

## Study of the State and Variability of the Northwestern Japan Sea in the Autumn–Winter Period on Cruise 62 of the R/V *Akademik Oparin*

V. B. Lobanov<sup>a, \*</sup>, A. F. Sergeev<sup>a</sup>, E. N. Maryina<sup>a</sup>, I. A. Prushkovskaya<sup>a</sup>, P. Y. Tishchenko<sup>a</sup>,  
V. V. Kalinchuk<sup>a</sup>, A. M. Koltunov<sup>a</sup>, D. S. Makseev<sup>a</sup>, S. G. Sagalaev<sup>a</sup>, D. A. Yurikova<sup>a</sup>, E. A. Akulova<sup>a</sup>,  
K. A. Aparina<sup>a</sup>, O. I. Zagoruyko<sup>a</sup>, S. A. Zverev<sup>a</sup>, G. A. Kraynikov<sup>a</sup>, S. P. Kukla<sup>a</sup>, A. E. Leusov<sup>a</sup>,  
N. B. Lukyanova<sup>a</sup>, A. A. Ryumina<sup>a</sup>, P. Y. Semkin<sup>a</sup>, M. G. Shvetsova<sup>a</sup>, E. M. Shkirnikova<sup>a</sup>,  
E. A. Yurikova<sup>a</sup>, A. Y. Yurtsev<sup>a</sup>, and T. S. Yakimov<sup>a</sup>

<sup>a</sup> V.I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences, Vladivostok, Russia

\*e-mail: lobanov@poi.dvo.ru

Received March 12, 2021; revised April 6, 2021; accepted April 15, 2021

**Abstract**—The results of research carried out on cruise 62 of the R/V *Akademik Oparin* from December 14 to 29, 2020 continued monitoring of the interannual variability of the Japan Sea water parameters, confirmed the long-term warming trend of bottom waters, revealed its slowdown during the last decade, demonstrated the formation of a cyclonic gyre in the northern part of the sea and development of upwelling, contributing to more intensive cooling of the sea surface layer. A detailed survey of a mesoscale eddy was carried out in the area of the Primorye Current. The hydrochemical parameters, zooplankton, and methane and tritium in various water structures were assayed. The mercury content in the atmospheric water layer was measured.

**Keywords:** Japan Sea, interannual variability, cyclonic gyre, anticyclonic eddies, zooplankton, mercury, methane, tritium

**DOI:** 10.1134/S0001437021050076

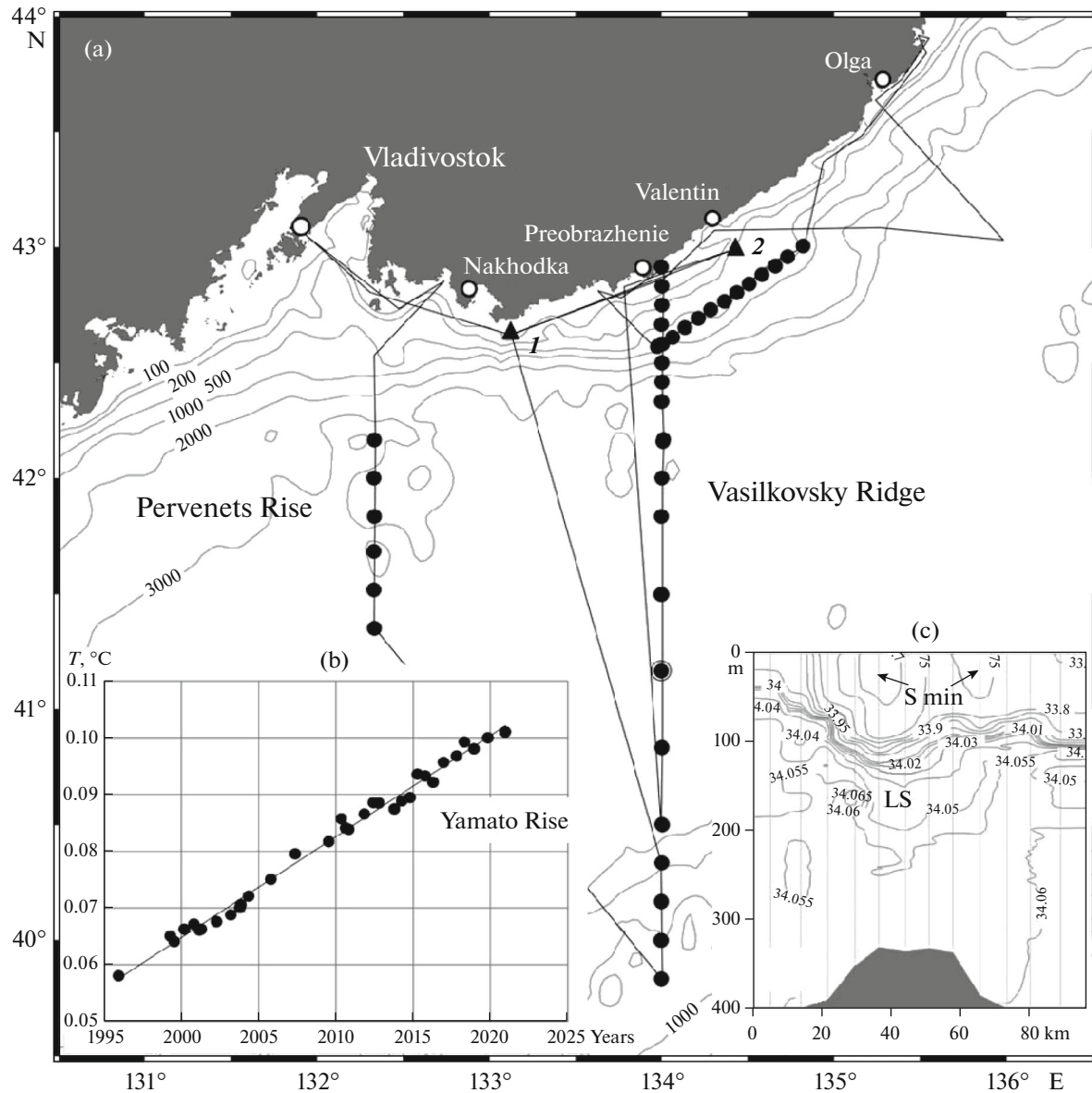
An expedition on cruise 62 of the R/V *Akademik Oparin* was organized by the V.I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences, and lasted from December 14–29, 2020. Its tasks included oceanographic measurements and water sampling for hydrochemical and zooplankton analyses along climate monitoring transects of the international programs CREAMS (132°20' E) and NEAR-GOOS (134°00' E); a survey of mesoscale eddies near the southern coast of Primorye Region; the recovering of two autonomous bottom stations (moorings); and a study of the mercury, methane, and tritium contents in water (and also in the atmospheric layer for mercury) in the northern part of the Japan Sea (Fig. 1a).

Due to the pandemic, the cruise was postponed to an unfavorable period in terms of weather conditions. The vessel often had to depart the operations area and take refuge in the coastal zone. Nevertheless, the majority of the expedition program was completed successfully. In a short time, a vast amount of operations were performed: 37 stations with CTD sounding were made, 23 of which with water sampling from surface to bottom, 12 stations with CTD sounding down to 1200 m on a transect across an eddy, and 6 samples

for an assay of the radioactive hydrogen isotope tritium were taken. Thirty-five zooplankton samples were collected at 20 stations. Mercury in the atmospheric water layer was measured along the entire route of the vessel, and its flux between the sea and the atmosphere was measured out at two stations in the open sea and three at coastal stations. Water sampling to determine the methane content was also carried out along the entire route of the vessel with an interval of 3 h; a total of 102 samples were taken. Hydrochemical analyses included onboard determination of dissolved oxygen, nutrients, pH and alkalinity (334 samples each), as well as collection and preservation of samples to determine salinity, chlorophyll-a, and humic substances at the laboratories of the institute (162 samples each).

The main preliminary results of the expedition are the following:

(1) The monitoring transects show a continuing increase in the temperature of bottom waters of the deepwater Central Basin of the Japan Sea, associated with weakening of convection. A decrease in the growth rate from 0.0018°C/year for the entire observation period from 1995 to 2020, up to 0.0016°C/year over the last 10 years has been noted (Fig. 1b).



**Fig. 1.** (a) Sketch map of operations of POI FEB RAS expedition on R/V *Akademik Oparin* (cruise 62) in northwestern part of the Japan Sea, December 14–29, 2020. Points show position of oceanographic stations; triangles, position of two moorings; isobaths in meters; (b) interannual variability of water temperature ( $^{\circ}\text{C}$ ) in bottom layer, 2900–3500 m, in Central Basin of the Japan Sea; linear trend of potential temperature of  $0.0018^{\circ}\text{C}/\text{year}$  for 1995–2020 is shown; (c) vertical salinity distribution (PSU) on transect across an anticyclonic eddy at Primorye shelf margin; vertical lines—CTD soundings; areas of extreme salinity values and secondary intrahalocline eddy core (LS) are shown.

(2) It was confirmed that the development of upwelling in the area of cyclonic circulation in the northwestern part of the sea in autumn–winter results in more intensive cooling of the surface layer. The influence of the topographic effect is shown: the upwelling has been linked to the Pervenets and Vasilkovsky seamounts, above which the ascent of water has been established, extending to the surface layer and resulting from cyclonic vorticity.

(3) A detailed survey of the anticyclonic eddy off the southeastern coast of Primorye showed a double-

core structure (Fig. 1c). A subsurface homogeneous layer formed by warm waters with low salinity (33.67–33.75 PSU), a secondary intrahalocline core of waters with low salinity (34.03–34.04 PSU) was found in the 120–190 m layer, indicating subduction of Primorsky Current waters during the evolution of the eddy. Anomalies in the anticyclonic zone can be traced down to the bottom layer (450 m).

(4) Based on the measurement results at two moorings equipped with acoustic Doppler current profilers and oceanographic parameter sensors and moored on

the shelf margin at depths of ~100 m in the vicinity of Nakhodka and the village of Valentin (Fig.1 a), at the beginning of September 2020, for the first time a pattern of changes in water circulation and temperature in autumn–winter period was obtained: transition of the structure of the Primorye Current from baroclinic at the end of summer to barotropic in autumn; development of upwelling; its relaxation; and periodic anomalies caused by mesoscale eddies.

(5) Zooplankton is represented mainly by wintering groups; therefore, the data obtained make it possible to characterize the life cycles of species that are the main source of food for commercial planktivorous fish: large copepods of the genera *Calanus*, *Eucalanus*, *Neocalanus*, *Metridia*, and *Pareuchaeta*. The greatest species diversity and maximum abundance in plankton are observed near the Yamato Rise. The uneven distribution of individual groups can serve as current markers.

(6) Mercury measurements performed for the first time in winter showed that, at this time, transfer of air masses from polluted regions of China has a significant effect on its content in the surface atmospheric layer over the Japan Sea. In general, winter concentrations were higher than autumn (October 2019 and 2020), probably due to the burning of more fuel. The

maximum mercury flux values from sea to atmosphere were in warmer and more saline waters of the central Japan Sea; the minimum fluxes, in the colder and less saline coastal waters of Primorye Region.

(7) Based on the methane measurements on this and previous expeditions, three areas with increased contents have been distinguished: above the Yamato Rise, off the coast of Primorye near the villages of Preobrazhenie and Olga, probably related to peculiarities in the tectonic structure of the seafloor.

#### FUNDING

The expedition was carried out under the state task of POI FEB RAS for 2020 (topic no. 5 “Study of the Main Processes Determining the State and Variability of Oceanological Characteristics of the Far Eastern Seas and Northwestern Pacific Ocean” (0271-2016-0005), no. 6 “Influence of Natural and Anthropogenic Factors on Biogeochemical Processes and the State of Biota in Marine Ecosystems” (0271-2016-0006), as well as the international programs “Exploration of the Marginal Seas of Asia CREAMS/PICES” of the North Pacific Marine Sciences Organization (PICES) and “Northeast Asia Regional Global Ocean Observing System (NEAR-GOOS) of WESTPAC/IOC-UNESCO.