# THE WEST ALEUT STRAITS CURRENTS IN THE MONITORING REGIME

**Moroz V.V., Polyakova A.M., Demenok M.N.**

Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences, Vladivostok, Russia

## Introduction

The previous studies (Favorite, 1974; Hughes *et al.*, 1974; Batalin, 1963; Bogdanov, 1961) have stated that the structure of currents and water exchange in the Aleutian Islands Straits area is conditioned by the complicated topography, variability of tidal and non-periodic currents and by the influence of atmospheric circulation. Along with this the problems concerning water exchange type in the Aleut Straits area, and its seasonal and inter-annual variability and its forecasting have not been solved yet up to the present time. An attempt to solve these problems on the basis of system approach using the monitoring mathematical model is the aim of this study.

## Materials and Methods of Studies

For this study the area bounded by 50-60ºN and 158-172ºE has been chosen, including the most dynamically active areas of the Aleutian Islands – the Kamchatka Strait and the Near Strait.

To estimate water circulation in the given area a mathematical quasi-stationary model based on the principle of self-similarity of the second order is used. It considers the spatial distribution of water density, interaction with atmosphere, bottom topography, and β-effect. As the function possessing natural self-similarity (similarity of the vertical distribution) the sea water density is used:

$$\rho(x,y,z,t) = \xi(x,y,t)\left[\sigma(z,t) + \alpha_1\alpha(x,y,t)(z - h_\partial^y)\right] + \rho^o(x,y,t)$$

$$a_1 = \begin{cases} 0 \ \alpha t \ z \le h_\partial^y, & \alpha(x,y,t) = -\dfrac{\partial\sigma(z,t)}{\partial z}\Big|_{z=H;} \\ 1 \ \alpha t \ z > h_\partial^y, & \dfrac{\partial\alpha(x,y,t)}{\partial x} = \dfrac{\partial\alpha(x,y,t)}{\partial y} = 0; \end{cases} \tag{1}$$

where, $\rho(x, y, z, t)$ is the spatial-temporal distribution of the sea water density;

$\rho^o(x, y, t)$ is known as sea surface density;

$\sigma(z, t)$ is a stratification function;

$H$ is the depth of the bottom;

$\alpha(x, y, t)$ is a discrete-constant function regulating zero flux through the bottom;

$h_\partial^y$ is the depth of the near-bottom layer of Ekman friction;

$\xi(x, y, t)$ is a self-similarity function;

$x, y, z$ are coordinates, corresponding to the axes directed eastward, northward or vertically down;

$t$ is time.

In a quasistationary statement, computation of currents and density distribution from the tangential stress of wind and surface density leads to the equation for the transport stream function Ψ:

$$-\frac{\partial\Psi}{\partial v} + \Delta\Psi = f(T, \rho^o, f) \quad \Psi^L = \Psi_1^L; \tag{2}$$

where, $L$ is the basin contour;

$T$ is the tangential stress of the wind;

$\rho^o$ is the sea surface density;

$v$ is the relaxation parameter;

$f$ is the error function related to some additional conditions on surface current velocities.

Bringing an additional condition to the surface current velocities allows to calculate the vertical distribution of currents and components of net fluxes both inside the area and on the liquid margin. Moreover, it permits derivation of the error function resulting from the need to satisfy the discontinuity equation and water balance in the region. The equation is solved by the method of minimal errors by reaching a steady state in time interval corresponding to the period of averaging marginal and surface conditions. The explicit solution of the equation provides the gradients of self-similarity function, the self-similarity function itself, water density, level inclinations, and horizontal and vertical distribution of currents.

In more detail a mathematical statement of the problem and the model description are presented in Vasiliev (1993), where the model was used for numerical experiments investigating water dynamics in the Northwestern Pacific.

In monitoring mode the model allows to determine the state of integral water circulation from the surface down to bottom in real time according to available data on the atmospheric state (real fields of atmospheric pressure) and the sea surface (fields of temperature and salinity), considering the density profile down to the bottom in a characteristic point of the studied area.

Modern data for Komandor Islands (World Ocean Atlas, 1994) and near area off Kamchatka peninsula (the R/V cruises of the POI FEB RAS for 1989-1991) as well as all available data on temperature, salinity on the ocean surface and the atmospheric pressure fields were used as the initial information for the study. Calculations were carried out at a grid of 20′ in latitude and 10′ – longitude.

The calculation of circulation was done for all four seasons of the year considering the predominant types of atmospheric circulation typical for each season (Polyakova, 1994). The classification of atmospheric circulation is based on distinguishing standard synoptic situations over the Northern Pacific, conditioning the motion direction of the air masses related to the state of major centers of atmosphere effect and the paths of cyclones. Correspondingly for this classification 6 standard atmospheric situations in the Northern Pacific have been distinguished. Their time of existence and repetition has seasonal and multi-year character. It was stated that the maximal time of occurrence during all four seasons had the so-called "north-western" type (Fig. 1a). The presence of the anti-cyclone over Siberia and the depression in the ocean create a high-gradient field above the studied region providing a stable transfer of air masses mainly from the north-east and east to the south-west and south. The rest of standard atmospheric situations possess a well-expressed seasonal character. During the cold months it is found maximal repeating and maximal time of effect of the standard synoptic situation "cyclones over the ocean", during the warm period of the year – "okhotsk-aleutian" type of atmospheric circulation. For the standard synoptic situation "cyclones over the ocean" (Fig. 1b) it is typical the predominance of cyclone near-terrestrial fields - the development of strong cyclone activity over the whole Northern Pacific in the band of 20°-60°N. Note that over the Komandor-Kamchatka area a transportation of the masses from the east takes place. The next one "okhotsk-aleutian" type of the atmospheric circulation (Fig. 1c) is characterized, first of all, by the Okhotsk Depression observed over the Bering Sea and over the Kamchatka area. Over the investigated area there is the air masses motion in a cyclone gyre. In this area, the southern and southeastern wind are predominant.

Considering maximal repetition and effect of the above enumerated three types of the atmospheric processes the calculation of the integral circulation of waters in the of Kamchatka and Near Straits was done for these standard situations.

## Analysis of the Obtained Results

Numerical calculations of integral water circulation in the studied region are given for typical months of each season when the circulation maximally concerns the impact of the seasonal atmospheric effect (Fig.2, 3).

### *Winter (December-March)*

For winter period with the "north-western" type of the atmospheric circulation water circulation (Fig. 2a) is quite corresponding to the direction of air masses transport (in the area of the Western Aleutian Straits transport is from the northeast). In the Near Strait two-way circulation with the well-expressed flow out of the Bering Sea is observed. In the Kamchatka Strait a predominant flow out of the Bering Sea is observed. Estimation of the integral discharge (Table 1) shows that in winter

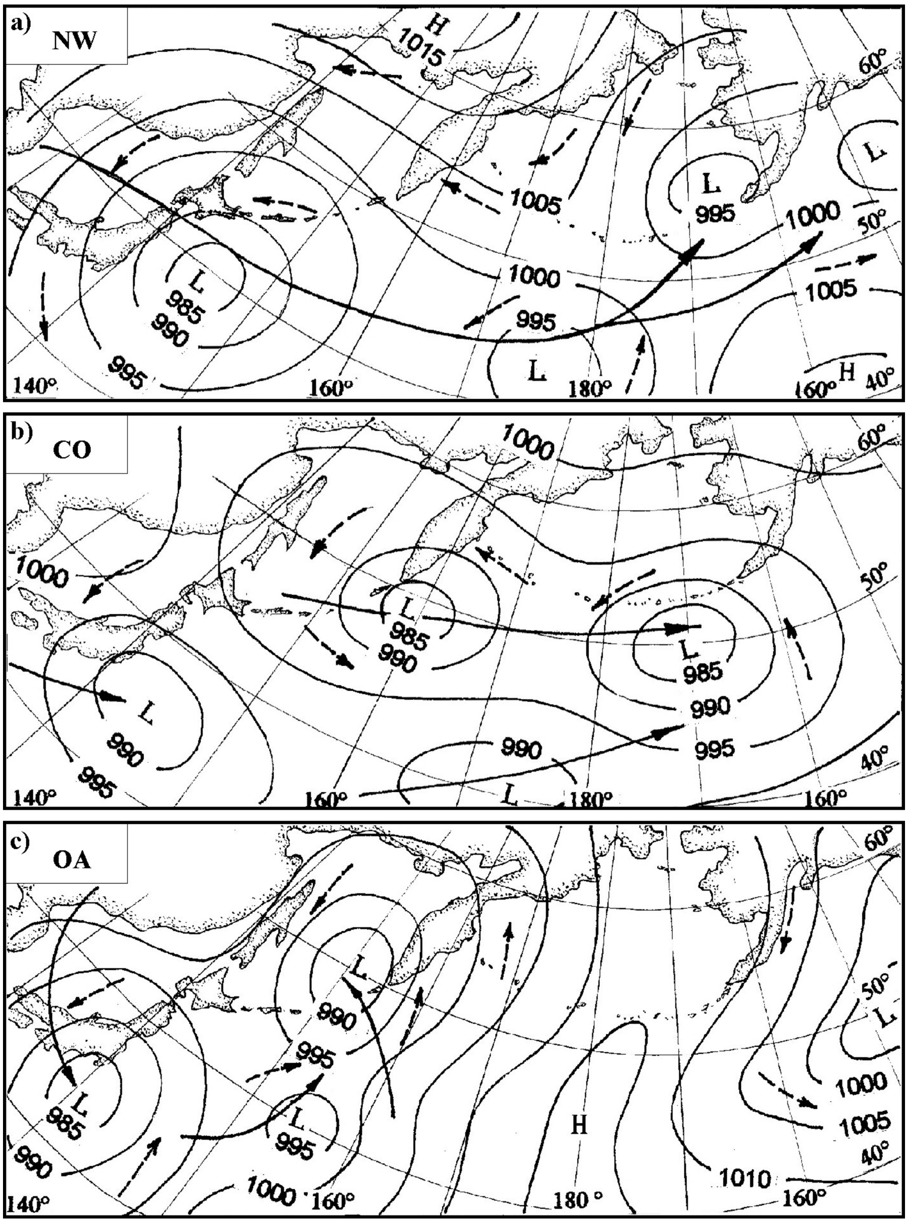

*Fig.1. Predominant types of the atmospheric processes in Spring (April-June)*

Table 1

***Integral Waters Circulation in the Aleutian Straits (0 m – the bottom) in Sv (Sv=$10^6$ m$^3$/s)***

| Winter | | Spring | | Summer | | Fall | |
|---|---|---|---|---|---|---|---|
| NW | CO | NW | OA | NW | OA | NW | CO |
| Kamchatka Strait | | | | | | | |
| -3.62 | -1.70 | -1.93 | -1.23 | -1.03 | -0.71 | -9.61 | -1.42 |
| 0.98 | 0.32 | 0.61 | 0.92 | 0.13 | 0.55 | 4.81 | 0.46 |
| Near Strait | | | | | | | |
| -0.49 | -2.00 | -0.46 | -0.50 | -0.25 | -0.44 | -3.90 | -2.08 |
| 4.82 | 3.32 | 1.38 | 2.07 | 0.96 | 1.24 | 6.58 | 3.38 |

Notes:
Positive values – input of the Pacific waters, Negative values – flow of the Bering Sea waters;
NW – “north-western” type of atmospheric circulation;
CO – “cyclones over the ocean” type of atmospheric circulation;
OA – “okhotsk-aleutian” type of atmospheric circulation.

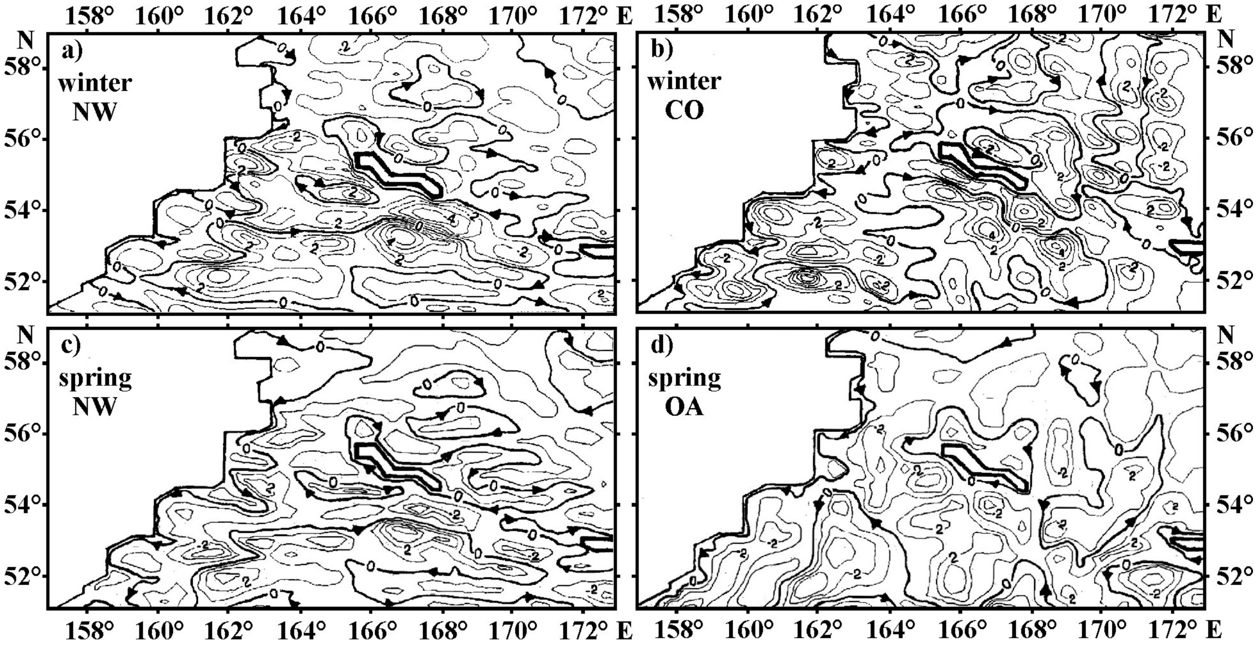

*Fig. 2 The transport stream functions (Sv) from the surface to the bottom in West Aleutian Islands Straits area at predominant types of atmospheric circulation: (a), (b)-winter; (c), (d)-spring*

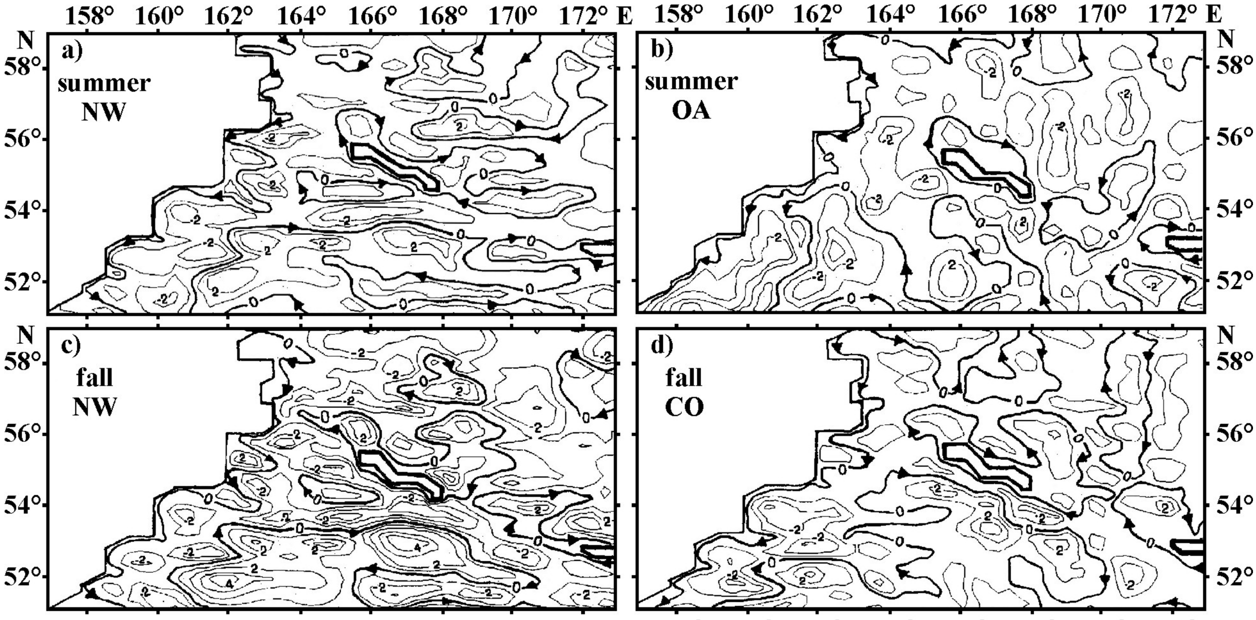

*Fig. 3. The transport stream functions (Sv) from the surface to the-bottom in West Aleutian Islands Straits area at predominant types of atmospheric circulation: (a), (b)-summer; (c), (d)-fall*

season with the "north-western" type of the atmospheric circulation the Kamchatka Strait is the outflow strait with the maximal transport of the Kamchatka current up to -3.62 Sv. Under the standard atmospheric circulation of "cyclones over the ocean" the scheme of waters circulation is significantly changed (Fig. 2b). It draws attention to the change of water circulation in the Kamchatka Strait where two-way circulation of water is formed. In the area of the Near Strait "a close package" of the vortex formations of non-uniform direction is observed.

For spring period with the "north-western" type of the atmospheric circulation the water circulation at the end of period (June) is increasing in comparison with winter period. In the Near Strait zone a growing number of the vortices of various sign is marked. On the Pacific side of this strait the anticyclone formed by the branch of Alaska current is well seen (Fig. 2c). In the Kamchatka Strait a predominant flow out of the Bering Sea water with the Kamchatka current is preserved and getting somewhat weaker (up to

-1.93 Sv). For spring period (Polyakova, 1994) a decrease in the frequency of synoptic situation of the “cyclones over the ocean ” type and an increase in the repetition of the “okhotsk-aleutian” atmospheric circulation are typical. The “okhotsk-aleutian” type of the atmospheric circulation (air mass transport in the area of the Aleutian Islands from the south, southeast) considerably changes the water fluxes direction especially in the Kamchatka Strait (Fig. 2d). Here the currents are oriented mainly to the Bering Sea providing predominant supply of the Pacific waters through the strait. Balance of discharge through the strait shows the increase in waters supply (as compared to the previous type of the atmospheric circulation) from 0.32 Sv up to 0.92 Sv (Table 1). In the area of the Near Strait a large number of various sign vortices is formed.

### Summer (July-September)

In summer period, the “north-western” type of the atmospheric circulation is the least intensive (Polyakova, 1994). It considerably changes the temperature field towards the higher values. The water circulation of the area changes as well (Fig. 3). Another type of the atmospheric circulation “okhotsk-aleutian” is typical for the summer period. It somewhat changes the scheme of water circulation in the area (Fig. 3b). In the Kamchatka Strait it forms a two-way direction of water motion (unlike winter season when at the given type of the atmospheric circulation the predominant flow out of the Bering Sea was observed). In the Near Strait there are also changes in waters circulation. We observe the cyclone gyre in central part of the strait. Estimations of water discharge through the strait show a considerable value of the Bering Sea waters flow out – 1.08 Sv, and for the Pacific waters supply – just 0.13 Sv (Table 1).

### Fall (October-November)

Fall period, like spring, is the time of atmospheric process reformation over the Northern Pacific. It increases the time of effect of the “north-western” type of the atmospheric circulation and is changing the “okhotsk-aleutian” type for “cyclones over the ocean” (Polyakova, 1994). The water temperature changes towards the lower values. Correspondingly, it changes the pattern of water circulation in the area (Fig. 3c, d). It is observed a significant increase in water circulation intensity. With the “north-western” type of the atmospheric circulation, like with the “cyclones over the ocean”, the scheme of currents in the Kamchatka and Near Straits preserves two-way orientation.

## Conclusion

Thus, presented studies of seasonal variability of water circulation in the area of Western Aleutian Straits carried out with concern for the predominant types of atmospheric circulation on the basis of monitoring mathematical model allowed to find out some peculiarities of water exchange through the straits at different types of synoptic situation typical for a certain season.

In the Kamchatka Strait it is observed the predominant flow out of the Bering Sea with the Kamchatka current under the “north-western” type of atmospheric circulation, as well as during the standard synoptic situation “cyclones over the ocean” in fall and winter period. The predominant supply of the Pacific water is observed only with the “okhotsk-aleutian” type of atmospheric circulation in spring period.

In the Near Strait the predominant flow in the Pacific ocean waters is observed with the “north-western” type of the atmospheric circulation in summer period. Well expressed a two-way scheme of the water circulation is formed with the standard synoptic situation “cyclones over the ocean” in winter and fall seasons. With the “okhotsk-aleutian” standard synoptic situations in spring and summer period the circulation in the straits is represented by the flows of non-uniform direction, which are conditioned by the “close package” of the vortex formations of various sign.

Comparison of the obtained schemes of circulation with the results of instrumental observations (Kinder *et al.*, 1980; Stabeno & Reed, 1994) in the area of the Western Aleutian Straits, as well as with the schemes obtained by various authors for this region (Favorite, 1974; Hughes *et al.*, 1974; Overland *et al.*, 1994; Batalin, 1963; Bogdanov, 1961) provided a good correspondence.

The obtained results can be used for developing the forecasts of hydrological conditions in the area of Western Aleutian Straits.

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