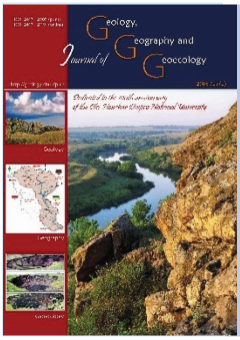

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Dynamics of the temperature regime of the North Atlantic coastal zone as an indicator of changes in the system of thermohaline circulation

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Abstract. The purpose of the article is to analyze dynamics of the temperature regime of the surface layer of the atmosphere in the coastal zone of the North Atlantic as an indicator of changes in the thermohaline circulation system. In carrying out the research, comparative-geographical and historical statistical methods of the analysis of meteorological series were used. For research, 20 control points of the eastern part of the United States and Western Europe, which are located along the flow course of the Gulf Stream, are selected. In the selected points, by means of the linear trend method, the regularities of the dynamics of the mean annual, average maximum and average minimum temperatures of the atmospheric surface layer for the period from 1973 to 2013 have been established. The results of the study showed that, contrary to the hypothesis of fall in temperature in Europe, an increase in average annual and average maximum temperatures is observed in all control points of the region - the range means the linear trend is from 0.9 to 4.4 °F and from 0.3 to 3.8 °F respectively. In most US control points, the average annual temperature rises from 0.1 to 3 °F and the average maximum temperature rises from 0.2 to 2.1 °F. For four points of the United States the decrease in the values of the linear trend of average annual temperatures is from -0.4 to -1.2 °F; for three points - a decrease in average maximum temperatures is from -1.3 to -1.9 °F. At 9 control points in the USA and 8 control points in Europe, the average values of the minimum temperatures in the research period increased - in the USA, from 0.1 to 3.1 °F; in Europe from 0.3 to 4.6 °F. The opposite dynamics in the regions is observed for the values of the temperature amplitude. In most control points in Europe, the difference between the average maximum and the average minimum annual temperatures ranged from 0.4 to 6.6 °F; in most US destinations, on the contrary, a decrease in the amplitude value from -1.6 to -3 °F is observed. The analysis of the temperature dynamics of the surface layer of the atmosphere indicates the prevailing warming processes in the coastal zone of the North Atlantic, more intense for control points in Western Europe. The obtained data give grounds for refuting hypotheses of the presence of critical deviations in the thermohaline circulation system of the Atlantic Ocean, which could lead to a cooling in the Northern Hemisphere. The change in the amplitude values is a manifestation of increasing instability of the climate, which is likely to remain in the future with a general increase in the mean annual temperature in the region.

Keywords: climate, climate change, thermohaline circulation, Gulf Stream, Atlantic Ocean.

Динаміка температурного режиму прибережної зони Північної Атлантики як індикатор змін у системі термохалинної циркуляції

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Анотація. У контексті сучасних кліматичних досліджень набувають поширення гіпотези щодо змін у системи термохалинної циркуляції Атлантичного океану внаслідок глобального потепління. Механізм трансформаційних процесів пояснюється розпрісненням океану при таненні льодовиків, що обумовлює зміну показників солоності і відповідно густини водних мас – чинника формування термохалинної циркуляції. Дослідники здебільшого пов'язують такі зміни із можливим чи вже існуючим відхиленням системи течій Гольфстрім, її ослабленням або навіть зупинкою. Серед прогнозованих наслідків виділяють значне похолодання в Європі із можливістю настання нового Малого льодовикового періоду. У статті представлено дослідження динаміки температурного режиму прибережної зони Північної Атлантики, як індикатора змін у системі термохалинної циркуляції. Охарактеризовано закономірності зміни середніх, максимальних та мінімальних значень температури приземного шару атмосфери у двадцяти контрольних пунктах східної частини США та Західної Європи за період з 1973 по 2013 рік. Результати дослідження узгоджуються із потеплінням, інтенсивнішим у Західній Європі. В усіх контрольних пунктах Європейського регіону спостерігається підвищення середньорічної і середньої максимальної температури – діапазон значить лінійного тренду складає від 0,9 до 4,4 °F та від 0,3 до 3,8 °F відповідно; у більшості контрольних пунктів спостерігається зростання значень середньої мінімальної температури від 0,3 до 4,6°F. Для більшості контрольних пунктів США характерне зростання значень середньорічної температури від 0,1 до 3 °F; середньої максимальної температури – від 0,2 до 2,1°F; середньої мінімальної – від 0,1 до 3,1 °F. Отримані дані дають підстави для спростування гіпотез щодо наявності критичних відхилень у системі термохалинної циркуляції Атлантичного океану, які б могли призвести до похолодання у Північній півкулі.

Ключові слова: клімат, зміни клімату, термохалинна циркуляція, Гольфстрім, Атлантичний океан.

Formulation of the problem. Today, the debate about the temperature rise in the surface layer of the atmosphere as a result of anthropogenic activity has been practically completed. The theory of the greenhouse effect has become paradigmatic knowledge. Scientific research has been transformed into a search for a solution to the problems of the climatic system's response to changes in the temperature regime, as well as shifting its focus towards adaptation of national and world economies to these changes. Among the main dangers there is probability of a significant cooling in Europe when the region's climate develops a sharply continental character with the subsequent threat of onset of aLittle Ice Age. This scenario becomes possible due to the weakening of the Gulf Stream flow system. Global temperature rise leads to melting of the Arctic ice sheet, making the Atlantic Ocean water fresh As a result, water salinity changes and, consequently, water density, which is the determining factor in the formation of thermohaline circulation. Changes in the parameters of ocean circulation is the main danger for the European region because the temperate climate of the territory is supported by the advection of warm air masses from the Atlantic.

Prerequisites for conducting research are the implementation of the United Nations Framework Convention on Climate Change (1992), the Cancun Agreements (2010), the Paris Agreement (2015) and implementation of key areas of Ukraine's environmental policy in terms of deepening scientific knowledge on climate change, forecasting climate dynamics and development of adaptation options.

Analysis of recent research and publications. Current research suggestsinconsistency of the scientific community's views on the causes and consequences of changes in the thermohaline circulation system, intense loss of salinity of the Atlantic ocean, presence of Gulf Stream mitigation processes, and so on. Some scholars generally regard the Gulf Stream as insignificant for Europe's climate. According to researchers from the United States (Seager, Battisti, Yin, Gordon, Naik, Clement & Cane, 2002), the oceanic heat transfer warms the northern part of the Atlantic to "a modest few degrees"; and the only place where the transport of warm ocean basically changes the climate is the coast of northern Norway. Hence, if it were not for warm Norwegian currents, the sea would be covered with ice. Russian scientist V.N. Malinin (Malinin, 2012) explains the absurdity of the hypotheses regarding the catastrophic consequences of the current's cessation by stating the significant contribution of the wind component to the surface layer of the ocean in the formation of circulation (about 80%) and one of the main properties of atmospheric circulation - stability.

According to prof. V.N. Malinin,the Gulf Stream cannot disappear because trade winds will not allow it.

Practical studies give significantly different results. For example, according to Rossby, Flagg, Donohue, Sanchez-Franks & Lillibridge, 2014; the Intergovernmental Panel on Climate Change, 2013, there has been no significant change in the characteristics of the Atlantic Meridian Overturning Circulation (AMOC) and its structural elements during the last few decades. No changes in the speed of the Gulf Stream have been detected. The opposite data were obtained by the British National Oceanographic Center (Bryden, Longworth & Cunningham, 2005). The comparative analysis conducted by the Center staff for the period from 1957 to 2004 indicates a 30% decrease in AMOC. According to studies by Russian scientists (Karlin, Malinin & Gordeyeva, 2013), during the same period the density of the Gulf Stream's waters decreased significantly as a result of global warming, but the density of the Labrador Currents remained unchanged. New results from paleoclimatic studies (Thornalley, Oppo, Ortega, Robson, Brierley, Davis, Hall, Moffa-Sanchez, Rose, Spooner, Yashayaev & Keigwin, 2018) indicate an abnormal weakness of the deep convection of the Labradorian flow and AMOC over the past 150 years in comparison with the previous 1500 years.

The results of prognostic studies mostly concur with the weakening of AMOC, but hypotheses and theories about response of the climatic system have an opposite character. According to the IPCC, it is likely that the GulfStream will slow down during the 21st century, but it is unlikely that there will be a "big jump". The slowing will have a cooling effect, the atmospheric temperature will continue to increase in the region as a whole. Certain models (Liu, W., Xie, Liu, Z. & Zhu, 2018) show the destruction of circulation after 300 years with an increase in CO2 concentration in the atmosphere by 2 times, which will lead to noticeable cold weather in the North Atlantic and neighboring regions. According to another model (Korzun, 2012), if the density of cold polar waters drops to a certain level, they can become an obstacle to the Gulf Stream penetration into Europe. As a result, the region will become colder by 5-10 ° C. That is, climatic conditions of Western Europe will approach the conditions of Eastern Canada.

At present, a number of researchers are already pointing to climate changes in the European region in the direction of cooling and their correlation with the weakening of AMOC. In particular, disturbance of ocean circulation is associated with an increase in winter frequency in the Netherlands with temperatures below the norm (Klein Tank, 2004), the trend to increasing frequency of cold winters in Belarus (Loginov & Tabalchuk, 2014), deficiency of precipitation and probability of cold weather in the European region (Merzlikin , 2011), changes in total ozone over the Arctic (Kholoptsev & Kuzmenko, 2012).

An overview of the literature suggests that insufficient attention is paid to changes in the climate parameters of the Atlantic region and their consequences on a global scale. Climate dynamics studies are largely localized to the level of individual countries and do not provide objective information about probable weakening of AMOC. Taking into account the above, it becomes necessary to study the dynamics of the climate parameters of the North Atlantic as a possible indicator of changes in the system of thermohaline circulation.

The purpose of the work is to analyze the temperature regime dynamics of the surface layer of the atmosphere in the coastal zone of the North Atlantic as an indicator of changes in the thermohaline circulation system.

Materials and methods of research. In carrying out the research, statistical methods of the analysis of meteorological series, comparative-geographical and historical methods were used. According to the Spanish Climate Information Archive (Tutiempo) and the National Oceanic and Atmospheric Administration (NOAA), graphs of the average annual, average maximum and minimum temperatures of the surface layer of the atmosphere in the North Atlantic coastal zone have been constructed. 20 test points of the eastern part of the United States and Western Europe were selected for the study. The magnitude of change in the studied indicators at control points was determined by the linear trend method. Statistical and graphical processing of the data was carried out using the Microsoft Office Excel software.

Results and their analysis. According to Ayslin,the name GulfStream means the entire system of western currents, including North Atlantic, Florida and GulfStreams. Stability of the oceanic conveyor is supported by the difference in density of water masses which occurs due to the heterogeneity of the temperature distribution and water salinity. Actually, density change is the basis of theories about the probable transformational processes in the AMOC system - weakening of the circulation, deviation of the direction or slowing down of individual flows**.**

One of the main reasons for changes in the water-salt balance of the Gulf Stream is melting of glacial cover caused by global warming. According to the IPCC, global temperature of the surface layer of the atmosphere increased by 0.85 oCfrom 1880 to 2012, and the temperature rise from 2003 to 2012 relative to the period from 1850 to 1900 is 0.78 oC. The process of warming inevitably has led to feedback from other parts of the climatic system, including the cryosphere. During the last decades, the Arctic basin has seen a rapid retreat of sea ice and temperature rise (Simmonds & Govekar, 2014). The results of satellite observations indicate that Arctic glaciation has fallen by 15-20% over the past 30 years (Zelenina & Antipin, 2015). As a result, the Atlantic Ocean water is becoming fresh and there are corresponding changes in the thermohaline circulation system. The mechanism of the process is described by us above.

The theory of AMOC weakening due to oil spills, which became widespread after the explosion of the Deepwater Horizon oil platform in the Gulf of Mexico (2010), is quite controversial. As a result of the accident about 5 million barrels of oil spilled into the Gulf of Mexico, the area of the oil spill was 75 thousand km2. Russian scientist V. P. Polevanov gives predictive data of an alarming character. Thus, the article (Polevanov, 2011) notes the beginning of catastrophic climate change on both sides of the North Atlantic. According to the scientist, the Gulf Stream has been slowing since 2006 as a result of the desalination of the Labrador Currents, and already in 2010 the oil tanker accident led to a cessation of the current. V.P. Polevanov's conclusions are denied by prof. V.N.Malinin (Malinin, 2012), assuming that the formed oil clumps affect physical characteristics of water and prevent the heat exchange between its layers, but they cannot lead to spatial density differentiation and, accordingly, influence the formation of the flow. Agreeing with the opinion of professor Malinin,it should be noted that the time interval from the moment of the accident at the "Deepwater Horizon" is too short to confirm the climate change. In addition, the intensity of the oil film influence on the thermal mode of flow decreases with the purification of water masses.

The consequences of the weakening of AMOC are mostly attributed to the lower average temperature in the European region. Considering the course of the North Atlantic as part of a global thermohaline circulation, McGuire (2003) suggests that its destruction could have consequences far beyond a colder Europe and could lead to dramatic climatic changes throughout the planet. The results of the research (Klein Tank, 2004; Klein Tank & Können, 1997) have shown that the cooling of the Atlantic Ocean would reduce the air mass temperatures and advection to Europe with prevailing Western circulation. A regularity has been established: a European region will cool of about half the size of the cooling zone of the Atlantic Ocean.

The analysis of historical data confirms the prognostic assumptions about the consequences of weakening AMOC for the climate of Europe. About 14,000 years ago on the territory of North America melted ice formed a huge lake, filled with an unbroken glacier. The glacier continued to melt and at some point, water from the lake began to flow into the North Atlantic, reducing its salinity it and thus creating an obstacle to the North Atlantic flow. Then it led to a significant cold weather in Europe (Volodin, 2011). According to other data (Hopkin, 2006), from 1200 to 1850, when the average temperature in the Northern Hemisphere was reduced by 1 oC, the Gulf Stream's power decreased by 10%. The reduced flow of heat contributed to the glacial conditions which remained until the 19th century.

There is no doubt that connection between climatic conditions and the dynamics of AMOC provides grounds for considering the temperature regime of the Gulf Stream Impact Zone as an indicator of changes in the thermohaline circulation system. Taking into account the above, we have studied changes in the temperature regime of the coastal zone of the North Atlantic. 20 test points have been selectedfor the study – towns in the eastern part of the United States and Western Europe, which do not belong to large industrial centers or densely populated areas (Fig. 1). The checkpoints are located from north to south along the flow of the Gulf Stream system, as far away as possible from the powerful "islands of heat." The selection of control points is caused by the need to minimize the microclimate of the city and to ensure homogeneity of the factors and conditions that influenced the temperature regime of the region during the chosen study period.

United States checkpoints: 1. Belfast, 2. Amherst, 3. Edgartown, 4. Allentown, 5. Dover, 6. Suffolk, 7. Conway, 8. Waycross, 9. Fort Pierce, 10. Key West.

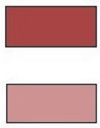
Checking points in Europe: 1. Bear Island, 2. Tromsø, 3. Lervik, 4. Kristiansan, 5. Stornoway, 6. Belmullet, 7. Shannon, 8. Cognac, 9. Braganza, 10. Faro.

Fig. 1. Location of control points of the study (satellite image received by Yandex Search and Information Cartographic Service 2014)

According to the data of the Spanish Climate Information Archive (Tutiempo) and the National Oceanic and Atmospheric Administration (NOAA), graphs of the average minimum, average, maximum and average annual temperatures of the atmospheric surface layer have been constructed for the period from 1973 to 2013. The selected period is characterized by a substantial contribution of the anthropogenic component to the impact of the global and regional climate, in particular, due to the intensification of industrial production, which is analyzed in detail (Maksymenko & Beliaeva, 2012). With the help of the linear trend method, the value of temperature changes in each of the points was determined (Fig. 2). Note that meteorological data in the archives of the United States and Europe are given in different units of temperature measurement: Fahrenheit and Celsius, respectively. Therefore, for the sake of convenience, the data of the control points in Europe were converted into the Fahrenheit scale.

The results of the study have shown that despite the thesis on cold weather in Europe, in all control points of the region for the period from 1973 to 2013, an increase in the average and average maximum temperature is observed - the range of values of the linear trend is from 0.9 to 4.4 °F and from 0 , 3 to 3.8 °F, respectively. For most of the points in Europe, an increase in the average minimum temperature from 0.3 to 4.6 °F is typical. The decrease in the average minimum temperature occurred only in two towns in the north of Scotland: in Lerwick at -3.1 °F and in Stornoway at -4.1 °F. Most control points in the United States also have an increase in average annual temperatures - from 0.1 to 3 °F; average maximum temperature - from 0.2 to 2.1 °F; the average minimum temperature - from 0.1 to 3.1 °F. Two points located in the north of the United States are characterized by a decrease in average annual and average maximum temperature: in Belfast city -0.8 and -1.9 °F, respectively; in Amherst city at -1.2 °F and -1.3 °F. Cooling processes are also typical for the south of the United States. The range of values of the linear trend of average annual and average maximum temperatures in Fort Pierce (Florida) is -0.8 and -1.6 °F, respectively. In Weiqross (Georgia), the negative dynamic of the average annual temperature was -0.4 °F.

Dynamics of average annual temperature



* according to Fig.1

Dynamics of minimum temperature

Dynamics of maximum temperature

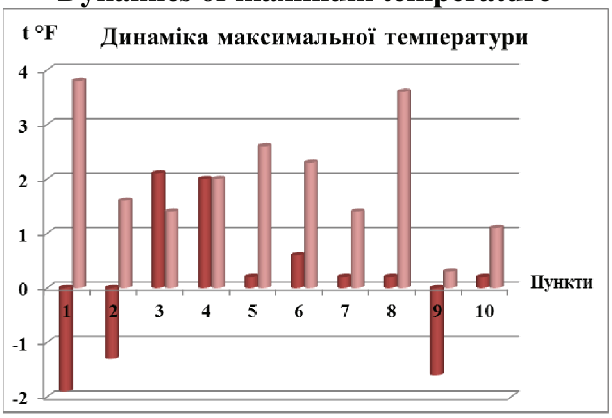


Fig. 2. Temperature regime dynamics of the coastal zone of the North Atlantic (1973 - 2013)

The obtained results provide grounds for refuting the thesis for the Gulf Stream's deflection towards North America, since the magnitude of the rise in temperature, and hence the intensity of warming, is higher for Western Europe. The increase in average annual, average maximum and average minimum temperatures in most control points indicates the inappropriateness of panic about the Gulf Stream and the low probability of a threat of catastrophic cold weather in Europe or the onset of a new Ice Age. According to the authors, the IPCC thesis is most acceptable,predicting a possible deceleration of the Gulf Stream during the 21st century, but without a "dramatic transition". That is, the slowing will have a cooling effect, but the temperature will continue to increase in the region as a whole.

The opposite dynamics are observed for the temperature amplitude. Dynamics of amplitude were determined by the linear trend method as the increase of the difference between the average maximum and the average minimum annual temperature at control points for the period from 1973 to 2013 (Fig. 3).

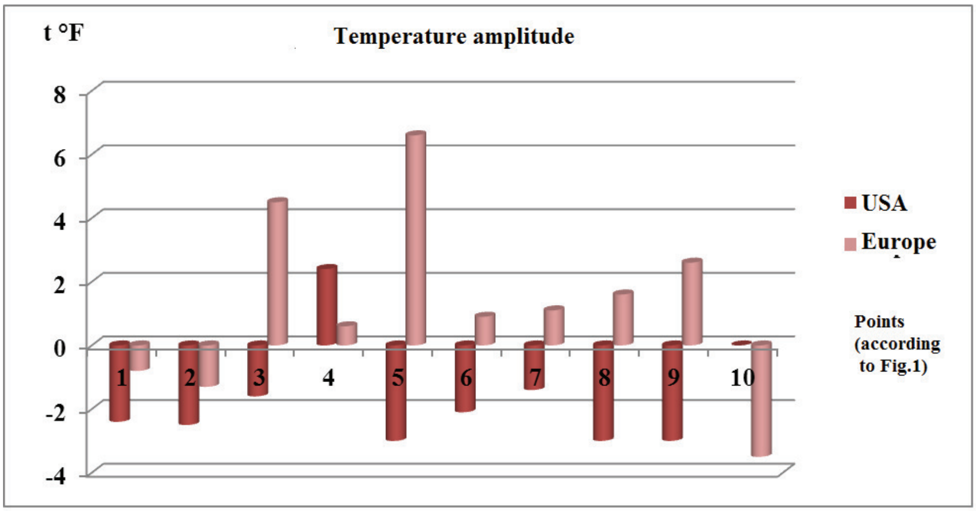


Fig. 3. Temperature range dynamics of the coastal zone of the North Atlantic (1973 - 2013)

As can be seen from Fig. 3, the studied regions have significantly different trends in the dynamics of temperature amplitude indices. In 8 out of 10 control points in the USA there is a decrease in the amplitude of the temperature from -1.4 to -3 oF; whereas for most parts of Europe, the amplitude increases from 0.6 to 6.6 oF. This trend is indicative of an increase in climate instability and is in line with the IPCC forecasts for increase in the frequency of extreme temperatures.

Conclusions. An analysis of the temperature dynamics of the North Atlantic coastal zone for the period from 1973 to 2013 indicates the prevailing warming processes in the region, which are more intense for Western Europe. The range of values of the linear trend of average annual temperatures for most control points in the United States is from 0.1 to 1.3 oF; average maximum - from 0.2 to 2.1 oF; the average minimum - from 0.1 to 3.1 oF. Significantly higher values of the linear temperature trends are for Western Europe. Average annual temperatures in most regions increased from 0.9 to 4.4 oF; average maximum - from 0.3 to 3.8 oF; the average minimum - from 0.3 to 4.6 oF.

The opposite dynamics are observed for the amplitudes of the average maximum and average minimum temperatures. For most control points in the United States, the decrease in the amplitude of the temperature is from -1.4 to -3 oF; whereas for most parts of Europe, the amplitude increases from 0.6 to 6.6 oF.

The obtained data give grounds for refuting hypotheses about the presence of critical deviations in the thermohaline circulation system of the Atlantic Ocean, which could lead to a cooling in the Northern Hemisphere. Changes in amplitude indicators are manifestation of increasing instability of the climate, which is likely to remain in the future with a general increase in the mean annual temperature in the region.

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