Russian Journal of Earth Sciences

Estimation of Volume, Heat and Salt Transport Between the Bering Sea and the Pacific Ocean Through the Near Strait

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Abstract: The work is devoted to the quantitative assessment of volume, heat and salt transport through the Near Strait based on GLORYS12V1 data for the period 1993–2021. The paper shows that the predominant direction of water exchange through the strait is inflow from the Pacific Ocean to the Bering Sea. The influence of atmospheric forcing has been established. There is a pronounced seasonal variability in all three parameters, volume, heat, and salt transport, with maximum values recorded in winter and minimum values in summer. The monthly averaged volume transport through the strait varies from 2.8 Sv (1 Sv = $10^6\,\mathrm{m^3\cdot s^{-1}}$) in September to 4.9 Sv in January, for the heat transport in winter it reaches maximum values of 1.0×10^{18} W, while summer values do not exceed 7.5×10^{17} W. Salt transport shows seasonal variability too: in the cold season, the monthly averaged values are 1.6×10^{15}–$1.8\times10^{15}\,\mathrm{g\cdot s^{-1}}$ and in the warm season it does not exceed $1.3\times10^{15}\,\mathrm{g\cdot s^{-1}}$. The analysis of interannual variability revealed extreme values: in 1995, 2017 and 2018, the maximum average daily volume transport exceeding 15 Sv was recorded, while the minimum values (less than −5 Sv) were observed in 1998, 2000 and 2021. The absolute peaks of salt transport ($5.7\times10^{15}\,\mathrm{g\cdot s^{-1}}$) and volume transport (15.6 Sv) were recorded in 1995, and the peak of heat transport (3.2×10^{18} W) occurred in 2017–2018. On the contrary, 2021 was marked by record low values of all parameters: heat transport reached -1.7×10^{18} W, salt transport $-2.7\times10^{15}\,\mathrm{g\cdot s^{-1}}$, and volume transport −7.6 Sv. The influence of mesoscale eddies on water exchange is described: an inflow in 2018 was formed when the Alaskan jet Stream passes through the strait in the absence of the blocking action of eddies or when the waters leave the periphery of the eddies in a northerly direction, while the negative transport rate (outflow) in 1998 was formed by "blocking" the penetration of the Alaskan Stream by mesoscale eddies with an increase in the North Aleutian slope current in the southeastward direction.

Keywords: water exchange, Bering Sea, GLORYS12V1 reanalysis, Near Strait, volume transport, heat and salt transport

Citation: Khudyakova S. P., Belonenko T. V., Budyansky M. V., and Uleysky M. Yu. (2026), Estimation of Volume, Heat and Salt Transport Between the Bering Sea and the Pacific Ocean Through the Near Strait, *Russian Journal of Earth Sciences*, 26, ES1004, EDN: FFMOSM, https://doi.org/10.2205/2026es001053

Research Article

Received: June 22, 2025
Accepted: September 1, 2025
Published: February 25, 2026

1. Introduction

The Aleutian Ridge straits are an important part of the water exchange system between the subarctic North Pacific and the Bering Sea [*Ueno et al.*, 2009]. One of the main factors determining the dynamics in straits is the presence of strong ocean currents. To the south of the Aleutian Islands, there is an Alaskan Stream, which moves westward along the archipelago and continues as the Aleutian North Slope Current [*Stabeno et al.*, 2009]. According to research, about half of the Alaskan Stream waters penetrate the Bering Sea through the deepest straits of the archipelago, such as Amukta, Amchitka and Near straits [*Mordy et al.*, 2023]. Also, the water exchange in the area of the Aleutian Islands determines the interannual variability of sea level in this region [*Belonenko et al.*, 2009].

Of particular interest is the spatial inhomogeneity of the waters of the Aleutian Archipelago, which are divided into two ecologically different regions: east of the Samalga Strait (169°W), warm, fresh and chlorophyll-rich waters of the Alaskan coastal current dominate, while westward, colder and saltier waters with a reduced concentration of chlorophyll-*a* predominate, which, according to research data [*Hunt and Stabeno*, 2005; *Mordy et al.*, 2005], it contributes to the spatial separation of some commercial fish species.

The Near Strait is the widest among the straits of the Aleutian archipelago (Figure 1). The strait is located in the western part of the Aleutian Ridge and is a key route for the Alaskan Stream waters to the Bering Sea. According to [*Stabeno et al.*, 1999], this transport is estimated in the range of 6–12 Sv. Earlier observations by [*Reed and Stabeno*, 1993] recorded volume transport in the Near Strait at about 5 Sv in September 1992. In general, the waters of the Alaskan Stream mainly flow into the Bering Sea through the Near Strait in a northward direction [*Hunt and Stabeno*, 2005; *Reed et al.*, 1992].

While a typical circulation is characterized by the inflow from the Alaskan Stream into the Bering Sea through the Near Strait, significant circulation anomalies are noted in some cases. The first such anomaly, documented by [*Reed and Stabeno*, 1993], occurred in 1990 and lasted for more than a year. During this period, the Alaskan Stream did not pass through the Near Strait, but deviated south from Attu Island, followed by a turn to the east. These deviations from the typical circulation and the associated variability of volume transport emphasize the need to take into account mesoscale dynamics, which influence on the flow in the straits of the Aleutian Ridge is noted in modern studies.

In the study [*Ezer and Oey*, 2013], the Near Strait is classified as a wide strait with a specific type of circulation – its hydrodynamic regime is formed under the influence of a complex system of currents generated by mesoscale eddy formations. Subsequent works [*Budyansky et al.*, 2022; *Khudyakova et al.*, 2023] contain a detailed description of these eddy structures observed in the strait area, including an analysis of their spatial and temporal variability and impact on regional water exchange.

In [*Lyman and Johnson*, 2015], a quantitative assessment of the heat transport carried by eddy structures in the Alaskan Stream system was carried out for the period from January 2003 to April 2012. The authors identified two types of anticyclonic eddies: 1) eddies of the Subarctic gyre and 2) eddies of the Alaskan Stream. The study revealed significant interannual variations in western heat transport by these eddies in the range from 0 to $50.4 \times 10^{18}\,\mathrm{J \cdot yr^{-1}}$ ($\approx 1.6 \times 10^{12}$ W). It is noteworthy that the total contribution of cyclonic eddies to the transport of heat and fresh water along 150°W turned out to be significantly lower in comparison with anticyclonic eddies, which indicates the dominant role of the latter in the processes of heat and salt transfer in the region. The study [*Freeland*, 2002] presents the first quantitative estimates of the heat transport in the Gulf of Alaska. An analysis of the data on the line-P section revealed a pronounced maximum of heat transport in late 1997 and early 1998, when the values reached 25×10^{12} W. It is important to note that this value turned out to be comparable with subsequent estimates of heat transport carried out by eddy structures [*Lyman and Johnson*, 2015], which emphasizes the key role of mesoscale eddies in the formation of the thermal balance of the region.

The Bering Sea water circulation was analyzed based on numerical modeling in the study [*Clement Kinney and Maslowski*, 2012]. The results revealed significant interannual variability of water exchange in the area of the western Aleutian Islands (Buldir, Near and Kamchatka Straits) and the key role of mesoscale eddies in the dynamics of currents causing changes in their direction. Volume transport through the Strait over the 26-year observation period (1979–2004) ranged from −9.5 Sv (outflow) to 18.3 Sv (inflow). The observed positive (northward) transport showed pronounced instability with multiple speed drops to zero and seven complete changes of direction. The duration of these abnormal periods varied from three months to two years. Such complex dynamics is directly related to the eddy activity forming on both sides of the strait (its northern and southern parts). Of particular interest is the discovered dependence of current reversals on the spatial position of mesoscale eddies, which emphasizes their key role in the formation of the hydrodynamic regime of the strait. The obtained results clearly indicate the insufficiency of short-term observations (even lasting several years) for a reliable assessment of the average values of water exchange, which must be taken into account when planning future studies and interpreting their results.

Despite the existing publications on the assessment of water exchange through the straits of the Aleutian Ridge, most of the presented studies have significant gaps: they do not take into account the accompanying heat and salt fluxes, nor do they cover measurements during the 21st century. Modern methodological approaches combining numerical modeling with data from satellite remote sensing of the ocean are fundamentally changing the situation. They are based on advanced measurement technologies and make it possible to study the mechanisms of current reversal in the Near Strait, including analysis of the role of mesoscale eddies, seasonal and interannual variability. The purpose of this study is to evaluate the key parameters of water exchange through the Near Strait using modern ocean reanalysis GLORYS12V1, including not only volume transport, but also heat and salt transport that are fundamentally important for climate research.

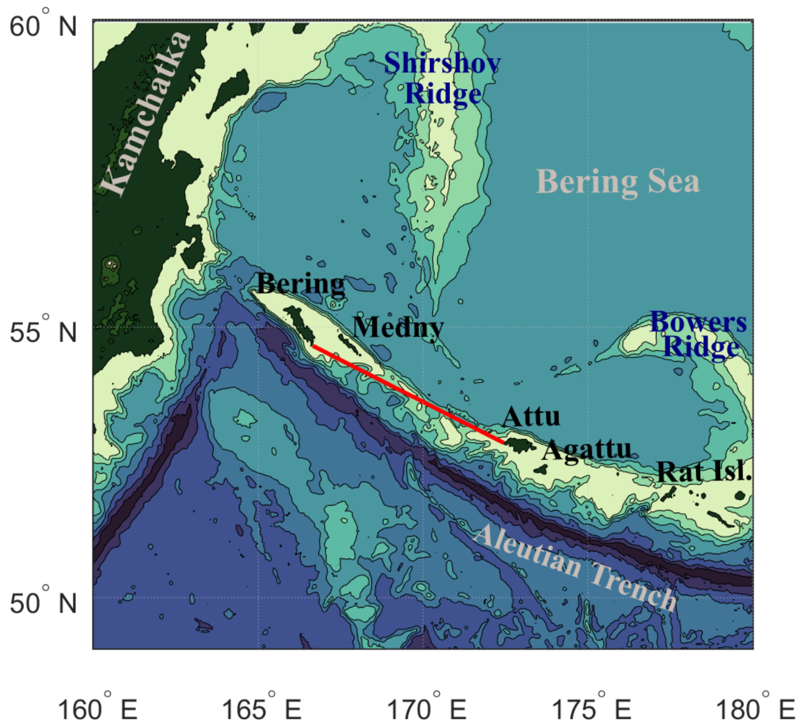

Figure 1. The Near Strait (red line) on the GEBCO_2021 depth chart.

2. Data

2.1. Ocean Reanalysis GLORYS12V1

The work uses the ocean reanalysis GLORYS12V1, based on the global CMEMS forecasting system (Copernicus Marine Environment Monitoring Service, http://marine.copernicus.eu) and covering satellite altimetry data since 1993. The output data is displayed on a standard regular grid with a spatial resolution of 1/12° (approximately 8 km) and at 50 z-levels. The GLORYS12V1 reanalysis assimilates along-track data from high-resolution altimeters, as well as satellite observations of sea surface temperature, sea ice concentration, and in situ temperature and salinity profiles. The basis of the reanalysis is the NEMO (Nucleus for European Modeling of the Ocean) model, where ECMWF ERA-Interim reanalysis is used as an atmospheric forcing. Observations are assimilated using a reduced-order Kalman filter. For the analysis, the daily zonal (u) and meridional (v) components of the flow velocity were used at 50 available horizons in the period from January 1, 1993 to June 30, 2021.

2.2. Atmospheric Circulation Indices (NPI and ALPI)

Atmospheric circulation indices were used to analyze the influence of atmospheric processes on oceanic dynamics.

The North Pacific Index (NPI) is an anomaly (relative to the long-term average) pressure at sea level in the region of 30°–65°N, 160°E–140°W for five months (November–March). The method of calculating the index based on sea-level pressure (SLP) is described in [*Trenberth and Hurrell*, 1994]. Positive NPI values indicate a weaker than usual Aleutian Low. The data is available on the website of The National Center for Atmospheric Research (NCAR) and covering the period from 1899 to the present (https://climatedataguide.ucar.edu/climate-data/north-pacific-np-index-trenberth-and-hurrell-monthly-and-winter).

The Aleutian Low Pressure Index (ALPI) is an index that is used as an indicator of the relative intensity of the low atmospheric pressure system in the North Pacific Ocean (from December to March). It is calculated as an average value over an area (km^2) with a sea-level pressure of more than 1005 gPa and expressed as a deviation from the average value. The positive value of the index reflects a relatively strong Aleutian Low. In 2015, the index was completely updated using a new method [*Surry and King*, 2015]. The data is available for the period from 1900 to 2015 on the portal of Fisheries and Oceans Canada (https://open.canada.ca/data/en/dataset/4bb821ce-bef7-46d3-95d2-064065f1bda4).

The interpretation of the NPI and ALPI indices is the opposite: negative NPI values indicate an increase in the Aleutian Low, while positive ones indicate its weakening. For the ALPI positive values correspond to an increase, and negative values correspond to a weakening of the Aleutian Low. It is important to note that ALPI, unlike NPI, takes into account not only pressure anomalies, but also the spatial characteristics of the Aleutian Low, such as depth (minimum pressure in the center), position (coordinates of the center) and area (an area with a pressure below a given threshold, for example, 1000 gPa).

3. Methods

3.1. The coordinate system rotation

In order to accurately calculate the volume transport, as well as the heat and salt transport through the Near Strait, it is necessary to determine the components of the flow velocity normal to the strait axis. To do this, we carried out a transformation of the initial geographical coordinate system (where the x-axis is oriented to the east and the y-axis to the north), reorienting the axes in accordance with the direction of the strait. Formulas for rotating the coordinate axes are used:

$$U = u\cos\theta - v\sin\theta,$$

$$V = u\sin\theta + v\cos\theta,$$

where u, v are the zonal and meridional components of the current velocity, $\theta = 25°$ is the angle between the parallel and the axis of the strait. The values of the velocity component V normal to the strait along its axis were obtained at each point on the calculated horizons using bilinear spatial interpolation.

3.2. Volume Transport Calculation

To estimate the volume of water flowing northward (Q_+) from the ocean to the Bering Sea (inflow), and southward (Q_-) from the Bering Sea to the Pacific Ocean (outflow), the following expressions are used:

$$Q_+ = \iint\limits_{X_1 Z_0}^{X_2 Z_b} V_+(x,z)\,dz\,dx,$$

$$Q_- = \iint\limits_{X_1 Z_0}^{X_2 Z_b} V_-(x,z)dzdx,$$

where V_+ are positive (northward) values of the normal velocity component, V_- are the negative (southward) values of the normal velocity component, x_1 and x_2 are the horizontal boundaries of the section, and z_0 and z_b are the lower and upper limits of vertical integration, with the z-axis pointing upward. The net volume transport (Q) is calculated using the formula:

$$Q = Q_+ - |Q_-|.$$

3.3. Heat and Salt Transport Calculation

Heat transport from the Pacific Ocean to the Bering Sea (Q_{T+}) and in the opposite direction (Q_{T-}) are calculated using the formulas:

$$Q_{T+} = \iint\limits_{X_1 Z_0}^{X_2 Z_b} V_+(x,z)H\rho dzdx,$$

$$Q_{T-} = \iint\limits_{X_1 Z_0}^{X_2 Z_b} V_-(x,z)H\rho dzdx.$$

Salt transport from the Pacific Ocean to the Bering Sea (Q_{S+}) and in the opposite direction (Q_{S-}):

$$Q_{S+} = \iint\limits_{X_1 Z_0}^{X_2 Z_b} V_+(x,z)S\rho dzdx,$$

$$Q_{S-} = \iint\limits_{X_1 Z_0}^{X_2 Z_b} V_-(x,z)S\rho dzdx,$$

where H is the heat content (specific enthalpy) of seawater ($\mathrm{J \cdot kg^{-1}}$), ρ is the density of seawater ($\mathrm{kg \cdot m^{-3}}$), S is the salinity of seawater ($\mathrm{g \cdot kg^{-1}}$), T is the temperature of seawater (°C). The net heat and salt transport (Q_T, Q_S) are defined as:

$$Q_T = Q_{T+} - |Q_{T-}|,$$

$$Q_S = Q_{S+} - |Q_{S-}|.$$

The thermodynamic equations of seawater 2010 (TEOS-10) were used to calculate the density and heat content (specific enthalpy) of seawater. Additionally, the conversion of practical salinity (psu) to absolute salinity (g/kg) was performed.

4. Results

4.1. Daily Volume, Heat and Salt Transport for the Period 1993–2021

The temporal variability of the volume transport of waters from the Pacific Ocean to the Bering Sea through the Near Strait is shown in Figure 2. It turned out that for most of the time interval from 1993 to 2021, the inflow Q_+ from the Pacific Ocean to the Bering Sea significantly exceeds the outflow Q_-, which indicates the predominance of ocean water supply to the Bering Sea. In some years, only positive transport rates have been observed (in 1994, 2003, 2004, and 2005), indicating a predominance of the northward flow direction through the strait. The maximum annual volume transport for the period from 1993 to 2021 varies from 7.2 Sv in 2021 to 15.6 Sv in 1995. In some years (1995, 2017, 2018), the maximum average daily transport exceeded 15 Sv. Nevertheless, there are some episodes with negative transport rates, when the outflow from the Bering sea exceeds the inflow. The lowest negative transport rates (less than -5 Sv) were recorded in 1998, 2000 and 2021. The minimum transport was recorded in March 2021 and amounted to -7.6 Sv.

The volume transport through the Near Strait is both in the northern (inflow) and southern (outflow) directions, which is also typical for the heat and salt transport. The heat transport varies in a wide range: from -1.7×10^{18} W in 2021 to 3.2×10^{18} W in 2017–2018. The extreme values of the salt transport are also multidirectional: a maximum of 5.7×10^{15} $g \cdot s^{-1}$ was recorded in 1995, and a minimum of -2.8×10^{15} $g \cdot s^{-1}$ in 2021 (Figure 2).

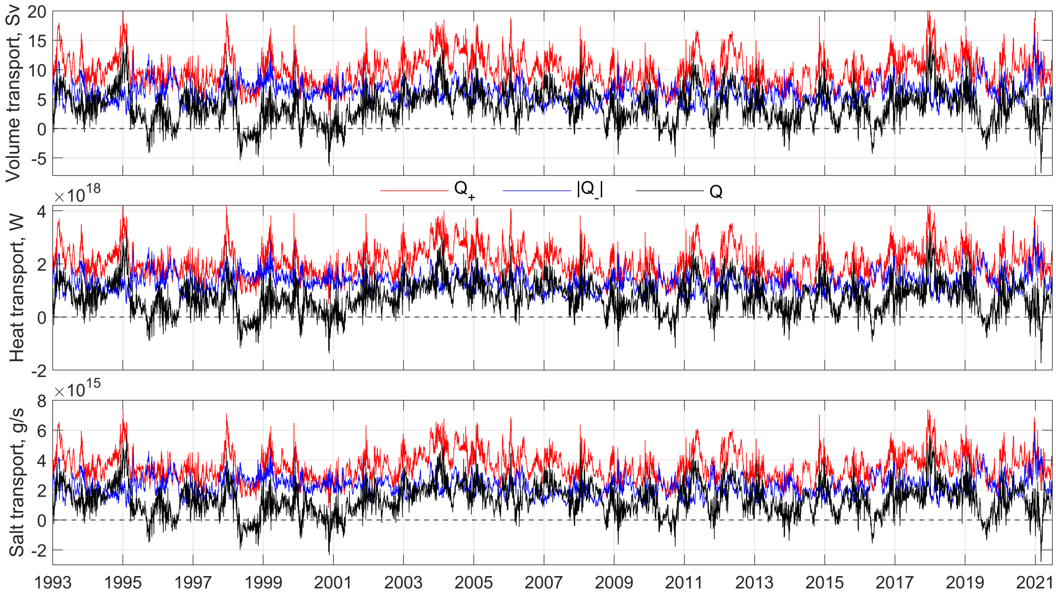

Figure 2. Inflow (in red), outflow (in blue) and transport (in black) of water (above), heat (in the center) and salt (below) and through the Near Strait according to GLORYS12V1.

In the period from 2002 to 2007, the daily volume transport practically did not fall below zero, demonstrating the stability of hydrological processes. As well as for other certain years – 1993, 1994, 1997, 2012, 2017 and 2018 – where negative values of volume transport were recorded on less than seven days a year. A similar dynamic can be traced in the heat and salt transport: their curves cross the zero mark, which is explained by the inclusion of the normal velocity component in the calculations. These patterns reflect the subtle interrelation of hydrodynamic processes and provide valuable information about the mesoscale variability of the system.

Table 1 summarizes the average values of volume, heat, and salt transport for the period from 1993 to 2021. On average, the Near Strait passed 3.7 Sv of water, confidently demonstrating the dominance of the northern component of the current. Together with this powerful jet of water, an average of 7.4×10^{17} W of heat and 1.3×10^{15} $g \cdot s^{-1}$ of salt were transported, as indicated by positive averages.

Comparing our results with other estimates [*Yang and Yuan*, 2016], it can be noted that in the North Pacific Ocean (between 45°–50°N), the meridional heat flux is 0.1×10^{15} W, and the meridional salt flux is 0.3×10^{9} $g \cdot s^{-1}$. These estimates are significantly lower than our estimates, which may be due to the fact that they were calculated for the period 2004–2012 and only for the upper 50-meter layer. According to the results of numerical modeling [*Clement Kinney and Maslowski*, 2012], the average heat transport through the Near Strait for the period 1979–2004 was 1.4×10^{14} W, while the maximum depth of the strait was taken into account up to 1500 m. In our study, all available horizons (up to 3500 m) were used for calculations and the area to the north (52°–53°N) was taken, where the influence of the Alaskan Stream is traced. This may be due to the authors' underestimation of heat and salt fluxes in this region, which we clarified in our study.

Table 1. Comparison of modeled and observed net volume, heat and salt transport for Near Strait

Observation	GLORYS12V1	[*Ezer and Oey*, 2013]	[*Clement Kinney and Maslowski*, 2012]	[*Stabeno et al.*, 1999]	[*Reed and Stabeno*, 1993]
Volume transport, Sv	3.7 (1993–2021)	2.6 (13 years of simulation without any forcing)	5.1 (1979–2004)	6–12 (discontinuous)	4.5 (September 1992)
Heat transport, W	7.4×10^{17} (1993–2021)	–	1.4×10^{14} (1979–2004)	–	–
Salt transport, $g \cdot s^{-1}$	1.3×10^{15} (1993–2021)	–	–	–	–

4.2. Seasonal Variability of Volume, Heat and Salt Transport

Figure 3 shows the monthly average values of volume, heat and salt transport through the Near Strait for the period from 1993 to 2021. The monthly average volume transport ranges from 2.8 Sv in September to 4.9 Sv in January, reflecting a clear seasonal trend, with the maximum transport occurring in the winter months and the minimum in the autumn months. This pattern is partially confirmed by the results of [*Clement Kinney and Maslowski*, 2012], which record an annual minimum in September and a maximum in November, but our observations show a shift of the peak to January. Perhaps the peak shift is due to the fact that Kinney and Maslowski analyzed the period 1980–2004, while our study covers 1993–2021. Climatic changes and long-term variability can affect the seasonal transport, which leads to a shift in extremes.

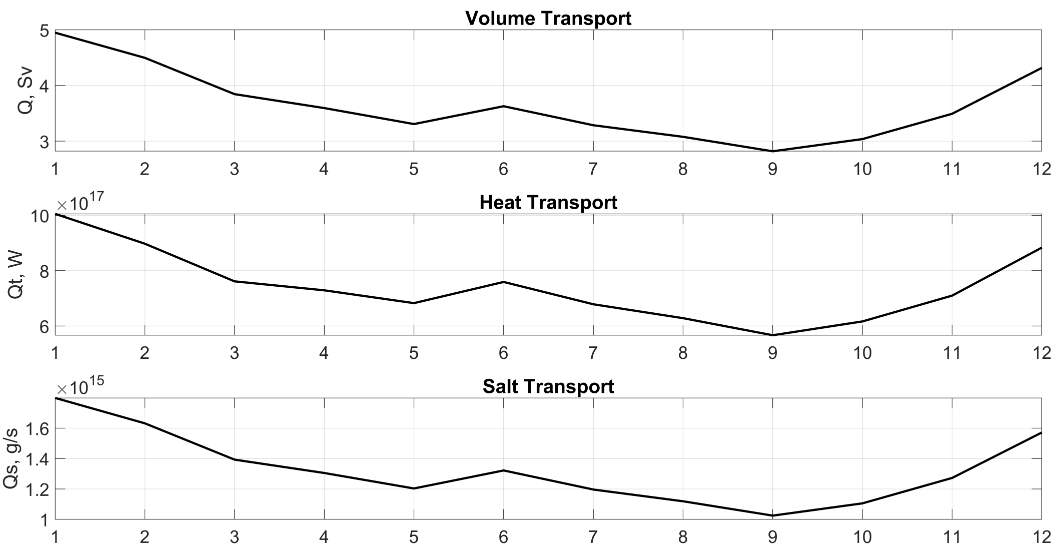

Figure 3. Monthly average volume (top), heat (center) and salt (bottom) transport through the Near Strait according to GLORYS12V1 data.

In the period from December to March, the Near Strait is characterized by intensive water exchange, with a transport rate reaching 4–5 Sv, which reflects increased circulation during the cold season. In the summer months (July–October), the volume transport decreases to about 3 Sv, which is a typical seasonal phenomenon.

The transport of heat and salt in the strait demonstrate a pronounced seasonal variability. In winter, the heat transport reaches significant values – from 8.8×10^{17} W in December to a peak of 1.0×10^{18} W in January, while in the summer months its intensity decreases markedly, not exceeding 7.5×10^{17} W. In parallel, the salt transport repeats this trend: in winter it ranges from 1.6×10^{15}–1.8×10^{15} $g \cdot s^{-1}$, and in summer it falls below 1.3×10^{15} $g \cdot s^{-1}$. These synchronous seasonal changes emphasize the profound influence of the atmospheric cycles on the salt and heat balance of the strait, forming its unique regime.

The authors [*Prants et al.*, 2019; *Zhabin et al.*, 2021] have identified a clear relationship between the seasonality of the hydrological characteristics of the Near Strait and atmospheric processes. In winter, when the Aleutian Low increases over the islands of the archipelago, the strait becomes the scene of powerful winds that cause maximum values of daily volume transport, as well as heat and salt transport. In summer, on the contrary, the calm of the summer wind circulation regime is established, which leads to a weakening of the wind and, as a result, to a noticeable decrease in transport rates through the strait.

4.3. Interannual Variability of Volume, Heat and Salt Transport

Figure 4 shows the average annual values of volume, heat and salt transport through the Near Strait for the period from 1993 to 2021, reflecting the dynamics of these key parameters in different years. The average annual volume transport shows remarkable variability: from a relatively modest 0.6 Sv in 1998 to an impressive 6.2 Sv in 2004. Interestingly, it was only in 1998 and 2000 that the transport rates were below one, whereas in years such as 1994, 2003, 2004, 2012, 2017 and 2018, the transport steadily exceeded the 5 Sv, demonstrating periods of significant intensification of water exchange. The heat transport during these same periods also indicates powerful energy transfer processes, significantly exceeding 1.0×10^{18} W. In parallel with the heat during these periods, significantly increased salt transport values are observed: with absolute values from 2.0×10^{15} $g \cdot s^{-1}$ to 3.1×10^{15} $g \cdot s^{-1}$. Such consistency in the increase of thermal and salt fluxes indicate a close relationship between the processes that form the dynamics of the strait and have an important impact on the marine ecosystem and the hydrological balance of the region.

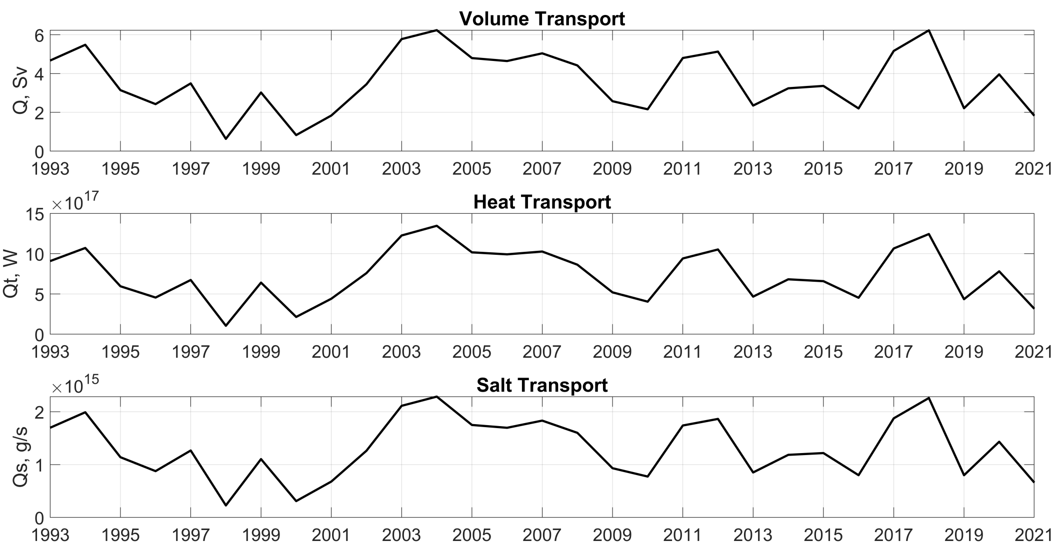

Figure 4. Annual average volume (top), heat (center) and salt (bottom) transport through the Near Strait according to GLORYS12V1 data.

4.4. Mesoscale Dynamics Contribution to Water Exchange Through the Near Strait

The dynamics of water masses in the area of the Near Strait is significantly influenced by mesoscale oceanic eddies, which play a key role in the formation of seasonal and interannual variations in volume, heat and salt transport discussed above. This section analyzes the mechanisms responsible for the observed variability. Further analysis showed that these phenomena are directly related to the blocking effect of mesoscale eddies on the penetration of the Alaskan Stream into the strait. It is the interaction of eddy structures with the main current that creates stable conditions under which transport changes direction, limiting the flow and forming long periods of outflow. The inflow of water is limited, and the outflow becomes dominant and extended over time. The study showed that it is the anticyclonic eddies steadily stagnating on the northeastern periphery of the strait that generate a steady southward current. A detailed analysis of the average velocity field from

June to November 1998 (Figure 5) revealed a powerful anticyclonic eddy on the western side of the strait and a cyclonic eddy on the eastern side. The interaction of these two eddies blocks the northward flow, as a result of which the south stream, the outflow through the Near Strait, becomes dominant. Thus, mesoscale eddies play a key role in the formation of a complex and stable hydrodynamic regime of the strait, significantly changing the regional water exchange.

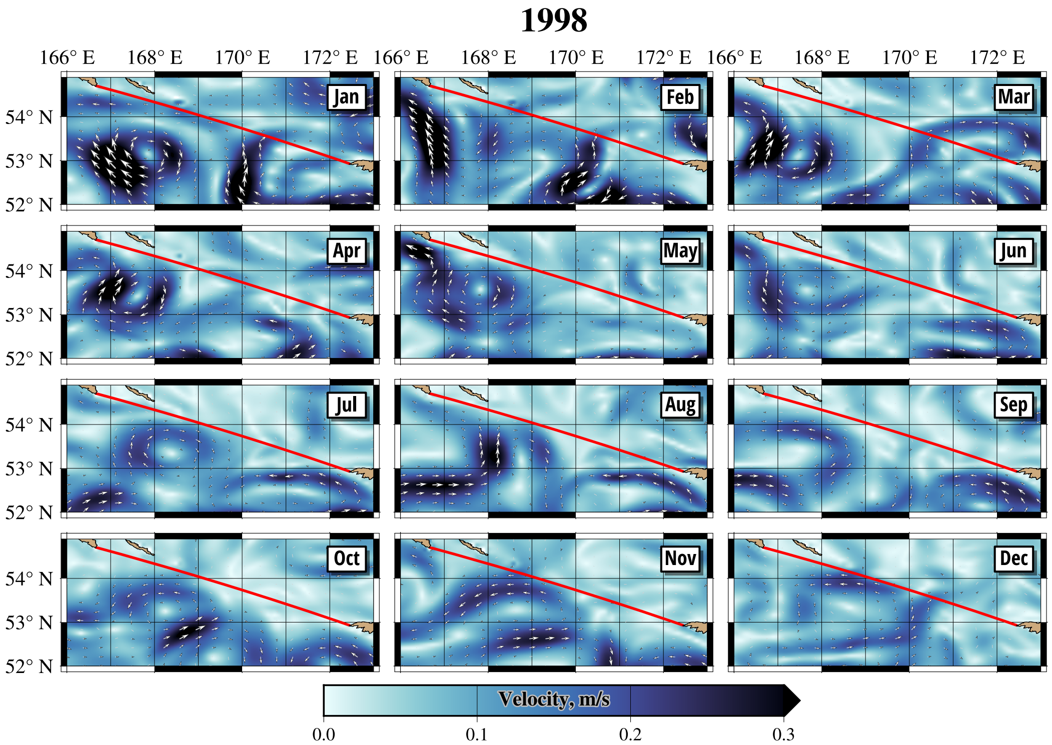

Figure 5. Monthly average surface velocity field in the area of the Near Strait according to GLORYS12V1 data for 1998.

Another episode of the eddy's influence on the water flow in the Near strait is described in the paper [*Khudyakova et al.*, 2025], but this case in March 2021 differs from those described above. Rather, it was the result of a unique combination: the presence of a mesoscale eddy south of the axis of the strait, the passage of a string of atmospheric cyclones over the Bering Sea, and the strengthening of the Aleutian North Slope Current. It is noteworthy that in the first half of 2001, a similar pattern was observed: the jet increased north of the axis of the strait in a south and southwesterly direction, which was also accompanied by the outflow of waters from the Bering Sea into the Pacific Ocean.

A positive transport (inflow in the Bering Sea) is noted during periods of dominance of the Alaskan jet Stream in the Near Strait in the absence of the blocking influence of eddy formations or during the outflow of waters from the periphery of the eddies to the north (as, for example, in 1994, 2003, 2004, 2018). Figure 6 shows the fields averaged for each month of 2018, which show a steady flow of Pacific waters through the central part of the Near Strait throughout the year. This phenomenon correlates with the positive values of volume, heat and salt transport in 2017–2018, shown in Figure 2.

Along with this, periods of relative balance between inflow and outflow of waters are observed in the hydrodynamics of the Near Strait. Thus, in the first half of 1997, the Alaskan Stream was oriented parallel to the axis of the Near Strait. During this period, there are relatively low transport rates (less than 3 Sv), which is due to the slight predominance of inflow over outflow.

4.5. Transport Connection With Atmospheric Circulation Indices and the Strengthening of the Alaskan Stream

To assess the connection between volume, heat and salt transport, and atmospheric circulation indices – the North Pacific Index (NPI), the Aleutian Low Pressure Index (ALPI),

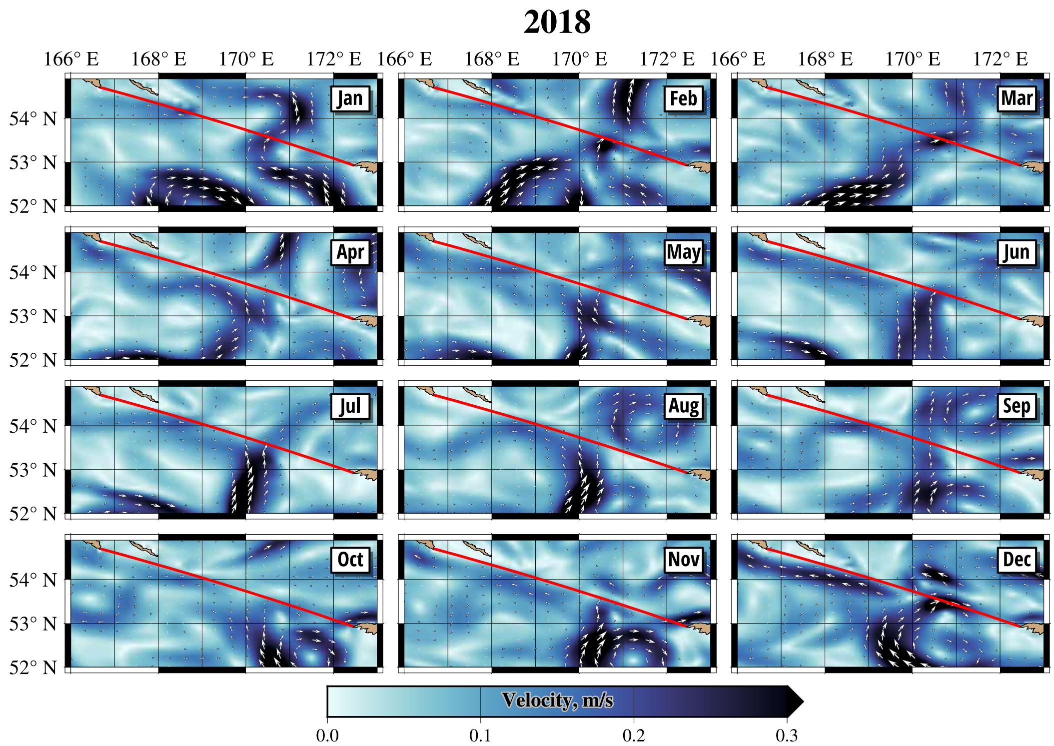

Figure 6. Monthly average surface velocity field in the area of the Near Strait according to GLORYS12V1 data for 2018.

and the intensity of the Alaskan Stream – a correlation analysis was performed (Figure 7). The correlation coefficient was calculated using monthly average values (NPI: November to March, ALPI: December to March) for the period 1993–2021 (for ALPI, before 2015 due to the lack of more recent data) without a time lag. The coordinates of the transect along the Alaskan Stream for calculating volume transport were selected based on the average velocity field and taken as 52.25°N–52.66°N, 169°W. With respect to NPI, a positive correlation with all considered hydrological parameters is noted, reaching the maximum is about 0.33 for heat transport and volume transport. However, these correlations do not reach statistical significance ($p > 0.05$), which indicates a weak connection. The opposite is shown by ALPI, which is characterized by the lowest values of correlation coefficients: for all parameters, a weak negative correlation was registered, not exceeding -0.1, and also statistically insignificant. These results indicate that, despite the expected influence of atmospheric processes on the dynamics of the Alaskan Stream, the ALPI index in the period under review does not show a stable or significant correlation with changes in volume, heat and salt transport. This highlights the need for a deeper analysis of the factors regulating the strengthening of the Alaskan Stream, taking into account the complex interaction of the atmosphere and the ocean.

Our study did not reveal a statistically significant positive correlation between the Alaskan Stream and the hydrological parameters under consideration – heat and salt transport, as well as volume transport; the maximum value of the correlation coefficient does not exceed 0.17. In the context of previously published works, for example, in [*Panteleev et al.*, 2012], there is a pronounced negative correlation ($r = -0.84$) between the volume transport in the Near Strait and the intensity of the Alaskan Stream, as well as a moderate positive correlation ($r = 0.5$) with a leading lag of 4–5 years. This range of relationships may be due to the influence of mesoscale eddies forming in the Alaskan Stream, which are capable of blocking the transport through the Aleutian Straits. Nevertheless, our results indicate that there is no positive or negative connection between the Alaskan Stream and volume transport in the region under study, which indicates the need for further in-depth analysis of dynamic processes affecting the interannual variability of hydrological parameters.

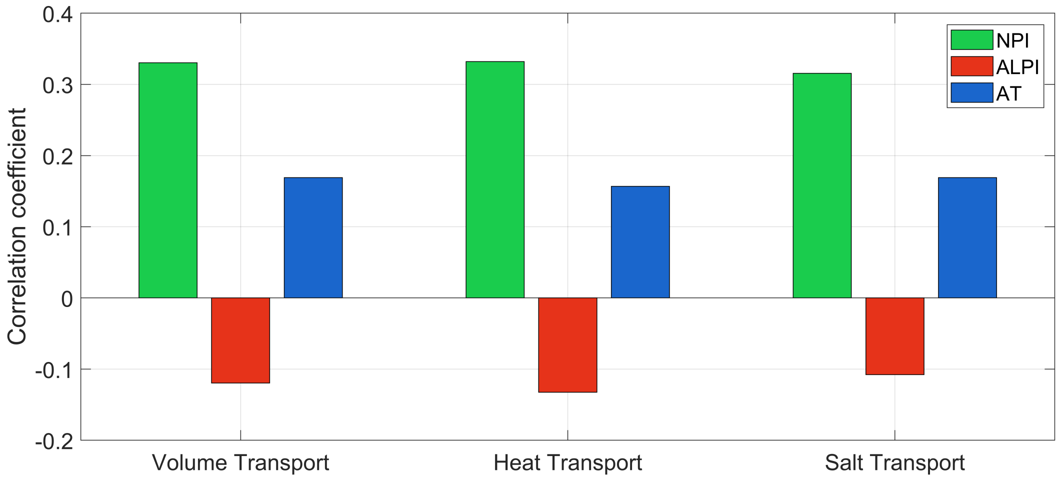

Figure 7. Correlation coefficient between the annual average volume (left), heat (center) and salt (right) transport in the Near Strait and the indices NPI (green), ALPI (orange), and transport in the Alaskan Stream (blue).

5. Discussion and Conclusions

Based on the analysis of GLORYS12V1 data for 1993–2021, estimates of the long-period variability of volume transport through the Near Strait were obtained. The key conclusion is the established predominance of the inflow of Pacific waters into the Bering Sea throughout the study period. Extreme values of daily volume transport were recorded in 1995, 2017 and 2018 (exceeding 15 Sv) and in 1998, 2000 and 2021 (less than −5 Sv). The year 2021 is characterized by minimum values of heat (-1.7×10^{18} W), salt (-2.7×10^{15} g $\cdot$ s^{-1}) and volume transport (−7.6 Sv). The maximum values of heat transport were recorded in 2017–2018 (3.2×10^{18} W), while salt (5.7×10^{15} g $\cdot$ s^{-1}) and volume transport (15.6 Sv) – in 1995.

Estimates of the seasonal variability of the volume, heat and salt transport through the Near Strait have been obtained. It is established that the maximum values of all characteristics are fixed in the cold season of the year (spring–winter), and the minimum – in the warm (autumn–summer). This feature may be due to the strengthening and weakening of the Aleutian Low. The influence of the Aleutian Low on the water exchange of the Bering Sea and the Pacific Ocean was noted earlier in [*Prants et al.*, 2019]. According to our estimates, the average monthly volume transport in the Near Strait for the period 1993–2021 ranged from 2.8 Sv in September to 4.9 Sv in January. These estimates differ from those obtained in [*Clement Kinney and Maslowski*, 2012], where it was shown that the annual volume transport varies from 4.3 Sv in September to 6 Sv in November. The average volume transport for the entire period (1979–2004), according to the authors' estimates, was 5.1 Sv (Table 1). However, our estimate for the period 1993–2021 is 3.7 Sv. In addition to the shift of the average monthly maximum from November to January, an underestimation of the average volume transport over the entire period was recorded. It should be noted that the problems leading to inaccuracy in estimating the average transport through the Near Strait according to numerical modeling data were also described in [*Ezer and Oey*, 2013]. These authors point out that in the Near Strait (as in the Kamchatka Strait), the standard deviation is greater than the average transport, which indicates the difficulty of estimating the average transport based on short-term observations. The average transport for the 1st model year was estimated by [*Ezer and Oey*, 2013] to be −0.96 Sv, and the standard deviation was 3.2 Sv. The authors explain these inaccuracies by complex mesoscale dynamics in these straits. At the same time, earlier estimates of the transport through the Near Strait in 6–12 Sv, given in [*Stabeno et al.*, 1999], are underestimated in relation to our estimates. This once again suggests the need to evaluate water exchange over longer periods of time using modern reanalysis, which was done in this study.

According to [*Stabeno and Reed*, 1994], contrary to the traditional view of the prevailing northward transport through the Near Strait, the inflow can vary significantly over time ranges from several weeks to a year. For example, in 1991 there was no recorded inflow, and in 1992 there was a pronounced northward transport. Which correlates with the obtained result: we indicate a strong outflow in 1998 and the opposite transport during 1997. Also, our results were compared with [*Khen and Zavolokin*, 2015]. Geostrophic transport according to drifters in the upper 40-meter layer during 2002–2010 in the fall ranged from 0.4 to 2.0 Sv, in our case, the volume transport in the upper layer for this period does not exceed 0.4–0.6 Sv, which may indicate an underestimation by reanalysis of the flow velocity in the region.

The relationship between volume transport, heat and salt transport with atmospheric circulation indices has been established. Interannual fluctuations in volume, heat and salt transport are not related to atmospheric variability, since the correlation coefficients are small and statistically insignificant.

The influence of mesoscale eddies and the Alaskan Stream on water exchange through the Near Strait is described using the example of the two most illustrative years (1998 and 2018). It is noted that a positive transport rate in 2018 was formed when the Alaskan jet Stream passes through the strait in the absence of the blocking action of eddies or when the waters leave the periphery of the eddies in a northerly direction. The negative transport rate (outflow), which has been observed for a long time in 1998, was formed by “blocking” the penetration of the Alaskan Stream by mesoscale eddies with an increase in the North Aleutian slope current in the southeastward direction.

Acknowledgments. The research was supported by grant No. 129659573 from Saint Petersburg University and grant No. 25-17-00021 from the Russian Science Foundation. The calculation was carried out on the high-performance computing cluster at the Pacific Oceanological Institute (State Task No. 124022100072-5).

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