The impact of water mass movements on the Earth's climate

The Big Mix

Profesor Czesław Druet, a geophysical hydromechanics specialist, studies marine dynamics and phenomena occurring at the boundary between the ocean and the atmosphere

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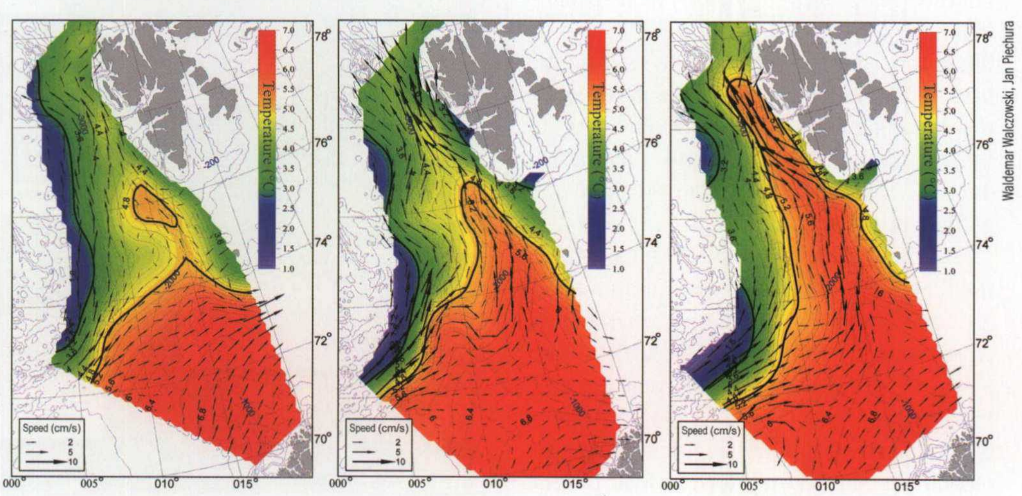
Water masses that differ in temperature and salinity come into contact along turbulent fronts and form vast eddies. The ocean is just as complex a medium as the atmosphere, and the two are inextricably intertwined

The equatorial currents generated by the trade winds transport the oceans' warm upper layers to the west and north. Those waters ultimately reach the Arctic Ocean. Giving up their heat to the atmosphere along the way, they become cooler as well as heavier, having a higher salinity than the local waters. They fall to the ocean bottom and then flow along the bottom layer to the south and east. This circulation of water masses and oceanic heat takes around a thousand years to come full circle. However, climate warming is now causing the Arctic ice cover to start to melt and the resulting inflow of meltwater is making the upper Arctic gradually less salty. If this trend continues, the Atlantic waters reaching the Arctic could become insufficiently salty to fall downwards. That will likely trigger a slowdown in the large-scale transport of water and heat in the ocean, which in turn will dramatically alter the conditions of the biosphere, including for human beings.

Climatologists differ over whether it is possible to predict what conditions will then prevail, but they do agree on one thing: humanity might not survive such a change. As a result we have to take action to stop or at least slow this negative process. The industrialized countries must limit their CO_2 emissions, while scientists need to develop more precise methods for predicting climate change.

The latest report by the Intergovernmental Panel on Climate Change touched off heated debate in Paris about the modeling methods used by climatologists. It confirmed that global warming stems in large part from increased CO_2 concentration in the atmosphere. It likewise conceded that serious gaps in our knowledge about the exchange of carbon compounds between continental vegetation, bottom sediments, the ocean,



Changes in the distribution of temperatures and current speeds seen in July, 2004–2006, attest to the gradual warming of the Greenland Sea

and the atmosphere are one of the main sources of inaccuracies in short-term climate change modeling.

Spinning heat pumps

One of the problematic issues involves the ocean's capacity for further absorption of CO_2 from the atmosphere and its long-term storage in the form of calcium carbonate in the shells and skeletons of marine organisms. There is a fear that the ocean will be absorbing less and less of the gas. Two factors seem to play a key role here. Firstly, the rising CO_2 saturation of waters is causing them to grow more acidic, hampering the precipitation of calcium carbonate. Secondly, the quantity of the gas that the ocean can absorb depends on the effective mixing of surface and bottom waters. That process is still poorly understood, the basic question being as follows: What source of energy allows the heavy, cold bottom waters that have settled deep in the Arctic region to rise to the surface and to constitute the return flow of the large-scale, global oceanic circulation loop?

In principle researchers concur that the temperature increase that occurs in cold return waters in the oceanic loop, thus enabling them to rise, is caused by processes that mix upper and lower waters. Yet small-scale processes of turbulent mixing are not of much significance here, since the power of such movement is nowhere near the scale of the power that drives the global circulation (reaching 2 petawatts) and thus such turbulence can be ignored when modeling planetary-scale climate change. One group of researchers even suggests that such mixing could be the effect of billions of living organisms moving together with the main oceanic currents. However, that view is not accepted as it lacks factual grounds - such mixing represents small-scale turbulence and as such does not count on the global scale.

What is responsible for the mixture of oceanic layers therefore must be some large-scale process. A number of researchers believe that a phenomenon known as equatorial upwelling, the lifting of cold waters to the ocean's surface caused by the Coriolis effect, may be of key importance here. That hypothesis is nowadays being eagerly adopted in computer climate modeling, because it considerably simplifies the initial assumptions and calculations. Nevertheless, recent research findings indicate that mixing processes are in fact of a more complex nature.

Many recent empirical and theoretical findings have increasingly corroborated the notion that tropical cyclones in fact play a major role in the process of mixing ocean

The rapid melting of ice in the Arctic results in large part from the increasingly intensive influx of warm waters from the North Atlantic

Tropical cyclones churn up more than just the atmosphere: after they pass across the ocean, surface waters have been shown to decrease in temperature due to the admixture of colder bottom waters

waters. Temperature differences seen in the upper ocean layer before and after a cyclone passes through indicate that the resulting medium-scale mixing of top and bottom waters corresponds to an energy of 0.26 petawats per year. That is an amount of energy sufficient to allow deep waters to rise to the surface in the Indian and Pacific Oceans.

This cyclone factor would explain why the global circulation of heat in the ocean did not wane during warmer periods of the Earth's history. For example, 50 million years ago the Earth's climate was significantly warmer than at present. Studies of Arctic seafloor sediments suggest that the region then had a Mediterranean climate, with a summer temperature fluctuating around 24°C. Climate models, however, are not able to reconstruct such a situation. Such high Arctic temperatures would require a very effective circulation of oceanic heat, much more effective than seen nowadays.

The human-induced global warming of the Earth's climate, accompanied by the gradual increase of ocean surface temperatures, is giving rise to more frequent tropical cyclones and storms. In the long term, such a link between climate conditions and the number of cyclones finds confirmation in studies of Caribbean region lagoon deposits. The frequency of hurricanes in this part of the world over the past 5,000 years has been shown to be closely correlated to the phase of the El Niño Southern Oscillation (ENSO) and to the intensity of monsoons in West Africa.

Focusing on the Arctic

There are more and more research results now indicating that an important role in medium-term oceanic processes of exchanging water masses and heat is played by the friction of the water against the ocean floor. The geographic shape of these zones and their relief both significantly determine the routes of water movement and the emergence of diverse eddy structures that cause water mixing. Together with strong winds they seem to have a decisive impact on the transformation of Atlantic waters in crucial areas of the Arctic Ocean.

European countries, the US, and Canada have for many years been allocating considerable funding to thoroughly studying the routes for the movement and transformation of North Atlantic waters. Large international programs studying the Arctic Ocean have been launched, in which numerous Polish teams are actively taking part. These include such projects as the Arctic-Subarctic Ocean Flux Array (ASOF-N), Integrated Arctic Ocean Observation System (IAOOS), Developing Arctic Modelling and Observing Capabilities for Longterm Environmental Studies (DAMOCLES), the Integrated Western Arctic Climate Study (IWACS) and the Shelf-Basin Exchange (SBE) initiative.

The staff members of the Institute of Oceanology, Polish Academy of Sciences, have for years been pursing hydrodynamic, chemical, and ecological research in Arctic waters. Every year since 1987, the "Oceania" research vessel sets forth on a research expedition, always heading for the same regions. The oceanographic data gathered there annually since 1985 forms a precious resource used by many researchers in various analyses and research studies. Another example can be found in the very important research carried out by a team led by Prof. Jan Piechra, which has shown that the waters of the North Atlantic are gradually contributing more and more heat into the Arctic Ocean. This is clearly accelerating the pace of ice melting in the region.

An analysis of a series of data on temperature and salinity variations in the northern portion of the Norwegian Sea in 1991–2000, in turn, has led to the discovery that these parameters have both changed in correlation with the winter North Atlantic Oscillation (NAO) index. The borders of the Atlantic water core have also been found to be shifting longitudinally, and its waters cooling since 2000. Measurements of water mass and heat exchange in the Arctic Front region, which divides Arctic air from polar air, have enabled the mechanisms of its breakdown to be observed. Such many-year measurements taken by researchers from the Institute of Oceanology, especially in the Norwegian Sea region, are simplifying the prediction of climate change in the North Atlantic region.

Quite a few studies in recent years have shed new light on the medium-term processes of North Atlantic water mixing and transformation which occur in the Arctic Sea. Measurements taken in the Fram Straight, linking the Arctic Ocean to the Nordic seas, have shown that large differences in the thickness of these water masses have a significant impact on flows between the two basins. The findings of such research have also improved our understanding of the mechanisms which govern the movement of waters over an inclined bottom, empirically confirming the intuitive notions that the movement of water masses in the Nordic seas is guided in large part by the topography of the ocean floor and that the accurate representation of such topography enables real flows to be modeled with little error.

Realistic modeling of oceanic water mixing processes is of key significance for forecasting climate change – and it is especially important for the North Atlantic, the site of the main "driving force" of the global oceanic circulation. It is there, at the confluence of ocean and atmosphere, that "the main decisions are made," determining both current weather patterns throughout Europe and long-term climate trends. We must keep close tabs on the processes occurring there, so as not to miss the first signs of changes that could have a fundamental impact on the Earth. ■

Further reading:

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Jerzy Dąbrowski

The Oceania research vessel sets out for the Arctic every year