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Short communications: Simulation of transferring fresh waters near the shore

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Abstract

The suggested model simulates advection and turbulent diffusion by Monte-Carlo method. As an example, the results of the calculation for fresh water transfer by East Greenland current in the North Atlantic are considered. It is shown that during warm season incoming Arctic water have no time to be distributed uniformly in the zone 50-70º N, as it was suggested in thermohaline catastrophe models. The currents width was set at 100 km, and horizontal turbulent diffusion coefficient was 1000 m^2/s. After calculations for 1.5 months, the initial particles concentration near the coast was 100 times more than at the distance of 250 km from the coast.

Keywords: Numerical simulation; Thermohaline catastrophe; Ice melting; Horizontal turbulence; Monte-Carlo method.

1. Main body

The data of modern precision studies of ice samples from the glaciers of Greenland and sediments at the bottom of several lakes in the UK and other countries of Northern Europe show that several thousand years ago with a slow warming of the climate in Europe there were rapid cooling (Ellison *et al.*, 2006). Thus, 8,200 years ago, in just 1-2 years, the average annual temperature in the north of Europe decreased by almost 10 °C, mainly due to a decrease in winter temperatures. Moreover, it was not just one anomalous year - then low temperatures were kept for 200–300 years, all this time in the UK, there were Siberian frosts in the winter. Climatologists associate this phenomenon with the ice melting in the Arctic, which led

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to the influx of large amounts of desalinated melt water into the North Atlantic and thereby increased the vertical stratification in areas of the formation of deep waters. At the same time, vertical circulation was blocked and, as a result, the transfer of warm waters by the Gulf Stream was stopped. In this regard, in recent years, along with the well-known problem of predicting global warming, much attention is necessary for studying this phenomenon. The rapid ice melting of Arctic may lead to similar consequences, which makes the study of the redistribution of fresh water in the North Atlantic urgent.

From observations, it is well-known that, in the presence of a coastal flow near the coast, a relatively narrow strip of polluted water is formed, while seaward is much cleaner. This is an example of the western coast of the Black Sea, where the main Black Sea Current carries the diluted waters of the Danube and the Dnieper. Obviously, a similar effect occurs in the Arctic off the coast of Greenland when the waters of the East Greenland Current desalinated due to melting ice melting into the North Atlantic and intermix with the surrounding water masses (Vellinga and Wood, 2002). As you know, during the transition to the Holocene, this happened repeatedly, for example, 12,700 and 8,200 years ago (Ellison *et al*., 2006), and was accompanied by a rapid and severe cooling in northern Europe, which lasted for hundreds of years (Vellinga and Wood, 2002).

It would seem that this problem could be fully solvable with the help of global models of ocean and atmosphere circulation. However, the practice of such calculations shows that due to computational difficulties in order to solve such problems, it is necessary to set a uniform distribution of the desalinated waters in the North Atlantic in the entire zone of 50 - 70 º N (Stouffer *et al.*, 2006). As a rule, when modeling a thermohaline catastrophe, fresh water is supplied to the considered basin for many years with a given intensity (from 0.1 to 1 Sv), where are immediately evenly distributed over its surface (Stouffer *et al*., 2006). At the same time, since the blocking of water immersion is associated with increased stratification, it is quite clear that the main effect is due not only to the integral flow of fresh water, but also to the uneven distribution of their distribution in the water area. Furthermore, if the intensification of freshwater in the waters of fresh water is associated with the melting of glaciers of Greenland or the melting ice of the Arctic (and not with increased precipitation, for example), then they fall into the North Atlantic near the coast of Greenland. On the other hand, the main areas of formation of deep waters are located in the Irminger Sea and the Labrador Sea. Taking into account the above-mentioned effect of pressing the impurity to the shore indicates that the non-uniform distribution of fresh water in the zone of 50-70 ºN will lead to a stronger impact on the deep convection and the intensity of the thermohaline circulation than it follows from calculations based on global circulation models (Stouffer *et al.*, 2006). Therefore, in this case a non-stationary process is considered. Intensive influx of melt water takes place only in the summer. Therefore, the distribution of these waters in the North Atlantic is not steady. Consider for definiteness the removal of melt-water from the Arctic by the East Greenland Current running along the southeast coast of Greenland. At its speed of up to 0.5 m/s during the warm season, these waters move along the coast of Greenland and North America over a distance of several thousand kilometers,

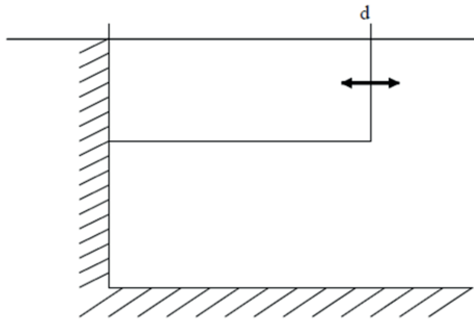

Figure1. Schematic cross-section of the coastal surface flow

exchanging due to horizontal turbulent diffusion with the adjacent waters of the open ocean. This raises the question of how far from the coast of Greenland will be able to spread the desalinated water during this time due to horizontal mixing. To answer this question, we consider the simplified problem of the diffusion of an impurity from a jet stream of width *d* that runs along the coast (Figure 1). The arrow shows the turbulent exchange through the lateral boundary of the flow.

The exchange through the lower boundary of the flow is neglected, that is, only the horizontal diffusion of the impurity is taken into account. To model it, we used the trajectory-imitation version of the Monte Carlo method (Degterev and Mordashev, 2008).

Considering the fact that the width of the Danish Strait is up to 300 km and in addition to the East Greenland Current off the coast of Greenland, the oppositely directed Irminger current passes closer to Iceland, we assume the width of the main jet of the current is d = 100 km. On the interval [0, d], a uniform distribution of water particles was set, after which we could share each of them randomly. To do this, at each time step, using a random values sensor with a uniform distribution in the range (–π, π), the direction of the turbulent jump in the horizontal plane (azimuth angle φ) was determined. The particle displacement along the x-axis over the time interval Δt was calculated by the formula

$$L_x = L \cdot \cos\varphi \qquad (1)$$

where, L is the length of the turbulent jump, which remained constant and was previously determined as a function of the given coefficient of horizontal turbulent diffusion A_L and the time step Δt:

$$L = \sqrt{2A_L \Delta t} \qquad (2)$$

In this case, based on the specifics of the problem, in various numerical experiments the time step were taken from 8 hours to 3 days, respectively the length of the turbulent jump L was from 7.6 to 22.9 km. The calculation essentially came down to determining the coordinates of the moving water particles at successive time moments. Such the approach was used for solving of some other ocean circulation problems too (Degterev, 2011).

This corresponds to the assignment of a turbulent boundary layer near the shore, in which there is no turbulent mixing. Tracing in this way the trajectories of the order of a million particles with different initial coordinates, we can calculate for any given moment of time (for example, in a month) the number of particles per unit length at a different distance from the coast. This kind of density distribution of particles along the x-axis is shown in Figure

2 with a spatial resolution of 10 km. In this sense, the initial distribution corresponds to zero values for x>d, while in the region [0, d], the initial density was 10^5 particles/10 km. Since the distance from the Danish Strait to the southern tip of Greenland and the Irminger Sea is about 1000 km, at a current speed of 40 cm/s it will take a month to overcome it. In this connection, Figure 2 shows the distribution of particles after 0.5–1.5 months of a countable time.

As Figure 2 indicates, during the period under consideration most of the particles remain within the limits of the jet flow. For an upper estimate of the distance over which fresh water spreads from the coast, in the first approximation, it was sufficient to consider a turbulent diffusion from a stationary flow "tape" into the adjacent water mass. It represents that in all cases the concentration of particles monotonously decreases with distance from the coast. Some deviations from the monotonous course of the curves are related to the statistical error arising in the Monte Carlo calculation. In general, the distributions correspond to the maps of salinity anomalies, obtained based on the calculations based on global circulation models (Stouffer *et al.*, 2006).

It is also clear in Figure 2 that after 1.5 months, the distribution of primary particles along the x-axis remains very uneven at a distance of 250 km from the coast and their concentration is two orders of magnitude less than that at the coast. This means that incoming waters of the Arctic origin during the warm season in the same proportion are distributed at different distances from Greenland.

Thus, the flow of desalinated waters through the Danish Strait directly affects the stability of water stratification only within the coastal strip with a width of no more than 1–2 degrees of longitude. Accordingly, in the case of an extreme large influx of melt-water, local blocking of the vertical circulation will require much lower flow intensity if we assume that these desalinated waters are distributed in the 50-70º N zone. Numerical experiments within the framework of general circulation model show that in the latter case, the circulation stops at the 1 Sv flow rate of freshwater (Stouffer *et al.*, 2006). However, our results suggest that due to the uneven distribution of freshened waters, the process of formation of deep waters near Greenland can be blocked even at a freshwater flow rate of about 0.1 Sv.

Further studies in this area maybe related to

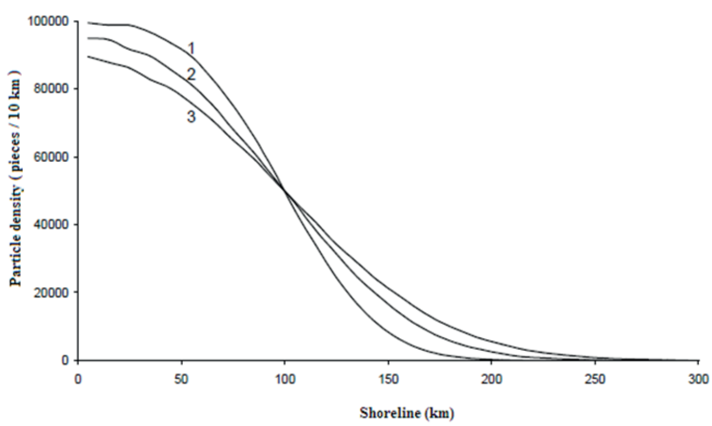

Figure 2. Linear particle densities normal to shore in: 1) 0.5 month, 2) 1 month, 3) 1.5 months

the modeling of the redistribution of freshened waters with the current intensity varying on a scale of several months. Considerable interest is also on the problem of vertical mixing of melt waters, an assessment of their accumulation at different depths over several years, and the effect on the stability of stratification. The solution of these questions is not connected with the use of cumbersome models of the general circulation of the ocean, which, although available on the Internet, as the practice shows, in fact it does not allow major changes to the parameterization schemes.

References

Degterev, A.Kh., and Mordashov V.I. 2008. Trajectory–simulation modeling of transport processes in geophysics. Sevastopol: Publishing House of SevNTU.

Degterev, A.Kh. 2011. Estimation of the rate of water renewal in the ocean conveyor. Russian Meteorology and Hydrology, 36(6): 403-408.

Ellison, C.R., Chapman, M.R., and Hall, I.R. 2006. Surface and deep ocean interactions during the cold climate event 8200 years ago. Science, 312(5782): 1929-1932.

Stouffer, R.J., Yin, J., Gregory, J.M., Dixon, K.W., Spelman, M.J., and et al. 2006. Investigating the causes of the response of the thermohaline circulation to past and future climate changes. Journal of Climate, 19(8): 1365-1387.

Vellinga, M., and Wood, R.A. 2002. Global climatic impacts of a collapse of the Atlantic thermohaline circulation. Climatic change, 54(3): 251-267.