

Article

Volume Transport through the La-Perouse (Soya) Strait between the East Sea (Sea of Japan) and the Sea of Okhotsk

Aleksandr Vladimirovich Saveliev¹, Mikhail Alekseevich Danchenkov^{*1}, and Gi-Hoon Hong²

¹*Far Eastern Regional Hydrometeorological Research Institute
24 Fontannaya st. Vladivostok 690600, Russia*

²*Marine Environment and Climate Change Laboratory, KORDI
Ansan P.O. Box 29, Seoul 425-600, Korea*

Abstract : Seasonal and interannual variation of volume transport through the La-Perouse Strait were estimated using the difference of sea level observed at Krillion of Sakhalin, Russia, and Wakkanai of Hokkaido, Japan, during the period of 1975-1988. Historical sea level measurements between Russian and Japanese tide gauge data were normalized using an independent direct volume transport measurement. Volume transport from the East Sea (Sea of Japan) to the Sea of Okhotsk varied from -0.01 to 1.18 Sv with an annual mean value of 0.61 Sv. Monthly water transport rates showed a unimodal distribution with its maximum occurring in summer (August) and minimum in winter (December-February). The annual mean volume transport varied from 0.2 to 0.8 Sv during the period of 1975-1988 with the maximum variance of 0.6 Sv.

Key words : the La-Perouse (Soya) Strait, the East Sea (Sea of Japan), the Sea of Okhotsk, volume transport, sea level, multiyear variability.

1. Introduction

The East Sea (Sea of Japan) is located in the northwestern margin of the Pacific Ocean. It has four straits: the Korea/Tsushima Strait (130 m deep) with the East China Sea, the Tsugaru Strait (130 m deep) with the Pacific Ocean, the La-Perouse Strait (Soya Strait, 40 m deep) and the Tartarsky Strait (10 m deep) with the Sea of Okhotsk. Among the four straits, the Korea/Tsushima, Tsugaru, and La-Perouse straits are significant in terms of volume transport. The Korea/Tsushima Strait is the main source of water inflow. Outflow from the East Sea occurs mainly through the Tsugaru and La-Perouse Straits. Climatologically, the amount of outflow through the Tsugaru and La-Perouse Straits may account for 70-80% and 20-30% of the amount of the inflow through the Korea/Tsushima Strait, respectively (Leonov 1960; Radzikhovskaya 1961; Yasuda *et al.* 1988; Yoon 1991; Seung *et al.* 1993; Mooers

et al. 1996). The La-Perouse Strait is a sole conduit of warm and saline waters of the Kuroshio introduced into the Sea of Okhotsk via the East Sea from the North Pacific. However, the volume transport through the La-Perouse Strait has not received scientific attention as much as those of other two main straits until recently. There has been a limited data set available for the volume transport through the La-Perouse Strait (Table 1). Occasional direct current measurements were made only in summer at a single point or at a fixed depth in the water: May-June 1933 (Nakamura 1985), July-August 1947, August 1956 (Supranovich *et al.* 2001), May 1971, June-August 1973, August 1987-July 1988 (Aota *et al.* 1985).

As seen in Table 1, the volume transport estimations obtained up to date are very limited, it is nearly impossible to look at the seasonal and interannual variations of the volume transport through the La-Perouse Strait. Most of previous works were largely based on the geostrophic calculations and numerical modeling (Leonov 1950, 1960; Vasiliev *et al.* 1994; Mooers *et al.* 1996), the water mass

*Corresponding author. E-mail : danchenk@fastmail.vladivostok.ru

Table 1. Total volume transport (Sv) through the La-Perouse Strait obtained by previous works.

Period	Sources							
	Leonov 1950, 1960	Radzikho- vskaya 1961	Vasiliev, Dudka 1994	Mooers and Kang 1996	Aota <i>et al.</i> 1985	Aota 1975	Tanaka <i>et al.</i> 1996	Supranovich <i>et al.</i> 2001
	Methods of volume transport calculation							
	Geostrophic current	Total water balance	Geostrophic current	Numerical modeling	Current meter	Constant current velocity through the strait	Current meter	Current meter
November	–	0.44	0.40	0.56	–	–	–	–
May-June	–	0.22	–	–	0.80	–	–	–
August	–	–	–	–	–	1.30	1.18	1.02
Year	0.42	0.33	–	–	–	–	–	–

balance calculation (Radzikhovskaya 1961) or the assumption of constant velocity along all sections of the strait (Aota 1975).

In this study, we have made an attempt to estimate seasonal and interannual volume transport through the La-Perouse Strait using sea level data measured at the coastal sites facing the strait in both Sakhalin and Hokkaido Islands.

2. Methods and database

Monthly mean values of sea level were obtained from the tidal measurements in Wakkanai (Hokkaido, Japan)

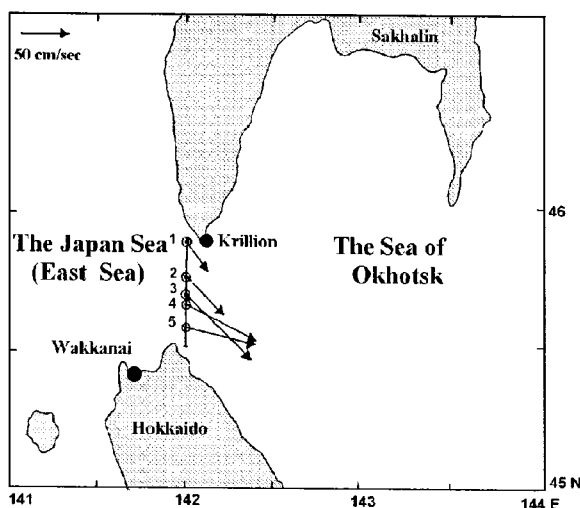


Fig. 1. Positions of tidal gauge stations at Wakkanai (Hokkaido, Japan) and Krillion (Sakhalin, Russian Federation). Tanaka *et al.* (1996)'s data was reproduced here for the reference. Arrows show depth-averaged residual currents obtained by direct observations (ADCP) on 8-9 August 1995.

and Krillion (Sakhalin, Russia) during the period of 1975-1988 (Fig. 1).

Volume transport was determined as follows:

$$Q = C \times S \quad (1)$$

where C is a depth - averaged velocity through the strait; S is a cross sectional area of the strait. The value of C was calculated from known relationship between sea level slope and flow velocity (Zubov 1935):

$$\Delta h = (2\omega L \sin\varphi / g) \times C \quad (2)$$

where Δh is the difference between level heights; ω is an angular velocity of Earth rotation; φ is a latitude of the site; L is a distance between points on the section; C is the depth-averaged velocity.

Linear and dynamic meters are practically identical (Beriozkin 1947): difference is not more than 3%. Therefore, in the present study, we used common linear metric units.

The velocity vector calculated according to the formula (2) is directed in such a manner that higher sea level is at the right hand side of a flow. Sea level slope (Δh) was calculated between Wakkanai and Krillion. Since there is no intercalibration of datum level (tide gauge) used in Japan and Russia, sea level values measured at Japan and Russian Federation cannot be directly compared. Therefore, sea level slopes across the La-Perouse Strait cannot be calculated directly by differences of level heights between the two coastal tidal stations.

An alternative method to calculate the "basic sea level slope" (Δh) across the strait for "basic month" is offered here. The "basic month" is a month for which volume transport is measured. Calculation of "basic sea level slope" (Δh) is made as follows:

- 1) by (1), depth averaged velocity (C) is derived;
- 2) by (2), "basic sea level slope" (Δh) is calculated.

Table 2. Data used for normalizing the sea level measurements in tidal gauge stations in the La-Perouse Strait on August 8-9, 1995 (Tanaka *et al.* 1996).

Stn.	Latitude (N)	Longitude (E)	Observation level (m)	Water depth (m)	Velocity C (cm/sec)	Direction F (degree)
1	45°53.5'	142°00'	12-32	37	40	144
2	45°46'	142°00'	25-45	69	61	134
3	45°42'	142°00'	10-50	59	99	133
4	45°40'	142°00'	10-46	56	86	116
5	45°35'	142°00'	10-32	42	77	103

Notation: C-depth- averaged residual (detided) current velocity; F- averaged current direction.

Then, using historical sea level data (in both Wakkanai and Krillion), the monthly mean sea level deviations from mean sea level for the “basic month” is determined. The difference between sea level deviations in Wakkanai and Krillion (for every month) is the correction for mean sea level slopes for other months. After that, the monthly mean volume transport through the strait is calculated by equation (1).

In order to apply the proposed method, reliable and accurate volume transport data should be available. Reliable values of volume transport through the La-Perouse Strait are obtained (Fig. 1, Table 2) on the ADCP observations on August 8-9, 1995 (Tanaka *et al.* 1996). All stations were located along 142°E, and their ADCP observations were made at all stations within a day. Tanaka *et al.* (1996) used the vertically averaged residual current components perpendicular to the cross section (Table 2) in order to calculate volume transport through the strait. The cross section was also divided into some sectors according to the distances between the stations. For each sector, the individual volume transport was defined. The total volume transport was estimated as the sum of the volume transport through each sector.

In calculation of “basic sea level slope” for August 8-9, 1995, the next values are used: volume transport = 1.18 Sv, the cross sectional area of the strait (S) = $2.08 \times 10^6 \text{ m}^2$.

3. Results and discussion

The analysis of results is carried out based on two assumptions. The first one is that the chosen volume transport value for the “basic month” (August) is regarded as a ‘norm’ for a given month. The second one is that there is an outflow in general through the La-Perouse Strait (into the Sea of Okhotsk). The second assumption is in conformity with available information on the water exchange of the East Sea of Korea through the straits (see

Introduction). The Krillion Current flowing from the Sea of Okhotsk to the East Sea has been observed near the Krillion Cape (Maidel 1879; Brodskiy 1959; Leonov 1960; Veselova 1963; Danchenkov *et al.* 1999). The Krillion Current appears to be pronounced when easterly winds prevail, and it depends on tides; therefore, it is unstable. The width of the current is about 20 km and the maximum volume transport is less than 0.05 Sv (Leonov 1960). Therefore, it doesn't play a key role in total volume transport through the strait. In a whole, available current observations (Nakamura *et al.* 1985; Aota *et al.* 1988; Tanaka *et al.* 1996) show that flow along all cross section of the strait has southeast direction towards the Sea of Okhotsk.

The results of calculations for the seasonal variability of volume transport according to (1) and (2) are presented in Table 3. A positive sign (+) in Δh and C corresponds to the case when sea level is higher in Wakkanai, Hokkaido Island and there is a flow into the Sea of Okhotsk (outflow). A negative sign (–) in Δh and C corresponds to the case when sea level is higher in Krillion, Sakhalin Island and there is a flow into the East Sea (inflow).

Monthly mean values of volume transport Q shows a unimodal distribution with a maximum in the warm period and a minimum in the cold period of the year. Maximum water transport into the Sea of Okhotsk occurred in August-September (Table 3). It corresponds to period of maximum inflow through the Tsushima Strait (Miyazaki 1952; Leonov 1960; Radzikhovskaya 1961; Hata 1962; Yi 1966; Pokudov 1975) and to period of maximum volume transport (1.2 Sv) of the Soya Current as well (Aota 1975).

The minimal volume transport through the La-Perouse Strait is observed in December-February (Table 3).

Sea level slope is reversed in winter of some years, and there is a return flow from the Sea of Okhotsk into the East Sea (Table 3, Fig. 2). This inflow is most well

Table 3. The multiyear monthly mean values of sea level slopes (Δh), mean flow velocity (C) and volume transport (Q) through the La-Perous Strait (the characteristics, obtained for "basic month", are marked by grey colour). The standard deviations (σ) of each parameter are put in as denominators.

Parameter	Month												Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
h_w , cm	-15	-20	-21	-18	-14	-10	-5	0	-2	-4	-9	-11	-10
σ_{h_w}	4.7	3.6	3.3	5.2	4.2	2.1	3.7	5.5	4.8	5.3	6.7	5.1	2.7
h_k , cm	+12	+4	-1	-6	-4	-4	-2	0	-1	+2	+6	+13	0.7
σ_{h_k}	6.6	3.0	4.8	4.4	3.2	2.7	3.8	3.8	3.1	6.0	4.0	5.6	2.2
Δh , cm	-2	+1	+5	+13	+15	+19	+22	+25	+24	+19	+10	+1	+13
$\sigma_{\Delta h}$	6.8	3.8	5.1	4.5	4.8	2.4	3.8	5.2	3.2	6.4	5.6	5.7	3.1
C , cm/sec	-5	+2	+12	+31	+35	+44	+51	+57	+55	+44	+23	+2	+30
σ_C	15.8	9.0	11.9	10.6	11.1	5.6	8.8	12.1	7.4	14.9	12.8	13.2	7.3
Q , Sv	-0.10	0.04	0.25	0.62	0.73	0.91	1.06	1.18	1.14	0.91	0.48	0.04	0.61
σ_Q	0.28	0.18	0.24	0.21	0.23	0.12	0.18	0.25	0.15	0.31	0.26	0.27	0.15

Notation: h_w , h_k - multiyear monthly mean sea level deviations relative to appropriate level for August ("basic" month) in Wakkanai and Krillion, respectively.

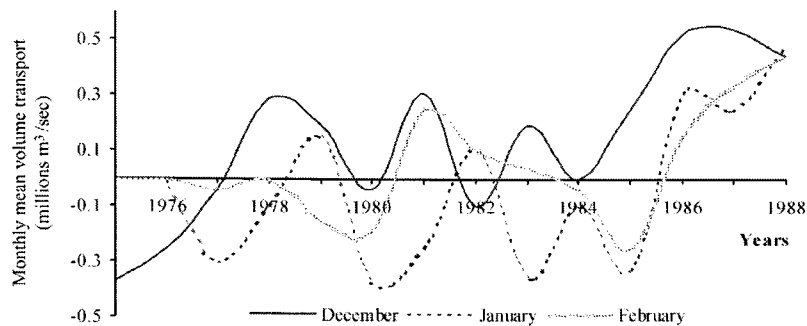


Fig. 2. Year-to-year variations of monthly mean volume transport through the La-Perouse Strait in winter.

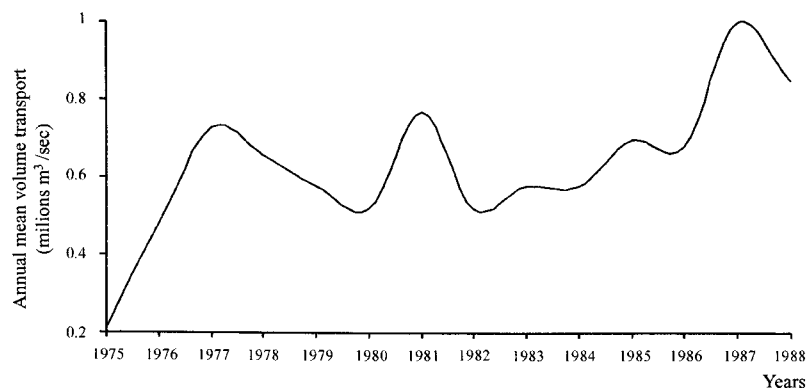


Fig. 3. Long-term variation of annual mean volume transport through the La-Perouse Strait.

exhibited in January and can reach 0.4 Sv.

The comparison of calculated volume transport (Table 3) and that given in other sources shows a good

conformity. For example, volume transport calculated during May-June (0.82 Sv) is similar to one (0.80 Sv) published earlier (Aota *et al.* 1985). Volume transport

calculated for November (0.47 Sv) is close to ones (0.44 Sv, 0.40 Sv, 0.56 Sv) given earlier (Table 1) as well.

To estimate year-to-year variation of volume transport through the La-Perouse Strait, we used the method described earlier, using annual mean sea level data for the period of 1975-1988. The multiyear annual mean sea level slope between Wakkanai and Krillion which equals +13 cm (Table 3) was applied as the "basic sea level slope". The obtained results show, that the maximal amplitude of the long-term variation of volume transport in the strait can reach 0.6 Sv (Fig. 3), which corresponds to 51% of amplitude of seasonal variability.

4. Conclusions

1. The indirect method to calculate total volume transport through the La-Perouse Strait using sea level slopes across the strait is proposed here. The calculated volume transport shows a good conformity with available estimations of other authors.

2. The estimations of seasonal variability of volume transport through the strait are obtained. The maximal water outflow (1.14-1.18 Sv) occurs in August-September and its minimum in winter months. In some years, there is current in an opposite direction (from the Sea of Okhotsk to the East Sea) in winter. This flow is most well displayed in January (volume transport reaches 0.4 Sv).

3. The interannual variability of volume transport through the La-Perouse Strait for the period 1975-1988 is estimated. Maximal amplitude can reach 0.6 Sv.

References

- Aota, M. 1975. Studies on the Soya warm current. *J. Low Temperature Sci., Ser. A33*, 151-172.
- Aota, M., Y. Nagata, H. Inaba, Y. Matsuyama, N. Ono, and S. Kanari. 1985. The Soya Warm Current - A typical oceanic current flowing over shelf region. p. 164-187. In: *Ocean Characteristics and Their Changes*. Koseisyakoseikaku, Tokyo.
- Aota, M., M. Ishikawa, and T. Yamada. 1988. Dynamics of flow in the Soya Strait. *J. Low Temperature Sci., Ser. A47*. 147-160.
- Berizkin, B.A. 1947. *Dynamics of the Sea*. Hydrometeoizdat, Leningrad. 683 p. (In Russian).
- Brodskiy, K.A. 1959. Zooplankton in sea waters of southern Sakhalin and southern Kuril Islands. p. 5-46. In: *Research of the Far Eastern Seas of USSR, Vol. 6* (In Russian).
- Danchenkov, M.A., D.G. Aubrey, and S.C. Riser. 1999. Oceanographic features of the La Perouse Strait. p. 159-171. In: *PICES Sci. Report, No.12*.
- Hata, K. 1962. Seasonal variation of the volume transport in northern part of the Japan Sea. *J. Oceanogr. Soc. Jap.*, 20, 168-179.
- Leonov, A.K. 1950. Experience of application of the Bierknes circulation theory for definition of water balance of the Japan Sea. p. 18-27. In: *To Memory of Shokalsky*. USSR Academy of Sc., Moscow (In Russian).
- Leonov, A.K. 1960. *Regional Oceanography. Part 1*. Hydrometeoizdat, Leningrad. 765 p. (In Russian).
- Maidel, E. 1879. Extra notes on the cold current in the La-Perouse Strait. *Navy Collection*, 171(4), 47-53. (In Russian).
- Miyazaki, M. 1952. The heat budget in the Japan Sea. *Bull. Hokkaido Reg. Fish. Res. Lab.*, 4, 4-45.
- Mooers, C.N.K. and H.S. Kang. 1996. A note on some aspects of the spin-up of the Japan (East) Sea circulation model (SOJ-POM). p. 123-132. In: *Proc. Forth CREAMS Workshop*. Far Eastern Hydrometeorological Research Ins., Research Inst. Oceanogr. (Seoul Nat. Univ.ers.), Vladivostok-Seoul.
- Nakamura, K., M. Aota, and T. Ohtsuki. 1985. Coastal area of the Okhotsk Sea Physics. p. 7-22. In: *Oceanogr. Soc. Japan. Coastal Oceanogr. Res. Committee*, Tokyo.
- Pokudov, V.V. 1975. Water and heat exchange of the Japan Sea through the Korean Strait in summer. p. 11-23. In: *Proc. Far Eastern Hydrometeorological Research Inst. (FERHRI)*. Vol.50. Hydrometeoizdat, Leningrad (In Russian).
- Radzikhovskaya, M.A. 1961. Water and thermal balance of the Japan Sea. p. 132-146. In: *The Basic Features of Geology and Hydrology of the Japan Sea*. Hydrometeoizdat, Leningrad (In Russian).
- Seung, Y.H. and K. Kim. 1993. A numerical modeling of the East Sea circulation. *J. Oceanol. Soc. Korea*, 28(4), 292-304.
- Supranovich, T.I., G.I. Urasov, and G.A. Kantakov. 2001. Unperiodical currents and volume transport in the La Perouse Strait. *J. Meteorology and Hydrology*, 3, 80-84 (In Russian).
- Tanaka, I., A. Nakata, H. Yagi, A.D. Samatov, and G.A. Kantakov. 1996. Result of direct current measurements in the La Perouse Strait (the Soya Strait) during 1995-1996. p. 1-13. In: *Presentation at the 5-th Annual PICES Meeting*. Nanaimo, Japan (the manuscript).
- Veselova, L.E. 1963. Some features of a temperature regime of waters near southwest coast of Sakhalin. p. 42-63. In: *Proc. Far Eastern Hydrometeorological Research Inst. (FERHRI)*. Vol.13. Hydrometeoizdat, Leningrad (In Russian).
- Vasiliev, A.S. and K.V. Dudka. 1994. About water exchange of the Japan Sea and the Sea of Okhotsk with the Pacific Ocean. *J. Meteorology and Hydrology*, 10, 56-64 (In Russian).
- Yasuda, I., K. Okuda, M. Hirai, Y. Ogawa, H. Kudoh, S.I. Fukushima, and K. Mizuno. 1988. Short-term variations

- of the Tsugaru Warm Current in Autumn. *Bull. Tohoku Region. Fish. Res. Lab.*, 50, 153-191.
- Yi, S.U. 1966. Seasonal and secular variations of the volume transport across the Korea Strait. *J. Oceanol. Soc. Korea*, 1(1-2), 7-13.
- Yoon, J.H. 1991. The branching of the Tsushima Current. *Rep. Res. Inst. Applied Mech.*, 37(108), 1-21.
- Zubov, N.N. 1935. *Dynamic Method of Processing of Oceanological Observations*. Hydrometeoizdat, Moscow-Leningrad. 104 p. (In Russian).

Received Dec. 19, 2001

Revised Mar. 11, 2002

Accepted Jun. 24, 2002