

Anticipated changes in the Nordic Seas marine climate: Scenarios for 2020, 2050, and 2080.

By

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Abstract:

Possible future changes in the Nordic Seas marine climate are here discussed. The wide range of climate models used in the Intergovernmental Panel on Climate Change predict a global mean temperature increase between 1-6°C by the end of this century, with the estimates using the intermediate IPCC B2 scenario being in the range 1.9-3.4°C. For climate models forced by a 1percent per year CO₂ increase only, the so-called CMIP2 integrations, the increase in temperatures is close to 2°C after CO₂ doubling. For the Arctic region, the warming will probably be twice as high. A result is a rapid decline in the sea ice extent simulated by most models. Changes in the Nordic Seas region have been analysed in a CMIP2-integration with the Bergen Climate Model. In this model there is a trend towards more westerly winds, and by 2080 the entire Barents Sea is ice-free for all months of the year, and the Arctic Ocean ice-free during the summer months. There is a 1-2°C warming of the Nordic Seas and Barents Sea, and a slight increase in the salinity. The Arctic Ocean is freshened, probably due to more ice melting and river runoff from the Eurasian continent. There is no indication of a reduction of the deep-water formation in the Nordic Seas.

1. Introduction

This is a contribution to the Arctic Climate Impact Assessment (ACIA) work, which goal is to “evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences”. The impact assessment will address projected future changes focusing on the periods near the years 2020, 2050, and 2080. ACIA is using the B2 scenario, which is an intermediate scenario of the Intergovernmental Panel on Climate Change (IPCC) Special reports, and describes a world with moderate increasing population, economic development and technology change. The assessment will discuss the changes in the Arctic in four different sub-regions (Figure 1): The Nordic Seas (including the Barents Sea) sector towards the Pole, the Kara and Laptev Seas sector, the Chukchi and Bering Seas and Alaskan coast sector, and finally the Labrador Sea, Baffin Bay, and Canadian Archipelago sector. This note is an input to the marine climate part of ACIA sub-region 1, the Nordic Seas sector.

This note is divided into seven sections. In the next section, predictions for the increase in the global mean temperatures based on different models and emission scenarios are shown, and the uncertainties in the climate scenarios are addressed (Section 2). In the following sections we discuss the observed and predicted variability in the atmospheric temperatures and wind systems (Section 3), the ocean circulation and water mass distribution (Section 4), the sea ice

distribution (Section 5), and finally the mixing and deep-water formation (Section 6). A summary table is given in Section 7.

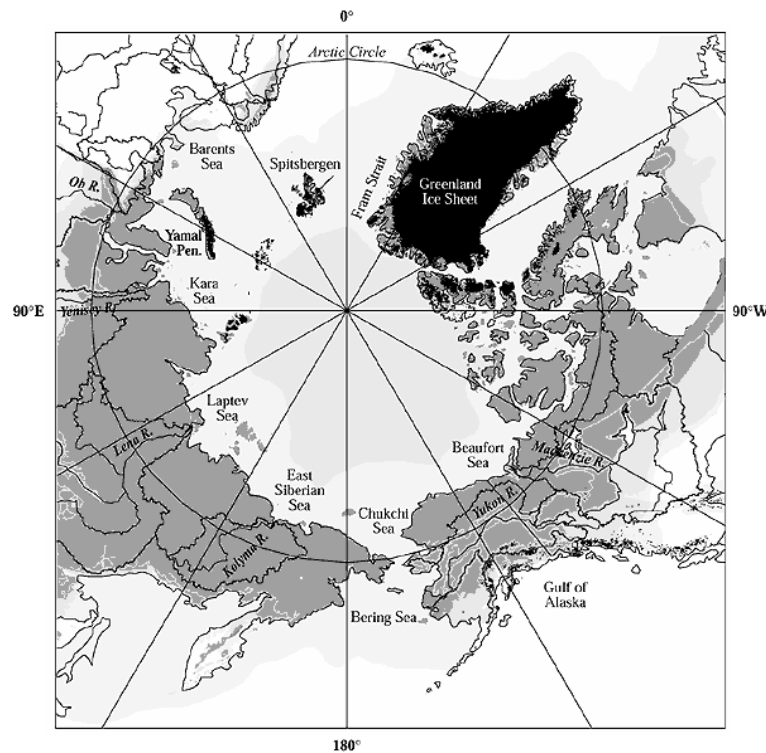


Figure 1: The Arctic region. Dark shading marks permanent glaciers, and gray shading marks permanent permafrost (Figure 16-1 in IPCC TAR: Impacts, adaptation and vulnerability).

2. B2 scenario predictions

Climate models using the moderate B2 scenario in average predict an increase in the global mean temperatures of 0.7°C by the year 2020, 1.4°C by the year 2050 and 2.1°C by the year 2080 (Figure 2). The different climate models using this scenario predicts a temperature increase by the year 2100 ranging from 1.9°C to 3.4°C, illustrating the large uncertainties in the predictions.

An interesting program has been the coupled model inter-comparison project (CMIP), where a control-integration and a perturbation-integration with a 1 percent increase in CO₂ have been compared for a range of different climate models. The change in the global mean temperature for 18 of the models is shown in Figure 3, left. After 80 years (doubled CO₂), the average global mean temperature increase for the models is 2°C, or 0.25°C/decade, in the lower range of the values found from the B2 scenario integrations. For the four models used in the B2 scenario (Figure 3, right), the average temperature increase averaged over the region north of 60°N is 0.4°C/decade, or almost twice the global trend.

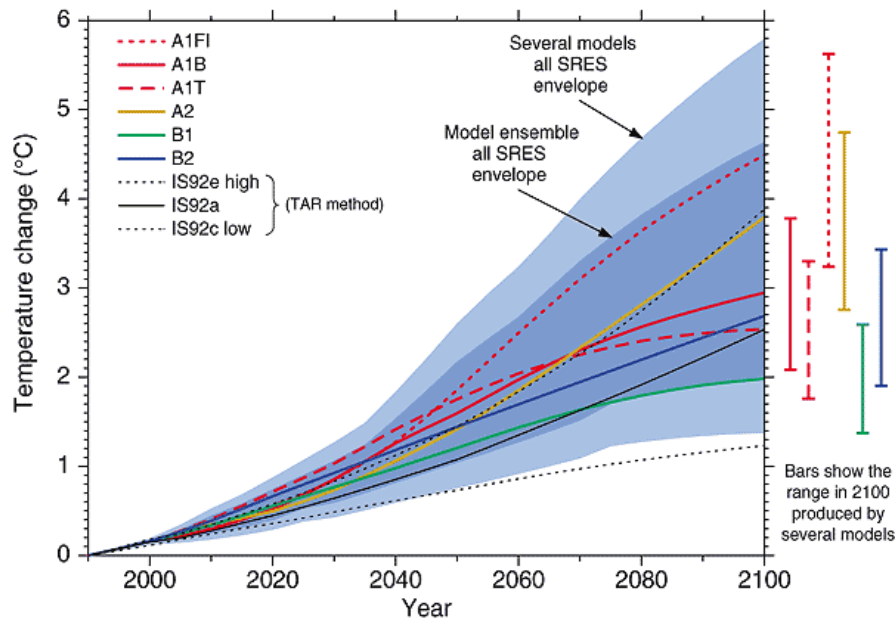


Figure 2: Future changes in global mean temperature different emission scenarios using several different climate models. The bars show the range of simple model results in 2100 (Figure 9.14 in IPCC TAR: The Scientific Basis).

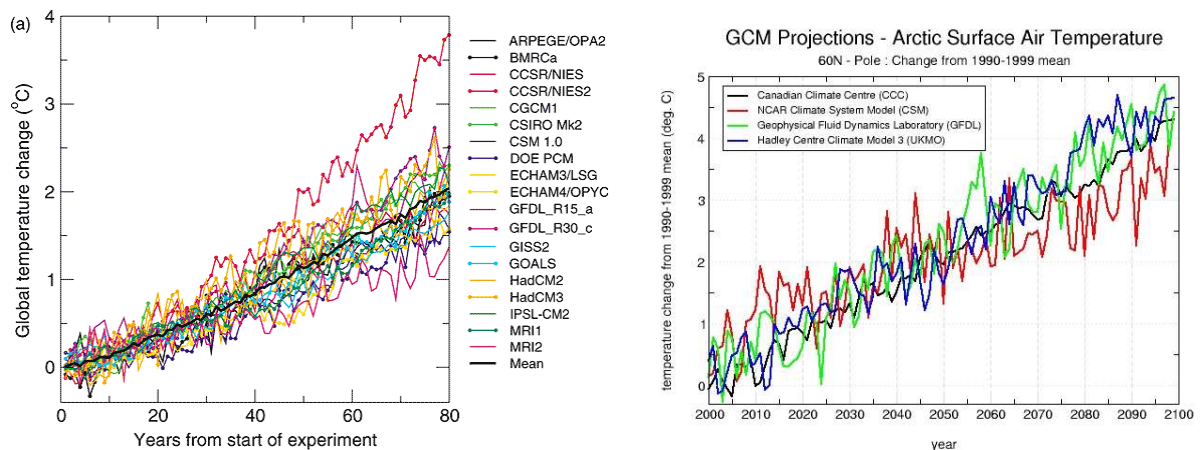


Figure 3: Left: Future changes in global mean temperatures for 18 different models participating in the coupled model inter-comparison project second phase (CMIP2). The only change from the control runs is a 1 percent increase in CO_2 per year from ca 1990 values (Figure 9.3 in IPCC TAR: The Scientific Basis). Right: Future changes in Arctic mean temperatures for 4 models using the B2 scenario (ACIA web pages, <http://zubov.atmos.uiuc.edu/ACIA/>).

Turning from global to regional scale climate change, the uncertainties are generally much larger. There are at least three reasons for this: 1) The natural variability in the local climate may in many places be of an order of magnitude larger than the variability in the global mean state of the climate, so the signal to noise ratio becomes small; 2) we do not know all the physics behind the variability; and 3) parameterisations of unresolved topography and physics may be inaccurate.

As the climate models have typically been too coarse to resolve local or regional topography (typical grid size has been 200 km – 400 km), the usual approach to get high resolution climate scenarios has been to take the results from a global model and use as input to a regional atmospheric model. As there are large discrepancies between the climate scenarios from the coarse models, output from several models should be dynamically downscaled in this way, in order to give a best possible statistical significance for the results.

3. The atmosphere temperatures and wind system.

Observations

During the last decades, there has been a significant warming trend over the Arctic, corresponding in average to approximately 5°C/century. The warming has not been uniformly distributed, as there has been a slight cooling over the eastern Canada, northwest Atlantic and Greenland area, and a stronger warming over Siberia.

The observed temperature pattern is related to the large-scale atmospheric pattern known as the North Atlantic or Arctic Oscillation (NAO/AO), an atmospheric sea-saw in pressure between the low-pressure region in the north, and the sub-tropical high in the south. The strongest pattern is found in the North Atlantic, where the Icelandic low and the Azorean high are the centers of action. A much-cited index for the NAO is the pressure difference between the two poles, typically Lisbon or Gibraltar to the south, and southwest Iceland, to the north. The NAO index resembles the global temperature pattern, with a preferred positive state during the 1930s and 40s, a steadily decrease to a minima in the 1960s, and then a steady increase towards record highs in the 1990s. The trend is a manifestation of a strengthening of the North Atlantic westerlies, with increased heat and moisture transport responsible for a row of warm and wet winters experienced in the North-east Europe experienced in the end of last century.

Predictions

Figure 4 shows the predicted temperature increase from the 1961 to 1990 period, to the last three decades in this century, as a mean over all models using the B2 scenario. They show a general warming of typically 1-2°C over the oceans and 2-3°C over the continents. There is a strong increase in the temperature trends towards the Arctic, with a temperature increase over Norway ranging from 3°C in the south to 5°C in the north, and temperature increase over northern part of Canada and Siberia reaching 6°C.

For the Nordic Seas area, the predicted temperature increase is ranging from 3°C in the south to 6°C in the Fram Strait and eastern part of the Barents Sea region. In the Arctic Ocean, the warming is exceeding 8°C north of the Siberia, while north of Alaska, Canada, and Greenland it is only 5°C.

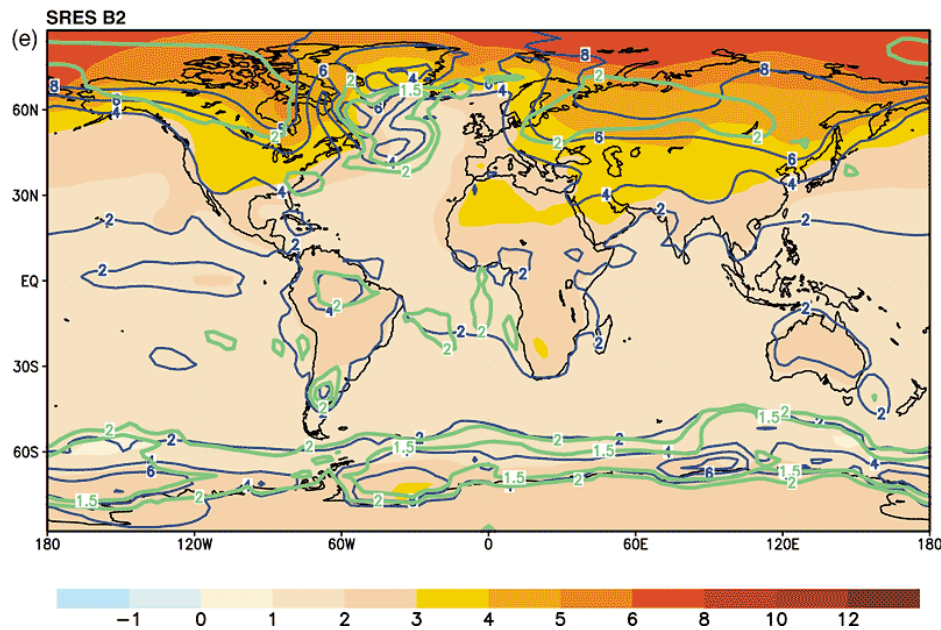


Figure 4: The multi-model ensemble annual mean change of the temperature (color shading), its range (thin blue isolines) (Unit: °C) and the multi-model mean change divided by the multi-model standard deviation (solid green isolines, absolute values) for the SRES scenario B2. Both SRES scenarios show the period 2071 to 2100 relative to the period 1961 to 1990. See text for scenario definitions and description of analysis technique. In (b) and (d) the ratio mean change/standard deviation is increasing towards the low latitudes as well as in (a), (c) and (e), while the high latitudes around Antarctica show a minimum (Figure 9.10 in IPCC TAR: The Scientific Basis).

Here a warning should be given: The strongest temperature increase is evidently found in areas where there is ice in present day climate (in the models), and not ice in the future climate. Thus the strong warming found in the northern and eastern parts of the Nordic Seas, is a result of errors in simulating the present day climate, giving too large ice cover, rather than a warming of the open sea areas of the present day climate. In order to give realistic scenarios for the atmosphere and ocean parameters in the Nordic Seas region, it is essential to know how the NAO or AO will behave in a world with higher concentrations of greenhouse gasses and sulphate (aerosols). However, the physics leading to the variability and recent trend in the NAO/AO are not known. Several recent simulations with a relatively high-resolution atmospheric model indicate that the NAO is forced from the tropics, and in particular from the Pacific and Indian Ocean. The exact mechanism is not clear, but it seems to be linked to changes in the precipitation pattern and release of latent heat. If they are right, with increased greenhouse gas forcing and warmer waters in the tropical regions, we may expect a continued trend towards stronger and more persistent westerlies, with especially warmer and wetter winters as the result.

Analysis of the model output from several different climate models (Benestad, Cicerone 6, 2000), show a large spread in the simulated development of the NAO. However, in average the models give no significant change in the NAO during the next 100 years. We should not put too much confidence into this result, as the present day climate models are not able to capture the observed trend in the NAO. There may be several reasons for this, among the

most cited are too coarse resolution in the ocean models (especially in the tropics), too low vertical resolution in the stratosphere, or simply that the observed low frequency variability and trend in the NAO is an accumulated result of high frequency noise (weather). While the two first two problems may be solved with better computer resources, the latter point gives bad prosperities, as in that case the NAO and a significant part of the development in atmospheric and oceanic climate in our region cannot be predicted.

In a recently finished CMIP2 integration with the Bergen Climate Model (BCM), there is a trend in the NAO during the 75 years of integration, representing an increase in the westerlies of approximately 2 percent/decade. There is also a weak tendency to become more variability in the winter NAO, a feature that has been seen in observations during the last 50 years (Figure 5).

To summarize, it is probably that the low frequency variability in the westerlies (NAO) may be linked to the global warming, either as a direct feedback from the tropics, as a result of stratospheric cooling, or as a combination of both. If that is the case, the possibility for a further strengthening of the westerlies is certainly realistic.

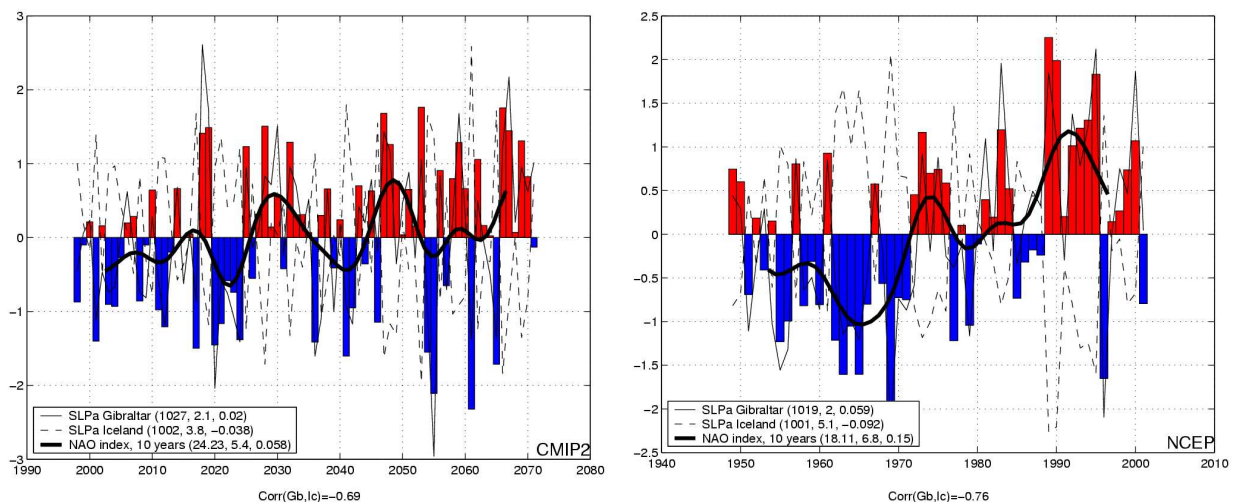


Figure 5: The NAO index in the BCM CMIP2 integration (left) and the NCEP data (right). The bars show the unfiltered NAO index calculated using the grid points nearest to the positions 22°W, 64°N (Iceland) and 5°W, 36°N (Gibraltar). The thick line shows the 10 years low pass filtered index, and the thin lines the normalized pressure anomalies at Iceland and Gibraltar. Values in the legend box are means, standard deviations and trends in the unfiltered pressure and pressure difference time series.

4. Water mass distribution and currents.

Observations

There has been a substantial change in the climate conditions in the Nordic Seas during the period with reliable instrumental records. Here are some key observations: large salinity anomalies, more polar water and eastward shift of the front between Atlantic Water (AW) and Polar Water (PW), a reduction in the deep water formation in the Greenland Sea, a warming

of the deep waters and reversal of the deep currents in the Nordic Seas, and a reduction in the Faroe Bank overflow.

Predictions

Due to the large thermal capacity of the water, the oceans will probably be less warmed than the atmosphere. Estimates for the Nordic Seas by the Hadley Center model give a temperature increase of the range 1-3°C during the next 100 years, which is in agreement with other models (e.g. Max Planck). However, due to lack of ocean data from the other models, and to a common problem with the sea ice distribution in the models, it is difficult to use the models in discussions of the development of the regional climate. We will therefore quote some numbers from a newly finished 80 years CMIP2 integration (1 percent/year increase in the CO₂ concentration) with the Bergen Climate Model (BCM). The evolutions of the temperature and salinity fields are shown in Figures 6 and 7.

BCM CMIP2

From the experiment with the BCM, we have looked at the model years 1) 20-28 (ca 2016-24), 2) 50-58 (ca 2046-2054), and 3) 76-80 (ca 2072-2076), thus the three periods are approximately the focus time periods in the ACIA framework. There are no significant differences between summer and winter temperature changes, so only March values are shown here.

sea surface temperatures (Figure 6)

From today and to 2020 there is a cooling of between 0 and -1°C in most of the model area. Largest drop in temperature is found along the marginal ice zone in the Barents Sea and off the east Greenland coast, with maximum of more than 1°C in the Denmark Strait. Some of this cooling is probably associated with the weak westerlies in this period (see Figure 5). In the central Nordic Seas there is a warming of 0.5°C compared to the start state. In 2050 the entire Nordic Seas has become warmer than the initial state, with the exception of a small spot in the Denmark Strait. Largest warming is now found in the northeastern Barents Sea, in the Baltic Sea, and to the south of Iceland. By the time of a doubling of the CO₂ (2070), surface temperatures in the Nordic Seas have increased by 1-2°C, with highest values found in the Baltic Sea, the North Sea and the Barents Sea. Minimum warming (less than 0.5°C) is found in the Denmark Strait.

sea surface salinities (Figure 7)

Salinity changes in the Nordic Seas are generally small, except for the areas influenced by coastal runoff and melting of sea ice. By the year of 2020, there has been a freshening of typically 0.1 to 0.3 psu in the Baltic Sea, southeast in the Barents Sea and in the Kara Sea, and also a weak freshening along the east Greenland coast. The freshening trend continues to the 2050s, with values in the Baltic Sea and north of Siberia in the range of 0.1 to 0.5 psu. There is also a significant freshening in the Polar Ocean (0.3 to 0.5 psu), which is evidently advected south with the East Greenland Current (EGC) into the Denmark Strait and East Icelandic Current (EIC). In the AW regime the waters have become slightly more saline, but still without exceeding 0.1 psu. In the 2070s the model gives a 0.1 to 0.2 psu more saline water south of the inflowing area, and less than 0.1 psu more saline AW in the Nordic Seas. In the Baltic Sea, north of Siberia and in the Polar Ocean, salinities have decreased between 0.5 and 1 psu, and again the tongue of negative salinity change can be seen along the East Greenland Coast.

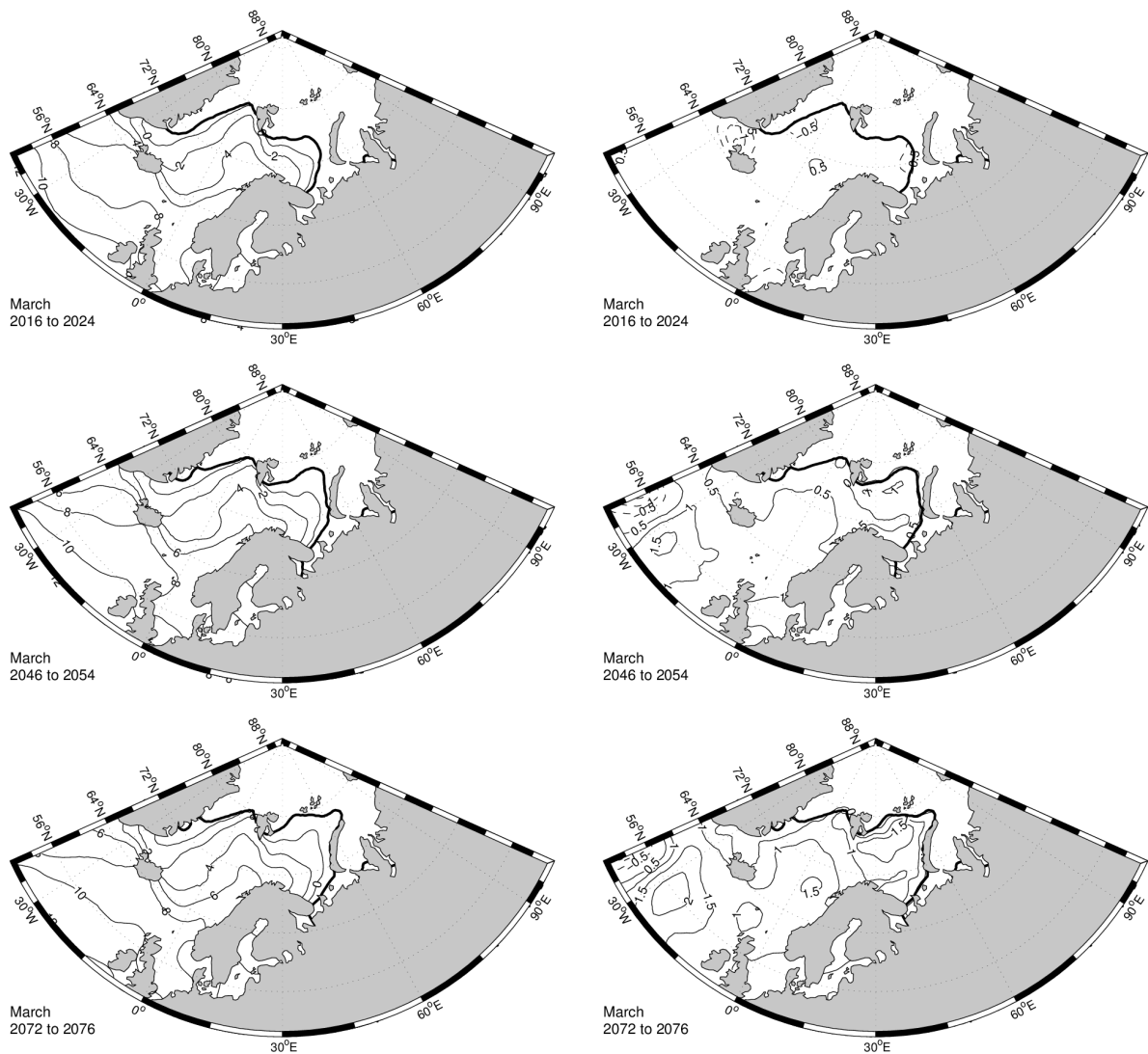


Figure 6: Evolution of the temperature (SST) and sea-ice field in the BCM CMIP2 integration. Left column shows the March SST and sea ice distribution around the years 2020, 2050, and 2075, and right column changes from year 2000 to 2020, 2050 and 2075 respectively.

Currents (figure not shown)

From 2000 to 2020 there is a small (<10%) increase in the net inflow through the Iceland-Scotland Gap, mainly near Iceland, and a corresponding increase in the Denmark Strait outflow. There is generally a weakening of the cyclonic gyre in the Nordic Seas of a few percent. By the year of 2050, the Nordic Seas gyre has weakened further more (10%). It is more inflow of AW in the eastern branch (east of the Faroe Island), and less in the western. No significant changes are seen in the Barents Sea. Towards the 2070s there is a further reduction in the internal cyclonic flow in the Nordic Seas. There seems to be a weak strengthening (~0.25SV) of the AW transport trough the Barents Sea, and a similar reduction of the flow through the Fram Strait.

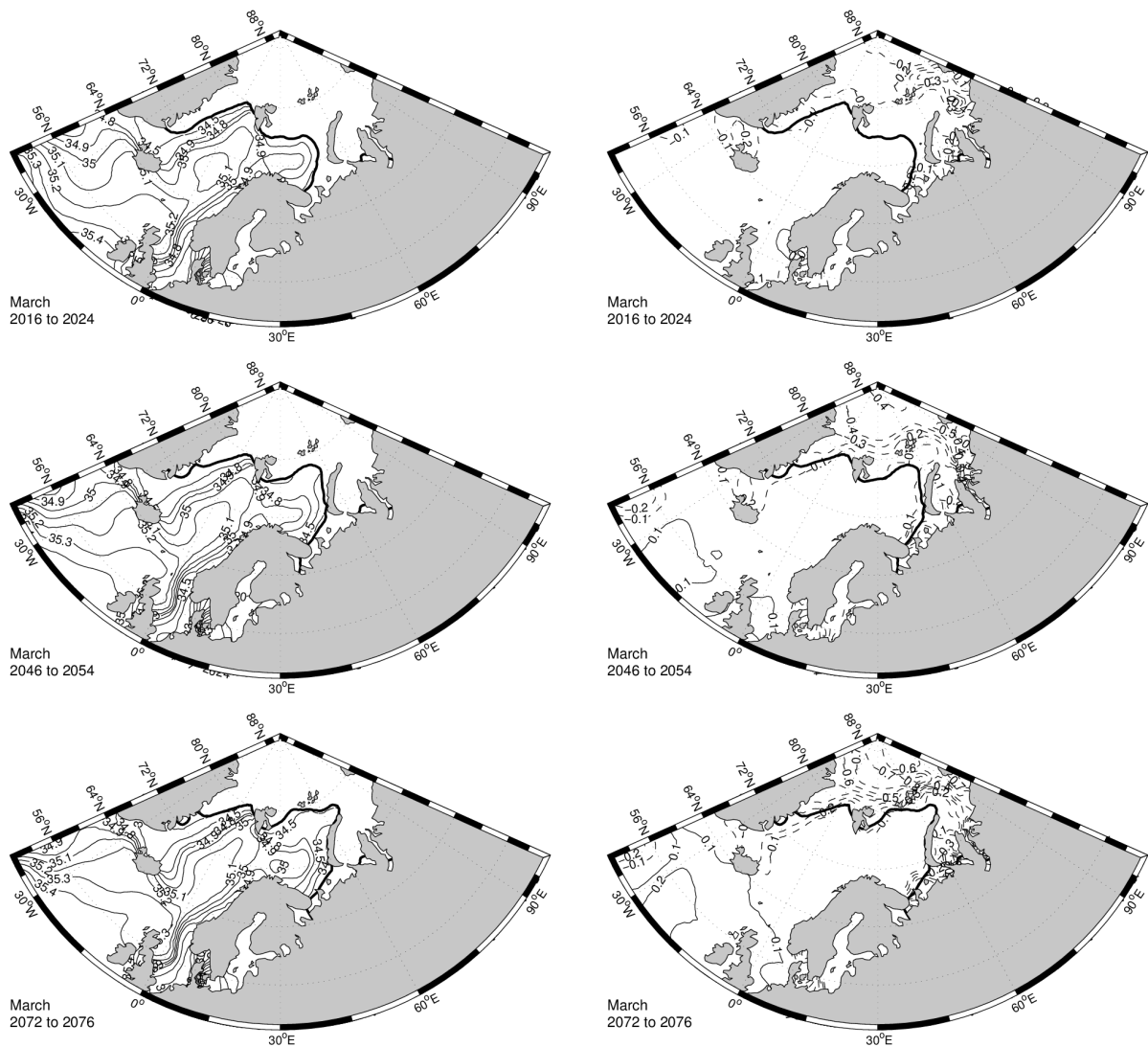


Figure 7: Evolution of the salinity (SSS) and sea-ice field in the BCM CMIP2 integration. Left column shows the March SSS and sea ice distribution around the years 2020, 2050, and 2075, and right column changes from year 2000 to 2020, 2050 and 2075 respectively.

5. The sea ice thickness and distribution.

Observations

It has for a long time been a well-established fact that the strongest climate warming will be in the Arctic, and in the Arctic region covered by thin ice. The Arctic basin has therefore been looked upon as a “canary bird”, which should give an early warning about changes in the climate. As a result, especially three papers which were published in the last month of the previous century got much attention in the newspapers and televisions around the world. There had been a 20 percent decrease in the summer extent of the Arctic sea ice the last 30 years (Johannessen et al, 1999, Science), the ice had thinned by 40% in the central Arctic the last 30-40 years (Rothrock et al 1999, Geophysical Research Letter), and finally the measurements fitted well with the results obtained by model simulations using climate models forced by CO₂ and aerosols (Vinnikov et al, 1999, Science). See left panel in Figure 8.

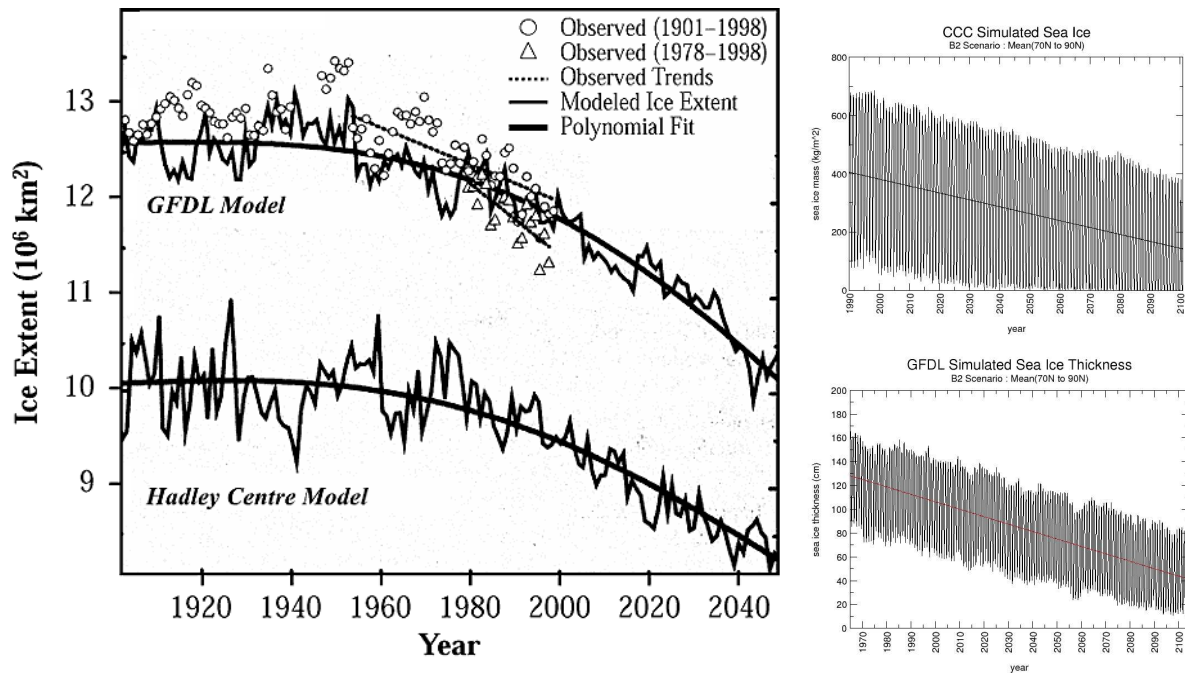


Figure 8: Left: Change in annual mean sea-ice extent for two different climate models with CO₂ and aerosols, compared to observations (Figure 16-6 in IPCC TAR: Impacts, adaptation and vulnerability). Right: Predicted decrease in the sea ice volume in the Arctic from two different climate models (ACIA web pages, <http://zubov.atmos.uiuc.edu/ACIA/>).

Predictions

The decline in the ice cover seems to be a robust result obtained by many different climate models. Some results are shown in the right hand panels in Figure 8. In the Canadian Center climate model (CCC), Arctic becomes ice free during summer as early as in 2030, while for the American model (GFDL), Arctic does not become ice free before after the turn of the next century.

The change in ice cover between present day climate and the twenty years period around year 2055, is shown for four different models in Figure 9. Note that both the HadCM3 and CSM models predicts a decrease in the ice cover in areas where we do not have ice today, thus emphasizing the problems of using the climate scenarios to do regional climate studies. There is also a large discrepancy in the simulated changes in the ice cover in the Arctic Ocean. However, to a degree of certainty we can expect a large decrease in the sea ice cover in the Nordic Seas – Arctic Ocean during this century, and most of the areas will be ice-free at least during summer. Thus we may expect the marginal ice zone in the Barents Sea to gradually retreat towards north and east, and the entire Barents Sea and Siberian Shelf will probably be ice-free during summer already in a few decades.

Results from the CMIP2 experiment with the Bergen Climate Model, where the CO₂ concentration was increased with 1 percent/year, showed that the winter maximum in the Barents Sea will retreat with an average speed of 10 km/year, leaving the entire shelf area ice-free by the year of 2070. Also much of the East Greenland Coast will be ice free in the second half of this century. During most summers there is only ice present in the region north of Greenland and Canada, and for some summers it is ice-free also here.

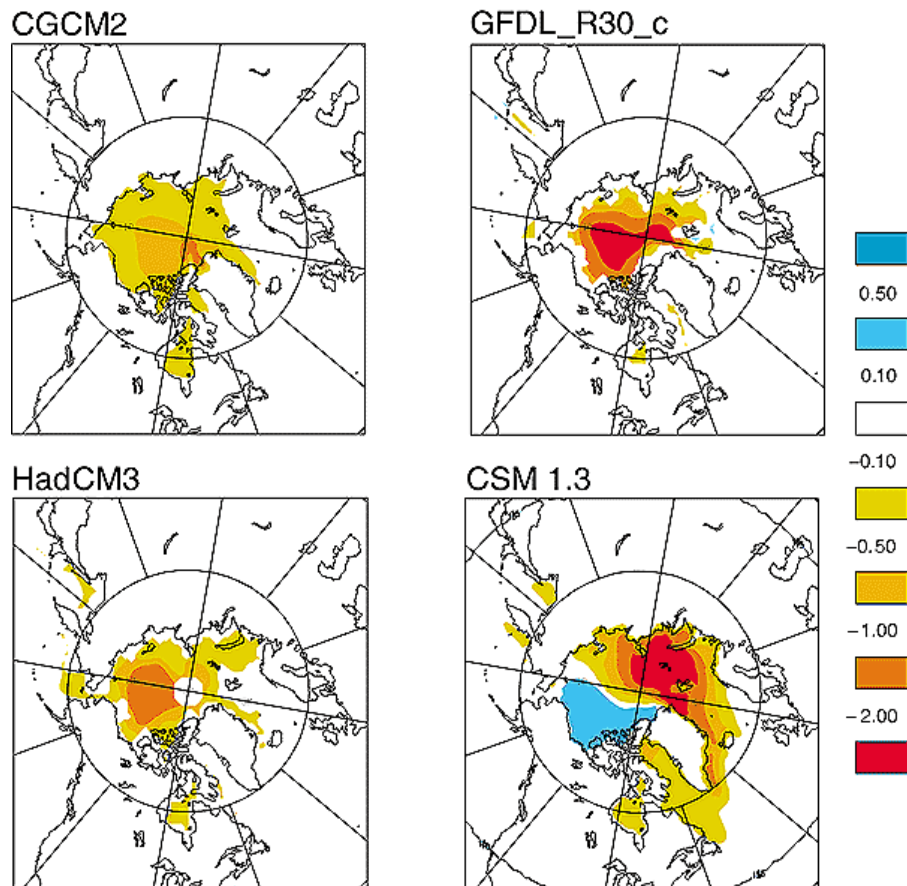


Figure 9: Change in annual mean sea-ice thickness between the periods 1971 to 1990 and 2041 to 2060 as simulated by four of the most recent coupled models. All models were run with similar forcing scenarios: historical greenhouse gas and aerosol loading, then future forcing as per the IS92a scenario. The color bar indicates thickness change in meters - negative values indicate a decrease in future ice thickness (Figure 9.9 in IPCC TAR: The Scientific Basis).

6. Deep water formation

Observations

Since the 1960s when there was an active and deep-reaching convection in the Greenland Sea, there is evidence of a reduction in the deep-water formation in this area (Dickson et al, 1996, progress in oceanography). In addition, measurements from the Faroe-Shetland overflow indicate a reduction in the transport of dense water from the Nordic Seas toward the North Atlantic (Hansen et al, 2001, Nature). It is uncertain to what extent this is influencing the global thermohaline circulation, and the heat transport towards our latitudes.

Predictions

There have been many warnings about an abrupt stop in the thermohaline circulation, and a possible rapid change towards a colder climate in the northern Europe, as a possible scenario under global warming.

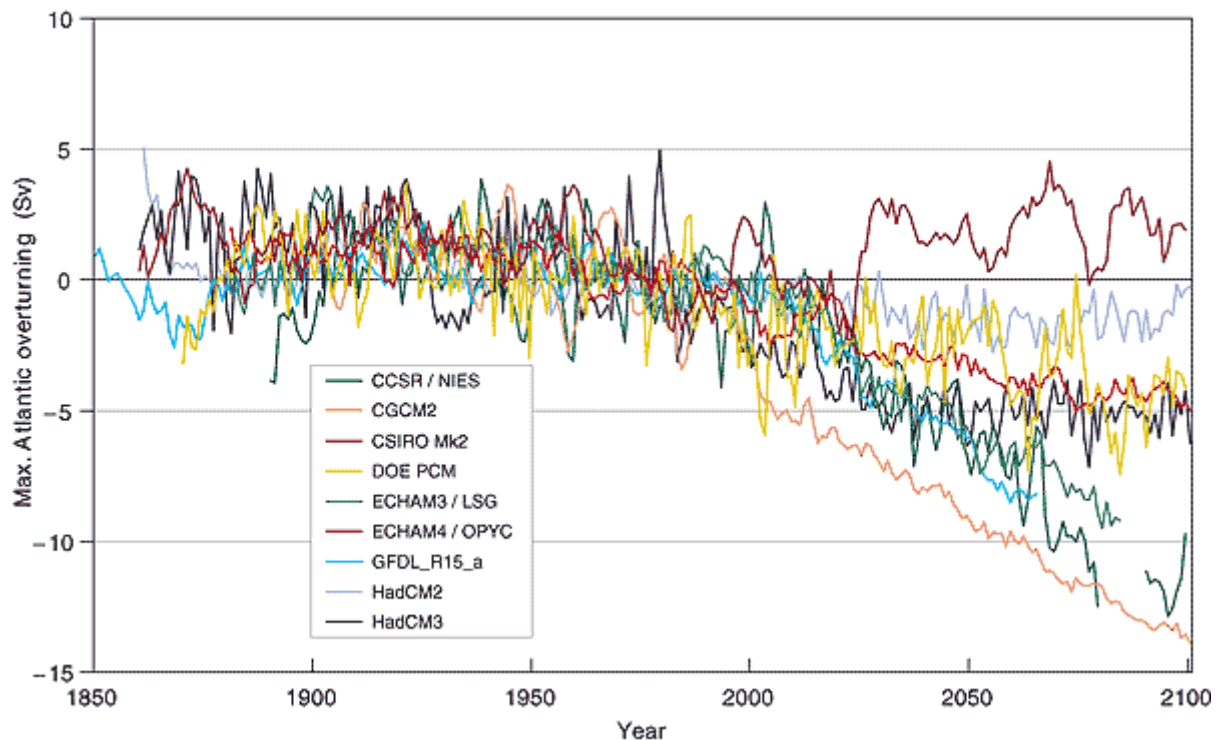


Figure 10: Simulated water-volume transport change of the Atlantic “conveyor belt” (Atlantic overturning) in a range of global warming scenarios computed by different climate research centers. Shown is the annual mean relative to the mean of the years (1961 to 1990) (Unit: Sv, $10^6 \text{ m}^3 \text{ s}^{-1}$). The past forcing is only due to greenhouse gases and aerosols (Figure 9.21 in IPCC TAR: *The Scientific Basis*).

These scenarios are all built on idealized experiments, or experiments with very coarse resolution models, not necessarily simulating a realistic climate and physics. From Figure 10 it is seen that many of the models in IPCC simulate a reduction in the overturning in the North Atlantic, but none of them an abrupt stop as many have warned about. In the German model, ECHAM4/OPYC, there is no reduction at all. This is explained by better resolution in the tropics, as more fresh water is transported from the tropical Atlantic to the Pacific, resulting of advection of more salty water into the sinking regions in the northern parts of the Atlantic.

In the CMIP2 integration with the BCM no significant reduction in the overturning is found (not shown). In the central Nordic Seas, there is a tendency for the mixed layer depth to become shallower as a response to slightly less density in the area, indicating more shallow convection here. There is a tendency for deeper mixing closer to the ice edge, as the mixed layer depth increases in the Barents Sea and in the western and northern parts of the Greenland Sea.

7. Summary

Due to large discrepancies between the different models, and the failures in many models to simulate the sea ice extent in the Norwegian and in particular the Barents Seas, it is difficult to give qualified guesses for the state of the Nordic Seas and Arctic region for the years 2020, 2050, and 2080. The spatial and temporal time scales are simply too small. While the overall

trends can be given with some sort of confidence, the presence of the possible unpredictable North Atlantic Oscillation can for periods of several years mask the trends in the data sets.

In Table 1 we have given a summary of this note. While most results are objectively analyzed based on many models, some of the specific values may be biased towards the scenario given by the Bergen Climate Model. The reasons are the availability of the data, and the fact that the BCM gives a more realistic ice cover in the Barents Sea, than most of the other models.

	Observed variability/change in the Nordic Seas during the last 3 decades.	2020	2050	2080
Atmospheric temperature	A warming trend in the eastern part, cooling in the western part, probably associated with the NAO	Ca 1°C warmer. Spatial differences due to NAO	Ca 2°C warmer. Spatial differences due to NAO	Ca 3°C warmer. Spatial differences due to NAO
Wind systems	Increased westerlies	Ca 5% (?) more westerlies. Depends on the state of the NAO.	Ca 10% (?) more westerlies. Depends on the state of the NAO.	Ca 15% (?) more westerlies. Depends on the state of the NAO.
Ocean currents	Probably increased NAC. More narrow NWAC, and possible increased flux to the Barents Sea and Arctic Ocean. Decreased flux out through FS channel.	Ca 5% weakening of the Nordic Seas Gyre. Less inflow of AW (?)	The Nordic Seas Gyre further reduced. The inflow of AW more in the eastern (Faroe-Shetland) branch.	AW distributed more East. Possibly a strengthened transport to the Barents Sea, and a reduced flow through the Fram Strait.
Water mass distribution	Increased influence of PW. Warmer water in the NWAC. More fresh intermediate water. Warming of the deep water.	The observed trends will probably continue. Possibly cooling in negative NAO years.	Ca 1°C warmer and 0-0.1 psu saltier in the AW domain. Fresher water along the coast.	1-2°C warmer, most in the Barents Sea. More continental runoff. More salty AW inflow.
Sea ice	Substantial reduction in both the extent and thickness.	The observed trends will probably continue. Possibly more ice in negative NAO years.	The se- ice edge in the Barents Sea moves towards northeast ca 100 km/decade.	Barents Sea and most of EGC ice-free entire winter. Most of the Arctic Ocean ice free during summer.
Deep-water form.	Less convection in the Greenland Sea, and more convection in the Labrador Sea. The total overturning has probably been fairly constant.	Deeper mixed layer southwest of Iceland and in the central Nordic Seas. Possibly related to NAO state.	Generally a shallower mixed layer depth in the Nordic Seas, indicating less deep water formed.	Deeper mixed layer in the Barents Sea and western Nordic Seas. Elsewhere more shallow.

Table 1: Summary of the results given in this report.