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TRANSARKTIKA-2019: WINTER EXPEDITION IN THE ARCTIC OCEAN ON THE R/V "AKADEMIK TRYOSHNIKOV"

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ТРАНСАРКТИКА-2019: ЗИМНЯЯ ЭКСПЕДИЦИЯ В СЕВЕРНЫЙ ЛЕДОВИТЫЙ ОКЕАН НА НЭС «АКАДЕМИК ТРЁШНИКОВ»

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Summary

Preliminary results of the Transarktika-2019 winter expedition in the Arctic Ocean on the R/V "Akademik Tryoshnikov" are presented. The expedition program included studies on meteorology, hydrology, hydrochemistry, hydrobiology, geology, geophysics and an extensive complex of ice measurements in the Northern Barents Sea from the drifting ice and from the ship. During the expedition, it was possible to complete a wide range of tasks. The data obtained comprise a unique material for a comprehensive study of the current state of the environmental conditions in the Barents Sea. This paper highlights the most significant preliminary results of multidisciplinary observations in various environments, which will be further comprehensively analyzed and published in separate thematic articles.

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Ключевые слова: Баренцево море, геология, геофизика, гидробиология, метеорология, морской лед, океанография, полевые наблюдения, Северный Ледовитый океан.

Представлены предварительные результаты зимней экспедиции «Трансарктика-2019» в Северном Ледовитом океане на НЭС «Академик Трёшников». Программа экспедиции включала в себя исследования по метеорологии, гидрологии, гидрохимии, гидробиологии, геологии, геофизике и обширному комплексу измерений ледяного покрова в северной части Баренцева моря с дрейфующего льда и с борта судна. Во время экспедиции удалось выполнить широкий круг задач. Полученные данные представляют собой уникальный материал для всестороннего изучения текущего состояния условий окружающей среды в Баренцевом море. В статье обозначены наиболее значимые предварительные результаты междисциплинарных наблюдений в различных средах, которые в дальнейшем будут всесторонне проанализированы и опубликованы в отдельных тематических статьях.

1. INTRODUCTION

On May 20, 2018, with the arrival of the research vessel "Akademik Tryoshnikov" in Murmansk, the first stage of the "Transarktika-2019"multidisciplinary expeditionary program of the Roshydromet of the Ministry of Natural Resources of the Russian Federation (http://www.aari.ru/transarctika2019/transarctika2019.html) was completed. In total, under the program in 2019, four marine expeditions to the Russian Arctic seas and the adjacent deep-water part of the Arctic basin are planned. A distinctive feature of the first stage was conducting field research at the end of the winter season, when the Arctic ice cover reaches seasonal maximum. Despite the obvious navigational difficulties, the value of scientific information obtained during this period of a year is very high. This is due to the fact that key physical processes, which shape the water mass structure, exhibit pronounced annual variability. Thence, the measurements made in this season, allows better understanding of the driving forces and verification of the validity of the existing theoretical concepts. An important task of the expedition was the online transfer of the obtained information on land, thus providing Russian contribution to the international PPP (Polar Prediction Project) program of WMO. Three-hour meteorological and 12-hour aerologic observations, continuous geophysical measurements, as well as information on ice drift and meteorological parameters from 6 buoys installed at spaced points were permanently transmitted on land. The scientific staff of the expedition included 52 specialists, representing fifteen research organizations in Russia and Germany. A significant number of participants were students, graduate students and young scientists. The expedition also involved two helicopters KA-32, which were served by 12 people of flight personnel. Detailed information about the expedition was regularly transmitted from board by two correspondents of the television company St. Petersburg, and a documentary about the expedition was shot by two employees of the RT news agency (https://youtu.be/BCCvtg2a-Go). The present paper highlights the most significant preliminary results of multidisciplinary observations in various environments, which will be further comprehensively analyzed and published in separate thematic articles.

2. THE CRUISE ROUTE AND THE SCOPE OF WORK

The ice-strengthened research vessel "Akademik Tryoshnikov"set sails to the operational area from Murmansk on March 21, 2019, after transit from St. Petersburg, with

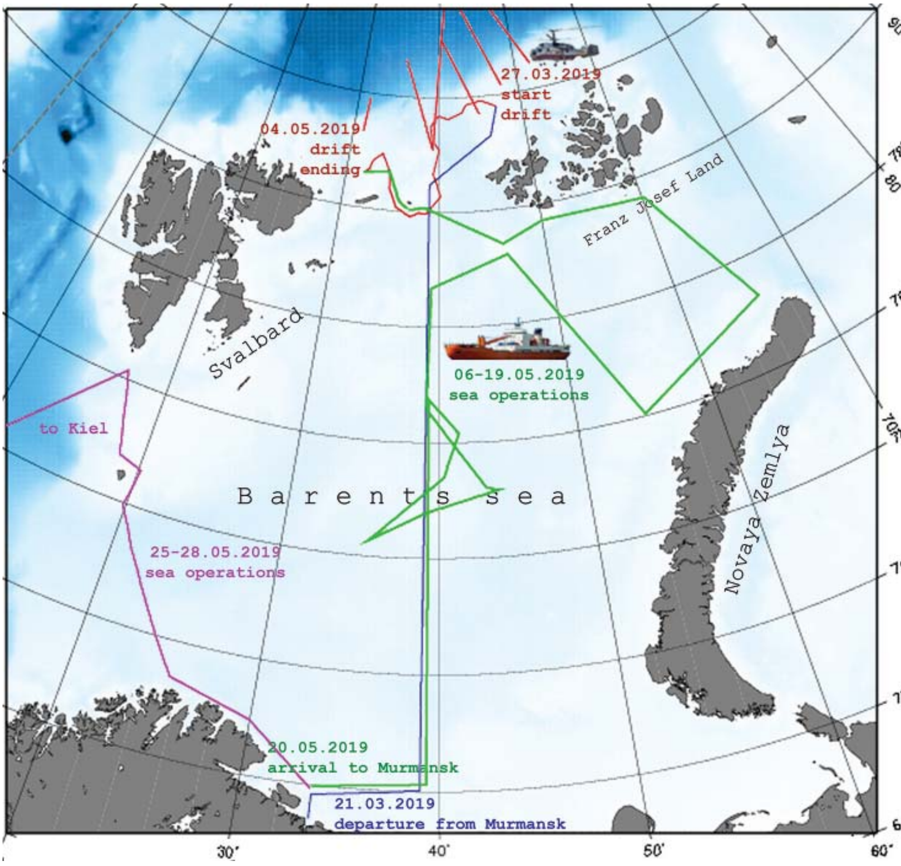

Fig. 1.The expedition route of the R/V "AkademikTryoshnikov" from March 21 to May 28, 2019.

The blue color shows the way from Murmansk to the point of the beginning of the drift with hydrological sections; the red color shows the drift pathway and the transects, done with the helicopter; the green color shows the way back to Murmansk with hydrological transects; the magenta color shows the return way to Kiel with hydrological transect

Рис. 1. Маршрут экспедиции на НЭС «Академик Трёшников» с 21.03 по 28.05 2019 г.

Синим цветом показан переход из п. Мурманск в точку начала дрейфа с гидрологическими разрезами; красным цветом показана траектория дрейфа и разрезы, выполненные с помощью вертолета; зеленым цветом показан обратный переход в п. Мурманск с гидрологическими разрезами; фиолетовым цветом показан обратный переход в Киль с гидрологическим разрезом ship call at Kiel for receiving equipment of German expedition members. From March 21 to March 27, the ship moved northward with a hydrological transect along the meridian of 39° E. After choosing a suitable ice field and anchoring the vessel to it, an ice camp was deployed over three days. Planned studies on meteorology, hydrology, hydrochemistry, hydrobiology, geology, geophysics and an extensive complex of ice measurements began on March, 30 from the ice. At the same time, regular hydrological profiling was carried out from the ship with sampling for chemical analyzes, geological stations (using a direct-flow soil tube and box corer), sampling for contamination with radionuclides, ozonometric measurements, and monitoring of ice pressure on the ship hull. During the drift, in addition to the 194 hydrological profiles from the ship and from the drifting ice, 59 hydrological profiles were carried out at remote oceanographic sections oriented perpendicular to the continental slope, within a radius of 300 km with the delivery of people and equipment by Ka-32 helicopter. On May, 4 after the completion of work on ice, the ship headed to north-eastern part of the Barents Sea, where six hydrological sections were occupied, and some of these sections repeated standard historical transects (e.g. from Salm Island, Franz Joseph Land to cape Zhelaniya, Novaya Zemlya archipelago). The main stage of the expedition was completed on May 20 with a ship call to Murmansk, where most of the expedition participants disembarked. After leaving Murmansk on May 24, at the way to Kiel (Germany), a hydrological transect between cape Nordkap and cape Zuidkap was done. The expedition route is shown in Figure 1.

3. RESEARCH HIGHLIGHTS

3.1. Turbulent sensible heat flux controls the heat balance at the snow-ice surface in spring

The main goal of studying the processes of energy-mass exchange of the atmosphere with the sea ice cover was to obtain estimates of the spatiotemporal variability of the main parameters of the boundary layers of the atmosphere and ocean along the drift route of the R/V "Akademik Tryoshnikov" by performing complex synchronous observations in the boundary layer of the atmosphere, snow-ice cover and in the upper ocean. The tasks of the work included: (i) the study of the structure and dynamics of the atmospheric boundary layer and the features of its dynamic-thermodynamic interaction with the ice cover at the end of the polar night (dark) season; (ii) the study of thermodynamic processes that determine seasonal evolution of the snow-ice cover to identify the features of diffusive, convective and radiative heat transfer; (iii) obtaining new data on the physical mechanisms responsible for the formation of the structure of the upper layer of the ocean under the ice cover, including the processes of heat transfer from the Atlantic-origin waters to the lower surface of the sea ice cover.

Calculation of the components of the heat balance at the snow-ice surface is based on the results of measurements made using the Campbell Scientific gradient meteorological complex installed in the ice camp. This complex provides continuous every minute registration of atmospheric pressure (P), temperature (T_a) and relative humidity (RH) of air at a 2 meter height, wind speed (V) at 10 m height and components of the radiation balance at the underlying surface (incoming Q_{dn} and reflected short-wave Q_{up} solar radiation, long-wave radiation of the atmosphere R_{dn} and underlying surface R_{up}). To calculate the components of the heat balance at the snow-ice surface, the approach described in [1] was used. To estimate the turbulent fluxes of sensible (H) and latent heat (LE), a calculation scheme was used based on the Obukhov similarity theory [2, 3]. In the calculations of

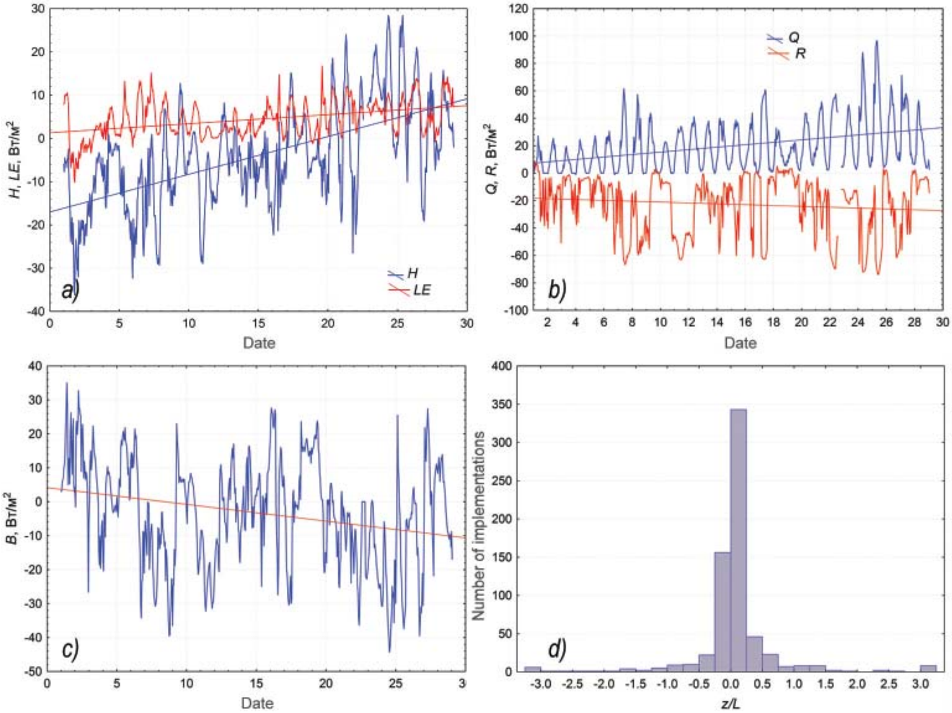

Fig. 2. Characteristics of energy exchange processes in the "ice – atmosphere" system in April 2019: (*a*) turbulent sensible and latent heat fluxes; (*b*) short-wave and long-wave balances at the underlying surface; (*c*) the total heat flux from the atmosphere to the ice-snow surface; (*d*) a histogram of the recurrence of the stratification parameter at the near-to-ice air layer during the drift

Рис. 2. Характеристики процессов энергообмена в системе приледный слой атмосферы – поверхность снежно-ледяного покрова в апреле 2019 г.: (*a*) турбулентные потоки явного и скрытого тепла; (*b*) коротковолновый и длинноволновый балансы подстилающей поверхности; (*c*) суммарный поток тепла от атмосферы к снежной поверхности; (*d*) гистограмма повторяемости параметра стратификации приледного слоя атмосферы в период дрейфа

H and *LE*, the fluxes are considered positive if they are directed from the underlying surface to the atmosphere. The direction of the total heat flux to the underlying surface (*B*), calculated by the formula $B = Q + R - H - LE$ (where $Q = Q_{dn} - Q_{up}$ and $R = R_{dn} - R_{up}$) is considered positive from the atmosphere to the underlying surface.

Figure 2 shows the spatiotemporal variability of heat fluxes in the "ice-atmosphere" system in April 2019 along the drift route. Despite the increase in the incoming short-wave radiation, and, accordingly, the increase in the short-wave radiation balance (*Q*) due to the increase in the duration of daylight and the height of the sun, the total heat flux from the atmosphere to surface *B* decreases from 4 to –8 W/m^2 from the beginning to the end of April. This is due to the large albedo of the snow cover (0.82), a slight increase in heat consumption for evaporation (*LE*), a slight increase in cooling due to long-wave radiation (*R*), and a significant, up to a change in sign, decrease in the turbulent sensible heat flux directed to the surface (*H*). The latter is confirmed by temporal variability of the temperature contrast between 2 meter height and the surface ($T_a - T_s$), and by the histogram of the recurrence of stratification in the near-to-ice air layer, which shows a significant number of unstable stratification cases(see Fig. 2 *d*).

Obtaining correct estimates of the turbulent flux of sensible heat, based on various parameterizations [4], still poses a challenge. Correct estimates are especially important when modeling sea ice cover in spring, when a slight increase in heat influx leads to a sharp decrease in albedo and the onset of intense melting. A significant contribution to the solution of this problem is expected after careful processing and analysis of complex observations carried out during the expedition.

3.2. Inhomogeneous ice cover activates processes at the ocean – air interface in winter

Sea ice cover is one of the key indicators of the state of polar climate systems. At present, the most detailed information on the state of sea ice is provided by satellite measurements. However, the accuracy of measuring sea ice thickness from processed satellite data is still insufficient. With this in mind, contact measurements of ice thickness at spaced points provide valuable information for validating satellite measurements and improving the quality of sea ice volume calculations. Due to the organization of remote observations using a helicopter, the expedition collected a unique array of contact measurements of sea ice thickness at the helicopter landing points during hydrological profiling. This data array covers an area of about 50 thousand km^2 along the continental

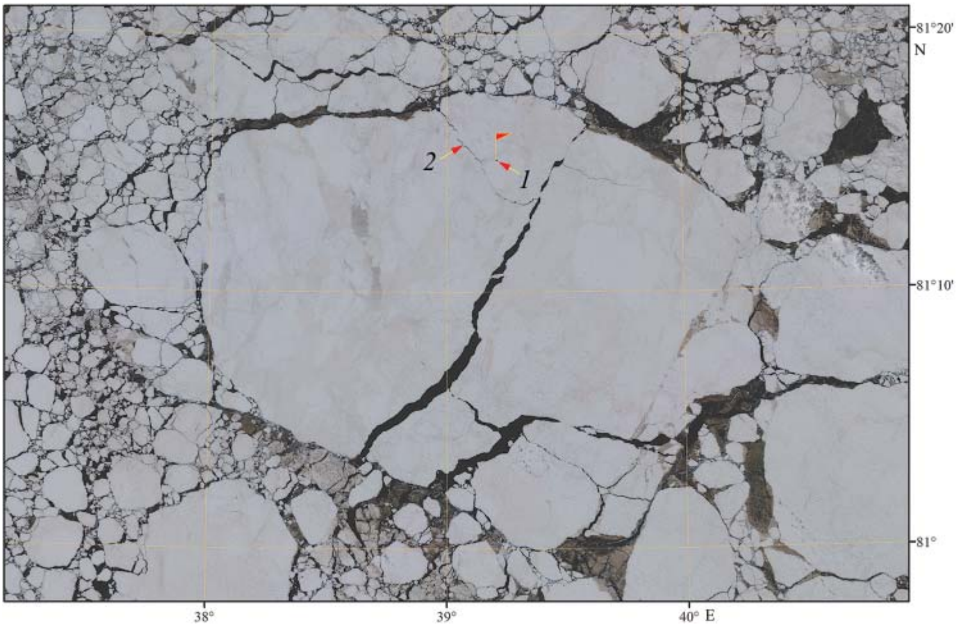

Fig. 3. Ice conditions around the drift area of the R/V “AkademikTryoshnikov” according to multichannel surveys from the Sentinel-2a satellite at 11:56:51 UTC on 04.17.2019 with a spatial resolution of 10 m. (*1*) denotes the position of R/V “Akademik Tryoshnikov”, (*2*) denotes developing crack in the ice field

Рис. 3. Ледовая обстановка в районе дрейфа НЭС «Академик Трёшников» по данным многоканальной съемки с ИСЗ Sentinel-2a на 11:56:51 UTC 17 .04.2019 с разрешением 10 м. Цифрами обозначены: (*1*) положение НЭС «Академик Трёшников», (*2*) развивающаяся трещина в ледяном поле

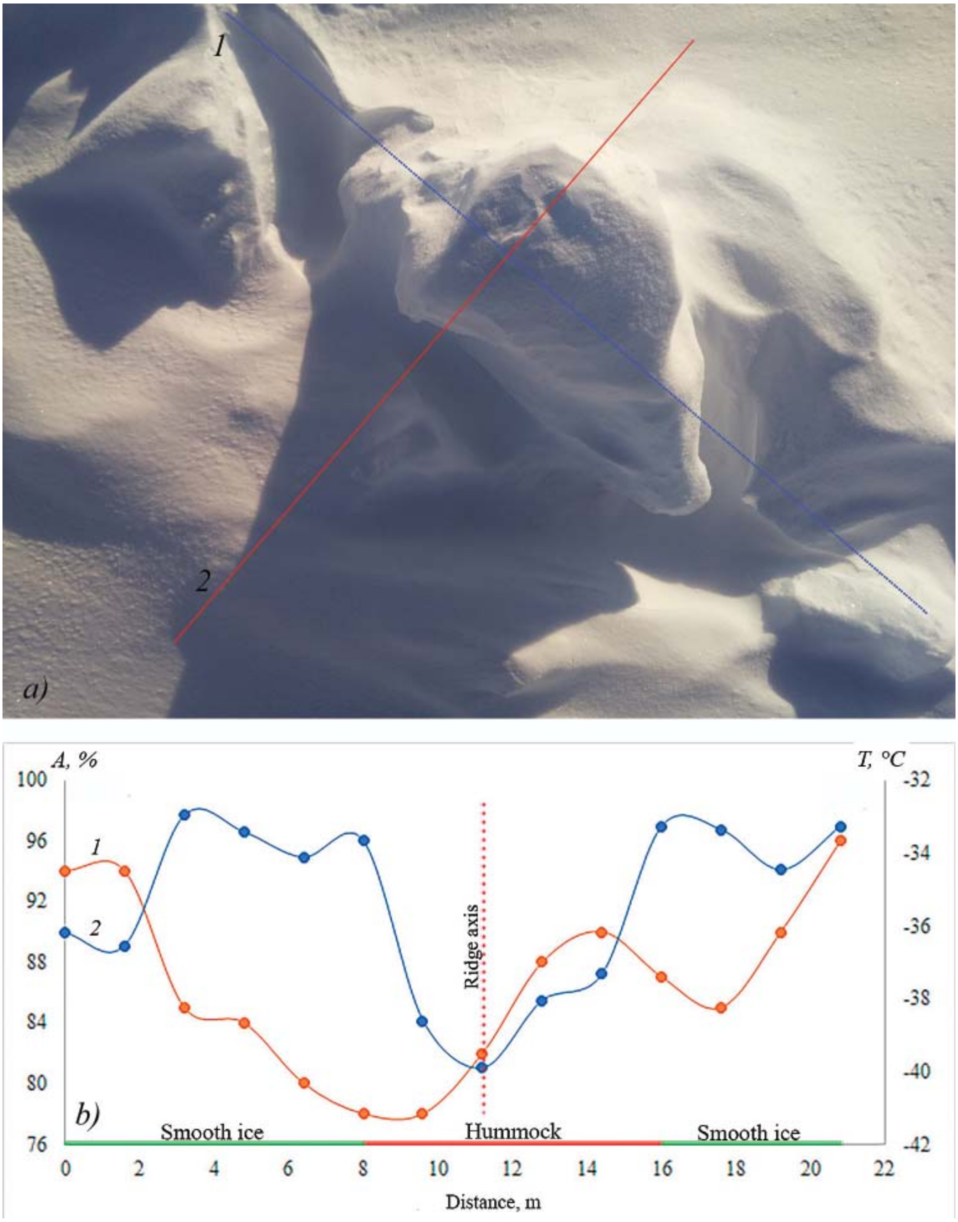

Fig. 4. (*a*) Photograph of the hummock and UAC flight route. (*1*) denotes the axis of the ridge, (*2*) denotes the UAC flight route on April, 11, 2019 at 15 m height; (*b*) Spatial distribution of surface temperature (*1*) and albedo (*2*) over flat ice and hummock

Рис. 4. (*a*) Фотография тороса и маршрут полета БПЛА. Цифрами обозначены: (1) ось тороса, (*2*) траектория полета БПЛА 11 апреля 2019 г. на высоте 15 м; (*b*) пространственное распределение температуры поверхности (*1*) и альбедо (*2*) ровного и всторошенного льда slope and will be used together with the data on ice concentration for calculation of the volume of sea ice in the study area at the end of the 2019 winter season.

Studies of the features of energy and mass transfer processes in the polar regions are primarily related to taking into account the areas occupied by young ice and open water (cracks, leads, polynyas), which are the main sources of intense heat transfer to the atmosphere in winter and the areas of solar energy absorption in summer. During the entire drift of the R/V "Akademik Tryoshnikov", the surface of the ice cover was constantly changing (Fig. 3). Under the influence of dynamic factors in the vicinity of the ice camp there was a constant formation of cracks that transformed into leads and polynyas, and, on the contrary, closing polynyas led to fast building of ridges, sometimes reaching 2-meter height.

Such competitive processes can probably be considered as quite typical for the conditions of the present-day warming in the Arctic, not only in the drift region, but also in other areas. This is due to the increasing fraction of thinner seasonal ice in the total balance. Taking this into account, the expedition program included experimental studies of understudied processes of energy exchange over hummocks. A few experimental and theoretical studies show that the nature and intensity of energy transfer processes in the presence of hummocks noticeably differ from the conditions observed on flat ice [5, 6, 7, 8, 9, 10]. There are practically no technical and methodological tools for the correct assessment of energy exchange near hummocks [11]. To study the features of the spatial distribution of albedo and surface temperature over flat ice and hummocks, an Explorer Quad (unmanned aerial copter, UAC) was used. The UAC housed the original measuring unit designed in AARI, which consists of a LI-190SA photometer manufactured by LICOR LTD (USA), an infra-red thermometer (Russia), a camera, and a control unit [12]. To conduct ground-based verification measurements in parallel with UAC flights over a flat ice, a rack with pyranometers similar in design and spectral range to the UAC sensor was installed close to the studied hummocks. For continuous recording of incoming and reflected radiation at the sea ice surface were used pyranometers: LI-192SA and ADC (programmable data-logger LI-1000), manufactured by LICOR LTD.

On the basis of accomplished measurements it was found that the reflectivity of a flat surface is higher than that of hummocks. In some cases, the difference between the albedo of flat ice and the albedo of hummocks exceeded 10 per cent, with the maximum differences up to 30 per cent. This means that the recorded differences are significant, since the relative error of a single albedo measurement in real conditions does not exceed ± 5 % [13].

A snapshot of the hummock shown in Figure 4 *a* made it possible to perform a detailed analysis of the data obtained during UAC flights. For example, it was possible to reveal that shaded areas at slopes of hummocks have the minimum albedo (points No. 8 and 10 in Figure 4 *a*). Small, in comparison with flat ice, albedo values cause large absorption of solar radiation. The latter was revealed experimentally during the expedition and partially confirmed theoretically [8, 9]. However, the surface temperature near the hummock ridge is noticeably lower than that at the neighboring flat ice. This can lead either to an increase in the influx of heat from the atmosphere (at a constant air temperature) or to the formation of stable stratification in the near-to-ice air layer (inversion), which impedes vertical turbulent exchange. Thus, a preliminary analysis of collected data suggests that the energy exchange near hummocks significantly differs from that over flat ice. These features should be taken into account in mathematical models as well as the differences in ocean-air energy exchange between a consolidated ice cover and an open water surface.

3.3. Two branches of Atlantic water shape hydrological and ice regime of the Barents Sea

The main external factor controlling the hydrological regime of the Barents Sea is the inflow of warm and salty Atlantic origin waters from adjacent basins. Across the western border, a wide strait between the Scandinavian Peninsula and the Bear Island, Atlantic water enters from the Norwegian Sea to the central and southern parts of the Barents Sea. Atlantic water from the Nansen Basin flows in through deep-water trenches at the northern border of the sea. In modern literature, these water masses are commonly referred to as the Barents Sea Atlantic Water (BAW) and the Fram Strait Atlantic Water (FAW), respectively. We will adhere to this terminology in the further presentation. To assess the state of both branches of the Atlantic waters at the end of the winter season, a hydrological section was performed along 39° – 40° E. from 70° to 84° N (see Fig. 1). During the transition, hydrological profiling was carried out by a regular CTD (Conductivity Temperature Depth) device Seabird SBE911plus (www.seabird.com). During the drift measurements in the northern part of the section were performed by a SeaCAT Profiler CTD SBE 19plus (www.seabird.com)with the delivery of equipment to the transect points by helicopter. The consistency of the data obtained using both devices was checked by inter calibration at several stations, and after the expedition was completed, the sensors passed standard verification in a certified company.

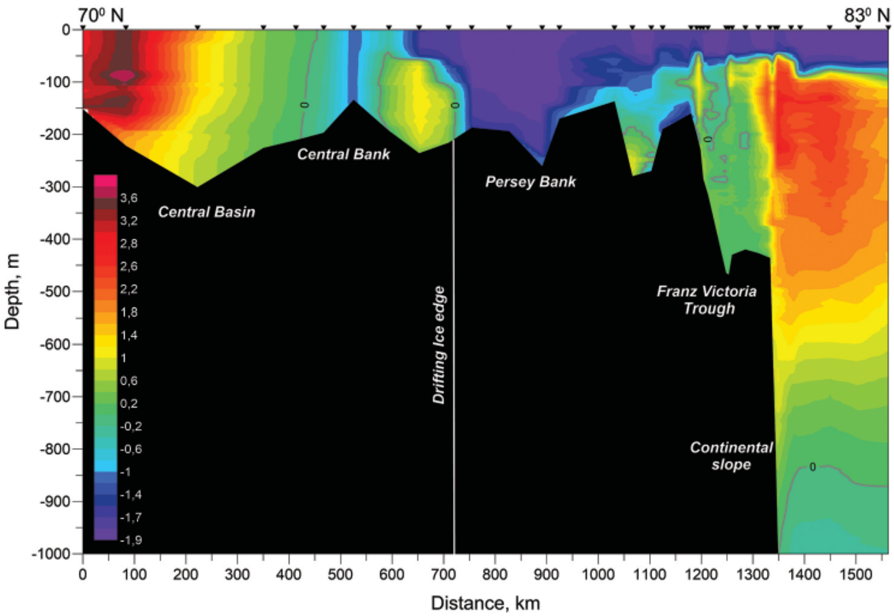

Fig. 5. Temperature distribution (°C, color) at the meridional transect along the meridian 39–40° E. during the time interval May, 21 – April, 4, 2019. Black triangles at the top show position of CTD casts

Рис. 5. Распределение температуры (°C, показано цветом) на меридиональном разрезе вдоль меридиана 39–40° в.д. 21.03 – 05.04. 2019. Положение точек CTD-зондирований показано черными треугольниками в верхней части рисунка

The characteristic features of the hydrological structure in the central part of the Barents Sea and on the continental slope of the Nansen Basin are well distinguished by the meridional temperature distribution (Fig. 5).

The main warm core of BAW with a maximum temperature of 3.8°C at a depth of 100 m is revealed at the southern border of the transect in the Central Depression. At the periphery of the warm core, a quasi-homogeneous vertical temperature distribution from surface to bottom is observed, indicating an intensive winter convective mixing. The secondary core of BAW with a maximum temperature of 1.1 °C is located in the trench between the Central Bank and the Perseus Bank from a depth of 50 m to the bottom. Two warm cores are separated by a frontal section with a minimum temperature of –1.1 °C above the Central Bank. The Central Bank is an important element of the bottom topography of the Barents Sea, affecting its hydrological regime through the formation of cold dense waters in the winter season [14]. These waters flow down along the slopes of the bank into the adjacent deep-water basins, which leads to the separation of the initially single stream of BAW into two jets. A fundamentally new result obtained during the expedition is the establishment of the fact that winter convection over the Central Bank can be purely thermal, i.e. the formation of a homogeneous "column" of dense water above the bank does not necessarily require salinization during ice formation, which was previously assumed as a necessary condition [15]. The obtained new knowledge is confirmed by the fact that at the end of March 2019, the boundary of consolidated one-year ice was located 80–100 miles northward off the Central Bank (Fig. 5), while the appearance of drifting ice in the Central Bank region dates by the second half of April. The polar front separating BAW (in the south) from the surface Arctic water mass with a surface temperature close to the freezing point is located above the southern spur of the Perseus Bank. Further to the north, to the northern peaks of the Perseus Bank, as well as in the southern part of the transect, there is a high uniformity of temperature along the vertical, which indicates intense convective mixing. However, convection in this region is obviously of haline origin. The densification of surface water in this case occurs as a result of salinization during ice formation. To the north of the Perseus Bank, the deep and bottom layers of water are characterized by a positive temperature, which is associated with the influence of the heat of FAW, which main core with a temperature of 2.6 °C is in the depth range of 100–200 m on the Nansen Basin continental slope. The lowering of the bottom topography along the transect begins well before the continental slope, in the Franz Victoria Trough, where the maximum depth reaches 450 m. However, within the trough, the water temperature does not exceed 0.1–0.3 ° C, which is associated with the intense formation of cold dense waters along the trough perimeter and their runoff down the trough slopes.

3.4. Intensive formation of dense waters on shelves and their cascading into the adjacent water basins is the main mechanism of water masses transformation in winter

Observations on a series of successive hydrological transects in the north-eastern Barents Sea (see Fig. 1) cast doubt on the existing concept that the transformation of BAW is largely due to the open sea winter convection. A preliminary analysis of the collected data suggests that the role of cascading (descent of dense cold water forming on shallow

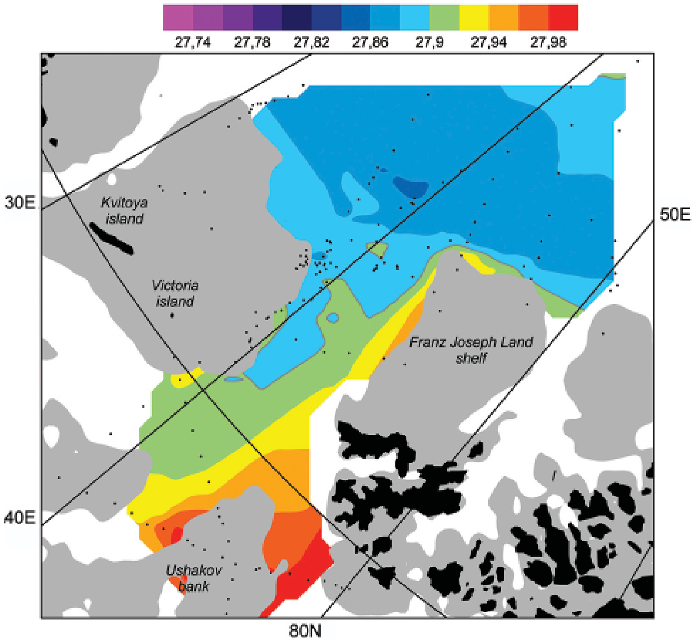

Fig. 6. Distribution of potential density (kg/m^3, color) in the Franz Victoria Trough at 250 m depth in April – May 2019. Black dots show position of CTD casts

Рис. 6. Распределение потенциальной плотности (кг/м^3, показано цветом) в желобе Франц-Виктория на глубине 250 м в апреле–мае 2019 г. Положение точек CTD-зондирований показано черными точками

shelves) is more significant. To illustrate this statement, Figure 6 shows a chart of potential density at 250 m depth in the Franz Victoria Trough, where a large number of CTD profiles made it possible to generate horizontal distribution of hydrological parameters. The Franz Victoria Trough is the main water exchange channel with the deep Nansen Basin in the northern part of the Barents Sea. The average depth of the trough is about 300 m, facilitates free penetration of the warm FAW from the north. As showed a preliminary analysis of observations, the nature of water exchange through the trough is fundamentally different from the patterns established earlier on the basis of summer and fall surveys [16].

As a result of mixing with cold and slightly fresher dense waters formed on the island shelves surrounding the trough and flowing downslope, the FAW entering from the Nansen Basin rapidly cools down and freshens throughout the entire thickness. Through the southern channels, colder (with temperature less than zero) and slightly saltier water, which formed on the southern island shelf of Franz Joseph Land and Ushakov Bank, enter the trough. As a result, at depths below 200 m a density front forms between cooled (but still keeping positive temperature and increased salinity) FAW, which tongue is stretched southward along the western flank and the denser water with a negative temperature and slightly lower salinity moving northward along the eastern flank of the trough. At the mouth of the trough dense water flow turns eastward along the continental slope under the influence of the Coriolis force and mixes with FAW, leading to cooling and freshening of the latter [17].

3.5. Zoobenthos in the Franz Victoria Trough

The bed and slopes of the Franz Victoria Trough are interesting not only in terms of oceanographic characteristics, but in terms of zoogeographic features of the fauna inhabiting it as well. FAW penetrates into the trough from the north, forming specific environmental conditions for the bottom fauna [18]. In addition, the northernmost deep-water segments of the trough bed are affected by the Arctic waters, which also affect the composition of the fauna. The main goal of the work was to study the communities of bottom biotopes at the northern edge of the Arctic shelf and the Franz Victoria Trough, the vertical distribution of animals in the bottom sediments' profile and their interaction with the environment. Preliminary results of the primary processing of the collected biological material show that polychaetes, mainly *Spiochaetopterus typicus* (M. Sars, 1856) and Maldanidae gen. spp., dominated qualitatively and quantitatively at all stations. At depths of 150–200 m, the biomass and abundance of bivalves (families Astartidae, Thyasiridae) also increased significantly. In addition, a high diversity of crustaceans was noted in the deep part of the Franz Victoria Trough. In soft sediments of the bed of the trough the number of echinoderms sharply increased, in particular starfish *Ctenodiscus crispatus* (Bruzelius, 1805).

Study of the vertical distribution of benthic organisms in the bottom sediments helps to better understand the biology of certain species, the ways of organic matter utilization in the community, and the influence of biota on the structure of sediments. A preliminary analysis of the vertical distribution of higher taxa in the sediments' profile showed that, with the exception of organisms living only on the sediment surface, the number of higher taxa of infauna (16) in the sediments didn't change to a depth of 5–6 cm. This horizon approximately corresponds to the maximum thickness of the upper water-saturated sediment layer, sometimes with an adjacent intermediate layer with a less degree of water saturation. Deeper than 5–6 cm, the number of taxa began to decline, and only Polychaeta were present from 22 to 31 cm.

Figure 7 shows the result of a DistLM analysis of the connection between the vertical distribution of higher taxa in the sediments' profile and the environmental factors: depth, near-bottom temperature, type of sediments. The values of near-bottom salinity practically did not change between the stations. Expectedly, the influence of this factor was not reliable and it was excluded from the final analysis. Other factors had a high degree of significance ($P = 0.001$), however, the share of the explained total variation was relatively low (11 % for the temperature, 16 % for the sediment type, 10 % for the depth). This may be due to the use of rather "rough" data, both biological (only higher taxa) and lithological (few grades of sediments' fractions). However, this preliminary analysis provides already some results to be checked and developed when a detailed processing of the samples is carried out and quantitative data are obtained. At the Figure 7, two groups of stations are seen, matching biotopes characterized by different abiotic characters and different higher taxa composition and vertical distribution:

1 (marked by circles) – shallow-water (depth less than 300 m) biotopes of the trough slope, with negative near-bottom temperature and high sand content in bottom sediments. As a rule, a large number of stones or pebbles were present. The depth of penetration of invertebrates into the sediments was on average 1.5 less than in the biotopes of the second

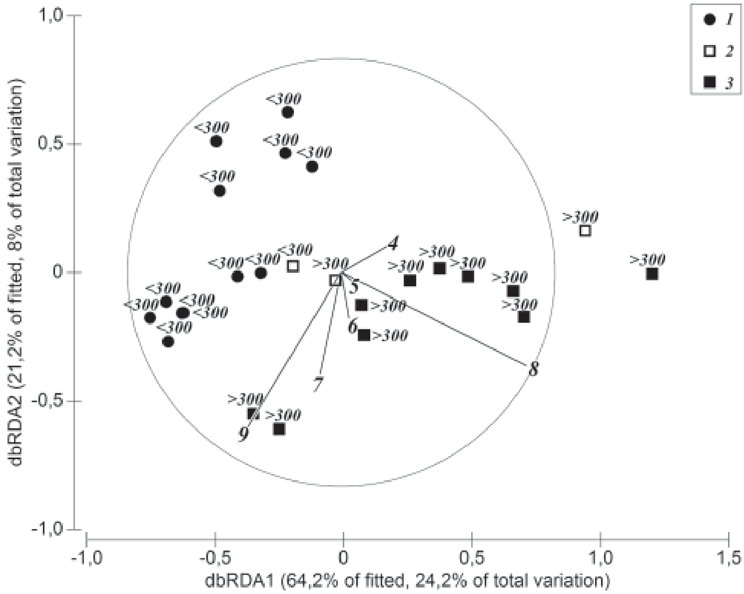

Fig. 7. Results of the DistLM-analyses of the environmental predictors' influence on the vertical distribution of the number of higher taxa in the bottom sediments'profile (*1–3*) near-bottom temperature: (*1*) negative (–0.7…–1.8°C), (*2*) slightly negative (–0.2… 0°C), (*3*) slightly positive (0… 0.7 °C); (*4–9*) predictors: (*4*) clay sediments, (*5*) fine sandy sediments, (*6*) sandy sediments, (*7*) pebbles and stones, (*8*) depth, (*9*) near-bottom temperature; numbers at the stations' symbols mark depths over and below 300 m

Рис. 7. Результат DistLM-анализа зависимости вертикального распределения числа крупных таксонов в толще осадков от факторов среды. (*1–3*) придонная температура: (*1*) отрицательная (–0,7… –1,8 °C), (*2*) слабо отрицательная (–0,2… 0 °C), (*3*) слабо положительная (0… 0,7 °C); (*4–9*) предикторы: (*4*) глинистые осадки, (*5*) мелкопесчанистые осадки, (*6*) песчанистые осадки, (*7*) галька и камни, (*8*) глубина, (*9*) придонная температура; цифрами у значков станций обозначены глубины более и менее 300 м

type, but the distribution along the profile was even, showing gradual decline of number of taxa with the depth under the sediments' surface.

2 (marked by squares) – stations with depths below 300 m, close to zero or slightly positive bottom temperatures (due to the inflow of FAW) and clay bottom sediments. The deepest penetration into the sediments of the mass polychaetes S. typicus and Maldanidae gen. spp. was recorded; but the other groups mostly occurred not deeper than the upper water-saturated layer.

3.6. Icebergs rafting in the late Pleistocene deglaciation period is a probable source of large-sized rock fragments

The Barents Sea continental margin is a unique region due to its variable geological structure, complex tectonics, diversity of sediment source areas, dissected relief and high hydrocarbon potential. Franz Victoria Trough, one of the most important morphological and structural elements of the shelf, is the largest channel connecting the Barents Sea with the Arctic Ocean. Here, FAW enters the Barents Sea, and sediment material is transported in the opposite direction, to the deep Nansen Basin. These background processes setup prerequisite conditions for massive redistribution of terrigenous material around the Arctic Ocean. Similar processes were acting in the geological past and therefore they can be reconstructed by a comprehensive study of bottom sediments. Paleo-oceanographic studies in the northern part of the Barents Sea are extremely significant for understanding the general evolution of climate during the Quaternary. In accordance with the direction of the ship's drift, geological profiles were taken through the northern part of the Franz Victoria Trench, along its western side, and in a shallow area north of Kvitoya Island. Sediment samples were obtained at 48 geological stations with the help of a small box-corer and a gravity corer.

The results of the initial analysis of the sampled material allow figuring out preliminary considerations on the features of sedimentation in the northern part of the Barents Sea in the Late Quaternary. The Upper Quaternary section of bottom sediments in the region was formed under the conditions of two radically different sedimentation regimes. Their change is associated with the transition from cold late Pleistocene climate to warm Holocene. Sediments accumulated during the Holocene is represented by brown, gray-brown, and brown-gray silty clay (sometimes with a noticeable sand admixture), including rare psephitic material of gravel-pebble dimension. Their thickness, as a rule, is not large (10–50 cm). Below lay gray sandy silty clay saturated with gravel-pebble (up to boulder size, more than 10 cm) material. The majority of psephytes are represented by non-rounded acute-angled samples, or sub-angular and ribbed ones with noticeable frayed edges. They correspond to 0 and 1 rounded points (the lowest) in accordance with the Khabakov scale, or vary from 0.15 to 0.35 according to the Wadell roundness scale (Fig. 8). Theoretically, the sources of coarse fragments can be local outcrops [19, 20], gravitational slope flows, or rafting by sea ice and icebergs. Most likely, the first two of the listed sources did not have leading significance in the studied region. If they prevailed, coarse clastic material would be distributed more or less evenly along the section. However, the increased content of psephytes is recorded only in its deeper part, which suggests higher probability of delivery by icebergs. The intensity of iceberg calving culminated during deglaciation stage. After relative stabilization of climate in the Holocene, the icebergs rafting ceased to play a noticeable role, which led to significant decrease in the number of psephytes in the shallower part of the section.

Fig. 8. Geological station AT19-09GC. The erosion boundary is clearly visible between the Holocene brown silty clay (left) and the Late Pleistocene dense gray sandy silty clay with gravel-pebble sized material (right). The cavernous surface of the gray sediment is associated with a large amount of fine gravel

Рис. 8. Геологическая станция AT19-09GC. Хорошо видна эрозионная граница между голоценовыми коричневыми алевропелитами (слева) и позднеплейстоценовыми плотными серыми песчаными алевропелитами с материалом дресвяно-щебневой размерности (справа). Кавернозная поверхность серого осадка связана с большим количеством мелкой дресвы

Preliminary estimates show that the petrographic composition of large-sized rock fragment material (psephytes) varies greatly within the studied area. Basalts and dolerites, which are a kind of marker of the Franz Joseph Land, are extremely rare among the studied psephites. Quartz sandstones, quartzites and carbonates (mainly dolomites, less often limestones) prevail. Such variability indicates the diversity of iceberg sources and the complex circulation of the latter during the deglaciation period. Further research will be aimed at reconstruction of the general direction of the movement of paleo-icebergs, and at identification of their sources. This will significantly improve the general understanding of the evolution of the Late Quaternary processes within the northern margin of the Barents Sea shelf.

3.7. Geophysical monitoring in the Arctic zone of the Russian Federation

Thermonuclear reactions occurring in the core of the Sun are the source of continuous emission of solar plasma and electromagnetic radiation into the outer space. The complex of phenomena and processes in outer space due to these emissions is called space weather. The main agents of space weather effects include: continuous outflow of magnetized low-

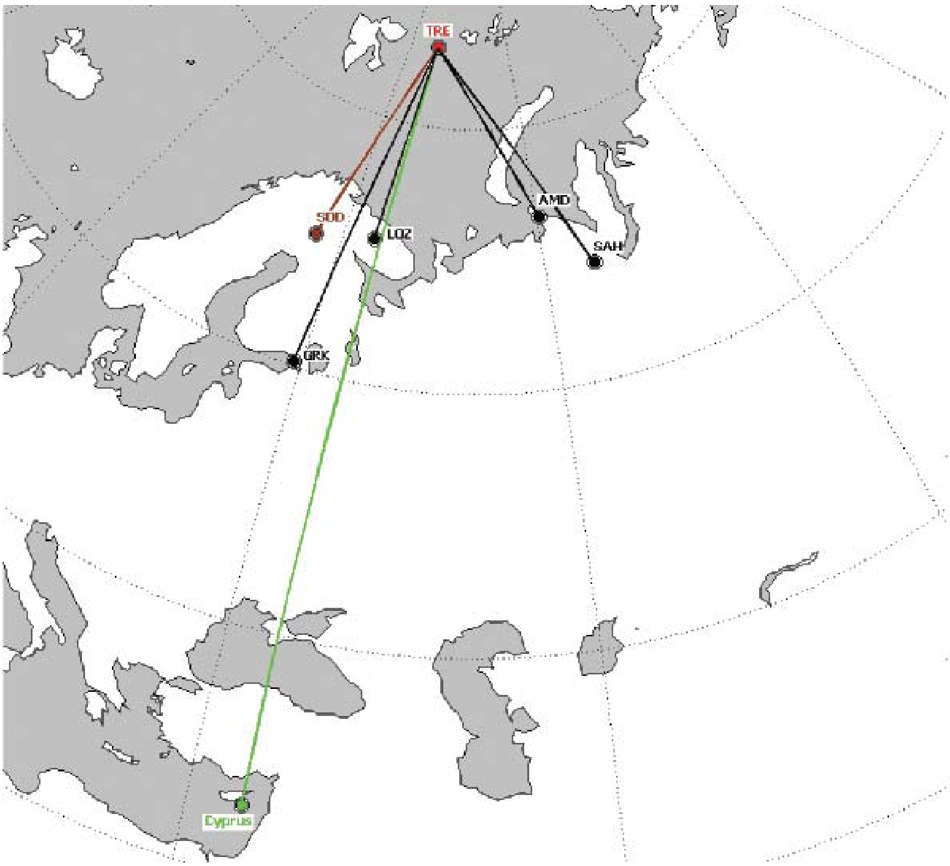

Fig. 9. Oblique sounding paths of the ionosphere March 25, 2019

Рис. 9. Трассы наклонного зондирования ионосферы 25 марта 2019 г.

energy solar plasma (solar wind); coronal mass ejection (CME) associated with solar flares and including high-intensity magnetic fields (“magnetic clouds”); solar ultraviolet (UV) radiation; fluxes of high-energy solar protons and electrons (“solar proton events”, SPE) that invade the Earth polar caps. Taking this into account, the actual tasks of geophysical monitoring in the Arctic zone of the Russian Federation include: (i) the nowcast of the influence of space weather on the state of the magnetosphere and the polar ionosphere (assessment of the probability of development and intensity of auroral substorms and world magnetic storms according to operational data on the PC index; (ii) operational diagnosis of magnetic-ionospheric disturbances in various regions of the Arctic; (iii) operational diagnosis of sudden frequency deviations (SFD) in order to prevent disturbances in the operation of systems of radiolocation, navigation and GPS (based on multichannel Doppler measurements); (iv) monitoring the propagation conditions of decameter radio waves in the Arctic region (on the basis of ionospheric oblique sounding); (v) developing methods and means for monitoring the effects of artificial high frequency radio waves in the high-latitude ionosphere; (vi) monitoring the effect of space weather on human health.

A necessary condition for solving these problems is the permanent ionospheric measurements (vertical and oblique sounding of the ionosphere) in the polar cap area with the immediate transfer of information to receiving centers on land. During the expedition novel technical approaches were developed to solve a number of the listed above tasks. The measurements were conducted from the nonmagnetic pavilion in the ice camp in combination with continuous measurements from board. A similar approach is planned to be used when organizing geophysical observations from an ice-resistant platform (LSP). During the expedition, a large amount of data was collected and immediately transmitted to the AARI Polar Geophysical Center. The significance of the additional point for oblique sounding of the ionosphere in the polar cap region is illustrated in Figure 9, which shows the radio signal paths that can significantly expand the field of operational monitoring of the high-latitude ionosphere.

4. CONCLUSIONS

The most important outcome of the expedition was the practical implementation of multidisciplinary observations from the ice with the immediate transfer of the received information to the ship and to reception centers on land. During the expedition, specific procedures were developed for the efficient organization of observations at a new type of ship-ice drift station, which will be taken into account during the construction, equipment and operation of the North Pole ice-resistant self-propelled platform (LSP). The field studies carried out in March-May 2019 made a significant contribution to the study of the transformation of Atlantic waters in the Barents Sea, including the continental slope of the adjacent Nansen Basin under changing climatic conditions, as well as to the study of the mechanisms of formation of dense shelf waters in the Barents Sea. Comprehensive information was obtained on the state of the Barents Sea environment.

During the expedition, it was possible to complete a wide range of tasks. The data obtained comprise a unique material for a comprehensive study of the current state of the environmental conditions in the Barents Sea. The data collected make it possible to obtain more reliable estimates of the spatiotemporal variability of the main elements of hydrometeorological regime, to better understand the mechanisms of water masses formation, their influence on climate changes at high latitudes, and to contribute to solving the tasks of sustainable development of the Arctic region.

The first stage of the Transarktika-2019 expedition was a logical continuation of the expeditions at the North Pole drifting stations under the current conditions of declining ice cover. The implementation of the expedition program made it possible to test new technologies for organizing and conducting modern integrated scientific research in terms of ensuring the safety of work, internal, interdepartmental and international cooperation, which is necessary for the forthcoming operation of the LSP.

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Трансарктика-2019: зимняя экспедиция в Северный Ледовитый океан на НЭС «Академик Трешников» (расширенный реферат)

Двадцатого мая 2018 г. с прибытием НЭС «Академик Трёшников» в п. Мурманск завершился первый этап комплексной экспедиционной программы «Трансарктика-2019» Росгидромета Минприроды РФ. Всего в рамках указанной программы в 2019 г. запланировано четыре морских экспедиции в российские арктические моря и прилегающую глубоководную часть Арктического бассейна. Отличительной особенностью первого этапа было проведение полевых исследований в конце зимнего сезона, когда арктический ледяной покров достигает пика сезонного максимума. Несмотря на очевидные навигационные трудности, ценность научной информации, полученной в этот период года, оказывается весьма высокой. Это связано с тем, что ряд ключевых структурообразующих гидрофизических процессов проявляет ярко выраженную сезонную изменчивость и измерения, выполненные в наиболее подходящий сезон, позволяют лучше понять механизмы процессов и проверить справедливость существующих теоретических концепций.

После выхода в район работ на севере Баренцева моря и выбора подходящего ледяного поля в течение трех дней на льдине был развернут лагерь, с которого были начаты плановые исследования по метеорологии, гидрологии, гидрохимии, гидробиологии, геологии и геофизике, а также выполнялся обширный комплекс ледовых измерений. Одновременно с борта судна проводились регулярные гидрологические зондирования с пробоотбором на гидрохимические анализы, отбор проб на загрязнение радионуклидами, озонометрические измерения, проводился мониторинг ледовых нагрузок на корпус судна.

В дополнение к 194 гидрологическим зондированиям с борта судна и с дрейфующего льда за время дрейфа было выполнено 59 гидрологических зондирований на выносных океанографических разрезах, ориентированных перпендикулярно континентальному склону, в радиусе до 300 км с доставкой людей и оборудования вертолетом Ка-32. После окончательного завершения работ на льду 4 мая судно направилось в северо-восточную часть Баренцева моря, где было выполнено шесть гидрологических разрезов, часть из которых в точках повторяющихся исторических разрезов.

Важнейшим результатом экспедиции стала практическая реализация мультидисциплинарных наблюдений со льда с оперативной передачей получаемой информации на судно и в приемные центры на берегу. Во время экспедиции были отработаны конкретные процедуры по эффективной организации наблюдений на дрейфующей станции нового типа «судно – лед», которые будут учтены при строительстве, оборудовании и эксплуатации ледостойкой самодвижущейся платформы (ЛСП) «Северный полюс».

Экспедиционные исследования, осуществленные в марте–мае 2019 г., внесли значительный вклад в изучение роли трансформации атлантических вод на материковом склоне и примыкающей глубоководной части Арктического бассейна в изменившихся климатических условиях, а также в исследование механизмов формирования уплотненных шельфовых вод в Баренцевом море и их вклада в процессы обновления водных масс. Была получена комплексная информации о состоянии природной системы в Баренцевом море, включая континентальный склон на северной границе моря и Арктического бассейна СЛО.

В ходе экспедиции удалось выполнить широкий круг задач. Полученные данные представляют собой уникальный материал для всестороннего исследования текущего состояния природных условий арктических морей СЛО. Собранные данные позволяют получить более надежные оценки пространственно-временной изменчивости основных элементов гидрометеорологического режима, более глубоко изучить механизмы формирования водных масс, их влияние на изменения климата высоких широт и способствовать решению задач комплексного освоения Арктики.

Первый этап экспедиции «Трансарктика-2019» явился логическим продолжением экспедиций на дрейфующих станциях «Северный полюс» в современных условиях сокращающегося ледяного покрова. Выполнение программы экспедиции позволило опробовать новые технологии организации и проведения современных комплексных научных исследований, в том числе в аспекте обеспечения безопасности проведения работ, внутри-, межведомственного и международного взаимодействия, необходимые для подготовки и начала эксплуатации ЛСП. В предлагаемой статье обозначены наиболее значимые предварительные результаты выполненных наблюдений в различных средах, которые в дальнейшем будут всесторонне проанализированы и опубликованы в отдельных тематических статьях.