

# Our climate out of order?

*By comparing data from geological studies to modern climate data, we believe that we are now able to distinguish between natural climate variations and anthropogenic climate change. The results indicate that the last 20-30 years of global warming cannot be explained by natural processes.*

By Marit-Solveig Seidenkrantz, Antoon Kuijpers and Torben Schmith

■ Nowadays we hear one doomsday prophecy after another about anthropogenic climate change. But there are also those who would dispute that we humans have any effect on the climate. The debate sometimes descends into trench warfare, where nuances are not tolerated. Hence the need to better differentiate between natural and anthropogenic climate change arises. This has now been accomplished through comparison of geological studies of past climate and modern weather data. These studies suggest that although a significant proportion of the global warming of the 20th century probably was caused by natural variations, the significant warming that has happened over the last 20-30 years cannot be explained by natural processes alone. There is in fact strong evidence indicating that the climate system is undergoing a fundamental change.

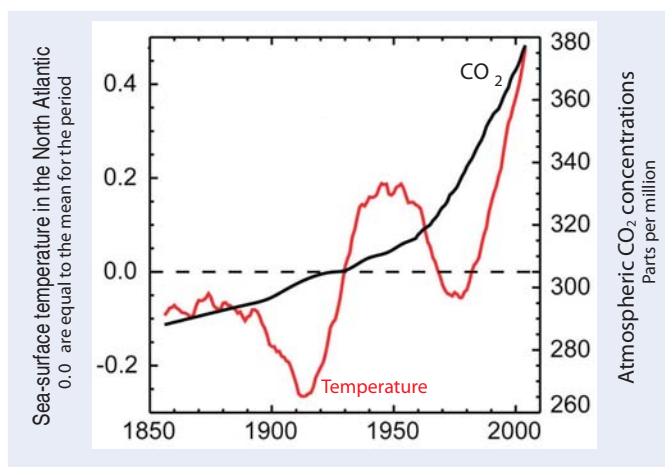


Figure 1. Sea-surface temperature in the North Atlantic compared with atmospheric CO<sub>2</sub> concentrations since 1856.

## More than one explanation for climate change

In the ongoing debate about the significance of the current climate changes, the discussion is mostly limited to a comparison of the evolution of the climate during the last 100-150 years. This is because a systematic recording of climate data (such as temperature, precipitation and pressure) first began in the middle of the 19th cen-

ture. One would also think that 150 years is ample time to get a good picture of how a "normal" climate behaves. But it is often forgotten that the middle of the 19th century was precisely the time when the so-called Little Ice Age, which was the coldest period in of the last 6000-8000 years, came to its conclusion.

The long-term trend of the last 150 years has been a warming of the climate, but there

have also been cold periods – most recently in the 1960s. We know that the concentration of greenhouse gases in the atmosphere is of great significance to climate. In Earth's history there have previously been periods with very high concentrations of greenhouse gases in the atmosphere. In general these periods were also significantly warmer than is the case today. But if we compare the temperatures of the 20th century with the amount of CO<sub>2</sub> in the atmosphere (see figure 1), we can see that there is no directly linear relationship. This means that greenhouse gases are not necessarily the only explanation for climate changes and we must therefore look for additional explanations.

## Considerable variations over the last 2000 years

If we are to understand the longer-term trend of the climate, we need to study the past through geological data. Our climate has been characterized by significant variations over the last 2000 years. The best-known



*It requires a lot of equipment and work to retrieve samples from the ocean floor, especially if the layering is to be kept intact.*

phenomena, which are known to have left a mark on European cultural history in particular are the Roman Warm Period (about 500 BC - 400 AD), the European Dark Ages Cold Period (400-700 AD), the Medieval Warming (800-1200 AD), the Little Ice Age (1350-1850 AD) and finally the 20th Century Modern Warming which began approximately in 1850. Current climate changes do not represent a simple change from a stable “normal” climate, but they should be seen in a context of generally unstable climatic conditions, which have shaped the Earth over the last millennia.

Only by understanding the processes, contexts and timescales for these climatic variations, it is possible to understand how and why the climate is changing now and tomorrow. One of the partly unresolved issues is to be able to distinguish between natural climate variability and anthropogenic influences. By comparing geological data with instrumental measurement data we have managed to make a first step in this direction.



Photos:  
Esben Villumsen Jørgensen  
Anja Kinnberg Gunvald  
Marit-Solveig Seidenkrantz



*Samples from the ocean floor in tubes and ready for storage and for further study at home in the laboratory.*

### **The North Atlantic Oscillation**

A number of theories have been proposed to explain the current climate changes. They include variations in solar radiation, sul-

phur gases from volcanic eruptions, emissions of greenhouse gases and large scale variations in oceanic circulation. It would be too extensive to discuss all of these theories here, so we will

focus on only one of the major natural mechanisms: *the North Atlantic Oscillation (NAO)*.

*“In Greenland all winters are severe, yet they are not alike. The Danes have noticed that when the*



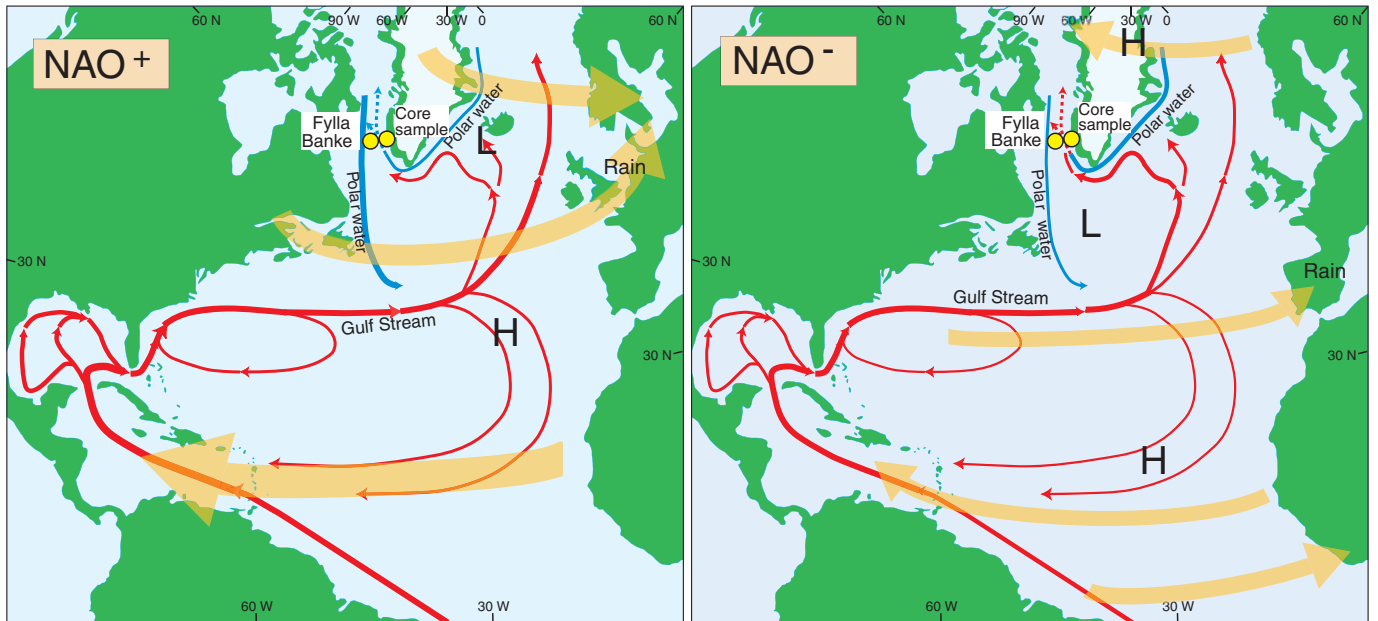
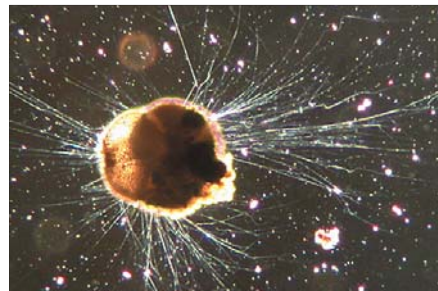


Figure 2. Currents and the North Atlantic Oscillation: ocean currents (red arrows = warm water, blue arrows = cold water), wind direction (orange arrows) and location of high pressure (H) and low pressure (L) in the North Atlantic during NAO<sup>+</sup> (left) and NAO<sup>-</sup> (right) situations. The studied cores near Nuuk and the oceanographic station at Fylla Banke are shown as yellow dots.

## Foraminifera - good climate indicators

Foraminifera are microscopic, unicellular organisms belonging to the group Protozoa and in the same family as amoeba. They are a very important group of organisms representing a large proportion of all life in the ocean. The oldest fossilized foraminifera are approximately 560 million years old, but the group has probably existed for 1000 million years, and has been very successful ever since. We know of about 40,000 species, of which 10,000 are still alive - the rest being extinct. Most foraminifera vary in size between 0.04 and 1.0 mm, but are commonly between 0.1 and 0.5 mm. They consist of a slimy "body" with strands of cytoplasm, or pseudopods, which extend from the body and are used to collect or capture food. The body is usually surrounded by a shell of either lime or mortared sand that they have collected from the ocean floor. These shells are easily preserved as fossils and can be found in sediment layers going far back in time.

Based on their lifestyles foraminifera can be divided into two main groups: the planktonic species, which float freely in the water column of the open seas, and the benthic living on the seabed. The planktonic foraminifera predominantly live off phytoplankton or small zooplankton, while the benthic foraminifera also devour the remains of dead animals or plants, which sink to



Live foraminifera with pseudopods: *Ammonia tepida*

Photo: Scott Fay, UC Berkeley

Fossilized fauna from the Little Ice Age deposition from core 248260-2G from Ameralik Fjord, Greenland.

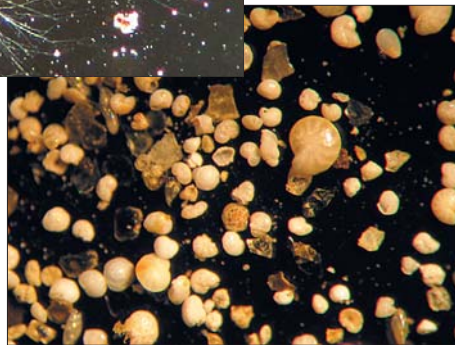


Photo: M.S. Seidenkrantz

the bottom.

Foraminifera represent 2.5% of all animal species that have existed throughout the history of Earth. Given that many species have risen and disappeared again foraminifera are successfully used to date layers of soil. They are also extremely useful for determining past climate and environment, since the different species make different demands of their habitat. They can therefore tell us about seawater temperature, salinity, current strength and the amount of oxygen in the sea bed - for instance whether there have been periods of oxy-

gen depletion. That way, we can learn how ocean circulation has worked in the past and how it has affected the climate. Since foraminifera are also sensitive to pollution (such as organic matter, nutrients and heavy metals), they are also used to investigate pollution at sea.

The calcareous foraminifera also build their shell in chemical equilibrium with the seawater. This means that you can measure chemical constituents such as stable oxygen and carbon isotopes, which in turn give information about sea temperature, the extent of glacial ice, nutrient content, etc.

winter in Denmark was severe, as we perceive it, the winter in Greenland in its manner was mild, and conversely."

This quote is from the diary of Hans Egede Saabye, a missionary in Greenland in 1770-1778. It is one of the oldest historical sources reporting these opposing temperature pattern seen between Europe and West Greenland. Today this phenomenon is well-known and is in part a consequence of the so-called North Atlantic Oscillation (NAO), which are temperature fluctuations affecting both the atmosphere and the ocean. It is basically driven by air pressure over the North Atlantic. During the so-called NAO<sup>+</sup> stage there is a strong low pressure over Iceland and a strong high pressure over the Azores. This pressure difference creates strong westerly winds, moving warm air towards Denmark, especially in the winter. The westerly wind also forces the waters of the Gulf Stream closer towards the coast of Europe (Figure 2), while the coast of West Greenland is mainly washed by the cold waters of the Arctic Ocean. In some years there is a smaller difference in air pressure, and westerly winds

are weaker (the NAO<sup>-</sup> stage). The Gulf Stream is to a lesser degree pressed towards Europe, and part of the warm water will swing further to the west and bring heat to West Greenland. NAO<sup>+</sup> thus causes mild winters with a lot of precipitation in northwestern Europe and very cold winters in West Greenland. Conversely, the NAO<sup>-</sup> triggers cold and dry winters in northwestern Europe and warmer winters in West Greenland.

**Natural climate changes over the last 2000 years**

Results of studies of marine core samples from West Greenland show that there have been large variations in the amount of warm Atlantic water reaching this area over the last 2000 years. Comparisons of calculations of the temperature in Europe and other parts of the northern hemisphere (Figure 3A) with estimates of water temperature off West Greenland (Fig. 3B) also show an opposed pattern. In some periods the Gulf Stream led warm water to Europe. This caused a hot and humid climate especially in Northwestern Europe during the Roman Warm Period and the Medieval Warming. In other periods, less water from the warm Gulf Stream reached Europe, but came instead to West Greenland. During these periods the European climate was colder (the European Dark Ages Cold Period and the Little Ice Age). During these periods the European climate was colder (the European Dark Ages Cold Period and the Little Ice Age). This new research shows that the major climate changes that have characterized the last 2000 years largely were caused by changes in wind direction and ocean currents.

Recent research suggests that mechanisms other than the NAO can create variations in the strength and path of the Gulf Stream. Without going into too much detail, these mechanisms involve internal variations in the so-called thermohaline circulation, with changes in the sinking of Atlantic waters off Greenland and Labrador. These changes may last several centuries, creating changes in air temperature of a



*The rising temperatures cause increased calving of icebergs from glaciers in Greenland.*

similar duration. Mechanisms such as variations in the solar radiation and El Niño Southern Oscillation seem to play a role in climate variability as well.

**The 20th century warming**

Modern measurements and geological data from the last 2000 years tells us that the climate, both past and present, has to a large extent been character-

ized by a complex interaction between atmospheric conditions and oceanic currents. The instrumental measurements also show that the 20th century has seen the climate change from being dominated by the NAO<sup>-</sup> to being NAO<sup>+</sup> dominated. This means that a significant part of the temperature increase probably can be explained through a natural change from

a climate dominated by weak westerly winds and a modest transport of heat to Europe, to a climate characterized by strong westerly winds and an increased transport of heat to Europe.

During the recent decades, Earth's climate has, however, undergone changes even faster than before. The understanding that the geological data has given us, can be used to deter-

**Figure 3 - Natural climate changes over the last 2000 years**

A) Atmospheric temperature in Europe throughout the last 2000 years compared with the mean temperature for the period 1961-1990. The curve is based on a series of geological data and indicates the temperature difference from the average for the 1961-1990 period.

B) Reconstruction of sea water temperature (cold Polar / warm Atlantic) off West Greenland during the last 2000 years. This shows the clear distinction between hot water from the Atlantic and cold water from the Arctic. The result is based on the occurrence of different species of foraminifera in sediment core samples from near Nuuk. These data indicate a warming of waters off West Greenland during periods when the climate in Europe was colder than today, while seawater off West Greenland was colder than today during the periods when the climate in Europe was warm.

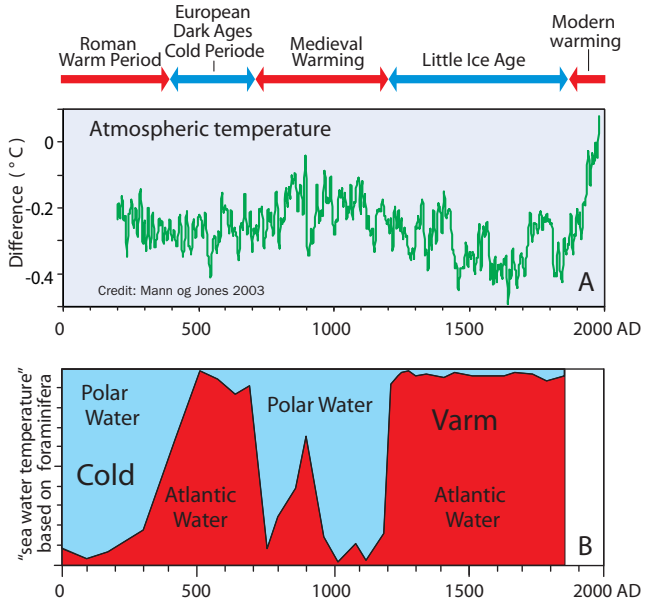






Photo: Colourbox

Greenland has taken a key role in raising awareness of global climate changes.

mine whether the system that has worked for 2000 years, is still active. We have therefore compared seawater temperatures in June from Fylla Banke off Nuuk, West Greenland, with the average air temperature during winter in northwestern Europe for the period 1950-2005 (Figure 4). Both curves show significant variations. Until around 1985 there was a reverse pattern between the temperature in Europe and in West Greenland, but with a delay of 4-5 years, so that a climate change in western Greenland, first would reach Europe after 4-5 years. This delay is presumably due to the inertia of the system due to the slow speed of sea currents. We can in other words say that until 1985

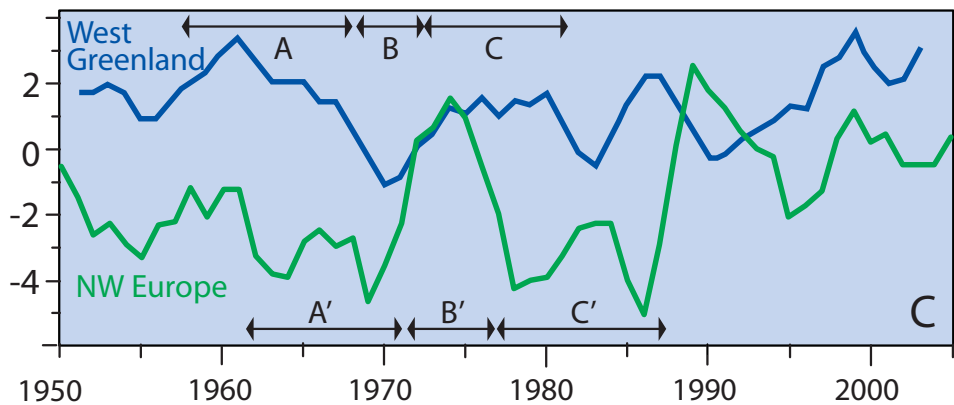
we experienced a climate that was ruled by the same principles that we've seen over the last 2000 years.

#### Man changing the climate

After 1985 that situation has apparently changed. Although the data from Fylla Banke indicates a number of variations in ocean currents, the climate in Europe no longer follows the expected pattern. It is known that the global temperature began to rise significantly during the past decades and the last three decades (after 1973) have probably been the warmest period of the last 500 years. In fact, measurements of the atmospheric pressure between Iceland and the Azores suggest that we are currently in

a NAO<sup>-</sup> dominated period, which should cause a cooling, but still temperatures in Europe have risen. Meanwhile, the Sun has in recent years emitted less energy than average. Changes in the solar radiation can therefore not explain the phenomenon either.

This means that although a large part of the temperature rise that has been seen over the last 100-150 years, probably is due to natural climate variations, the significant global warming which has marked the last 20-30 years, cannot be explained through currently known natural processes. This suggests that greenhouse gas emissions are causing a fundamental change in the whole climate system. ■



Credit: DMI and Northwest Atlantic Fisheries Organization, Canada.

Figure 4. Sea-surface temperature (June) by Fylla Banke, West Greenland, and the air temperature in winter in northwestern Europe in the period 1950-2005. The letters A, B and C mark periods when the surface sea temperatures in western Greenland were either higher or lower than average, while A', B' and C' show delayed and reverse variations of temperature in northwestern Europe.

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#### Further Reading:

Kuijpers, A., Malmgren, B.A. & Seidenkrantz, M.-S. 2009. Termination of the Medieval Warm Period: linking subpolar and tropical North Atlantic circulation changes to ENSO. PAGES News 17 (2), 76-77.

Seidenkrantz, M.-S., Kuijpers, A. & Schmith, T. 2009. Comparing past and present climate – a tool to distinguish between natural and human-induced climate change. IOP Conference Series: Earth and Environmental Science.

Seidenkrantz, M.-S., Aagaard-Sørensen, S., Møller, H. S., Kuijpers, A., Jensen, K.G., Kunzendorf, H., 2007. Hydrography and climatic change during the last 4.400 years in Ameralik Fjord, SW Greenland. The Holocene 17 (3), 387-401.