The Crafoord Prize 2006

The Royal Swedish Academy of Sciences has decided to award the Crafoord Prize in Geosciences for 2006 to ***Wallace S. Broecker****, Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, USA, "for his innovative and pioneering research on the operation of the global carbon cycle within the ocean - atmosphere - biosphere system, and its interaction with climate".*

Climate change and "the big unplanned carbon dioxide experiment"

By combining his biogeochemical research on ocean composition with knowledge of the ocean currents, and the complexities of carbon exchange between the hydrosphere, atmosphere and biosphere, **Wallace S. Broecker** is making a fundamental contribution to our understanding of how climate can change and of the mechanisms triggering climate change.

Changing climate

Change has characterised climate on Earth for billions of years. During the last million years alone, Earth has experienced at least ten climate cycles, moving the environment from icehouse to greenhouse and back to icehouse again with global temperature changes of >10ºC. Some of the changes have been gradual, others rapid – the glacial periods in particular have experienced rapid shifts, occurring over decades to a few hundreds of years, with local temperature changes of 10-20ºC. These icehouse - greenhouse alternations are readily correlated with the variable insolation into the glacially sensitive high northern latitudes, the effect of Earth's variable orbit around the Sun and changes in its axis of rotation and timing of seasons. Superimposed on these major cycles are more frequent rapid changes that are related to other, still partly enigmatic, processes; they all greatly influence the environment. What happened in the past; how fast and why? What is happening today?

To find answers to these questions it is necessary to understand the complex interplay between Earth's five main spheres; the atmosphere, hydrosphere, cryosphere, biosphere and geosphere. This interdisciplinary approach to geoscience has grown rapidly over the last fifty years and is now generally called Earth System Science.

The 2006 Crafoord Prize is awarded to Wallace S. Broecker, who has spent a long career integrating his special expertise in biogeochemistry with Earth System Science in order to understand ocean-atmosphere interactions and climate change. He has made pioneering contributions to our understanding of the composition of the oceans, particularly the carbon cycle and the gas exchange between the oceans and the atmosphere. He has combined these data with evidence of ocean circulation, developing models that provide insight into the processes behind climate change in the past, insights that he has then applied to the understanding of ongoing change.

Broecker has addressed a number of important questions, such as: How is the natural carbon dioxide content of the atmosphere regulated by various processes in Earth's carbon cycle? How does the interaction between these processes function and in what way is Earth's climate related to them and their effects? What happens for instance today with the carbon dioxide emitted to the atmosphere? How much do we really understand of the still somewhat enigmatic carbon cycle and how cautious must we be about future growth of the greenhouse effect?

How the ocean influences climate

Water covers about 70 per cent of the Earth's surface and the oceans are a huge living environment, interacting with the atmosphere and responding continuously to change in temperature. And, water, which exists in three phases, solid (ice), liquid and gas, plays a dominant role in safeguarding the balance of the climate. Water vapour is the predominant greenhouse gas; as a liquid in the oceans it serves as a huge reservoir for the other greenhouse gases, the most important of these being carbon dioxide.

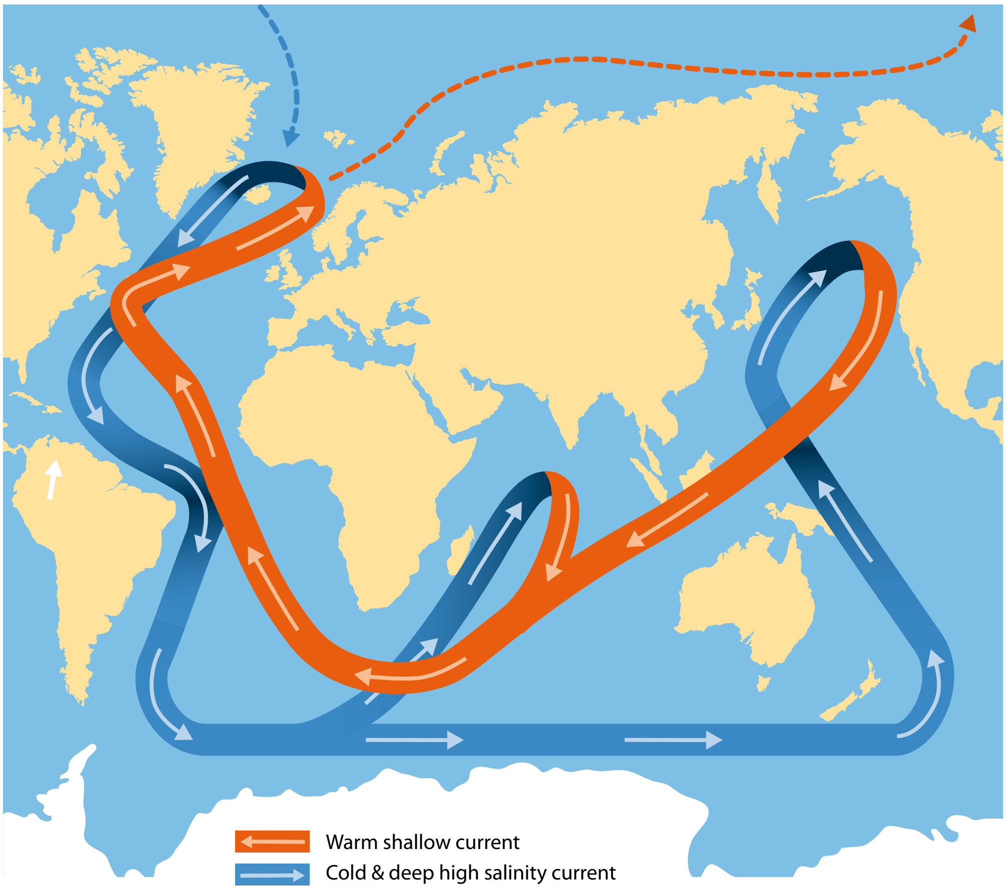

Figure 1. The major ocean currents are an important element in the interacting Earth System. If they change they can have major impact on the climate. The diagram presents a simplified illustration of the global conveyor system of warm water that reduces temperature differences between the higher and lower latitudes of the Atlantic.

One of the motors behind global oceanic circulation is deep water formation. In the northern Atlantic, surface water is cooled (especially in the winter) by the cold air from Greenland. Moreover the formation of sea ice increases the concentration of salt in the surface water. Together these imply that the surface water becomes heavier than the water below it. It then sinks into the deeper areas of the ocean to replace the "old" deep water which flows southwards at great depths. This water is replaced by warm surface water transported northwards by ocean currents – in the Atlantic by the North Atlantic current, part of which is what we call the Gulf Stream. This circulation system extends throughout Earth's oceans and is extremely complex.

Any alteration in the ocean currents can have a major impact on the climate. If the region in which deep water is formed shifts southward, for instance, the warmer surface water would not be transported as far north as it is today. The amount of deep water that sinks could also be reduced as the lower density of the surface water at more southerly latitudes means that it does not sink as far. One conceivable effect of this could be a considerably colder climate in Scandinavia, a climate comparable to Alaska's.

The carbon cycle

The concentration of carbon dioxide in the atmosphere has risen by 30 per cent during the 20th century. One third of the annual emission of carbon dioxide from the burning of fossil fuels is absorbed by the oceans, which are the most important "carbon sink" and therefore play an important role in regulating the level of carbon dioxide in the atmosphere.

Perhaps Broecker's most pioneering contribution has been the study of the carbon cycle in the Earth System. Earlier the composition of seawater had been explained, for instance, by chemical equilibrium processes. A good 35 years ago, Broecker introduced instead a flow model that is based on the interaction of land, atmosphere and the oceans. Rivers and the atmosphere supply water and chemical substances to the surface waters, where biological material is produced which then sinks towards the ocean floor. Flows in the opposite direction take place, for instance, through mixture in the oceans and evaporation to the atmosphere.

What enables the oceans to absorb carbon dioxide and what does the cycle look like? Broecker was one of the first to use methods for tracing carbon in the oceans based on the radioactivity of some of the carbon that exists naturally, i.e. the carbon-14 isotope. This comes from natural sources but has also been influenced by nuclear tests and the combustion of fossil fuels. There are also other substances that have radioactive isotopes, for instance uranium and boron, which Broecker has used to measure present day and earlier carbon dioxide levels, pH values and other variables.

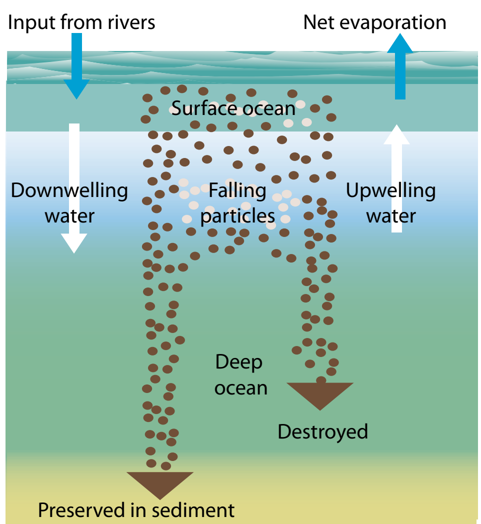

Figure 2. The interaction of land, atmosphere and the oceans is important for our understanding of the carbon cycle. Two decisive factors for how much carbon dioxide the oceans can store are how much organic material and calcite "rains" down to the bottom of the oceans, and how this material decomposes or dissolves at various depths.

Through his work Wallace Broecker has contributed to our understanding of the link between the level of carbon dioxide in the atmosphere and ocean chemistry. For instance he has studied the amount of calcite in sediment on the ocean floor. Calcite is formed from calcium and carbonate ions that are of great importance for the ocean's absorption of carbon dioxide. Broecker discovered two decisive factors for how much carbon dioxide the oceans can store, one being how much organic material and how much calcite "rains" down to the bottom of the oceans and the other how this material decomposes or dissolves at various depths.

Ice and sediment as climate archives

Broecker had already begun to take an interest in climate change in Earth's history at the beginning of the 1960s. The history of Earth's climate is recorded in the inland icecaps of Greenland and the Antarctic and in sediment on the continents and at the bottom of the oceans. One example is that air from the ice ages has been "imprisoned" as bubbles and can be found preserved inside the ice. This means that researchers can measure the carbon dioxide content of these bubbles to estimate the composition of the atmosphere at various earlier periods in Earth's history.

When the first findings of carbon dioxide variations in ice from the Antarctic were published in the early 1980s they revealed that the level of carbon dioxide had varied extensively with the ice ages. Broecker made a decisive contribution to finding an explanation. He was able to link the carbon cycle in the oceans with changing patterns in ocean currents and could then create models on which continued research in this area could be based.

He was 20-30 years ahead of his time when he proposed that climate changes have often been very rapid and were related to changes in the global circulation system in the oceans. One concrete example is the climate "setback" that took place during the Younger Dryas cooling event that began about 12,700 years ago. At that time the latest ice age had begun to recede, but the climate abruptly became glacial again for 1,100 years as deep water formation suddenly collapsed. One explanation for this is that the flows of large volumes of water in North America changed course and were quickly discharged through the St. Lawrence basin into the North Atlantic, and that the Baltic Ice Lake simultaneously drained into the North Sea. These meltwater surges on both sides of the North Atlantic lowered the density of the surface water so that it was prevented from sinking to form deep water.

Researchers consider that the driving mechanism behind the many major shifts of climate during the most recent ice age consists of fluctuations in or interruption of northern deep water formation followed by sudden return to deep water formation similar to today's. The following chain of events can be envisaged. During warm periods with extensive melting of sea ice and the calving of icebergs salinity gradually declined and with it the density of the surface water. This finally led to a decline in or the interruption of northern deep water formation, which shifted southwards. The result was a colder climate around the North Atlantic so that the glaciers grew and sea ice became more widespread. When salinity gradually began to increase again because there was less thawing, sea ice formation also increased and at the same time evaporation was constant. The surface water was cold and became heavier and heavier as its salinity rose. Suddenly the surface water began to sink again in the north and north-western Europe was quickly warmed up by water from the south.

It seems paradoxical that warmth can disturb the mighty conveyor system for warm seawater, but in the context of on-giong climate discussions rapid global warming with increasing precipitation and temperatures could result in a reduction of the density of the surface waters of the North Atlantic. Theoretically this could be the start of a colder climate in the higher latitudes.

Broecker has also coined the concept of "the bipolar seesaw" from the latest ice age. There has been much discussion about the lack of synchronicity between the two hemispheres which means in very simple terms that when the northern hemisphere was warmed by an increased flow of warm water from the southern Atlantic the southern hemisphere cooled down. The opposite effect resulted from a weakening of the conveyor system in the north: then most of the warmth remained in the south while the north was cold.

Will the greenhouse effect lead to climate change?

Wallace Broecker has been particularly adept at communicating his science to the public. He participates actively in general discussions to spread knowledge about the interacting Earth System to the general public, politicians and other decision makers. He urges caution and always bases his arguments on scientific grounds, warning against exaggerating the dangers or not taking them seriously enough. He is respected on all sides and for many years, especially during the Clinton administration, he has regularly been summoned to the White House for hearings on the climate situation. He has not only described the problems related to our on-going "unplanned experiment", but has also emphasized the challenge – the need to apply our science to finding solutions. These include both reducing the impact of the use of fossil fuels (for instance by pumping liquid carbon dioxide at least one kilometre down into the Earth's crust), and also finding new ways of extracting carbon dioxide from the atmosphere.

It is hardly likely, in Broecker's opinion, that deep water circulation in the North Atlantic will stop because of our emissions of carbon dioxide, but it could be impaired. What we have learnt about the climate earlier shows how quickly it can change also for natural reasons. Many are convinced that the rise in temperature in recent years is not natural but has been caused by the growing greenhouse effect, which is the result to some extent of the combustion of fossil fuels.

We do not, however, have detailed knowledge of the mechanisms behind these changes and still lack important information. Broecker claims that global warming may have major consequences that we cannot foresee today. One of his comparisons is that the complex climate system is like a dragon that should not be disturbed without good reason. But if the dragon wakes, we have to know how to put him back to sleep again!

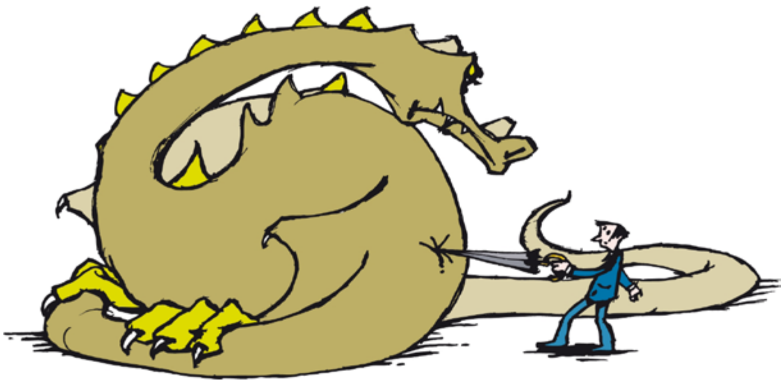

Figure 3. Broecker compares the complex climate system with a sleeping dragon that we should not distrub.

LINKS AND FURTHER READING

Articles:

Advanced information on the Crafoord Prize in Geosciences 2006
Oceans & Climate - The Ocean's Role in Climate & Climate Change, Oceanus volume 39, Number 2, 1996
Atlantic Ocean Circulation, Oceanus volume 37, Number 1, Spring 1994

Books:

Broecker, W.S., Greenhouse puzzles. 1992a, New York: Eldigio press
Broecker, W.S. The Glacial World according to Wally. 1992, 1995 New York: Eldigio press

Links:

Wallace Broecker, The Lamont-Doherty Earth Observatory (LDEO)
http://www.ldeo.columbia.edu/vetlesen/recipients/1987/broecker_bio.html
Ocean and Climate Change, Woods Hole Oceanographic Institution
http://www.whoi.edu/institutes/occi/index.htm

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