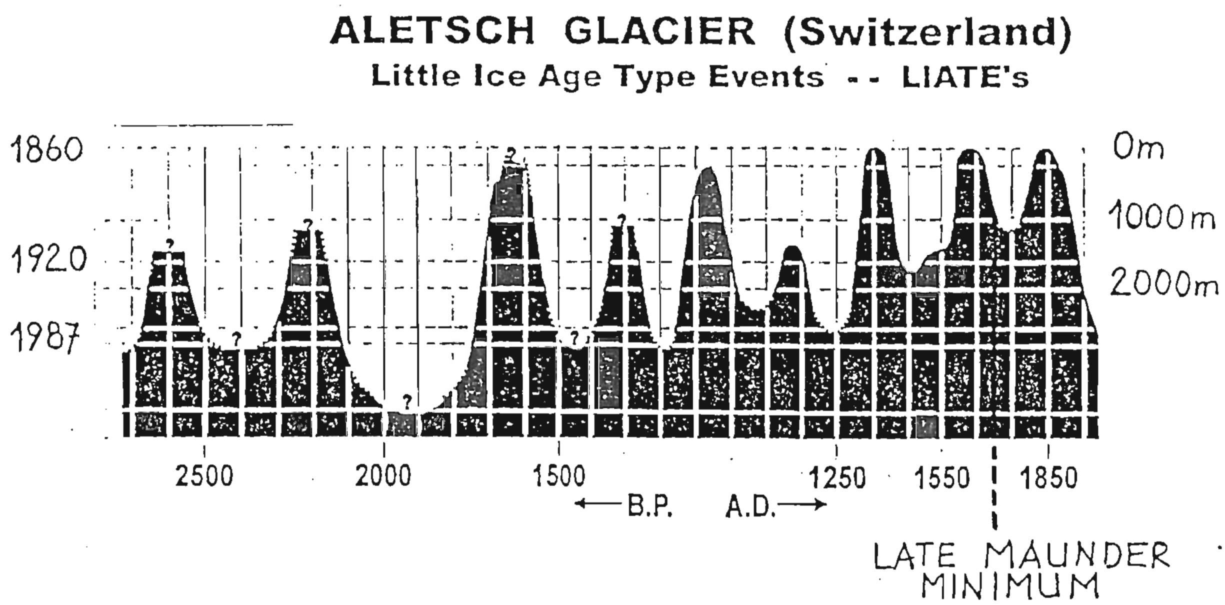

Fig. 1. Advances and retreats of the Aletsch Glacier (Swiss Alps) during the last 2700 years (Holzhauser and Zumbühl 1998).

Three of such remarkable events took place in the classical period of the Little Ice Age. The glacier tongues reached their maximum position around 1350, 1640 and 1850. Some authors use the doubtful term Little Ice Age by only including the two last LIATE's in their considerations. The relation between the glacier mass balance and the climate is very complex, varies individually and can therefore not be attributed to a single factor. For example, it is quite considerable that the Aletsch glacier did not grow during the very cold Late Maunder Minimum around the 1690s when the solar activity was extremely low. The analysis of a large proxy data set (Pfister 1984) shows clearly that the glacier mass balance could not be positive because of the very dry winter season. A careful synoptic reconstruction of the monthly mean surface pressure fields reveals the fact that the cold periods during the Late Maunder Minimum (Luterbacher et al. 1998) as well as during the last LIATE in the 19th century were connected with extreme negative North Atlantic Oscillation (NAO) indices.

The influence of the NAO becomes even better visible by comparing the curve with the averaged temperature of high Alpine stations above 2500 m above msl with synoptic indices which were derived by adapting the Hess and Brezowsky Grosswetterlagen system to the Alpine region (Fig. 2). More than one fourth of the positive temperature trend of about 0.0075°C per year between 1881 and 1994 can be explained by the increased zonal flow. A spectral analysis of high Alpine temperature data points to two weakly significant peaks around 2.3 and 25 years. Even the European continent exerts a strong influence on the Alpine weather and climate (especially during anticyclonic winter situations with advection of continental air), the time spectra of Alpine weather observations are highly correlated with NAO events. Figure 2 shows that the negative (or meridional) phase during the late 19th century leads to clearly lower temperatures than the positive (or zonal) one since about 1975. By summarizing it can be stated that the Alpine climate, on its decadal to century time scale, is strongly influenced by the variability of the North Atlantic climate system, namely the NAO (Wanner et al. 1997). The almost regular glacier advances occurring about every 250 to 500 years seem to be the combined effect of several consecutive periods with negative NAO indices. However, extreme negative NAO reversals like during the LMM (Wanner et al. 1995) do not cause positive glacier mass balances. Even those distinct negative forcing events like the low solar activity during the LMM or the explosive Tambora eruption in 1815 are detectable in the analyzed time series, internal oscillations in the North Atlantic ocean-sea ice-atmosphere system (roughly represented by the NAO) must play a decisive role in Alpine and European climate variability. Because the North Atlantic-European climate system with its complex system structure (subtropical SST dipole, subpolar ocean gyre, gulf stream, North Atlantic deep water formation, sea ice cycles, freshwater influx of the rivers around the polar basin, etc.) is very sensitive to climate change and actually almost unpredictive, it will be a challenge to study the increasing effects of anthropogenic climate change like greenhouse effect or the land-use changes in this area.

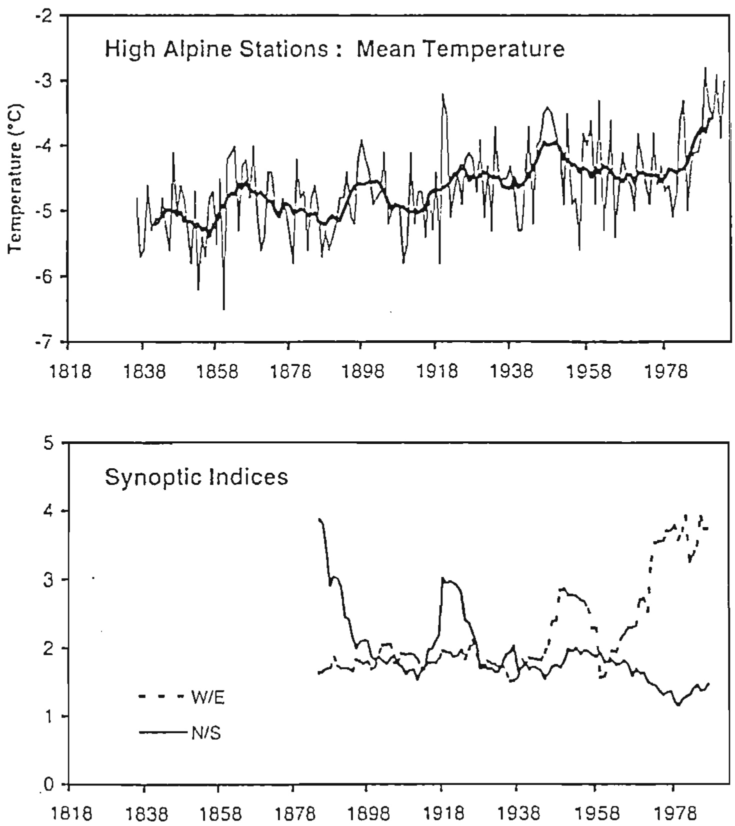

Fig. 2. Average air temperature of the higher Alps above 2500 m above MSL between 1835 and 1994 (upper Fig.) and synoptic indices of the circulation over the Alps (lower Fig.; the full line denotes a meriodional, the dotted line a zonal flow regime).

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MONTHLY SEA LEVEL PRESSURE PATTERNS DURING THE LATE MAUNDER MINIMUM (1675-1715) COMPARED WITH 20TH CENTURY CIRCULATION

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The Late Maunder Minimum (LMM; 1675-1715) delineates a period with marked climate variability within the so-called Little Ice Age (LIA) in Europe. Within the ADVICE (Annual to Decadal Variability In Climate in Europe) project, we aimed at reconstructing the mean monthly pressure fields over Europe during this period and at comparing them with the corresponding 20th century pressure fields.

The gridded monthly mean pressure fields for the LMM were reconstructed for the eastern part of the North Atlantic and Europe (25°W to 30°E and 35°N to 70°N) based on 21 (winter), 18 (spring and summer) and 17 (autumn) continuous European station records with proxy data (indexed temperature and rainfall values, sea-ice conditions from Iceland and the Western Baltic and limited instrumental data, like air temperature from Central England and Paris, reduced mean sea level pressure (SLP) from Paris and monthly mean wind direction in the Oresund (DK)). The reconstructions are based on a canonical correlation analysis (CCA) with the standardized station data as predictors and the large-scale atmospheric circulation as predictand.

90 years of recent data were used in the CCA, the first 60 years (1901-1960) to calibrate the statistical model and the remaining 30 years (1961-1990) for validation of the reconstructed monthly pressure fields. The calibrated CCA model was then used to predict the monthly atmospheric circulation patterns during the LMM under the assumption of climate stationarity.

The verification results illustrate that the regression equations developed for the large majority of grid points contain good predictive skill, especially in winter. Nevertheless, there are seasonal and geographical limitations to the regions for which valid spatial SLP reconstructions can be assessed.

The overall performance expressed by the averaged explained variance over all 96 grid points is best in winter, with 70% of total variance explained, followed by spring and autumn (56%) and summer (45%, respectively). During the verification period, the values are generally 10% lower.

Based on seasonal and monthly mean SLP difference patterns (LMM minus analysis 1961-90) a distinct pattern of ocean-atmosphere relationship associated with interdecadal variability in the North Atlantic-European area is postulated for the LMM.

It is supposed that the LMM as a whole was a period of above normal SSTs in some parts of the northern North Atlantic including the Icelandic-area and the Labrador sea, leading to above normal SLP over the Greeland-Icelandic, Scandinavia-Baltic area, but below SLP south of about 55°N. More blocking situations over Europe are expected in winter. From spring to autumn the storm tracks shifted southwards. Higher than normal winter SSTs in the Labrador Sea are related to less sea ice there and severe sea ice conditions over the Barents Sea connected with anomalous high pressure leading to negative precipitation anomalies in the Arctic-Siberian area.

Based on different objective classifications the dominant pressure patterns in the last 30 years are also prevalent in the LMM and show similar relative frequencies and seasonal distribution. Nevertheless, some classes, although not that frequent are unique during the LMM and appear in winter connected with strong cold air outbreaks from East to Northeast without advancing of the glaciers in the Alps. In addition, the results generally suppose an increase of wetter and cooler conditions during late spring and summer. These classes are responsible for the climate variability within the LMM.

COMPARISON OF WIND DIRECTIONAL DATA FROM COPENHAGEN AND LUND (1753–) WITH FOCUS ON ESTIMATION OF WATER FLUX ANOMALIES OF THE BALTIC SEA

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Monthly wind directional data from Copenhagen (1751–1994) and Lund (1740–1992) are used to create a single record which describes the regional wind pattern in the Öresund. Besides description of the wind climate one main objective is to connect the wind direction statistics in the Öresund with the modern record for water flux at the Baltic entrance. The wind pattern in the Öresund region plays a key role in the sea level variations in the Baltic Sea, which are the primary cause for major salt water intrusions into the Baltic Sea. The variations in sea level are most pronounced during the winter months; the season with the highest wind speeds. Persistent easterly wind gives low sea levels while westerly wind increases the sea level in the Baltic Sea. The comparison of the Copenhagen and Lund records showed that the main wind direction over the year was south west at both stations. It also visualised large discrepancies between the stations during the earliest period (1753–1810). Preliminary results of the comparison during the early period shows that Lund has greater influences of (north) easterly winds than Copenhagen during all months except the summer months (June to August). During the summer both stations mainly experiences westerly wind. A comparison of wind directional data with high time resolution (three observations per day) during severe storm events between 1753–1801 and during a selected month (March 1799) were performed in order to identify the detailed behaviour between the stations. The storm events were selected from wind registrations in Danish log-books of ships in the Öresund. The result showed that the wind directions in Lund are twisted counter-clockwise with regard to the Danish sources, in both the easterly (N to SSE) and westerly (S to NNW) sector. The declination of the compass, which were used for wind directional observations on ships, ranges from -13 to -19 degrees to the east during 1750–1800. This error would reduce the differences between Lund and the Danish log-books. These small differences that remains can, however, not totally explain the discrepancies between Copenhagen and Lund during the period 1753–1810. Further investigation of meta data and data quality is needed before the two records are joined.

EARLY INSTRUMENTAL METEOROLOGICAL OBSERVATIONS IN GREENLAND AND LABRADOR

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Knowledge regarding the climatology and meteorology of Greenland and Labrador was given a significant impetus by the fishing activities and the related discovery voyages of several European nations in the waters close to these areas. Thus, for example, in the seventeenth and eighteenth centuries, the Dutch collected non-instrumental, and, later on, instrumental meteorological information. The meteorological observations carried out onboard of (two) Dutch ships in the Davis Strait and Greenland waters in the summer of 1760 are among the first such attempts to collect information in the region.

The next such undertaking was the instrumental meteorological information collected by Christopher Brasen, physician, at the mission of the Moravian Brethren in Neu-Herrnhut, Greenland, from September 1767 till July 1768. A manuscript of these observations has been located in the Archives of Brüder-Unität, as well as contemporaneous copies and printed works may be found elsewhere.

The Danish pastor, Andreas Ginge, began compiling meteorological observations in Gothåb in September 1784. Daily observations from October 1786 till June 1787 are included in the volume 1787 of the Societas Meteorologica Palatina.

In August 1771, a group of Moravian Brethren established a first mission post at Nain on the Labrador coast under the leadership of Brasen. From October 1771 onwards, the missionaries started a long-lasting tradition of meteorological observations in their Labrador missions. This may have continued, with possibly some interruptions, until the approach of the Second World War.

The Moravian Brethren (Unitas Fratrum) are also called Herrnhuters from the name of the locality where they settled in the early eighteenth century. Their practice of making meteorological observations was done alongside their missionary activities. The observations were carried out under standard conditions by observers well trained in natural sciences at their theological seminaries and pedagogical schools. Extracts of these meteorological records were published in local newspapers and scientific journals in the core region of the Herrnhuters in eastern Germany. This paper places these meteorological observations in their historical and climatological context.

Some of these observations have been used in early meteorological works like those of Cotte, Kirwan, Gronau, Dove and others but seem to have been forgotten in later years. Further research in archives and libraries has brought to light a wealth of information. This information is extremely important for the period before the start of the systematic climatological observations by the Danish Meteorological Institute in Greenland in the last quarter of the nineteenth century.

It is remarkable that the early observers had a clear idea of the existence of a seesaw-like behaviour in winter temperatures between Greenland and northern Europe.

The above-mentioned records form a potentially valuable tool in the climate reconstruction of the North Atlantic region over the last two and a half centuries and, furthermore, constitute a source of information which should be coupled with that coming from natural archives such as sea ice or ice cores from Greenland.

FRESH WATER IN THE NORDIC SEAS

Steingrímur Jónsson, University of Akureyri / Marine Reasearch Institute, Iceland

CONSIDERATIONS ABOUT AN OBJECTIVE SPECTRAL ANALYSIS

Roberto R. Barrera, University of Barcelona, Spain

TEMPERATURES IN SVALBARD AND GLOBAL TEMPERATURE VARIATIONS

Páll Bergþórsson, former director, Icelandic Meteorological Office

PERSISTENT MILLENNIAL-SCALE CLIMATE INSTABILITY IN THE NORTH ATLANTIC DURING THE HOLOCENE

Gerard C. Bond, Lamont-Doherty Earth Observatory, USA

CURRENT PLANS FOR ORGANISATION OF WCRP RESEARCH INTO CRYOSPHERE AND CLIMATE

Victor G. Savtchenko, World Climate Research Programme, Switzerland