# Towards an ice-free Arctic?

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*If the rapid melting of the ice in the Arctic continues, the perennial ice will disappear by the end of this century. The consequences of an ice-free Arctic will be particularly dramatic for its biodiversity.*

The thickness and extent of the sea ice in the Arctic depends on a fine balance between major energy sources and sinks, both in the sea and the atmosphere. This is why it has long been argued that the effect of a global warming will be seen first in the earth's polar regions. Monitoring of sea ice has been carried out for a number of years by using submarines, ice breakers, and satellites. For more than a decade, researchers have reported a gradual shrinking of the ice cover, and over the last year reports have come in showing that the changes are occurring far more rapidly and dramatically than most had envisioned. This raises the question of whether the changes in the ice are a result of global, human-induced warming, or whether they can be seen as natural variability.

## Observations of ice thickness and area

The first measurements to indicate that the ice was thinning were made by English researchers who measured the ice thickness by using sonar (echosounder directed upwards) from submarines that patrolled under the ice north of Greenland in the Eurasian Basin (Figure 1). The observations published in *Nature* in 1990 (1) indicated a 15% reduction from 1976 to 1987.

The sea ice cover is best measured by satellite, since satellites can cover the entire surface of the earth in just a couple of days. The satellites measure the long-wave radiation emitted by the earth, and they can distinguish between ice and water because the emission from the sea ice is far less than the emission from the water surface (mainly due to differences in albedo). In an article from 1997 (2), researchers at the Nansen Environmental and Remote Sensing Center in Bergen demonstrated that there had been a 3% reduction in the ice cover every ten years since 1978, primarily due to the reduction in ice in the Eurasian Basin during the summer months.

Two works have recently spawned speculations that the ice in the Arctic may be in the process of disappearing. By comparing sonar readings from 1958–1976 with readings from the 1990s, American researchers have now shown that the thickness of the sea ice has decreased by between 0.9 and 1.2 meters in all of the main areas of the Arctic Ocean (3). This implies a reduction of 42% from the average thickness of 3.1 m in the first period (Figure 2), and corresponds to a 15% reduction in ice thickness per decade (3).

**Figure 1: Map of the Arctic with the deep basins and surrounding seas. The sea depths are indicated with 500 m equidistance.**

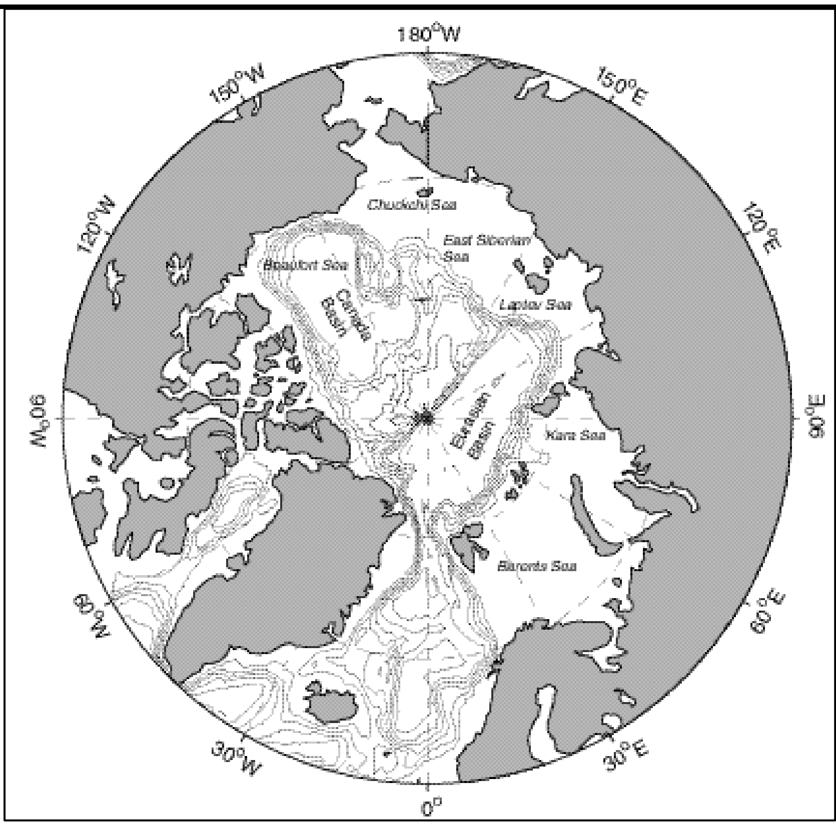
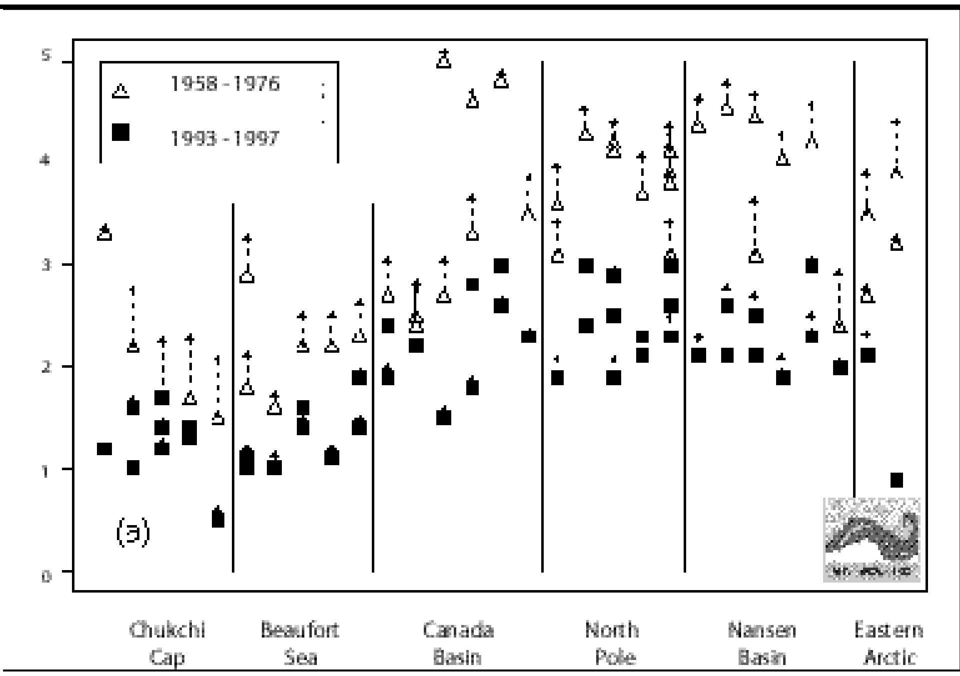



**Figure 2: Average sea ice thickness from submarine readings from the 1990s compared with measurements from an earlier period. The thickness is adjusted to a minimum over the year (September 15) by using a numerical model. From Rothroch et al. (1999).**



Since the ice surface in first-year ice (seasonal ice) is different from the ice surface of perennial ice (multiyear ice, i.e., ice that has survived one or more summers), researchers from the Nansen Environmental and Remote Sensing Center have succeeded in distinguishing between the two types of ice in satellite observations (4). The results show that the area covered by the thick perennial ice has shrunk more than twice as fast as the total ice cover, and that the volume of ice is therefore shrinking far more rapidly than the area (Figure 3).

The results from climate models that include observed changes in the atmosphere's greenhouse gases and aerosols (atmospheric particles) have been compared with identical calculations where anthropogenic contributions to greenhouse gases and aerosols were left out. Recent published results show that human-induced changes correspond with those that have been observed in the ice cover (5). Figure 4 shows the ice extent as measured by two different models. Statistic analysis of the changes in the sea ice over the last 40 years compared with changes in a reference analysis over 5000 years gave a 99.9% probability that the observed changes were human-induced.

Modeling of sea ice is difficult, and there is a long way to go until the models describe nature in a completely realistic manner. Nevertheless it now seems clear that the sea ice is undergoing significant changes and that the large global models are able to simulate this.

**Figure 3: Total area of sea ice in the Arctic in the winters from 1978 to 1998. The months from November to March are shown for each winter. The solid line shows the trend, which represents a shrinking of 610,000 km$^2$ (14% in the 20 years). From Johannessen et al. (1999).**

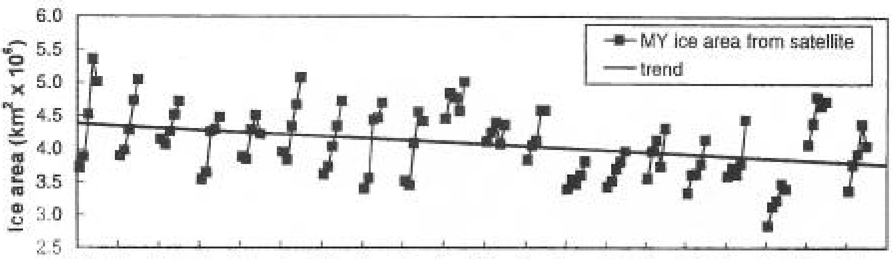
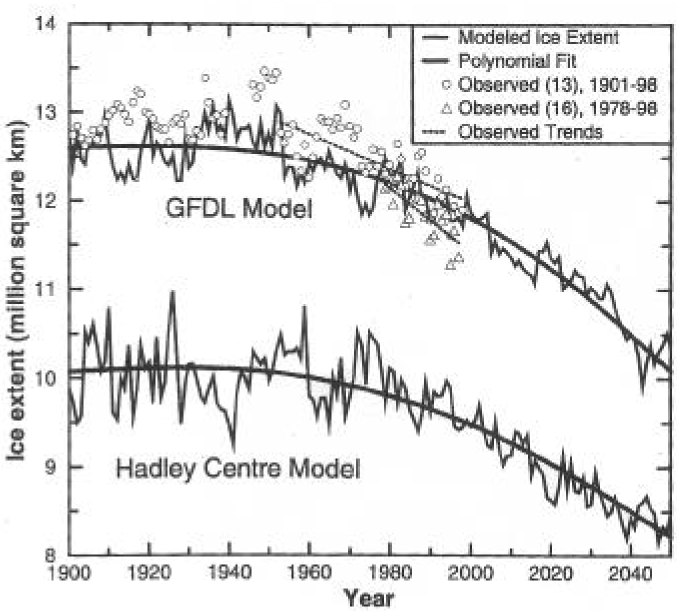


**Figure 4: Observed and modeled variation of annual mean sea ice area from 1901 to 1998, and modeled ice area up to 2050. The two models use realistic forcing from greenhouse gases and aerosols. From Vinnikov et al. (1999).**




## Observations of the sea and atmospheric climate

Changes in the sea ice correspond with observed changes in the atmosphere and sea. Research undertaken in this area can thus provide indications of the reasons for the observed changes.

Compared to the global mean temperatures over the last hundred years, the temperature of the atmosphere has increased by 0.2 °C every ten years over the last few decades. This temperature increase is representative of the areas of the Arctic that have been monitored, and atmospheric warming has been greatest over central areas of Alaska and Siberia.

In the 1990s, this warming has coincided with a stronger westerly wind belt in the North Atlantic. This pushes more marine air masses in over Europe, as well as over the Barents Sea, the Kara Sea, and the Laptev Sea (Figure 1). Between the Kara Sea and the North Pole there has also been a marked increase in the number of cyclones from 1970 to the present (6). This leads to stronger and warmer winds from the south that both melt ice because of the added warmth and move it away from the coasts and into the continuous drift of ice known as the Transpolar Drift. This ice moves between Spitsbergen and Greenland and southward along Greenland's eastern coast where it gradually melts.

Along with the increasing westerly wind, a relatively permanent high-pressure system over the Canada Basin has been weakened. This has led to a reduction in the predominant wind front over the Canada Basin, which has until now driven the Beaufort Gyre, a gigantic circular stream that has maintained the ice in this part of the Arctic for many years. In recent years, this gyre has become weaker, giving the sea ice less time to grow.

Significant changes in the sea itself have also been observed during the 1990s. In the European Basin, the part of the water column comprising water from the Atlantic Ocean (from about 200 to 1000 m deep) has become warmer and shallower. Compared with older Russian data, the temperature in this Atlantic layer has increased between 0.1 and 1.2 $^{o}$C along the continental slope from Svalbard and to the east (7). This temperature increase may seem small, but it represents a warming that far exceeds the amount required to melt all the ice in the Arctic.

Above the layer of Atlantic water lies a water layer that is primarily made up of a mixture of river water and water resulting from freezing processes at the Siberian continental shelf areas. This water layer forms an isolating blanket between the sea ice and the warm Atlantic water underneath, keeping the heat from rising to the surface and melting the ice. Readings taken by American researchers over the last few years (8) show that this type of water has disappeared in many places, possibly leading to greater melting in the Eurasian Basin than is normal. The changes have probably occurred as a result of water flowing from the major Russian rivers Ob, Yenisey, and Lena along the coast further to the east than before and not mixing in the Arctic Ocean until it reaches the Canada Basin. This is associated with changes in atmospheric circulation.

In the middle of the Canada Basin, the saline content in the surface layer has become significantly reduced from 1975 to 1997 (9, 10). Converted to freshwater, this corresponds to 1.2 meters. Some of the reduction in salinity appears to be related to a net melting of sea ice in the area, but it mostly seems to come from fresher water flowing into the Canada Basin as a result of changes in the atmosphere.

Over the last ten years researchers at the Norwegian Polar Institute have monitored the ice transport out of the Fram Strait, and by comparing it to air pressure the measurement series has been calculated as far back as 1950 (11). This ice transport is an important part of the puzzle of ice changes in the Arctic because the readings can determine whether the changes are caused by ice melting in the Arctic Ocean or by increased transport out of the area. Preliminary results show great variations from year to year, but that there has not been any general increase in transport. On the contrary, there appears to have been an increase in the transport of fresh water out of the Arctic. Both of these results indicate that the ice melting is taking place within the Arctic Ocean. There are now plans drawn up to monitor the ice and water transport out of the Fram Strait more closely.

## Possible reasons for the changes

The observed changes in the sea ice in the Arctic Ocean appear to be a result of two processes:

a) Warmer currents: Research conducted at the Department of Geophysics, University of Bergen, shows that the flow of Atlantic Ocean water along the Norwegian coast and into the Arctic Ocean carries more heat than before (12). While the amount of water appears to have been relatively constant, the temperature in the 1990s has been more than 1 $^{o}$C above the normal. This has led to increased ice melting, mainly in the Eurasian Basin.

b) Atmospheric circulation: Changes in the atmospheric circulation in the Arctic Ocean have moved the perennial ice away from the coasts, especially in the Eurasian Basin. This has caused large areas of become free of ice in the summer.

Even though many of the changes in the ice and sea discussed above can be traced back to changes in the atmosphere, there are several positive feedback mechanisms that can make the causal relationships more complex than first assumed. For example, sea ice limits the exchange of warmth, moisture, and amount of movement between the atmosphere and the sea. If the ice cover shrinks, albedo will be reduced and the ocean will absorb more heat. At the same time, the ocean will probably give off more heat and moisture into the atmosphere. The increased flux to the atmosphere will affect the low-pressure systems and wind fronts, which again can affect the ice cover. In other words, a change in one of the three components of atmosphere, ice, or sea, leads to changes in the other two.

## Will melting in the Arctic affect the climate in Norway?

The current of warm water that flows from the Atlantic Ocean and into the Norwegian Sea (the North Atlantic Current) brings heat that corresponds to 75,000 kW per capita in Norway. The Gulf Stream is the direct cause of the uniquely favorable climate Norway has compared with other areas located at similar latitudes. In the last few years, there has been much speculation about whether this current will stop or change direction and thereby contribute to a far colder climate than we experience today.

The North Atlantic Current is primarily driven by three main components: (a) Submersion of water in northern regions; (b) entrainment from water flowing out of the Arctic Ocean (i.e., the estuarine circulation); and (c) wind forcing in the North Atlantic and the Arctic.

The melting of the sea ice in the Arctic will probably reduce the submersion since the surface layer will be able to be fresher and lighter, and thereby be more difficult to submerse. But at the same time, less ice in the Arctic Ocean will possibly lead to a completely different vertical mixing here than what has been observed until now, resulting in an increasing strength in the current of water flowing out of the Arctic Ocean. To compensate for this, the transport of warm water towards the north must increase. It is also uncertain how the atmosphere will respond to the changes in the sea ice and ocean waters. Observations of the winter and water temperatures over the last ten years show that in any case there is no sign of a weakened transport to the north, rather the opposite.

There is therefore no obvious correlation between less ice in the Arctic and a weaker North Atlantic Current. Good numerical models of the processes in the Arctic are needed to determine the probability of what effects will be strongest. Such studies are a part of the modeling activity in the RegClim program, where the developments in the North Atlantic and the Arctic will be studied with the help of global models that couple ice, sea, and atmosphere. The resolution in the models can vary geographically, so that it will be possible to carry out relatively long model runs, and at the same time have a high-resolution focus on the North Atlantic and Arctic.

## Towards an ice-free Arctic?

It is still too early to say with any certainty that the changes observed in the Arctic are due to a human-induced warming, but everything indicates that this is the case. What is completely certain is that if the trend in the ice cover and the ice thickness does not level off soon, the perennial ice in the Arctic will disappear by the end of this century. In other words, the entire Arctic will be free of ice during the summer months.

An ice-free Arctic will have dramatic consequences for everything we know about animal life in the Arctic. Just think about the rich biodiversity we have near the ice edge, where polar bears, seals, and walruses dominate the food chain. All of these animals are most likely to face a more difficult life in an ice-free Arctic.

At the same time, an ice-free Arctic will present a number of economic issues. The ancient dream of direct shipping routes between Europe and Asia via the Arctic Ocean will be realizable. New oil fields that are currently covered by ice could be exposed on continental shelf areas. New fishing areas might appear, while others might lose their hold.

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