WARM OCEANIC WATERS

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Despite many years of research, we have yet to discover all the myriad ways various components of the climate interact. For instance, it looks likely that the circulation of oceanic waters has a much broader impact than previously thought.

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At around the beginning of the 21st century an astounding atmospheric phenomenon occurred in the northern hemisphere, and the consequences were felt by populations in many countries. Unexpectedly, the frequency of severe continental winters increased here, especially in Eurasia. Over the last thirty years, seven of the ten coldest winters on this continent (classified by average surface air temperatures from December to March) were indeed recorded in the second half of this period (2002–2016). These cold winters and related weather extremes appear despite the increase in average annual air temperature over land associated with global warming. At the same time, we are witnessing the intensification of the so-called arctic amplification phenomenon, in which the air temperature in the Arctic rises faster than the global average. Both phenomena, possibly interdependent, appear in the large scale distribution of wintertime air temperature anomalies in the form of a distinct dipole referred to as "warm Arctic/cold continents," "warm Arctic/cold Eurasia," or "warm Arctic/cold Siberia," depending on the location and the extent of the continental "cold spots." The Arctic "warm spots" also change their position from year to year.

The arctic amplification is largely linked to the dramatic melting of the Arctic sea ice. There is increasingly more evidence that changes in the Arctic

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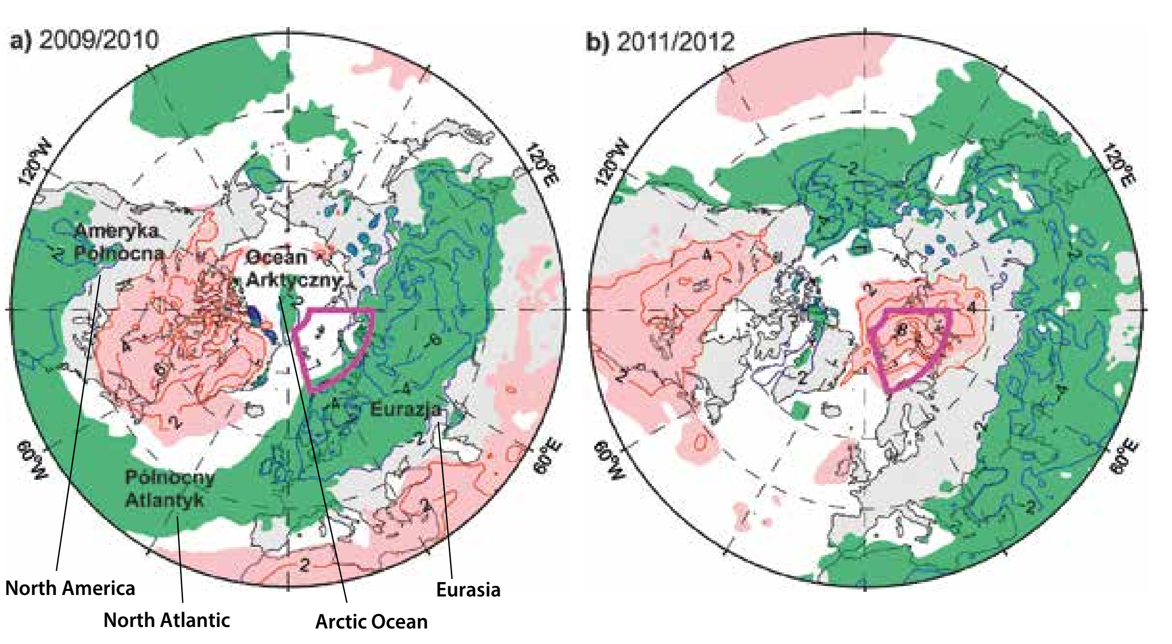
sea ice cover affect the climate and weather extremes in temperate latitudes. The first publications on this topic suggested that the autumn-to-winter atmospheric circulation, air temperature and snowfall in northern continents "remember" the Arctic sea ice anomalies of the previous summer. Further research has shown that this "memory" is selective, as it only works for certain periods or years, and fails in others. The dependence of winter climate conditions and weather extremes in Eurasia on the simultaneous anomalies of sea ice, especially in the Barents and Kara Seas, is, statistically speaking, more stable. The disturbances of ice concentration in the Barents and Kara Seas are probably the second most important factor, after the North Atlantic Oscillation, and in the last several years perhaps even the most important factor, shaping the winter anomalies of air temperature in Eurasia.

Atlantic Heat

The cause-and-effect relationships between the rapidly changing Arctic climate and the climate of the temperate zone of the northern hemisphere are poorly understood due to their high degree of complexity and the uniqueness of individual events. Understanding these relationships is one of the greatest challenges for modern science. It should help in making strategic decisions on the adaptation of societies to the effects of climate change. The research I have been conducting for the past several years at the PAS Institute of Oceanology is an attempt to partially meet this challenge. The goal of the research is to document and clarify the role of the ocean in the feedbacks of the Arctic climate system and their relation to the mid-latitude climate. Previous results were based on statistical analysis and interpretation of physical oceanographic data from various sources, as well as atmospheric reanalysis (compilation of observation data with the atmospheric circulation model) from NCEP/NCAR (*National Centers for Environmental Prediction/National Center for Atmospheric Research*) in the years 1982–2006.

Previous research has indicated the following:

- Approximately 70% of the total variance in ice cover of the Nordic Seas (the basin which includes the Greenland, Iceland, Norwegian and Barents Seas) during the winter season can be statistically explained by the Atlantic water temperature anomalies observed at the entrance to the Barents Sea during the previous summer;



The distribution of surface air temperature anomalies in the extratropical northern hemisphere in the winter of (a) 2009/2010 and (b) 2011/2012. The anomaly at a given point was defined as the deviation of the local average temperature from December to March from the value of its linear trend in the satellite observation era (1979–2016). The red and blue contours represent positive and negative anomalies, respectively. Contours were plotted at 2°C. The zero contour was omitted. The pink and aquamarine shading represent respectively positive and negative anomalies of absolute value exceeding one standard deviation of local anomalies in the period of 1979–2016. The Barents and Kara Seas are marked in purple.

The anomalies shown are deviations in temperature from its local trend in the satellite observation era (1979–2016). In the winter of 2009/2010 positive temperature anomalies in Greenland and eastern Canada were locally above 5°C (Fig. 1a). They were accompanied by negative temperature anomalies of similar absolute values in the vast areas of Eurasia, and slightly lower absolute values in the United States. This distribution is characteristic of the negative phase of the North Atlantic Oscillation associated with the varying intensity of the Icelandic Low and the Azores High. The index (intensity and sign indicator) of this oscillation was indeed extremely negative in the winter of 2009/2010. In winter 2011/2012 the distribution of anomalous temperatures was slightly different (Fig. 1b). In the Arctic, instead of a "warm spot" in Greenland an Eastern Canada, a "warm spot" with temperature anomalies of up to 10°C appeared in the Barents and Kara Seas (the purple box in Figures 1a and 1b). In North America positive anomalies dominated, while the "cold spot" in Eurasia occurred at lower latitudes (maximum anomalies at about 45°N) than in the winter of 2009/2010 (maximal anomalies at about 60°N).
Air temperature data from the ERA-Interim collection of the European Center for Medium-Range Weather Forecasts (http://www.ecmwf.int/en/research/climate-reanalysis/era-interim).

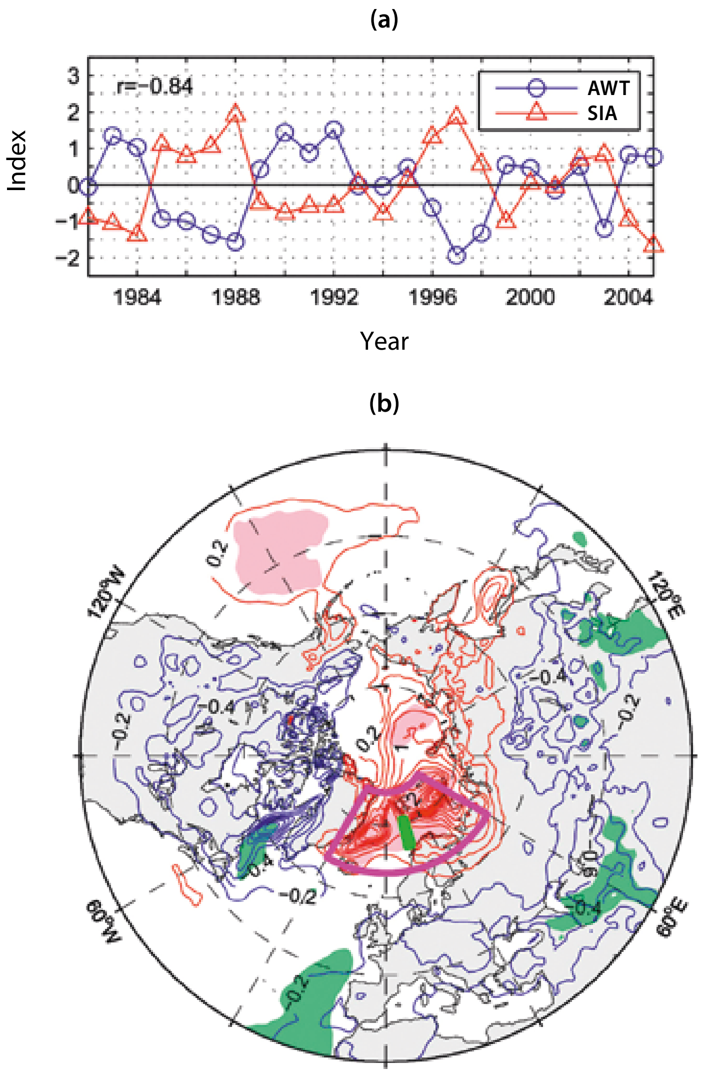


Fig. (a)
The index of Atlantic Water Temperature (AWT) averaged over the 100–300 m depth at the entrance to the Barents Sea (area marked with a green rectangle in (b)) during the summer (June-September) season in the period of 1982–2005 (blue circles) and the index of Sea Ice Area (SIA) in the Nordic Seas region (purple box in (b)) during the following winter (red triangles). Both indices represent the standardized (divided by their standard deviation) anomalies relative to the linear trend.

AWT index from the author's website (http://www.iopan.gda.pl/ClimateDG/) and sea ice data from the National Snow and Ice Data Center, Boulder, Colorado, USA: http://www.nsidc.org/data/NSIDC-0051.

Fig. (b)
The coefficient of regression of the average winter anomaly (December-March) of the surface air temperature in the extratropical northern hemisphere in the period of 1982/83–2005/2006 with the AWT index in the previous summer season (blue circles in (a)). Red and blue contours represent positive and negative anomalies, respectively. Contours were plotted at 0.2°C per 1 unit of the AWT index. The zero contour was omitted. The pink and aquamarine shading represent respectively positive and negative anomalies, statistically significant at the 95% confidence level.

Air temperature data from the European Center for Medium-Range Weather Forecasts (http://www.ecmwf.int/en/research/climate-reanalysis/era-interim).

- Heat anomalies in the Nordic Seas not only affect sea ice, but also the local atmospheric conditions, both in the layer near the sea surface, as well as in the upper troposphere;
- The summer anomalies of the Atlantic water temperature at the entrance to the Barents Sea are also statistically significant precursors to winter changes in tropospheric circulation and, above all, to the activity of weather systems in Eurasia. For example, Atlantic water temperature anomalies explain as much as 60% of the variance of the meridional heat transfer through synoptic eddies in the lower layer of the troposphere over western Eurasia in the area between 45° and 60° N. It should be emphasized here that changes in the atmospheric circulation during the years 1982–2006 related to the Atlantic water temperature anomalies at the entrance to the Barents Sea were not correlated with the simultaneous changes caused by the North Atlantic Oscillation. This increases the possibility of predicting atmospheric climate variability in the winter season based on previous ocean anomalies. This potential will be better explored within the EURAKLIM project.

How will the atmosphere respond?

EURAKLIM will expand on the existing research by analyzing longer time series (from 1979 to the present), other ocean predictors (both from the Nordic Seas and other regions), alternative atmospheric data (higher resolution reanalysis), additional atmospheric variables (such as precipitation), and a wider spectrum of potentially significant physical processes (such as planetary waves). It may be determined that, for example, the spectacular "warm Arctic/cold Eurasia" dipole observed in the winter of 2011/2012 was the result of the ocean's influence on the atmosphere. This dipole actually resembles the distribution of air temperature anomalies in the Arctic-Eurasian region associated with the Atlantic water temperature index. If the relationship between the observed summer Atlantic water temperature in the Nordic Seas and the climate conditions in Eurasia during the next winter prove stable over time, or if EURAKLIM discovers even better ocean predictors of these conditions, then it may be assumed that the inclusion of the Atlantic water temperature at the entrance to the Barents Sea, or its equivalent, into the statistical systems for predicting winter climate variability will increase the effectiveness of forecasts. In addition, these results can be used to verify the current global climate models (extremely complex dynamic prediction systems) and contribute to a better understanding of the dynamics of our planet.

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Further reading:

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