# Hydrochemical Atlas of the Sea of Okhotsk 2001

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**CONTENTS**



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**Message from the chief of the department of oceanology, physics of the ocean, and atmosphere of the Russian Academy of Sciences**

Dear Oceanographers!

Welcome to the first *Hydrochemical Atlas of the Sea of Okhotsk*, a product of joint Russian - American work on systematization of hydrochemical data and development of new information systems for World Ocean studies within the framework of the UNESCO IOC GODAR project (Intergovernmental Oceanographic Commission, *Global Oceanographic Data Archeology and Rescue*).

The study of hydrochemistry promotes a better understanding of marine organic matter synthesis and the formation of oceanic biological resources. Unfortunately, despite the great importance of this branch of oceanography, it has been long neglected. Now hydrochemistry is highlighted because of the necessity to estimate the rate of carbon dioxide flux from atmosphere to the ocean; to exploit biological resources and assess potential biological productivity; to anticipate contamination of shelf areas associated with oil and gas extraction, *etc*.

The importance of marginal seas for the population of coastal regions is obvious. Establishment of Exclusive Economic Zones brought the Sea of Okhotsk under almost exclusively Russian jurisdiction. Recently, problems of coastal environment in the Sea of Okhotsk have become more urgent due to the initiation of large-scale oil and gas extraction on the shelf. These activities carry possible danger to the shelf sources of biolo-gical productivity of the Sea of Okhotsk. Coastal shallow zones in the Sea of Okhotsk are spawning and feeding grounds for numerous commercial fish species, as well as areas of alga Laminaria growth and accumulation of numerous populations of crab, shrimp, mollusk, and other invertebrates. Valuable species of salmon (*e.g*. pink salmon, sockeye, coho, etc.) enter the rivermouths bordering on the Sea of Okhotsk for spawning.

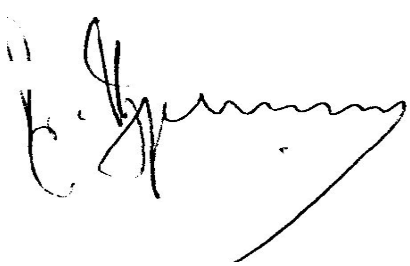
Due to the biochemical history of the Earth, oil and gas fields always occur in highly productive areas of the World Ocean. Therefore, conflicts of interests between fishers and oil developers are inevitable. Availability of maps of hydrochemical characteristics can help groups reach reasonable settlement of such conflicts; fishery experts can protect the industrial interests using the best scientific data. On the other hand, a better knowledge of dynamics of coastal waters and hydrochemical processes allows appropriate technological approaches to minimization of the negative impact of industrial wastes and pollution.

Maps and sections presented in the *Hydrochemical Atlas of the Sea of Okhotsk 2001* reveal systems of currents and quasi-stationary mesoscale eddies and allow one to assess dynamics of production and destruction processes as well as to determine highly productive fishery areas.

The World Ocean is a unified global system, which requires comprehensive studies. It is impossible to understand processes, which occur in one region without consideration of its relationship with other seas and oceans. Therefore, international cooperation in oceanic studies is essential for successful resolution of numerous problems of mankind. The present work is a first step towards understanding of one part of the complex functioning of the World Ocean ecosystem.

Studies of the World Ocean have always brought together scientists of Russia and the United States, two of the greatest oceanographic explorers. Each nation has completed many expeditions and we have acquired unique materials. Now it is important to optimize the usage of these data. Accumulated information, knowledge, and experience should be transferred to succeeding generations to support scientific progress.

One should appreciate this edition of the *Hydrochemical Atlas of the Sea of Okhotsk 2001*, a good example of both fruitful, joint usage of accumulated data and cooperation between Russian and American scientists which resulted in production of the latest and most convenient form of data presentation.



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## PREFACE

The Marine Ecology Laboratory of VNIRO (Russian Federal Research Institute of Fisheries and Oceanography) in cooperation with the World Data Center for Oceanography, Silver Spring and Ocean Climate Laboratory of the National Oceanographic Center/NOAA, USA are carring out joint work devoted to the development of oceanographic databases of the World Ocean under the umbrella of the Global Oceanographic Data Archeology and Rescue (GODAR) project of the Intergovernmental Oceanography Commission. The main components of the joint work are:

- rescuing ocean hydrochemical data, their digitizing, and archiving;
- assessing data precision associated with the use of different chemical and analytical methods and equipment;
- developing methods of quality control of hydrochemical data.

The present *Hydrochemical Atlas of the Sea of Okhotsk 2001* summarizes the first stage of the work. At this stage we have restricted data used to the highly precise data of recent years, which were obtained with state-of-the-art equipment. This hydrochemical material is a necessary and sufficient base for revealing the main regularities of the spatial distribution of nutrients in the Sea of Okhotsk, and also to identify quasi-stationary mesoscale eddies and assess their impact on bioproductivity. In the future, this precise hydrochemical data can serve as a database for quality control, calculations of primary production and the "yield" of organic matter due to the winter stock of nutrients in the euphotic layer.

This Atlas and associated data are being distributed internationally without restriction via CD-ROM, and the Internet in accordance with the principles of the World Data Center System of the International Council of Scientific Unions and the UNESCO Intergovernmental Oceanographic Commission.

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## ACKNOWLEDGEMENTS

This work could not have been done without the support of the State Committee of Fisheries of the Russian Federation, which over many years, organized and funded complex ecosystem research in the Bering and Okhotsk Seas. Understanding the scientific and practical importance of these investigations, the Ministry of Industry, Science and Technology of the Russian Federation and Russian Foundation of Fundamental Research have also assisted in studies of hydrochemical processes in the Sea of Okhotsk.

We acknowledge the help the directors of VNIRO and the Pacific Research Institute for Fisheries and Oceanography (TINRO), who directly assisted the hydrochemical investigations over the entire period.

We are particularly grateful to the entire staff of the Marine Ecology Laboratory of VNIRO, which participated in expeditions to the Sea of Okhotsk from 1989 to 1997, and then analyzed and sys-tematized the hydrochemical data. We thank the specialists of the laboratory V. Krukov, V. Maslennikov, M. Karpushin, D. Tolmachev, M. Sapozhnikov, for their help.

We acknowledge staff of the Laboratory of Oceanographic Measurement Systems and Head of the laboratory, Dr. D.E. Levashov, for maintenance of CTD-zonde "Neil Brown" equipped with cassette of Go-Flo bottles, and oxygen and chlorophyll sensors during all cruises in the Sea of Okhotsk.

We are indebted to staff of NODC and WDC, Silver Spring, J. Antonov, T. Boyer, T. O'Brien, C. Forgy, S. Phillips, R. Gelfeld, D. Johnson, C. Sazama, C. Stephens, and G.Trammell, who have contributed significantly to the database development. We acknowledge Mike Chepurin for the preparation of the interface for the CD-ROM accompanying of this Atlas.

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## ABSTRACT

Maps of the spatial distribution of temperature, salinity, oxygen, percent oxygen saturation, phosphate, nitrate, ammonium nitrogen, silicate, organic nitrogen and phosphorus constructed using data from complex ecosystem studies by VNIRO and TINRO during the 1989-1997 period are presented. All maps were constructed for July-August because all expeditions were conducted during this period. Hydrochemical maps were constructed for horizons (standard depth levels) of 0, 20, 50, 75, and 100 m to cover the entire euphotic layer. Besides these maps, we also present the vertical distribution of salinity, oxygen, phosphate, silicate, nitrate, ammonium nitrogen, organic phosphorus and organic nitrogen at seven sections crossing the main structures of the Sea of Okhotsk.

Concentrations of all nutrients are expressed in micromoles (μM). Such a form of expression facilitates a comparison of nitrogen, phosphorus, and silica stocks in the euphotic layer and solution of the problem on the limitation of primary production within the frameworks of Redfield-Richards' model.

The most important result of this work is associated with the identification of quasi-stationary eddy structures and illustration of their role in formation of bioproductivity of the Sea of Okhotsk.

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## 1. INTRODUCTION

Despite the Sea of Okhotsk being located in temperate latitudes, it may be considered as one of the sub-Arctic seas. Nearness to the cold of the Siberian pole and development of the Siberian High determine the severity of winters. Nevertheless the "echoes" of tropical cyclones and influence of the Soya current are responsible for a mild summer climate, especially in the southwestern sea.

The diversity of natural conditions, such as water exchange within the North Pacific and Sea of Japan, deep winter vertical convection, and a large shelf area all determine the extremely high bioproductivity of the sea. A large amount of organic matter is generated on the Okhotsk Sea shelf. This amount is sufficient to sustain the high biological productivity of commercial species. A part of this organic matter is advected into the deepwater regions of the sea, and another part is lost to sedimentation processes. Sedimentation of the huge amounts of organic substance during the geological epochs resulted in the formation of oil and natural gas deposits.

Unfortunately, previous oceanographic and hydrobiologic descriptions of the Sea of Okhotsk (Shmidt, 1950; Ushakov, 1953; Leonov, 1960; Zenkevich, 1963; Moroshkin, 1966) were based on measurements made during the period of formation of Russian oceanology and hydrochemistry, when the equipment and the methods were far from perfection. Most of these data, did not allow authors to consider the main pattern of distribution of biochemical variables which follows the chaotic alternations of concentration maximums and minimums. In monographs such as *Chemistry of the Pacific Ocean* (1966) and *Chemistry of Ocean Waters*, (1979) the Far Eastern Seas were practically not considered.

The goals of the present work are:

- to make available to the international scientific community the most precise data carried out in the Sea of Okhotsk
- to quantify and explain the spatial distribution patterns of hydrochemical variables in the Sea of Okhotsk

The main factor in formation of high biological productivity is associated with the transport of nutrient-rich intermediate cold waters into the surface layers. It has the most effect when the vertical transport is localized spatially which occurs during the warm period of the year. Examples of such areas are the following: Kashevarov Bank, straits of South Kurils, and the eddies along the Sakhalin and West Kamchatka shelves.

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## 2. METHODS OF MEASUREMENTS

During oceanographic cruises in the Sea of Okhotsk conducted by VNIRO, not only phosphate, nitrate, nitrites, and silicate were determined but also organic compounds of phosphorus and nitrogen and ammonium nitrogen. This allowed not only closing the balance of different forms of nutrients, but also the tracing of production-destruction processes in the sea, assessment of "new" primary production, and production formed due to recycling of nutrients in the euphotic layer.

The data used for the present Atlas were obtained in the Sea of Okhotsk by the staff of the Marine Ecology Laboratory of VNIRO. Each vessel had a satellite navigation unit. Samples of temperature, salinity, dissolved oxygen and chlorophyll were made with the use of a Neil Brown CTD-zonde equipped with cassette Go-Flo bottles and oxygen and chlorophyll sensors. Go-Flo bottles of 2 and 6 L volumes were used to take water samples not only for hydrochemical and biochemical measurements but also for determination of phytopigments (chlorophyll a, b, c, phaeophytin, caratinoids), phytoplankton, and primary production. The construction of Go-Flo bottles allows putting them into the water in closed state. Thus, preventing the contamination of the inner surface of Go-Flo battles at the moment thay pass throught the sea surface film. At a depth of 10 m, the bottles are opened under pressure of 1 atmosphere and then are sunk in the open state.

Observation procedures at each station were as follows. First, the CTD-zonde was put into the sea at a depth of 2-4 m for 3-5 min (depending on wave height) for adaptation of sensors to seawater. Then, a sampling of the water column was conducted down to 1000-1500 m at a speed of not more then 0.5 m/s. On the computer display we could see the vertical distribution of temperature, salinity, oxygen, and chlorophyll "a". According to profiles observed on the display, the horizons (depth levels) of water samples used for hydrochemical analysis were selected.

For the determination of inorganic forms of phosphorus, nitrogen and silica the rapid flow analyzers *Technicon* and *Alpkem* were used. Correspondingly, the reagents and analysis methods which were recommended by the companies were used.

Wet combustion of total phosphorus and nitrogen and determination of ammonium nitrogen content were made manually according to the methods of Strickland and Parsons (1968), Koroleff (1972), Valderrama (1981), Sagi(1966), Solorzano, (1969).

Some analytical methods were modified. The modification does not change the essence of the methods but facilitate the analyses on board the vessel. During the determination of phosphate, the methods of Murphy and Riley (1962) were used, meaning that the scheme of adding the mixed reagents in form of two solutions was used. The first solution contained sulfuric acid, potassium tartrate, ammonium molibdate and the second solution included only the ascorbic acid. In this case both solutions are stable for a long time and may be kept in dark flasks for about a month until the blue shade would appear. A method developed by Sapozhnikov (1978 a) was used for the processing of turbid samples taken in the coastal zones.

Standards were prepared on the basis of phosphate-free water or artificial seawater. Nitrate were determined by the Strickland and Parsons method. To avoid the interference of ammonium nitrogen in the laboratory atmosphere under the simultaneous determination of ammonium nitrogen, the alkaline solution of EDTA instead of ammonium chloride was used (Sapozhnikov *et al.*, 1978).

For determination of ammonium nitrogen we used a combined procedure of Sagi (Sagi, 1966) and Solorzano (Solorzano, 1969) methods. From Sagi�s method we used the high sensitivity of the Bertlo reaction with sodium nitroprussid, and from Solorzano method we used sodium citrate to prevent precipitation of calcium and magnesium hydroxides in the highly alkaline environment. Sodium hypochlorite with relatively high content of chlorite was obtained by the reaction:

$$CaOCl + Na_2CO_3 = CaCO_3^{\overline{\ }} + NaClO + NaCl$$

The main difficulty in analysis of ammonium nitrogen ($NH_4$) is associated with obtaining $NH_4$-free water for preparation of blank and standards. Usually, we used the procedure of boiling the dis-tilled seawater in an alkaline environment down to half of the volume. Residual concentration was determine by an add-in method (Sapozhnikov, 1978 b).

Determination of dissolved silicate was made by the method of Koroleff (1972). However, under the high silicate concentrations in the deep Sea of Okhotsk the water samples were twice diluted.

Total nitrogen and phosphorus were determined by the method of Koroleff (1972) - Valderrama (1981) based on wet combustion of potassium persulphate in special flasks, which were placed for 1.5 hours at temperature 115-120° C in a pressure-cooker. Importantly, after taking 5 ml of the digested sample for determination of total nitrogen, the measurement of total phosphorus was conducted from the same flasks. In this flask, the acid solution of ammonium molibdate was added and after strong shaking the second solution of ascorbic acid added.

In the analysis of total nitrogen it is practically impossible to get free of organic nitrogen water. That�s why after double distillation with potassium persulfate in an alkaline environment and with potassium bichromate in acidic media, the residual concentration of organic nitrogen was determined by the add-in method.

Silicate were determined by a method almost identical to Koroleff� method (Koroleff, 1972).

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### 3. DATA

Present work is based on the data of 5 cruises carried out during the period June-August 1990-1997 . Original data is in the Data directory. The database is characterized by:

| | |
|---|---|
| Temperature (T, °C) | 422 stations |
| Salinity (S, pss) | 422 stations |
| Oxygen ($O_2$, ml/l) | 422 stations |
| Percent oxygen saturation ($O_2$, %) | 422 stations |
| Nitrate ($NO_3$, µM) | 416 stations |
| Ammonium nitrogen ($NH_4$, µM) | 413 stations |

| | |
|---|---|
| Organic nitrogen ($N_{org}$, μM) | 422 stations |
| Phosphate ($PO_4$, μM) | 416 stations |
| Organic phosphorous ($P_{org}$, μM) | 403 stations |
| Silicate ($SiO_3$, μM) | 415 stations |

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**4. DISTRIBUTION PATTERNS OF HYDROCHEMICAL VARIABLES**

The recent VNIRO studies of the hydrochemical basis of biological productivity in the Sea of Okhotsk are of great importance because the Sea of Okhotsk and the Bering Sea together provide up to the 80% of fish catches in Russian waters. Unfortunately, our knowledge of the spatial and temporal variability of the major nutrient salts in the Sea of Okhotsk is not sufficient.

Even recent summaries (Shuntov, 1985; *The Sea of Okhotsk*, 1993) contain a small amount of not precise hydrochemical data. Due to the relatively low quality, these data can't be use for the study of production/destruction processes.

Using *Technicon* and *Alpkem* autoanalyzers in field hydrochemical studies has allowed scientists to determine concentrations of phosphate, nitrate, and silica acid with accuracy and reproductivity which make it possible to verify current fields by hydrochemical parameters (Sapozhnikov, 1997). This modern determination and verification of mesoscale eddies are inconceivable without coupling analyses of temperature-salinity-density fields and measurements of phosphate, nitrates, silica, and oxygen.

Introduction of reliable, fast methods of determination of $P_{org}$, $N_{org}$, as well as ammonium nitrogen and urea has made it possible:

- to find the balance of various forms of nutrient salts;
- to trace marine production/destruction processes;
- to differentiate new production versus recycling production which does not contribute to nutrition in the upper trophic levels, *i.e.* it does not make a biological basis of fishing.

Maps of the spatial distributions of temperature, salinity, oxygen, percent oxygen saturation nitrates, ammonium nitrogen, organic nitrogen, phosphate, organic phosphorous, and silicate during the summer season allow us to make a joint analysis of the fields of temperature and salinity with those of hydrochemical parameters. No old data were used in these maps because we are concerned about homogeneity of the used materials; besides, it is not clear whether the old data are representative. For instance, the following result based on the older less precise data was published in the book *Sea of Okhotsk, 1993, p.59*.: "the pattern of phosphate distribution in the surface waters is patchy with alternating spots of high and low concentrations. The minimum concentrations of mineral phosphorus are observed in cyclonic eddies"? We believe this is incorrect. Actually, strong cyclonic eddies, *e.g.* those over the Kashevarov basin, in the Yamsk upwelling zone, in the north-eastern coastal waters of Sakhalin, and slightly weaker cyclonic eddies off Kamchatka, exhibit maximum concentrations of phosphate (up to 1.4-1.8 μM;).

A glance at the distribution maps of the organic and mineral compounds of phosphorus, nitrogen, and silica could be enough to notice patches of elevated concentrations of mineral forms of nutrients over the strong quasi-stationary cyclonic eddies. These eddies are shown in the scheme of the general circulation in the Sea of Okhotsk (Figure 1) updated based on recent publications (PICES , 1995; Verkhunov, 1997; Gruzevich *et al*., 1997). Particularly significant changes were made in the well-known circulation scheme (Markina and Chernyavsky, 1984; Sea of Okhotsk, 1993) concerning the waters of the east coast of Sakhalin, the Yamsk upwelling zone, the Sakhalin Bay, the waters along the coastline of Kamchatka, and the Kuril Basin. Though the long-term mean maps present the Eastern Sakhalin Current as a rather strong one (Leonov, 1960; Moroshkin, 1996; Luchin, 1982; Watanabe, 1963), some researchers doubt its existence during the warm season (Leonov, 1960; Verkhunov, 1997).

Contrary to the common belief of the 1990s that there is a joint cyclonic circulation in the southern Sea of Okhotsk (Figure 1), recent data have shown that the circulation has an anticyclonic nature and is formed by two or four large anticyclonic eddies 100-150 km wide. The anticyclonic nature of circulation in the Kuril Basin is confirmed by satellite data and Japan Fishing Agency observations (Aizatulin and Nazirov, 1972; Rogachev and Lobanov, 1990; Watatsushi and Martin, 1991; PICES, 1995).

The joint VNIRO-TINRO polygon studies in 1992-1994 (51-53°N, 143-146°E) showed a clear northward flow along the continental slope of eastern Sakhalin; (Fig. 1). Visual observations and casual sampling during the summer period revealed that in shallow waters, *i.e*. from the water edge down to the 10-15 m depth level, there is a narrow flow of brackish waters with elevated content of silicon both in water, and in particulate matter. When such flows of opposite directions meet, it results in the formation of coupled eddies; thus, a strong anticyclonic eddy (diameter 40-50 km) forms over the continental break to drive development of a cyclonic eddy (diameter 10-20 km) in the shallow waters. A chain of anticyclonic eddies along the outer shelf edge forms a frontal zone. The scheme of coupled mesoscale eddies along the Kamchatka coastline is similar to the described one. Cyclonic eddies in shallow waters off Sakhalin and Kamchatka cause a flux of cold nitrate-rich waters into the euphotic layer.

We also note a significant expansion of our knowledge about the circulation in Sakhalin Bay. Most of the year there is a cyclonic eddy with a highly intensive flow of brackish waters along the eastern coast of the bay (Figure. 1). This flow carries transformed waters of the Amur River and is characterized by high turbidity, elevated alkalinity, and large silicon stocks. Sailing round the Elizabeth Cape, the flow mixes with another flow of brackish waters coming from the northern shelf of the Sea of Okhotsk. As a result, salinity of the local waters (the section from Cape Elizabeth to the Kashevarov Basin) sometimes can drop down to a salinity of 15-19 pss. However, in summer a northward warm and salty flow forces these cold brackish waters to the Sakhalin coastline. Then the concentrations of phosphate, nitrate, and silicate increase up to

0.6-1.4 μM, 8-14 μM, and 14-16 μM, respectively, particularly, during formation of the previously mentioned cyclonic eddy in coastal waters.

**Figure 1. Surface currents of the Sea of Okhotsk**

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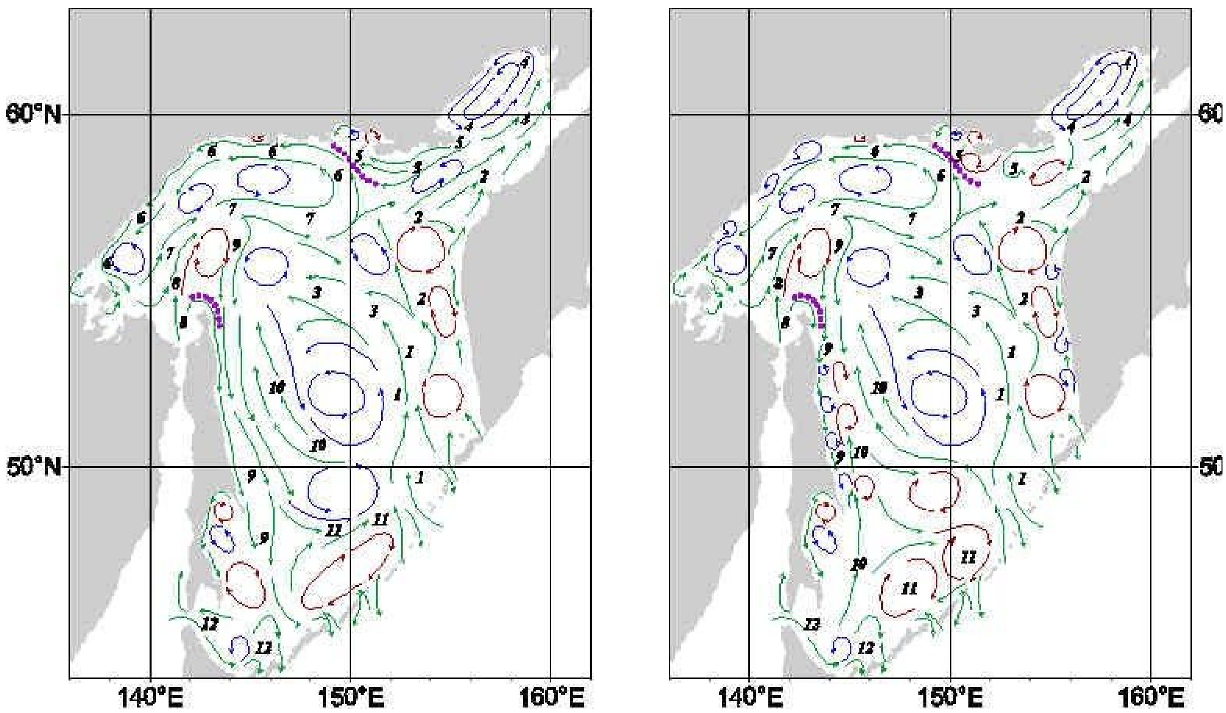
Summer circulation of the active layer of the Sea of Okhotsk:

(left) by Markina and Chernyavsky, 1984; (right) clarified by hydrochemical data




 - cyclonic eddies;  - anticyclonic eddies; - hydrological fronts.
1 - Western Kamchatka current; 2 - Northern branch of the Western Kamchatka current; 3 - Central current; 4 - Penzhin current; 5 - Yamsk current; 6 - North-Okhotsk current; 7 - North-Okhotsk countercurrent; 8 - Amur current; 9 - East-Sakhalin current; 10 - East-Sakhalin countercurrent; 11 - anticyclonic eddies of the Kuril basin; 12 - Soya current.

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In the anticyclonic eddies over the continental edge, the concentrations of phosphate and silicate decline down to 0.2-0.4 μM, and 2-4 μM, respectively, while the oxygen saturation concentration exceeds 140%. The values of $P_{org}$ and $N_{org}$ increase up to 1.2-1.4 μM and 20-22 μM, respectively, in the core of the anticyclonic eddy.

According to our observations, the Yamsk upwelling zone is especially prominent because of its connection with a mesoscale quasistationary cyclonic eddy where the upwelling rates approximate those of the Kashevarov Basin. The surface waters near Evreinov Cape reveal the concentrations of phosphate, nitrate, and silicate totaling 1.4-1.6 μM, 10-12 μM, and 30-32 μM, respectively, *i.e*. the nutrient stocks in the Yamsk upwelling zone are similar to those over the Kashevarov Basin. However, the Yamsk upwelling zone is influenced by a stronger freshwater runoff and a flux from bottom sediments in shallow waters which is proved by a high content of ammonium nitrogen (3.0-4.5 μM).

Maps of the spatial distribution of nutrients in summer show the low concentrations of these variables in the central deep waters and in the areas of mesoscale anticyclonic eddies where phosphate decreases down to 0.1 μM.

Very low concentrations of nitrate (less then 0.1 μM) characterize the Western Kamchatka Current and in the Northern Okhotsk countercurrent over the continental break. Also, the same low concentrations of nitrate can be observed at the southern boundary of the northern shelf of the Sea of Okhotsk, and in the southern and southwestern waters of the Sea of Okhotsk basin, and in the area of anticyclone eddies, and in the Soya Current. Low concentrations of phosphate (below 0.2 μM) and silicate (below 2 μM) are also observed in these waters, however, the distribution patterns of phosphate, nitrate, and silicate are obviously different.

The Western Kamchatka Current and the Northern Okhotsk Countercurrent are characterized by low concentrations of $N_{total}$ and $P_{total}$; this is shown in maps of the spatial distribution of these variables. Consequently, the surface waters of these two currents are depleted of these nutrients; the bulk of nitrogen and phosphorus has already sunk down from the euphotic layer with the remnants of phyto- and zooplankton, as well as feces.

The western coastal waters of the Sea of Okhotsk reveal the low concentrations of $N_{org}$ and $P_{org}$ (below 15 μM and 0.4 μM, respectively) in the summer Eastern Sakhalin countercurrent and in the anticyclonic eddies of the Kuril basin. The ratio of nitrogen and phosphorus in dissolved organic matter of the local waters is around (30-40):1, while in the highly productive upwelling zones this ratio could attain a value of 50:1; this is another example of the importance of nitrate nitrogen. Production-destruction processes are weak here due to nutrient depletion, and oxygen saturation does not exceed 103%.

For the first time, the nutrient maps , allow us to identify mesoscale quasistationary eddies and update the scheme of currents along Sakhalin and Kamchatka.

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## 5. CD-ROM CONTENTS

The accompanying CD-ROM contains original data, figures and text of the Atlas in MS Word format. The CD-ROM also contains a stand-alone interface in Visual Basic allowing one to retrieve figures and text. The interface consists of the three main sections: **Information, Maps, Sections**.

**Atlas** section. This section allows one to retrieve text of the Atlas, data distribution maps, a bathymetric map of the Sea of Okhotsk, and the chart of the surface currents.

**Maps** section. This section allows one to retrieve the distribution of the following variables:

Temperature (C, °)

Salinity (S, pss)

Oxygen ($O_2$, ml/l)

Percent oxygen saturation ($O_2$,%)

Nitrate ($NO_3$, µM)

Ammonium nitrogen ($NH_4$, µM)

Organic nitrogen ($N_{org}$, µM)

Phosphate ($PO_4$, µM)

Organic phosphorous($P_{org}$, µM)

Silicate ($SiO_3$, µM)

The distributions of these variables are plotted for depths 0, 20, 50, 75, 100 meters.

**Sections** section. This section allows one to retrieve the distribution of the parameters listed above along the 7 sections. These sections cross the main water mass structures of the Sea of Okhotsk.

**About** section. This section contains the list of authors and their addresses.

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## 6. CONCLUSION AND FUTURE WORK

The maps of ammonium nitrogen and organic forms of phosphorus and nitrogen based on modern data are presented for the first time for the Sea of Okhotsk. They clarify the production-destruction process in summer, when both phosphate and nitrate are thoroughly utilized. Also, photosynthesis continues during the summer time due to uptake of ammonium nitrogen and fast regeneration of nutrients from their organic compounds.

The most important feature of the salinity and nutrient distribution maps presented in the Atlas, is their detailed correspondence to each other at the level of identification of quasistationary meso-scale eddy structures. Moreover, the distribution of dissolved oxygen and nutrients allows us to identify cyclonic structures where upwelling of cold intermediate waters with high content of phosphate, nitrate and silicate occurred, but values of oxygen saturation were low. Mesoscale anticyclonic eddies characterized by low concentrations of inorganic compounds of phosphorus, nitrogen and silica (down to about analytical zero) but high values of oxygen saturation (up to 120%) and a sharp increase in organic nitrogen and phosphorus concentrations are also identified (Fig.3). Thus, we believe that maps presented in this Atlas produce strong evidence for the necessity of combined analysis of temperature, salinity and hydrochemical variables to identify quasistationary mesoscale eddy structures. The use of hydrochemical tracers allow us to construct the schemes of currents more correctly then before.

The *Hydrochemical Atlas of the Sea of Okhotsk 2001* is the first step in the study of this ecosystem. As the second step, we intend to prepare an Atlas of the Sea of Okhotsk (chlorophyll and primary production). Along with chlorophyll distribution maps it will include maps of primary production and calculated values of organic matter "yield" on the basis of winter nutrient stock. Maps of dissolved and weighted organic matter, proteins, lipids, and carbohydrates distribution will be also presented. This will allow us to assess indirectly biomass of phyto- and bacterio-plankton and contribution of natural processes in terms of pollution values.

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