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GEOPHYSICS

Evaluation of the Impact of Oceanic Heat Transport in the North Atlantic and Barents Sea on the Northern Hemispheric Climate

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Abstract—In this work, we evaluate the impact of terminated oceanic heat flux in the North Atlantic and Barents Sea on the Northern Hemispheric Climate in January by numerical experiments with a combined model of atmospheric general circulation and a thermodynamic model of the upper mixed layer of the ocean. We analyze the variations in the atmospheric circulation and near-surface temperature. We found that the termination of the oceanic heat flux leads to a depression in atmospheric centers of action in the Northern Hemisphere (by 3–5 hPa) and a significant cooling over the continents with the strongest temperature decrease down to −10°C in northwestern Eurasia.

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The climate of high latitudes of the Northern Hemisphere and its relation to the global climate are highly dependent on heat transport from the Atlantic to the Arctic. Being relatively small in absolute values, these fluxes can significantly affect global climate changes [1]. The temperature difference between the equator and poles leads to a meridional heat transport into high latitudes by the atmosphere and ocean. According to estimates obtained from empirical data, the annual-mean meridional transport heat transport in the Northern Hemisphere reaches a maximum of around 6 PW near 40° N. Here, approximately 80% falls to heat transport by the atmosphere [2]. Despite the relatively small contribution to the total zonal-mean transport, the oceanic heat transport can play a key role in the formation of the regional climate. The ocean surface temperature (OST) in the subpolar North Atlantic considerably exceeds the zonal-mean values [3], which is caused by the oceanic heat transport from tropical latitudes by the upper branch of the meridional water circulation (MWC), mainly, by the North Atlantic current, which is an extension of the Gulf Stream. The continuing global climate warming is accompanied by increased precipitation at high latitudes of the Northern Hemisphere and glacier melting, which leads to freshened surface waters in the Atlantic, reduced deepwater convection, and delayed MWC. This scenario is reproduced by modern climate models [4]. It cannot be excluded that the MWC may be fully stopped and the ocean circulation may go to another stable mode without MWC and the heat transport related to it [5]. Apart from the MWC stopping, the oceanic heat influx into the Barents Sea may be fully stopped due to positive feedback between the heat influx and the boundary of the sea-ice extent [6]. Although both of these scenarios are unlikely to occur, they cannot be excluded in principle, including in the current climatic period with a significant natural climatic fluctuation (caused, for example, by the Atlantic long-period multidecadal oscillation [1] or by a strong external forcing, for example, a series of volcanic eruptions), and the consequences of these events are of great interest. In this work, we evaluate the possible changes in the winter climate when the oceanic heat flux is stopped in idealized experiments with the climate model.

The numerical experiments were performed using the combined atmospheric general circulation model ECHAM5 and the thermodynamic model of the upper (50 m) mixing layer of the ocean, developed at the Max Planck Institute of Meteorology in Germany [7]. The spectral horizontal resolution of the model used for numerical experiments is T31 (approximately 3.75° × 3.75° by latitude and longitude). The oceanic surface temperature (OST) in the ocean model is determined from the equation of heat balance on the

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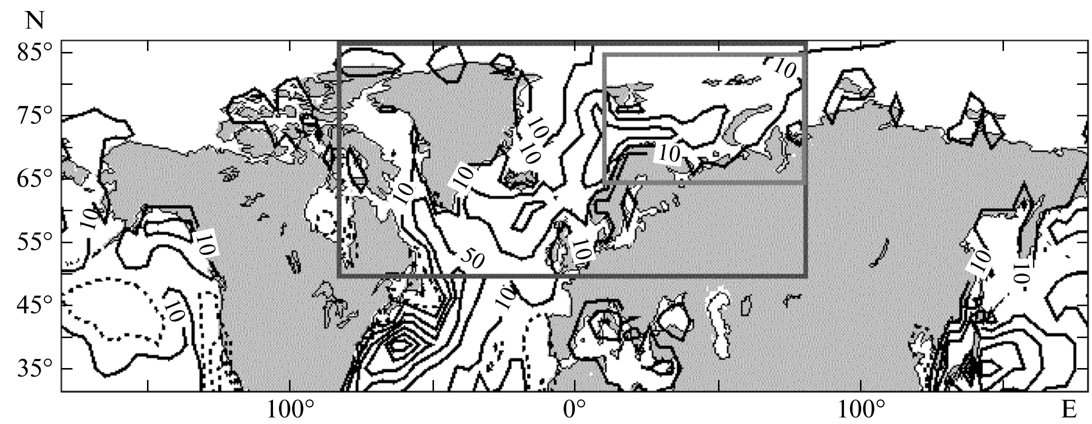

Fig. 1. Annual-mean values of oceanic heat convergence (W/m^2) used in the experiments with the combined model of general circulation and thermodynamic model of the upper mixed layer of the ocean. The North Atlantic and Barents Sea regions where the oceanic heat convergence has vanished are shown.

oceanic surface, and sea-ice generation is assumed to occur when this temperature falls to −1.8°C. To make the climate reproduction realistic in this type of models, the heat balance equation is modified: the radiation and turbulent heat fluxes are appended by the so-called oceanic heat convergence (OHT) flux, which describes the heat influx to a model cell due to oceanic dynamics. The OHT flux is estimated from an experiment using the model of atmospheric general circulation with given boundary conditions for OST and the sea-ice concentration (SIC) as a disbalance of heat fluxes at the oceanic surface. We used the annual-mean climatology of OST and SIC from HadISSTI data [8] averaged over the period from 2000 to 2009. The concentrations of greenhouse gases were specified at current levels. The pattern of the annual-mean OHT is shown in Fig. 1.

To analyze the working hypotheses, three experiments were performed: a control experiment reproducing the climate of the first decade of the twenty-first century (experiment 1) with a vanishing OHT flux in the Atlantic sector (80° W–80° E, 50° N–90° N) and experiment 2 with a vanishing OHT flux in the Barents Sea (10° E–80° E, 65° N–85° N). These areas are marked in Fig. 1. The length of each experiment was 100 years. Here, we will present the results for January, when the OHT flux is a maximum. The OHT flux in January averaged over the indicated areas constitutes 1.9 and 0.4 PW for experiments 1 and 2, respectively.

The approach used in this study is very similar to that used previously in [9] but has a number of significant differences. The OHT flux was set to zero only in a limited region of the North Atlantic, including separately in the Barents Sea. Thus, the results presented below should be regarded as a response of the climate system atmosphere–upper oceanic layer to the cessation of OHT flux. In the model used, the relaxation time to equilibrium for the global temperature is around 10 years. The analysis is based on the last 80 years of each experiment. It should be emphasized that the most significant changes between the experimental results and the control occur in the extratropical latitudes of the Northern Hemisphere. In the southern hemisphere, the changes are insignificant.

Figure 2 shows the changes in the January air pressure at sea level (APSL) in the extratropical latitudes of the Northern Hemisphere as the difference between the experiment minus control for experiments 1 and 2, respectively. In general, the stopped OHT flux in the Atlantic sector leads to a decrease in pressure over the continents and an increase over the oceans with the strongest changes in the North Atlantic and generation of the contrast dipole of APSL with a positive anomaly centered over the Labrador Sea and a negative anomaly over Greenland (Fig. 2). It should be noted that the most significant changes (with a decrease in pressure down to 5 hPa) occurred in the Canadian High. One can also note the positive anomaly of APSL (more than 5 hPa) in the region of the Black and Caspian seas. When comparing the APSL distribution patterns in the control experiment and experiment 1 (not shown), it turns out that the stopped OHT flux leads to a decrease in the amplitude of the atmospheric centers of action with a small change in their position. In this case, the position of the stationary anticyclones over the continents remains almost unchanged and the depressions over the oceans (by 5°–10° longitude) are shifted eastward.

It is interesting to note that the effect of the eastward shift of stationary low-pressure areas is found in the experiments performed to simulate the human impact on the climate [10], as well as that found between the 1970s and 1980s, in analyzing the intensity of synoptic variability [11]. These results are generally consistent with the results of simulations of the MWC collapse in the experiment with the combined model of the general circulation of the atmosphere,

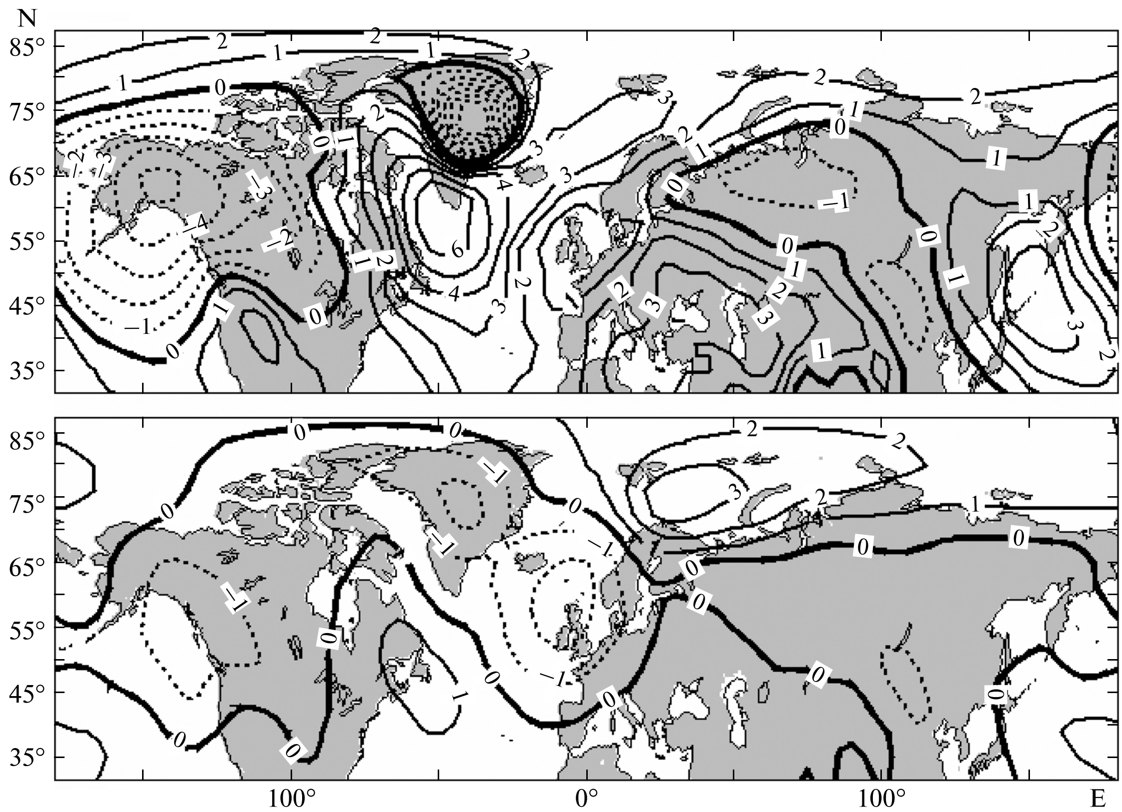

Fig. 2. Changes in air pressure at sea level (hPa) in January for experiments with vanishing oceanic heat convergence in the Atlantic sector (top) and Barents Sea (bottom) against the control experiment. The contour interval is 1 hPa; dotted and solid lines indicate negative and positive values, respectively.

ocean, and sea ice [12] and can be explained by a decreased temperature contrast between the continents and the oceans.

Experiment 2 is characterized by considerably smaller APSL changes and the formation of anticyclonic anomalies over the Barents Sea, generated due to the complete coverage by sea ice and the cyclonic anomaly north of the British Isles (Fig. 2).

Changes in the near-surface temperature and ice-cover boundary (determined by the isolines of 15% concentration of ice in a model cell) are shown in Fig. 3. The stopped OHT flux in experiment 1 leads to a significant cooling with the maximum amplitude reaching –20°C in the Norwegian and Greenland seas, which, like the rest of the north Atlantic north of 50° N, become covered with ice. A strong cooling by more than 7°C occurs in the northern part of Eurasia (Fig. 3). The isotherms of temperature anomalies have a wave structure associated with the corresponding changes in the atmospheric circulation (Fig. 2). For example, the cold tongue to the east of the Caspian Sea is associated with the local anticyclonic anomaly and the advection of anomalously cold air. The smaller (in comparison with the zonal mean) temperature anomalies in the Siberian and Canadian anticyclones are explained by a decreased pressure in these centers of action in experiment 1. One can see a significant cooling over the territory of Russia. For example, the temperature decreases by 3–4°C on the Black Sea coast, 7°C in the Moscow region, and 10°C in the Leningrad region. Cooling by more than 7°C occurs in the Far East, with the Sea of Okhotsk being completely covered with ice. The cooling in North America is weaker than in Eurasia, with the largest negative anomalies on the east coast.

The stopped oceanic heat flux in the Barents Sea leads to the freezing of the entire Barents Sea and much of the Greenland Sea, accompanied by the strongest cooling over the Barents Sea (Fig. 3). Here, the cooling is significant only over the northern coast of Eurasia. It is interesting to note that the formation of the anticyclonic anomaly in the Barents Sea and the cooling over Eurasian regions can also occur when the area of ice cover is decreased [13, 14], which is due to the nonlinear response of the atmospheric circulation to the reduced ice concentration in the Barents and Kara seas, which was revealed in [13].

The changes in precipitation over the continents (not shown) in both experiments are relatively small. In general, the amount of precipitation over the continents decreases with the greatest changes reaching

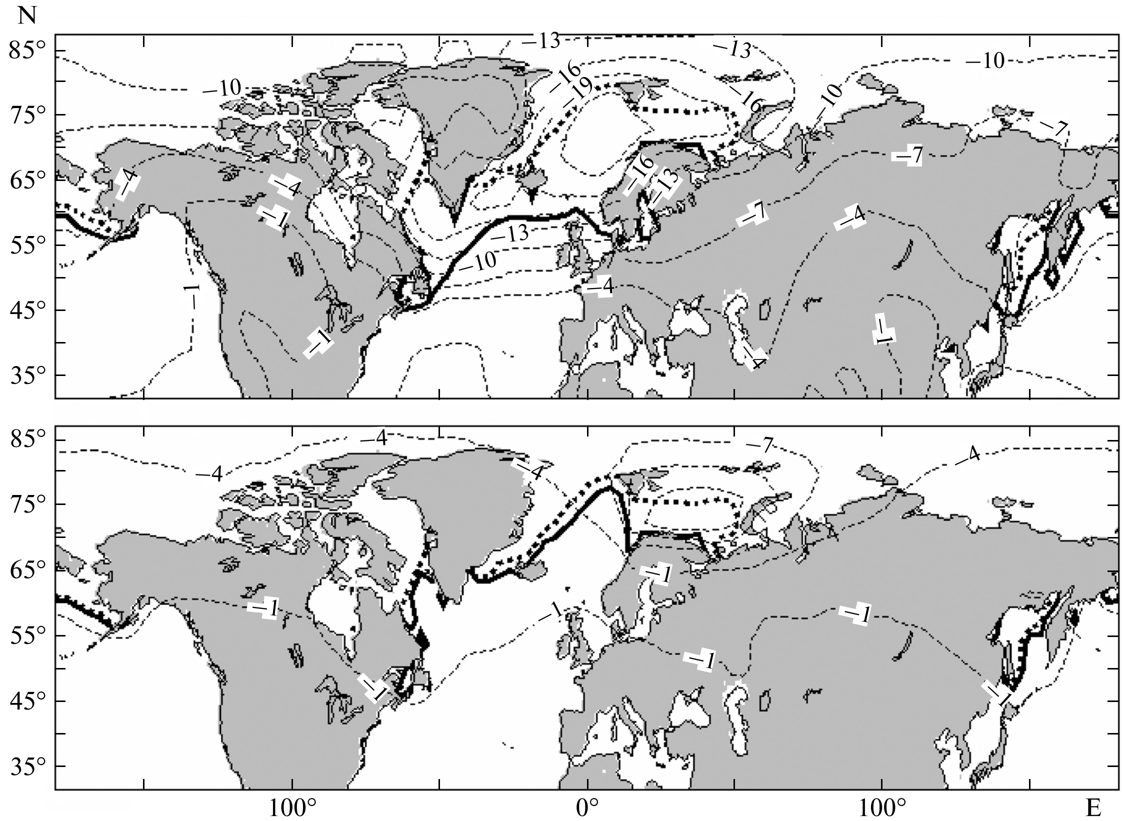

Fig. 3. Changes in near-surface temperature (°C, thin dashed lines spaced 3°C) in January for experiments with vanishing oceanic heat convergence in the Atlantic sector (top) and Barents Sea (bottom) against the control experiment and the corresponding ice-cover boundaries (isolines of 50% ice concentration) for the control experiment (bold split contour lines) and experiments with terminated fluxes of oceanic heat convergence (bold solid contour lines).

20% at high latitudes (north of 65° N) and south of 40° N.

The hemispheric-mean cooling in January in experiments 1 and 2 constitutes 2.7°C and 1.0°C, respectively, with the strongest anomalies in the northwestern part of Eurasia. This absolute value of cooling for experiment 1 is much greater than warming over the past 50 years, amounting to 1.0°C in the Northern Hemisphere [15]. However, this value is smaller than the estimates of warming (with respect to current climate) by the end of the twenty-first century (3.7°C), obtained according to climate models (on ensemble-average of models) in experiments of modeling the human impact on the climate [4]. At the same time, it should be noted that the sensitivity of hemispheric-mean temperature to changes in the concentrations of greenhouse gases in the models may be considerably overestimated, as follows, for example, from the results of [1]. In this case, the effect of the stopped OHT flux in the North Atlantic can lead to cooling in the Northern Hemisphere in the late twenty-first century even taking into account the anthropogenic impact on climate.

It should also be noted that the temperature difference between Western Europe and the northeastern part of North America in experiment 1 decreased by approximately 25% (from 11.5°C to 8.7°C), which confirms the conclusion about the predominant influence (compared to the oceanic heat transport) of the western transport and stationary wave structure of the atmospheric circulation at high latitudes of the Northern Hemisphere, caused by the orography and heat sources at the lower boundary of the atmosphere, in the formation of an abnormally warm climate in Europe and an abnormally cold climate in the eastern part of North America [9].

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