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Cruise 54th of the Research Vessel *Akademik Mstislav Keldysh* in the Kara Sea

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The modern state of the Arctic Basin and the variability of this basin are determined to a great extent by the processes on the shelf and continental slope of the Arctic marginal seas. Annually, the volume of 5000 km^3 of the rivers' runoff is transported to the shelf and continental slope. The rivers' runoff determines the significant freshening of the Arctic surface waters. It influences the formation of the seasonal stratification and the circulation pattern in the upper layer of the continental seas. The runoff of the rivers transports enormous volumes of allochtonous nutrients, suspended mineral and organic substances, and pollutions into the Arctic region. Water of high salinity are formed over the arctic shelf in the autumnal–winter season, which is transported to the central Arctic basin and participate in the formation of the main pycnocline-halocline. The volume and form of the allochtonous material transported to the deep Arctic Basin by the runoff of the rivers depends on the processes of it geochemical and biological transformation in the estuaries of the rivers and on the shelf, as well as on the character of the shelf circulation. It determines the direction and velocity of the spreading of the riverine water and the time of their residence in the continental sea; thus, it determines the influence of the climatic and anthropogenic signals contained in the runoff of the rivers over the Arctic Basin. The Arctic shelf and the continental slope are the places where the greatest proportion of the primary and secondary production of the Arctic ecosystem is formed in the pelagic and bottom communities. All the aforesaid determine the importance of the processes in the marginal Arctic seas for the Arctic ecosystem as a whole.

The Kara Sea is a boundary basin between the western and eastern parts of the Russian Arctic. It is a crucial transit region for the spreading of the relatively warm Barents and Atlantic waters in the eastern and northeastern directions. On the other hand, according to its climatic conditions, the Kara Sea is a typical marginal Arctic Siberian sea, and many processes occurring on the shelf of the Kara Sea can be considered characteristic of the vast region located east of Novaya Zemlya.

The key role of the Kara Sea in the Arctic ecosystem is in the fact that it accepts the greatest freshwater runoff of the rivers in the entire Arctic Basin. Its annual volume reaches 1200–1300 km^3/yr, 90% of which is the runoff of the Ob and Yenisei rivers. The river runoff into the Kara Sea is more than half of the entire runoff of the Siberian Arctic and more than one-third of the total freshwater runoff into the Arctic Basin. It corresponds to more than a one and a half meter layer of freshwater relative to the entire area of the Kara Sea basin, which is almost five times greater than the total amount relative to the Arctic Ocean and 15 times greater than the amount relative to the World Ocean on the average. According to the available data, the annual freshwater volume needed for the formation of the salinity field characteristic of the Kara Sea is on the average equal to 4200 km^3, which is 3.5 times greater than the annual continental runoff into the basin. Thus, the residence time of the freshwater transported into the Kara Sea with the runoff of a specific year can be extended over a few years. All these facts provide evidence about the strong influence of the continental runoff on the ecosystem of the Kara Sea and indicate the key role of the Kara Sea shelf ecosystem as an interface in the long-term transformation of the runoff before its further transport into the other shelf and deep regions of the Arctic Basin. The watershed of the Ob and Yenisei rivers is enormous. It is 6 300 000 km^2 (4.2% of the total land area of the earth). It covers the most developed industrial regions of Western Siberia, which determines the possible anthropogenic components in the runoff of these rivers.

The influence of the continental runoff and the shelf processes on the deep region of the Arctic Basin, as well as the impact of the adjacent Arctic regions on the ecosystem of the Kara Sea, is determined by the cross shelf transport processes and the cross shelf zonality existing in the region. The latitudinal zonality of the ecosystem from the estuaries of the Ob and Yenisei

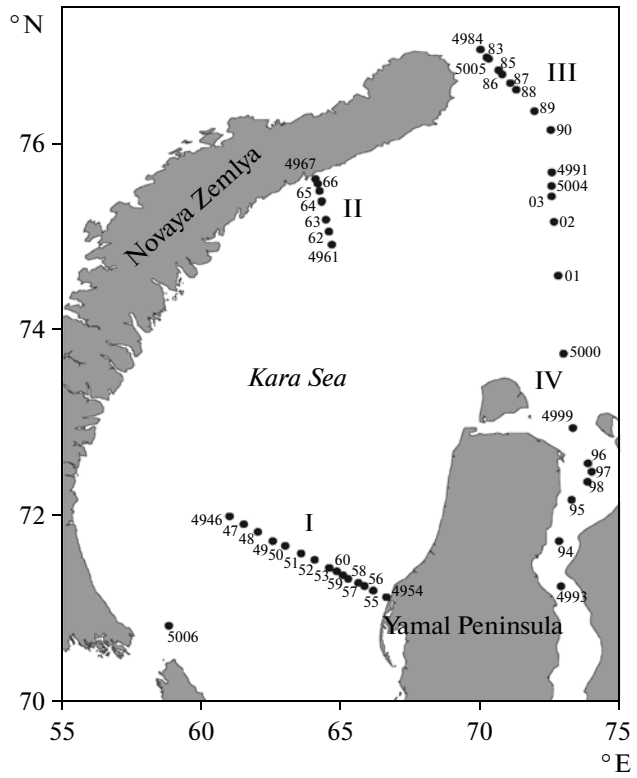

Fig. 1. Locations of the main sections and multidisciplinary stations. (I) Yamal section; (II) Novaya Zemlya section; (III) section in the St. Anna Trough; (IV) the Ob section.

rivers to the deep regions of the basin plays a key role in the formation of the hydrophysical and hydrochemical properties of the individual regions of the basin, the biotope boundaries, the maintenance of the hydrochemical and biogeochemical balance, the formation of the biological production, and the control of the horizontal and vertical fluxes of matter.

The hydrological frontal zones and the associated chemical, geochemical, and biological phenomena in the pelagic area and on the bottom are the most pronounced elements of the existing zonality. By the present time, the only investigated type of the frontal zones in the Kara Sea are the frontal zones in the estuaries of the Ob and Yenisei rivers [1–5, 7]. They are related to the marginal filter phenomenon. These frontal zones are extremely important for the processes of the primary transformation of the runoff of the rivers into the sea. The hydrophysical processes, which are the basis of the marginal filter and control its spatial parameters and variability, as well as the mechanisms determining the specific properties of the pelagic ecosystem in the frontal region, are not all understood completely.

In addition to the estuary frontal zone, we supposed that other fronts exist over the shelf and continental slope in the northern part of the Kara Sea related to the main currents and the spreading of the runoff of the rivers that have not been studied so far. The currents of the Kara Sea are topographically controlled due to their quasi-barotropic structure; their cores are localized in the regions with sharp depth changes. Thus, the peculiarities of the bottom topography strongly influence the circulation, the hydrological structure, the frontogenesis, and the water exchange within the basin and with the neighboring basins. The sharpest depth changes in the basin are related to the transition from the inner to the outer shelf (from 50 to 100 m) and with the continental slope. The core of the Yamal Current (flowing from the Kara Gates to the northeast over the shelf) and the core of the St. Anna Trough Current displaced to the slope of the trough are located in these regions.

The fronts not only divide the water masses with different properties but also limit their mixing and the horizontal matter fluxes. They are frequently the boundaries and regions of the interaction between communities and ecosystems that differ by their composition and functional properties, as well as zones of increased concentrations and productivity of different biota components. While planning the field research, we planned to investigate the possible frontal zones in greater detail to provide an understanding of their role in the formation of the cross shelf zonality of the Kara Sea's ecosystem and to estimate their possible influence on the interaction processes in the estuary–shelf–continental slope–deep basin system and on the formation of the biological production.

The cruise to the Kara Sea lasted from September 5 to October 7, 2007. It is worth emphasizing that the research was carried out during an anomalously warm year in the Arctic. The area of the ice cover during the northernmost location of the ice edge was the minimum for the past 30 years; its area was 5.32 mln km^2, which is 31% less than the average value related to the preceding 30-year period. In the first half of October, the ice boundary at the longitude of the northern end of Novaya Zemlya (Cape Zhelaniya) was 370 km northward and, in the central part of the sea, it was 930 km northward of the long-term mean position for this time over the period from 1979 to 2000 [6]. The R/V *Akademik Mstislav Keldysh* passed trough the Kara Gates Strait on September 9 and did not meet even traces of ice. Judging from the satellite data, small ice fields were observed in the first half of September to the north-northeast of the Kara Gates. This was also supported by a significant local temperature and salinity decrease, which we noticed in the surface layer of the sea in this region. The sea was free of ice over the entire route of the ship up to its northernmost point 76°55′N, 70°16′E. Only small icebergs were observed, which had separated from the coastal glaciers of Novaya Zemlya. Thus, the research that we carried out characterized the Kara Sea ecosystem's state under the warm climate conditions.

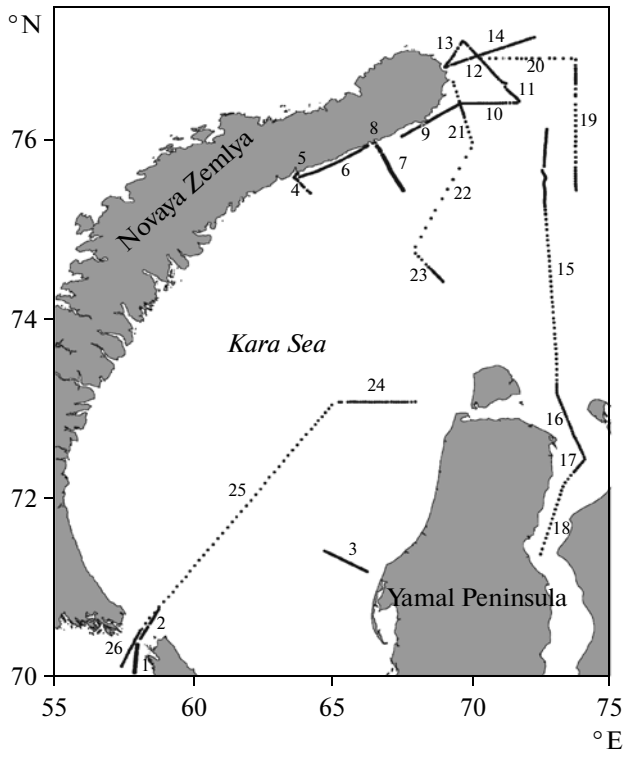

Fig. 2. Sections performed with the scanning CTD profiler.

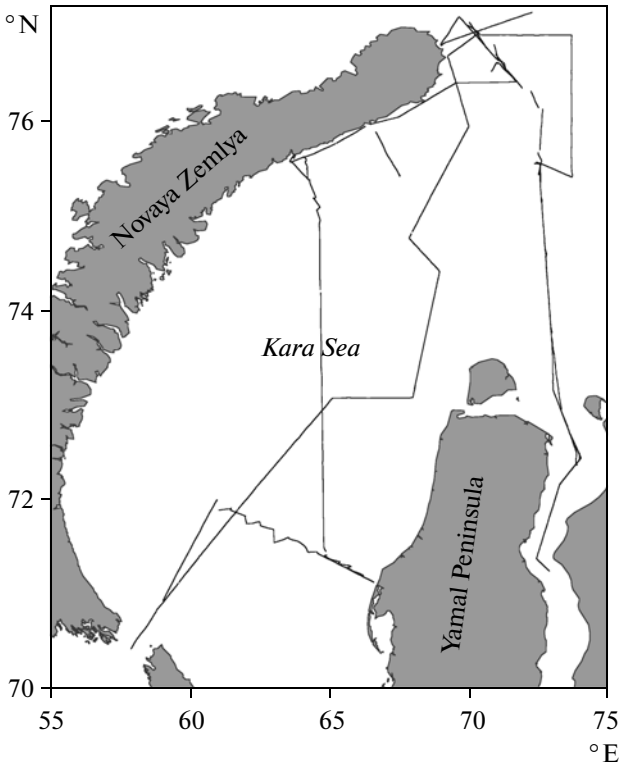

Fig. 3. The route with continuous measurements of the temperature, salinity, fluorescence, chlorophyll, and organic matter in the surface layer of the sea.

All the aforesaid determined the main objectives of the expedition studies, which included the following:

(1) estimating the present state of the key abiotic and biotic components of the Kara Sea ecosystem; the peculiarities of the circulation within the basin; the hydrochemical and geochemical processes in the water column and at the bottom, including those related to the transformation of the river runoff; and the investigation of the structure of the pelagic and bottom communities and the process of formation of the biological production;

(2) estimating the mechanisms of the matter transport in the river estuary–shelf–continental slope–deep basin system and the role of the frontal processes in the formation of the cross shelf zonality in the structure of the Kara Sea ecosystem and the distribution of the properties of the environment and biota, as well as the evaluation of the mechanisms determining the influence of the processes in the Kara Sea on the ecosystem of the deep Arctic Basin.

The locations of the stations with multidisciplinary observations and hydrophysical sections are shown in

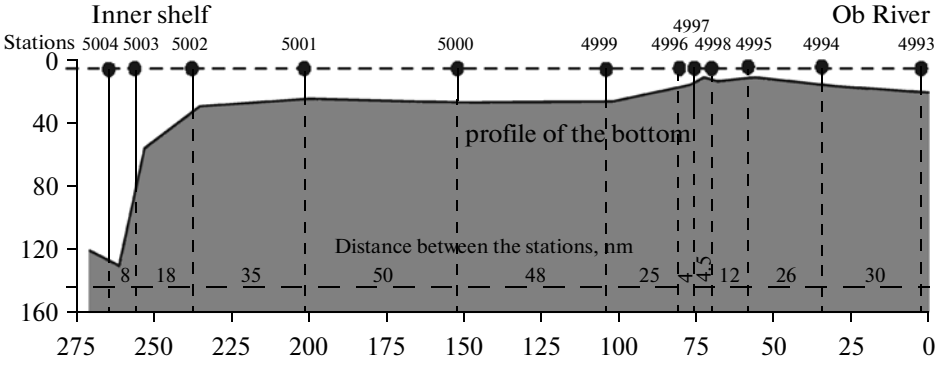

Fig. 4. Location of the stations and the profile of the bottom for section IV in the Ob estuary.

List of stations performed during cruise 54 of R/V "Akademik Mstislav Keldysh"

Number of the station	Coordinates at the beginning of the stations						
	date	time	latitude		longitude		depth, m
Yamal section							
4946	09.09.07	17:00	72°	0′.0	61°	0′.0	153
4947	09.09.07	22:05	71°	54′.9	61°	30′.9	153
4948	10.09.07	0:21	71°	49′.9	62°	1′.2	140
4949	10.09.07	4:35	71°	45′.2	62°	33′.0	128
4950	10.09.07	6:25	71°	40′.9	63°	0′.3	118
4951	10.09.07	12:40	71°	36′.0	63°	34′.3	102
4952	10.09.07	14:45	71°	32′.0	64°	3′.0	99
4953	10.09.07	19:00	71°	26′.8	64°	34′.9	102
4954	11.09.07	3:05	71°	7′.8	66°	37′.0	16
4955	11.09.07	7:40	71°	12′.0	66°	9′.0	24
4956	11.09.07	11:00	71°	15′.0	65°	50′.2	35
4957	11.09.07	14:37	71°	17′.0	65°	37′.4	46
4958	11.09.07	18:45	71°	19′.6	65°	19′.0	117
4959	11.09.07	22:50	71°	22′.1	65°	4′.0	144
4960	12.09.07	0:30	71°	24′.5	64°	50′.5	118
Novaya Zemlya Trough							
4961	12.09.07	23:30	74°	55′.3	64°	40′.1	149
4962	13.09.07	2:10	75°	3′.7	64°	34′.2	260
4963	13.09.07	5:55	75°	11′.4	64°	27′.3	320
4964	13.09.07	9:51	75°	23′.1	64°	18′.1	358
4965	13.09.07	13:00	75°	29′.9	64°	13′.7	303
4966	13.09.07	16:30	75°	34′.5	64°	9′.9	176
4967	13.09.07	18:55	75°	37′.8	64°	5′.3	58
4968	13.09.07	22:25	75°	23′.2	64°	18′.5	355
4970	14.09.07	21:33	75°	23′.2	64°	18′.3	361
4974	15.09.07	21:40	75°	34′.6	64°	10′.7	170
4975	16.09.07	0:00	75°	37′.8	64°	5′.2	62
Blagopoluchye Bay							
4969	14.09.07	4:20	75°	38′.7	63°	38′.2	39
4971	15.09.07	5:00	75°	39′.9	63°	41′.2	173
4972	15.09.07	9:20	75°	38′.0	63°	43′.1	54
4973	15.09.07	12:40	75°	39′.0	63°	45′.8	32
4976	16.09.07	4:45	75°	39′.9	63°	41′.1	177
4977	16.09.07	6:40	75°	39′.0	63°	46′.4	28
Techeniy Bay							
4978	18.09.07	12:15	75°	58′.8	66°	31′.1	55
4979	19.09.07	5:10	75°	57′.8	66°	18′.7	26
4980	19.09.07	12:00	75°	57′.8	66°	17′.2	43
4981	19.09.07	15:37	75°	58′.5	66°	18′.8	47
4982	20.09.07	5:30	75°	57′.8	66°	18′.7	35

Table. (Contd.)

Number of the station	Coordinates at the beginning of the stations						
	date	time	latitude		longitude		depth, m
St. Anna Trough							
4983	23.09.07	4:10	76°	55′.2	70°	16′.2	555
		7:25	76°	55′.5	70°	17′.2	555
		13:30	76°	55′.5	70°	17′.6	555
4984	23.09.07	15:42	77°	1′.2	69°	58′.7	562
4985	23.09.07	21:30	76°	47′.0	70°	37′.9	440
4986	24.09.07	0:49	76°	45′.0	70°	44′.4	375
4987	24.09.07	5:30	76°	39′.5	71°	2′.7	255
4988	24.09.07	11:30	76°	35′.3	71°	15′.4	183
4989	24.09.07	17:40	76°	21′.4	71°	54′.3	155
4990	24.09.07	21:55	76°	9′.2	72°	29′.8	128
4991	25.09.07	5:40	75°	41′.9	72°	31′.9	102
4992	25.09.07	12:05	75°	33′.0	72°	33′	150
Ob section							
4993	25.09.07	5:00	71°	14′.9	72°	51′.9	20
4994	27.09.07	14:52	71°	44′.0	72°	47′.3	16
4995	27.09.07	21:57	72°	10′.0	73°	14′.3	11
4996	27.09.07	4:45	72°	34′.2	73°	49′.3	15
4997	28.09.07	9:00	72°	28′.8	73°	57′.3	11
4998	28.09.07	11:00	72°	22′.3	73°	48′.2	13
4999	28.09.07	19:10	72°	57′.2	73°	17′.1	26
5000	28.09.07	3:49	73°	45′.1	72°	56′.6	27
5001	29.09.07	11:42	74°	35′.0	72°	45′.5	24
5002	29.09.07	18:05	75°	10′.1	72°	37′	29
5003	29.09.07	5:55	75°	26′.4	72°	31′.9	55
5004	30.09.07	11:30	75°	33′.2	72°	31′.3	110
		15:55	75°	33′.6	72°	30′.8	150
5005	01.10.07	16:30	76°	55′.0	70°	12′.1	570
5006	04.10.07	10:10	70°	49′.4	58°	50′.7	214

Figs. 1–3; the coordinates of the stations are given in the table. The main research was carried out in the following locations:

(1) the region adjacent to the Yamal Peninsula from the west, where the influence of the rivers runoff on the ecosystem is minimal; the northeasterly Yamal Current propagates here, which transports the transformed Barents Sea waters and forms a frontal boundary between the inner (depth <50 m) and outer shelves (section I, Fig. 1);

(2) the region of the Novaya Zemlya Trough with depths down to 380 m isolated from the main continental slope; the Eastern Novaya Zemlya Current propagates here along the western slope of the trough;

(3) the region of the continental slope and the deep depression of the St. Anna Trough in the northern part of the sea, where we expected the interaction between the currents flowing from the Kara Sea and the flow transporting waters from the north, which leads to the formation of a frontal (barrier) zone between the shelf and the deep sea regions;

(4) the inner and outer shelf regions between the estuary of the Ob River in the south and the slope of the St. Anna Trough in the north, where the final transformations of the river runoff occur;

(5) the estuary of the Ob River, the transition region from fresh to brackish waters where the initial stages of the freshwater runoff occur. Intense frontogenesis is observed here, and a number of geochemical and biological processes forming the marginal filter occur. The detailed positions of the stations of the Ob section are shown in Fig. 4.

ACKNOWLEDGMENTS

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NOTE

This issue of the journal *Oceanology* is completely dedicated to the materials of the expedition to the Kara Sea onboard the R/V *Akademik Mstislav Keldysh*. Due to the limited volume of the issue, a few articles will be published in no. 6, 2010.

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