In situ observations of Tsushima and West Sakhalin currents near La Perouse (Soya) Strait

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Abstract

Several current meters were deployed in 1996–1998 in the vicinity of La Perouse (Soya) Strait aiming to provide *in situ* observations of the Tsushima and West Sakhalin currents. Simultaneous moorings at two stations, Tetany 106 and Tetany 202+, clearly demonstrated convergence of these currents in the summer period on the southwestern shelf of Sakhalin Island. For both moorings more than 70% of the total energy was related to diurnal tides. Non-tidal currents were mainly barotropic and had significant seasonal and fortnightly components. The West Sakhalin current was found to play a key role in water exchange between the Sea of Okhotsk and the Sea of Japan.

Introduction

Oceanographic conditions on the southwestern slope and shelf of Sakhalin Island in the Sea of Japan in the vicinity of La Perouse (Soya) Strait are mainly determined by the Tsushima and West Sakhalin currents. The oceanographic features in this region have been investigated by oceanographers beginning in the last century and included a wide range of observations, descriptions, and modeling (Maidel, 1879 (see Veselova (1972) for a review); Makarov, 1895, Matsudaira, and Yasui, 1935, Derugin, 1940 (see Samarin (1996) for a review); Biryulin, 1954; Leonov, 1960; Budaeva et al., 1981; Klimov, 1984; Aota and Matsuyama, 1988; Oshima and Wakatsuchi, 1990; Yurasov and Yarichin, 1991; Bobkov and Foux, 1997; Tanaka and Nakata, 1998; Watanabe et al., 1998). The Tsushima Current transports the subtropical water mass from the south to the northern part of the Sea of Japan, the seasonal flow peak (up to 2 Sv) is normally observed in the early fall. The details of the West Sakhalin Current are poorly known because of lack of data. Calculations of geostrophic currents and some unpublished observational data near the Krilion Peninsula showed that the flow intensity in this area is about 2 Sv (Yurasov and Yarichin, 1991) and that this flow is directed to the south with residual currents up to 0.53 m/s (Zhukov, 1992). Thus, the Tsushima and West Sakhalin currents flow in opposite directions forming the ‘convergence zone’ (CZ) in the area of the southwestern slope and shelf of Sakhalin Island. However, the interaction of the Tsushima and West Sakhalin currents has never been carefully investigated.

The digital CTD archives for this region were created by Pishchalnik and Bobkov (1993). Kantakov and Samatov (1996) used these archives for preliminary estimation of the CZ duration and found that it is present primarily during the period April to November. The recent discovery of the La Perouse (Soya) Upwelling (or Cold Water Belt) in the northeastern part of the Sea of Japan off the Krilion Peninsula (Yagi et al., 1996; Nakata et al., 1998) modified previous understanding of water exchange between the Sea of Japan and Sea of Okhotsk. The former existing “clear” and “simple” perception about water exchange turned out to be much more complicated. The data collected during the La Perouse Project showed that the exchange through the strait depends on the Soya Current (Tsushima Branch), West Sakhalin Current (WSC) and the Okhotsk Sea water. The significance of the latter component in the water exchange through La Perouse (Soya) Strait is still overestimated (Danchenkov and Aubrey, 1998).

As part of the cooperative Russian-Japanese La Perouse Project, the oceanographic team of the Sakhalin Research Institute of Fisheries and Oceanography (SakhNIRO) in 1996–1998 made several *in situ* experiments to measure parameters of the Tsushima and West Sakhalin currents. The results of these experiments are presented below.

Data

For the present analysis we used observations of currents made using Aanderaa RCM4 and RCM7 current meters at 2 moorings, Tetany 106 and Tetany 202+ (Fig. 1), as well as some archive data on current in this region (Table 1). The sampling intervals of current records were from 15 to 60 min, the mooring horizons were from 10 to 100 m (see Table 1). We estimated the spectral characteristics of currents in this region, and examined tidal and non-tidal components of the Tsushima and West Sakhalin currents.

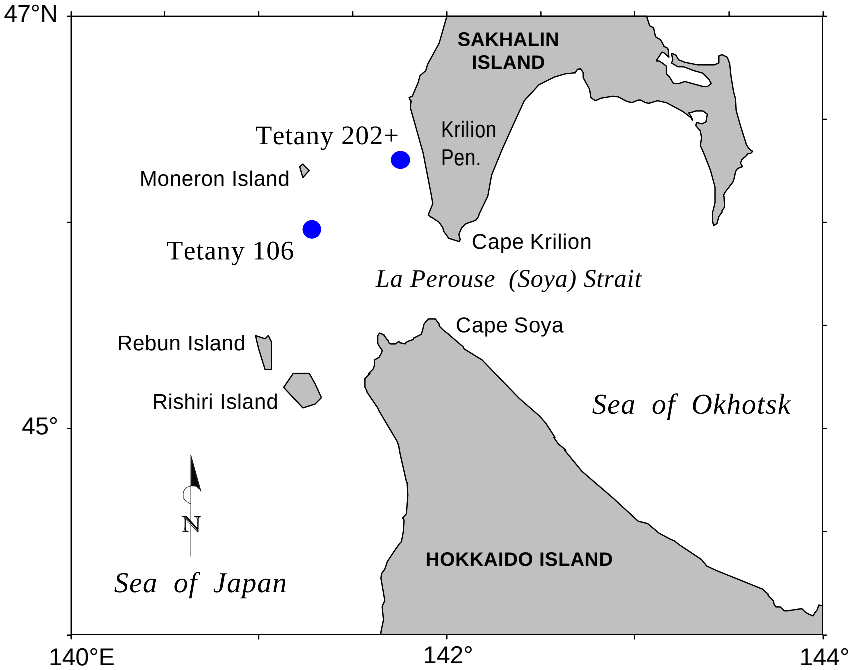

Fig. 1 Location of stations Tetany 106 and Tetany 202+ made during the 1996–1998 La Perouse Project.

Table 1 Submooring log features.

Project	Year	Site	Observation period	Hor	Tem	Con	Dir	Vel	Meter	DT
LP+	1996	Tetany 202+	11.08.96/ 22.08.96	40	+	+	+	+	RCM4 4079	15
LP	1996	Tetany 106	02.08.96/ 16.10.96	10	+	-	+	+	RCM7 11927	30
LP	1996	Tetany 106	02.08.96/ 16.10.97	100	+	+	+	+	RCM4 5759	30
LP	1996/97	Tetany 106	07.12.96/ 04.05.97	15	-	-	-	-	RCM4 5759	60
LP	1997	Tetany 106	13.05.97/ 28.08.97	15	+	+	+	+	RCM4 4079	30
LP	1997	Tetany 106	28.08.97/ 18.12.97	15	+	+	-	+	RCM4 4079	60
LP	1997/98	Tetany 106	18.12.97/ 16.03.98	20	+	-	+	+	RCM7 11927	60

Comment: ‘Hor’ is the observation horizon (m), ‘Tem’ is the water temperature, ‘Con’ is the conductivity, ‘Dir’ and ‘Vel’ are the direction and magnitude of currents, ‘Meter’ is the type of the current meter and its number, DT is the sampling interval (min), ‘+’ is the existing data.

Mean currents

To examine low-frequency variability of currents on the southwestern shelf of Sakhalin Island we computed and removed tides from the initial series. The residual currents were used for further analysis. There were only 11.5 days of simultaneous observations in August, 1996 at sites Tetany 106 and Tetany 202+, but these observations show very clear convergence between Tsushima and West Sakhalin currents: The former is relatively weak (about 7.5 cm/s), located over the slope of Sakhalin Island, and directed to NNW; the latter is much stronger (about 44 cm/s), located very close to the shoreline, and directed to SSE (Fig. 2a).

The historical data collected in the late 1970s (during the oil and gas exploration in this area) gave results, which were very similar to those obtained during the La Perouse Project. These results show that the West Sakhalin Current is a narrow shelf flow directed to the South (Fig. 2b). The estimated non-tidal currents were 42 cm/s at site Vindisskaya and 24 cm/s at Kuznetsovskaya. The difference in the current speed at these two sites is apparently related to the fact that Kuznetsovskaya was farther offshore than Vindisskaya, proving that the WSC is a very narrow current bound to the shore.

Seasonal variations of the Tsushima Current (station Tetany 106) are characterized by the decline to zero of the North transport component in the middle of October (Fig. 3) and by the further abrupt heat loss of the corresponding water (Fig. 4). As was emphasized by Aota and Matsuyama (1988), strong seasonal changes of currents are a remarkable feature of the area of La Perouse (Soya) Strait.

Tidal currents

Diurnal tidal motions strongly prevail in the original of current records measured on the southwestern shelf of Sakhalin Island (Fig. 5). Apparently this is typical for the whole area of La Perouse (Soya) Strait (cf. Aota and Matsuyama (1988); Odamaki (1994)). To examine statistical properties of the velocity field and the relative contribution of various periodic components in the total variance of currents in this area, we used rotary spectral analysis. The velocity records at stations Tetany 106 and Tetany 202+ were Fourier transformed to clockwise u^- and counterclockwise u^+ rotary components (Gonella, 1972) and the corresponding spectral estimates, S^- and S^+, were then obtained for each component. It was found that more than 70% of the total energy at these stations is in the diurnal tides, in agreement with the results of previous analysis of some historical data in this region (Kantakov and Gustoev, 1998).

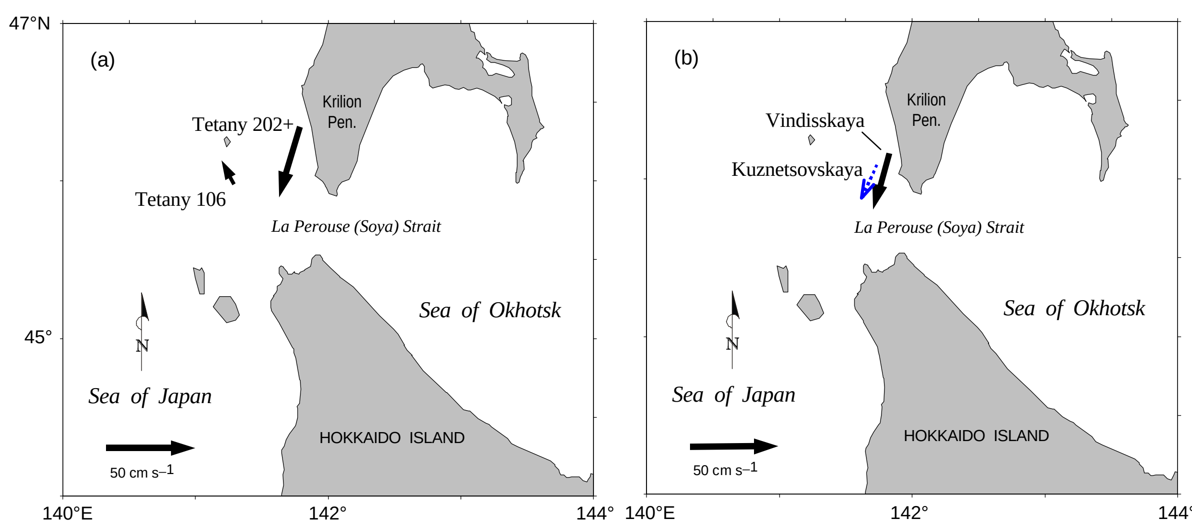

Fig. 2 (a) Mean currents in the convergence zone off the Krilion Peninsula recorded at stations Tetany 106 and Tetany 202+ (August 1996, SakhNIRO). (b) Mean currents at Kuznetsovskaya (dashed line, May-June 1978) and Vindisskaya (solid line, June 1979) during oil and gas exploration (with permission of the Ecological Company of Sakhalin).

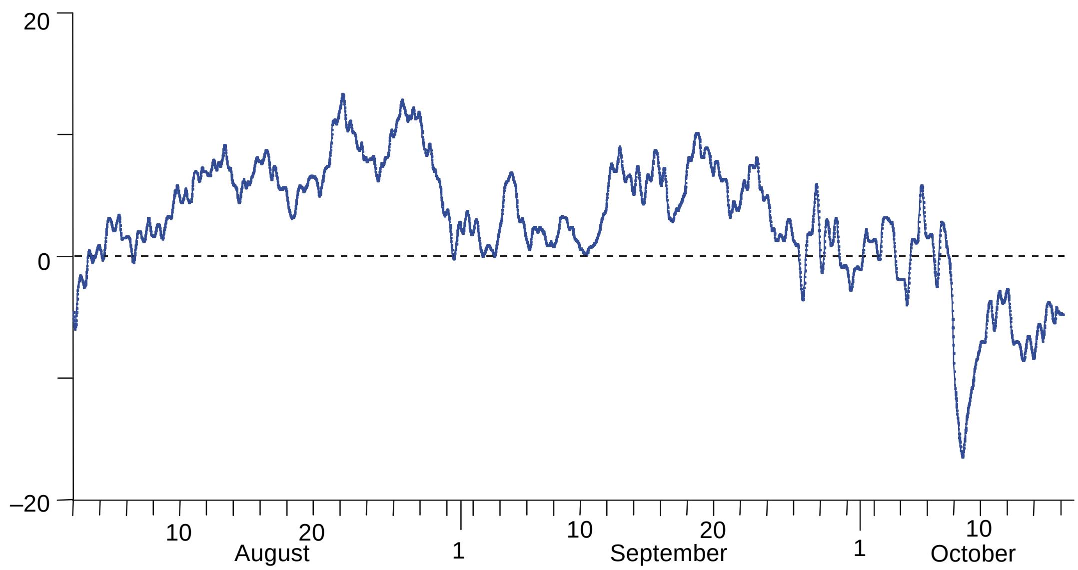

Fig. 3 Variations of the meridional (north-directed) component of non-tidal currents at station Tetany 106 (10 m) for the period August–October, 1996 (after smoothing by the 25-h sliding window).

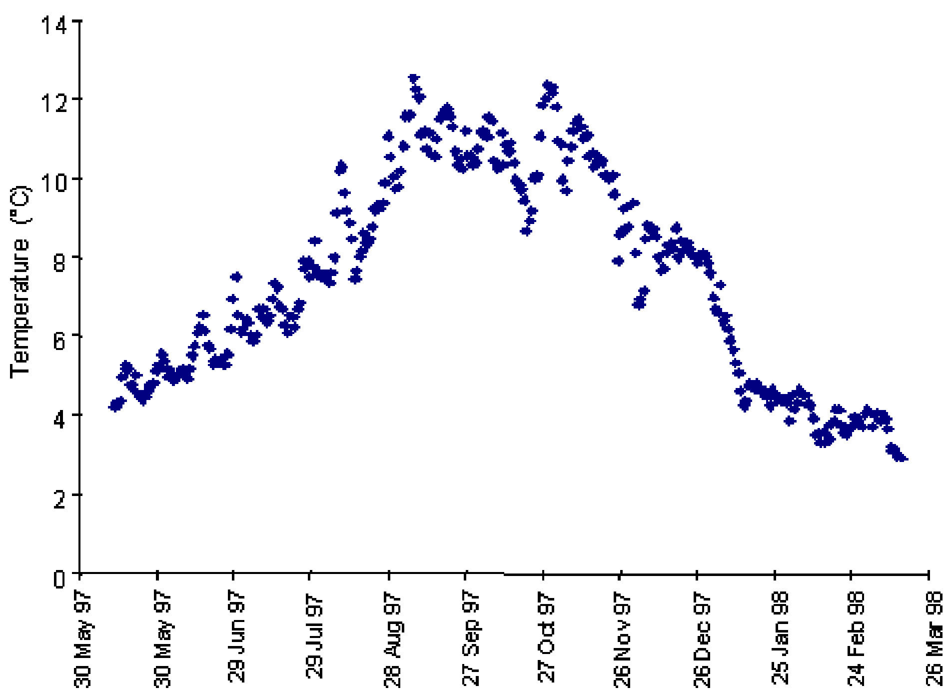

Fig. 4 Variations of daily temperatures at station Tetany 106 in 1997–1998 at 15 m depth.

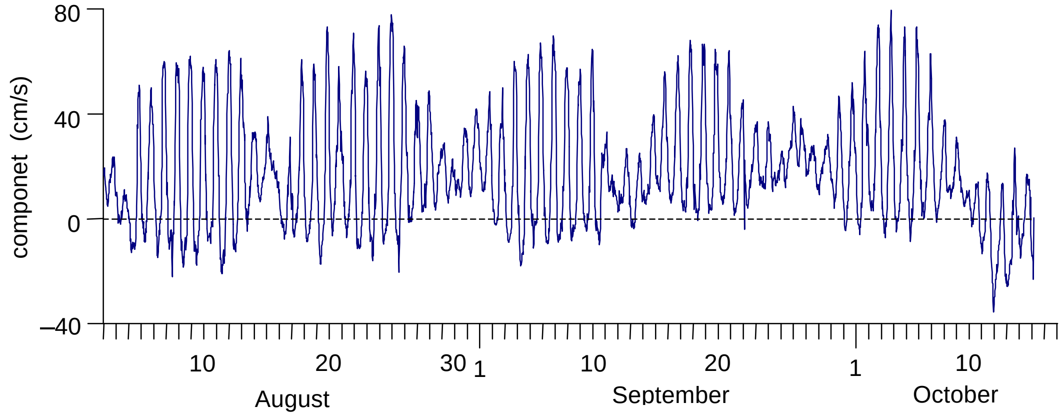

Fig. 5 Variations of the meridional (north-directed) component of currents at station Tetany 106 (depth 100 m) from August to October 1996.

The results of rotary spectral analysis of current velocities measured at station Tetany 106 (depths 10 and 100 m) are presented in Figure 6. For both depths the general character of the spectra is similar, clockwise (anticyclonic) motions dominate at all frequencies higher than 3 cpd (i.e. on periods more than 8 h). The diurnal tidal peak is the main feature of the spectra. The semidiurnal currents are surprisingly weak: The M_2 peak at the upper (10 m) layer is not seen at all, and at 100 m it is approximately two orders of magnitude lower than the diurnal peak. The energy of diurnal tides in the near-bottom layer is 5 times greater than in the upper layer. The remarkable feature of the near-bottom and especially upper currents is the existence of inertial oscillations with a period of 16.7 h, which is very close to the inertial period $T = 2p / f$, where $f = 2\Omega \sin j$, Ω is the frequency of the Earth's rotation, j is the latitude. Fortnightly oscillations, found in the northern part of the Sea of Japan by Isoda et al. (1996), are not seen in the spectra of Tetany 106 (Fig. 6), probably because of insufficient spectral resolution at low frequencies. However, they were evident at depth 15 m in summer 1997 (Figure 4 indicates similar oscillations of water temperature). Probably, these currents are associated with an anticyclonic eddy occurring in the area of the Tsushima Current. Additional information (atmospheric pressure, wind and satellite images) will be useful to examine fortnightly oscillations more carefully.

We used least square method to estimate the amplitudes and phases of tidal constituents both for zonal, *u*, and meridional, *v*, components of currents (A_u, G_u, and A_v, G_v, respectively). The results of tidal analysis of currents measured at station Tetany 106 (Table 2) are in good agreement with the results of similar analyses of historical data from the same area (Table 3). Amplitudes of diurnal constituents K_1 and O_1 were about 15–20 cm/s while the major semidiurnal constituent M_2 was only 3–5 cm/s. Ellipses of the diurnal tidal currents are extended in the northwest direction, approximately along the coastline of the Krilion Peninsula, southern Sakhalin (Fig. 7).

The reason for such strong diurnal currents (in comparison with semidiurnal) is not clear. As was shown by Aota and Matsuyama (1988) and Odamaki (1989), diurnal tides in the northeastern part of the Sea of Japan are formed mainly by the tidal waves incoming through La Perouse (Soya) Strait from the Sea of Okhotsk. Several scientists (cf. Ogura (1933); Aota and Matsuyama (1988); and Odamaki (1989)) noted two specific features of the area of La Perouse Strait: (1) Sea level tidal oscillations in the Sea of Japan are much weaker than in the Sea of Okhotsk resulting in a significant gradient and strong tidal currents in the strait (40–80 cm/s); (2) Amphidromic points both for K_1 and O_1 diurnal harmonics are located just at the entrance of La Perouse Strait. The strength of diurnal currents, in comparison with semidiurnal, and the evident difference between the corresponding current ellipses clearly demonstrates that diurnal and semidiurnal tidal currents have different generation mechanisms. Rabinovich and Zhukov (1984) explained similar effects on the northeastern shelf of Sakhalin Island by the influence of barotropic trapped shelf waves on diurnal tides (quasi-geostrophic subinertial shelf waves produce much stronger currents than ordinary gravity waves forming semidiurnal tides). Odamaki (1994) showed that such diurnal shelf waves exist also on the Okhotsk Sea shelf of Hokkaido Island causing strong diurnal tidal currents in this area. Probably the same mechanism is responsible for the formation of diurnal tides on southwestern shelf of Sakhalin Island, i.e. in the area of present study.

The parameters of tidal ellipses (major and minor axes, phase, orientation, etc.) measured at station Tetany 106 at depth 100 m in August-October, 1996 and at depth 15 m in May–August 1997 were stable and in a good agreement, the differences between currents recorded at different years and at different depths were negligible (Fig. 7). Such character of diurnal tidal currents supports an assumption that these currents have been produced by a barotropic tidal flow. However, tidal currents measured in August-October, 1996 at 10 m depth were unstable and much smaller than at 100 m (see Figure 6). Apparently the upper mixed layer at that time was strongly influenced by baroclinic processes.

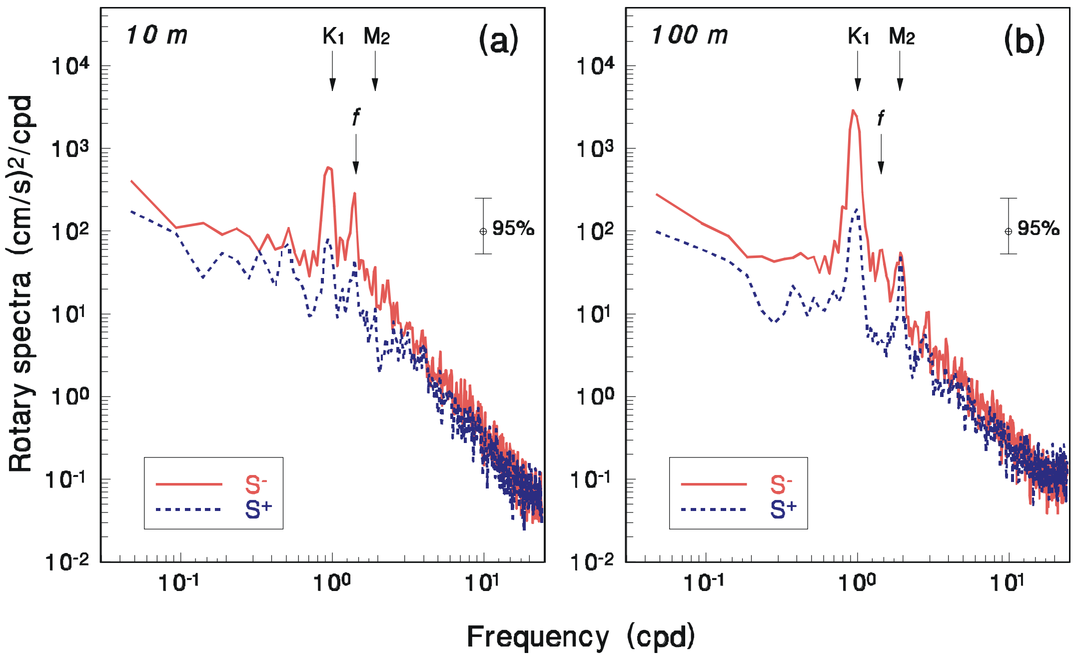

Fig. 6 Rotary spectra of currents measured at station Tetany 106 at depths (a) 10 m and (b) 100 m.

Table 2 Computed amplitudes and phases of *u* (eastward) and *v* (northward) tidal components at station Tetany 106, depth 100 m (August–October, 1996).

Tidal constituent	*u*-component		*v*-component	
	A_u (cm/s)	G_u (deg)	A_v (cm/s)	G_v (deg)
Q_1	1.9	29	2.6	245
O_1	14.5	12	19.4	256
K_1	12.8	54	17.5	298
P_1	4.2	54	5.8	298
N_2	0.7	11	1.3	200
M_2	3.1	7	5.0	213
S_2	1.8	41	2.0	239

Table 3 Computed amplitudes and phases of *u* (eastward) and *v* (northward) tidal components at station Kuznetsovskaya, depth 3 m (May–June 1978)

Tidal constituent	*u*-component		*v*-component	
	A_u (cm/s)	G_u (deg)	A_v (cm/s)	G_v (deg)
Q_1	3.5	300	1.2	114
O_1	7.5	337	16.2	251
K_1	0.7	264	29.6	232
M_2	3.2	292	8.5	220
S_2	7.4	35	10.1	8

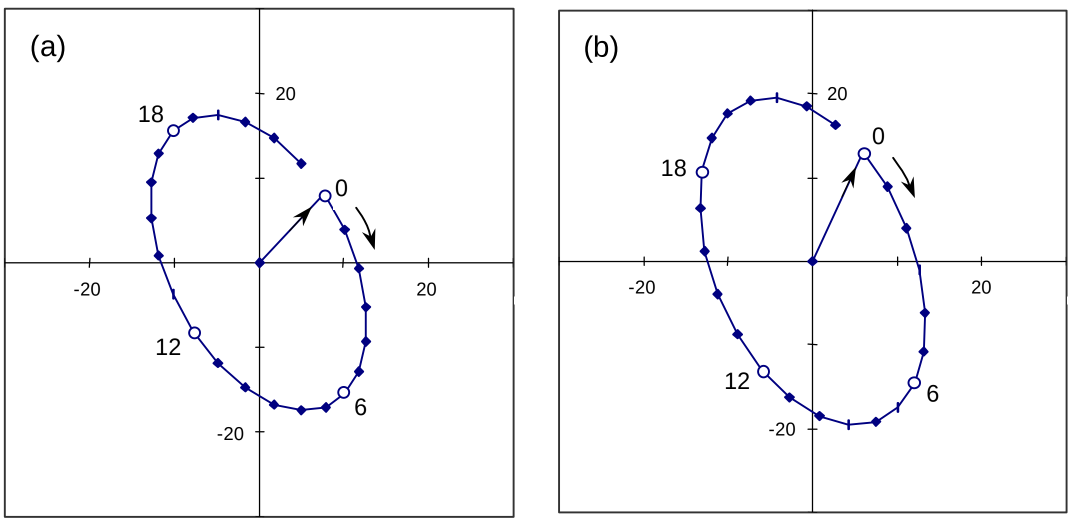

Fig. 7 Tidal ellipses for K_1 constituent at station Tetany 106. (a) depth 15 m, May–August 1997; (b) depth 100 m, August–October 1996.

Conclusions

Based on the results of current measurements made in 1996–1997 on the southwestern shelf of Sakhalin Island in the vicinity of La Perouse (Soya) Strait, as well as on some historical data obtained in the same area, we can make the following conclusions:

1. Simultaneous measurements of currents at stations Tetany 106 and Tetany 202+ in August, 1996 demonstrate existence of the convergence zone in this area formed by the Tsushima and West Sakhalin currents. Historical data show that the West Sakhalin Current is a narrow along-shelf stream directed to the south.

2. According to the Tetany 202+ data the minimum intensity of the West Sakhalin Current in August 1996 was about 1 Sv. The West Sakhalin Current together with the Soya Current play an important role in heat and salinity exchange between the Sea of Japan and the Sea of Okhotsk.

3. Strong seasonal variability is a typical feature of the Tsushima Current. The cessation of the northward transport by the Tsushima Current occurring in October does not produce immediate heat losses. These losses in

the upper layer of the Tsushima Current are normally observed later (in November–December).

4. More than 70% of the total spectral energy of currents in the vicinity of La Perouse (Soya) Strait are related to diurnal tidal constituents K_1 and O_1. Semidiurnal tidal currents are negligible in comparison with diurnal currents. Diurnal tidal currents at depths 15–100 m are mostly barotropic. A noticeable influence of baroclinity on tidal currents is observed only in summer time and only in the upper mixed layer (0–10 m).

5. There are two important peaks in spectra of non-tidal currents: (1) *inertial* with a period of about 16.7 h, which is evident in the upper layer, and (2) *fortnightly*, which is better seen in the lower layer. The fortnightly oscillations are apparently a common feature of the eastern Sea of Japan (there are numerous observations of these oscillations in the vicinity of Tsugaru Strait), but were not recorded on the south-western shelf of Sakhalin Island, probably because of the short observational time.

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