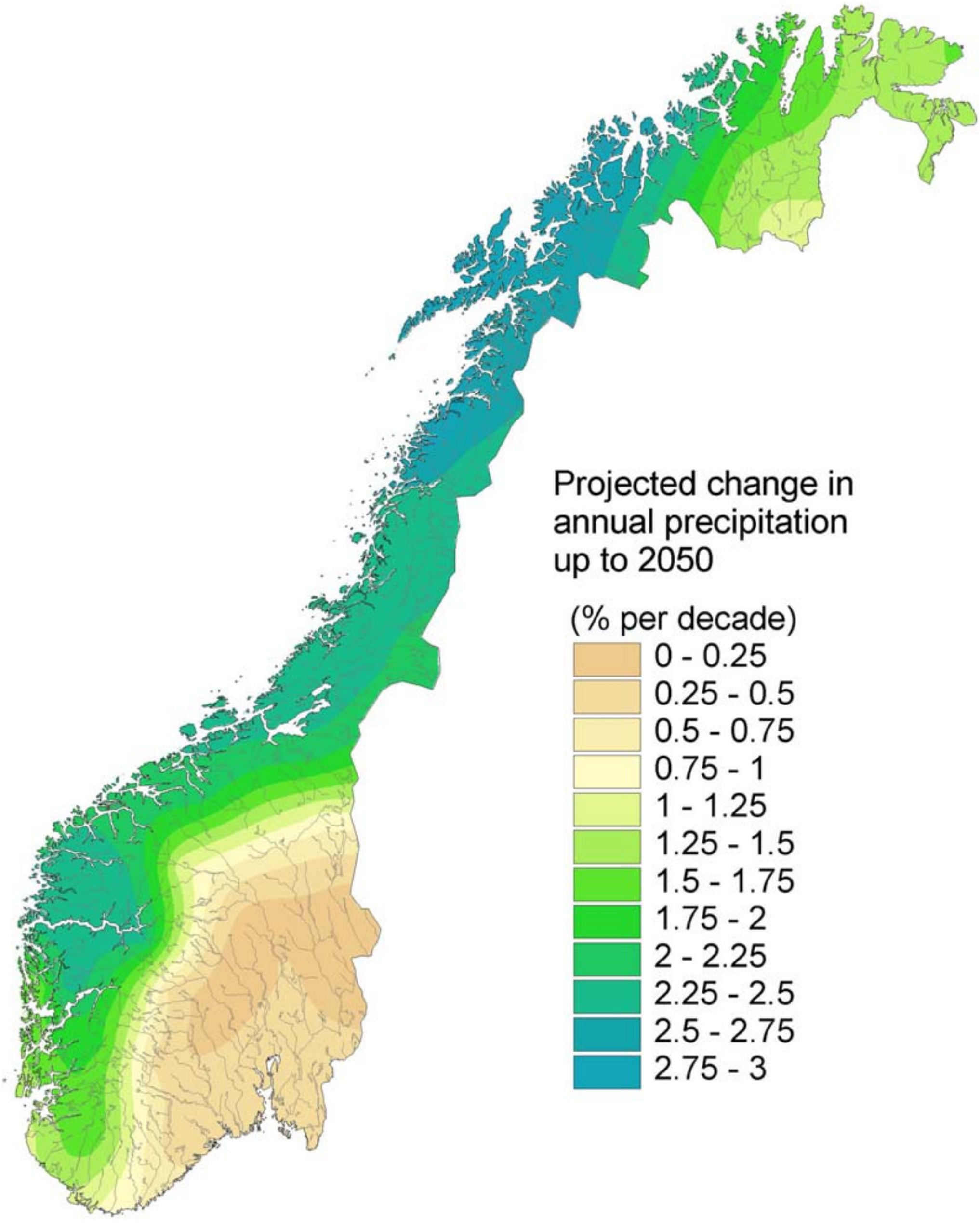
Climate and Ozone Programme Conference

Bergen, 27-29 November 2001



Norges forskningsråd

NILU: OR 66/2001
REFERENCE: N-95102
DATE: NOVEMBER 2001
ISBN: 82-425-1319-8

Climate and Ozone Programme Conference

Hotel Rosenkrantz, Bergen
27–29 November 2001

Edited by Inga Fløisand

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The front page figure was kindly provided by Inger Hanssen-Bauer and Ole Einar Tveito (DNMI).

Preface

As long as the Nordic region has been populated, the changing climate has influenced the living conditions and the development of society in the region. For a long time we have had the benefit of a much milder climate than average at these latitudes. Presently we are experiencing a period of rapid climate change. At the same time climate research is approaching the stage where it seems possible to forecast future climate with at least some degree of confidence. Such a forecast requires that we are able to understand and quantify all the important processes in the climate system and their interactions without large systematic errors.

In this situation the Norwegian Government, through its Research Council, has upgraded the priority of climate research. Simultaneously with an increase in the funding of this research, steps have been taken to enhance cross-institutional cooperation through larger coordinated research projects involving several institutions. A large part of the national competence resources in the relevant scientific fields now participate in these coordinated projects.

This development started under the research programme ”Changes in Climate and the Ozone Layer”(1997-2001), and is now being continued and consolidated by its successor programme “Climate and Climate Change” (2002-2011). (The latter programme is often referred to as “KlimaProg”.)

The present conference is being organized as a part of the transition from one climate research programme to another. The goal is to give the participating scientists and the Research Council a clear picture of how far Norwegian climate research has come today, and relate this to the international development in the field. Substantial attention will be given to the progress of the larger coordinated projects, and in particular to “Regional Climate Development Under Global Warming (RegClim)”, the first project of this type to be initiated. To provide the international context, invited scientists from leading research groups in Europe and North America will present their work. In addition to these oral presentations, the poster session comprises more than forty titles.

In this volume you will find the abstracts of the oral presentations as well as the poster abstracts.

The conference is supported financially by the Research Council of Norway and the Norwegian Meteorological Institute.

Anton Eliassen
Chairman of the Conference
Programme Committee

Inga Fløisand
Programme Coordinator

Norges forskningsråd
The Research Council of Norway

DNMI

Contents

Programme

Climate and Ozone
Programme conference

Hotel Rosenkrantz, Bergen, 27–29 November 2001

Programme

Tuesday 27th November

09:30 – 10:30	Registration, coffee

Scientific presentations

10:30 – 10:40	**Anton Eliassen,** DNMI Welcome, opening remarks
10:40 – 10:45	**Eiliv Larsen**, NGU The NorPast project, short introduction
10:45 – 11:05	**Morten Hald**, Univ. Tromsø Climate change during the recent past
11:05 – 11:25	**Atle Nesje**, Univ. Bergen Climate reconstructions for the entire Holocene
11:25 – 11:45	**Hilary Birks**, Univ. Bergen Past climate changes in the Norwegian Region during the glacial-Holocene transition, 14,000 – ca. 10,000 cal yr BP
11:45 – 12:05	**Eiliv Larsen**, NGU The last glacial maximum
12:05 – 13:15	Lunch
13:15 – 14:15	**Peter Haugan,** Univ. Bergen The Norwegian Ocean Climate Project (NOClim)

14:15 – 15:00	**Jochem Marotzke,** SOC Thermohaline Circulation Dynamics and Climate Change
15:00 – 15:25	**Eystein Jansen**, Univ. Bergen Bjerknes Collaboration for Climate Research – status, results and perspectives
15:25 – 15:50	Coffee
15:50 – 18:00	Oral presentation of posters
18:00 – 19:30	Poster session
20:15 –	Conference dinner

Wednesday 28th November

Scientific presentations continued

08:30 – 09:30	**Geir O. Braathen**, NILU The Coordinated Ozone and UV project (COZUV)
09:30 – 09:55	**Jostein K. Sundet**, Univ. Oslo Tropospheric chemistry and climate (ChemClim)
09:55 – 10:20	Coffee
10:20 – 11:05	**Kevin Trenberth**, NCAR Outstanding issues in the hydrological cycle in climate change research
11:05 – 11:50	**Richard Jones,** Hadley Centre Simulating regional climate change: Progress and requirements
11:50 – 13:00	Lunch
13:00 – 13:10	**Trond Iversen**, Univ. Oslo RegClim, Climate modelling with focus on regional features
13:10 – 13:35	Dag Bjørge, Jan Erik Haugen and **Thor Erik Nordeng**, DNMI Dynamical downscaling of present-day and future scenario climates for Northern Europe and adjacent oceans
13:35 – 14:00	**Inger Hanssen-Bauer** and Eirik Førland, DNMI Climate in Norway from 1900 to 2050: Observations and empirically downscaled scenarios

14:00 – 14:20	Jens Debernard, **Lars Petter Røed** and Øyvind Sætra, DNMI The future wave and storm surge climate using RegClim's dynamical downscaled results, and the Arctic sea-ice climate using MPI's GSDIO climate
14:20 – 14:40	**Jens H. Christensen**, DMI Regional climate modelling and international collaboration
14:40 – 15:00	**Markku Rummukainen**, SMHI Regional climate modeling in SWECLIM (The Swedish regional climate modelling program)
15:00 – 15:20	**Rasmus Benestad**, DNMI Uncertainties associated with climate scenarios
15:20 – 15:45	Coffee
15:45 – 16:10	**Helge Drange** and Mats Bentsen, NERSC Key results from numerical simulations of the flow, hydrography and sea ice in the Atlantic-Arctic region for the present day climate
16:10 – 16:35	**Nils Gunnar Kvamstø,** Paul Skeie and David B. Stephenson, Univ. Bergen On the significance of the Labrador Sea in controlling the NorthAtlantic Oscillation
16:35 – 17:00	Gunnar Myhre, **Frode Stordal,** Terje Berntsen, Tore F. Berglen and Ivar Isaksen, UiO and NILU Radiative forcing due to tropospheric ozone and aerosols, including historic evolution
17:00 – 17:25	**Jón Egill Kristjánsson**, Trond Iversen, Alf Kirkevåg, Øyvind Seland, UiO Direct and indirect effects of sulfate and black carbon aerosols estimated from a mechanistic life-cycle scheme in the NCAR CCM3
17:25 – 17:35	**Trond Iversen**, Univ. Oslo Concluding remarks
19:30 –	Dinner

Thursday 29th November

Discussions

09:00 – 09:20	**Anton Eliassen**, DNMI Comments on the presentations of the first two days
09:20 – 10:00	**Introductory remarks** What are the important unanswered questions in climate research? Implications for future Norwegian climate research? What should be given priority?
10:00 – 11:45	**Discussion**
11:45 – 12:00	**Frode Stordal,** NILU Summary of discussion and future plans

Abstracts of oral presentation

Climate change during the recent past – contribution from the NORPAST project

by

Morten Hald

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During the first three years of NORPAST (1999-2001) there has been a large effort to produce paleo-records from various archives for the recent past, here defined as the last c. 500 years. Given the high time resolution for many of the records, they are of ultimate importance in order to calibrate so-called paleoclimatic proxies and historical data against instrumental time series. Further they can be used to extend the instrumental time series back in time prior to the invention of the thermometer and other relevant climate monitoring instruments. They also have a potential for elucidating possible climate forcing factors.

In the NORPAST-project we have established paleoclimatic records from the following areas: Eastern Norway, Western Norway and Trøndelag (Mid Norway) based on historical harvest data; southern Norway (Haugstjørn) based on lake sediments; the North Sea (Ormen Lange), Northern Norway (Malangsfjorden), based on marine sediments and the Rana area based on speleothems.

The reconstructions from historical data are based on the first day of grain harvest. Documentary evidence for harvest is quoted from farmer's diaries. Reconstructions based on this proxy are established in three climatic regions, since 1843 in Western Norway, 1805 in Trøndelag, and 1749 in Eastern Norway. All results are nested to homogenised instrumental observations in order to form composite series, so that climate analysis can be performed up to the present. From the longest series, the composite Eastern Norway series (1749 – 2000), the following results are presented: A marked long-term trend was detected, amounting to 1.4^0C. The trend was largely concentrated within the 20th century, where it was estimated to 0.9^0C, while in the 19th century the trend was only 0.5^0C. In the last half of the 18th century no significant trend was detected. The coldest decade, 9.9^0C, occurred in 1796 – 1805, while the warmest one, 11.9^0C, occurred in 1988 – 1997. The series from Trøndelag and Vestlandet also showed marked trends of about the same magnitude as the one from Austlandet. Also cold and warm summers tend to cluster in the same years in all regions.

In central parts of Eastern Norway lake sediments from Haugtjørn near Mjøsa were analysed by means of loss-on-ignition. Many features present in the temperature reconstruction based on harvest data also appear in the loss-on-ignition data. The lowest temperatures are located in the latest years of the 18th century and in the beginning of the 19th century. This is in agreement with the Austlandet series. The coldest summer reconstructed by the harvest data is rather famous for its severity also in other documentary sources. It also turns out that the year shows very low loss-on- ignition, only 17% while the loss at the end of the 20th century is around 50%. The organic content in non-glacial lakes in different parts of southern Norway shows a quite consistent pattern and variations in the organic content therefore seems to reflect variations in summer temperature.

The marine records for the recent past represent a break-through in the climate scientific community for reconstructing past ocean temperatures with a time resolution comparable to that of instrumental time series. So far the highest time resolution, 1-3 year, is obtained in the records from the Malangen fjord, Northern Norway. Based on oxygen isotopes measured on benthic foraminifera bottom water (November) temperature record from 1770 to the present has been established. The Ormen Lange record is based on planktic foraminifera, reflecting the surface summer temperatures (SST). In this record SST is reconstructed from early 17th century to the present with a 30-year time resolution. Both marine records appear to reflect changes in the Atlantic Water heat flux into the Norwegian Sea, and in general there is a good correlation to instrumental data for the last 150 years.

The reconstruction based on speleothems from Rana, Northern Norway reveals a signal of annual mean temperature. It shows that the latest phase of the 'Little Ice Age' around AD 1800 was the coldest period, but also the middle and last part of the 17th century was cold, while the first part of the 18th century was relatively mild.

The various recent past paleoclimatic records reflect many similar features, but also some discrepancies. However, the cool conditions during the Little Ice Age is seen in most records, also the warming trend during the last 100 years. There also seems to be an over all good correlation between instrumental temperatures both from land and sea to the proxy records. We currently investigate the relation between the paleo records to possible climate forcing factors such as e.g. North Atlantic Oscillation (NAO), solar irradiance and volcanic aerosol particles. Some of the marine records and maritime glaciers show an NAO correlation. However, correlation of the records and their relation to forcing factors is in progress in will be a main focus in 2002.

So far the data clearly demonstrate that it is possible to reconstruct past climate with a time resolution that allows a direct link to instrumental data. They also provide an important data set for climate modelling. With these promising results we recommend to increase the number of sites with this type of data in order to better understand geographical trends, land-ocean links and climate forcing factors.

Contribution from the NORPAST project: Climatic reconstructions for the entire Holocene

by

Atle Nesje

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A synthesis of climatic development during the Holocene (ca. 11,500 cal. yr BP to the present) is based upon records of Holocene glacier variations in southern Norway, pollen-based quantitative temperature and precipitation reconstructions, and on data from marine sites along the coast of Norway. Reconstructions of glacier fluctuations have been made from studies of moraine sequences and lake sediments. Quantitative climatic reconstructions using transfer functions derived from modern data-sets have been obtained from terrestrial fossils (plant macrofossils, pollen, chironomids) and marine fossils (diatoms, dinoflagellate cysts, planktonic and benthic foraminifera) and oxygen isotope measurements.

The records of Holocene glacier variations in southern Norway show that the early Holocene was characterised by glacier retreat, except for two abrupt periods of glacier readvance around 10,100 - 9700 cal. yr BP (the 'Erdalen event') and around 8200 cal. yr BP (the 'Finse event'). These events have been correlated with similar climate 'anomalies' recorded in Greenland ice cores and north European marine and lake records. The mid Holocene was characterised by reduced and periodically absent glaciers. Glacier regrowth started close to 6000 cal. yr BP and significant glacier expansion occurred at approximately 4000 and 2000 cal. yr BP. Most glaciers reached their post-8000 cal. yr BP maximum during the 'Little Ice Age'.

A comparison between glacier mass balance records from maritime glaciers and the North Atlantic Oscillation (NAO) index over the last ~30 years, demonstrates a close correspondence between the winter and net mass balance and the NAO index. This suggests that Holocene records of glacier variations from maritime glaciers in southern Norway may potentially be used as indicators of variations in winter weather and probably the 'North Atlantic Oscillation weather mode' throughout the Holocene.

Quantitative temperature (mean July and January) and precipitation (mean annual) reconstructions have been obtained from pollen sites along a north/south transect in Setesdalen and an east/west transect between Kiruna and Lofoten. The results from the two transects indicate differences in the timing of temperature and precipitation changes. Maximum July temperatures were reached at 7000 and 8000 cal. yr BP in the north, whereas they occurred between 5000 and 7000 cal. yr BP in the south. Warmest mean January temperatures were between 6000 and 7000 cal. yr BP in the north, and between 5000 and 6000 cal. yr BP in Setesdalen. The highest annual precipitation occurred between 6000 and 9000 cal. yr BP in the north and between 6000 and 7000 cal. yr BP in the south.

A Holocene record of sea-surface temperature (SST) reconstructed from a planktonic foraminiferal oxygen isotope record (*N. pachyderma* sinistral) and % polar foraminifera in core MD992011 from the Vøring plateau in the eastern Norwegian Sea shows a significant cooling coincident with the 8200 cal. yr BP event in the Greenland ice cores. The early part of the Holocene does not show a significant thermal optimum. The later part (from ~4000 cal. yr BP) shows higher climate variability than the first part of the Holocene. Summer sea-surface temperature reconstructed from planktonic foraminifera in the Troll core, North Sea, shows an early Holocene thermal optimum, a significant cooling coincident with the 8200 cal. yr BP event, and relatively stable temperatures up to the present. A record of summer sea bottom temperatures based on benthic foraminifera in the Troll core, North Sea, shows a significant warming around 10,000 cal. yr BP. Subsequently the summer sea bottom temperature varied from ca. 6 to 8.4 ^{o}C, with a slightly declining temperature trend up to the present. Reconstructions of the Holocene sea-bottom water temperatures based on isotopes in Malangen, northern Norway, indicate that the bottom water at 400 m has been warmer than at present for most of time after 11,500 cal. yr BP. In the early part of the record, the temperature of the bottom water was between 11 and 12 ^{o}C, which is 3-4 ^{o}C warmer than at present.

Some Holocene marine and terrestrial records show a remarkable degree of consistency, indicating strong links between the atmospheric and marine mean climate state in the North Atlantic region throughout the Holocene. In addition, both annual and winter precipitation seem to have been significantly higher in the early- to mid Holocene than in the later part of the Holocene.

The Holocene climate records reconstructed from marine and terrestrial proxies indicate that the Holocene climate, at least in the North Atlantic region, has not been as stable as previously suggested from the Greenland ice-core records. In particular, the early Holocene was punctuated by several significant and abrupt climate ‘anomalies’. In southern Norway, a distinctly cool but oceanic climate in the early Holocene was possibly due to enhanced westerly airflow that was replaced about 8200 cal. yr BP by a more meridional flow pattern and by the development of predominantly blocking anticyclonic summer conditions and a more southerly and south-easterly air flow. The inferred low summer temperatures in the early Holocene in the south contrast with the predicted early Holocene orbitally-induced higher radiation (47 W/m^2 higher at 70^{o}N) than at present. It is possible that the inferred low summer temperatures may be partly due to the influence of remnants of the Scandinavian ice sheet, and that until about 8200 cal. yr BP the effect of higher summer solar radiation was dampened by the cooling effect of enhanced Atlantic air flow.

In the future, a larger number of well-dated, high-resolution terrestrial and marine quantitative climate reconstructions are needed in order to be able to better reconstruct Holocene variations in atmospheric and oceanic climate changes along east-west and north-south gradients in the NORPAST study region. Of particular importance is to define climatic anomalies and the scales and patterns of decadal to multidecadal variability. Correlations with records of similar time resolution in the lower latitudes are required to understand possible teleconnections and causal mechanisms (solar activity, volcanic eruptions, meltwater spikes, variations in the thermohaline circulation). For this, much improved chronology is required.

The combined Holocene climate reconstructions based on terrestrial and marine proxies provide data for climate modelling experiments of special interest in the early Holocene, when the magnitude of the Scandinavian ice sheet, meltwater input into the North Atlantic, and of westerly oceanic flow varied significantly, and the climate system was forced by higher summer insolation.

Contribution from the NORPAST Project: Past climate changes in the Norwegian Region during the glacial-Holocene transition, 14,000 - ca. 10,000 cal yr BP

by

Hilary H. Birks

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Late-glacial sediments have been found from southernmost to northernmost Norway, and from 60 - 72°N in the adjacent sea. Terrestrial late-glacial sites are concentrated near the coast beyond the limit of the Younger Dryas ice advance. Marine sites are restricted to the coastal area of the Norwegian Sea, due to extensive ice-cover to the west.

Quantitative climatic reconstructions have been obtained from both terrestrial fossils (plant macrofossils, pollen, chironomids, Coleoptera, Cladocera) and marine fossils (diatoms, dinoflagellate cysts, planktonic and benthic foraminifera). In most cases, quantitative reconstructions have been made using transfer functions derived from modern data-sets collected in relation to environmental variables. Terrestrial animal groups and pollen yield mean July temperature reconstructions, and pollen transfer functions also include mean January temperature and annual precipitation. Transfer functions combined with stable isotope data from marine fossils can be used to reconstruct summer and winter sea-surface temperatures and sea-surface salinity. Dinoflagllates can also be used to reconstruct ice cover and benthic foraminifera can be used to reconstruct sea-bottom temperatures. A comparison of all the results shows consistent patterns. Some discrepancies indicate that further work is required for refining the training sets and modern environmental data collection.

The glacial-Holocene transition can be divided into 3 time-slices; the Interstadial (Bølling + Allerød, GI-1), 14,000–12,700 cal yr BP, the Younger Dryas (GS-1), 12,700–11,500 cal yr BP, and the earliest Holocene, 11,500 - ca. 10,000 cal yr BP, that covers the period of maximum rate of temperature rise. Temperature reconstructions have been mapped for the different time slices. Both marine and terrestrial interstadial mean July temperature reconstructions are remarkably consistent at around 9°C in the south and 5-7°C in the north. Terrestrial mean January temperatures are much colder than in the sea. The temperatures in the Younger Dryas are cooler, and there is a consistent fall on land and in the sea of ca. 1-2°C. This was sufficient for the ice sheet to readvance towards the coast and for the ice-free corridor along the Norwegian coast that reflects the inflow of warm North Atlantic water to be reduced. At the end of the Holocene rapid temperature rise, mean July temperatures reached ca. 11-13°C in the south and 8-10°C in the north. This is a consistent rise over the whole region of ca. 4°C, and shows the westwards withdrawal of the polar front and sea ice. Mean July temperatures reached present-day values in the north, but were ca. 2°C below today's in the south, perhaps reflecting the greater intensity of early-Holocene insolation in the north. Various problems, inconsistencies, and deficiencies, have been highlighted with reconstruction data-sets. The distribution of fossil sites and the gradients in the data show where future work is required.

The synthesis has indicated the potential for producing quantitative climate reconstructions from fossil data of diverse sorts. The comparison of marine and terrestrial results indicates a way forward towards an improved understanding of the interacting terrestrial-marine system. The synthesis is necessarily preliminary and simplified, showing mean reconstructed climate values over whole time periods. It does not take into account the variability during each time period or the chronological timing of the main events delimiting the responses to the climate changes in the individual records. Radiocarbon chronology is complex during the deglacial period, and chronological comparisons between marine and terrestrial sequences are further complicated by the marine reservoir effect (^{14}C dates are older in marine sediments) which changes in an unknown manner through the interstadial and Younger Dryas. At present, we are unable to determine chronological leads or lags between the different records that may reveal the influences of the various forcing factors on the climate system. A primary forcing factor was undoubtedly the late-glacial maximum of summer solar insolation that induced ice melting, which had large effects on North Atlantic Deep Water production and the magnitude of the northward flow of warm Atlantic water, affecting both marine and adjacent terrestrial environments.

The quantitative climate estimates available now and in the future provide data suitable for the making and validation of global and regional climate models. With these boundary conditions, it may be possible to deduce the processes of climate change and the role of the various forcing factors involved using modelling experiments to test hypotheses about climate change.

The last glacial maximum

by

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During the first three years of NORPAST (1999-2001) there has been a joint effort to obtain new data and compile previous data concerning ice-sheet behaviour for the time period just before, during and just after the last glacial maximum. The ice sheets over Fennoscandia and the Barents Sea were responses to an extreme palaeoclimatic setting, and had important feedbacks on the climate through their impact on atmospheric circulation and the hydrologic cycle. The emphasis in the Norpast project has been placed on the Scandinavian ice sheet, and the western part of the Svalbard/Barents Sea Ice Sheet. The main scientific questions have been the lateral extent, the geometry, and the of the ice sheets during the Late Weichselian glacial maximum. These are key questions to understand the climatic response and feedback mechanisms of the ice sheets, and are crucial for correct definition of boundary conditions in GCM models.

During the isotope stage 3 interstadial predating the last glacial maximum in Scandinavia and on the Baltic shield, glacier ice seems to have been restricted within the Norwegian and Swedish mountain chain. On the Atlantic continental margin west of Norway, the glacial maximum was attained some 29,000 - 30,000 calendar years before present. Following the maximum position, the shelf and outer coast was deglaciated before a subsequent re-advance onto the continental shelf between some 23,000 and 18,000 calendar years. Also in Denmark two maximum positions are recorded, one at some 28,000, and after an ice free interlude again at 22,000 calendar years before present. In the White Sea region to the northeast, ice sheet extent culminated about 16,000 – 17,000 calendar years before present. This suggests a difference in timing of the maximum position between the SW and NE sectors of the ice sheet of some 10,000 – 12,000 years. The two-fold glacial maximum on the western ice-sheet margin corresponds to so-called High-Productivity Zones (HP-Zones 2 and 1) in the marine records. HP-zones are periods interpreted to represent seasonally ice-free conditions with increased flux of Atlantic Water. HP1 and 2 can be followed as an almost synchronous signal in marine record from the Faeroe-Shetland Channel in the south, via the Barents-Svalbard margin and into Arctic Ocean continental margin NE of Svalbard. The early glacial maximum corresponds to HP2 and coincides with a low summer insolation, assumed to reflect a period of increased precipitation an ice build-up. The second glacial maximum corresponds to HP1, and an IRD maximum and increased insolation interpreted to reflect to onset of the deglaciation.

As outlined above the eastern (continental) glacial maximum was greatly delayed relative to the western side. This side also was out of phase with the HP-zones. This was probably caused by topographic and internal dynamic factors in the ice sheet during growth more than external climatic factors. Firstly, the main sources of precipitation in the North Atlantic lead to initial expansion of glaciers in the western Scandinavian mountains followed by rapid ice advance through the present fjords towards the west. The maximum position in the west was reached relatively quickly due to preferential growth in the area of maximum precipitation and also because this position (the continental shelf edge) is a topographic barrier to further westwards growth. Towards the east and northeast no such barrier exists, and the maximum position was attained as the ice divide gradually shifted eastwards during further growth.

The vertical distribution and geometry of ice during the last glacial maximum is still open to some debate. Our present hypothesis favors a complex geometry characterized by zones of fast flowing ice streams draining most of the ice sheet across the coastal Norway and western Svalbard. In western Norway (Nordfjord), northern Norway (Andøya – Skånland) and northwestern Spitsbergen, the lower limit of the *in situ* block field is very consistent, and exposure ages suggest that this surface marks the upper ice boundary during the last glacial maximum. In the Romsdalsfjorden area the block field is as well developed as in the above areas. Exposure ages are still pending, but based on the morphological expressions one might assume ages that lead to similar conclusions regarding ice thickness. A problem in this area is that analyses of consolidation in sediments overrun by ice during the last glacial maximum indicate that the ice was covering the block field.

Both regarding lateral and vertical distribution of ice during the last glacial maximum considerable progress has been made. However, since the ice sheet maximum was so delayed in NW Russia, it is not possible on geological grounds to reconstruct the outer distribution of ice in that part of the ice sheet at the same time as the global glacial maximum (19,000-23,000 calendar years ago). This is now attempted in ice sheet modeling experiments recently started in cooperation with an American group. For both vertical and lateral ice sheet variations, a very dynamic picture of the ice sheet is emerging. In the future the effort should be placed on separation between climatic forcing of ice sheet variations and internal reorganizations in the ice-sheet not directly linked with climate. This should be done for the last deglaciation for which good morphological and chronological control is available. This will lead to a better understanding of ice sheet behaviour and to a better link between ice sheets as a climate proxy and the other climate proxies.

The Norwegian Ocean Climate Project (NOClim)
www.noclim.org

by

Peter M. Haugan

Geophysical Institute and Bjerknes Centre for Climate Research, University of Bergen

The Norwegian Ocean Climate Project started its first phase in July 2000. The overall objectives of the project are to contribute in a coherent and rational way with Norwegian resources and expertise to:

A. Improve and enhance our understanding of rapid changes in the thermohaline circulation in the northern seas
B. Improve and enhance our understanding of ocean and ice processes related to climate, and mechanisms causing significant variability in the hydrography, circulation and ice cover in the northern seas
C. Maintaining time series for detecting climate change in the northern seas

The project is organized in 7 scientific tasks, each with a principal investigator (PI). The PIs are drawn from three university departments, one private research institute and three national institutes. Several institutions and research groups contribute to each of the tasks. One task primarily deals with rapid climate changes in the past, three tasks deal with process studies based on combination of modelling with new observations to be collected during the project period, two tasks deal with analysis of large existing data sets from model runs and observations, and one task deals with maintaining long term observations. The main approach of the project is to combine observation oriented activities, numerical modelling, and interpretation of past climate variability in studies where different kinds of expertise complement each other. The emphasis is on possible rapid and dramatic changes with potential major consequences for air-sea interaction and regional and global climate.

During the first year, emphasis has been put on efforts that can start to unite Norwegian palaeo, modelling and observation oriented communities. This is considered essential for progress in understanding past and future climate changes, and rather challenging due to the considerable differences in background. Good links have been established with the RegClim project via mutual representation in the steering groups of the two projects, and via scientists participation in several joint meetings. In accordance with the original intentions of the Norwegian Research Council, links are also being developed with the emerging RAPID thematic programme which has recently been funded by the UK NERC. The implementation phase of RAPID will closely match the second phase of NOClim from 2003, yet to be funded. This concerted effort in combination with other international linkages, gives good prospects for making significant contributions towards key global climate problems in a limited time frame.

Thermohaline Circulation Dynamics and Climate Change

by

Jochem Marotzke

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The ocean's thermohaline circulation (THC) consists of cooling-induced deep convection and sinking at high latitudes, upwelling at lower latitudes, and the horizontal currents feeding the vertical flows. In the North Atlantic, where most of the deep sinking occurs, the THC is responsible for the unusually strong northward heat transport, which results in the relative mildness of western European climate. Abrupt changes in the THC are a plausible cause of observed past climate changes and might occur again in the future. Climate models have demonstrated the possibility that globally rising temperatures will cause increased rainfall in high latitudes, disrupting deep convection and the THC. But the extant models differ widely in their estimates of current and future THC strength, reflecting that fundamental aspects of THC changes remain poorly understood.

I will first use a very simple conceptual model to show why, at present, it is impossible to tell whether a temporary increase in greenhouse gases will lead to a temporary or a permanent change in the THC. The cause of the uncertainty is the role of the wind-driven circulation in transporting freshwater in the ocean; this effect is represented poorly in present climate models.

Motivated by some observational and modelling results, I will then discuss the importance of convective mixing for the THC, especially in connection with the – apparently conflicting – idea that mixing in stratified waters controls the strength of the THC. A second, seemingly unrelated, question is, if salinity is so important in determining the global THC pattern, why does the North Atlantic mainly gain its high-latitude surface density through heat loss? I will show that, at a conceptual level, the answer to the first question leads the way to answering the second as well. Including interhemispheric circulations in our theoretical framework is crucial in this, forcing us to broaden our perspective beyond the use of the now classical Stommel box model of multiple equilibria of the THC. This leads us to ask whether increased freshwater flux indeed always weakens the THC. I will end with some speculations on consequences of this revised perspective for defining future research foci.

Bjerknes Collaboration for Climate Research – status, results and perspectives

by

Eystein Jansen and Beatriz Balino

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with contributions from Bjerknes Collaboration co-workers

The Bjerknes Collaboration for climate research is based on a formal agreement between the University of Bergen, the Institute of Marine Research, Bergen and the Nansen Environmental and Remote Sensing Center in Bergen to join forces to establish a joint research center for climate research.

The primary scientific objectives are:

- Enhance our understanding of the nature, causes and likelihood of rapid climate change and the role of ocean circulation in abrupt climate changes
- Understand and predict climate variability in the North Atlantic-Arctic region
- Understand key processes that drive climate change of the past, present and future, both natural climate changes and those which originate from human influences

The Bjerknes collaboration is led by a research director (Prof. E. Jansen), it comprises a secretariat and 4 thematic research groups. An international scientific advisory board is also set up. The Bjerknes Collaboration/Bjerknes Centre are named in honour of Vilhelm and Jacob Bjerknes, whose research within and originating from the "Bergen School of Meteorology" paved the way for many aspects of modern climate research. In 2000, the Bjerknes Collaboration was awarded a five-year grant from the Norwegian Research Council as an "advanced research group" .

In depth understanding of the past, present and future climate system requires integrated and extended use of paleo- and instrumental observations, analysis and theoretical work, and *numerical modelling*. Since the climate system is characterized by strong interaction between the atmosphere, terrestrial and ocean systems, coupled atmosphere-ocean general circulation models (AOGCMs) are required to describe many of the most important features of the system. A unique climate model has been developed over the last three years by the Bjerknes Collaboration, the Bergen Coupled Model (BCM). The model, which is now operative, consists of the global atmosphere and ocean models ARPEGE and MICOM, respectively, with OASIS as the coupler. The BCM can be run with stretched grid systems in both the atmosphere and in the ocean, a feature that is used to place special emphasis on the climate processes in high latitude regions. The various groups of the Bjerknes Center will play an active role in defining the model experiments to be performed by the coupled and the ocean-only and atmosphere-only models, and to improve the representation of key processes in the model system. Likewise, the output from the model system will be analysed and used by both observationalists, theoreticians and modellers.

Scientists from the groups have been awarded 3 contracts as Marie Curie Training Sites from the EU. These will provide dedicated training of European doctoral students.

Over the last two years scientists from the groups have authored or co-authored a series of papers in high profile journals, including 5 papers published in *Nature* and *Science*.

Some examples of recent scientific achievements:

- Documentation of reduced Arctic Sea ice cover over recent decades.
- Evidence for how the mode of deep convection changes during abrupt millennial scale climate events
- Documentation of how the North Atlantic Oscillation influences the dynamics of the North Atlantic current, its flow towards the Arctic, frontal dynamics and glacier mass balance on maritime glaciers.
- Reconstructions at decadal scale resolution of glacier fluctuations, summer temperature and winter precipitation in Southern Scandinavia over the past 10,000 years
- Initiation of a large-scale tracer experiment which casts new light on the mechanisms of oceanic mixing, advection and overturning.
- Documentation of a tendency for deep-ocean warming in the Nordic Seas and reduced outflow of deep waters to the North Atlantic.
- Estimates of interannual and seasonal carbon fluxes in the Nordic Seas.
- Production of a completely new reconstruction of the Eurasian Ice Sheet dimensions during the last ice age.
- Quantitative reconstructions of the rate of late-glacial temperature change and its magnitude from lakes and ocean sediments.
- Establishing a fully coupled global climate model with stretched grid function.
- Production of some of the most sensitive and robust quantitative organism-climate transfer functions that transform fossil assemblages into quantitative reconstruction of past climate.

The institutions involved in the Bjerknes Collaboration co-ordinate major national and European collaborative projects and are involved in a number of projects funded by the Norwegian Research Council and the EU. The institutions have access to a wide range of infrastructure for climate research. The establishment of the Bjerknes Collaboration which formally integrates climate research between the University, the Institute of Marine Research and the Nansen Center last year, has already led to improved integration of climate research in Bergen and is an important basis for further developments:

- Joint leadership team between three institutions is established
- 4 joint research groups encompassing scientists from the three institutions were set up
- New joint projects are developed
- Improved quality due to better inter-institutional and interdisciplinary contacts.

This integration process has strong institutional backing.

The Coordinated Ozone and UV project (COZUV)

by

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Introduction

The Coordinated Ozone and UV project was initiated by the Climate and Ozone programme committee in order to improve collaboration between the various groups in Norway that work within the fields of stratospheric ozone depletion and UV radiation. The project started in Jan. 1999, and the first phase of COZUV (also called COZUV-1) ran through 2000. The second phase of COZUV started in Jan. 2001 and will last until the end of 2002.

The problem

The decline in stratospheric ozone both in the southern and in the northern hemisphere leads to great concern over the possible effects on humans, animals, plants and materials. The Antarctic ozone hole is a well known phenomenon that manifests itself every year in September and October. Also in the Arctic one has observed substantial ozone loss during several of the last winter and spring periods. It is important that we obtain more knowledge on the future development of the ozone layer and the resulting changes in UV radiation. Norway has a strategic location with respect to the Arctic region, so it is of particular importance that we follow the situation closely.

The Partners

The COZUV project includes all research groups that are active in the field of ozone and UV research. The project is coordinated by the Norwegian Institute for Air Research (NILU) and there are participants from:

- The University of Oslo, Dept. of Geophysics
- The University of Oslo, Physics Dept.
- The Norwegian Univ. of Science and Technology, Trondheim
- The Norwegian Defence Research Establishment (FFI), Kjeller

The Tasks

COZUV is divided into 10 main work packages or so-called tasks:

1. 3-D modelling of atmospheric chemistry
2. Dynamical studies
3. Ozonesonde observations
4. DOAS measurements
5. Ozone lidar measurements

6. Analysis of ozone change
7. Ground based UV measurements
8. Airborne UV measurements
9. UV modelling
10. Coordination

Several of these tasks are divided in to sub-tasks or so-called activities.

Links between tasks

Many of the tasks are interlinked. Data from the observational tasks (3, 4 and 5) are used for validation of the 3-D CTM that is under development in Task 1. In the future, results from this model will be used to interpret the measurements. Data from Task 1 are also used to initialise the trajectory model used in Task 2.

Data from the observational tasks, together with model results, are used in task 6 to assess the degree of ozone depletion in the Arctic.

Data from the long-term simulations in Task 1 will be used in task 9 for the calculation of UV maps for the next 50 years. Data from Task 7 will be needed in Task 9 for validation of maps of the present UV radiation levels.

Data from Task 5 are used as support for the dynamical studies in Task 2. The high temporal resolution of the ozone lidar makes it well suited to study rapid dynamical phenomena, such as ozone laminae.

Data from Task 8 will in the future be used in order to improve the atmospheric chemistry models.

Results

We will only show some examples here. More results will be shown during the presentation at the conference.

Comparison of modelled and measured ozone

The ozone field calculated by the Oslo CTM-2 has been compared to ozone measured by the GOME satellite instrument. Fig. 1 shows an intercomparison for 15 March 1997. This figure shows that the model and measurements agree quite well, both on the general distribution of ozone and the absolute level of ozone.

A comparison made for 1 October 1997 shows that the model is not yet capable of reproducing the Antarctic ozone hole. This is shown in Fig. 2.

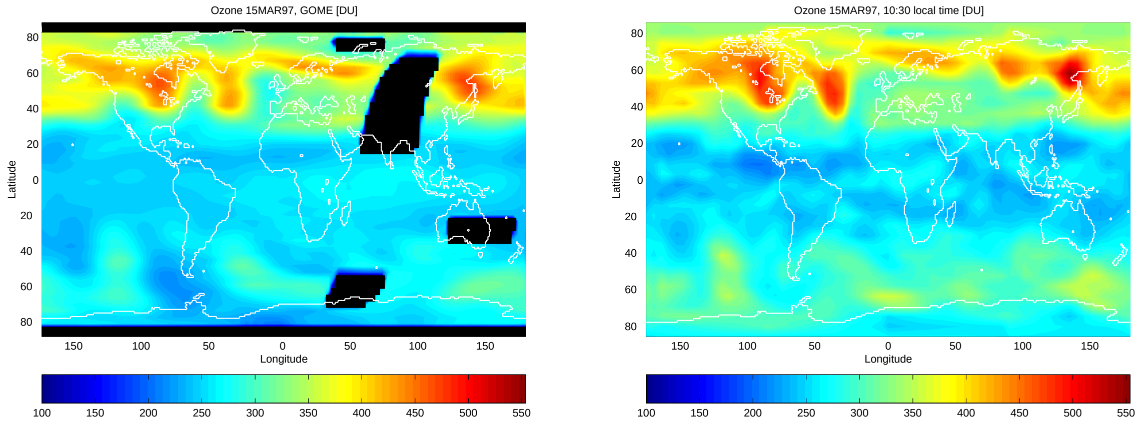

Fig. 1. Left: GOME total ozone for 15 March 1997. Right: Total ozone from the Oslo CTM-2 model.

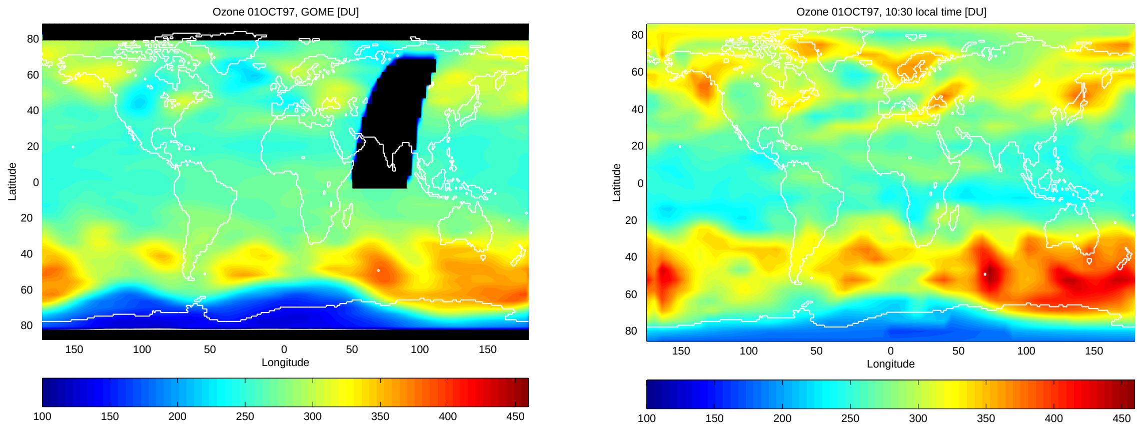

Fig. 2. Left: GOME total ozone for 1 October 1997. Right: Total ozone from the Oslo CTM-2 model.

The NAO index and ozone miniholes

Analysis of the ozone field from the Total Ozone Mapping Spectrometer (TOMS) from 1979 to present shows that there is a correlation between the NAO index and the incidence of episodes with ozone miniholes. These small ozone holes are not caused by chemistry but rather by a dynamical effect where the ozone is pushed up and away. Fig. 3 displays a histogram that shows the number of days with miniholes as a function of the North Atlantic Oscillation (NAO) index. It is clearly seen that the distribution is skewed with a higher number of minihole days when the NAO is in the positive phase.

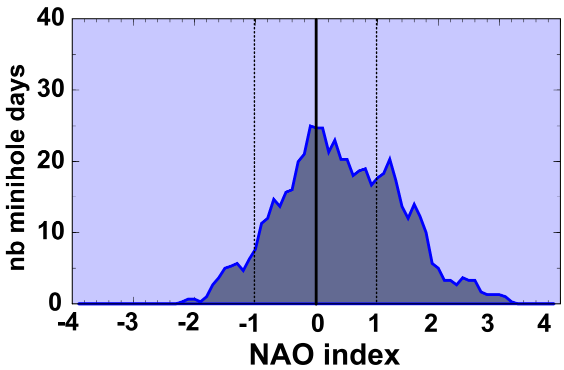

Fig. 3. Ozone minihole histogram. The abscissa is the index of the North Atlantic Oscillation and the ordinate is the number of days with miniholes. The time period covered is from 1979 to present.

Analysis of ozone loss

The degree of chemical destruction of ozone inside the north polar vortex has been calculated for the 13 winters from 1988-89 up to 2000-2001. This study is based on ozonesonde data from the Arctic network of ozonesonde stations. The ozone mixing ratio at the isentropic level of 475 K (approx. 19 km) has been studied as a function of time during individual winters. It is shown that the degree of ozone loss correlates well with the occurrence of polar stratospheric clouds, or more precisely, with the occurrence of temperatures low enough to form such clouds. Fig. 4 shows to winters with very different meteorological conditions, namely the winter of 1991-92 and 1999-2000, respectively. The 1991-92 winter was cold to begin with, but a major warming in late January led to evaporation of the PSCs from about 25 Jan. 1992. The 1999-2000 winter, on the other hand, was very cold from early December through mid March and PSC temperatures existed for long periods of time. It can be seen from the figures that the degree of ozone loss was considerably larger in 1999-2000 than in 1991-92. The amount of ozone loss is given in the figure caption.

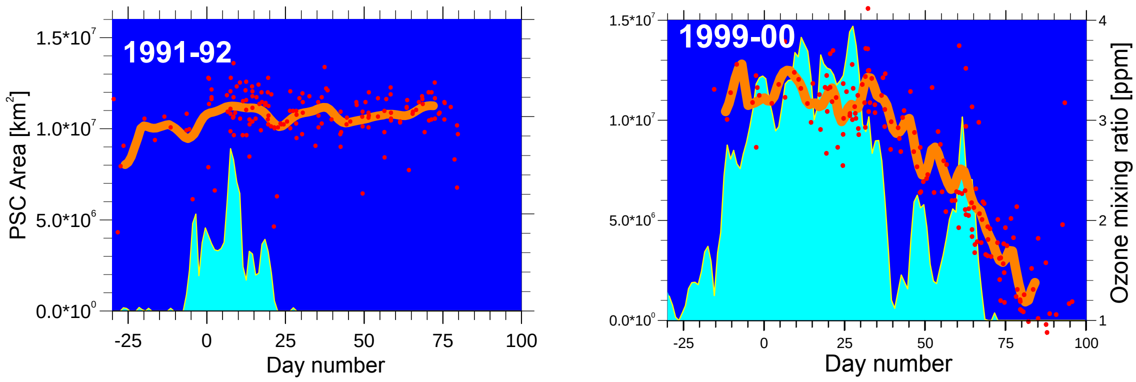

Fig. 4. Ozone mixing ratio (ppm) as a function of time of the year for two different winters, 1991-92 and 1999-00. The red dots are the mixing ratio at 475K from individual soundings. The orange curve is a 7 days moving average. The light blue shaded curve is the area where temperatures are low enough for the existence of polar stratospheric clouds. The much longer period of possible PSC existence in 1999-00 led to much more extensive ozone loss. When diabatic descent is taken into consideration the ozone loss is 1991-92 amounted to 23 ± 10% and in 1999-00 it amounted to 73 ± 5%. Diabatic descent data are calculated with the SLIMCAT 3-D at the University of Leeds.

UV scenarios

The main reason for our concern about the ozone layer is the increased UV radiation that will result from ozone declines. In addition to the ozone amount the cloud properties of course play a very important role in determining the amount of UV that reaches the ground. In Task 9 of COZUV a technique for the calculation of maps and time series of UV doses has been devised. Updated inputs to a radiation transfer model such as ozone column, surface topography, cloud thickness and cloud cover, are collected from various sources. The aim is to use ozone data for the future as calculated by the Oslo SCTM model to produce UV maps for the future. Fig. 5 shows how maps of ozone, cloud cover and topography are combined into a UV map.

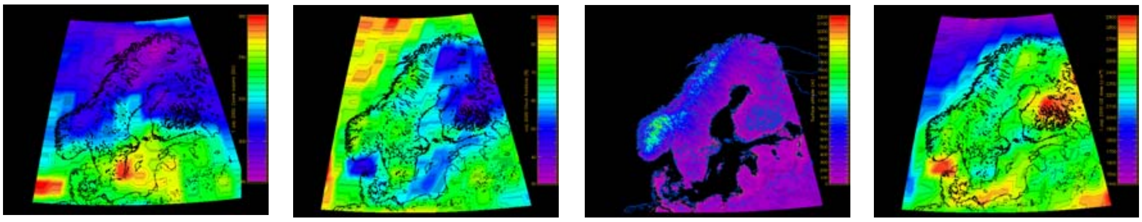

Fig. 5. From left to right: TOMS total ozone for 1 July 2000, cloud fractions for July 2000, topography and the resulting UV dose map.

Synergies from a joint project

Although the groups who participate in COZUV had knowledge of each other and also some collaboration before the start of the project, it is clear that the participation in a joint project has led to much more extensive collaboration. In this respect COZUV has played a very important role for the Norwegian ozone and UV community.

CHEMCLIM:
Tropospheric Chemistry and Climate

by

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Introduction

The idea that atmospheric trace gases and chemical processes could have a significant impact on climate is not new, and that, indeed, there are links between climate and chemistry. The 1985 international ozone assessment report (WMO, 1985) discusses thoroughly the trace gas effects, including indirect effects from primary pollutants like NO_x, CO, due to their impact on tropospheric ozone. The progress in incorporating chemical processes in climate model studies has been gradual and up to now chemical processes has largely been taken into account through off line calculations using Chemical Transport Models (CTMs). Integration of chemistry in General Circulation Models (GCMs) to account for the climate-chemistry interaction is just starting and will likely take years with testing before the processes are fully integrated (IPCC, 2001). It is therefore important to continue the study of processes affecting the chemical active greenhouse gases and particles with CTMs, and at the same time proceed with the integration of chemical processes in the GCMs.

The long-term objective in CHEMCLIM is:

> To improve our understanding of how emissions from different sources of pollutants affect the distribution of chemically active greenhouse gases and particles, and their impact on climate in different regions.

This is achieved through the following activities:

- Improved emission database
- Preparation of observational data
- Chemical process studies
- Budget studies of greenhouse gases
- Aerosol budget studies
- Chemistry-cloud processes
- Radiative forcing from greenhouse gases and particles
- Chemical active compounds in GCM studies

Coordination

Since the CHEMCLIM is a strategic research group (spissforskningsgruppe) the activities are no coordinated to a specific goal, but more to stimulate and coordinate activities within the scope of CHEMCLIM as defined in the overall goal. As such the coordination is to utilize the competence in the participating groups and to strengthen scientific links between them. Both national (MI, NILU, CICERO) and international institutions (SUNY, UCI, NCAR) are participating. One important aspect of the strategic research group is the maintaining of knowledge and also education of new scientists, and therefore a significant part of the budget is to finance PhD (4) and Post. Docs (1).

Activities

The core activity is modelling of the regional and large-scale chemical, radiative and dynamical interactions. The focus is on two main chemically active greenhouse gases methane (CH_4) and ozone (O_3), and on primary and secondary particles affected by atmospheric physical and chemical processes. Their sources, atmospheric trans-formation, removal, atmospheric distributions, interaction with clouds and radiation and their role in the climate system is studied. Studies on impact on climate an atmospheric chemistry code will be implemented in a dynamic coupled global circulation model (GCM) including ocean and sea-ice.

Natural Particles

Process studies with emphasis on particles have been a major task in the project the initial period of the project. As is described in a poster at this conference, sea salt and mineral modelling, with the Oslo CTM2, are done to describe parts of the natural particle environment globally. Sea salt seasonal variations are simulated to with good precision at a number of stations globally with both the right absolute levels and the right variability. Mineral particles are currently studied with the Oslo CTM2. These together with sulfur, black and organic carbons and particle generated from chemical species constitutes the particles we are able to simulate and will be integrated into a particle models that will be used in the Oslo CTM2.

Climate-Chemistry coupling ability

Coupling of climate and chemistry is done in collaboration with Professor Wey-Chyung Wang in SUNY, Albany, NY, USA, and we have made some integration with a comprehensive chemical module that is incorporated. The chemical scheme is limited in the sense that the numbers of advected species are 20 compared with our chemical package in the Oslo CTM2 where around 50 tracers are advected. The chemical package focuses on ozone with diurnal variations, on-line photodissociation, wet and dry removal. The CCM3 with the Oslo chemistry package manages to describe the ozone and CO annual variation very well, with somewhat high ozone at northern latitudes. Comparison with ozone sondes shows that the Spitfire advection scheme is appropriate for keeping the ozone gradient between the stratosphere and troposphere (which is not found with the standard semi-lagrangian advection scheme in the CCM3).

Emissions of trace gases

Updated emission of trace gases is a necessity, to be able to accurate high-resolution simulations of trace gases in comparison with measurements. This together with model development have made it possible to do high resolution (1.9x1.9 degrees) integrations for extended periods of chemical tracers globally. Time dependent emissions (for 1990, 1995 and 2000) are currently available for some species and this basis will be expanded and it will be possible in the CHEMCLIM project to study year to year variations in chemical distributions and processes.

International collaboration

In all our focused areas we are dependent upon international collaboration. Climate-Chemistry couplings are done in collaboration with SUNY, Albany, NY Prof. W-C Wang). Changes in the oxidation capacity of the atmosphere, is done in collaboration with UCI, CA (Prof. M. Prather) and studies of cloud-chemistry interactions is done in collaboration with NCAR, Boulder (Dr. P. Rash).

Outstanding issues in the hydrological cycle in climate change research

by

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We speak glibly about rainfall, or more generally, precipitation, and often place it on a par with other variables in the atmosphere such as temperature, pressure, wind, etc. Yet most of the time it does not rain and when it does, the rain rate varies. Steady moderate rains soak into the soil and benefit plants while the same rainfall amounts in a short period may cause local flooding and runoff, leaving soils much drier at the end of the day. In turn, soil moisture amounts influence surface heating and whether it is manifested as increases in temperature or increases in moisture, thereby affecting recycling of moisture. In climate models it is possible to "tune" parameters to improve the amounts of precipitation simulated, but unless the amounts are right for the right reasons - and these include the frequency and intensity of precipitation - it is unlikely that useful forecasts or simulations will result. Current evidence suggests that these aspects of climate model simulations are generally poor.

The character of the precipitation, more so than the amount, is also most likely to change as the climate changes. Trenberth (1998, 1999) shows that increased concentrations of greenhouse gases in the atmosphere increase downwelling infrared radiation, and this global heating at the surface not only acts to increase temperatures but also increases evaporation. Together these enhance the atmospheric moisture content, as is observed to be happening in many areas. The latter is governed primarily by the Clausius-Clapeyron relation and so increases about 7% for 1°C rise in temperature. All weather systems, ranging from individual clouds and thunderstorms to extratropical cyclones, feed on the available moisture through storm-scale moisture convergence, and hence are likely to produce precipitation rates enhanced at about the same rate as the moisture content. However, the speed up in the overall hydrological cycle, and the total precipitation amount, is governed by the surface heat budget, and estimates from models are about 1 to 2% for 1°C rise in temperature. So the total precipitation must increase much slower than the intensity, implying a decrease in duration and/or frequency of precipitation. Increases in heavy rainfall at the expense of more moderate rainfall are the consequence along with increased runoff and risk of flooding. Moreover, there is clear evidence that rainfall intensity is increasing in the United States and some other areas. At the same time, the increased potential evapotranspiration increases risk of drought in places where it does not rain.

An excellent example of these facets is the diurnal cycle of precipitation, whose correct simulation remains an unsolved challenge, but which is ripe for exploitation and use in model testing and evaluation. The diurnal cycle of precipitation is particularly

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[1] The National Center for Atmospheric Research is sponsored by the National Science Foundation

pronounced over the U.S. in summer. The mean pattern of the diurnal cycle of summer U.S. precipitation is characterized by late afternoon maxima over the Southeast and the Rocky Mountains and midnight maxima over the region east of the Rockies and the adjacent plains. The diurnal cycle in precipitation frequency accounts for most of the variations, while the diurnal variations in precipitation intensity are small (Dai et al. 1999). The solar driven diurnal and semidiurnal cycles of surface pressure (Dai and Wang 2000), also known as tides, result in significant large-scale convergence over most of the western United States during the day and over the region east of the Rockies at night (Dai and Deser 1999). As shown by Dai et al. (1999) the diurnal cycle of low-level large-scale convergence suppresses daytime convection and favors nighttime moist convection over the region east of the Rockies and the adjacent plains. The nocturnal maximum in the region east of the Rockies is also enhanced by the eastward propagation of late afternoon thunderstorms generated over the Rockies which not only do not die out as they progress eastward, they become more vigorous. Over the Southeast and the Rockies, both the static instability and the surface convergence favor afternoon moist convection in summer, resulting in very strong late afternoon maxima of precipitation over these regions.

The NCAR Community Atmospheric Model (CAM) systematically initiates convection in the diurnal cycle about two hours before it occurs in nature, resulting in more frequent and less intense precipitation than observed. It also fails to simulate the observed nocturnal maximum over the United States. More generally, the diurnal cycle is poorly simulated in models. For instance the ECMWF operational model tends to produce the maximum precipitation about local noon, corresponding to the time of maximum heating, and this is thought to be common. All model convection schemes explored by Dai et al. (1999) produced premature convection and too much cloudiness which reduced surface solar radiation and thus altered the daytime peak warming at the surface, although in different ways. This prevents the continental-scale "sea breeze" and its associated convergence and divergence patterns from developing properly. Thus the transport of moisture and its role in setting up convective instabilities is also disrupted. Model criteria for onset of moist convection appear to be too weak and fail to take into account the large-scale environment (such as subsidence), and so moist convection in the model starts too early and occurs too often. This also implies that there is more soil moisture and less runoff than there should be, and that subsequent heating produces increased moisture fluxes and a cooler climate.

Therefore from a climate perspective, the intensity, frequency, duration, and sequencing of rainfall events are as much of a concern as amounts, as these factors determine the disposition of rainfall once it hits the ground and how much runs off. Moreover, changes in the character of precipitation, rather than amount, are more likely as the climate changes, and have major implications for extremes. Making advances on these problems is very important for society. We suggest that the diurnal cycle is ripe for exploitation as a major test bed for models of all sorts owing to new datasets and analyses of the diurnal cycle.

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Simulating regional climate change: Progress and requirements

by

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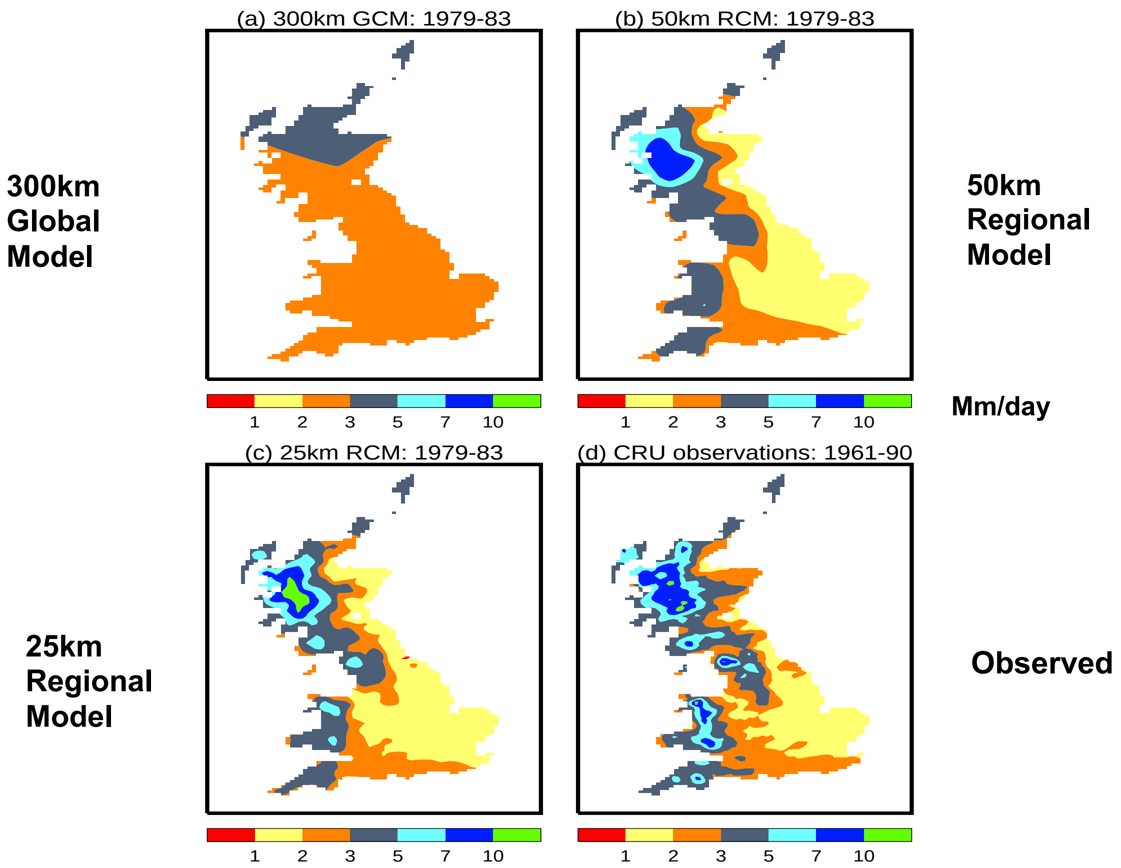
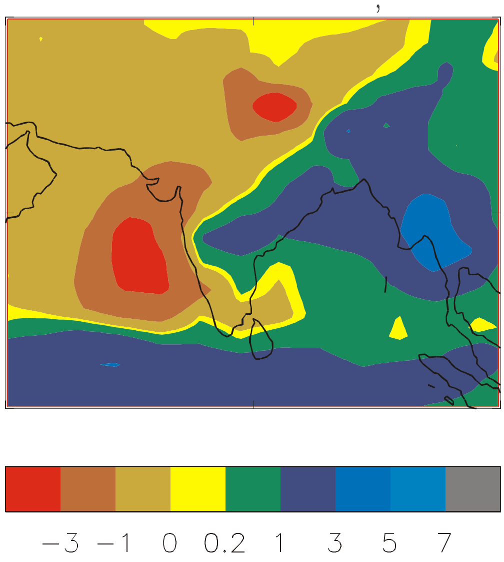
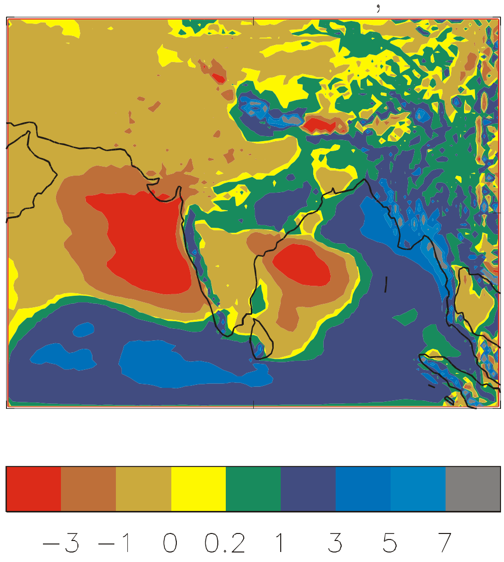
A regional climate model (RCM) describes mathematically the behaviour of the atmosphere, in the same way as a global climate model (GCM). But it does this with a much higher resolution, typically 50km, and over a smaller area, typically a 5000km square. It is driven at its boundaries by simulations of large scale climate from a GCM. Mountains and coasts are represented in the RCM with greater realism and hence so is their effect on weather and climate as can be seen in the figure below showing winter rainfall over the UK as observed and modelled at different resolutions.

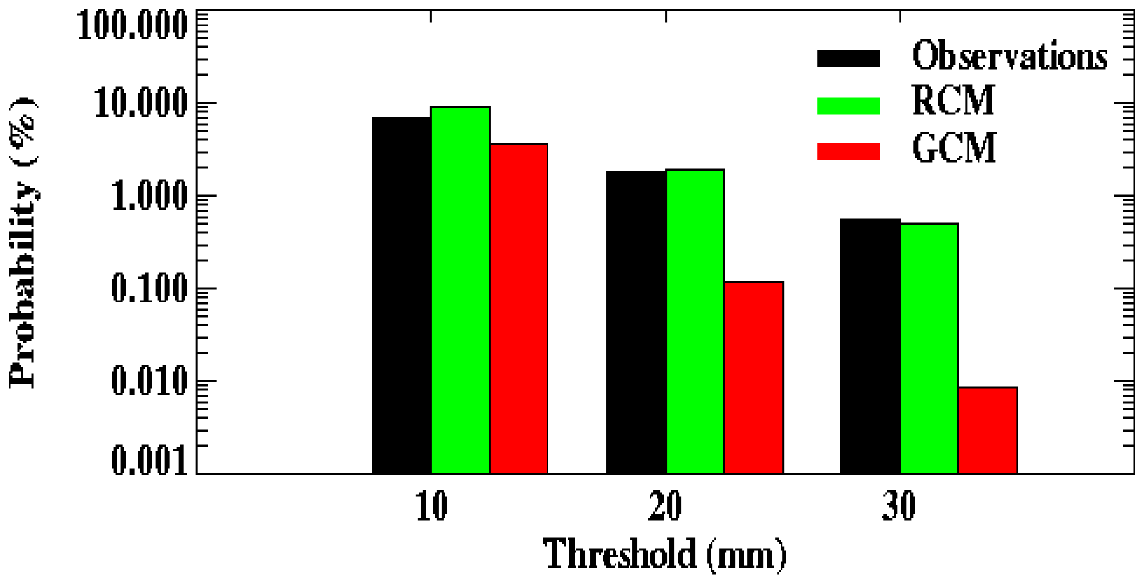


Climate change often gives different patterns of wind flow over a region, which mountains and other local features will interact with this to give local changes in the surface climate. For moderate hills and mountains, such changes will not be seen in the global model but the finer resolution of the RCM will resolve them. In the prediction below of rainfall changes (mm/day) for the 2050s these are clearly very different in the RCM over the Western Ghats in western India.

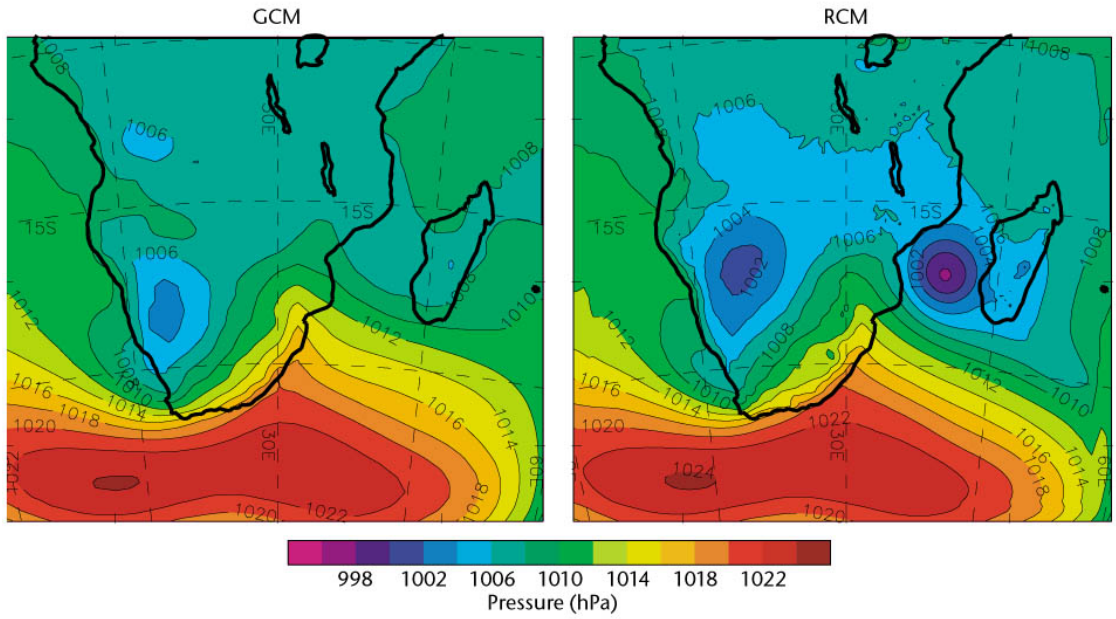




Regional Climate Models also have another important advantage over global models, in that they represent changes in extremes much better, such as the frequency of days of heavy rainfall. The figure below shows the frequency of days in the UK with rainfall thresholds of 10mm, 20mm and 30mm observed at individual stations alongside simulations from the global and regional models. The latter is much more realistic and hence is more likely to give credible predictions.



There are also events such as tropical cyclones, as shown in the Mozambique channel in the figure below, which are not resolved at all in the global model but can be simulated realistically in the RCM.



It is likely that the greatest impact of climate change will come about through changes in local climate, of both mean climate and extremes, so RCMs have a dual advantage over GCMs for assessing impacts of climate change. However, it is important to realise that predictions from an RCM are totally dependent on the realism of the global model driving it; if the global changes are wrong, so will be the detailed regional changes. Thus RCMs do not replace or supersede GCMs; indeed they give added impetus to the development of GCMs. Though predictions from GCMs are beginning to converge on the sub-continental scale, the magnitudes and regional patterns can still be very variable hence improved regional prediction will only be achieved if global model performance is improved in parallel.

RegClim, Climate modeling with focus on regional features

by

Trond Iversen
University of Oslo

Dynamical downscaling of present-day and future scenario climates for Northern Europe and adjacent oceans

by

Dag Bjørge, Jan Erik Haugen and Thor Erik Nordeng

Norwegian Meteorological Institute

The HIRHAM regional climate model (RCM), originally developed at Max-Planck Institute (MPI), has been used in the present study as a tool for dynamical downscaling experiments within the Norwegian RegClim project, with focus on the Nordic area and adjacent sea areas. Results from two major simulations are presented. The first run is the HIRHAM control experiment with 55 km resolution using so-called perfect boundary conditions, i.e. in our example from ERA data (ECMWF re-analysed data 1979-1993). The second main simulation is a 70-year continuous climate change experiment from 1980-2049. The lateral boundary values and sea/ice conditions have been gathered in 12-hour intervals from the global coupled atmosphere/ocean climate change experiment named GSDIO at Max-Planck Institute (MPI) in Germany. In this run the radiative effect of greenhouse gases, sulphur, ozone and the direct and indirect effects of aerosols are accounted for in the physical parameterisations. The results from the downscaling procedure are analysed in terms of the statistical distribution of usual weather parameters, i.e. 2-meter temperature, precipitation and 10-meter wind speed. Seeing the integration as one realization of the present and near future climate, the simulations displays the variability of these weather parameters for an extended range of large-scale climate conditions including various phases of the North Atlantic Oscillation Index (NAO). The analysis of temperature includes a comparison with results from an empirical downscaling of temperature for Norwegian stations on a smaller spatial scale than represented in the dynamical downscaling model.

With forcing from ERA data

- Temperature. The annual mean 2-meter temperature in HIRHAM is close to the analysed temperature in ERA. The difference is less than 1°C over most continental areas, but the wintertime temperature in HIRHAM is somewhat higher than in ERA over Scandinavian areas.
- Precipitation. In general good correspondence is seen between HIRHAM and ERA, but 10-20% higher mean annual precipitation is seen in HIRHAM over ocean areas. The distribution is improved in mountain areas due to increased horizontal resolution in HIRHAM. The maximum values over Norway correspond well with observations.
- Wind speed. The annual 10-meter wind speed in HIRHAM and ERA agrees well over the ocean. An expected increase is found in HIRHAM along the coasts and over elevated topography.

With forcing from MPI data

- Temperature. The annual mean temperature is expected to increase from 0.2°C per decade in southern Norway and central Europe and up to 0.4°C per decade in northern Norway. The warming over Norway is higher during winter than summer. In the Arctic area larger warming is expected.

- Precipitation. Increased values in Northern Europe and in the Arctic are expected during the next 50 years. Up to 30% more precipitation in western Norway during the autumn, which is statistically significant compared with the natural variability.
- Wind speed. A small annual increase is seen over Norway including coastal areas. During winter the increase is around 2.5-5% in northern Norway and during autumn around 5% over mountain area in southern Norway.

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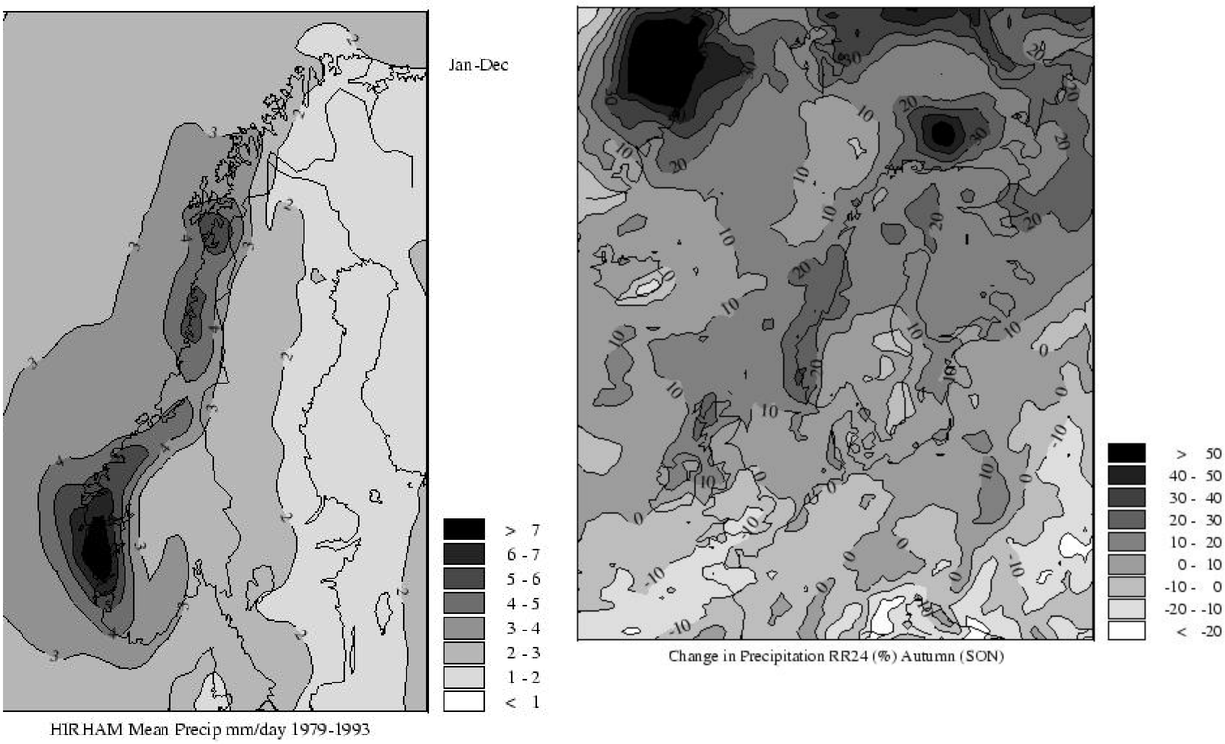

Fig. 1. Results from the HIRHAM simulations with boundaries from the ECMWF ERA data (left) and MPI GSDIO data (right). Left: Daily mean accumulated precipitation in mm/day, January-December. Right: Change in percent of daily mean precipitation from present-day to scenario climate, September-November.

Climate in Norway from 1900 to 2050: Observations and empirically downscaled scenarios

by

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The annual mean temperature in Norway increased at average by 0.05-0.10°C per decade during the 20th century (Hanssen-Bauer & Nordli, 1998). The increase is statistically significant in all regions except in the northern inland region. The warming was generally larger in the inland than along the coast. The trend is not linear: There is a positive trend from 1900 to the 1930s, a negative trend from the 1930s to the 1960s, and a positive trend from the 1960s to 2000. On Svalbard, the same periods of increasing and decreasing temperature are found (Hanssen-Bauer, 2001). Here, the temperature level in the 1930s was higher than during the 1990s. The average temperature trend at Svalbard from 1912 to 2000 is thus not statistically significant, though it is larger than anywhere at the Norwegian mainland (0.14°C pr decade). The annual precipitation has increased by up to 1.8% per decade in different parts of Norway during the last 100 years (Hanssen-Bauer & Førland, 1998a). The increase is statistically significant in western and northwestern regions. In parts of southeastern Norway, no trend is found in precipitation. At Svalbard, a highly significant positive trend of 2.8% per decade is found from 1912 to 2000. Both in Norway and at Svalbard, temperature and precipitation variations are to some extent accounted for by variation in the atmospheric circulation (Hanssen-Bauer and Førland 1998b, 2000). For precipitation, most of the long-term trends and decadal scale variability is accounted for by variation in the mean sea-level pressure (SLP) fields. For temperature, variation in the SLP field accounts for most of the warming after 1960, but not for the warming prior to 1940.

Empirical downscaling techniques were applied to produce local scenarios for temperature and precipitation for Norway and Svalbard under global warming. The downscaled scenarios were based upon the GSDIO integration (a transient integration including effects of greenhouse-gases and tropospheric ozon, as well as direct and indirect effects of sulphur aerosols) with the Max-Planck-Institute climate model ECHAM4/OPYC3. When applying empirical downscaling techniques, it is crucial that the predictor variables are realistically reproduced by the climate model. Hanssen-Bauer and Førland (2001) concluded that the large-scale SLP-field in the GSDIO integration is biased over the northern North-Atlantic under the present climate, but that the anomalies from the average are realistic. The large-scale 2m temperature (T) field, and also the links between the SLP and the T anomalies over Norway, are quite realistic. For downscaling temperature, T was used as the only predictor (Hanssen-Bauer et al., 2000). For precipitation, both SLP and T were applied (Hanssen-Bauer at al., 2001). Common EOFs (Benestad, 2001) from the observed and modelled SLP fields were used together with a regional temperature, which was included as a proxy for air humidity. The empirical links in summer indicated that either T is a poor proxy for air humidity or that air humidity is a poor predictor for precipitation in this season. Temperature was thus skipped as predictor during the summer months.

The empirically downscaled temperature scenario indicates average annual warming rates of 0.2 to 0.5°C per decade up to year 2050 at the Norwegian mainland, and 0.6°C per decade on Svalbard. The warming rates are generally smallest in southern Norway along the west coast. They increase when moving inland and northwards. At the west coast in southern Norway, the modelled warming rates are similar in all seasons (0.2-0.3°C per decade). Further north and in inland valleys, considerably larger warming rates are projected in winter (≥0.5°C per decade) than in summer. At the Arctic stations the modelled winter warming rates are of magnitude 1°C per decade. The empirically downscaled precipitation scenario indicates an increase in the average annual precipitation of 0.3 to 2.7 % per decade during the coming 50 years at the Norwegian mainland, and about 1.5% per decade on Svalbard. The projected increase rates are generally smallest in southeastern Norway, where they are not statistically significant, and largest along the northwestern and western coast, where they are highly significant. In winter and autumn, positive trends are found all over the country, and the modelled increase is partly accounted for by the temperature increase. Modelled changes in spring precipitation are statistically significant only in the northernmost regions in Norway and at Svalbard where an increase is projected. Modelled summer precipitation tends to decrease in eastern areas and increase in western areas, while only small changes are projected in northern regions.

The present results were compared to the results from dynamical downscaling (Bjørge et al., 2000). Most of the differences between the results from the respective approaches were within the 95% confidence interval. Concerning the temperature scenarios, an exception is that systematic differences in the warming rates were found in winter in the inland, especially at inversion-exposed locations. Here empirical downscaling gives larger warming rates. This may be caused by the fact that the dynamical model does not resolve ground inversions, which may be weaker under global warming. Concerning precipitation scenarios, an exception is that systematic differences are found during summer, when dynamical downscaling tends to project significant precipitation increase in larger areas. This may be caused by the fact that the present empirical downscaling model only includes changes which are linked to changes in the SLP field.

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The future wave and storm surge climate using Regclim's dynamical downscaled results, and the Arctic sea-ice climate using MPI's GSDIO climate

by

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Changes in the wave and storm surge climate may be of utmost importance to people living near ocean and coastlines. Therefore, some of the pressing questions that appear when talking of a global warming are whether or not this will give stronger winds, rougher wave climate or more devastating storm surges in the future. In an earlier work of Regclim by Bjørge et al 2000, possible future climate changes in Norway where studied, using a regional atmospheric climate model (HIRHAM). Here, this was carried out by means of dynamical downscaling of the MPI's GSDIO scenario from two time-slice periods, one representing the present (1980-1999) and the other representing the future (2030-2049) climate. To study what effects a warmer climate might have on the future sea state in Norwegian waters, the wind speed and sea level pressure from these regional simulations have been used to force a wave model and a storm surge model. Both the wave model (WAM) and the storm surge model (ECOM-3DH) are used on operational basis for daily wave and surge forecasts at DNMI and their credibility in this setting is known to be quite good.

The data have been analysed by utilising a linear regression analysis to calculate possible trends in the climate between the two periods. From this analysis we may also detect whether a trend is statistically significant or not. In this procedure, we look at different statistical measures, such as yearly or seasonal means, standard deviation or 99 percentiles of wind speed (FF), significant wave height (HS) and sea level (SL).

The main conclusions from the present study is that the predicted changes in both wave and storm surge climate are generally small and not statistically significant. However, there are some important exceptions. Figure 1a shows the trend in yearly mean HS and Figure 1b shows the level of significance from the analysis. Here, and in all plots of significance level, blue indicates a chance greater than 95%, and white a chance less than 80% for a trend different from 0. The general picture is small or insignificant changes in the wave-height for large areas, but with a minor increase along the West Coast of Norway. However, in the Barents Sea the increase is larger and is significant at a 95% level. In areas north and west of Iceland, and south of the British Islands the future wave height is decreasing. From the analysis it is evident that the regional distribution of HS closely follows that of the wind speed. However, changes in HS are generally less significant than changes in wind speed.

Of the four seasons, the most pronounced changes are found in autumn for wind speed, waves and storm surge. Figure 2 shows the trend in mean HS in autumn. There is an increase in wave height in the northern North Sea and westwards in the Atlantic with a decrease south of this region, but the figure is not statistically significant. This is in contrast to the mean wind speed that clearly shows the same trends significant at 95%

level. The regional distribution of trends in the 99 percentile of HS, which describes the extreme events, have much of the same tendency as the mean HS, with an significant increase in the Barents Sea and a decrease north and west of Iceland. Also, an increase in the 99 percentile for the North Sea during autumn, significant at an 85-95% level, is present. However, this increase does not dominate the yearly extreme statistics due to the fact that the most severe wind and wave climate occurs in the winter season. During that period, there is no significant trend in the data for this region. In contrast, for the Barents Sea, a large fraction of the increase is found in winter when the highest waves occur.

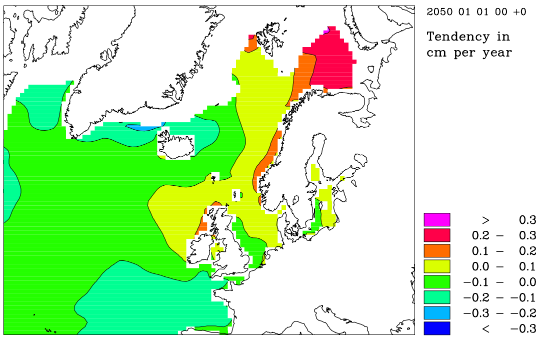

Fig. 1a: Trend (cm per year) of yearly mean HS.

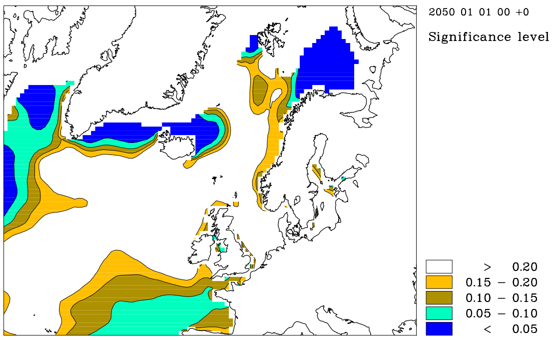

Fig. 1b: Level of significance for the trend in mean HS.

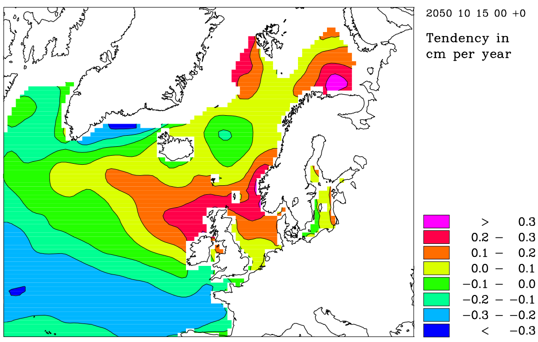

Fig. 2a: Trend (cm per year) in mean HS for autumn months.

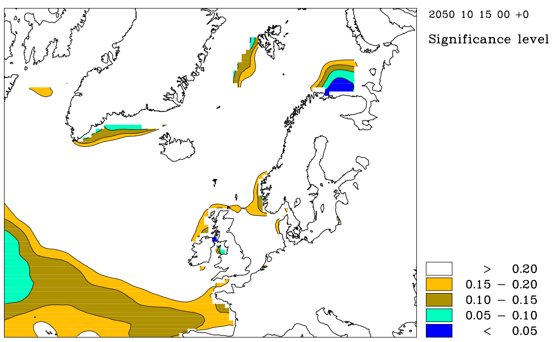

Fig. 2b: Level of significance for the trend in mean HS.

Except from a few offshore installations in the North Sea, storm surge is only important at the coastline, and mainly in low level, flat land areas around the North Sea. The problem of how a specific region is affected by a surge is highly set by the movement of the storm centre that generate the winds. Small changes in the direction of the winds may be crucial to whether a specific site experiences a high surge or not. The statistical analysis shows generally small and insignificant changes in the yearly 99 percentile of SL. However, there is a significant increase over large areas in autumn, but again, the most severe events are found in the winter season. Accordingly, the changes in the autumn extremes do not contribute much to the yearly extreme statistics. Figure 3 shows the trend in the yearly 99 percentiles of SL together with the significance level. Additional analysis of the 500 largest surge events in each time slice period confirms the picture of no significant changes to the surge climate.

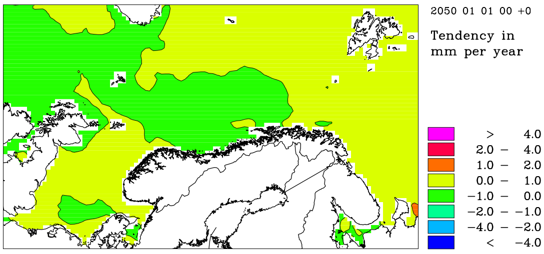

Fig. 3a: Trend (mm per year) in 99 percentile of SL for autumn months (SON).

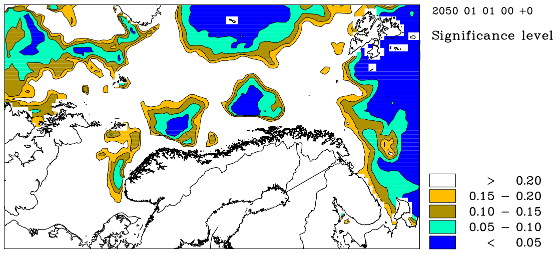

Fig. 3b: Level of significance for the trend in 99 percentile of SL.

This analysis of the changes in the wind, wave and surge climate draws a picture of rougher maritime conditions in the Barents Sea and along the coast of Troms and Finnmark. Much of the worsening occurs in autumn, winter and spring when these regions experience their roughest conditions already. However, we expect most of this change to be due to a large reduction in the sea ice extent taken from the global MPI-GSDIO simulation. Tests at DNMI with a coupled ice-ocean model system, show that the atmospheric output from the global MPI simulation gives a sea ice distribution in the Arctic for the present climate that are very different from results from simulations with reanalysed data (ERA15 + operational analysis) for the period 1979-1999. In addition, the analysis presented here is based on only one global scenario. Different global climate models give very different scenarios for the Arctic region and dynamical downscaling of a different global scenario is likely to give different results for this region. Therefore, the results for the Barents Sea and the areas around Svalbard should be considered as highly uncertain. Regional coupled atmosphere-ice-ocean models with high horizontal resolution are needed to better simulate the complex physical interactions in these regions. A considerable part of the ongoing work in Regclim at DNMI focuses on the development of such a coupled model system that should be used for dynamical downscaling of global scenarios from other climate models.

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Bjørge, D., J.E. Haugen and T.E. Nordeng (2000) *Future climate in Norway, Dynamical downscaling experiments within the Regclim project*. Research Report No.103. Norwegian Meteorological Institute

Regional climate modelling and international collaboration

by

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European decision-makers in government, non-governmental organisations (NGOs), and industry as well as the general public need detailed information on future climate. In this way it becomes possible to evaluate the risks of climate change due to anthropogenic emissions of greenhouse gases. Projections of future climate change already exist, but are deficient both in terms of the characterisation of their uncertainties and in terms of their regional detail. To date, the assessment of potential impacts of climate change has generally relied on projections from simple climate models or coarse resolution Atmospheric-Ocean General Circulation Models (AOGCMs), neither capable of resolving spatial scales of less than ~300km. This coarse resolution precludes the simulation of realistic extreme events and the detailed spatial structure of variables like temperature and precipitation over heterogeneous surfaces e.g. the Alps, the Mediterranean or Scandinavia. Simple models include, at best, a limited physical representation of the climate system.

A multiplicity of projects worldwide acknowledges this situation and regional climate models have been established in many centres to pursue this shortcoming and if possible add information at the regional scale. Many examples are given in the literature, that high-resolution models are able to resolve scales and processes relevant for the regional climate, which cannot be obtained by the course resolution models. A few examples of successful application of the HIRHAM model used at the Danish Meteorological Institute are compared to results produced directly by the driving GCM for illustration.

This general success has motivated the initiation of a large EU project, which seeks to improve the situation regarding simulations of climate change over Europe further. A project, which is coordinated by the present author. The project Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects – PRUDENCE is a European-scale investigation with the following objectives:

a) to address and reduce the above-mentioned deficiencies in projections;
b) to quantify our confidence and the uncertainties in predictions of future climate and its impacts, using an array of climate models and impact models and expert judgement on their performance;
c) to interpret these results in relation to European policies for adapting to or mitigating climate change.

Climate change is expected to affect the frequency and magnitude of extreme weather events, due to higher temperatures, an intensified hydrological cycle or more vigorous atmospheric motions. A major limitation in previous studies of extremes has been the lack of: appropriate computational resolution - obscures or precludes analysis of the events;

- long-term climate model integrations – drastically reduces their statistical significance;
- co-ordination between modelling groups – limits the ability to compare different studies.

These three issues are all thoroughly addressed in PRUDENCE, by using state-of-the-art high resolution climate models, by co-ordinating the project goals to address critical aspects of uncertainty, and by applying impact models and impact assessment methodologies to provide the link between the provision of climate information and its likely application to serve the needs of European society and economy.

Expected impacts:

PRUDENCE will provide a series of high-resolution climate change scenarios for 2071-2100 for Europe, characterising the variability and level of confidence in these scenarios as a function of uncertainties in model formulation, natural/internal climate variability, and alternative scenarios of future atmospheric composition. The project will provide a quantitative assessment of the risks arising from changes in regional weather and climate in different parts of Europe, by estimating future changes in extreme events such as flooding and windstorms and by providing a robust estimation of the likelihood and magnitude of such changes. The project will also examine the uncertainties in potential impacts induced by the range of climate scenarios developed from the climate modelling results. This will provide useful information for climate modellers on the levels of accuracy in climate scenarios required by impact analysts. Furthermore, a better appreciation of the uncertainty range in calculations of future impacts from climate change may offer new insights into the scope for adaptation and mitigation responses to climate change. In order to facilitate this exchange of new information, the PRUDENCE workplan places emphasis on the wide dissemination of results and preparation of a non-technical project summary aimed at policy makers and other interested parties.

Regional climate modeling in SWECLIM (The Swedish regional climate modeling program)

by

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The projections in the latest IPCC assessment indicate a substantial climate change during the next 50-100 years. E.g., a global mean warming of 1.4-5.8°C between 1990 and 2100, changing precipitation patterns and a global mean sea level rise are calculated. How the extreme aspects of climate will change (e.g. storms) is less well understood.

The observed global warming so far has been attributed primarily to the manmade emissions. Regionally, however, it is still difficult to separate any possible manmade contribution from natural variability. This is due to a lack of long homogeneous time series and, in particular, to the inherently larger regional climate variability compared to the global one.

In light of global scenarios, the manmade climate change will become visible even regionally during this century. However, as the resolution and thus the representation of regional climate systems in global models are limited by computational constraints, global scenarios are difficult to interpret in terms of regional climate change.

The difficulty in detecting regional climate change and the degree of ambiguity in regional-scale climate descriptions in global simulations represent a difficulty in national climate change adaptation and mitigation measures. Regional climate modeling and regional climate studies are ways of managing these obstacles.

In Sweden, regional climate scenarios and some time series analyses (hydrology, the Baltic Sea) are studied in the Swedish regional climate modeling program SWECLIM. The main tool is a regional climate modeling system that consists of coupled atmospheric (RCA), Baltic Sea (PROBE-Baltic, RCO) and hydrological components (HBV). The regional scenarios prepared have been useful in national discussions on climate change and the possible consequences.

SWECLIM regional climate scenarios

The Swedish regional climate modeling program (SWECLIM) climate simulations have so far been based on two global scenarios (HadCM2 and ECHAM4/OPYC3) in which the global mean temperature rises 2.6ºC. *A larger set of global simulations has been studied for an estimate of the range of global and regional climate change and an analysis how the specific SWECLIM-scenarios relate to the uncertainties. This is an important aspect in the communication of climate scenarios.*

The simulated temperature changes are substantially larger in the Nordic region than in the global mean. As the temperature increases, the growing season becomes longer and the snow season gets shorter. How soil frost will change is a more complicated issue as an increase in temperature and a decrease in snow cover give opposite effects. Other concretizations based on temperature have been made for aspects that matter for infrastructure such as roads as well as for the energy sector. *In general, an experience in SWECLIM has been that it is worthwhile to concretize regional climate scenarios into measures and diagnostics readily applicable and recognizable by end-users.*

Annual precipitation increases up to 20-30% in the western, northern and eastern parts of the region. A better measure for changes in water resources is the change in the net precipitation (precipitation minus evaporation). Increases are especially large in the fall in northern Fennoscandia whereas significant decreases are found in the summer in southern Sweden. The precipitation and snow changes increase the annual river runoff in the north and lead to a general tendency of decreasing peak floods in the spring and increasing peak floods in the fall. Water resources studies are an important area in SWECLIM.

Climate change impacts in the Nordic region

In the Nordic region, climate change is expected to impact forestry and water resources, agriculture, infrastructure and the environment, as well as e.g. fishing potential, road maintenance and uncertainty in the calculation of insurance policies. The energy sector will be affected in terms of both demand and production potential. Both negative and positive impacts on the energy sector can be expected. *The relative emphasis on specific climate change impacts varies from country to country which should be reflected in national research agendas.*

The issue of climate change certainly makes long-term planning more difficult. The vulnerability of the society is likely to increase. *Accurate projections of the timing and degree of climate change would be useful in designing and executing regional adaptation measures. The question is, can such projections be made?*

Lessons learnt from the development of the SWECLIM regional modeling system

The development of the SWECLIM regional climate modeling system is based on the operational weather prediction model HIRLAM. Rather than exchanging the physical parameterization package with one from a global climate model, work is undertaken to improve the operational schemes, part of the motivation being to network with the HIRLAM project. So far, the complete set of moist physics is replaced, with schemes designed for high-resolution simulations. The meteorological and surface, soil, soil water and snow routines are further developed, e.g. by tapping into experience on hydrological modeling. The model system is enhanced by incorporation of lake models, models for the Baltic Sea and regional river runoff.

The investment in model parameterization work is beneficial in furthering the skill in modeling the processes that act in the Nordic climate system. There are examples where the component models – even though seemingly performing well in offline simulation – are found to build on unfounded assumptions and principles. Coupled modeling provides for a method to remove hidden and compensating errors in the model components. This enhances the usefulness and applicability of regional climate models also in the calculation of climate scenarios.

Global climate models are and will be the principle climate projection tool. In a longer perspective, resolutions employed in global models and thus their representation of regional systems will certainly improve and eventually make regional models obsolete. However, more computing resources alone will not be enough to meet that goal. The global model process parameterizations and model couplings need to be redesigned, redeveloped and revalidated for higher-resolution simulations. This is an area where regional modeling today already contributes. And, of course, in the meanwhile the need of regional-scale climate scenarios for impact analyses and to support climate-related planning and decision-making will only increase in urgency. Regional climate modeling serves a purpose.

Uncertainties associated with climate scenarios

by

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The future emissions of greenhouse gases are not known, and climate models must used scenarios for these. This implies that there the scenarios in principle will be uncertain. Furthermore, the climate models are not "perfect" and may be biased because of model shortcomings. There is always a risk that not all relevant processes are taken into account by the climate models. There are also indications that processes such as cloud physics and their interaction with radiation, aerosols, ocean dynamics, landscape changes, biological processes, and sea-ice description are inadequate for the task of making future climate projections. The models' initialisation may also affect the response to a climate perturbation. One problem is that the state of the pre-industrial climate is unknown, and therefore the climate models' initial state may be wrong. Fig. 1 gives a specific illustration of diverging model description of the present-day conditions over the Nordic Seas and the Arctic. Different scenarios produced with different climate models and using different spin-up strategies tend to give different projections for the climate. The scenarios derived from these climate models are therefore accompanied by a degree of uncertainty, even if the emission scenarios were correct.

The climate models have in the past suffered from a mis-match between the oceanic and atmospheric components, which has resulted in an artificial climate drift. One way to cope with such climate drifts has been to introduce a fudge factor known as "flux correction" where fluxes had been added or subtracted, depending on the location, in order to get a stable climate. Such a flux correction is equivalent an imposed horizontal energy and fresh water transport. Hence, flux-corrected models are artificially constrained to present-day climate. This means that they may not be suitable for studies of local and regional features, such as how the ocean circulation may react to a global warming. Moreover, flux-corrected climate models may not be the right tools for studying changes to the thermohaline circulation. More recent climate models have eliminated the need for flux correction, partly as a result of improved resolution in the oceanic models. These are more promising in terms of describing the thermohaline circulation. But, Fig 1. shows that the climate models without flux correction tend to give a less realistic description of the present-day climate. In this comparison it is only the flux-corrected ECHAM4/OPYC3 GSDIO scenario that produces realistic conditions.

The global climate scenarios can be used to make inferences about future local climates through various (post-process) downscaling strategies. It is important to keep in mind that the global climate models are not designed to describe the climate on a local scale, and past studies have suggested a considerable spread between local scenarios produced using different climate models. But, it may nevertheless be possible to reduce the uncertainty associated with the local and regional scales if one may uses the relationship between large-scale climatic anomalies and the local variations to infer local climate change. The downscaling process, in essence, adds information about relationships between large and small scales to the global scenarios. Fig. 2 provides one example where 3 state-of-the-art climate models produce different scenarios for the Arctic summer. It can be shown that the warming rate in the Arctic is highly sensitive to the sea-ice extent (see poster by Benestad et al.), and much of the differences in the projected warming rates can be related to different sea-ice histories, in addition to the global climate sensitivity.

The post-processing step may introduce further errors, as nested dynamical modes and statistical analyses do rarely give a perfect description of this additional scaling information. One question is what large-scale spatial scales to use for the downscaling. Larger spatial scales may be associated with lower uncertainties according to S. Grotch & M. MacCracken (1991). But larger spatial scales also place more stringent requirements on the climate models and the observational data, and the correlation between large-scale anomalies and the local variability tends to diminish with the size. It is important to study the relationship between the spatial scales and the estimated local climatic trends. Fig. 3 shows the results from such study based on two different methods: common EOF downscaling (black crosses) and a more conventional PerfectProg type approach (grey circles) (From Benestad, 2001). If the results are robust, then the trend estimates ought to be insensitive to the domain size (D1 smallest, D6 largest). We see from this comparison that the choice of analysis (downscaling) may affect the results, and add to the uncertainty.

Further sources of uncertainty include natural variability that affects trend estimation. Long time series are needed to reduce the effect of these internal variations. There is also some uncertainty associated with the effect of changes in the sun (solar activity) and the effect on earth's climate, however, this is not believed to play an important role for the time scales associated with the enhanced greenhouse warming.

It is important to be aware of the various kinds of uncertainties associated with the climate scenarios. In order to achieve this, the model output describing the period "1860"-"2000" can be evaluated against observations. The models must demonstrate that they can reproduce the past climatic evolution if they are to make credible projections for the future. Therefore, model evaluation is an important part of climate change studies. Model evaluation may also be incorporated into empirical downscaling (Benestad, 2001) or implemented through "finger printing".

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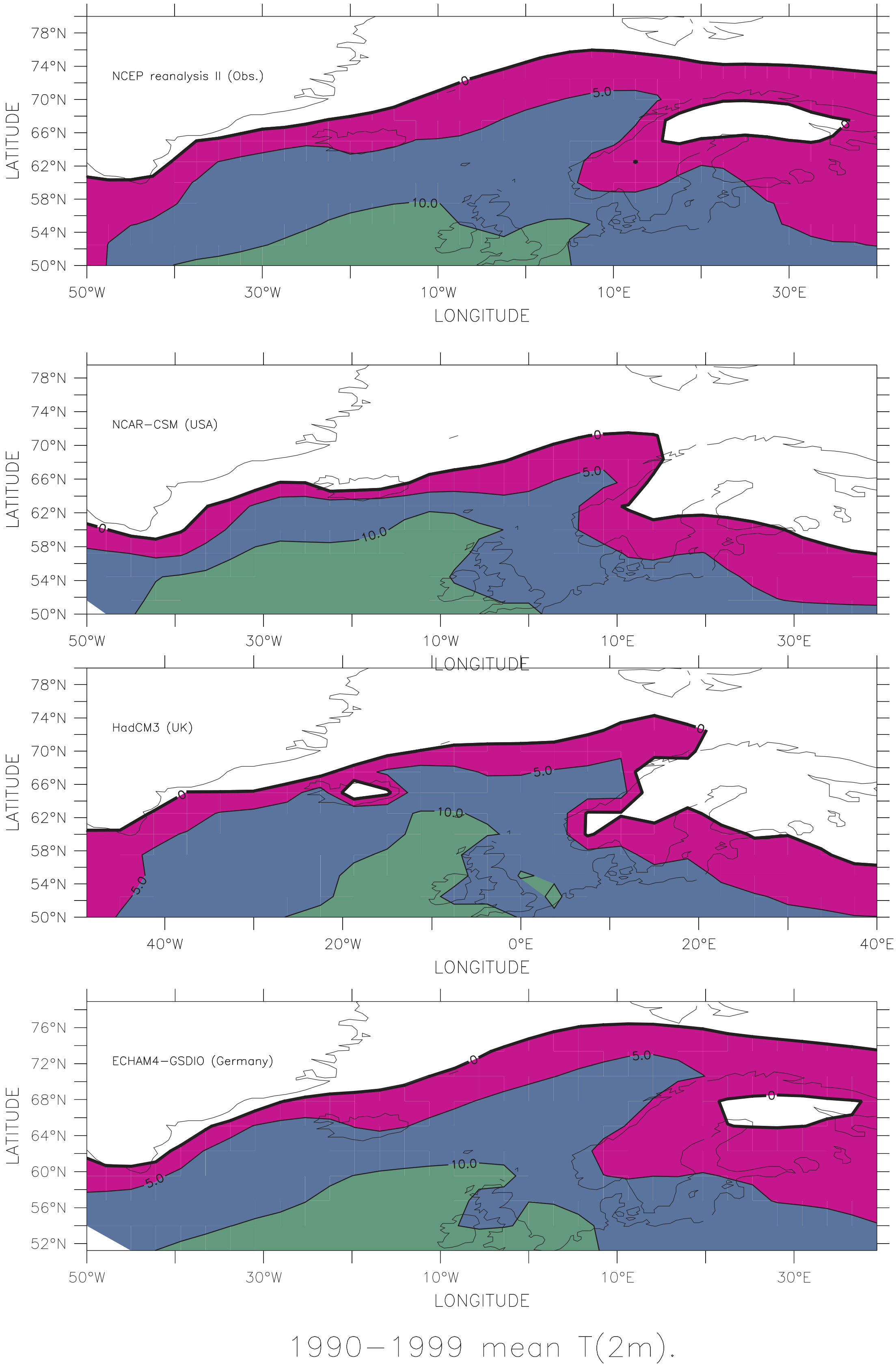

NCEP reanalysis II (Obs.)
NCAR-CSM (USA)
HadCM3 (UK)
ECHAM4-GSDIO (Germany)
LATITUDE
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Fig. 1.

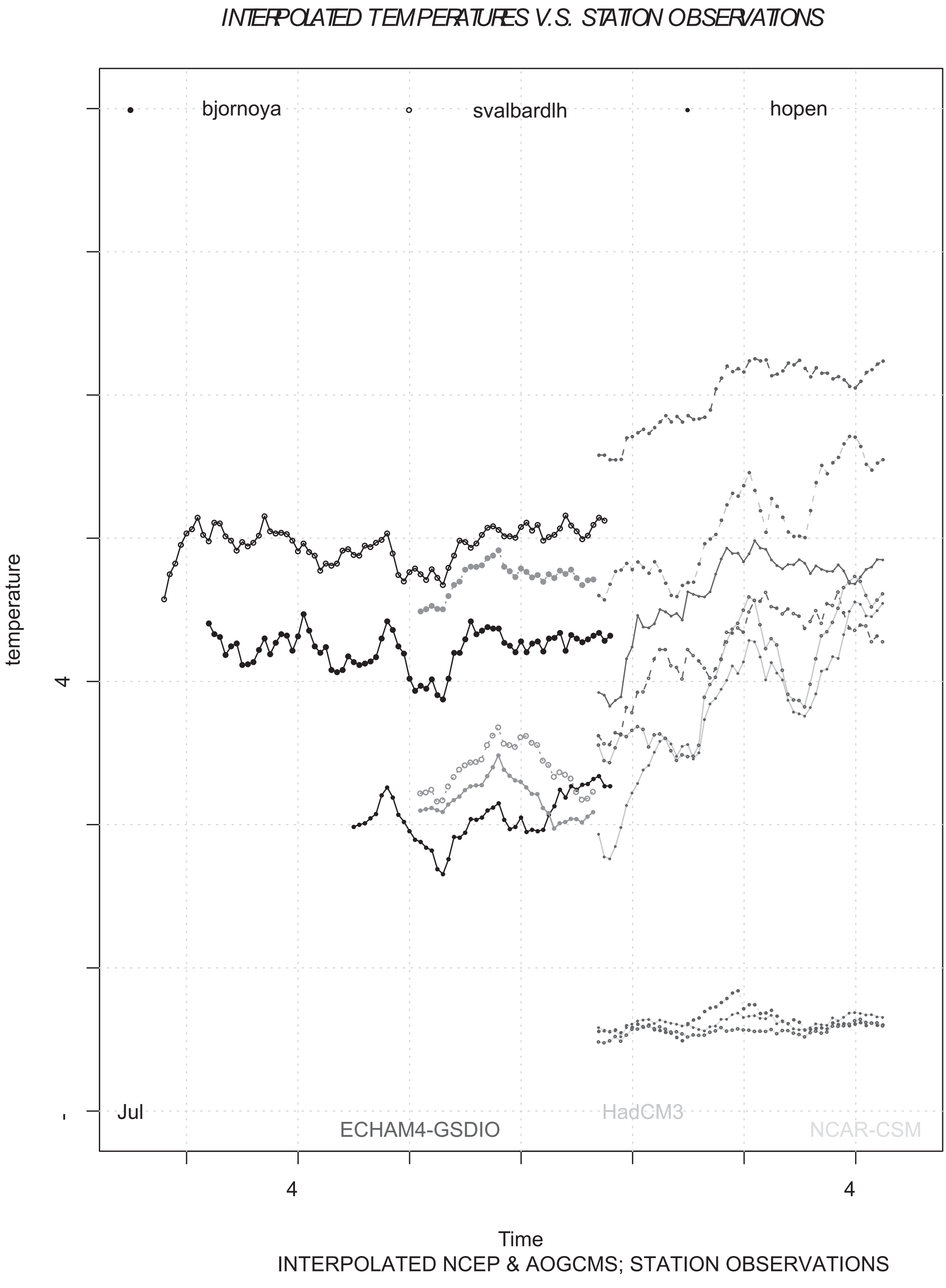
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Fig. 2.

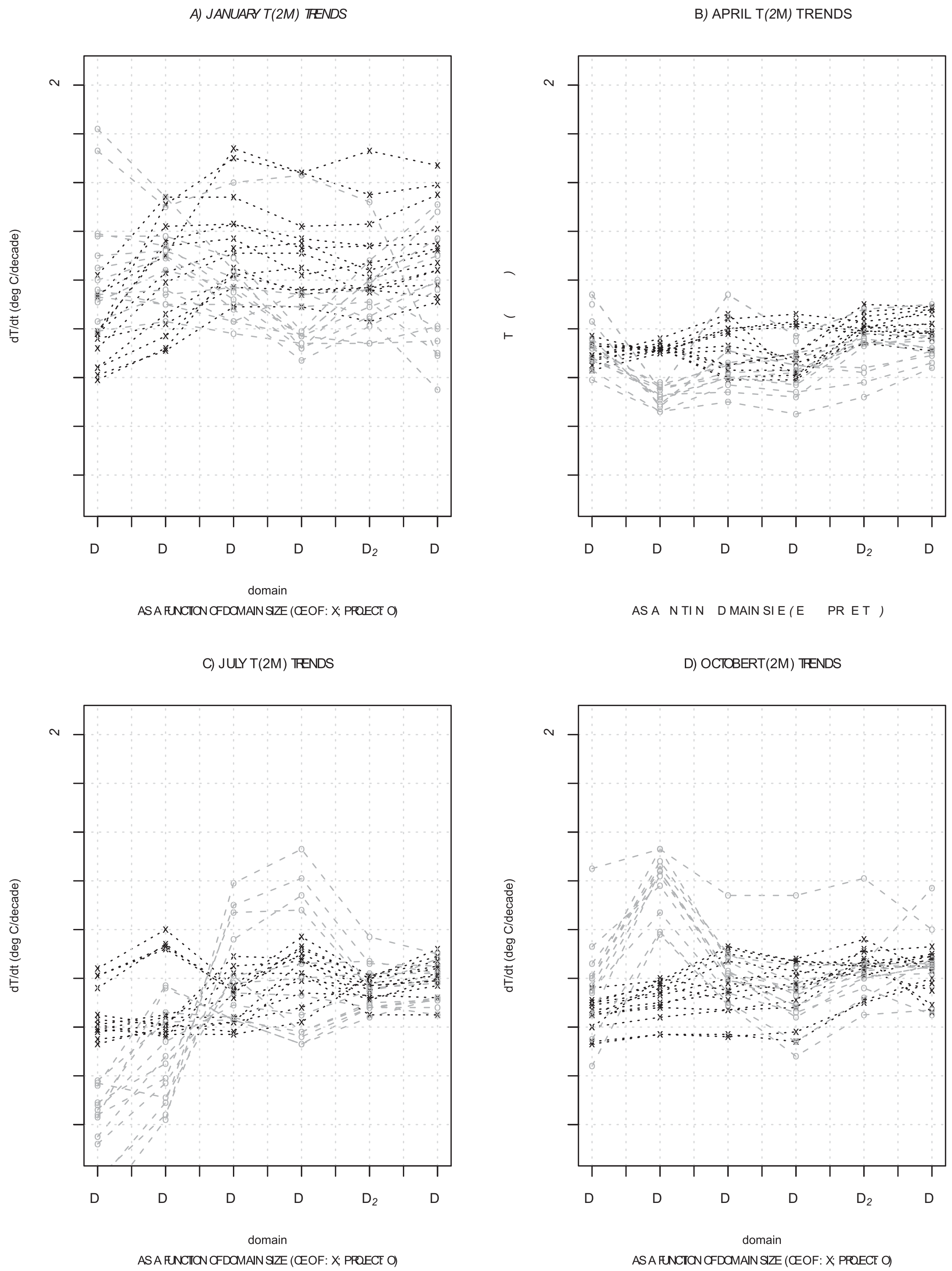
A) JANUARY T(2M) TRENDS
B) APRIL T(2M) TRENDS
C) JULY T(2M) TRENDS
D) OCTOBERT(2M) TRENDS
dT/dt (deg C/decade)
2
D
D
D
D
D2
D
domain
AS A FUNCTION OF DOMAIN SIZE (CE OF: X; PROJECT: O)

Fig. 3.

Key results from numerical simulations of the flow, hydrography and sea ice in the Atlantic-Arctic region for the present day climate

by

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The North-Atlantic-European climate, and then especially the winter climate, exhibits large scale spatial and temporal fluctuations. These fluctuations have been known for hundreds, and likely for thousands, of years. A description of the high latitude climate regimes is found in *the Kings Mirror* (*Kongsspegelen*), a Norse book written around year 1230, and the Norwegian priest Egede Saabye (1816) noted, based on his stay in Greenland between 1770-1779 the following: "*In Greenland, all winters are severe, yet they are not alike. The Danes have noticed that when the winter in Denmark was severe, as we perceive it, the winter in Greenland in its manner was mild, and conversely*".

A major challenge in present day climate research is to better understand the natural variability of the atmosphere-sea ice-ocean-land system. This is important since the major climate fluctuations, like the El Niño/Southern Oscillation or the North Atlantic/Arctic Oscillation, have direct consequences on society, economy and ecosystems. It is also of vital role to assess whether global warming may alter the characteristics and/or strengths of the major climate fluctuations. And as the knowledge of the climate system and climate fluctuations improve, the quality of seasonal to (possibly) decadal scale climate forecasts are expected to improve.

An interplay of long term and high precision observations of key climate parameters, a variety of proxy climate observations, theoretical considerations and numerical modelling are required to uncover the secrets of the natural variability modes of our climate system. In this presentation, special focus is put on some of the main features of the North Atlantic-Arctic ocean system.

The annual mean surface temperature in the eastern part of the Nordic Seas and over north-western Europe is 10-20 °C higher than the mean surface temperature at the same latitudes. The anomalous high surface temperature is mainly caused by the atmospheric gain of heat from the extension of the warm Gulf Stream current system. In most coupled atmosphere-ocean climate and climate change models, the horizontal grid spacing is rather coarse – typically 100-200 km for the ocean component. Given the complex topography in the North Atlantic-Arctic region, a deformation radius well below 100 km, small scale processes like convection, subduction, deep water overflows and subsequent entrainment of ambient water, intense heat and fresh water fluxes, formation and melting of sea ice, and frontal mixing of water masses of polar and tropical origins, it is an open question how accurate climate models need to be in order to describe the mean climate state and the natural fluctuations of the region.

The majority of the results to be presented are based on numerical simulations performed with the Nansen Center version of the Miami Isopycnic Coordinate Ocean

Model (MICOM). The model is truly global, it utilises a horizontal grid focus over the North Atlantic-Arctic sector (Bentsen *et al.*, 1999), and it is fully coupled to a dynamic-thermodynamic sea ice module (Drange and Simonsen, 1996). The model has been forced (Bentsen and Drange, 2000) with daily atmospheric NCAR/NCEP re-analyses fields for the period 1948-2000, after a decadal to centennial spin-up period based on monthly mean climatological forcing fields derived from the NCAR/NCEP re-analysed products. To examine the model sensitivity to the horizontal resolution, three versions of the model have been adopted: One with 80 km, one with 40 km and one with 20 km grid spacing in the central northern North Atlantic. In addition, the impact of the actual model state at the beginning of the hind cast integration period (at Jan 1, 1948) have been examined by integrating the coarse resolution model with three widely different model states.

In the presentation, the simulated mean thermodynamic and dynamic ocean climate will be compared with some of the available observations from the region. This comparison show that the various model versions are able to simulate the main features of the observed ocean state. In particular, the mass and heat transports and sea ice thickness and extent are well reproduced.

The simulated ocean response to high and low atmospheric NAO states is addressed next. The basin scale patterns and magnitudes in sea surface temperature, sea surface salinity, upper ocean mixed layer depth, sea ice thickness and extent, and barotropic mass transport will be presented and compared with observations as far as possible. Special attention will be put to the temporal evolution and the location of the maximum circulation cell of the North Atlantic meridional overturning stream function. It will be shown that the obtained temporal and spatial *fluctuations* are insensitive to the actual initial state and the horizontal grid resolution of the ocean model. However, the *magnitude* of the overturning increases as the horizontal model resolution increases. The latter result indicates that the horizontal ocean resolution in coupled atmosphere-ocean climate models need to be assessed.

The presentation will be closed with a few comparisons of the variability of the NCAR/NCEP forced ocean model to the fluctuations obtained during a 300 years control integration with the same ocean model coupled the ARPEGE/IFS atmosphere model (Furevik *et al.,* 2000).

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On the role of the Labrador Sea in controlling the North Atlantic Oscillation

by

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The atmospheric response to sea surface temperature and sea-ice anomalies in the Labrador Sea has been investigated by means of an AGCM. The simulated response shows a North Atlantic Oscillation (NAO) pattern in the low-level pressure field, with low temperatures and heavy ice conditions in the Labrador Sea being associated with a low NAO index. The result indicates that atmospheric response to changes in the sea ice and sea surface temperatures in the Labrador Sea constitutes a negative feedback, which may cause phase shifts in NAO. The results also indicate that changes in sea ice cause changes in the low level baroclinicity. The altered low level-structure perturbs the traveling baroclinic disturbances, which bring the signal downstream and manifests itself as a non-local response. In the case with reduced sea ice extent in the Labrador Sea, the diagnostics presented here indicate that a significant part of the decaying cyclones entering the Labrador Sea area are regenerated and decay farther downstream instead. Also, reduced sea ice conditions in the Labrador Sea invokes increased cyclogenesis downstream (or east) of the induced anomaly. This increases the baroclinic activity in the poleward part of the North Atlantic storm track and is associated with a high NAO index. Heavy sea ice conditions in the Labrador Sea inhibits regeneration of cyclones here. Also, these sea ice conditions reduce the cyclogenesis activity east of this area. These conditions are associated with a low NAO index.

Radiative forcing due to tropospheric ozone and aerosols, including historic evolution

by

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[1] Norwegian Institute for Air Research
[2] University of Oslo

Several studies of the radiative impacts of changes in tropospheric ozone and aerosols have been made by groups at NILU and the University of Oslo as a part of RegClim. In Berntsen et al. (1999) we estimated the time evolution of the tropospheric ozone change since industrialisation, and found that the present total tropospheric ozone burden is up to about twice the preindustrial burden. Plate 1 shows the change in the geographical distribution of the radiative forcing due to increase in ozone caused by emissions of ozone precursors. The results depict radiative forcing at several points in time, namely 1900, 1950, and 1990, with 1850 as a reference year. The results have been normalised to the maximum annual mean radiative forcing , which was 0.11, 0.29 and 0.86 Wm^{-2} for the three years, respectively. The spatial patterns in 1900 and 1950 are very similar with maximum forcing over the Mediterranean and relatively large values also over a large area over Europe, southern part of North America and the Atlantic Ocean. In 1990 the maximum forcing moved southward to the Arabian desert. The pattern is more zonal in 1990, except for an area around the maximum value. The time evolution of the global and annual mean radiative forcing from changes in ozone due to emissions of ozone precursors are shown in Figure 1. The forcing in 1950 was about 1/3 of the present forcing, whereas between 1950 and 1990 there has been a nearly linear increase in the forcing. The linear increase in this period is somewhat coincident as the development of regional forcings is less linear. In Europe and North America the increase was largest up to 1970 and weaker thereafter, whereas the forcing in South East Asia has even been strengthened after 1970.

Another study (Myhre et al., 2000) focused on the evolution of the global and annual mean radiative forcing due to change in tropospheric ozone from 1980 to 1996 resulting from changes in surface emissions and aircraft emissions of ozone precursors, changes in photolyses rates due to changes in stratospheric ozone, and altered net transport of ozone from the stratosphere to the troposphere resulting also from changes in stratospheric ozone. The increased surface emissions of ozone precursors were found to be the largest contributor to the radiative forcing due to change in tropospheric ozone over the period 1980 to 1996. The pattern of the forcing is different from the forcing due to changes in tropospheric ozone from preindustrial times as a very large contribution in the more recent years is from South-East Asia and much smaller contributions are from Europe and North America. Effects of reduced stratospheric ozone on tropospheric ozone were estimated to give a negative radiative forcing in 1996 of almost -0.04 Wm^{-2}. Reduced transport of stratospheric ozone to the troposphere yields a forcing which is about three times larger than the effect of changes in the photolysis rates in the troposphere. This makes about 10% of the forcing due to change in tropospheric ozone since preindustrial times. However, the results show large interannual variation for the effect of reduced stratospheric ozone. The largest effect of reduced stratospheric ozone on the radiative forcing due to tropospheric ozone is at high latitudes.

A few studies have also been made of the radiative forcing due to aerosols, with main emphasis on sulphate. In one study a high resolution regional model for sulphate aerosols was used to investigate the effects of spatial and temporal averaging of radiative forcing. Mie theory was used to calculate the aerosol optical properties. The strong hygroscopic growth with increasing relative humidity was the main focus. The results for the regional area selected in our study (Europe and much of the north Atlantic) show strong regional gradients in the cooling due to sulphate aerosols (Plate 2). Further, our results suggest that earlier global studies may have underestimated the magnitude of the radiative forcing due to sulphate aerosols by up to 30-40% due to coarse spatial and/or temporal resolution (see Figure 2 for the horizontal resolution), at least over certain regions. This underestimation in global models of the water uptake is important for all strongly scattering hygroscopic aerosols. Our results imply that representation of relative humidity at even higher spatial resolution than used in our study may be of importance. This could be incorporated in models using sub-grid scale parameterisations of the relative humidity.

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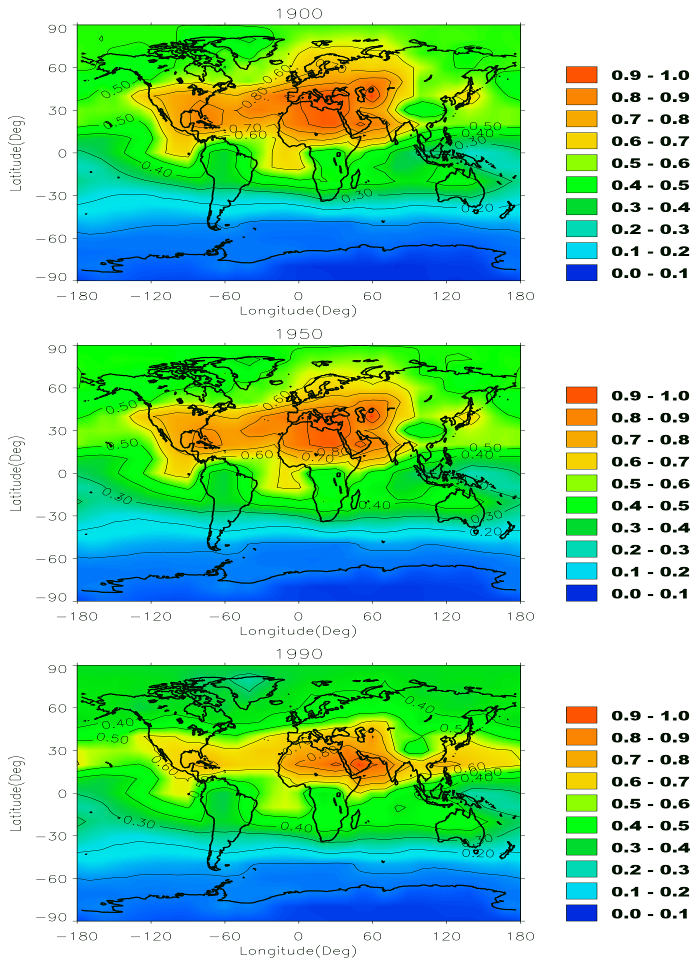

Plate 1: Annual mean radiative forcing due to change in tropospheric ozone since 1850 normalised to the annual maximum forcing. Results are given for 1900, 1950, and 1990.

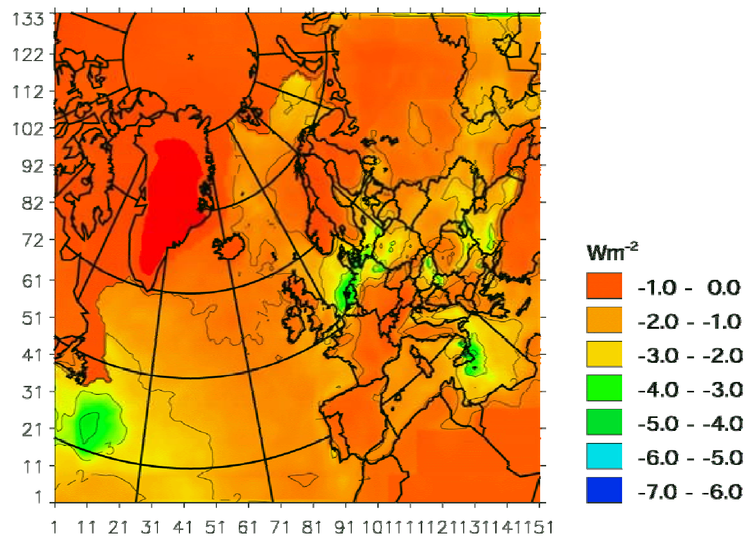

Plate 2: Annual mean radiative forcing due to sulphate (in Wm^{-2}) adopting a high spatial resolution in the calculations.

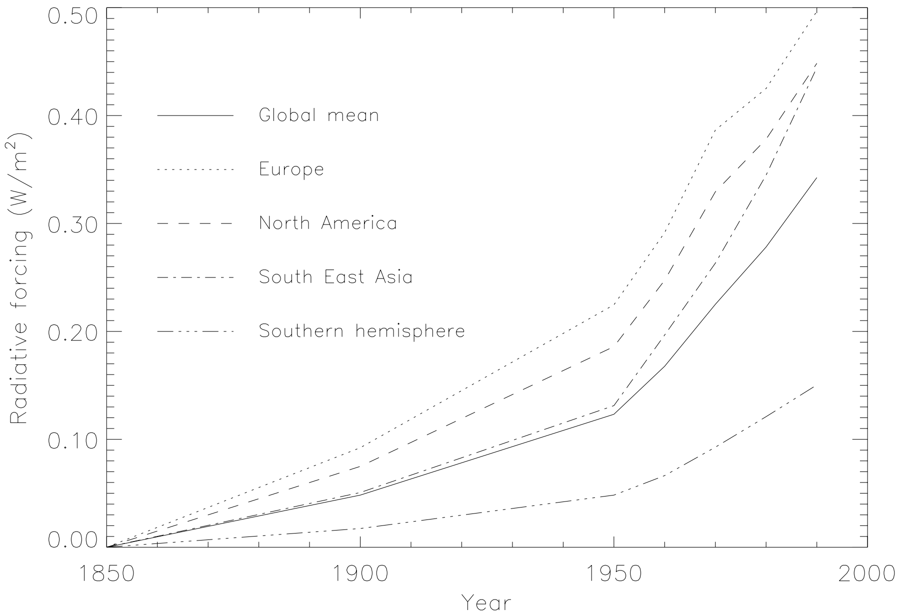

Figure 1: Time evolution of the radiative forcing, for global mean, Europe, North America, South East Asia, and the southern hemisphere. Values are given in Wm^{-2}.

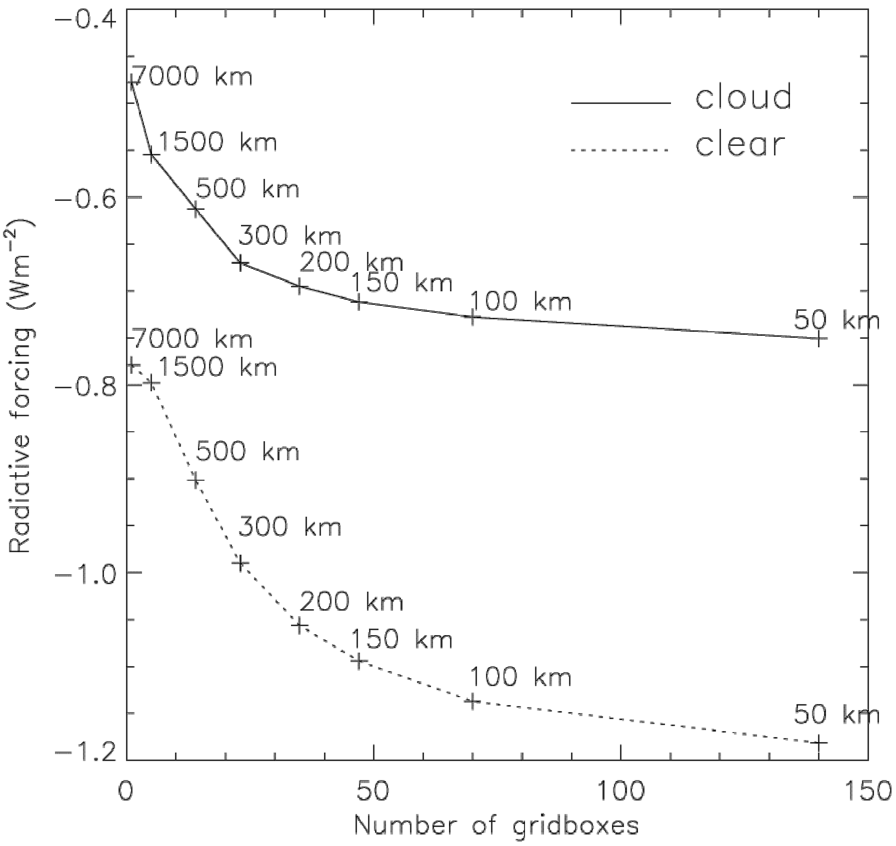

Figure 2: Radiative forcing due to sulphate (Wm^{-2}) as a function of horizontal resolution. Radiative transfer calculations are performed for horizontal resolution marked with +. The resolution is indicated (in km). “Clear” indicates that clouds are excluded in the calculations and “cloud” indicates that clouds are included.

Direct and indirect effects of sulfate and black carbon aerosols estimated from a mechanistic life-cycle scheme in the NCAR CCM3

by

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In order to estimate the impact of anthropogenic aerosols on regional climate, an aerosol-cloud module has been developed and implemented in the NCAR CCM3 global climate model. The focus is on two aerosol types, sulfate (SO_4) and black carbon (BC). A mechanistic life-cycle scheme, consisting of various chemical and physical processes, is used to calculate the conversion of DMS, SO_2, SO_4 and BC, emitted from natural and anthropogenic sources, into particulate SO_4 and BC. A size-segregated background aerosol is assumed, consisting of naturally occurring sea-salt particles over ocean and mineral and "water-soluble" particles over land. The background aerosols are combined with the sulfate and BC, accounting for condensation, coagulation, in-cloud oxidation and hygroscopic growth. The nucleation mode particles are assumed externally mixed, while internal mixture is assumed for the accumulation mode particles. Figures 1a,b show the column burdens of sulfate and BC averaged over the last 3 years of a 5-year simulation, using emission data for the year 2000 from IPCC as input. Since almost 80% of the sulfate is anthropogenic, the largest concentrations are found over SE Asia, followed by Europe and eastern North America (Fig.1a). Black carbon has a fairly different horizontal distribution (Fig.1b), mainly because biomass burning is a major source of these aerosols.

The radiation and cloud parameterization schemes of the NCAR CCM3 have been modified to allow calculations of the radiative forcing of anthropogenic aerosols, both directly and through changes in cloud radiative properties. Thus, cloud droplet radii are now calculated from the size-segregated aerosols, by making appropriate assumptions on the subgrid scale supersaturations. These droplet sizes are then used in the calculations of cloud albedo and the calculations of precipitation release. Multi-year simulations have been carried out, using the sulfate and BC fields from the life-cycle model as input. The direct effect (Fig.2a) shows maxima of more than 1 W/m^2 over central Africa due to absorption of solar radiation by BC from biomass burning, while significant cooling due to anthropogenic sulfate is found over SE Asia, eastern N-America and southern Europe. The indirect effect (Fig.2b) is negative everywhere, having a global average of -1.83 W/m^2, as compared to -0.11 W/m^2 for the direct effect. The largest indirect effect is found over SE Asia, followed by central Africa and the western North Atlantic. Corresponding results using estimated emissions for the year 2100 (IPCC Scenario A2) show enhanced warming due to BC, while the indirect cooling effect of sulfate is shifted towards lower latitudes (not shown). Consequently, the globally averaged direct effect is now $+0.11$ W/m^2, while the indirect effect is virtually unchanged at -1.85 W/m^2. In-depth analyses of these results, as well as highlights from various sensitivity experiments will be presented at the conference.

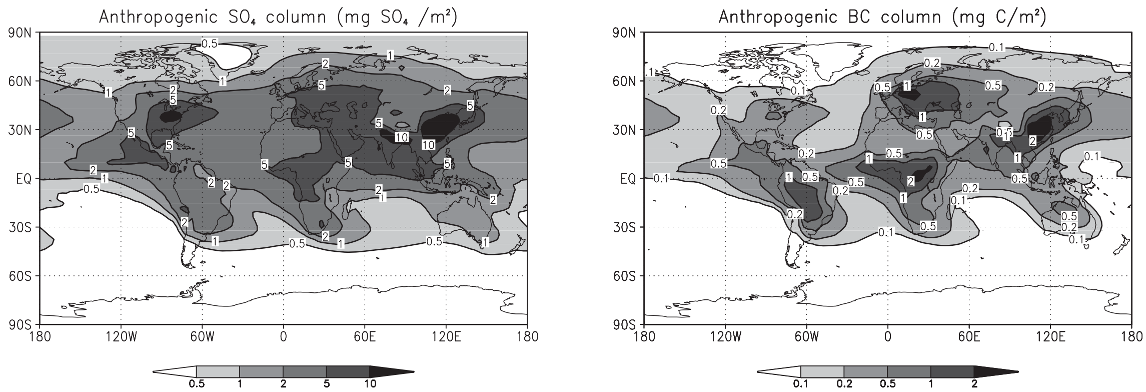

Fig. 1. a) Simulated column burden of anthropogenic sulfate in the year 2000. b) Simulated column burden of anthropogenic black carbon in the year 2000.

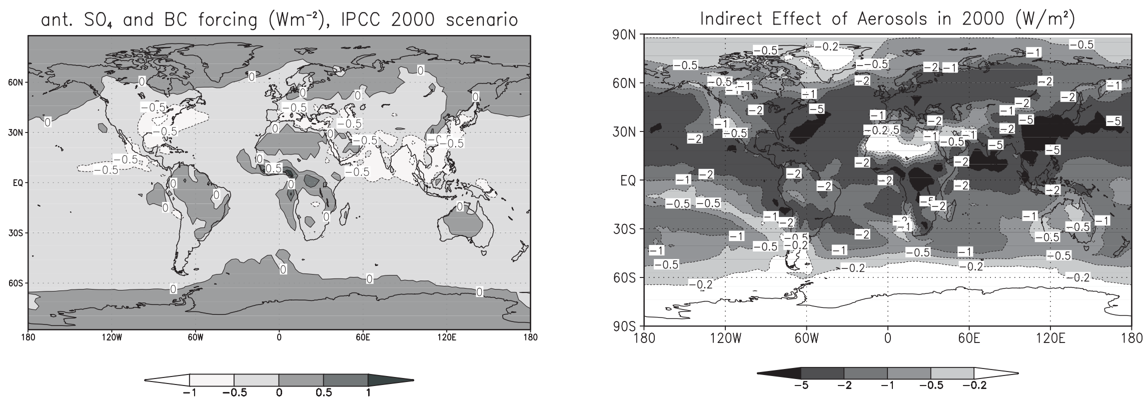

Fig. 2. a) Direct effect in the year 2000. b) Direct effect in the year 2000.

Abstracts of poster presentations

Late Glacial and Holocene glacier fluctuations in Lyngen, Troms, northern Norway

by

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The area north of the Kjosen fjord on the Lyngen Peninsula is mapped focused on glacial geomorphological features, and 13 cirque glaciers and their catchments are investigated in detail. The four lakes Aspevatnet (Holocene glacier fluctuations), Barheivatnet (bio-proxy lake), Elvejordsvatnet (Holocene glacier fluctuations) and Trollvatnet (early deglaciation, Holocene slope processes) are investigated and bathymetric maps produced. Based on the preliminary laboratory analyses it is possible to reconstruct detailed Holocene glacier fluctuations on glaciers with aspects both to the east and west on the Lyngen Peninsula.

From lake Aspevatn at the western side, it seems possible to reconstruct at least 14 local glacial events during the last c. 10 200 cal. yr BP (basin isolated from the sea). Some major glacial events are recorded during the Preboreal, while the glaciers seem to have advanced due to an increase in winter precipitation (as snow) during the Holocene climatic temperature optimum. The final neo-glaciation(s) started c. 3800 cal. yr BP with a marked maximum in the late 18-century. The reconstructed TPW-ELAs for the Aspevatn catchment are situated at altitudes of 790 to 1200 m. By using radiocarbon dated shorelines as age control, it is possible to date reconstructed valley glaciers with fossil ice-cored moraines in front, existing from c. 16000 to 11500 cal. yr BP (termination of the Younger Dryas). These glaciers are reconstructed with TPW-ELAs situated between 130 and 650 m when adjusted for land uplift. As these glaciers most likely existed in a cold and dry climate regime, they are suggested to have been polythermal (subpolar).

The preliminary results show that there is a great potential for reconstructing the complete glacial history of the northern Lyngen Peninsula from the early deglaciation after the LGM to at present. This is so far the northernmost complete Holocene glacier record in Scandinavia.

The Bjerknes Collaboration for Climate Research

by

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In 2000, the University of Bergen (UoB), the Nansen Environmental and Remote Sensing Center and the Institute of Marine Research formally agreed to establish the *Bjerknes Collaboration for Climate Research* with the aim at developing a climate research unit in Bergen. The vision of this joint venture is the furtherance of knowledge of past, present and future climate change with emphasis on the North Atlantic and the Arctic regions. Scientifically it focuses on ocean-ice-atmosphere climate processes, coupling of high latitude marine and terrestrial climates, and on past, present and future climatic evolution of the North Atlantic, the Nordic Seas, the Arctic Ocean and surrounding regions.

The operational organisation of the *Bjerknes Collaboration* builds upon an integration of the partner's scientific expertise into four collaborative teams, each around a sub-discipline as follows: (i) Climate processes in the ocean and ocean circulation; (ii) coupled ocean-ice-atmosphere processes and modelling; (iii) Paleoclimates; and (iv) Oceanic carbon and biogeochemical cycles. Within and across these sub-disciplinary teams the research is organised in joint projects. Current activities total about 50 man-years of scientific work and approximately 25 million NOK in externally funded projects.

The administrative organisation will be in charge of UoB´s newly established *Bjerknes Centre for Climate Research*. The Centre functions as the Secretariat for the *Collaboration* and will take care of the day-to-day administration of the activities, serve as a channel of communication within and outside the community and as well as organize all externally funded climate research. The Center will also network extensively with leading national and international centres and research groups.

In addition to the scientific scope, the *Collaboration* will have an academic, social and political mission as well. This will build upon: (i) research training and capacity building of young scientists and students, (ii) dissemination of results to assist in climate impact analyses for policy makers and socio-economic decisions, and (iii) outreach activities to enhance public awareness.

The Bjerknes Collaboration: Scientific Highlights

by

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NAO regulates glacier dynamics in Norway

The North Atlantic Oscillation (NAO) is one of the most important modes of climate variability in the North Atlantic region. NAO in negative modes results in colder winters in northwestern Europe while NAO in positive mode results in stormy, mild and rainy winters. Scientists from the Bjerknes Collaboration (Nesje et al. 2000) have found that there is a direct correlation between the modes of NAO and the mass development of maritime glaciers in southern Norway: the glaciers expand during NAO in positive mode while the glaciers shrink when NAO turns negative. An example of this correlation is shown for a maritime glacier in southern Norway, the Briksdalsebreen, a western outlet glacier from Jostedalsbreen. It is shown that the glacier expanded noticeably between 1993 and 1997, during several years of positive NAO index. These findings allow reconstructing NAO variations previous to instrumental records from glacier dynamics.

Source: Nesje, A., O. Lie, and S.O. Dahl. 2000. "Is the North Atlantic Oscillation reflected in Scandinavian glacier mass balance records?" *Journal of Quaternary Science* 15(6): 587-601.

Is global warming affecting ocean circulation?

The Nordic Seas connect the North Atlantic with the Arctic Ocean and thus play a leading role in the large-scale world circulation. Warm and salty surface waters from the North Atlantic reaching these latitudes during the winter are cooled and sink to great depths, a process called deep-water formation. This dense, cold water pours into the depths of Atlantic through submarine channels in the Denmark Strait and the Iceland-Scotland Ridge. From there, it starts its journey southwards, creeping along the ocean floor, where it joins newly formed cold deep water in Antarctica.

A team of scientists including researchers from the Bjerknes Collaboration (Hansen et al. 2001) have monitored the overflow in the Faroe Bank Channel, the deepest passage across the Greenland-Scotland ridge and responsible for about 1/3 of the total flow to the Atlantic Ocean. The monitoring combines high-quality current measurements and long-term hydrographic observations from a stationary ship. The monitoring has revealed that a substantial drop in the overflow through this passage has occurred in the past 50 years, i.e. the overflow is nowadays at least 20% less compared to 1950.

Why is this happening and what will be the consequences of less deep water flowing from the Nordic Seas to the Atlantic? Unless more water is flowing out of the Denmark Strait to compensate for this reduction, then one should expect less inflow of surface warm Atlantic water into the Nordic Seas. If this happens, then one could expect major consequences for the global ocean circulation. On a regional scale this would affect the climate of northwest Europe.

Source: Hansen, B., W. R. Turrell and S. Østerhus. 2001. "Decrease of the overflow from the Nordic Seas into the Atlantic in the Faroe Bank Channel since 1950." *Nature* 411: 927-930

Role of ice-ocean-atmosphere processes in high-latitude climate change: A Bjerknes/Marie Curie Training Site

by

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The Bjerknes Training Site at the University of Bergen facilitates short stays (3-12 months) to PhD students from member states of the European Union pursuing doctoral studies in dynamic geophysical processes inherent in high-latitude climate. The site is established with support from the European Union's 5th Framework Programme for Research "Marie Curie Fellowships" to help training and mobility of researchers in order to improve the human research potential and the socio-economic knowledge base.

The research

The Bjerknes Training Site offers doctoral students hands-on-training in high-latitude climate problems. The experience and research opportunity covers *in situ* oceanographic data collection from research vessels as well as application of remote sensing data and coupled atmosphere-ice-ocean models. Topics span from small scale boundary layer studies to large scale interactions, carbon cycling and palaeoclimate. The doctoral training will provide a better understanding of the dynamic geophysical processes inherent in high-latitude climate variability, climate response to external forcing and links to lower latitudes.

The facility

The Bjerknes Training Site consists of an interdisciplinary research team of academic scientists from the following institutions (i) the University of Bergen´s Geophysical Institute and Department of Geology, (ii) Nansen Environmental and Remote Sensing Center, and (iii) University Courses on Svalbard. The site offers expertise in the methodologies of collection and analyses of *in situ* data, remote sensing and numerical modelling.

Benefits and impact

European doctoral students will benefit intellectually from participation in interdisciplinary research on high-latitude climate change processes. The experience gained in this expanding field of research will add to the candidate´s range of skills. Exposure to international research teams involved in the training site will also promote the future mobility of the candidate.

For more information please contact:

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or

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http://www.bjerknes.uib.no/mcts.

Svalbard: the importance of sea-ice and future climate scenarios

by

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The role of sea-ice for the local climate in the Svalbard region is investigated using observed temperature records from Arctic climate stations and gridded sea-ice data. The coupling between sea-ice and sea level pressure as well as 2-meter temperature is also examined. The quality of the sea-ice product from the HadISST1.1 project is evaluated in relation with variations in the sea level pressure, 2-meter temperature fields, and climate station temperatures from the Arctic. Furthermore, the gridded sea-ice analysis is compared with the 1990's climate described by 3 atmospheric-oceanic general circulation models.

The analysis indicates that there is a close connection between the sea-ice extent and the local climate in the vicinity of Svalbard. The land temperature is sensitive to the location of the ice-edge. The good fit between the sea-ice and other climate variables since 1950 indicates that the sea-ice product is accurate for this recent period. But there are indications of severe degradation of the sea-ice data quality prior to the 1950s. The reduction in the quality is attributed to sparse observations. The comparison between 3 state-of-the-art climate models shows that there are important differences in their description of the Arctic climate, with a more than 10 degree difference in the location of the ice edge.

Empirically downscaled climate scenarios are presented for Svalbard and its vicinity, based on mixed 2-meter temperature and sea level pressure fields. The scenarios are derived using the large-scale fields from the ECHAM4-GSDIO, HadCM3, and NCAR-CSM climate change experiments, and utilizing common empirical orthogonal functions.

There are substantial differences between the scenarios derived from the various models. Those downscaled from the HadCM3 model indicate significantly stronger warming than those based on the ECHAM4-GSDIO and NCAR-CSM models, which describe weaker temperature trends. Much of these differences can be explained in terms of the different descriptions of the sea-ice extent. The sea-ice in the HadCM3 scenario is subject to a substantial retreat in the Barents Sea, whereas there is no melting in the same region in the NCAR-CSM model.

Late Holocene variability in THC; evidenced from the Norwegian margin

by

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The thermohaline circulation (THC) has a large influence on the North European climate. Warm and saline Atlantic waters flows northward into the Norwegian Sea basin where it follows the contours along the continental margin off Norway. Core P1-003-MC/-SC was retrieved in the Ormen Lange area on the Norwegian margin, at 851m water depth close to the lower boundary of the Norwegian Current (NC). The surface sediment deposited in this area is reflecting the ocean currents. The NC is winnowing the outer shelf and upper margin down to ca 700 m depth. Below this the sediment is relatively fine grained and becomes finer at deeper depths. The sediments at the core locality are mainly fine-grained (silt and clay) with small percentage sand reflecting the proximity to the NC. This transition zone between the cold deep water and the NC has a wave shaped structure with considerable vertical movement. The temperature increases at the core locality is reflecting Atlantic waters migrating towards deeper depths. Atmospheric low-pressure increases have been associated with an intensified vertical movement of waters in the transition zone, and hence increase in periods with high bottom currents at the site.

The aim has been to study the variability in geometry and the temperature of the Norwegian Current wedge. As a proxy for the depth of the transition zone we use grain size and benthic foraminifer assemblage data. We have measured stable isotopes on two planktonic foraminifera species *Neogloboquadrina pachyderma* (dextral) and *Globigerina bulloides* as a proxy for sea surface temperature (SST). To evaluate the potential quality of these proxy data we have compared with long time instrumental temperature data. The $\delta^{18}O$ in *N. pachyderma* (d) show good covariation to the summer record and the $\delta^{18}O$ in *G. bulloides* show good covariation to the spring record. This is in good accordance to the findings of Ganssen & Kroon (2000), who have shown that the *N. pachyderma* (d) calcificate in the summer time and *G. bulloides* in the spring bloom, and hence the $\delta^{18}O$ values in the two species can be used as summer and spring SST proxy.

We have estimated that since the “Little Ice Age” (ca AD 1400-1750; Bradley & Jones, 1993) the SST has increased with ca 1 °C in the summer record and ca 2 °C in the spring record. The summer record shows a stepwise increase, with steps at AD 1675 and AD 1930, while the spring record indicates a more smooth increase since AD 1750. The grain size record shows a decrease in sand contents since the Little Ice Age. We interpret that this is du to a shallowing of the transition zone, and this assumption is supported by the benthic foraminifera assemblage, which show higher amount of Atlantic water species simultaneous to increased sand contents. We suggest that deeper position of the transition between the waters is due to increased low pressure activity during the Little Ice Age.

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Long term trends in the polar vortices

by

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As part of the EU project PVC (Polar Vortex Change) and the Norwegian COZUV project NILU has acquired the ERA-15 data set for several meteorological parameters. This data set goes from 1979 - 1994. The data are global fields at 31 levels from the ground to 10 hPa. For the time period 1994-present we use regular T_{106} data that are acquired on a daily basis from ECMWF. This long time series of data have been used to study several characteristic parameters that pertain to the polar vortices. Several "environmental indicators" for vortex change have been calculated, and a climatology, as well as trends, for these parameters will be presented. These indicators can act as yardsticks and will be useful for understanding future changes in the polar vortex. Examples of indicators are: vortex mean temperature, vortex minimum temperature, vortex mean PV, vortex area, vortex strength (PV*area), vortex break-up time, maximum wind speed.

In the north polar vortex there are, over the time period 1979-2000, significant trends in the PSC area, vortex area, vortex strength and minimum temperatures for the later part of the winter (March and April). There is no significant trend for January and February. Table 1 shows the trends for these parameters.

Table 1. Linear trends (% per year) at 475 K. Uncertainties are one standard dev.

Parameter	Jan	Feb	Mar	Apr
Min. Temp.	0.04±0.08	-0.02±0.10	-0.16±0.07	-0.10±0.05
Vortex Area	-0.8±1.5	0.7±1.5	4.7±1.9	9.6±4.5
Mean PV	-0.1±0.2	0.36±0.29	0.69±0.29	0.38±0.17
Vort. strength	-0.8±1.0	0.3±1.1	2.7±1.3	5.2±2.9
PSC Area	-0.5±3.1	0.9±3.9	14.0±5.9	no PSCs

A similar study for the Antarctic vortex shows that there is a statistically significant increase in the area of the polar vortex at six isentropic levels from 400 to 550 K in November and December during the 1979-2000 time period. Monthly minimum temperatures show a decreasing trend for October, November and December during the same time period.

In addition to presenting results on vortex climatology the study also shows what is available at the NADIR data centre in terms of ERA-15 data, extraction tools, software for calculation of special products and routines for visualisation of the data.

Winter and spring ozone loss in the Arctic since 1988-89

by

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Several of the winters during the last decade have been characterised by substantial ozone loss in the north polar vortex. The Arctic ozonesonde network built since 1988 makes it possible to quantify this loss throughout the winter. The ozonesonde is one of the best tools to measure the vertical distribution of ozone inside the vortex during the polar night and spring.

The ozone mixing ratio based on ozonesonde data from a number of stations is studied as function of time at several isentropic levels (400, 435, 475 and 525 K).

The ozone data are corrected for the diabatic descent that takes place during the winter. Diabatic descent has been calculated with the Cambridge SLIMCAT model.

The ozone loss rates are compared to the extent of polar stratospheric clouds and there is a clear correlation between the degree of ozone loss and the incidence of NAT condensation temperatures.

Results for the 475 K level shows that the degree of chemically-induced ozone loss varies a lot from year to year. The following table gives the amount of loss in percent for most of these winters:

1988-89: 20±4	1995-96: 72±11
1989-90: 33±6	1996-97:47±8
1991-92: 23 ±10	1997-98: 24±6
1992-93: 43 ±□	1998-99: 15±11
1993-94: 38±9	1999-00: 73 ±5
1994-95: 67±18	2000–01: ~10% (no compensation for diabatic descent)

The data for the winter of 2000-01 are still preliminary as the effect of diabatic descent has not been accounted for.

Three winters stand out with regard to the amount of ozone loss, namely the winters 1994-95, 1995-96 and 1999-00. All these winters exhibit approx. 70% ozone loss at 475K. These three winters are the same as the three mentioned above as outstanding in terms of PSC area. These three winters have large PSC areas in the early winter, starting already in early December, and they also have PSC possibilities late in the winter. PSC temperatures in the early winter alone does not give rise to massive ozone loss. This was the case in 1989-90 and in 1992-93. Likewise, low temperatures late in winter alone is also not enough to cause the massive ozone loss of approx. 70% seen in 94-95, 95-96 and 99-00. Typical winters with low temperatures at a late stage are 1993-94 and 1996-97. These winters experienced chemical ozone loss on the order of 40-50% at 475K.

The contribution of biomass burning to the global ozone budget and oxidation of chemical compounds in the troposphere

by

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The 3 dimensional OsloCTM2 model was used to study tropospheric chemical changes initiated by emissions from biomass burning. The emissions of key primary pollutants from biomass burning have large uncertainties, and vary significantly depending on what sort of biomass source we consider. In particular the ratio of CO to NO_x in the emissions may vary significantly. This is important for the OH levels and therefore for the oxidation of methane in the atmosphere as well as for the efficiency of the ozone production. The biomass burning sources were therefore separated in four individual source categories: The use of biofuel, agricultural waste burning, savanna burning and forest burning. Without changes in the methane emissions, biomass burning decreased the yearly global averaged concentration of OH with 5.68%. This led to an increase in the global methane lifetime of 3.29 %. A study where the CO and NO_x from fossil fuel emissions in southern Asia were increased by 25 % showed different results. These emissions have a CO/NO_x ratio that is about a factor seven lower. The results were a small increase in yearly global averaged OH concentration, and a slight decrease in the calculated methane lifetime. Sensitivity studies for the different biomass source categories and within the emission uncertainties also suggest that the equilibrium for net methane change could be found at higher CO/NO_x ratios in the tropics than at mid latitudes. Biomass burning was found to explain up to 50 % of the surface ozone near regions with much burning. In the middle troposphere the contribution was around 20 % in almost closed zonal bands stretching across the globe. Rather effective convection close to the burning areas also resulted in significant biomass burning contribution in the upper troposphere where ozone has strong impact as greenhouse gas. Calculations indicate that biomass burning is responsible for one fourth of the estimated anthropogenic radiative forcing from tropospheric ozone.

Fast simulations of downward UV doses, indices and irradiances at the Earth's surface

by

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Many radiative transfer models are currently capable of simulating ultraviolet (UV) radiation levels with high accuracy, e.g., libRadtran. However, for applications requiring repetitive computations, such as computations of UV doses, operational quality assurance of measured UV spectra, production of UV maps, model pseudo-inversions and sensitivity studies, such models are generally too computationally demanding.

Fastrt is a fast but accurate simulation tool which remedies the above shortcomings. The first version computed downward surface irradiances in the spectral range 290-400nm as a function of bandwidth, solar zenith angle and ozone content. We have now enhanced and expanded the program to account for aerosols, clouds, surface albedo and topography.

We use the fast simulation tool for generation of UV doses throughout Norway as a part of our collaboration with of marine biologists and medical researchers.

We have also made a QA program to check incoming UV spectra for an EU-funded European UV database. The algorithm is based on distance metrics between measured UV spectra and simulations by Fastrt.

An interactive URL WWW site: http://zardoz.nilu.no/~olaeng/fastrt/fastrt.html allows the public to run the Fastrt program with most input options. This page also contains updated information about the Fastrt and QA programs and links to an anonymous ftp site for free download of all necessary source codes.

Results from a 300 years control integration with the Bergen Climate Model (BCM)

by

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In the last couple of decades, satellite measurements and improved weather forecast models have provided a rapidly increasing amount of high resolution observational and reanalysis data for a wide range of variables. Still the most important tool in the study of natural climate variability on annual to decadal time scales, and also the climate sensitivity to changes in forcing terms as greenhouse gas concentration, albedo or solar irradiance, is coupled atmosphere-ocean general circulation models (AOGCMs).

During later years much attention has been paid to the atmospheric and oceanic processes taking place in the North Atlantic and Arctic region. There are at least three good reasons for this: The presence of the North Atlantic Oscillation, the deep-water formation sites in the thermohaline circulation, and the reported shrinking of sea ice.

Common for all climate models is that their grid resolutions are coarse, and in many aspects too coarse to study the regional processes in the North Atlantic and Arctic region. To be able to increase the resolution in this highly sensitive region of the earth, a global atmospheric and a global ocean-sea ice model, both having the ability to use stretched grids with specified focus areas, have been coupled. The new model concept will here be discussed. It consists of the atmospheric model ARPEGE/IFS, coupled with a global version of the ocean model MICOM having a dynamic-thermodynamic sea ice model incorporated. The coupled model has been named the Bergen Climate Model (BCM).

The coupling between the two model components in the BCM is done with the software package OASIS, which takes care of the synchronising of the model components, and the transfer of data between them. The model components exchange data at 24 hour intervals. Then the atmospheric model receives sea surface temperature, sea ice cover, and albedo, and passes heat, fresh water and momentum fluxes to the ocean model.

Here the results from a 300 years control integration are shown. The atmospheric model has a resolution of T63 (2.8° by 2.8°), and the ocean model a resolution of 0.8° by 2.4° at the Equator, gradually transforming to square grid cells towards the poles. In order to avoid spurious drift in the surface variables a flux adjustment term for heat and fresh water has been added. This avoids rapid drift away from observed climate, but still gives realistic large-scale variability in the climate. There is still a weak drift in the global surface climate (0.3 ° in temperature and 0.05 psu in salinity over 300 years). While the ice in the Arctic is fairly stable, there is a slow retreat in ice in the Antarctica. The main reason for the drift is probably that the time period used to calculate the flux adjustment terms has been short (10 years), compared to the time scales of the large scale inter-decadal variability.

The weakest part of the model result shows up in the deep ocean, where there is a unphysical drift towards warmer and fresher water due to a net heat and fresh water input enforced by the flux adjustment, which is eventually mixed into the deep ocean. However, as the atmosphere is insulated from this water mass at least during the time span of this integration, it does not seem to affect the modelled climate in the atmosphere.

Comparison between atmospheric variables and observational data show generally a very good agreement. Corresponding to the weak drift in the sea surface temperature, there is a drift in the 2m temperatures and an associated positive drift in the amount of perceptible water and downward longwave radiation. The model is realistically simulating the different parts of the top of the atmosphere energy budget and its monthly variations.

The model system has also been analysed for large-scale variability. The strongest modes of variability in the global climate, are the El Nino – Southern Oscillation system in the eastern Pacific, and the North Atlantic – Arctic Oscillation system. Both modes of variability show up in the Bergen Climate model, with realistic amplitudes and phases.

Thus to conclude it seems that despite the mentioned problems with warming in the deeper ocean and a weak drift in the surface parameters, it seems that the control integration gives a realistic mean climate. The control integration will therefore be used as a reference experiment for future experiments with changes in grid resolution or distribution, or scenario runs with changes in the greenhouse gas concentration.

3D CTM model calculations of chemical processes in the troposphere and lower stratosphere

by

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Model studies of processes affecting ozone distribution and trends in the upper troposphere and the lower stratosphere (UTLS) have been performed. The model is specifically designed to study processes, which occur in the UTLS region. The studies focus on the chemical loss through reactions involving heterogeneous processes in the lower stratosphere and on stratosphere-troposphere exchange of ozone and chemical compounds affecting the ozone distribution and photochemistry. The model tool is a new 3-D chemical transport model (Oslo CTM-2) developed at the University of Oslo, which includes extensive chemical codes for processes in the troposphere and lower stratosphere. The model extends from the surface up 10 hPa. The transport and physical parameters used in the model are taken from ECMWF forecast data. Heterogeneous chemistry on aerosols and polar stratospheric clouds is calculated using a microphysical module.

An extensive model validation has been made using satellite observations of various chemical components and measurements from ozone sondes and LIDAR instruments. Estimates of the total ozone distribution and changes in stratospheric profiles are in agreement with observations. Heterogeneous chemistry, which is a function of lower stratospheric temperatures, is found to have a significant impact on the stratospheric ClO distribution and on the ozone loss process due to chlorine reactions. Estimates of the impact on ozone for different years (e.g. different temperatures) are performed showing significant variations in the ozone loss. Also the effect on photochemical ozone production in the upper troposphere is studied.

In addition to a brief description of the new model tool and comparisons with various observations, the field of applications of CTM-2 is exemplified by a detailed calculation of the tropospheric ozone budget, an assessment of the importance of heterogeneous chemistry, and the effect of NO_x emissions from civil aircraft. The latter study focuses on aircraft-induced changes in ozone and NO_y levels in the tropopause region and the lifetime of methane in the year 2000.

THE *ESPERE* PROJECT: Environmental Science Published for Everybody Round the Earth

by

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At present no global web site written by scientists is available that provides a reliable overview of climate related science comparable to the basic contents of the IPCC report for a wider public. Within the ESPERE project representatives of the scientific community, mediators to the public, educationists, teachers and students are planning to build up a user-friendly informative Network on climate change and related environmental processes. The address www.espere.net should become the multilingual gate to the current knowledge of scientists, presented in an easily understandable way for the public with a strong focus on schools.

A developing consortium is creating a multilingual web atlas on the climate system, written in an understandable way for the public and based on the results of the recent IPCC-TAR (2001). The structure of this atlas is based on thematic fields such as ENSO/NAO, solar cycle, paleoclimate, etc. as investigated by various research groups. The contents will be reviewed as is usual for scientific journals in order to provide a reliable source of information. This effort is assisted by educationists and teachers in order to put together topics from these fields for the use in classes and to complement the online sources with appropriate teaching material.

The dualism of the Internet as a medium of information (e.g. scientific journals) and a medium of communication (e.g. chat rooms) enables, unlike any other former tool, the selected connection and direct interaction of all groups involved in the field of education. ESPERE is going to use this opportunity of direct feedback, in order to evaluate and improve scientific publications already in the stage of their development. In this way an optimisation of the contents with respect to demands of the user and comprehensibility can be achieved. In particular, this will help to bridge the gap between science and the public and to pave the way leading to a knowledge society.

At present ESPERE is already under development on a smaller scale and providing teaching materials with partner schools in Germany, which are being translated into other languages.

ESPERE is a pilot project, which is designed to make accessible topical and reviewed scientific knowledge in an understandable manner for students and a wider public. The current experiences show that this effort could work on an international scale and contribute significantly to a raise in public awareness. Since the progress strongly depends on the readiness of researchers to make available their knowledge for a wider public, the ESPERE community invites scientists as well as representatives of the educational system in the respective countries to join this effort.

The work of ESPERE presented on our website has so far been built up on a voluntary basis by members of the scientific community from all over the world. We thank all supporters who have made possible a good start for this promising effort.

Modeling the annual cycle of sea salt in the global chemical transport model OsloCTM2, concentrations, fluxes and radiative impact

by

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Introduction

During the last years, there has been an increased focus on the climate effect of tropospheric aerosols from natural and anthropogenic sources. The most important aerosols from natural sources, are sea salt and mineral dust. Estimates for the global flux of sea salt range from 10^{15} to 10^{16} g/yr. (Seinfeld and Pandis, 1998). Previous estimates of clear sky radiative forcings from sea salt are in the range -1.0 to -3.5 W/m^2 (-1.5 to -5 W/m^2 over sea) (Haywood, 1999).

Methods and results

To study the production and transport of sea salt particles, a 3-D, global chemical transport model driven by meteorological data from the ECMWF was used. Sea salt is produced by wind stress on the ocean surface, and removed by wet and dry deposition. Atmospheric transport is done by advection and convection as described by Sundet (1997). In the radiative calculations a multistream model using the discrete ordinate method is used (Stamnes, 1988). The concentration, fluxes and radiative impact of sea salt in the atmosphere have been calculated using a 3-D CTM. Radiative forcing from sea salt aerosols is calculated to -1.1 W/m^2 when clouds are taken into account. The annual average radiative impact of sea salt is shown below in Figure 1.

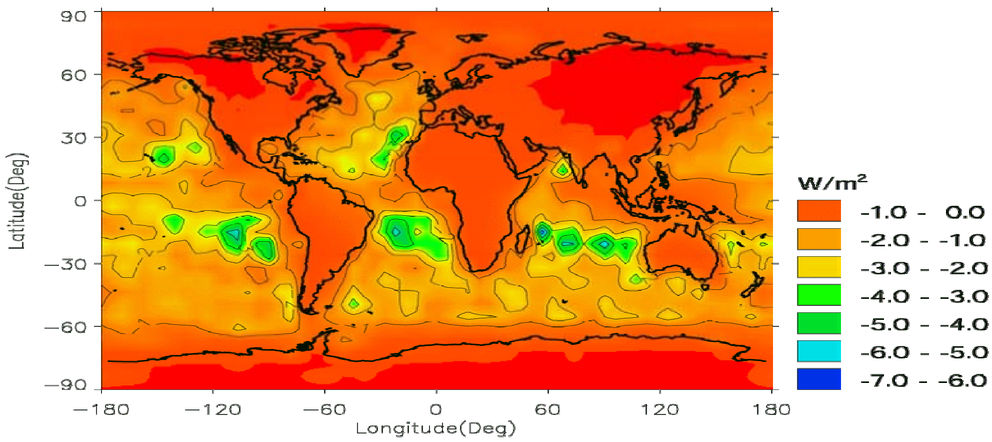

Fig. 1. Yearly average radiative impact of sea salt aerosols.

Acknowledgements

This work was supported by the Norwegian research council under the project CHEMCLIM.

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Sedimentary environment and climate during the holocene in the subarctic fjord, Malangen, Northern Norway: a multi proxy study

by

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A Holocene sedimentary record from the subarctic, deep-silled Malangen fjord in Northern Norway reveals regional changes in sedimentary environment and climate for the NW European region. We have investigated two sediment cores at the same location, JM98-1 (7, 6 meter long) and IMAGES-core MD99-2298 (36 meter long). The down core analysis includes, multi-core sensor logging, grain-size, X-radiography, foraminifera, oxygen and carbon isotopes, dinoflagellates, pollen +spores, trace elements and radiocarbon datings. The cores are located proximally to the submarine Younger Dryas moraine complex, and reveal the deglaciation after this event, as well as the postglacial evolution during the Holocene. Five sedimentary units have been in identified. The oldest unit (Unit V) is characterised by deformation structures, possibly formed during a late Younger Dryas glacial advance in the fjord. This unit is followed by a deglaciation c. 12100±500(?) cal years BP (c. 10,200 ^{14}C years) and deposition of glaciomarine sediments (Unit IV and III) and several turbidite layers. Glaciomarine sedimentation ceased in the fjord c. 10,300 cal years BP (9,200 ^{14}C years) and was replaced by interglacial marine sedimentation (Unit II and I). Sedimentation rates were extremely rapid during the deglaciation (on average 14 mm/cal. year) and slowed down during the last 8,700 years (16-0.4 mm/cal. year). A hiatus is detected between c. 10,100 and 8,700 cal years BP. A rapid fluctuating warming occurred during Preboreal. Onset of surface water warming lagged bottom water warming. Oxygen isotopes and benthic foraminifera indicate gradual bottom water cooling the last c. 9,000 years (c. 8,000 ^{14}C years), interrupted by brief warmings around 6000-5000 cal. years BP and 1700 cal. years. This main trend is also supported by the dinoflagellates. The pollen stratigraphy correlates well to terrestrial records from nearby land areas and also documents a close link between land and ocean climatic evolution. The changes may be driven by a.o. insolation as well as changes in the North Atlantic heat transport.

Arctic ozone depletion 1996-2000 derived from Arctic ozone lidars and the SLIMCAT model

by

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The ozone lidars at the Koldewey station, Ny-Ålesund, and the ALOMAR facility, Andøya, have been operated since 1988 and 1995, respectively, covering all Arctic winters since. These periods include several winters with severe ozone depletion, such as 1996, 1997 and 2000, and winters with an early break-up of the polar stratospheric vortex, leaving the ozone layer almost intact, such as 1998 and 1999. As lidar measurements cover almost the whole stratosphere, they are very well suited to quality-assess results from chemical transport models (CTM), which have been developed to determine chemical ozone depletion and to separate it from dynamical processes.

The SLIMCAT model is one of the most advanced stratospheric CTMs in use. It can be run both over long time periods (about 10 years) with moderate time and spatial resolution and at seasonal time scales with increased time and spatial resolution. Recently, results of the decadal SLIMCAT run were compared with lidar measurements during the winters of 1997/98, 1998/99, and 1999/2000, at ALOMAR also the winters 1995/96 and 1996/97. In addition, seasonal model results for the winter 1999/2000 were compared with lidar measurements at both stations.

The comparison yields a degree of agreement varying strongly from year to year and being very dependent on altitude. While the severe ozone depletion in 2000 in the 400-to-500-K potential temperature range is very well reproduced by SLIMCAT in both runs, there are severe deviations between measurement and model in the winters of 1995/96 and 1996/97, when similarly severe ozone depletion occurred. In the 500-to-650-K range, the long-term and seasonal SLIMCAT runs yield significantly different results. Generally, ozone mixing ratios in the long-term run are increasingly above values derived from seasonal run with progressing time, both in passiver-tracer and full-chemistry ozone. The effect is most pronounced inside the vortex, indicating a grid-induced mixing problem across the vortex edge. Since both passive-tracer and full-chemistry ozone in the model are affected, a quantification of ozone depletion from the model or from a comparison between model (passive-tracer) and measurements in this altitude range has to be regarded as very uncertain. This holds in particular for winters with marginal ozone depletion, such as 1998 and 1999.

The 65-year record of total ozone in Tromsø: signatures of atmospheric chemistry and dynamics

by

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The total ozone measurement series from Tromsø is the second longest in the world, starting in 1935 with Ferry spectrograph measurements and continuing with measurements by Dobson spectro-photometer no. 14 from 1939 to 1972 and from 1984 to 1999. Recently, this series has been re-evaluated and homogenised. This procedure included re-evaluation of calibration procedures, instrument parameters, ozone cross sections as well as empirical homogenisation of different episodes of instrument performance and measurement modes. As a result a unique series of Arctic ozone measurements has been established. The series reveals a remarkably stable autumn ozone minimum throughout the whole time period, while the spring ozone maximum shows large variations, both on a year-to-year and a decadal time scale.

In order to identify the contributions of natural and anthropogenic processes to ozone variations, a multi-linear regression analysis of monthly means of the series has been performed. It includes climate tele-connection patterns (as derived by rotated principal component analysis at the Climate Prediction Centre, NOAA), volcanic aerosols, quasi-biennal oscillation, solar variability and a (modified) linear trend since 1979. The analysis reveals a strong quasi-linear decrease in late winter since 1979, decreasing throughout spring and early summer and confirms a significant contribution to (chemical) ozone depletion during episodes with noticeable volcanic aerosols. Solar cycle and QBO, on the other hand, do not contribute significantly to ozone variability at Tromsø. The contribution from climate tele-connection patterns appears to be very complex, changing almost from month to month. The signature of the North Atlantic Oscillation (NAO) is much less pronounced than in Central European ozone series, while contributions from zonally oriented climate patterns, such as the East-Atlantic Jet pattern, and very remote patterns, such as the West Pacific pattern is very strong in periods.

Norwegian Ocean Climate Project

by

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The overall objectives of the coordinated research project Norwegian Ocean Climate Project (NOClim) is:

a) improve our understanding of rapid changes in the thermohaline circulation in the Northern seas
b) improve our understanding of ocean and ice processes related to climate including mechanisms causing significant variability in the hydrography, circulation and ice cover in the Northern seas
c) maintaining time series for early detection of climate change in the Northern sea

NOClim is funded by Norwegian Research Council, KlimaProg - Research Programme on Climate and Climate Change. The project includes more than 35 scientists from seven different institutions: The Norwegian Meteorological Institute (DNMI), Institute of Marine Research (IMR), Nansen Environmental Remote Sensing Center (NERSC), Norwegian Polar Institute (NP), University of Bergen (UiB), University of Tromsø (UiT) and University Courses on Svalbard (UNIS). Project leader is Peter Haugan (UiB), and in the Scientific Steering Group we find Eystein Jansen (Bjerknes/UiB), Harald Loeng (IMR), Eivind A. Martinsen (DNMI/RegClim) and Lars Petter Røed (DNMI). Official project contact is Solfrid Sætre Hjøllo, Scientific Secretary. The project is presented at internet at www.noclim.org.

The scientific work is divided into seven tasks, each managed by a group leader. The tasks and task leaders are: Task 1: Rapid and dramatic past changes. Trond Dokken, UNIS. Task 2: Deep water ventilation from shelves. Peter M. Haugan, UiB. Task 3: Deep water ventilation in the deep sea. Helge Drange, NERSC. Task 4: Cross front exchange and formation of intermediate water. Bjørn Ådlandsvik, IMR. Task 5: Variability and signal propagation from high resolution information. Arne Melsom, DNMI. Task 6: Coordinated analysis of long time series. Martin Miles, UiB. Task 7: Long term observations. Ole Anders Nøst, NP. Task 1 primarily addresses the first overall objective. Tasks 2 to 6 primarily address second overall objective, but in addition they also, and in particular tasks 2, 3 and 6, contribute towards first overall objective. Task 7 primarily addresses the last overall objective. In addition, there are also relations between tasks whereby individual tasks provide input to other tasks, and thus contribute to several more aspects of the project as a whole than their own primary objectives. Results from several of the tasks will be presented to highlight some of the activities from June 2000 until present.

Stratospheric Ozone 1995-2001at 69°N observed with the ALOMAR Ozone Lidar

by

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The ALOMAR Ozone Lidar has been in operation since early 1995, as part of the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR). ALOMAR is located at 69.5° N on the Vesterålen island of Andøya in Northern Norway. The observatory is situated about 380 m above mean sea level, 2 km from the Andøya Rocket Range. ALOMAR also includes a Rayleigh/Mie/Raman Lidar (IAP Kühlungsborn and collaborating groups) and a Na-Lidar (Colorado State University and collaborating groups). The Norwegian ALOMAR Ozone Lidar is a differential absorption lidar (DIAL) using 308 nm as the absorbed wavelength and 353 nm as the reference wavelength. In darkness an ozone profile from roughly 8 km to 40 km can be measured with about 1 hour of integration time. The altitude resolution is between 300 m at 8 km and 1 km at 40 km. At lower heights, e.g., 8-20 km, ozone profiles can be measured with greater temporal resolution, for instance 10 minutes. Since 1995 ozone profiles can to some extent also be measured in full daylight. ALOMAR being located north of the Arctic circle, the sun does not set from the end of May until the beginning of August. The daylight capability has been continuously upgraded. At the present time it takes approximately four times as long to measure in daylight as it does in darkness.

The southern edge of the Arctic Polar Vortex in the stratosphere is located above ALOMAR on average. Due to the motion of the Polar Vortex, ozone profiles within the vortex and outside it can be observed. This allows us to contribute to studies of transport processes across the edge of the vortex.

We have now collected 7 years of such data and are continuing to do so. This permits studies of trends, variability and the dependence of the ozone layer on various parameters, such as the solar cycle, anthropogenic gases, PSCs, transport, etc. Data from the ALOMAR Ozone lidar has also been used for MATCH studies.

The ALOMAR Ozone lidar also measures profiles of neutral density, which yield temperature profiles. With these, we can for instance identify sudden stratospheric warmings (STRATWARMS), where the stratosphere temperature increases by 40 to 70 K in the course of a few days. Such warmings have profound effects on the circulation, transport, and ozone density.

The ALOMAR Ozone Lidar (and the Rayleigh/Mie/Raman lidar, see above) detect and measure PSCs when they are present. Observing Mie scatter from PSCs with several wavelengths let us estimate the size distribution of the PSC particles.

In November 2000, these lidars detected a strange aerosol layer at 37 km. The layer was weak, but must have extended over a large area at high latitudes, as it was observed at the same height and with the same intensity over several days. This layer was too high to be a PSC, and the temperature (near 200 K) was too high for the formation of PSC. The layer was too low to be of meteoritic origin. The layer might have been formed by a vulcanic eruption, but no such eruption is known for this time period. The layer occurred during the formation phase of the Arctic Polar vortex. It must be studied if the formation or the stratospheric polar vortex can lead to an aerosol layer near 37 km.

The Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR)

by

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The ALOMAR observatory is a European Centre for atmosphere research with a focus on the middle atmosphere (about 8 km to about 115 km). ALOMAR is located at 69.5°N on the Vesterålen island of Andøya in Northern Norway. The observatory is situated about 380 m above mean sea level, 2 km from the Andøya Rocket Range. Research groups from six countries in Europe and North America contribute with their instruments. The instruments include three state-of-the-art lidar instruments, 4 radars, and a number of passive instruments. The Rayleigh/Mie/Raman Lidar (IAP Kühlungsborn and collaborating groups) measures atmospheric density, temperature, wind and aerosol particles in the height range 30-80 km. The Na-Lidar (Colorado State University and collaborating groups) measures Na-density, temperature and wind in the 80-115 km height range. The Norwegian ALOMAR Ozone Lidar is a differential absorption lidar (DIAL) measuring from 8 km to 40 km. The collocation of these active and passive instruments and the collaborations between the different research groups is an important asset. Furthermore, ground-based observations are frequently co-ordinated with rocket launches and balloon launches from the nearby Andøya Rocket Range.

ALOMAR provides scientists from the EU and associated states with opportunities for all-year, in-depth studies of the Arctic middle atmosphere. The facility comprises the observatory with optical instruments and several nearby sites with radar instruments. Andenes is easily accessible by commercial air transport with several daily flights, 3 hours from Oslo. The climate is mild, even in mid-winter the mean temperature is only a few degrees below freezing. Access is provided free of charge and includes all infrastructure, logistical, technical and scientific support normally provided to external users. Grants are restricted to cover travel and subsistence costs for field campaigns or laboratory work of up to 3 months duration, or shorter visits involving installation of well-automated instruments. Freight costs for instruments can also be covered on application. Application deadlines are: 1 March, 1 June, 1 September and 1 December each year. Applications are decided by a User Selection Panel with members from several European countries. It is conceivable that also applications from other fields than middle atmosphere studies can be accepted.

More information about ALOMAR can be found at the website http://www.rocketrange.no/alomar/.

Measurements of total ozone at Ny-Ålesund since 1991

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Introduction

Total ozone column abundances have been monitored at Ny- Ålesund (79°N, 12°E) since the fall of 1990 with an u.v. – visible spectrometer of the type SAOZ (System for Observations at Zenith). Vertical column amounts are measured during morning and evening twilights by analysis of the sunlight scattered at zenith with the differential optical absorption technique (DOAS). The spectral data have been re-analysed with an updated analysis procedure in order to provide a consistent data set (Fayt et al., 2001).

In this study we report ten years of total ozone measurements at Ny-Ålesund. The ozone data have been compared with total ozone data from TOMS and GOME. Observed ozone columns from the SAOZ have also been compared with data from a 3D-CTM (SLIMCAT) to see if there are any systematic differences between measured and modelled data.

Data for Model Evaluation (PT8 RegClim)

by

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The RegClim set up a Principal task with the major objective to establish links to data sets for model-validation and to maintain an information page on the availability of different data for model-validation in the project. Subtasks have focused on meteorological data, oceanographic data, air pollution data and sea ice data.

The meteorological data consist both of time series from observation stations in the region and meteorological analysis field. The station network of the Norwegian Meteorological Institute is the basis for the time series. However, time series of high quality for the other Nordic countries have also been made available through the project Nordklim. The meteorological fields of interest have been produced through the re-analyses performed by ECMWF (1979-1993) and NCEP/NCAR (1948-1999). An extension of the ECMWF-reanalysis covering a 40 years period is under preparation. Both reanalysis consist of 6 hourly data of different meteorological parameters from different pressure levels. The Norwegian Hindcast Archive is another re-analysis covering the period 1955-2000. From 6 hourly pressure analyses, sea level wind fields and wave fields have been established in a 75*75 km grid covering the NE-Atlantic, the Norwegian, the Greenland and the Barents Seas.

Institute of Marine Research (IMR) operates a net of repeated hydrographic sections in the Norwegian, North and Barents Seas. The main purpose of these sections is to monitor the inter annual climate fluctuations. In RegClim task 8, the sections in the Norwegian Sea have been worked up, gridded and saved in NetCDF format. These data are used for validation of ocean circulation models, with respect to mean water mass characteristics and inter annual variability.

The weather ship Polarfront has besides the meteorological observation program, measured hydrographical data down to the bottom (2000m) while at station (66°N, 2°E) since 1948 on behalf of the Geophysical Institute, University of Bergen. This time series is one of the longest of its kind in the world.

Norwegian Institute for Air Research (NILU) has collected data on air quality. The focus has been on aerosol data observed from satellites. Data for Aerosol Optical Thickness (AOT) has been submitted to the NoSerC database and made available for the RegClim community. AOT from three different satellite instruments are provided as monthly means; from the AVHRR, POLDER and OCTS instruments. Work has been done at NILU to compare the three datasets, in order to help the validation of aerosol distributions modelled within RegClim.

Sea Ice data are made available from two different sources. Through the NORSEX project, NERSC has established a dataset covering the period 1978-1999. A CD-ROM with monthly values of Total ice cover, Multi year ice (Nov.-Mar.) and First year Ice is available on request for scientific, non-commercial purposes from NERSC. The other source is the maps prepared by The Norwegian Polar Institute and DNMI since 1966. The maps for the periods 1966-1993 and for July 1997-June 2001 are available on digital form. The maps for the first period are also gridded. Norwegian Polar Institute (Torgny Vinje) has by means of different historical sources established a series of ice concentration maps back to 1553. This series exist as Arc View Shape files.

Decadal to century scale Ocean - Land linkages and Low/High latitude teleconnections during the Holocene

by

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Multi-proxy paleoclimatic time series have been developed from IMAGES Sites and adjacent supplementary cores in the Eastern Norwegian Sea. The records cover the last 10000 years at decadal resolution, allowing for a reconstruction of the surface and deep water hydrography of the main path of the northern limb of the Atlantic thermohaline circulation cell. Based on foraminiferal and diatom SST estimates and planktonic oxygen isotope analyses, the amplitude of SST changes are found to be in the range of 1-2 degrees.

Centennial to millennial scale events are recorded, such as the ”Medieval Warm Phase and the Little Ice Age, which constitute the main long term century scale features. Superimposed on these are multidecadal variability of somewhat less amplitude. There is a close correspondence with continental records reflecting summer temperature and winter precipitation in western Scandinavia over this period. The last 150 years of the record are well correlated with the instrumental record of summer temperatures in Southern Norway. This allows an intercalibration with the marine records, and to identify possible mechanisms for the observed close correspondence between continental and marine paleo-data sets for the last 10.000 years.

We suggest that there is a close link between NAO related changes in the width of the Atlantic inflow, associated E-W variations in the Arctic Front, and the SST variability in the Norwegian Sea. These oceanic variations apparently are linked with changes in Scandinavian summer temperatures.

The Early to Mid Holocene was characterised by long intervals of a dominant NAO+ - like mode in the North Atlantic.

There is also strong evidence for corresponding changes in the Northward position of the ITCZ and high latitude SST variations, pointing to a substantial influence of the tropics on high latitude climate changes.

Global direct radiative forcing by process-parameterized aerosol optical properties

by

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A parameterization of aerosol optical parameters is developed and implemented in an extended version of the Community Climate Model version 3.2 of the US National Center for Atmospheric Research (CCM3). Direct radiative forcing (DRF) by non-sea-salt sulphate and black carbon (BC) is estimated.

Inputs are production specific concentrations of BC and sulphate from Iversen and Seland (2001), and background aerosol size distribution and composition. The scheme interpolates between tabulated values to obtain the aerosol *single scattering albedo*, *asymmetry factor*, *extinction coefficient* and *specific extinction coefficient*. The tables are constructed by full calculations of optical properties for an array of aerosol input values, for which size distributed aerosol properties are estimated from theory for condensation and Brownian coagulation, assumed distribution of cloud-droplet residuals from aqueous phase oxidation, and prescribed properties of the background aerosols. Humidity swelling is estimated from the Köhler equation, and Mie calculations finally yield spectrally resolved aerosol optical parameters for 13 solar bands. The scheme is shown to give excellent agreement with nonparameterized DRF calculations for a wide range of situations.

Using IPCC emission scenarios for the years 2000 and 2100, GCM calculations yield a global net anthropogenic DRF of -0.11Wm^{-2} and 0.11Wm^{-2} respectively, when 90% of BC from biomass burning is assumed anthropogenic. In the 2000 scenario the individual DRF due to sulphate and BC is separately estimated to -0.29Wm^{-2} and 0.19Wm^{-2}, respectively. Examples of aerosol optical parameters will be shown, as well as preliminary results for atmospheric response of the aerosol forcing.

Solar radiation measurements under a cloudy sky

by

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Variability in the spectral radiation from the Sun has been studied the latest years. Studies of the ultraviolet radiation has been driven forward by the concern of the decreasing stratospheric ozone and the Antarctic ozone hole. One of the biggest causes of dynamic changes in the radiation pattern, in addition to the position of the Sun on the sky are clouds. Measurements done under these conditions are strongly influenced by the dynamics in radiation pattern from the sky. This complicates the measurements procedure and comparisons of modeled and measurements data under these conditions have to be done with special care.

A measurement system for measuring spectral solar global, solar direct, and sky radiance distribution has been developed around a double monochromator Bentham DM150. A computer controlled NTNU developed tracker system has been applied to perform radiance and direct measurements under all kind of weather conditions. Together all these components represents a dynamic and flexible measurement system for studies of the radiation from the Sun and sky, specially suitable for measurements under variable cloud conditions. Ancillary moderate bandwidth filter radiometer data are sampled at 3 Hz to provide information about the cloud dynamics during spectral scans. By combining filter instrument data with spectral solar scans we have shown that it is possible to remove the effects of variable clouds during scan time and hence make the spectral scans possible during all weather conditions at a sampling rate of approximately 1Hz.

The system has been applied to make measurements of the cosine error under cloudy and overcast conditions. 3Hz GUV data has also been applied to correct cosine error measurements for errors caused by changing clouds. Uncalibrated test measurements of radiance distributions under fractionally cloud covered sky are presented.

The developments has been financed by Norwegian Research Council (NFR) through the COZUV project.

Sea-surface temperature variability in the eastern vs. western Nordic Seas during the last 2000 years

by

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One of the main issues in paleoenvironmental research today is to understand the stability and variability of the current climates and natural environments, whether the natural system is stable in its present mode of operation, what internal and external forcings are required to maintain or change it, and what impacts such changes might have. In order to provide such assements it is important to assess variability by obtaining time series that extend beyond the length of instrumental records.

Sea-surface temperatures (SST) at decadal resolution have been reconstructed from core MD 95-2011 and core MD 99-2269 based on diatom transfer functions. The cores were collected during the IMAGES cruises of the R. V. Marion Dufresne. Core MD 95-2011 is located on the Vöring Plateau (66°58.18N; 07°38.36E, 1050 m water depth) along the main axis of the northward flowing warm Atlantic water. It is, therefore, in an ideal position to monitor changes in the northward heat flux to northwestern Europe. Core MD 99-2269 is located in the deep Hunafloi trough, off N Iceland (66°37.53N; 20°51.16W, 365 m water depth). Today the core lies under the influence of the Irminger current, but it also may be influenced by the cold East Greenland current as the Polar front migrates eastward. Core MD 95-2011 is dated by AMS C-14 and Pb 210 isotope profiles, and core MD 99-2269 by AMS C-14. Core MD 95-2011 has been studied at about 10-20 years resolution through the last 2000 years. Core MD 99-2269 is studied at about 5 years resolution through the last 600 years and about 50 years resolution through the rest of the record. Our SST reconstructions show that,

- Intensity of the NAC varied around a mean with amplitude of variations of 1-2°C.
- Intensity of the IC varied around a mean with amplitude of variations of 3-4°C.
- Both areas display decadal-scale SST variability.
- The «Little Ice Age» (LIA) starts in core MD 95-2011 with a SST fall of 1.5°C within a decade around 1400 AD and lasts until about 1750 AD.
- Coresponding interval in core MD 99-2269 is characterized by warm SSTs.
- The last 300 years is characterized by SSTs warmer than the mean for the last 2000 years over the Vöring Plateau, and SSTs colder than the mean over the N-Iceland Shelf.
- Reconstructed SSTs from core MD 99-2269 correlate well with reconstructed sea ice severity around Icelandic coasts since 1600 AD.
- North Atlantic Oscillation (NAO) type of atmospheric pattern might explain the observed anti-phase relation of SSTs between the eastern and the western Nordic Seas.
- If so, then during LIA a NAO – state and during the last 300 years a NAO + state dominated the atmospheric circulation.

Holocene SST-reconstructions from the Vøring Plateau and the Denmark Strait

by

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The main objective of this study is to provide information on the Holocene climatic development in the eastern and western part of the Nordic Seas. Reconstructions of sea surface temperatures (SSTs) have been performed on a box core (93030 19A) and a gravity core (BS88-6-5A) from the southern Denmark Strait (67?07.54 N, 30?54.26 W) and on sediment cores JM97-948/2A and MD95-2011 (both 66?58.18 N, 07?38.36 E) from the Vøring Plateau. Both areas have high sedimentation rates and act as potential archives for generating high-resolution paleoclimatic time series. The eastern site is today located under the warm inflowing Norwegian Current (NC), while the western locality is under the influence of the cold East Greenland Current and the warm Irminger Current (IC) flowing around Iceland. Our results show a general cooling trend after the climatic optimum of the early Holocene in both the eastern and western part. Both the NC and the IC were strengthened during the early Holocene and SSTs show temperatures of 4-5 °C warmer than at present. These results indicate that the Nordic Seas SST development through the Holocene has been forced by the high-latitude Northern Hemisphere insolation. Added to the general trend are local variations. The stable Holocene Climate Optimum between 9500 and 7500 over Vøring Plateau is not occurring in the Denmark Strait. In fact the early Holocene temperature curve from the Denmark Strait show a different shape than the eastern site. In the western locality the Optimum is a short-lasting event around 7500 BP followed by a cold phase between 7000 and 6300 BP. This cold period coincide with the starting temperature decrease over the Vøring Plateau after the Optimum in that area. For the second part of the Holocene, the warm currents over the sites get less prominent and the last 3-4000 yrs have been colder than average in both western and eastern part of the Nordic Seas. Rapid and short lasting changes occur throughout the last 3000 years with temperatures varying around a mean with amplitudes of 1-2 °C. On millennial scale the western and eastern part show the same trends, but on shorter scales differences are more apparent.

Holocene climate variability, evidence from the Norwegian Sea

by

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Within the NORPAST project (subproject PASTNOMA) further development of marine proxies has been one of the primary aims and, in particularly the ability to reproduce time series from the sediment archives that is comparable to instrumental records. To be able to reconstruct temperature changes on shorter time scale (last 100 yeas) in sediment archives bear important implications in the reliability of the reconstructions on a longer time scale record.

The sites studied are three fjord localities, Ranafjorden, Voldafjorden and Sognesjøen and in the more open marine environments the Troll core in the Norwegian Channel and a core north of the Storegga slide (P1-003MC) have been studied. The age models are based on lead-210 dating and ^{14}C datings (AMS). The proxies we have used here are stable oxygen isotopes in both planktonic and benthic foraminifera and temperature reconstructions based on dinoflagellates and planktonic and benthic foraminifera.

For comparison with instrumental data series the air temperatures from Bergen is used and from the marine environment temperatures at 300m water depth at Skrova is included.

The comparison of the instrumental data series and the reconstructed data series shows similar trends in the changes in temperatures through the last 100 years. Especially a decrease in temperature around 1920 followed by a rapid increase in temperature is evident in all records. The findings of the similar trends in the marine temperature reconstructions from the fjords and from the offshore records and the summer temperature from Bergen indicate that the co-variable temperature changes reflect regional changes in the atmospheric-oceanic circulation.

For the last 11,500 years (Holocene) the sea bottom summer temperature (SBST) shows a maximum in amplitude of 2°C and in the summer sea surface temperature (SSST) the amplitude is slightly higher based on the planktonic foraminifera in the Troll core. Through the Holocene the summer sea bottom temperature shows a slightly decreasing trend in the temperature and in sea surface summer temperature an early Holocene thermal optimum is found, a slight decrease in temperature in mid-Holocene and relatively stable temperatures from 5000 cal yr BP up to the present. In both the bottom and surface waters several cooling events are evident, especially significant drop in temperatures around 11200 cal yr BP and at 8200 cal. yr BP event are pronounced.

North Atlantic SST patterns and their effect on rainfall in Norway

by

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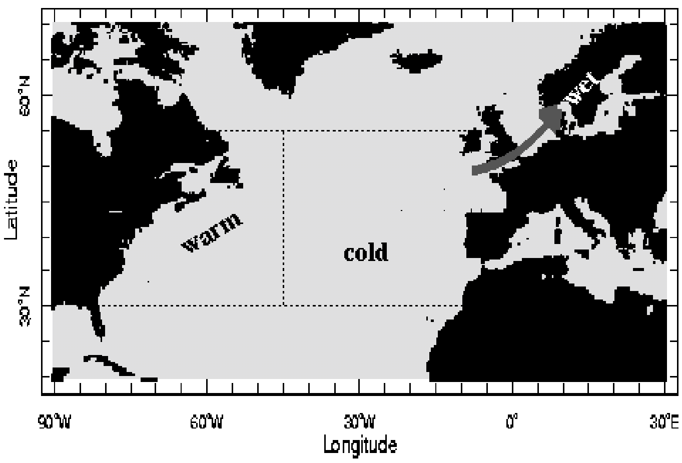
A study of the relationship between the North Atlantic sea surface temperature (SST) anomaly patterns and rainfall in southeastern Scandinavia has been performed. The starting point of the investigation was the fact that there were unprecedented data recorded for both of these variables. In southeastern Norway, the November precipitation reached values of about four times the November mean value. At the same time, the SSTs in a large part of the northwestern Atlantic were outside their range of reference (mean value ± the standard deviation). We found evidence that strongly suggests that the record rainfall in November 2000 was connected to simultaneous strong, positive SST anomalies in the northwestern Atlantic.

In the present study, we used a 101 year (1900-2000) reconstruction for North Atlantic SSTs. Only November months when the area with SST anomaly magnitudes > 0.5 K exceeds 10% in the latitudinal belt between 30°N and 55°N, are considered. For these months, we define a North Atlantic asymmetry index by dividing the North Atlantic (between 30°N and 55°N) along 45°W, and consider the western basin's fractional area of anomalies > 0.5 K to the corresponding area for the full domain.

Moreover, a homogeneous precipitation record for Bjørnholt (Oslo) for the same period (1900-2000) has been used. We define "wet", "normal" and "dry" months by normalizing the precipitation data. We found that the east/west distribution of North Atlantic SST anomalies affect the Oslo rainfall in November. Warm pools in the western basin in November, and cold pools in the eastern basin, coincide with wet spells in Oslo, with a confidence >99% (estimated using a bootstrap method). When the distribution of anomalies is reversed, there are frequently dry spells in Oslo, also with a confidence >99%.



Left:
Sketch displaying the relation between asymmetric SST anomalies in the North Atlantic, precipitation in southeastern Scandinavia, and low pressure paths, during November.

When we introduce the sea level pressure patterns into our study, we find that “wet Novembers” occur when the low pressures approach Norway from the south or southwest, as opposed to the normal pathway from the west (see the sketch below for an outline of the “wet November” situation).

Finally, we present a discussion of how the results depend on the quality of the SST data, and a result that indicates only a weak impact of the North Atlantic SST asymmetries on precipitation over western Norway.

Benthonic stable oxygen isotope records from Northern Norwegian fjords, showing temperature variations and regional climate changes

by

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The fjord Malangen is located in the northern part of Norway, close to the northern limb of the oceanic conveyer circulation. Malangen has a frequent bottom water exchange with the waters adjacent to the fjord (e.g. Soot-Ryen. 1931). Instrumental measurements of bottom-water temperatures at the core location show similar fluctuations as other Norwegian fjord basins, sea surface temperatures adjacent to the fjord and yearly average air temperatures in coastal Norway. Thus this fjord basin is reflecting regional temperature changes.

The instrumental measurements of temperature and salinity in the bottom water at the core location show that temperature has had amplitude of c. 2.5˚C and salinity has had an amplitude of c. 0.4 since AD 1980. These observations show that temperature and salinity follow the same trend.

Variations of $\delta^{18}O$ measured on foraminifera tests may depend on temperature, salinity and how much water that is stored on land. The latter can be excluded for the last c. 6000 years. A temperature change of 1˚C corresponds to 0.23‰ in the $\delta^{18}O$ signal and a salinity change of 1 unit corresponds to an $\delta^{18}O$ change of c. 0.43‰ (mixing line for northern Norwegian fjords). So temperature changes will dominate the $\delta^{18}O$ signal. Since the temperature and salinity follow the same trend, the salinity signal will work in the opposite direction of the temperature signal, and the response on the $\delta^{18}O$ records will be a minimum temperature signal.

The investigated material consists of one Box Core, one Piston Core and one Giant Piston Core (IMAGES). The Box Core was dated with ^{210}Pb and one AMS ^{14}C dating. The $\delta^{18}O$ curve was wiggle matched to the Kola Profile by changing the age model as little as possible. The Piston Cores were dated with 16 AMS ^{14}C dates and the cores were linked together. All AMS ^{14}C dates were calibrated to calendar years following Stuiver et al. 1998).

The Box Core record spans AD 1770 to AD 1995 with a 3 to 1 year resolution and shows that NAO (North Atlantic Oscillation) is the main forcing of the temperature shifts recorded in the fjord. The record shows no warming trend before AD 1900 and a 0.5˚C warming after AD 1900.

The Holocene $\delta^{18}O$ record has a high (5 to 40 years) resolution before 8100 cal. years BP. This part of the record reflects the same fluctuations and increase in temperature as recorded in the GRIP ice-core on Greenland. The sample resolution is lower after 8100 cal. The record shows a general temperature decrease during Holocene. This is in accordance with previous observations from the Nordic Sea (e.g. Koc Karpuz and Schrader, 1990).

The benthic $\delta^{18}O$ records from Malangen correlates well to instrumental records and other Holocene climate reconstructions. This in addition to the high sedimentation rates in the Malangen fjord makes this locality promising for investigations of Holocene climate variability in detail.

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Briksdalsbreen, western Norway: Rapid terminal response due to increased winter precipitation 1990-1997

by

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At present, most glaciers around the world experience negative net mass balance trends and frontal retreat as a result of rising ablation-season temperatures and/or reduced winter precipitation. Measurements of annual frontal fluctuations since the early 20th century show, however, that glaciers in western Scandinavia in the 1990s have experienced the largest frontal advance recorded during the 20th century, and possibly since the early 18th century 'Little Ice Age' glacier advances. Between 1955 and 1997 Briksdalsbreen, a western outlet glacier from Jostedalsbreen, the largest glacier on mainland Europe, advanced almost 600 m, of which 367 m occurred between 1990 and 1997. Between 1992 and 1997 Briksdalsbreen advanced 322 m, giving a mean advance rate of 18 cm/day! The maximum annual advance of 80 m occurred in 1993/94. Instrumental summer temperature and winter precipitation records from Bergen and Briksdal, respectively, clearly demonstrate that the main cause of the recent glacier advance was increased winter precipitation since AD 1988/89. The lag time of frontal response of Briksdalsbreen to a change in annual net mass balance has been calculated to be 3-4 years, demonstrating that glacier termini can respond rapidly to short-term climatic changes. Cumulative net mass balance records show that the maritime glaciers have experienced a significant mass increase since the early 1960s while the opposite has been the case for the continental glaciers. Correlation analysis between net mass balance and winter/summer balance shows that the maritime glaciers are best correlated with winter balance, while the net mass balance on the continental glaciers shows the highest correlation with summer balance.

Holocene glacier fluctuations and palaeoclimate at Hardangerjøkulen, central southern Norway

by

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Hardangerjøkulen is a nearly circular plateau glacier located at the main watershed between western and eastern Norway. Hardangerjøulen is the sixth largest glacier in Norway, covering an area of 73 km^2. Based on a reconstruction of the number, age and magnitude of Holocene glacier fluctuations of Hardangerjøkulen, variations in the equilibrium-line altitude (ELA) for the last 10,000 calendar years have been reconstructed. Present and past ELAs are based on an accumulation-area ratio (AAR) of 0.7, and the past ELA variations are adjusted for post-glacial land uplift. During the early to mid Holocene, glaciers existed during periods of high pine tree limits. This indicates that warm summers were compensated for by increased winter precipitation. Based on pine-tree limit fluctuations in southern Scandinavia as a measure of mean summer temperature, Holocene variations in winter precipitation at Hardangerjøkulen have been calculated by applying a close exponential relationship between mean ablation-season temperature and winter precipitation at the ELA of Norwegian glaciers. Setting winter precipitation in the 1961-90 period at 100%, mean Holocene values of winter precipitation varied from about 65 to 175%.

The impact of climate variations on primary production and oxygen fluxes in the Barents Sea

by

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Recent estimates of the oceanic and terrestial sink for fossil fuel CO_2 have been based on changes in atmospheric O_2/N_2. A key assumption have been that inter-annual variability in the global annual mean oxygen flux is negligible. Hence the variability of air sea oxygen fluxes have recently experienced interest. In the present study the validity of this assumption in a shelf sea marginal to the Arctic ocean, the Barents Sea, is tested. The Barents Sea is dominated by Atlantic influence in the south and Arctic in the north and is because of this extremely sensitive to climate change. The ice extent is for example, dependent on variations in the amount of heat supplied by the Norwegian Atlantic Current, and the inter-annual variation may sometimes exceed the annual. These variations have implications for the meltwater pool in the Atlantic part which again affects primary production. The impact of this climate variability on the fluxes of oxygen, both due to primary production and air-sea exchange, have been investigated by applying a simple box model on a set of historical data grouped into warm and cold years. This have shown that the bloom is delayed and prolonged in warm as compared to cold years. There is furthermore a decreased flux of oxygen out of the surface water during summer in cold years. This is because a meltwater pool, caused by extensive ice melt in the Atlantic part effectively limits the temperature increase in Atlantic water during summer. Inter-annual variability in the air sea oxygen exchange in the Barents Sea is in the order of ±20%.

Can cold brine formation intensify the oceanic uptake of atmospheric CO_2?

by

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On two different fall cruises in 1999 and 2000 we have measured salinity, temperature, total carbonate (C_T), total alkalinity (A_T), and nutrients in Brine enriched Shelf Water (BShW) in Storfjord. During the last cruise Northwest Barents Sea was also included. Based upon these data we try to differentiate between the relative importance of air/sea gas exchange, new ice formation, remineralization and mixing has on the chemical properties of the source water which we believe form BShW. Our calculations show that the enrichment in C_T measured in BShW is partly due to uptake of CO_2 from the atmosphere during formation of brine water and post formed brine, remineralized organic matter. Further C_T access is, CO_2 uptake from the atmosphere 80 micro mol/kg and remineralization 60 micro mol/kg. We have suggested that BShW are formed from a mixture of brine plumes and high nutrient water mass similar to that we observed in the deeper parts of water column in the Northwest Barents sea.

Carbonate system parameters in the Barents Sea calculated from measured salinity, temperature, oxygen, and phosphate

by

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We have measured total carbonate (C_T), total alkalinity (A_T), dissolved oxygen (O_2), seawater temperature (T), seawater salinity (S) and phosphate (PHOS) during two cruises in the Western Barents Sea. On the bases of these data we have constructed three quasi-empirical equations that calculates: A_T as a function of salinity, C_T as a function of S, T, Apparent Oxygen Utilisation (AOU) for the fall/winter season, and C_T as a function of S, T and the conservative parameter PO for the spring/summer season. We have applied these equation to historic T, S, O_2, and nutrient data and compared the results to pCO_2 versus temperature relationship observed in the Barents Sea in 1967. Our calculations show that the surface seawater pCO_2 in the Barents Sea have increased about $50 \pm 12\mu$Atm in the period 1967-2000, which is comparable to the atmospheric pCO_2 increase ($\simeq 58\mu$Atm) in the same period.

Signatures of the North Atlantic Oscillation on stratospheric ozone

by

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The primary modes of wintertime climate variability, such as the North Atlantic Oscillation (NAO) have a marked signature on the ozone layer. We examine nearly 20 years of satellite TOMS observations, and diagnose the signatures of the NAO upon total ozone, with a main emphasis on the European and Atlantic sector. These signatures are twofold.

First, we seek for influences on the fast, transient (eddy) ozone variability linked to passing weather systems. Satellite column ozone observations indicate a strong signature of storm tracks in ozone, akin to “ozone tracks”, with marked asymmetries between the Pacific and Atlantic sectors. Of particular interest are the large amplitude ozone "mini-hole" events that frequently develop over the Atlantic in winter. A very large amplitude ozone mini-hole event developed in late NOV-early DEC 1999 over northern Europe, and Scandinavia in particular. Record low total ozone (< 170 DU) for that time of year was observed in Oslo, Norway, in latest days of NOV 1999. We demonstrate that the NAO governs the interannual variability of both the “ozone tracks” and the ozone miniholes.

In addition, we discuss how the seasonal-mean (quasi-stationary) ozone, or even the ozone trends, are influenced by the NAO.

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Chemistry and transport in the summer polar stratosphere

by

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The transport and mixing of ozone and other chemically active trace constituents in the summer stratosphere has become the focus of recent studies. This interest is partly due to the failure of three-dimensional chemical transport models to fully reproduce the summer ozone distribution in the polar regions.

A new European-wide project funded by the EU Environment and Climate Programme "Spring-to-Autumn Measurements and Modelling of Ozone and Actives Species" (SAMMOA) has started in March 2000, with the goal to better understand the issues of ozone transport and chemistry in the summertime northern high latitudes. We coordinate this project at the Norwegian Institute for Air Research (NILU). SAMMOA comprises eight other European research institutes and relies on using an integrated approach combining ground-based and balloon-borne measurements, global satellite observations, as well as advanced chemical/dynamical modelling and data assimilation.

The chemistry of ozone and the transport of long-lived tracers in the northern hemisphere spring and summer are investigated using a combination of model studies and satellite observations. The results of dynamical-chemical simulations carried out with high-resolution transport models are examined. We discuss in particular the slow mixing of polar and midlatitude air after the polar vortex break-up, the fate of the polar vortex debris in the transition from the spring to the summer regime, and ozone chemical loss processes in the summer high latitudes.

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Model calculations of stratospheric ozone recovery

by

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Changes in the chemical partitioning and stratospheric ozone due to changes in the reaction rates of the nitrogen chemistry are studies using a two-dimensional model. The model used is the Oslo two-dimensional stratospheric model. Model calculations have been performed both for the past and for the future using reaction rates given in JPL 1997 and JPL 2000.

It will be shown that the new reaction rates in the nitrogen family increases the efficiency of the NO_x catalytic cycle. When calculating the recovery of the ozone layer it is important which scenario that is used. Model calculations for the future are performed using the last WMO ozone assessment scenario, and the IPCC A2 and IPCC B1 scenarios.

Development and improvements of coupled ice-ocean model systems suitable for climate studies at DNMI

by

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In modern climate model systems an ocean model coupled to a sea ice model is of utmost importance. It is decisive to the performance of the whole coupled system that these important components give reliable results. Unfortunately, at present, there is no definite choice of how the best possible ocean model should be constructed. Several different model concepts are utilized for global climate simulations.

At DNMI, much of the attention in this first phase of RegClim has been focused on improving water mass conservation in the ocean model used for operational forecasts at the institute. This model is a local version of the σ-coordinate Princeton Ocean Model (POM), called MIPOM. The model utilizes a terrain-following coordinate system designed for simulations in regions with large topographic variations, a common feature of the Nordic Seas. Initially, it was hoped that this model could be used as the ocean part in a regional climate model system. However, experiments in both idealized and realistic domains show that the original model produces considerable amounts of artificial water masses, both too salty and too fresh compared with physical realisable salinities. To improve the situation, we have implemented a new advection scheme for salt and heat. In addition, we have implemented a more realistic parameterisation of horizontal mixing by introducing a rotated diffusion tensor, which facilitates mixing along isoneutral surfaces and reduces dianeutral mixing. The new advection scheme makes considerable improvements to the conservation of water mass properties. Unfortunately, to sufficiently reduce the numerical diffusion in the vertical direction to be suitable for climate studies implies a considerable penalty of increase in computational costs. Therefore, we decided instead to use the Miami Isopycnic Coordinate Ocean Model (MICOM) as the ocean component of the regional atmosphere-ice-ocean model system that is currently development at DNMI. This is a model that has been used as the ocean part in several global climate model systems.

To simulate the regional climate in the northern Europe and in the Arctic region, a proper sea ice model is needed. Experiments with the existing ice model at DNMI initiated the development of a completely new thermodynamic-dynamic sea ice model based on the computationally efficient Elastic-Viscous-Plastic (EVP) rheology. In addition, we have developed a surface flux module that parameterises the uppermost millimetres of the ocean surface. This skin layer is responsible for the direct communication of fluxes between the ocean and the atmosphere. The flux module improves the diurnal cycle of the model system by modelling the rapid response of the sea surface temperature to incoming short wave radiation. As a consequence, also the long-wave back-radiation from the sea surface to the atmosphere is improved. The flux module is implemented as an integrated part of the ice model. In this way, it is appropriate to denote the ice model as a surface flux model that controls the exchange of fluxes between the ocean and the atmosphere whether or not the sea is ice covered.

One of the main advantages of introducing a stand-alone surface flux model is that it serves as an attractive platform for coupling of atmosphere and ocean models. This gives a rather modular model system where the amount of work necessary to e.g. change to another ocean model is limited. The surface flux model has been successfully coupled to both the MIPOM and MICOM ocean models.

Life cycle modelling of SO_4 and BC for on-line climate impacts

by

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A life-cycle scheme for sulphate and black carbon (BC) is implemented in an extended version of the US National Center for Atmospheric Research Community Climate Model version 3.2 (CCM3). The scheme includes emissions of DMS, SO_2 and sulphate from natural and anthropogenic origins, and emissions of BC from biomass burning and fossil fuel emissions. Chemical and aerosol-physical processes are parameterised based on pre-scribed oxidant levels and background aerosols of maritime and continental origins. Aqueous chemistry depends on an estimated exchange rate of cloudy and clear air. Particulate sulphate and BC are tagged by their production mechanisms, enabling off-line calculations of aerosol optical and water-activity properties. In this study, calculations have been made without any feedback to meteorology. The results presented in the poster are from calculations done using two emission scenarios from the IPCC Third Assessment Report, representing the years 2000 and 2100. Computed turnover-times are comparable to other works in the field, giving values of 1.5 and 1.6 days for SO_2, 3.5 and 4 days for SO_4 and 4.7 days for BC for the IPCC 2000 and IPCC 2100 scenario respectively. The modelled oxidised sulphur compounds compare well with observations at many ground-level sites, including North America and Europe, and reasonable well in the free troposphere. For BC the differences in results are comparable to those obtained in other published works. Considerable underestimates are seen for both BC and sulphate in the Arctic, and overestimates are produced at ground level at low latitude. The reason for the former is not clear, while the latter is caused by omitted transport in cumulus clouds. While transport in cumulus clouds is important for distribution of aerosols, the formulation of this process in the model is uncertain. Two sensitivity tests will be presented in the poster, showing both uncertainties and problems with present day parameterisation of the process. While including convective transport reduces the overestimate at ground level in the tropics, it also leads to an overestimate of the aerosol burden in the upper troposphere. Sulphate and BC burdens are also considerably sensitive to the assumed efficiency of scavenging, especially within convective clouds. Until one get a better understanding of the physics and especially the parameterisation of these processes in models, there will be pronounced uncertainties in the resulting aerosol distribution, hampering an exact evaluation of climate effects of anthropogenic aerosols.

Decreasing overflow from the Norwegian Sea to the Atlantic Ocean

by

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In a paper in Nature 21st June 2001, Hansen, Turrell and Østerhus report that the overflow of cold water through the Faroe Bank Channel has weakened since 1950. The Faroe Bank Channel is the deepest passage across the Greenland-Scotland Ridge and the flow of cold water through this channel has been estimated to carry about one third of the total overflow of cold water from the Nordic Seas into the Atlantic.

Using a combination of modern high quality current measurements and long-term hydrographic observations from a weather ship station M, we found that the flux of pure overflow water (colder than 0.3˚C) through the channel decreased by at least 20% in the period 1950 – 2000. Most of the decrease took place after 1970 and the decrease seems to have accelerated considerably during the last decade of the 20th century. We argue that the decrease most probably includes also warmer components of the overflow and other regions east of Iceland, so that the total Iceland-Scotland overflow has decreased in magnitude (flux).

The consequences of this work depend on the behaviour of the Denmark Strait overflow. It is conceivable that the Denmark Strait overflow has increased in magnitude in the same period as the overflow east of Iceland decreased; but there are no measurements or other indications to substantiate this. If that is not the case, then the total overflow from the Nordic Seas must have decreased during the latter half of the 20th century. This implies that the contribution from the Nordic Seas and the Arctic Ocean driving the global thermohaline circulation must also have decreased.

Furthermore, the cold overflow from the Nordic Seas requires a compensating inflow of water from the Atlantic to the Nordic Seas. A recent budget estimate indicates that about three quarters of the Atlantic inflow returns as overflow. The overflow is therefore important in driving the Atlantic inflow and reduced overflow can be expected to lead to reduced Atlantic inflow. We indicate that this may perhaps help explain why some of the areas most affected by the Atlantic inflow (like the Faroe Islands) have not experienced global warming. The heat and salt transported by the Atlantic inflow is vitally important for the conditions of the Nordic Seas and the Arctic Ocean and, if this conclusion is maintained, far-reaching consequences can be expected.

The observed overflow decrease may be part of naturally occurring variations, but the observations are also consistent with predicted consequences of anthropogenic climate change. Increased melting of sea-ice and increased freshwater supply due to global warming would tend to lower the density of surface waters in the areas affected. This can be expected to reduce the efficiency of convection and other processes that form the overflow water. Thus the observed effects may be a sign that global warming has affected the global thermohaline circulation and oceanic heat transport towards the Arctic in the manner predicted.

Ice and Freshwater transport through the Fram Strait

by

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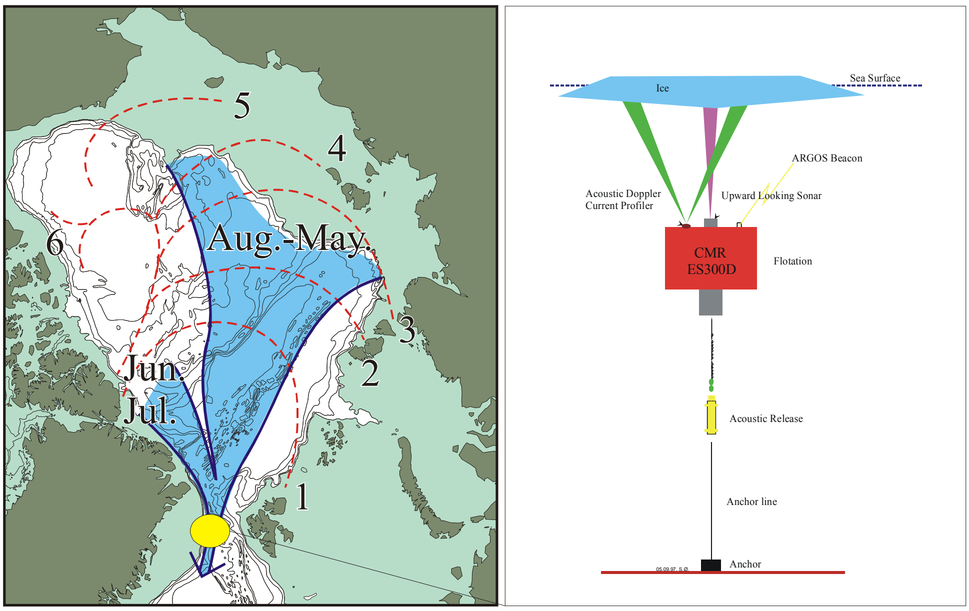
Measuring the magnitude and variability of the ice and freshwater flux through the Fram Strait is an important element in understanding the climate variability in the Arctic. Since the majority of the ice and freshwater that leave the Arctic Ocean pass through the Fram Strait, figure, this passage can be considered the key area for estimation of the net production of ice in the Arctic Ocean. As this ice export in turn represents the major part of the ice production in the Northern Hemisphere, it becomes an important climate signal. In addition the ice and liquid freshwater export from the Arctic Ocean represent the major input of freshwater to the Nordic Seas, where a variable input of melt water may effect the stability, and thereby be of crucial importance for the local convection. Since 1990 the Norwegian Polar Institute (NPI) has monitored the ice thickness and the ice transport through the Fram Strait, most years by means of two moorings. For the period 1990-96 the mean annual ice export was about 3000 km^3 pr year. This efflux shows significant variation from year to year, mainly caused by variation in the atmospheric forcing and to a lesser degree by variation in the annual mean ice thickness. Since 1997 Alfred-Wegener-Institut für Polar- und Meeresforschung (AWI) and NPI have operated fourteen moorings across the Fram Strait as a part of the EU founded project VEINS (Variability of Exchanges in the Northern Seas). Monitoring the Fram Strait flux of ice and freshwater is a key CLIVAR/ACSYS variable.



The ice and liquid freshwater in the Arctic Ocean is transported by the Transpolar Current through the Fram Strait. The yellow dot marks the monitoring position and the right a sketch of the mooring configuration

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REPORT SERIES SCIENTIFIC REPORT	REPORT NO. OR 66/2001	ISBN Anton Eliassen Inga Fløisand ISSN 0807-7207	
DATE	SIGN.	NO. OF PAGES 174	PRICE NOK 205.-
TITLE Climate and Ozone Programme Conference Hotel Rosenkrantz, Bergen 27–29 November 2001		PROJECT LEADER Inga Fløisand NILU PROJECT NO. N-95102	
AUTHOR(S) Edited by Inga Fløisand		CLASSIFICATION * A CONTRACT REF.	
REPORT PREPARED FOR The Research Council of Norway P.O. Box 2700 St. Hanshaugen N-0131 OSLO			
ABSTRACT Abstracts from oral and poster presentations.			
NORWEGIAN TITLE Forskningsprogram om endringer i klima og ozonlag. Programkonferanse			
KEYWORDS Climate	Ozone layer		
ABSTRACT (in Norwegian)			

** Classification*	*A*	*Unclassified (can be ordered from NILU)*
	B	*Restricted distribution*
	C	*Classified (not to be distributed)*