La mer 30: 169–177, 1992
Société franco-japonaise d'océanographie, Tokyo

Ventilation of the Japan Sea waters in winter

A. S. VASILEV* and V. P. MAKASHIN*

Abstract: The Japan Sea is characterized by the unique vertical homogeneity of waters. A numerical model of the transport stream function was developed. The model was based on a quasi-stationary vorticity equation integrated with depth. The equation includes effects of eddy viscosity and parametrizes mixing processes that are most intensive in the "cold" area. In integrating the equation, the relaxation and run techniques are used. The analysis of mixing processes has been done in the "cold" area of the sea. This area is not directly influenced by warm Tsushima and East Korea Currents. The model results and hydrological data show that wind mixing, winter vertical circulation, large-scale three-dimensional dynamics of waters, and deep convection of the open sea are responsible for ventilation in the upper kilometer of the Japan Sea waters. The minimum concentration of dissolved oxygen in a layer of 1000 to 2000 m is evidently a result of relatively weak ventilation in deep waters. Bottom waters (deeper than 2000 m) are periodically replenished by shelf waters (saturated with the oxygen), sinking down along the continental slope of Primorye. According to estimations of shelf water density, the depth of sinking along the continental slope is controlled by a narrow range of density in the place of formation. This provides an important criterion for ecological monitoring of the bottom layer.

1. Introduction

The Japan Sea is a deep marginal basin, characterized by the limited water exchange with the Pacific Ocean, the East China and the Okhotsk Seas. Numerous results of hydrological measurements during more than half a century invariably confirm the anomalously high concentration of dissolved oxygen throughout all the depths, and vertical homogeneity of waters, most prominent in winter to the north of 41° to 42°N. Suffice it to say, that 84% of sea-water volume is characterized by temperature of 0° to 1°C, salinity of 33.96 to 34.14 ‰, and the concentration of dissolved oxygen of 5 to 7 μlpl (FUKUOKA, 1965; POKUDOV *et al.*, 1976; Sudo, 1986; Stepanov, 1961). These data characterize the mixing intensity of the Japan Sea waters. For all this, by estimations, only an insignificant part of the Pacific Ocean water (inflowing through the Korea Strait) is involved in the exchanging processes (HARADA and TSUNOGAI, 1986).

The downwelling on the periphery of cyclonic gyre and winter vertical circulation (STEPANOV, 1961) have been considered as the main processes of mixing. This can give a complete explanation, in particular, of the Japan Sea homogenization, because these processes take place in the other Far-Eastern seas (FUKUOKA, 1965) as well.

Many scientists have come to a conclusion that water filling the Japan Sea basin is formed in its northwestern part on Primorye shelf, and then sinks along the continental slope (GAMO and HORIBE, 1983; GAMO *et al.*, 1986; NITANI, 1972; SUDO, 1986; ZUENKO, 1989). This process gives a deep convection near the margins (KILLWORTH, 1983).

FUKUOKA and MISUMI (1977) in winter cruises of 1966–1967 found areas of surface waters that sink in the northwestern part of the sea beyond the shelf. These processes apparently look like the results of deep convection in the open sea (KILLWORTH, 1983).

YARICHIN and POKUDOV (1982) proposed a hypothesis that the vertical circulation cells

---

* Pacific Oceanological Institute, Far-Eastern Branch, Russian Academy of Sciences, Vladivoskok, Russia

exist in the northern part of the sea and are separated by the divergence zones. Main divergence zone lies in the center of the northern deep water basin and is marked by temperature and salinity distribution. But the reason of the vertical circulation remains obscure.

Thus, there are direct and indirect indications of a number of mixing processes. They are developed in the Japan Sea and are different in nature, intensity and scales.

Development of techniques of measuring the oceanological characteristics gives the opportunity to determine fine structure of water in the northern part of the sea that was previously considered almost homogeneous. Under the surface layer which directly interacts with the atmosphere, bounded by the lower boundary, and extremely poorly exposed in winter, the intermediate water mass occurs, bounded at a depth of about 1000 m by a layer of the minimum oxygen content (Gamo *et al.*, 1986). Deep water (1000 to 2000 m) characterized by the exponential decrease of temperature is separated from the well-mixed bottom water by a transitional layer (Gamo and Horibe, 1983; Gamo *et al.*, 1986). Vertical structure gives the reason why each layer has the individual peculiarities of ventilation.

The authors make primary synthesization of hypotheses on mixing and ventilation of the Japan Sea water, on the basis of analysing its large-scale dynamic structure reproduced (concerning the lack of hydrological data in winter) with the help of the hydrodynamic model. Diagnostic calculations of the Japan Sea water circulation which are known from papers describe, as a rule, its separate elements (Kozlov, 1971; Sekine, 1986; Yurasov, 1979). In this study main attention is paid to the processes of mixing in the "cold " sea area which does not undergo the direct influence of warm Tsushima and East Korea Currents. According to the hypotheses, this is just the place where the most intensive mixing processes are developed in winter months.

2. Model and description of data

For calculating spatial evolution of current fields and of density, the authors use quasi-stationary friction model considering surface and bottom boundary layers, known spatial distribution of water density, β-effect, bottom relief, shore outlines and water exchange through the straits.

In developing the theory of diagnostic models the principles of the second generation self-similarity have been used; they give the opportunity to solve the spatial problem as a system of two-dimensional equations relative to some functions of self-similarity.

In this problem the natural self-similarity is used for distribution of sea-water density, which can be expressed as:

$$\begin{aligned} &\rho(x,y,z,t) \\ &\quad = \xi(x,y,t)[\sigma(z,t)+d_1 a(x,y,t)(z-h)] \\ &\qquad + d_2(z-h)c(t)+\rho^0(x,y,t) \end{aligned} \tag{1}$$

where $\xi(x,y,t)$ is self-similarity function, $\sigma(z,t)$ stratification function determining the vertical structure of waters and calculated by the observed data, $\rho^0(x,y,t)$ density of sea-water on the surface, $a(x,y,t)$ some adjusting function providing zero mass flux through the bottom at the variable depth of the basin.

$\rho^0(x,y,t)$ is given. $\sigma(z,t)$ and $a(x,y,t)$ are determined before solving the boundary problem. And $\xi(x,y,t)$ should be estimated. $c(t)$ is a regulator of the "frozen" abyssal zone. h_K^D *and* h_K^d are depths of abyssal zone and of bottom layer of Ekman friction. d_i is Kronecher's symbols with $d_i=0$ for $z<h_K^i$ and $d_i=1$ for $z \geqq h_K^i$.

Using the model (1) and linear form of the horizontal exchange due to water movement, the vector of horizontal velocity (U) is found as a linear combination:

$$\vec{U}=\sum_{i=1}^{i=k} \tilde{\mathrm{B}}_i \vec{F}_i, \tag{2}$$

where $\tilde{\mathrm{B}}_i$ are square matrices determined as a result of integrating the equations of motion on the vertical coordinate. The non-linear inertial terms, horizontal and vertical turbulent exchange, variable Coriolis parameter (β-effect) and variable topography of sea bottom are concerned in these matrices. $\vec{F}_i$ is the external parameter of the problem which are related to the dynamics and thermohaline conditions of the sea-surface and to the self-similarity function. The self-similarity function $\xi(x,y,t)$ is necessary for calculating the spatial distribution of density with the help of Eq. (1). It is determined after solving the equation of stream function (3) given as a result of integrating Eq. (2) on the vertical coordinate.

$$-\frac{\partial\Psi}{\partial\nu}+\Delta\Psi+\delta^{x}_{N1}\frac{\partial^{2}\Psi}{\partial x^{2}}+\delta^{y}_{N1}\frac{\partial^{2}\Psi}{\partial y^{2}}+\mu\frac{\partial\Psi}{\partial x}+\theta\frac{\partial\Psi}{\partial y}=F(\vec{T},\rho^{0}) \qquad (3)$$

where ν is the relaxation parameter, δ^{x}_{N1}, δ^{y}_{N1}, μ and θ the known integral coefficients, $\vec{T}$ the tangential stress of the wind, ρ the density of water at the surface.

The scheme of solving the problem is as follows. After solving Eq. (3) by a method of relaxation, splitting and run, and after determining the stream function of transport Ψ and the self-similarity function of density $\xi(x,y,t)$, the spatial distribution of currents velocities is determined by using (2), and the spatial distribution of sea water density is determined by (1). For calculations, a uniform grid with spacing of 30' in latitude and longitude and standard vertical coordinate have been used. Estimation of the dynamic influence of the atmosphere upon the sea surface has been performed on the basis of the semi-empirical relationships. Flow rates in the straits and through the sea margins ("liquid" margins) of the region have been determined as a result of calculating the currents with the help of a special model similar to the one considered above. For numerical calculation the "Relaxation Method of Minimum Errors" (MARCHUK, 1974) has been used. Mathematical statement of the problem and description of the model are given in VASILIEV (1988).

The initial fields of temperature and salinity of the sea surface and vertical profiles of hydrophysical characteristics for determination of stratification function are taken from the published oceanographical data on the Japan Sea by the R/V "Priliv" (DVNIGMI) from March 14 till April 4 in 1974 (POKUDOV *et al.*, 1976). During the survey, weak variable winds predominated. This allows us to use mean field of the surface atmospheric pressure for March (Altas of the Oceans, 1974), and to assume stationary regime of real geostrophic currents.

3. Results

The results of modelling the circulation integrated over depth (transport) are given in Fig. 1a. In the northwestern part of the sea, an elongated gyre is distinguished, the northern periphery of which forms the the Primorskoye Current beginning from 44° N. The southern periphery of the gyre is bounded by the East Korea Current. To the northeast of the Yamato Seamount, there is a vast anticyclonic pattern with two gyre centers. In the southern part of the sea, a zone of the divergence is observed from 40° N, 132° E southward. The Tsushima Current proper streaming along the Japan seashore and becoming weak in winter appears in a narrow coastal area. Resulting diagnostic description of the circulation essentially agrees with the general scheme of the Japan Sea circulation (YARICHIN, 1980) deduced by using the "dynamic heights method" (POKUDOV and TUNEGOLOVETS, 1975) and from the satellite data in winter (HUH and SHIM, 1987). The cyclonic gyre of the northwestern part of the sea is absent in some studies on circulation models (KOZLOV, 1971; SEKINE, 1986; YURASOV, 1979). In the present model, the inflow of the Pacific Ocean water through the Korea Strait amounts to 0.63 Sv. This value exceeds the estimate of water transport through the strait in March of 1974 (0.26 Sv) (POKUDOV and TUNOGOLOVETS, 1975). Still, it is close to the mean value for March (0.58 Sv) (LEONOV, 1960). According to this calculation, outflowing transport through the Straits of Tsugaru, La Perouse, and Tatarskiy are: 89%, 8% and 3%, respectively.

An additional numerical experiment aiming at determination of circulation pattern induced by the wind stress and surface heating and cooling has been performed. In this experiment, the gradients of atmospheric pressure three times as large as those of the previous experiment have been considered. This corresponds to the pressure gradients when deep cyclones pass in the northern part of the sea area. The temperature of water surface in the northwestern barotropic part of the sea has been decreased by 0.1 to 1.4 ℃ to such an extent that the density of surface

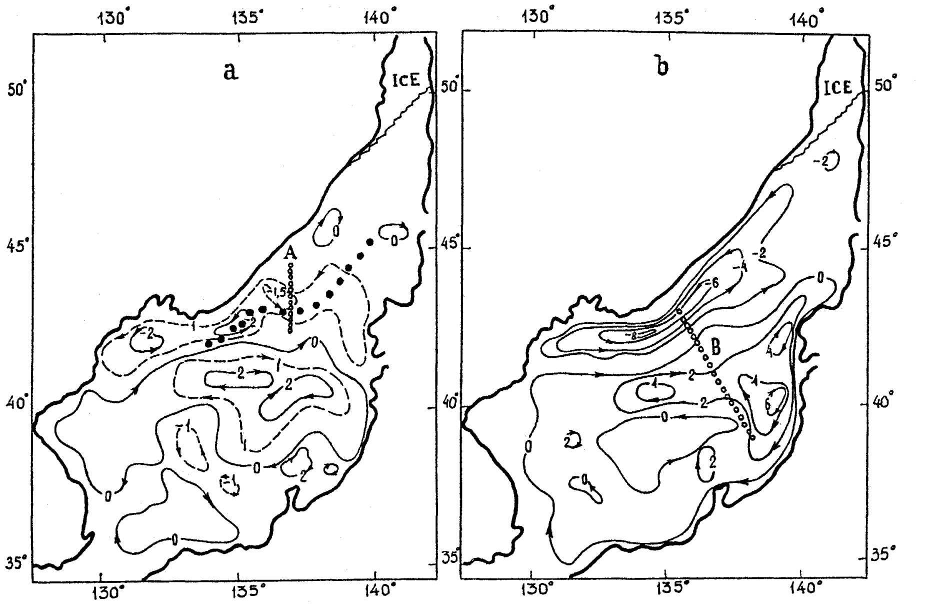

Fig. 1. Stream lines of integral circulation of the Japan Sea water (Sv).
a-average March field of atmospheric pressure is used;
b-atmospheric pressure gradients are increased by a factor of 3.
solid circles - divergence zones
open circles - oceanological sections

water becomes the same as that at 400 m depth. This shows the result of the convective mixing in the whole active layer.

The change in atmospheric pressure field has led to the increase of the maximum velocity of the wind from 6 mps in the initial field to 17 mps (affer data of Vladivostok weather station in March). At the coast the wind of more than 15 mps speed has been observed during 5 to 6 days. So, general intensification of the circulation has taken place. The quasi-stationary cyclonic gyre centered within 42° to 43° N and 134° to 135° E has been formed (Fig. 1b). In the infrared image of the sea surface obtained from the satellite on March 29 in 1979, a vast area of upwelling water characterized by low temperature has been observed exactly at this place (HUH and SHIM, 1987).

4. Discussion

The data on ventilation processes of the Japan Sea waters is presented (Table 1). The results of model calculations are used to explain these processes.

The thickness of surface homogeneous layer mixed by the wind (without considering the convection) was calculated by a previous model (VASILIEV, 1988). With the climatological atmospheric pressure data, thickness of the homogeneous layer is varied from 3 m in the southwestern part of the sea to 33 m near the seashore of Primorye. Increased gradients of the atmospheric pressure simulating storm in the numerical experiment lead to lowering the lower boundary of the mixed layer in the northwestern and northern parts of the sea down to 50 to 100 m. It may be concluded that even during strong winds, direct atmospheric influence does not penetrate deeper than 100 m, thus it restricts the role of wind mixing in ventilation of the lower layers (Table 1, Item 1).

The calculation of scales of the vertical circulation conditioned by winter cooling of the surface and salinity increase during the ice formation was carried out by IZUMI and ISHINO (1985) in the Okhotsk Sea. At the latitude of the La Perouse Strait, vertical scale of the thermohaline convection does not exceed 80 m.

Table 1. Main processes of ventilation of the Japan Sea in winter

Item number	Process	Area of predominant development	Vertical scale (m)	Layer	Source of information	Notes
1.	Wind mixing	in all places	100	surface layer	Vasiliev, Makashin (1990)	authors' calculations of thickness for the mixed layer
2.	Vertical circulation conditioned by winter cooling of the surface layer and salinity increase during ice formation	ice formation in the northern and northwestern parts of the sea	40-80	surface layer	Izumi, Ishino (1985)	estimations for the Okhotsk Sea at the latitude of the La Perouse Strait
3.	Vertical circulation conditioned by the large-scale dynamic structure	divergence zone in the northern part of the sea	1000	surface layer, intermediate layer	Yarichin, Pokudov (1982); Yurasov, Yarichin (1990)	hydrological data
4.	Deep convection of the open sea, intensively influenced by the atmosphere	to the north of latitude 41 °N	200-300	intermediate layer	Fukuoka, Misumi (1977)	hydrological data
5.	Shelf water, sinking along the continental slope (deep convection near the margins)	shelf and slope of the northwestern coast	depends on density of shelf water	bottom layer	Nitani (1972), Gamo et al. (1986)	hypothesis based on analysis of oxygen dynamics of the bottom water

However, this order of magnitude can not be considered as definitive for the Japan Sea. Along with the wind mixing, winter vertical circulation takes part in forming the surface mixed layer (Table 1, Item 2). The vertical circulation modified by large-scale processes (upwelling in the central part of the cyclonic gyre and downwelling in the anticyclone) involves an essentially thick layer of water. Fig. 2 presents dome-like isolines of salinity and dissolved oxygen concentration at a section carried out in March of 1982 (YURASOV and YARICHIN, in press). Disturbance of salinity field (and correspondingly, density field under a condition of more or less uniform temperature) is traced only down to 1000 m. The section intersects the quasi-stationary divergence zone described by YARI-CHIN and POKUDOV (1982). Coincidence of divergence zone and the quasi-stationary cyclonic gyre presents interesting features of embedded mesoscale eddies (Fig. 1a). It is supposed that the origin of convergence zone and related pattern are associated with the areas of upwelling in the center of cyclonic gyre. By the large-scale vertical circulation, the intermediate layer (up to 1000 m) is also ventilated. Below that layer the dissolved oxygen content reaches the minimum (Table 1, Item 3).

It is known that increased wind stress may lead to mixing of the upper layer with decrease of the buoyancy of that layer and eventually affects convection of the deep layer. Besides, intensified wind stress may cause weakening of stratification in the density field. The process of deep convection in the open sea passes through several phases of its development and is characterized by the hierarchy of scale ranging from the elementary cells to the inner areas of meso-scale cyclonic vortices, of which the scale is determined by the Rossby deformation radius (GASCARD and CLARKE, 1983; KILLWORTH, 1983). Along the section carried out in February

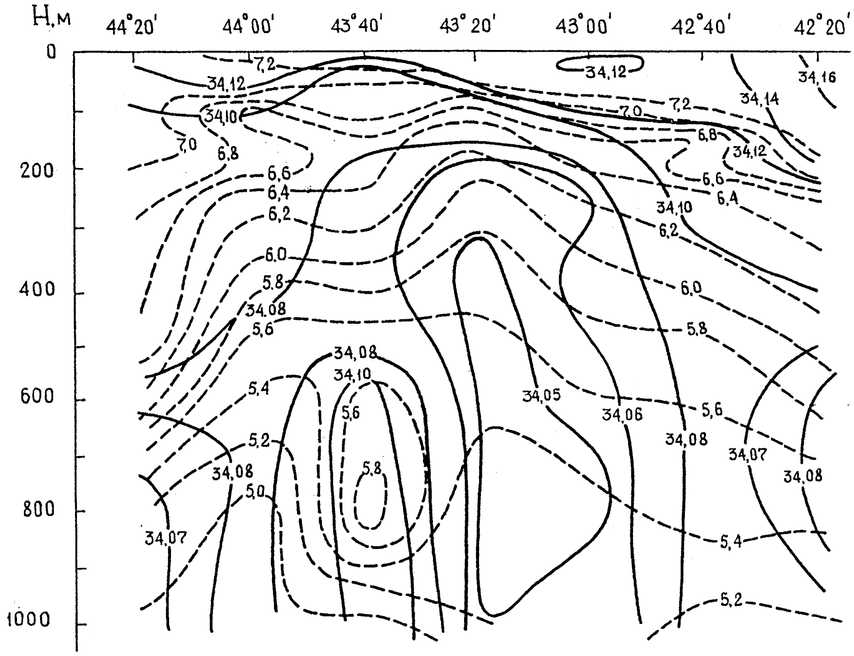

Fig. 2. Vertical section of salinity and concentration of dissolved oxygen in a divergence zone (Fig. 1a-A) in March of 1982 (YURASOV and YARICHIN, in press). solid line - salinity, ‰; dashed line - dissolved oxygen, μlpl

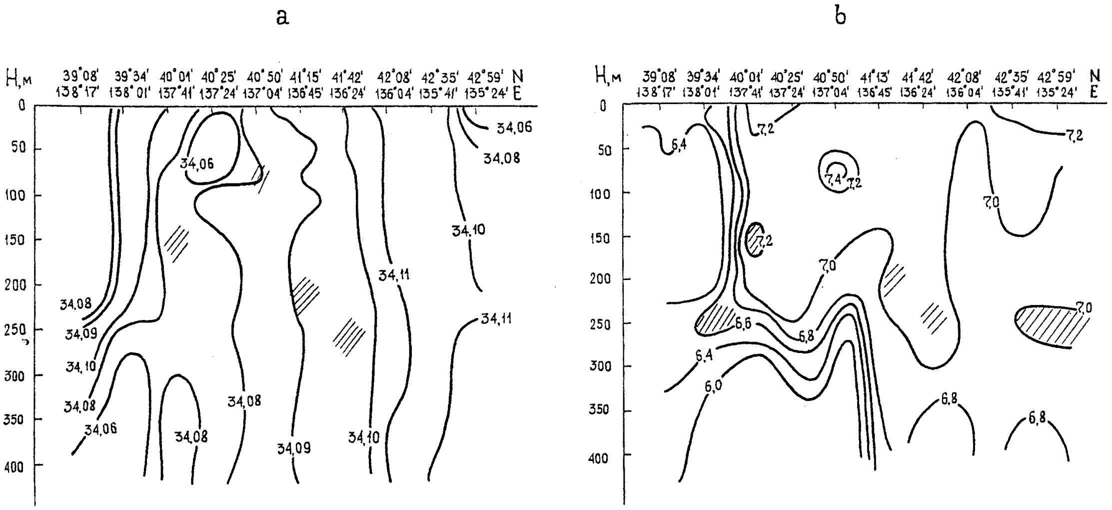

Fig. 3. Vertical section of: a) salinity (‰), b) concentration of dissolved oxygen (lpl) (Fig. 1b-B) in February of 1966. Dashed lines show secondary salinity minimum and oxygen maximum. The depth of extreme occurrences varies from 75 to 250 m (FUKUOKA and MISUMI, 1977).

of 1966 (FUKUOKA and MISUMI, 1977) the near-surface salinity minimum and maximum of dissolved oxygen concentration are lowered at some locations from 50 m to 250 m (Fig. 3b). The data of coastal weather stations indicate that the period of survey of the section was

Table 2. In situ density of the northern basin water of the Japan Sea, and of adiabatically sinking shelf water with different initial characteristics; T and S values of the under-surface layers are taken from Gamo and Horibe (1983) and Ohwada and Tanioka (1972)

Layer	H (m)	Background values			$\sigma_{s,t,p}$ of shelf water	
		in situ T (℃)	S (‰)	$\sigma_{s,t,p}$	T=0.00℃ S=34.00‰	T=−1.86℃ S=34.10‰
Surface layer	0	>0.00	<34.100	<27.380	27.299	27.450
Intermediate layer	500	0.42	34.068	29.686	29.658	29.836
	1000	0.15	34.070	32.036	31.993	32.197
Deep layer	1585	0.15	34.074	34.800	34.760	34.994
	2084	0.17	34.076	37.072	37.022	37.222
Bottom layer	2583	0.20	34.076	39.317	39.272	39.483
	3145	0.26	34.068	41.530	41.498	41.721

preceded by short periods (3 to 5 days) of strong wind with speeds of 20 to 25 mps accompanied by the air temperature drop of 22 to 25℃. Position of the area of surface water sinking coincides with the periphery of the quasi-stationary cyclonic gyre (Fig. 1b-B). These data indicate the presence of the neutral stratification extending to the north of 41° N as a result of accumulated effect of deep convection during previous weeks (Fig. 3b). The temperature range is small and density of the Japan Sea water depends on the salinity. The subsequent development of the vertical process is probably due to the absence of intermediate water mass with anomalous thermohaline characteristics relative to the upper and lower layers. Heavier upper layer density caused by interaction with the surface layer leads to the release of additional potential energy, leading to the convection down to the bottom, as it takes place, for example, in the Mediterranean (Killworth, 1983). In the Japan Sea, deep convection causing sinking and isentropic spreading provides ventilation of the intermediate layer (Table 1, Item 4).

Dissolved oxygen in the well-mixed Japan Sea bottom water (deeper than 2000 m) is mixed into the bottom layer of the oxygen saturated shelf water that sinks along the continental slope of Primorye to the south of 45° N (Table 1, Item 5; Gamo and Horibe, 1983; Gamo *et al.*, 1986; Nitani, 1972; Zuenko, 1989). Therefore, this process may be classified as deep convection near the margins (Killworth, 1983). Indeed, the shelf area including the shelf of the Peter the Great Gulf is a natural source of the cold dense water. Extremely intense ice cover of the gulf leading to salinity increase during a formation period of the permanent ice is an additional source of negative buoyancy. Winter monsoon provides removal of the dense water towards the continental slope. Table 2 gives the background values of in situ density of the northern basin water and corresponding density of the shelf water that sinks adiabatically. Comparison between these values shows that the depth of shelf water penetration is controlled by the small range of temperature and salinity. Their characteristics are determined within this range in winter. At T= 0.00℃ and S = 34.00 ‰, shelf water spreads only in the surface layer. By lowering the temperature to −1.86℃ (freezing point at S = 34.10 ‰), the shelf water may reach to the bottom, when taking account of the density distribution.

The observed exponential temperature change in a deep layer of the Japan Sea (1000 to 2000 m) indirectly confirms that it is formed by sinking of the intermediate layer to the homogeneous bottom layer. Deep layer is the most probable place where the small-scale heat and mass transfer processes develop. Mixing of the bottom layer may be partially initiated by the shelf water injections. Nitani (1972) considered the entering of shelf water into the bottom layer to occur only in severe winters. Studies of the long-period series of freezing dates for Suva Lake

(GORDON *et al.*, 1985; TANAKA and YOSHINO, 1982) lead us to the conclusion that the occurrences of the extremely severe winters in the Japan Sea are at about ten years intervals. Such periodicity is also confirmed by spectral analysis of the time series of the surface water temperature near the western coast of Japan (WATANABE *et al.*, 1986). There is yet no answer to the question of how often shelf water reaches to the bottom. For correctly estimating the volume of bottom water produced above the shelf of Primorye and renewal time of the deep sea layer, special investigations are needed. Only the first steps have been taken to resolve this problem (GAMO and HORIBE, 1983; HAMADA and TSUNOGAI, 1986). At the same time, determination of place of the bottom water formation and of conditions necessary for development of deep convection is the key to the ecological monitoring of the Japan Sea bottom layer.

5. Summary

1. Unique combination of the bottom topography, coastline shape outlines, climatic conditions and large-scale dynamic structure of the northwestern Japan Sea leads to intensive development of the mixing processes (different in nature and scales) responsible for the vertical homogeneity of the sea-water in the Japan Sea.

2. Wind mixing, winter cooling, large-scale vertical circulation and deep convection of the open sea drive the processes of ventilation in the upper kilometer of the Japan Sea waters. Bottom layer is injected by shelf waters sinking mainly along the continental slope of Primorye. Minimum concentration of the dissolved oxygen in a layer of 1000 to 2000 m is probably the result of the relatively weak ventilation of the deep water.

3. The depth of shelf water penetration is controlled by a small range of temperature and salinity at the location of deep water formation, which is important for ecological monitoring of the bottom layer.

References

Atlas of the Oceans (1974): The Pacific Ocean. Moscow, Glavnoye Upravleniye Navigatsii i Okeanografii.

FUKUOKA, J. (1965): Hydrography of the Adjacent Sea. (1) The Circulation in the Japan Sea. J. Oceanogr. Soc. Japan, **21**, 95–102.

FUKUOKA, J. and A. MISUMI (1977): Sinking in the Japan Sea (Preliminary Report). Bull. Fac. Fish. Hokkaido Univ., **28**, 143-153 (in Japanese).

GAMO, T. and Y.HORIBE (1983): Abyssal Circulation in the Japan Sea. J. Oceanogr. Soc. Japan, **39**, 220–230.

GAMO, T., Y. NOZAKI, H. SAKAI, T. NAKAI and H. TSUBOTA (1986): Spatial and Temporal Variations of Water Characteristics in the Japan Sea Bottom Layer. J. Mar. Res., **44**, 781–793.

GASACARD, J. C. and R. A. CLARKE (1983): The Formation of Labrador Sea Water. Part 2: Mesoscale and Smaller-Scale Processes. J. Phys. Oceanogr., **13**, 1779–1797.

GORDON, G. A., J. M. LOUGH, H. C. FRITTS and P. M. KELLY (1985): Comparison of Sea Level Pressure Reconstructions from Western North American Tree Rings with a Proxy Record of Winter Severity in Japan. J. Clim. Appl. Meteorol., **24**, 1219–1224.

HARADA, K. and S. TSUNOGAI (1986): ^{226}Ra in the Japan Sea and the Residence Time of the Japan Sea Water. Earth and Planetary Science Let., **77**, 236–244.

HUH, O. K. and T. SHIM (1987): Satellite Observations of Surface Temperatures and Flow Patterns in Sea of Japan and East China Sea, late March 1979. Remote Sens. Environ., **22**, 379–393.

IZUMI, M. and M. ISHINO (1985): Estimation for the Bottom Depth of the Vertical Convection Layer in the Southern Okhotsk Sea during Cooling Seasons. J. Tokyo Univ. Fish., **72**, 1–11.

KILLWORTH, P. D. (1983): Deep Convection in the World Ocean. Rev. Geophy. and Space Phys., **21**, 1-26.

KOZLOV, V. F. (1971): Approximate Calculation Results of the Integral Circulation in the Japan Sea. Meteorologiya i Gidrologiya, **4**, 57–63. (in Russian).

LEONOV, A. K. (1960): Regional Oceanography. Part I. Leningrad, Gidrometeoizdat, 766 pp. (in Russian).

MARCHUK, G. I. (1974): Numerical solving the problems of the ocean and atmosphere dynamics on the base of splitting methods. Leningrad, Gidrometeoizdat, 303 pp.

NITANI, H. (1972): On the Deep and Bottom Waters in the Japan Sea. *In*: Research in Hydrography and Oceanography. ed. D. SHOJI, Hydrographic Department of Japan, 151–201.

OHWADA, M. and K. TANIOKA (1972): Cruise Report on the Simultaneous Observation of the Japan Sea in October 1969. Oceanogr. Mag., **23**, 47–58.

POKUDOV, V. V. and V. P. TUNEGOLOVETS (1975): New Scheme of the Japan Sea Winter Currents. Trudy DVNIGMI, **50**, 24–32 (in Russian).

POKUDOV, V. V., A. N. MAN'KO and A. N. KHLUSOV (1976): Peculiarities of the Hydrological Regime of the Japan Sea in Winter. Trudy DVNIGMI, **60**, 74–115 (in Russian).

SEKINE, Y. (1986): Wind-Driven Circulation in the Japan Sea and Its Influence on the Branching of the Tsushima Current. Progr. Oceanogr., **17**, 297–312.

STEPANOV. V. N. (1961, ed.): Main Features of the Japan Sea Geology and Hydrology. Moscow, USSR Academy of Sciences, 224 pp. (in Russian).

SUDO, H. (1986): A Note on the Japan Sea Proper Water. Progr. Oceanogr., **17**, 313–336.

TANAKA, M. and M. YOSHINO (1982): Re-examination of the Climatic Change in Central Japan Based on Freezing Dates of Lake Suwa. Weather, **37**, 252–259.

VASILIEV, A. S. (1988): Monitoring of Main Physical Fields of the Atlantic Tropical Zone, Using the Satellite Data (Decade Discreteness). Deposited in VINITI, May, N 5754–B88, 24 pp. (in Russian).

WATANABE, T., K. HANAWA and Y. TOBA (1986): Analysis of Year-to-Year Variation of Water Temperature along the Coast of the Japan Sea. Progr. Oceanogr., **17**, 337–357.

YARICHIN, V. G. (1980): Standard of Studying Circulation of the Japan Sea Water. Trudy DVNIGMI, **80**, 46–61 (in Russian).

YARICHIN, V. G. and V. V. POKUDOV (1982): Formation of Structural Features of Hydrophysical Fields and Currents in the Northern Deep Water Area of the Japan Sea. Trudy DVNII, **96**, 86–95 (in Russian).

YURASON, G. I. (1979): Investigation of the Threedimentional Circulation in the Japan Sea Water by Numerical Methods. *In*: Gidrofizicheskiye Issledovaniya v Severnoi Chasti Tikhogo Okeana i Dal'nevostochnykh Moryakh. Vladivostok, 83–97 (in Russian).

YURASOV, G. I. and V. G. YARICHIN. Currents of the Japan Sea. Vladivostok, Pacific Oceanological Institute, in press (in Russian).

ZUENKO, Yu. I. (1989): Formation of the Japan Sea Bottom Water on the Shelf of Primorye. Intern. Symp. on the Japan and Okhotsk Seas. USSR, Nakhodka, Sept. 14 to 20, 1989. Theses of the Soviet Participants Repts. Vladivostok, Pacific Oceanolog. Inst., 14 (in Russian).