RUSSIAN ACADEMY OF SCIENCES

NATIONAL GEOPHYSICAL COMMITTEE

РОССИЙСКАЯ АКАДЕМИЯ НАУК

НАЦИОНАЛЬНЫЙ ГЕОФИЗИЧЕСКИЙ КОМИТЕТ

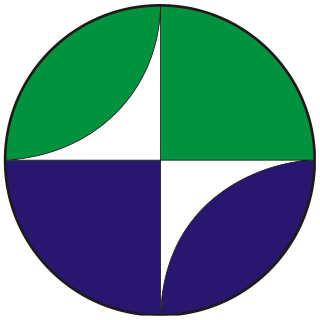
NATIONAL REPORT

for the
International Association for the
Physical Sciences of the Oceans
of the
International Union of Geodesy and Geophysics
2015–2018

НАЦИОНАЛЬНЫЙ ОТЧЕТ

Международной ассоциации
физических наук об океане
Международного
геодезического и геофизического союза
2015–2018

Москва 2019 Moscow



Presented to the XXVII General Assembly

of the

International Union of Geodesy and Geophysics

Представлен к XXVII Генеральной ассамблее

Международного геодезического и

геофизического союза

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Moscow

This report presents the activity of the Russian oceanographers for the period of 2015–2018. The short reports are presented by the authors of researches.

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В данном отчете представлены результаты российских океанографов в 2015–2018 гг. Авторами исследований были подготовлены краткие обзоры.

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The main goal of the research was to study the processes in the World Ocean, to study the available resources of the oceans and seas, and to develop proposals for their rational use. To achieve this goal, a complex of tasks was carried out, among which were the following:

Investigation of the deep-sea circulation of the Atlantic Ocean, variability of the structure and dynamics of the waters of the northern part of the North Atlantic, currents and thermohaline characteristics of the Southern Ocean, synoptic and mesoscale processes in the seas and oceans.

The study of the role of the oceans in climate change, global oscillations of the thermodynamic characteristics of the ocean and their climatic significance.

Deep-water contourits of the Atlantic Ocean. Clay and fine clastic minerals in waters and bottom sediments of the North Atlantic and adjacent parts of the Arctic.

The dynamics of hydrocarbons in natural environments as an indicator of pollution. The carbon cycle and biogeochemical processes in the ocean. The role of aerosols in pollution of the seas and oceans and climate change.

The study of the coastal zone as an indicator of the response of sea level to climate change. Seismic danger of the bottom of the internal and marginal seas of Russia. Morphodynamic changes of shallow coasts under the influence of storm waves

A brief summary of the most important results.

An enormous amount of scientific research has been carried out, greatly advancing our knowledge of the oceans. The most important results include the following.

Antarctic Bottom Water flow through the fractures in the North Atlantic Ridge in the Central Atlantic was studied on the basis of temperature, salinity, and velocity (CTD and LADCP) measurements in 2014–2018. Abyssal channels in the ridges connect the deep-water basins of the East and West Atlantic. In addition to the well-known fact that the main transport of bottom water to the East Atlantic passes through the Vema Fracture Zone (11° N), it is established that about half of this flow additionally passes through other fractures.

Analysis of winter convection in the Irminger Sea and the formation and variability of Labrador intermediate water in 1991–2017 showed that from 1996 to 2011 (with the exception of the winters 2007/08 and 2008/09) there was no deep convection in the Irminger Sea. The long period of weak convection has been replaced by a period of regular and intense convection in 2012-2017. According to the data in 2002-2017 modifications of Subpolar modal waters (SPMW) are highlighted, their mean long-term characteristics are calculated, and the interannual and long-period variability are analyzed.

Based on the analysis of a 22-year set of satellite altimetry charts in the Drake Passage and the Scotia Sea, the fundamental dependence of the kinetic energy fluctuations of individual jets of the Antarctic Circumpolar Current (ACC) on the meandering phase and the formation of synoptic ocean eddies and their reverse absorption by jets has been shown. It was found that among the ACC jets, the northern and middle jets of the South Polar Current are leading in terms of the intensity of the generation of eddies. The average flow transport from west to east in the Drake Passage was 160 Sv, with fluctuations from 149 to 173 Sv. The estimates close to these transports were obtained over the Africa – Antarctica section (21° E). In the Australia-Antarctica section (117° E), the average transport was 178 Sv, with fluctuations from 165 Sv to 194 Sv. On the northern borders (along 35° S) of the Atlantic, Indian and Pacific sectors of the Southern Ocean, the average transport of water and heat, respectively, were 0.6 Sv to the south and 0.3 PW to the north, 15 Sv and 1.15 PW to the south; 16 Sv and 0.45 PW to the north.

A numerical model of the Gulf of Finland was developed with a submesoscale resolution (232 m grid step). Three types of submesoscale structures with Ro> 1 were found: cyclonic threads with characteristic lengths and widths of 10–50 km and 1–2 km, respectively, cyclonic gyres with a characteristic diameter of 3–7 km, and spiral cyclonic eddies with a characteristic horizontal size of 10–15 km.

It has been established that the “forced” boundary layers arising under external forcing (for example, tangential stresses applied at the surface of the liquid) are much more intense than the

“free” forces resulting from the free linear evolution of the initial perturbation. Strong vertical gradients of horizontal velocity and buoyancy in the boundary layers can lead to instabilities and elevated levels of turbulence and mixing in these areas.

It is shown that geostrophic and hydrostatic adjustments can be considered as special cases of a more general wave adjustments occurring in any physical system (not necessarily hydrodynamic), in which linear invariants and a complete system of waves harmonically depend on time in a linear approximation.

The processes and mechanisms characterizing the phase transitions from one climate change regime to another are studied. Horizontal advection of heat by currents, transfrontal heat and mass transfer, and deep-water convection are considered as the most important processes. These processes are associated with the main features of the formation of heat fluxes at the ocean surface and in its active layer.

Based on a series of data on the temperature of the water surface of the North Atlantic in 1948–2014, as an indirect characteristic of the intensity of the meridional transport of oceanic water masses, a wavelet-based multi-scale analysis of the North Atlantic meridional thermohaline circulation was made, slowing down in a warming climate, as many are supposed to be the source of unexpected climate “surprises” in the future. Three scales were found that determine the temporal variability of this series: from two to four, from seven to ten, and about twenty-two years. These are the same scales that determine the temporal variability of a series of average global surface air temperatures.

The processes of generation and migration of methane due to diffusion are considered. It is shown that, depending on the intensity of methane generation in the sediments, a layer of methane emission forms into an independent phase. In shallow water it is a gas phase. At greater depths, corresponding to the zone of hydrate stability, such processes lead to the formation of a layer of solid gas hydrates. The difference between shallow-water and deep processes is that the gas phase, while remaining mobile, forms a system of channels through which gas will be released through the bottom in the form of bubbles.

The statistical dependence of the modern microfossils of the arctic and subarctic marine basins on the main environmental factors: temperature and salinity, stratification, and nutrient elements has been established. The original hypothesis of the formation of ore fields of ferromanganese nodules is presented.

A comprehensive study of the collection of the composition of carbonaceous deposits common in the bioproductive areas of the seas and oceans (the Black and Baltic seas, the Namibian shelf in the Atlantic Ocean, the shelves of Chile, Peru and California in the Pacific Ocean) was carried out. The content of 12 rock-forming and more than 30 trace elements has been determined. It is shown that in the ferromanganese nodules of the Arctic seas the same complex of elements accumulates as in the pelagic nodules of the ocean, but in different concentrations and proportions, with a reduced content of most ore elements as a result of active terrigenous sedimentation.

Laptev Sea Shelf, shelf of Sakhalin, the northern and central parts of the Caspian Sea and the Black Sea shelf in the Anapa region are distinguished by increased parameters of possible seismic effects and the presence of offshore oil and gas fields already under development or planned. A seismically active line was selected on the southeastern shelf of the Baltic Sea according to data on historical earthquakes of the region and observational data from the Institute of Oceanology, which runs along the bottom of the Baltic Sea and is oriented in the northeastern direction.

The possible deformations of the coastal profile were investigated depending on the initial slope of the bottom, both for different scales of storm seasons, and on the scales of individual storm events. It was revealed that the slope of the storm profile of the equilibrium of the coastal slope and the slope of the coastal profile during seasonal deformations are not constant at equal wave conditions and at different initial slopes.

Samples of surface bottom sediments, rock fragments and nodules were obtained at stations with previously measured bottom currents in the Vema transform fault zone (11° N), which show that significant facies variability within the study region is associated with a significant difference in the current transport of Antarctic Bottom Waters in the northern and southern branches of the transform valley.

New data were obtained on the mineral composition of the submicron fraction of the scattered (aerosols, sea suspension) and condensed (bottom sediments) sedimentary substances in the surface layer in the regions of the Arctic and North Atlantic. Complexes of clay minerals are identified, localized in various regions of the North Atlantic in terms of area and depth, differing in composition and degree of perfection of the crystal structure.

The simulations of the circulation of the North Atlantic - Arctic Ocean in 1948-2009 were performed. A system of diagnosis and prediction of thermohydrodynamic characteristics and wind waves for the Azov and Black Seas, taking into account ice conditions and the assimilation of observational data, has been created.

Characteristics of the circulation of the Atlantic, the impact on climate change

Goals of research

Investigation of the exchange of kinetic energy between the jets of the Antarctic Circumpolar Current (ACC) and oceanic synoptic eddies in the near-surface layer of the Drake Passage and the Scotia Sea. Analysis of the variability of the Falkland Current according to data on sections along 46° S in the period from 1982 to 2005 using new oceanographic data sets based on measurements of drifting Argo floats in combination with climatic fields in areas of no measurements and at depths of more than 2 km.

Studying the deep limb of the three-dimensional thermohaline circulation in the Atlantic, estimating the mass and heat exchange between the deep-sea basins of the West and East Atlantic, analyzing the dependence of the thermohaline properties of bottom waters on the scales of the ocean basins on the flows in the channels on the scales several kilometers, and estimating the mass transport by two-component gravitational flows into narrow channels and fracture zones of the Mid-Atlantic Ridge.

Construction of the mean multi-year kinematic structure of the Sub-polar gyre and analysis of its interannual and long-period variability.

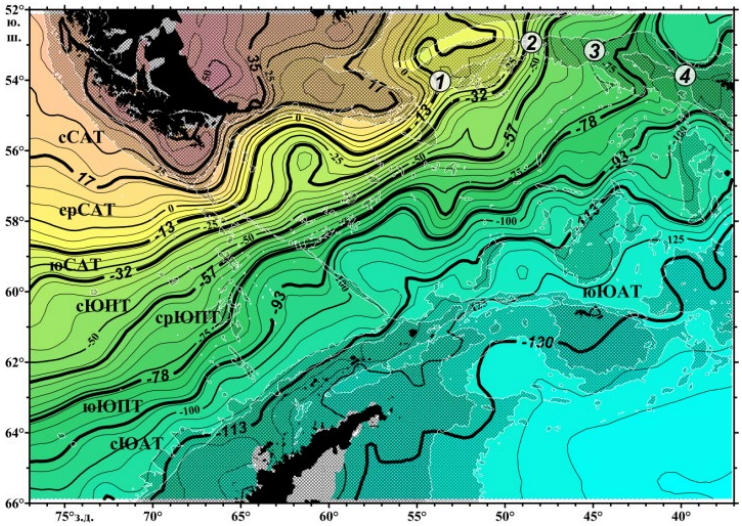


Fig. 1. The average for 1993–2014 Absolute dynamic topography (ADT) ocean surface (cm) in the Drake Passage and the Scotia Sea. The iso-gypsums are selected, which are the boundaries between the jets of the ACC. The numbers in the circles indicate the passages in the North Scotia Ridge: 1) passage 54°-54°; 2) Shag Rocks; 3) Nameless pass; 4) Black Rock Pass.

Results

Eight ACC jets were identified that are confined to specific ranges of absolute dynamic topography (ADT) of the ocean surface (Fig. 1). The strongest jumps in the time variation in energy are not directly related to the energy of the eddies. Small mesoscale eddies with a radius of the order of ¼° make a negligible contribution to the eddy kinetic energy balance.

Reliable estimates of mass, heat and salt exchange of the Southern Ocean with the Atlantic, Pacific and Indian oceans were obtained on the basis of the Argo floats, which provides the basis for the study and analysis of the current state of the Southern Ocean climate and the selection of intraclimatic trends in the last decade.

A map of the average density of icebergs shows that the greatest density of icebergs is observed in areas of the Antarctic glaciers with high productivity. In the seaward part of the ocean, the main role in the redistribution of icebergs belongs to the sea currents. The influence of wind is manifested in the formation of two quasi-meridian tongues of increased density of icebergs in the Weddell Sea.

Characteristics of Antarctic Bottom Water (AABW) in the northern main channel of the Vema Fracture Zone: the minimum temperature at the bottom in the deepest part is 1.403° C, the velocity is up to 45 cm/s over a channel depth of 4650 m. In the southern channel the minimum temperature on the sill (depth 4500 m) is 1.627° C, the velicities above the sill at a depth of 4416 m are up to 40 cm/s (Fig. 2). Downstream, a waterfall was found with a water fall of 150 m to 4,720 m. The speeds are maximum in the bottom layer up to 23 cm/s. The temperature two miles downstream of the waterfall increases from 1.534° C to 1.627° C.

In the eastern part of the Doldrams Fracture (08°15.8’ N, 36°53.4’ W.) the minimum temperature is 1.872° C, the velocities are up to 22 cm/s to the east, bottom water transport id is 0.045 Sv, channel depth is 4856 m. In the passage between the Nameless Fracture Zone and the Vernadsky Fracture Zone, the minimum temperature at the bottom is 1.572° C. In the eastern part of the Vernadsky Fracture Zone, the minimum temperature is 1.836° C, there is almost no current: speeds of the order of 1-2 cm/s are directed to the east. The depth of the channel in the Fracture Zone is 4072 m. In the eastern part of the Nameless Fracture Zone, the velocity in the bottom layer is 2-3 cm/s to the east. The minimum temperature in the channel is 1.759° C, the depth of the channel is 4528 m. The bottom water transport in the Nameless Fracture Zone is 0.09 Sv. In the Bogdanov Fracture Zone, the minimum temperature is 1.99° C, speeds up to 7 cm/s are directed to the east. The depth of the channel in the fracture zone is 3820 m. The transport of the bottom water is 0.02 Sv. The velocity of the bottom water over the threshold of the southern entrance to the Romanche Fracture Zone (4570 m) is up to 65 cm/s. At the entrance to the Romanche Fracture Zone, there is a deep-waterfall from a depth of 4570 m to 5000 m. The velocity in the waterfall is about 40 cm/s (maximum 65 cm/s). The vertical speeds reach centimeters per second. The transport of water in the stream is 0.23–0.27 Sv, which is about 40% of the known estimates of the total AABW flow through the middle part of the channel in the Romanche Fracture Zone.

The coldest type of deep water of the Weddell Sea (temperature <0.0° C) follows north through the Santos Plateau and the Vema Channel in two streams, one of which is located in the deep channel of the channel, and the other about 300 m above the western slope of the channel.

The subpolar circulation of the North Atlantic is a complex open dynamic system, the main influence on the evolution of which is provided by deep winter convection in the Labrador and Irminger seas, water exchange with the Arctic through the Greenland-Scottish Ridge and interaction with the Subtropical circulation. Analysis of the database of annual observations along 59.5° N, from 2002 to present, allowed us to detect new elements of the kinematic structure of the gyre, to conduct long-term monitoring of the variability of its thermohaline structure, to calculate the meridional water transfer, which is a key indicator of the Earth’s climate and variability. The average long-term picture of the system of absolute geostrophic currents of the Subpolar circulation in 2007-2017 has been composed (Fig.3). Testing the hypothesis of zonal compression-expansion of the Sub-polar gyre depending on the state of the

atmosphere showed that at 59.5° N, the width of the cycle is to a greater extent determined by the bottom relief, rather than by the activity of the atmosphere.

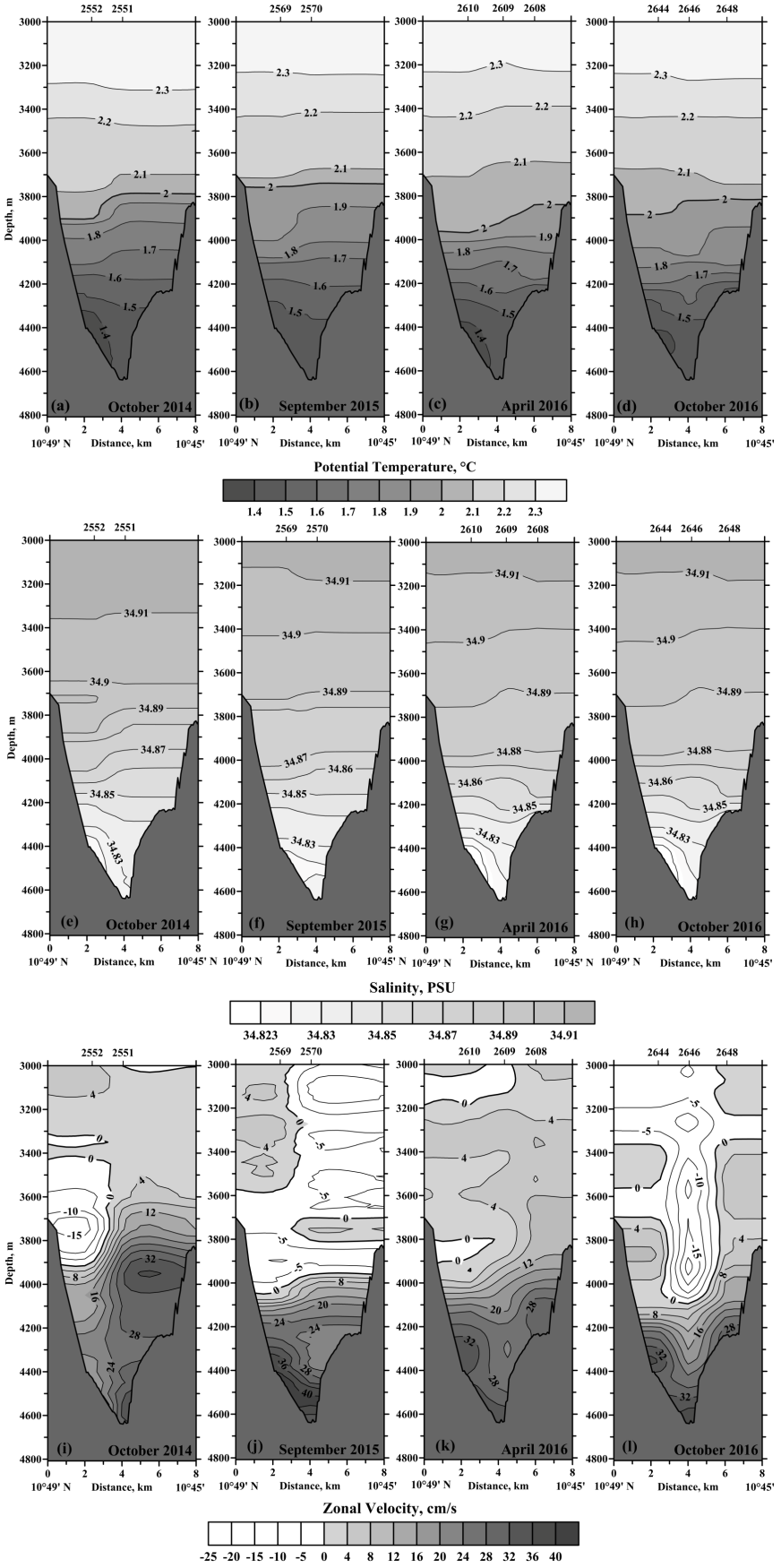


Fig. 2. Temperature sections (left), salinity (in the middle) and speed (right) through the northern channel of the Vema Fracture Zone

The inter-annual and long-term variability of the structure-forming water masses of the Subpolar circulation in the main basins (the Irminger Sea, Iceland Basin, Rokall Pass) in the period of 1991-2017 was estimated. The characteristics of quasistationary circulation jets and their mean multi-year thermohaline indices are calculated.

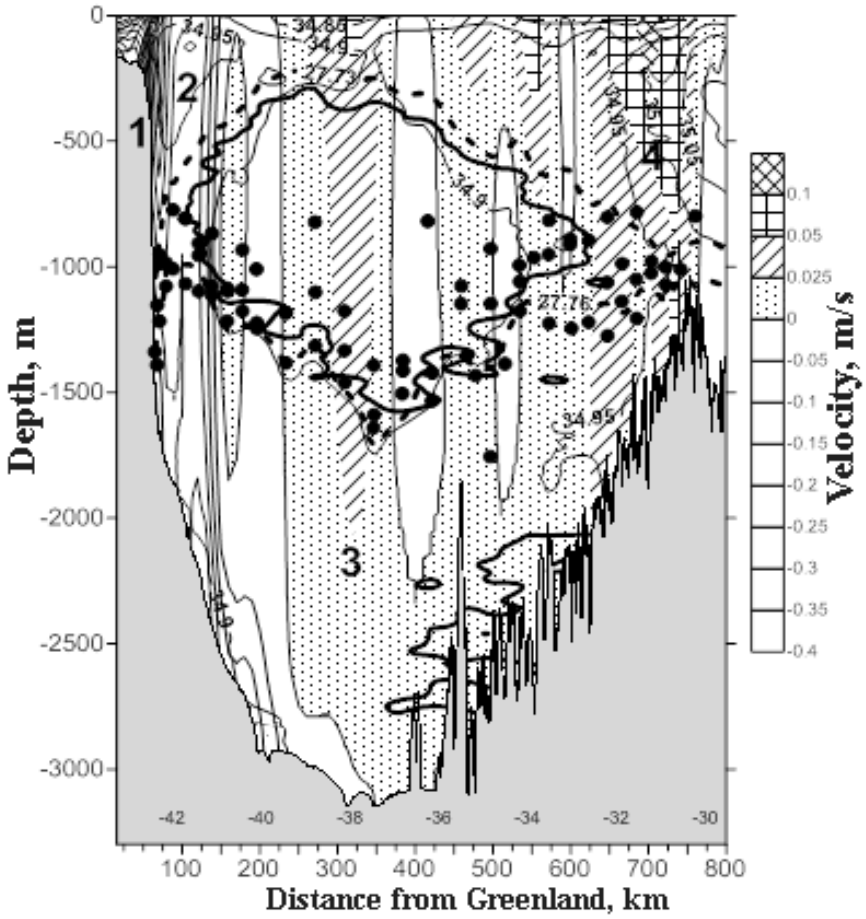


Fig. 3. Long-term kinematic structure (shaded, m/s) and vertical salinity distribution (solid thin lines, PSU) of the system of the western boundary currents east of Greenland between 59.5-60° N. in 2007-2017. Salinity contour line 34.8 PSU is shown by a thick white line. Dashed thick lines show the distribution of potential density (kg/m^3). Dots denote the regions of flow instability (Richardson number Ri <0.25). The vertical lines on the upper axis show the standard position of CTD stations. The depths of biological samples in which living cells of phytoplankton were found are shown in black squares. Western longitude is shown by numbers above the lower axis of the figure. The main structural elements of the western boundary currents are denotes as: (1) the coastal East Greenland Current, (2) the East Greenland Current, (3) the Irminger Current, 4a, 4b, 4b are the bottom jets of the overflow waters, (5) east branch of the Irminger gyre. The bottom relief is shown in gray.

Velocity and structure of the subsurface Lomonosov Equatorial Undercurrent in the equatorial zone of the Atlantic Ocean has been studied on the basis of measurements by acoustic Doppler current profiler in 2014-2017. Seasonal variability of the current and its outcropping to the surface in the boreal spring are shown. In 2014-2017, we conducted velocity measurements of this current from the R/V *Akademik Sergey Vavilov.* The measurements were carried out from the moving ship over six meridional sections across the equator using the shipborne current profiler OS-75 ADCP (76.8 kHz) RDI- Teledyne (Acoustic Doppler Current Profiler). Five crossings of the equator were performed in the West Atlantic between 33° and 36° W, and one in

the Central Atlantic at 22° W. As an illustration, meridional velocity sections in the spring and autumn periods are shown in Fig. 4.

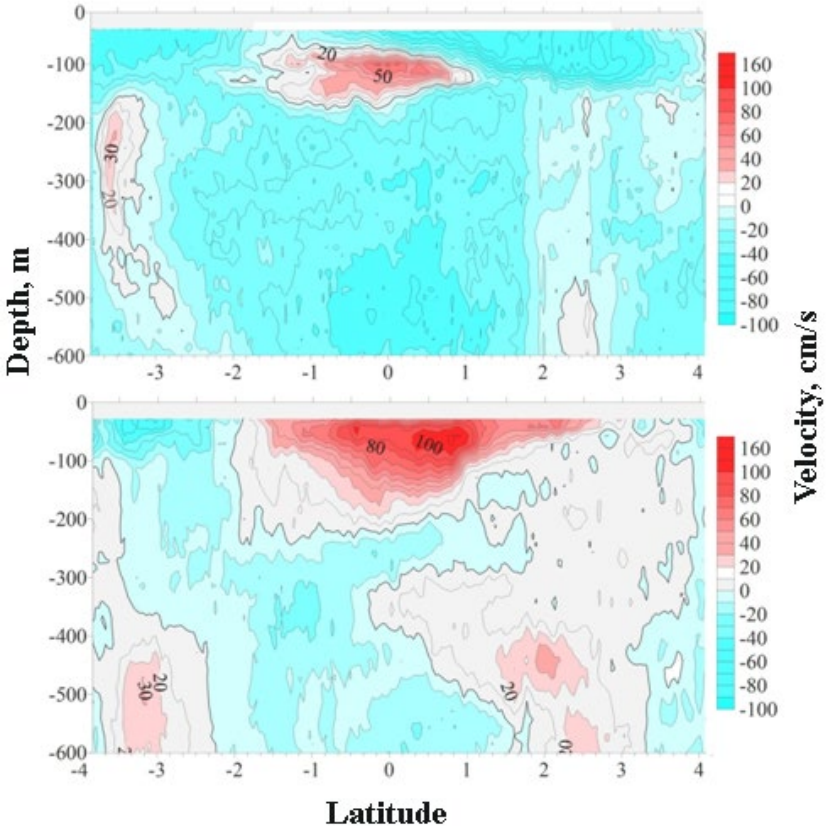


Fig. 4. Sections of the zonal velocity component of the Lomonosov Current in the West Atlantic: (a) autumn of the Northern Hemisphere (September 26, 2015, 34°40' W), (b) spring of the Northern Hemisphere (April 17, 2016, 33°45' W); Velocity units are cm/s, positive values (red tones) correspond to the eastern direction of the current, negative values (blue tones) correspond to the western direction.

Antarctic Bottom Water flow in the Vema Channel (31° S, 39° W) has been studied. A flow of high velocity was repeatedly measured in the channel with mean velocities of 25-40 cm/s and the maximum reaching 60 cm/s. The total transport of Antarctic Bottom Water through the channel within the liquid boundaries above the walls of the channel is approximately 3±0.3 Sv. The core of the coldest (θ = -0.120°C) and low saline water is usually displaced to the eastern wall. Numerical simulations confirm the field measurements and reveal the spatial structure of velocity field in the channel (Fig. 5).

Synoptic and mesoscale processes in the ocean, their role in the transport of heat and mass

Goals of research:

Study of the mechanisms of seasonal and mesoscale variability of water circulation in a semi-enclosed basin (using the example of the Gulf of Riga in the Baltic Sea).

Construction of the theory of wave adjustment in arbitrary physical systems and the application of this theory to the ocean. The development of the theory of a new physical phenomenon: wave boundary layers in a stratified ocean.

Study of the global distribution of oceanic eddy meridional heat transport.

Obtaining a closed system of thermodynamic equations for the atmosphere on a meteorological or climatic scale, numerical calculation of time dependence for the intensity of the

Earth's irradiance with solar radiation, calculation of time dependence of temperature, humidity, vertical velocity of air in the atmosphere, temperature of the Earth's soil layer having thermal contact with the atmosphere.

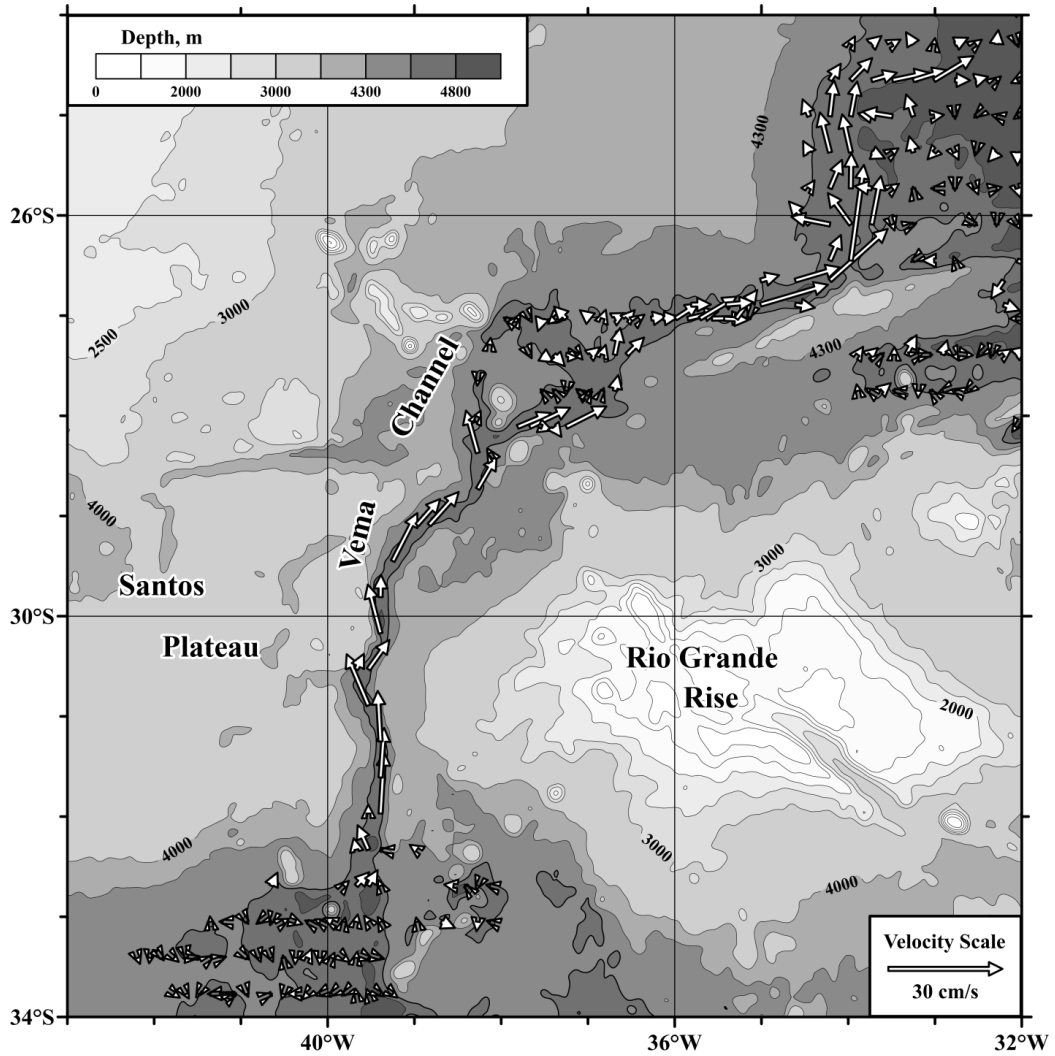


Fig. 5. Simulated velocities in the bottom layer of the Vema Channel presented from the data of the deepest σ-level (approximately 50 meters above the seafloor).

Results.

The role of the salinity field in strengthening/weakening of baroclin upwelling fronts in the Gulf of Finland is analyzed. Two of the three upwelling events in the bay in the summer of 2006, namely, upwelling along the southern coast in August and upwelling along the northern coast in September, were characterized by baroclinic upwelling fronts, which were enhanced by both temperature and saltiness. The baroclinic front associated with the July upwelling event on the north coast was relatively weak, since the temperature contribution to the density drop was weakened by the salt contribution and, as a result, submesoscale structures were poorly developed.

Reducing the grid spacing of the model from 0.5 to 0.125 nautical mile (i.e., from 926 m to 232 m) led to a significant increase in the fluctuations of relative vertical vorticity in the surface layer of the sea. Three types of submesoscale structures were found: threads of high cyclonic vorticity (elongated areas with Ro> 1 with typical lengths of 10-50 km and 2-3 km, respectively), submesoscale cyclonic eddies with a Ro> core 1-6 km in diameter, and cyclonic spirals, consisting of spiral strips of high cyclonic vorticity (Ro> 1) 1-2 km wide with a total horizontal size of 12-15 km. The threads of high cyclonic vorticity are mainly formed during the active phase of upwelling, and cyclonic eddies and helixes during the upwelling relaxation phase.

Submesoscale cyclonic filaments, cyclonic eddies and spirals occupied a relatively large part of the investigated sea area up to (4%) during upwelling events in August and September (up to 4% and 5.5%, respectively) in direct dependence on wind and upwelling baroclinic front power.

One of the submesoscale cyclonic eddies with the core Ro> 1, stretching to a depth of 31-66 m was traced for 33 days (Fig. 6) until it left the high resolution area (step 0.125 nautical mile) of the model.

The possibility of the efficient use of the simulation of Lagrangian particles-drifters for the visualization of submesoscale structures and the interpretation of satellite images of the sea surface is shown.

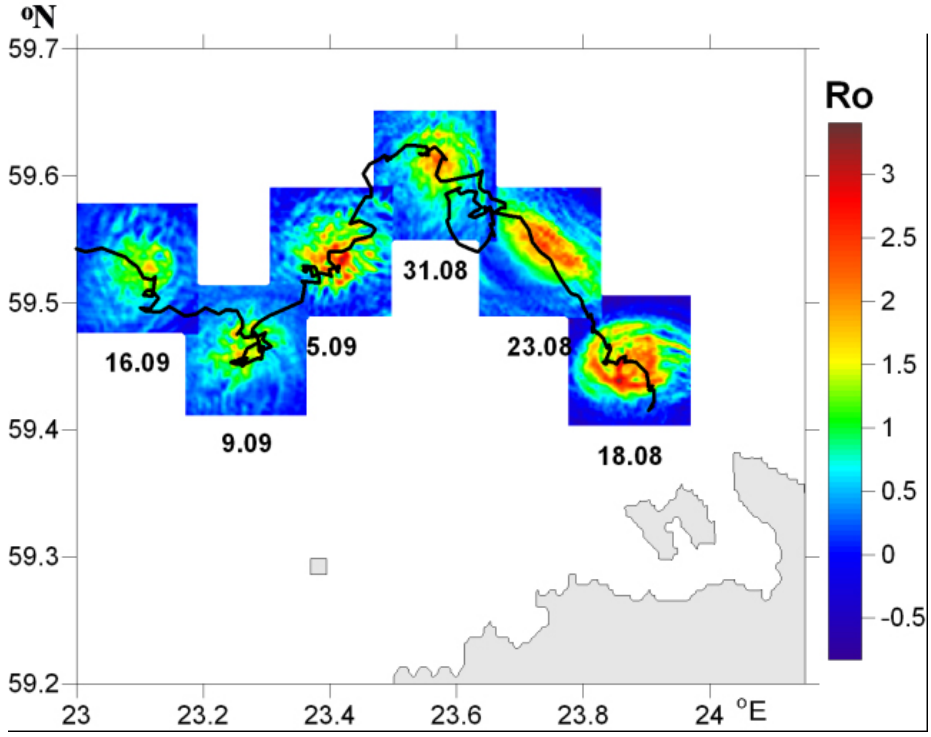


Fig. 6. Trajectory of the submesoscale cyclonic eddy (black line), on which images of the eddy in the Ro field are superimposed at different times. Simulation data on a 0.125 nautical mile grid.

A general theory of wave adjustment, suitable for any physical system (not necessarily geophysical or even hydrodynamic), characterized by certain properties. It is assumed that in the linear approximation in the system there are linear invariants and a complete system of waves that are harmonically dependent on time. Invariants are determined by the initial conditions and vanish on wave solutions, i.e. the waves do not affect invariants and do not transfer them. The evolution of such a system is naturally represented as a sum of a stationary component with non-zero invariants and a non-stationary part with zero invariants.

Wave boundary layers arising in a stably stratified fluid at large times are studied. Such a boundary layer is a narrow area near the surface and/or bottom of the basin, characterized by sharp, increasing in time gradients of buoyancy and horizontal velocity; the thickness of the boundary layer with increasing time tends to zero. The transient wave boundary layer can arise both as a result of the free linear evolution of the initial perturbation, and under external forcing (in our case, tangential stresses applied at the surface of the liquid).

A numerical experiment to study of the eddy meridional heat transport (MHT) in the World Ocean was carried out using a model with a resolution of 0.1º. The eddy component was calculated as the deviation of the total MHT from the temperature and salinity calculated from the average fields. The spatial and quantitative characteristics of the global distribution of eddy MHT are estimated. The latitudinal distributions of the integral MHT in the World Ocean and its

individual basins are analyzed (Fig. 7). It was found that in a number of regions, the eddy transport makes a significant contribution to the complete transport of ocean heat, in particular, in the Southern Ocean, in the vicinity of the equator, in the regions of the western coastal currents, and in the regions of confluence of currents. Several qualitative discrepancies were found with the results of other models and estimates from observational data. It is shown that the eddy transport can have a component along the direction of the temperature gradient, which makes it difficult to parameterize it using the classical formula of thermal conductivity with a positive diffusion coefficient.

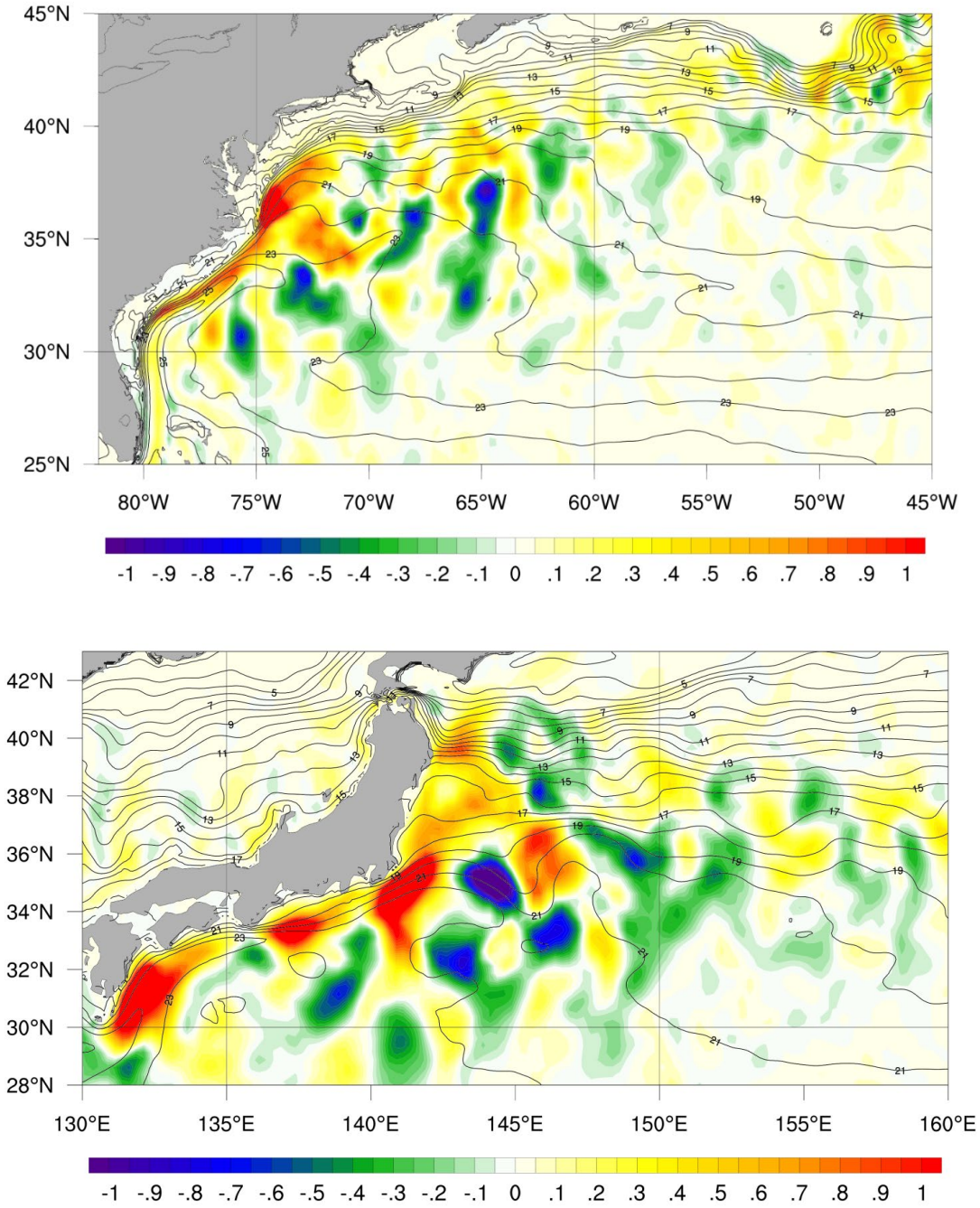


Fig. 7. Eddy MHT, integrated over the upper 100-meter layer of the ocean (color gradations, 108 W/m) and temperature averaged over this layer (ºC, contours) for the Gulf Stream (above) and Kuroshio (below).

A model was built that allows for joint solution of the equations of heat-hydraulic processes and radiation transport processes. The calculations carried out within the framework of the model showed that an increase in the mass fraction of carbon dioxide in the atmosphere

increases the average temperature of the atmosphere near the Earth's surface in summer and winter (Fig. 8).

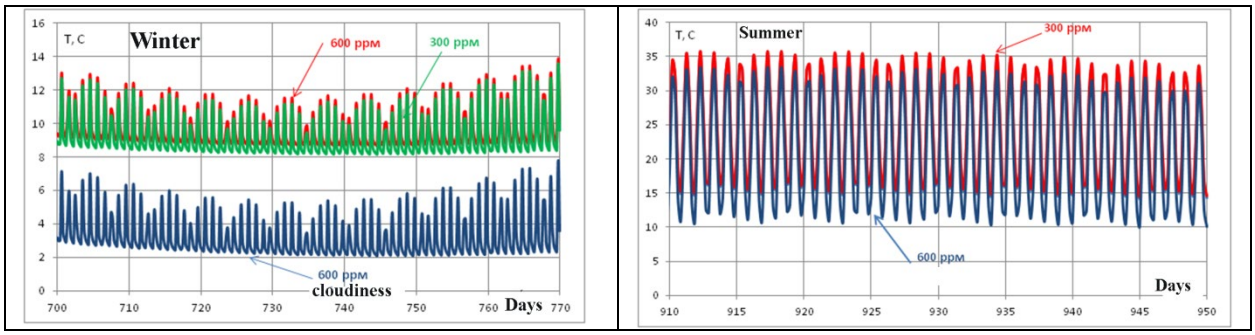


Fig. 8. Time dependence of air temperature near the Earth's surface for two months of the winter (top) and summer (bottom) seasons for various given mass CO_2 contents in the absence of clouds taking into account the absorption of direct solar radiation by clouds.

However, the response to this increase due to evaporation and condensation is so strong that the increase in cloud formation becomes the main factor influencing the temperature distribution.

Interannual variations and their role in climate variability

Goals of research

Study of the space-time structure of planetary oceanic oscillations, as well as the causes and climatic consequences of their occurrence.

The study of relatively short-period (inter-annual and inter-decade) variations of the current climate as a manifestation of the internal dynamics of the global climate system.

Analysis of the most reliable series of data on the temperature of the water surface of the North Atlantic in 1948 - 2014 using wavelets.

Results

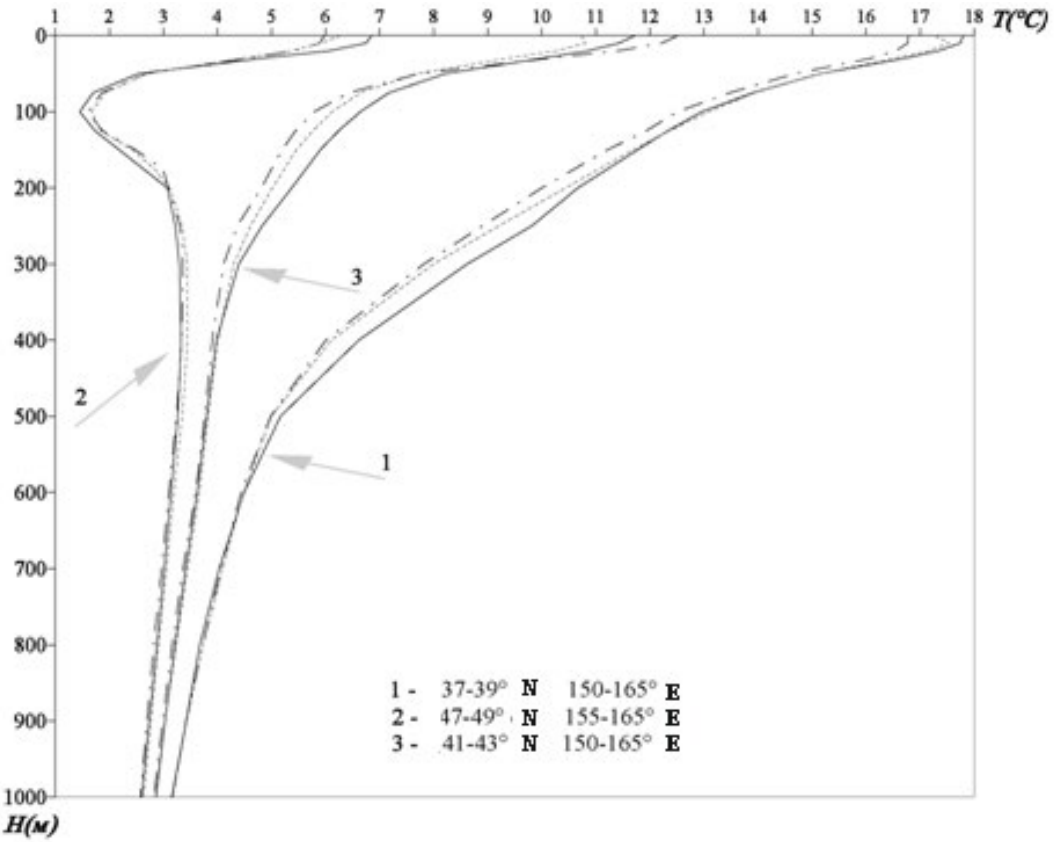
Studies of the processes of the upper active layer of the Atlantic, Pacific and Southern Oceans have shown that the upper active layer in a number of regions is experiencing quasi-synchronous multi-decade phase changes, during which alternating episodes of heat accumulation and thermal unloading of the ocean lasting 25-35 years are observed (Fig. 9).

A hypothesis is formulated that the detected multi-decade oscillation of the ocean heat content influences the formation of the global atmospheric oscillation corresponding to the time scale, manifested as a short-period phase variability of the current climate in the Northern Hemisphere.

Observed regional cooling of the upper active layer of the ocean in a certain phase of its thermodynamic state, apparently, was accompanied by the transport of ocean heat and moisture into the atmosphere, which contributed to the warming of the continents, as it happened, in particular, in the North Atlantic region during the Climate Scenario 1975-1999. When the ocean upper layer accumulates heat, the climate on the continents as a whole becomes more continental, which was observed until the mid-1970s, and can be traced at the beginning of this century.

It has been established that the short-period variability of the current climate on a scale of several decades arises as a result of inter-decade oscillations in the dynamics of the climate system. The source of these oscillations is the quasicyclic process of heat accumulation and ocean thermal discharge, undoubtedly accompanied by a change in the direction of heat flux within the climatic system. Potential internal reservoir and source of heat, quasi-cyclically entering the ocean upper layer are its deep layers, from where this heat is extracted due to the

periodically occurring deep seasonal vertical density convection. Each phase of this climatic cycle has distinct hydrometeorological characteristics, which on the continents are united by the concept of "continental index". The increased values of this index, which are observed now, indicate the occurrence of relatively more severe climatic conditions: a sharp intra-annual temperature and humidity difference, cool winters and hot arid summer seasons, off-season thaws and frosts, etc.



Based on a series of data on the temperature of the water surface of the North Atlantic in 1948–2014, as an indirect characteristic of the intensity of the meridional transport of oceanic water masses, a multi-scale analysis of the North Atlantic meridional thermohaline circulation (Fig. 10) was performed based on wavelets, it is supposed to be a source of unexpected “surprises” of the climate in the future.

Fig. 9. The average vertical distribution of water temperature in the upper 1000-meter layer in the three structural zones in the Northwest Pacific Ocean: subtropical (1), subarctic (2) and transitional (3). Average profiles are presented for periods: 1960–1974 (continuous curve), 1975–1999 (dash-dotted), and 2000–2014 (dotted).

Three scales were found that determine the temporal variability of this series: from two to four, from seven to ten, and about twenty-two years. These are the same scales that determine the temporal variability of a series of average global surface air temperatures. It is assumed that the sources of oscillations of the first two of these scales are swinging of the axis of rotation of the Earth (Chandler wobble with a period of 14 months and lunar-solar nutation with a period of 18.6 years), and the source of oscillations of the third scale is the 22-year Hale heliomagnetic activity cycle.

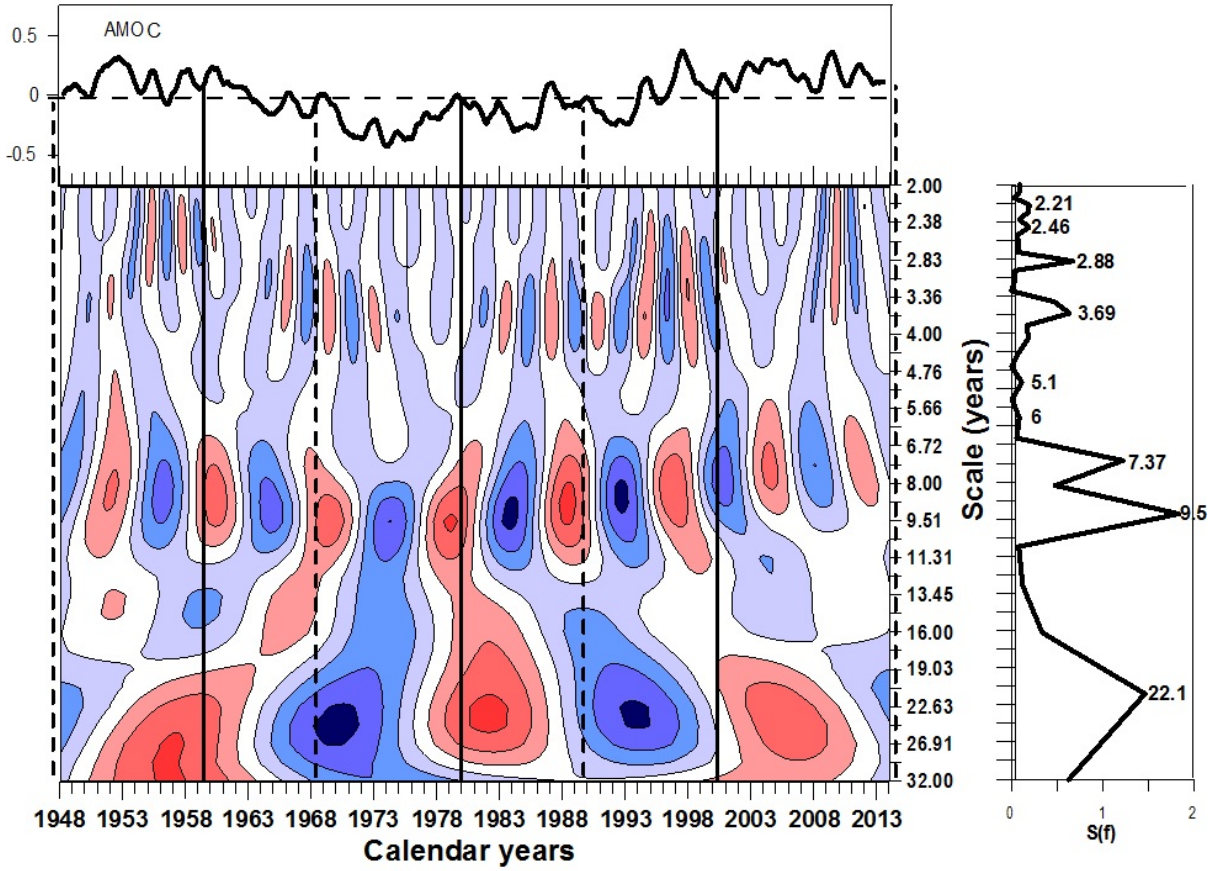


Fig. 10. Time series of variations in the average temperature of the water surface in the North Atlantic (above) and the result of its complex wavelet transform (below). Positive values of the real component of the wavelet transformation are shown in shades of red; negative values are in shades of blue. On the right is the energy spectrum. Periods of spectral peaks (years) are shown.

Marine response to coastal anthropogenic impacts and climate change

Goals of research

To identify the kinematics of the Late Holocene sea level and its manifestation in the development of the coasts of the post-glacial period on the example of key areas of South Georgia; evaluate modern morphodynamics and forecast the development of coastal zones of the analyzed territories.

Refinement of seismic hazard for the waters of the internal and marginal seas of Russia using data on marine earthquakes based on seismic monitoring repeatedly conducted in the waters of the Black, Caspian, Okhotsk, Baltic and Laptev seas using temporary and permanently operating seismographs of the IO RAS.

Investigations of the influence of the soil strata on the parameters of seismic effects from the data on bottom sediments obtained in a number of expeditions during soil sampling and the records of strong earthquakes.

Comparative classification and typification of morphodynamic processes and manifestations of nonlinear dispersive effects of the evolution of storm waves in the coastal zone of the sea, which are the fundamental basis for creating simplified engineering models in the problems of forecasting coastal development and protecting them from wave action.

Results

It was found in the of research on the coast of South Georgia that the kinematics of the sea level in the Late Neopleistocene post-Late period - the Holocene was not characterized by the

excess of its modern marks, which it had previously reached one thousand years. The current state of not only abrasive, but even low-lying accumulative sections of the shores of the studied area is characterized by stability; and in the nearest future the situation will not change. This is confirmed by the positive directional of the tectonic movements of the surrounding land (it is known that the newest tectogenesis is characterized by the manifestation of inheritance). Secondly, small glaciers at the tops of the mountains will continue to form and deliver to the coastal zone, including as a result of the formation of water flows, detrital material from the easily collapsing sediments of the Cumberland suite (Fig. 11).

Fig. 11. An example of the distribution and morphology of modern glaciers in South Georgia

To predict the development of the coastal zone under study (as well as for the environment as a whole), it is necessary to know not only the current natural processes, but also an understanding of the scale, conditions and mechanisms of the past changes in nature. The conclusion is made that the coastal zone of South Georgia will develop according to a regressive scenario, due to the continuation of the differentiated elevation of tectonic blocks. Short-term small rises in sea level from the meltwater of glaciers in the phases of warming with some delay will be compensated for the subsidence of the seabed inherited from the Mesozoic and contraction of underwater sediments.

It is noted that the shelf of the Laptev Sea, the northeast section of the shelf of Sakhalin, the northern part of the Caspian Sea, the Black Sea shelf in the Anapa region and the southeastern part of the Baltic Sea are characterized by increased parameters of possible seismic effects. In addition, within these waters, either the development and transportation of hydrocarbon raw materials (the Y. Korchagin field in the Caspian Sea, the Kravtsovskoye oil and gas field in the Baltic Sea) is already underway, or these works are planned. This determines the relevance and practical significance of this research.

In the Laptev Sea shelf, the seismically active structure is the main seismic hazard: the Gakkel submarine rift and its extension to the shelf and continent. A graph of earthquake frequency was plotted based on the analysis of earthquakes (Fig. 12).

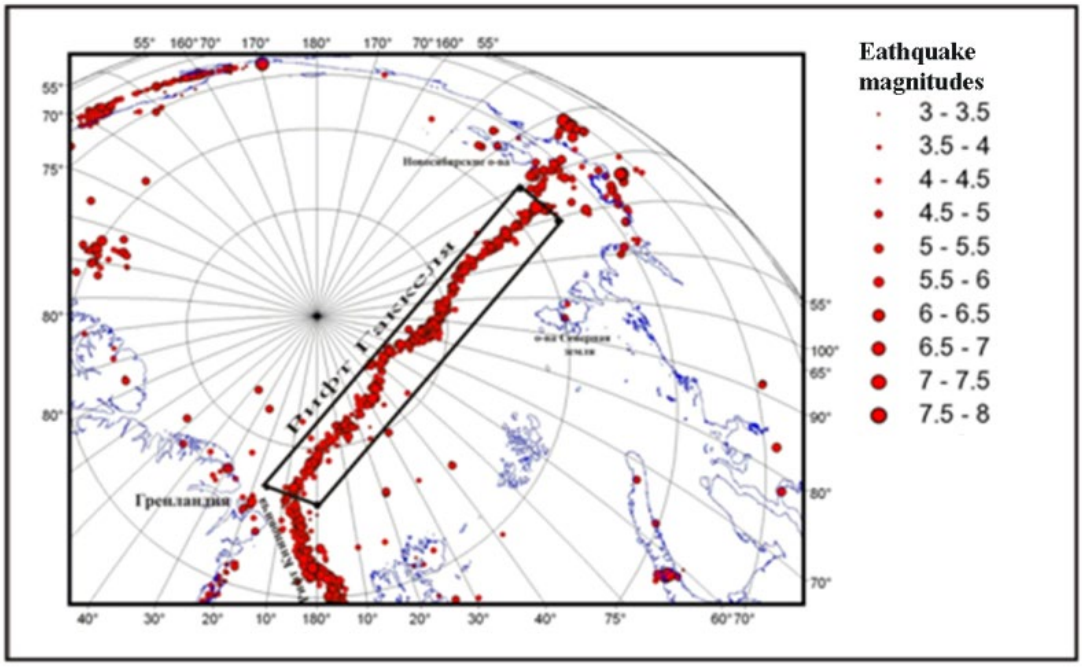


Fig. 12. Epicenters of earthquakes in the Arctic region according to the catalog of the US Geological Survey for the period of observations from 1920 to 2015.

Extrapolation of the graph of the frequency of earthquakes for the Hakkel Rift towards large magnitudes suggests that earthquakes with a magnitude of Mw ~ 6.5–7.0 with a frequency of 10^{-2} yr^{-1} and with a magnitude of Mw ~ 7.5 with a frequency of 10^{-3} yr^{-1} are expected here, i.e. the first earthquakes can occur in the Laptev Sea once every 100 years, and the latter once every 1000 years.

An analysis of the earthquake catalogs carried out in the framework of this work for the northeastern shelf of Sakhalin (Sea of Okhotsk) discovered earthquake sources in the Lunskoye oil and gas field. All of them occurred in October 2013 and had magnitudes from 4.1 to 5. Possibly, these seismic events also have a technogenic nature associated with the intense pumping of oil and gas condensate. Earthquakes occurred 8 years after the start of development of the Lunskoye field. In the same scenario, earthquakes may occur in the Kirinskoye and Yuzhno-Kirinskoye gas condensate fields.

A new seismotectonic model of the Middle Caspian, the Apsheron threshold, the Western and Eastern Caucasus has been developed on the basis of data on the earthquakes of the region using bottom and surface seismological observations.

For the Black Sea shelf in the Anapa region, studies were performed on the spatial distribution of earthquake sources and seismic regime parameters in the Western Caucasus region and the adjacent Black Sea area using bottom seismological observations to estimate the seismic hazard. In addition, calculations were made of the effect of bottom soil on the parameters of synthesized and real seismic effects by two methods: seismic rigidity and nonlinear analysis.

As a result of the analysis of historical seismicity data of the southeastern part of the Baltic Sea and data on modern seismicity using seismological monitoring performed by the IO RAS in a number of years using autonomous marine and land seismic stations, a seismic lineament was identified passing along the bottom of the Baltic Sea oriented in the northeast direction (Fig. 13).

Apparently, the selected seismic lineament determines the main seismic hazard of the southeastern part of the Baltic Sea and the Sambiisky Peninsula. The maximum magnitude of earthquakes characteristic of this zone of possible earthquakes can be assumed as M = 5.5, and their frequency of occurrence is T = 700 years.

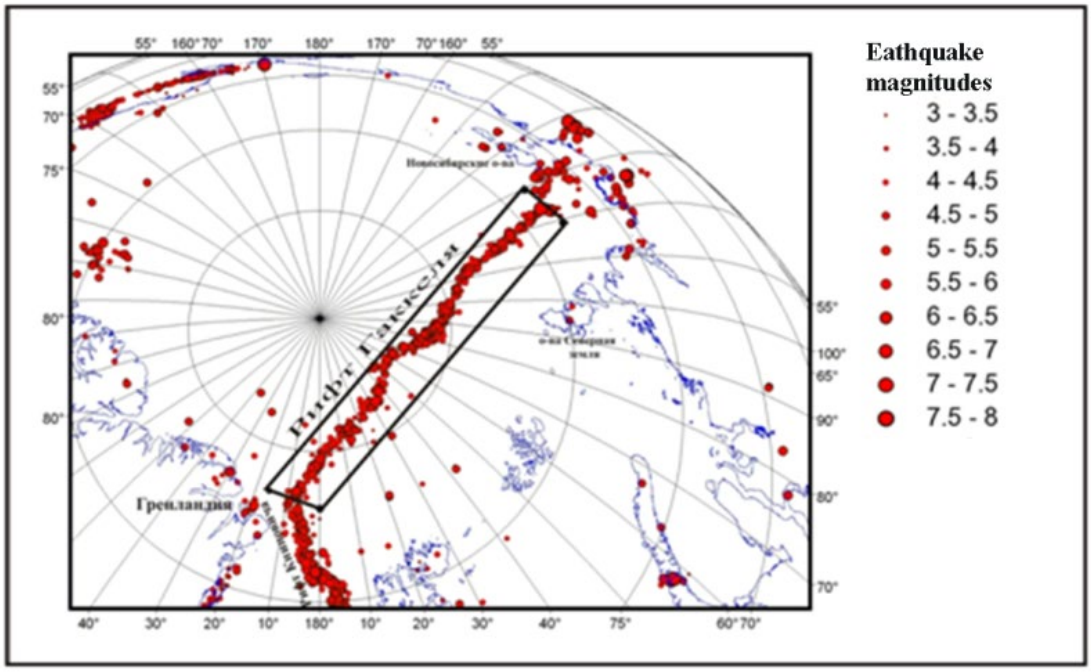


Fig. 13. Summary map of the southeastern Baltic earthquakes

It should be noted that the possible zone identified as a result of this work is not indicated on any of the patterns of the possible zones, the previously proposed seismotectonic models of the southeastern part of the Baltic Sea and the Sambian Peninsula. In addition, it is necessary to point out that the selected seismic lineament was found in this work according to seismological data, in contrast to other works, where possible zones were mainly distinguished according to geological and geomorphological data.

A study on the influence of the position of the underwater ridge on the transformation of waves above it and on the corresponding transverse movement of sediments in the coastal zone of the sea on the scale of the characteristic storm impact showed that the position of the underwater ridge affects the retreat of the coastline and the distance of sediment. The maximum movement of precipitation towards the sea is within the distance between the edge and the top of the underwater ridge. Minimum movement of precipitation will be at the location of the ridge from the edge at a distance less than half the wavelength in deep water. The coastline retreat is minimal when the ridge is located from the edge at a distance of 0.7-0.82 of the wavelength in deep water. In these cases, the profile with the underwater ridge will have a protective effect on the erosion of the shore, compared to the profile without it. The presence of the underwater ridge at some relative distances from the coast can lead to an increase in the degradation of the coastline. In the presence of a longshore underwater ridge located at an angle to the coastline, a non-uniform receding of the coastline along its length is possible as well as the formation of the corresponding morphodynamic forms of the coastline. The greatest difference in the speed of the coastline retreat, associated with the position of the underwater ridge, is observed in the first hour of storm waves. Regardless of the location of the underwater ridge on the initial profile for the selected storm, after 6 hours an equilibrium profile is formed containing an underwater terrace and close to the classical profile, while the erosion rate slows down significantly and becomes equal for all profiles. Changing the parameters of the waves during their transformation over different profiles has a significant impact on the degree of transformation of the underwater profile of the beach. The decrease in the average period of excitement associated with the growth of higher harmonics during the passage of the waves above the ridge also reduces the degradation of the coastline. The discharge of sediment into the sea, namely the distance to which the material is carried, is directly dependent on the height of significant waves.

The change in the direction of the transverse sediment flow from the bank towards the coast and from the coast leads to the formation of natural positive forms of relief on the coastal slope (sand ridges). The presence of a sediment flow directed from the shore near the wall of the bar facing the coast will lead to the accumulation of material near it and its flattening; near the edge, the flow of sediment thus directed will lead to the erosion of the beach and the retreat of the coastline. The growth of the sediment discharge directed to the shore behind the bar (situation 1) will lead to an erosion of the wall nearest to the edge; Situation 2, in which the sediment discharge does not change after the passage of the waves above the bar, contributes to the stability of the underwater structure; a drop in the consumption of the structure will lead to the accumulation of sediment on it.

The greater the gradient of sediment flow, the greater the rate of deformation of the bottom relief. The positive sediment discharge gradients located along the coast lead to a fast alluvial of the beach and the erosion of the deeper part of the submerged slope. If the purpose of coastal protection measures is to maintain the beach in its current state, and not to restore it, it makes sense to choose the length of the bar at which the maximum values of the sediment discharge gradient will be minimal.

Tectonic and sedimentary structures in the oceans

Goals of research

Detailing the structure of the East Indian Ridge based on the data of multipath bathymetry and high-resolution seismic profiling analysis of the structural-tectonic differences of its individual segments.

Identification of the role of lateral sedimentation under the forcing of bottom currents in the process of Pliocene-Quaternary sedimentation in the deep-water basins of the ocean and on the continental slope of South America.

Diagnostics of minerals and mineral complexes in the submicron fraction of dispersed and condensed sedimentary substances for further climatic paleoreconstructions.

Stratigraphy of high and ultra-high resolution of bottom sediments of the Arctic seas for the reconstruction of environmental and climate conditions using the latest methods of marine geological research.

Identification and correlation of the paleogeographic events of the last deglaciation in the northern and southern hemisphere using the example of the Scandinavian and Patagonian ice sheets.

Investigation of the mechanisms of hydration and dehydration of rocks in the subduction zone and the fluid transport and migration caused by these processes.

Typification of alkaline magmas of the Cape Verde Islands (Cape Verde, Central Atlantic) in comparison with the rocks of the Canary Islands; petrological characterization of primary magma types of the Cape Verde Islands and

Canarian archipelago; geochemical characteristics of the primary magmas of the islands of Cape Verde and the Canary Archipelago.

Identification of the facial structure and quantitative parameters of sediments of the World Ocean of the Pleistocene age.

Reconstruction of the conditions of petrogenesis, geochemical nature of the sources of magmatism and geodynamic regime responsible for the formation of the lithosphere of the northwestern sector of the Pacific Ocean.

The study of hydrothermal activity and ore formation in the global system of mid-ocean ridges.

Results

As a result of structural-tectonic and seismic stratigraphic analysis new seismic profiling data in the sedimentary cover of the East Indian Ridge identified additional internal boundaries, tectonic elements, disagreements, and seismic stratigraphic complexes formed under tension conditions (Fig. 14).

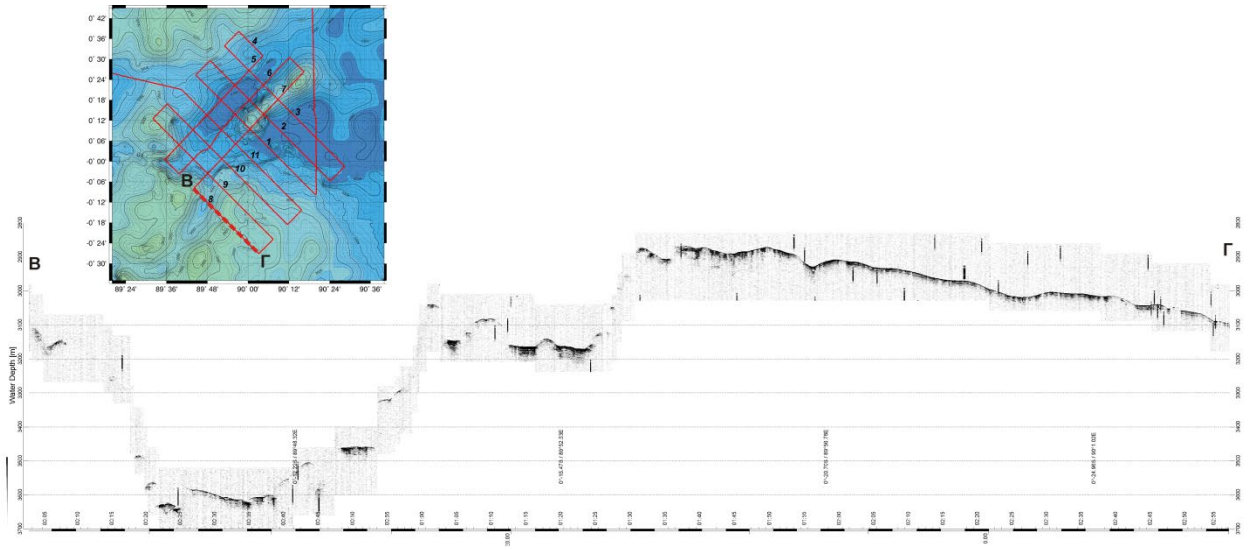


Fig. 14. East Indian Ridge: an example of the “parasound” record, showing the tectonic fragmentation of the depression slopes of the northeastern extent.

In the expeditions on the R/V “Akademik Ioffe”, new seismic acoustic data were collected on the relief forms and structure of the upper sedimentary cover of the Atlantic Ocean from the Cape Verde and North American basins to the upper continental slope of Argentina.

It has been established that biogenic carbonate sediments of the Norwegian Sea in the surface layer contain from 16 to 69% of calcite, clay minerals are of lesser importance (from 10 to 25%). The clastic terrigenous group is represented by a wide range of minerals. Mineral complexes diagnosed in bottom sediments are redeposited products of aeolian transfer, as evidenced by the characteristic mineral species and their associations, as well as their chemical composition. The composition of the aeolian material is not diagnosed, which is a mandatory component of the bottom sediments of the North Atlantic.

It is shown that oceanic lithospheric plates plunging under the continents carry huge volumes of fluids (water). As the rock of the oceanic plate containing water is immersed, both the stresses and the processes of hydration and dehydration are subjected to mechanical stresses. It is assumed, first of all, according to the data of the deep geoelectrics, that the transition zone of the mantle contains a large amount of water, comparable in volume to the World Ocean. The increased water content is provided by the properties of the rocks composing the transition zone. The subduction mechanism is an important, if not the main, method of hydration of the upper mantle and the transition zone of the mantle (Fig. 15).

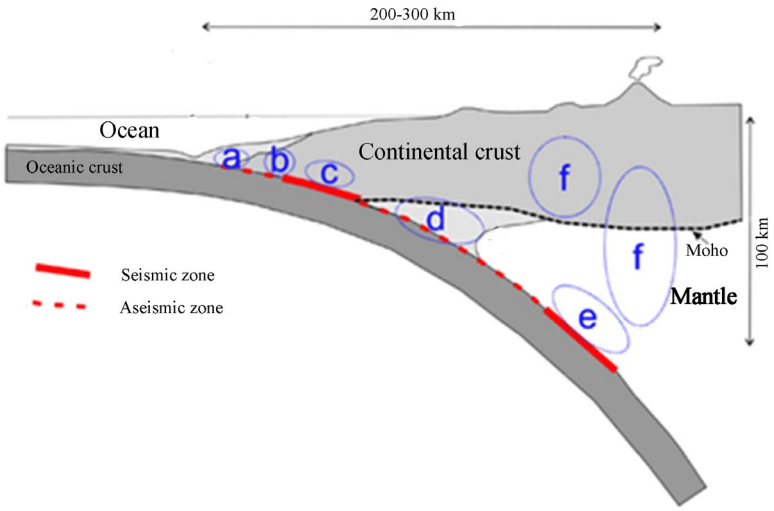


Fig. 15. Conceptual model of geophysical anomalies in the subduction zone.

The main features of the distribution of average sedimentation rates over the past 130 thousand years in the pelagic part of the Arctic Ocean are identified; the thin structure of the Polar stratum (the circumpolar segment of the submarine Lomonosov Ridge) and precipitation of the continental slope of the Kara Sea was established.

Based on a comparison of silica accumulation and other sedimentation processes in the Pacific and Indian oceans, the concept of two Pleistocene oceans has been created: “ice” and “iceless”; quantitative parameters of pelagic sedimentation are described for two time sections of the Pleistocene in the Atlantic Ocean; global patterns are revealed and regional features of the Pleistocene pelagic sedimentation in the World Ocean are established.

It has been proven that the Sverdrup and East Barents sedimentary basins have never been part of one large sedimentation basin; established patterns of evolution of sedimentation (on a quantitative basis) in the Bering Sea Pleistocene; established patterns of evolution of sedimentation (on a quantitative basis) in the Pleistocene of the Sea of Japan.

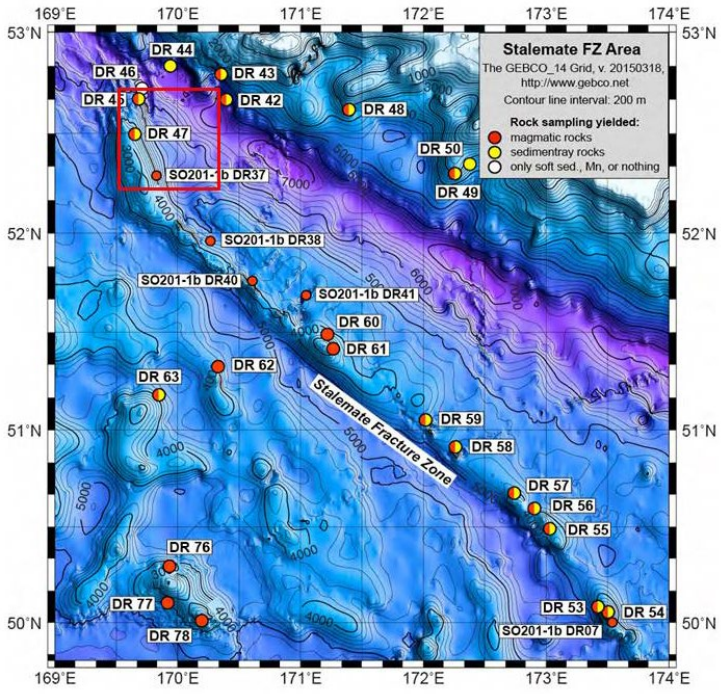


Fig. 16. The sampling area of the ocean floor at the northwestern end of the Stelmeit Fracture Zone (red square not filled). Samples dredged at the So249-DR45 and So249-DR47 stations were studied.

Numerical and laboratory modeling of processes the oceans and seas

Goals of research

Development of new computational methods for solving problems of hydrodynamics of the seas and oceans with algorithms of variational control of a model solution for the initial condition and flows on the ocean surface.

Investigation of the sensitivity of the Atlantic meridional circulation to the melting of the ice of Greenland using the eddy model of the global ocean.

Development and validation of the prognostic model of the Black and Azov Seas, methods for assessing the quality of models of marine hydrodynamics.

Identification of the most favorable conditions (type of fluid, its pressure and temperature, initial dimensions and geometry of bubbles) for the realization of extreme degrees of compression of the medium in cavitation bubbles.

Construction of mechanical models of the forms of destruction of regional ice cover associated with the development of systems of ruptures and stratifications and their role in the system of ice cover - the ocean.

Results

The k-omega splitting algorithm of the turbulence equations, parametrizing vertical turbulent exchange in the ocean general circulation model, is developed. The equations are split into two stages, describing the transfer-diffusion and generation-dissipation of the kinetic energy of turbulence (k) and frequency function (omega). The method is used to parameterize the viscosity and diffusion coefficients in the general circulation model of the ocean.

The calculations of the circulation of the North Atlantic - Arctic Ocean in 1948-2009. Experiments demonstrate adequate reproduction of hydrophysical characteristics and high efficiency. It is shown that an important factor in improving the accuracy of the modeled fields is taking into account observational data describing the average annual frequency of buoyancy.

A system of diagnosis and prediction of thermohydrodynamic characteristics and wind waves in the Azov and Black seas, taking into account ice conditions and the assimilation of observational data, has been created. The developed system includes the calculation of hydrological characteristics using the full three-dimensional INMOM circulation model with a high spatial resolution from 4 km to 250 m, and the calculation of waves for a wave model with a spatial resolution of 4 km. For real atmospheric impact, the regional non-hydrostatic model with a spatial resolution of 10 km is used. The created complex of interrelated models allows determining hydrometeorological and ecological conditions for the waters of the Black, Azov and Marmara seas. The simulation of the circulation of the Azov Sea and the features of the reproduction of extreme surges in 2013 and 2014 was carried out in Taganrog Bay (Fig. 17).

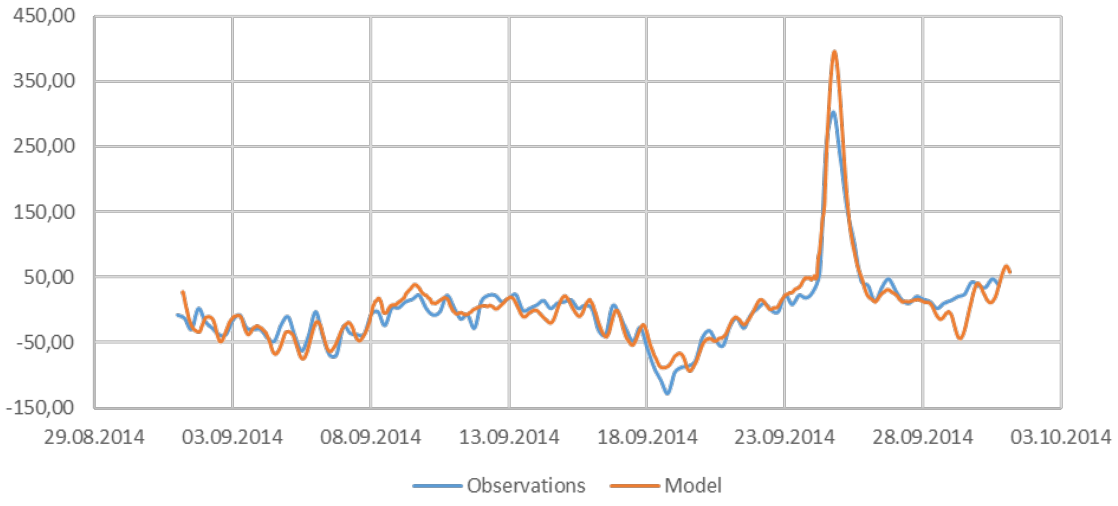


Fig. 17. Simulation of extreme surge in the Sea of Azov on September 24, 2014 (cm). Observational data are shown in blue, and simulation results in orange.