Annual report on GEOTRACES activities in Russia

May 1st, 2021 to April 30th, 2022

New GEOTRACES or GEOTRACES relevant scientific results

Arctic Ocean

- In recent years, cryoconite has received growing attention from a radioecological point of view, since several studies have shown that this material is extremely efficient in accumulating natural and anthropogenic radionuclides. The Novaya Zemlya Archipelago (Russian Arctic) hosts the second largest glacial system in the Arctic. From 1957 to 1962, numerous atmospheric nuclear explosions were conducted at Novaya Zemlya, but to date, very little is known about the radioecology of its ice cap. Analysis of radionuclides and other chemical elements in cryoconite holes on Nalli Glacier reveals the presence of two main zones at different altitudes that present different radiological features. The first zone is 130–210 m above sea level (a.s.l.), has low radioactivity, high concentrations of lithophile elements and a chalcophile content close to that of upper continental crust clarkes. The second zone (220–370 m a.s.l.) is characterized by high activity levels of radionuclides and "inversion" of geochemical behavior with lower concentrations of lithophiles and higher chalcophiles. In the upper part of this zone (350–370 m a.s.l.), ^{137}Cs activity reaches the record levels for Arctic cryoconite (5700–8100 Bq/kg). High levels of Sn, Sb, Bi and Ag, significantly exceeding those of upper continental crust clarkes, also appear here. We suggest that a buried layer of contaminated ice that formed during atmospheric nuclear tests serves as a local secondary source of radionuclide contamination. Its melting is responsible for the formation of this zone (Miroshnikov et al., 2022).

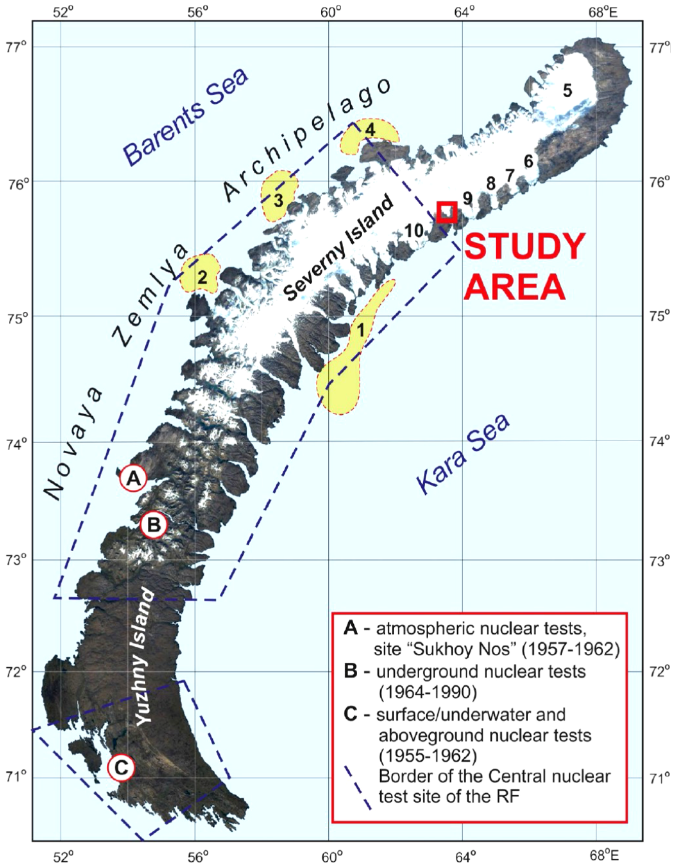

Figure 1. Location of the sampling site on Nalli Glacier (red box). Zones of high ^{137}Cs activity in bottom sediments: 1–4 (Miroshnikov et al., 2022).
Glaciers: 5 – northern icecap; 6 – Roze, 7 – Sredny, 8 – Rozhdestvensky, 9 – Vershinsky, and 10 – Moshchny.

- In high latitude regions, thawing of snow provides a sizable contribution of dissolved trace metals to the hydrological network. Towards a better understanding of natural and anthropogenic control on heavy metals and metalloid input from the atmosphere to the inland waters of Siberian Arctic and subarctic regions, the chemical composition of dissolved (<0.22 µm) fractions of snow across a 2800 km south–north gradient in Western Siberia was measured (Figure 2) (Krickov et al., 2022). Fe, Mn, Co, Ni, and Cd demonstrated sizable (by a factor of 4–7) decrease in concentration northward, which can be explained by a decrease in overall population density and the influence of dry aerosol deposition. Many elements (Mn, Ni, Cu, Cd, Pb, As, and Sb) exhibited a prominent local maximum (a factor of 2–3) in the zone of intensive oil and gas extraction (61–62° N latitudinal belt), which can be linked to gas flaring and fly ash deposition. Overall, the snow water chemical composition reflected both local and global (long-range) atmospheric transfer processes. Based on mass balance calculation, we demonstrate that the winter time atmospheric input represents sizable contribution to the riverine export fluxes of dissolved (<0.45 µm) Mn, Co, Zn, Cd, Pb, and Sb during springtime and can appreciably shape the hydrochemical composition of the Ob River main stem and tributaries.

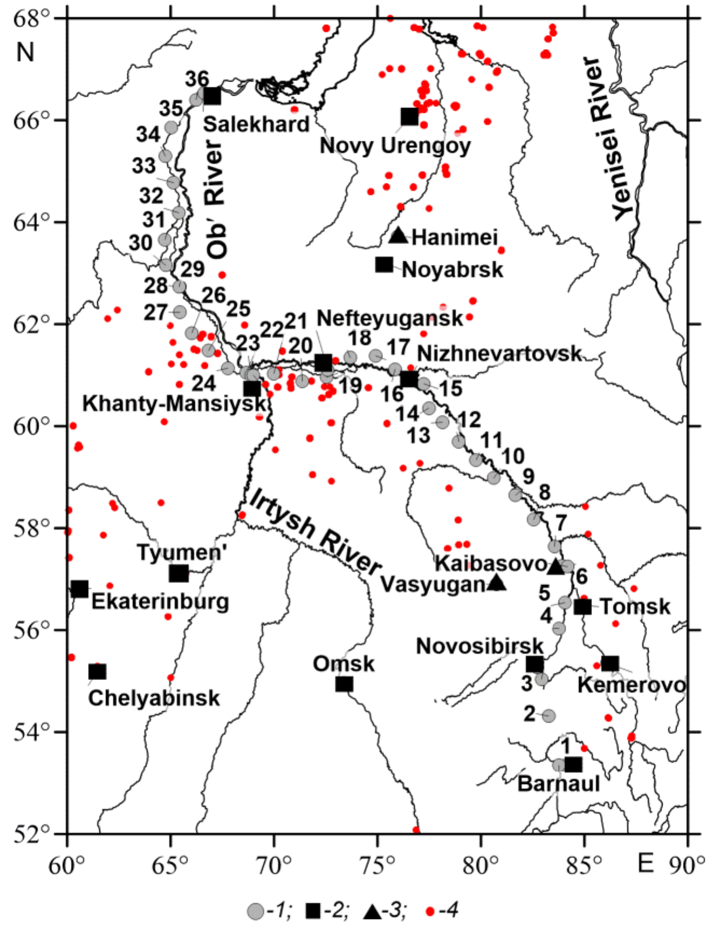

Figure 2. Studied area of the Western Siberian Lowland (Krickov et al., 2022): 1 – sampling sites; 2 – large cities; 3 – scientific stations of Tomsk State University; 4 – the position of gas flaring on 25 July 2020 taken from: https://firms.modaps.eosdis.nasa.gov/download/accessed

- The first-order principles of seep carbonate formation are currently quite well constrained, little is known regarding the duration or mode of carbonate formation in the Siberian Arctic shelf. Currently available data on carbonate formation in the Siberian Arctic seas have reported that the methane-derived carbonates (MDACs) can form in recent sub-surface sediments but cannot form pavements or large carbonate slabs at the sediment/water interface. Newly discovered crusts of methane-derived authigenic carbonate deposits were observed on the seafloor and sampled at the cold seep field with an area of approximately 13 km² on the outer shelf of the Laptev Sea (Kravchishina et al., 2021). Seafloor observations indicated evidence of gas flares, and microbial colonies were recorded in the southern area, suggesting that the seep field is currently active. The retrieved carbonates are the result of paleo-methane seepage. The crusts containing fingerprints of gas mixtures could be the result of the physical mixing of different methane pools in response to the vertical and lateral diffusion of gas. This mixing involves admixtures of thermogenic and microbial gases as well as an admixture of bicarbonate from seawater. Therefore, both thermogenic methane and microbial methane participated in the carbonate precipitation. Methane cold seepage is related to deep-seated faults belonging to the Laptev Sea Rift System and the Khatanga-Lomonosov Fracture Zone. A similar origin of methane seepage has been reported in sediment deposits within Arctic seas at 72°–79° N. The methane seepage could have been controlled by the last deglaciation that triggered changes in the fault system and favored gas migration from offshore hydrocarbon reservoir.

- The ecosystems of the Arctic Ocean and their expected changes in a context of Global climate processes are crucially dependent on the freshwater input. The freshwater signal is assumed to be the main structuring factor for the marine fauna on the shallow shelf of the Siberian Arctic seas. The Laptev Sea is a key area for understanding the land–ocean interaction in high latitude regions. The largest freshwater input is provided by the deltaic Lena River followed by the estuarine Khatanga River. The plumes of these rivers differ considerably in their hydrophysical characteristics, suggesting differential impacts on ecosystems of the adjacent shelf. The key component of pelagic ecosystems is zooplankton, which transfers energy from primary producers to higher trophic levels and modifies sedimentations processes. This study is focused on the influence of river discharge on zooplankton in the Laptev Sea at the end of productive season in August–September 2017. Despite large spatial extension of the Khatanga plume, the impact of river discharge on zooplankton species composition was restricted mainly to the inner Gulf where the brackish species shaped the community. Contrary to the Khatanga input, the Lena freshwater inflow was highly variable and under certain conditions (discharge rate, wind forcing) governed the structure of zooplankton community over a vast shelf area. Analysis of demographic structure of *Calanus glacialis* suggests that seasonal development of the population was largely controlled by the time of ice retreat. Observed climatic changes in the Arctic were not reflected in the total zooplankton biomass and composition of the dominant species (Pasternak et al., 2022).

- The important information on the impact of a riverine discharge and time of ice retreat on the magnitude and biogeochemical composition of the vertical particle fluxes on the Laptev Sea shelf was provided in the paper by Drits et al. (2021). The effect of the river discharge was manifested by the increase of the total particle flux dominated by the lithogenic component and a higher share of lithogenic organic carbon in the total particulate organic carbon flux than outside the river plume (Figure 3). A high share of freshwater phytoplankton species in the trapped material indicated that phytoplankton was transported onto the shelf by the river plume and subsequently exported to the underlying water column. The most pronounced influence of the freshwater discharge was observed close to the river mouth and the plume signature decreased progressively towards its periphery. The large contribution of the lithogenic matter to the vertical particle flux on the Laptev Sea shelf is suggested to result not only from the riverine discharge but also from sediment resuspension, lateral offshore transport of sediment just above the seabed, and coastal abrasion. The timing of ice cover retreat appears crucial in determining the patterns of vertical particle export, with the higher fluxes observed soon after the sea ice break up. The ice-released matter and phytoplankton bloom in the marginal ice zone are expected to contribute to the increase of the particle flux. The timing of ice retreat determined also the biogenic carbon composition. The observed changes in the vertical flux magnitude and composition which result from different time of ice retreat are similar to seasonal succession in the pelagic communities.

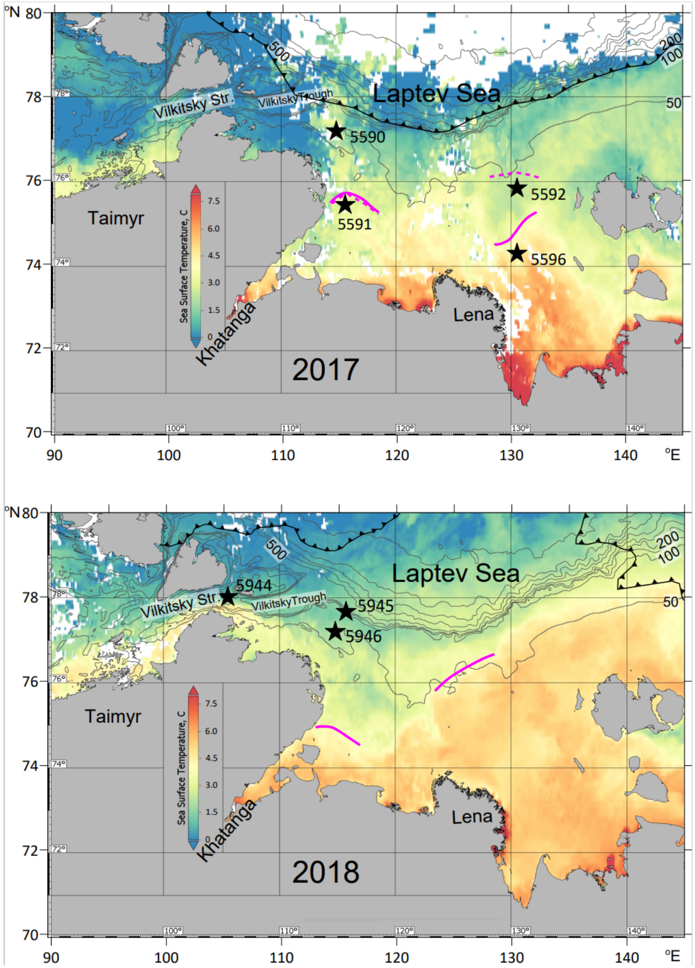

Figure 3. Map of the study area with location of the stations (Drits et al., 2021). Sea surface temperature (°C) distribution: average for 29 August – 6 September 2017 (MODIS-Aqua_L3_SST_8d_4km vR2019.0) (Berrick et al., 2009). Bold lines show the position of the ice edge (http://www.aari.ru). Magenta lines indicate river plume extension (isohaline of 25): solid line – at the time of first sampling (31.08–3.09. 2017), dashed line - at the time of the repeated sampling (14.09-20.09.2017). Contour depths in meters. When sampling was repeated, the Lena plume considerably extended to the north, while Khatanga plume remained at the same position.

- Spring processes in phytoplankton communities in the Arctic shelf seas, when the primary production is increased up to 50% of the annual bulk value, are extremely poorly studied. The hotspots of huge primary production in the northern Eurasian seas are correlated with regional climatic changes, a significant reduction of sea ice cover, a decrease in ice thickness, and a prolonged period of open water (Sergeeva et al., in prep.). Early spring communities are formed by a few species of diatoms. These species massively form resting spores which settle down to the upper sediment layer under the biogenic depletion and lack of light. The species composition and abundance of diatoms resting spores in the sediment surface layer can correlate with the intensity and composition of spring blooms. The aim was to study the composition and intensity of the early spring sea ice-associated phytoplankton bloom in the Kara Sea areas affected and not affected by Atlantic waters. The planktonic diatoms viable spores from the upper sediment layer were studied in 2020 and 2021. The results of two-year variability in the number and composition of viable spores demonstrate the relationship with sea ice conditions. On the continental slope (ice melting in May) with pronounced influence of warm waters of Atlantic origin the diatom taxa is more diverse, and prevail species: *Thalassiosira constricta*, *Thalassiosira oceanica*, and *Detonula confervacea*. On the shelf (ice melting in mid-June) the species of *Navicula pelagica* and *Thalassiosira constricta* are predominate. The dense sea ice on the shelf during a winter leads to *Chaetoceros socialis* predominate, what can form massive blooms associated with spring melting of sea ice.

- The relationship between the composition of the microbial community and the processes of methane and sulfur cycling was established in the northern Barents Sea (Begmatov et al., 2021). The data revealed differences between microbial communities and processes in the upper and deep layers of sediments, probably reflecting oxic versus anoxic conditions (Figure

4). The upper layer was dominated by autotrophic ammonium-oxidizing *Crenarchaeota* and various groups of typical aquatic aerobic heterotrophic bacteria of the phyla *Actinobacteria, Proteobacteria, Verrucomicrobia,* and *Bacteroidetes* fed by falling organics. In the deep sediments, the sulfur and nitrogen cycles seemed to be linked. Nitrate formed as a result of ammonia oxidation is utilized by *Campilobacterota*, which oxidize sulfide formed by sulfate reducers back to sulfate. Nitrate, in turn, is reduced to gaseous nitrogen, and possibly to ammonia. Methane arriving from sediment layers located below the sulfate-rich zone is oxidized by ANME archaea in the anoxic zone in a process coupled to sulfate reduction and denitrification, or by aerobic methanotropic bacteria in the upper oxygenated layer. Methane concentrations and rates of microbial biogeochemical processes in sediments in the northern Barents Sea are noticeably higher than in oligotrophic areas of the Arctic Ocean, indicating that an increase in methane concentration significantly activates microbial processes in sediments.

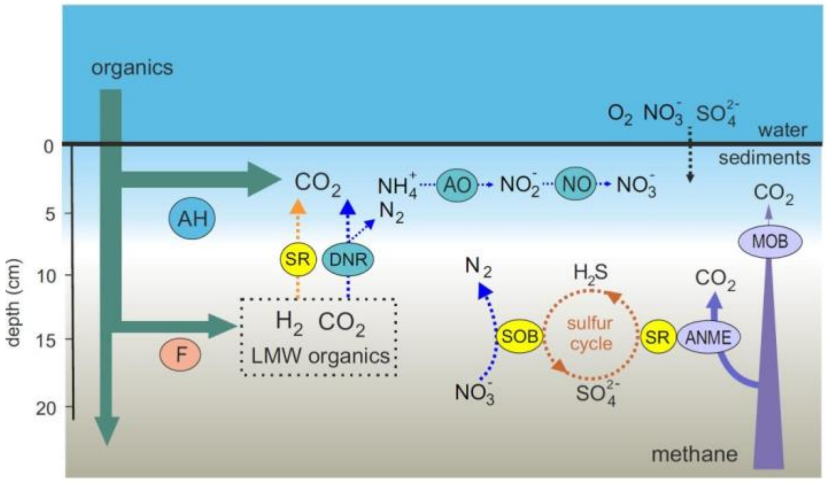

Figure 4. Microbial processes related to methane, sulfur and nitrogen cycling in the Barents Sea sediments. AH, aerobic heterotrophs; F, fermentative microorganisms; SOB, sulfur-oxidizing bacteria; SR, sulfate-reducing bacteria; ANME, anaerobic methane oxidizing archaea; MOB, aerobic methane-oxidizing bacteria; AO, ammonia oxidizing microorganisms; NO, nitrite-oxidizing microorganisms; DNR, dissimilatory nitrate reducers; LMW, low molecular weight (Begmatov et al., 2021).

- The Yamal tundra lakes (Yamal Peninsula, Kara Sea, Arctic) were found to exhibit high phytoplankton production (340–1200 mg Cm^{-2} d^{-1}) during the short summer season (Savvichev et al., 2021). The research was carried out in four lakes in August 2019. Organic matter was deposited onto the bottom sediments, where methane (33–990 µmol CH_4 dm^{-3}) was the main product of anaerobic degradation. The rates of hydrogenotrophic methanogenesis appeared to be higher in the sediments of the deep lakes than in those of the shallow ones. In the sediments, *Methanoregula* and *Methanosaeta* were predominant in the archaeal methanogenic community. Methane oxidation (1.4–9.9 µmol dm^{-3} d^{-1}) occurred in the upper sediment layers simultaneously with methanogenesis. *Methylobacter tundripaludum* (family *Methylococcaceae*) predominated in the methanotrophic community of sediments and water column. The activity of methanotrophic bacteria in deep mature lakes resulted in a decrease in the dissolved methane concentration in lake water from 0.8–4.1 to 0.4 µmol CH_4 L^{-1} d^{-1}, while in shallow thermokarst lakes the geochemical effect of methanotrophs was much less pronounced (Figure 5). Thus, only small, shallow Yamal lakes may contribute significantly to the overall diffusive methane emissions from the water surface during the summer season. The water column of large, deep lakes on Yamal acts, however, as a microbial filter preventing methane emission. Climate warming will lead to an increase in the total area of thermokarst lakes, which will enhance the effect of methane release into the atmosphere.

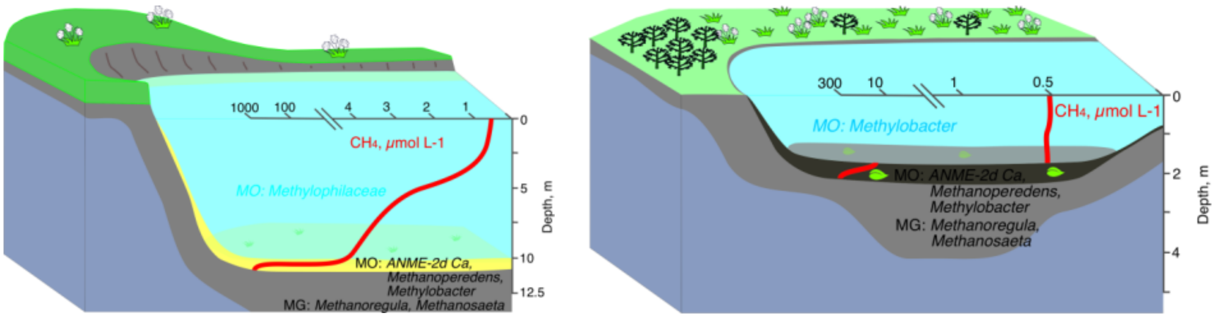

Figure 5. Microbial processes and microbial communities of the methane cycle in the water columns and bottom sediments of deep (a) and shallow tundra lakes (b) of the Yamal Peninsula (Savvichev et al., 2021).

- Relationship between long-term variability of sea ice cover in the Barents Sea with changes in current velocity and surface temperature in the North Atlantic was revealed (Krasheninnikova et al., 2022).

- The study of aliphatic (AHCs) and polycyclic aromatic hydrocarbons (PAHs) of bottom sediments was carried out in the Norwegian and Barents seas. The anthropogenic input of HCs into bottom sediments leads to an increase in their content in the composition of C_{org}. The fluids influence on the Svalbard shelf and in the Medvezhinsky Trench determines the specificity of local anomalies in the content and composition of HCs. This is reflected in the absence of a correlation between HCs and the grain size composition of sediments and C_{org} content as well as a change in hydrocarbon molecular markers. The bottom sediments are enriched in light alkanes and naphthalenes due to discharge of gas fluids (Nemirovskaya, Khramtsova, 2021).

Atlantic Ocean

- To clarify one more mechanism of the Fe, Mn, Cu, Zn, and Pb accumulation in the biogenic foraminiferal-coccolite sediments, the metalliferous sediment core 184k was taken at the hydrothermal vent cluster Pobeda (17° N, Mid-Atlantic Ridge), and the background core 215k of carbonate sediments from the Central Atlantic were examined (Demina et al., 2022). In metalliferous sediment core the main Fe mineral phase was goethite FeOOH (37–44% on a carbonate-free basis, cfb). Rather small quantities (≤ 10–12%) of talc, serpentine, quartz whose total amounts increased down the core reaching up to 50% (cfb). Down the 184k core, the calcite $CaCO_3$ content decreases sharply from 77% to 20% which was obviously due to its substitution with authigenic goethite, on the one side, and an increase in the number of modified ultrabasite fragments, on the other side. The metal enrichment factor (EF) in 184k core relative to background values reached up to 125 for Cu, while for Mn, no increased EF was recorded. The Fe total content (cfb) increased down the 184k core and reached maximum 41% (on a carbonate-free basis, cfb) in the deep layers, wherein the elevated concentrations of the rest metals were recorded, an observation that might be attributed to influence of hydrothermal diffused fluids. Essential mass of Fe (up to 70% of total content) was found in the residual fraction composed of crystallized goethite, aluminosilicates. Among geochemically mobile fractions, 90–97% of total Fe was determined in the form of authigenic oxyhydroxides. The same fraction was the predominant host for Mn in both metalliferous and background sediments (55–85%). In sum, 40–96 % of Cd, Cu, Zn, and Pb were associated with the Fe-Mn oxyhydroxides. A substitution of Ca in foraminiferal tests with the Fe oxy-hydroxides, might serve one of the mechanisms of the ore metals, primarily Fe, accumulation in the biogenic carbonate sediments at the hydrothermal vent field.

• Vertical particle fluxes at hydrothermal vent fields of the southernmost Mohns Ridge (Arctic Mid-Ocean Ridge) are discussed in Klyuvitkin et al. (2021). Sediment traps were deployed at the Trollveggen and Soria Moria hydrothermal vent fields in June 2019. The particles were deposited in the near bottom layer under a dominant northeastern water flow. Numerous short-period positive temperature anomalies up to 0.86 °C were registered in the study area. The values of particle fluxes in the near bottom layer are much lower than at the hydrothermal vent fields of the Mid-Atlantic Ridge. A significant amount of hydrothermal minerals (barite, sulfides, etc.) were detected in trapped material of the near bottom layer.

GEOTRACES or GEOTRACES relevant cruises

• The 84th cruise of the RV *Akademik Mstislav Keldysh* was carried out in the western Eurasian Arctic from July 24 to August 26, 2021 (Figure 6). Dr. Marina Kravchishina and Dr. Alexey Klyuvitkin are the cruise leaders, Shirshov Institute of Oceanology, Russian Academy of Sciences. The research of processes of paleo and modern sedimentation and reconstructions of past climate conditions were carried out in the regions where cold Polar and warm Atlantic water masses are contacted, and in the areas under the influence of cold (seep) and hot (hydrothermal) fluids in the western Eurasian Arctic. The consequences of atlantification are ‘recorded’ in all components of the ecosystems of the studied area, as well as the reverse effect of the Arctic amplification on the ecosystems of the Northern North Atlantic, occurring both at the present days and in the Pleistocene–Holocene (Kravchishina et al., 2022).

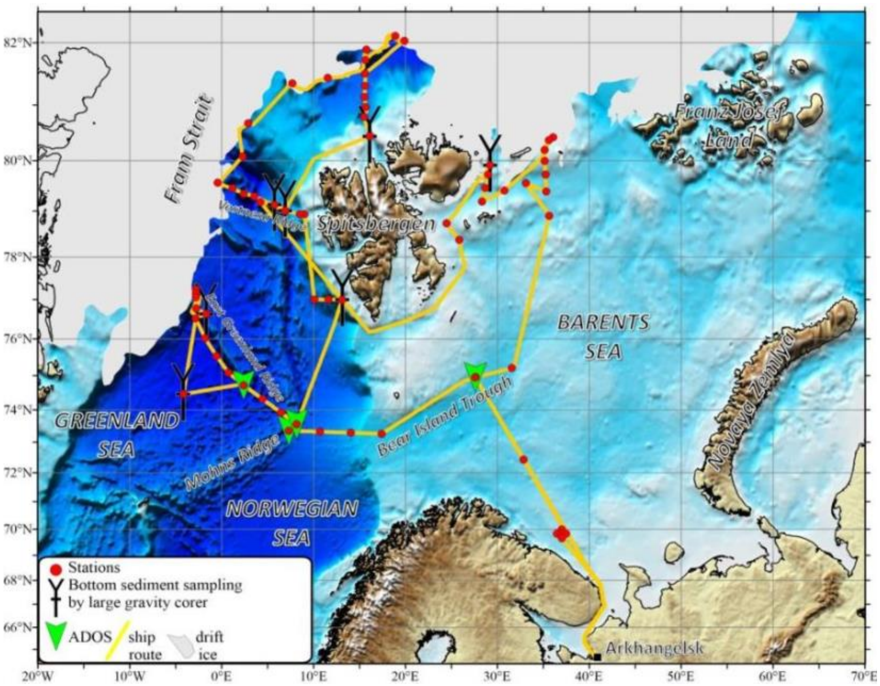

Figure 6. The map of the route and sampling stations carried out in the cruise in July–August 2021. An analysis of the Arctic sea ice for the sampling area was carried out according to https://cryo.met.no/

New projects and/or funding

• The grant of the Ministry of Science and Higher Education of the Russian Federation (grant no. 075-15-2021-934) “Study of anthropogenic and natural factors of changes in the composition of air and environmental objects in Siberia and the Russian sector of the Arctic in conditions of rapid climate change using unique scientific facility “Airplane Lab *Tu-134 Optic*”, 2021–2023. Dr. Boris Belan is a project leader, V.E. Zuev Institute of Atmospheric Optics of Siberian Branch of the Russian Academy of Science, Tomsk.

- The project of the Russian Science Foundation (no. 21-77-10064) "Variability of the composition of dissolved organic matter in the Arctic shelf seas of Russia according to long-term observations of the optical properties of sea water", 2021–2023. Dr. Anastasia Drozdova is a project leader, early career researcher, Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow.
- The project of the Russian Science Foundation (no. 21-17-00235) "Natural Events of the Late Holocene (neoglaciation) in the subpolar North Atlantic and seas of northern Eurasian as reflection on global climate variability", 2021–2023. Dr. Alexander Matul is a project leader, Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow.

New GEOTRACES or GEOTRACES-relevant publications (published or in press) *(Please identify those publications acknowledging SCOR funding and for these publications include the number of PhD or postdoc students involved, if possible)*

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  2 PhD students involved.
- Sakerin, S.M., Kabanov, D.M., Kopeikin, V.M., Kruglinsky, I.A., Novigatsky, A.N., Pol'kin, V.V., Shevchenko, V.P., and Turchinovich, Y.S. (2021). Spatial distribution of black carbon concentrations in the atmosphere of the North Atlantic and the European sector of the Arctic ocean. *Atmosphere*, *12*(8). https://doi.org/10.3390/atmos12080949

  1 PhD student involved.
- Savvichev A., Rusanov I., Dvornikov Y., Kadnikov V., Kallistova A., Veslopolova E., Chetverova A., Leibman M., Sigalevich P., Pimenov N., Ravin N., Khomutov A. (2021). The water column of the Yamal tundra lakes as a microbial filter preventing methane emission. *Biogeosciences*, *18*(9), 2791–2807. https://doi.org/10.5194/bg-18-2791-2021

Completed GEOTRACES PhD or Master theses (please include the URL link to the pdf file of the thesis, if available)

- Svetlana Krasheninnikova completed PhD thesis at A.O. Kovalevsky Institute of Biology of the Southern Seas of Russian Academy of Sciences. Krasheninnikova S. revealed correlation between temperature and velosity of surface currents in the North Atlantic and reduction of sea ice cover in European Arctic, using the oceanic reanalysis ORA-S4 and data from 1958 to 2014 (Krasheninnikova et al., 2022). The correlation coefficient between mean annual temperature of water in the Barents Sea with the temperature and velocity of the Gulf Stream current is 0.9 and 0.8, respectively. The correlation between water temperature of the Barents Sea and the velocity of the current northwest of Spitsbergen is –0.7. Current velocity in the area of northern border of the Gulf Stream and the South Equatorial Current, temperature in the Gulf Stream and the Barents Sea have positive trends in interannual variability, and the velocity in the Transpolar Drift Stream and the sea ice extent of the Barents Sea are negative.

GEOTRACES presentations in international conferences

- 27^{th} International Symposium on Atmospheric and Ocean Optics, Atmospheric Physics, 15 December 2021:

  Turchinovich Y.S., Kopeikin V.M., Novigatsky A.N., Pol'kin V.V., Sakerin S.M., Shevchenko V.P., Shmargunov V.P. Comparison of measurements of black carbon concentrations in aerosols, using two aethalometry methods. *Proceedings of SPIE.* V. 11916. doi:10.1117/12.2600593.

  Sakerin S.M., Kabanov D.M., Kopeikin V.M., Kruglinsky I.A., Novigatsky A.N., Pol'kin V.V., Shevchenko V.P., Turchinovich Y.S. Variations in black carbon concentrations in European sector of the Arctic Ocean and seas of the North Atlantic. *Proceedings of SPIE.* V. 11916. doi:10.1117/12.2601518.

  Sakerin S.M., Kabanov D.M., Kruglinsky I.A., Novigatsky A.N., Pol'kin V.V., Pochufarov A.O., Shevchenko V.P., Turchinovich Y.S. Measurements of aerosol characteristics in three expeditions on board RV *Akademik Msticlav Keldysh*: from the Baltic to Barents Sea. *Proceedings of SPIE*. V. 11916. doi:10.1117/12.2601743.

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