THE TATAR STRAIT SEA LEVEL SESONAL VARITIONS BY SATELLITE ALTIMETRY DATA

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ABSTRACT: In this work Topex/Poseidon altimeter data 1993 – 2002 were used. There are three altimetry tracks (one ascending and two descending) that cross Tatar Strait. The data were collected in the points of sub-satellite tracks with the step 0.25 degree. 10-years average values were calculated for each month. The seasonal sea level variations were compared with tide gauges data. The well expressed annual cycle (with maximum at July-August and the minimum at February-March) prevails in the Tartar Strait. However, the seasonal variations expressed much weakly in both the altimetry track points and Kholmsk – Nevelsk tide-gauges that locate close to La Perouse Strait because of Okhotsk Sea influence. The sea level slopes between the Sakhalin Island and the continent coasts were analyzed in different seasons. We found that sea level increases near Sakhalin coast in spring and summer that corresponds to the northward flow. In autumn, otherwise, the sea level decreases near Sakhalin Island that corresponds to southward current. This result is verified by the CTD data gathered on the standard sections. Well-expressed upwelling is observed near coastline of Sakhalin Island in fall season. This phenomenon is caused by the northerly and the northwesterly wind which are typical for cold season.

KEYWORDS: Sea level, tide gauge, satellite altimetry data, circulation, seasonal variations, Tatar Strait

INTRODUCTION

Sea level is one of the most significant parameters of ocean dynamics. Various processes in the world ocean such as lager-scale circulation, energy exchange with atmosphere, climatic fluctuations, etc. The significance of sea level measurements in the Far East seas increased last years because of decreasing of number of ship oceanological surveying. The number of Russian coastal tide gauges decreased too. So the sea level measurements using satellite altimeters give us a new way to investigate marine dynamic.

Seasonal changes of circulation in the Tatar Strait (northern part of Japan Sea) are poorly investigated. The regular oceanological surveying on several standard sections were carried out in this area, however the data of section Cape Slepikovskogo - Cape Zolotoy (along a latitude 47°20') in the southern part of the strait were analyzed only. The oceanological data of several expeditions in the northern part of the Tatar Strait were analyzed in the paper [Danchenkov, 2004].

Sea level seasonal changes were analyzed in the works [Rabinovicn et al, 1991, Oh et al, 1993, Saveliev, 2003] on the base of coastal tide gauges data. In the article [Saveliev, 2003] sea level slopes between coasts of Tatar Strait for various seasons have been studied. The differences of sea level heights about 60 – 70 cm were estimated. These values are several times more than obtained from vertical water density distributions on the oceanological sections [Sea of Japan]. They also contradict to the data of current velocities, which are relatively weak in the Tatar Strait [Kantakov, Shevchenko, 1999].

DATA

We used for analysis Topex/Poseidon (TP) satellite altimetry data (1993-2003). All necessary altimetry signal corrections were taken from the TP MGDR-B dataset and taken into account according to recommendations (Benada, 2002) including mean sea surface and inverse barometer corrections. We did not use recommended tidal corrections because global ocean tide model is not enough exact for the near-shore areas as the Tatar Strait. We used special modification of least squares method (Shevchenko, Romanov, 2004) for direct definition of tides.

Five TP tracks - two ascending (127, 203) and three descending (60, 136 and 212) crossing the Tatar Strait. Sea level data were formed in the spots with along track step about 0.25° (fig.1).

For the analysis we also used monthly mean sea level at the following tide gauges: De-Kastri (1974-1993), Sovetskaya Gavan (1948-1979), Innokentievka (1944-1986), Cape Zolotoy (1967-1985), Terney (1948-1965), Rudnaya Pristan (1940-1988), Aleksandrovsk-Sakhalinsky (1929-1931, 1939, 1941-1945), Uglegorsk (1963-2002), Chekhov (1954-1963), Kholmsk (1947-2002), Nevelsk (1954-1992) and Moneron Island (1952-1960). The location of stations is shown in fig. 1.

In the given work the temperature and salinity data that were measured on standard oceanological sections in the Tatar Strait also were used. In the database "Atlas" by Dr.

V. Pishchalnik these data have been resulted in average monthly values (from May till November) on standard depths 0, 10, 20, 30, 50, 75, 100, 150 and 200 m. The data are interpolated to 17 zonal sections. In the given work we used two of them which are taking place along latitudes 49,5°N (the seventh section) and 50,5°N (fourth).

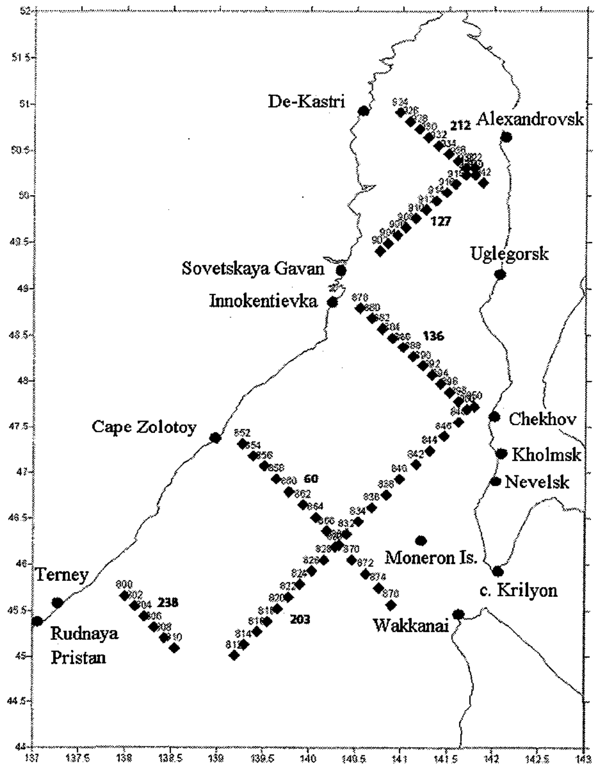

Figure 1. The map of Tatar Strait. The location of coastal tide gauges and TP tracks are shown.

SPATIAL VARIABILITY OF SEASONAL VARIATIONS

The well expressed annual cycle (with maximum values at July-August and the minimums at February-March) prevails in sea level fluctuations in the Tartar Strait as the whole Japan Sea. Let's consider in the beginning seasonal sea level changes on the base of coastal tide gauges data (fig. 2). Parameters of seasonal fluctuations were determined by a least squares method under the formula

$$h\ (t) = A_0 + A_1 \cos\ (\omega t - g_1) + A_2 \cos\ (2\omega t - g_2) + \xi(t),$$

where $h\ (t)$ - the measured monthly mean sea levels, A_0 - an average level; A_1 and A_2 - amplitudes of annual and semi-annual harmonics; g_1 and g_2 - their phases, $\omega = 2\pi/12$ - annual frequency, t - time in months, $\xi(t)$ - residual sea level fluctuations.

Results of calculation for coastal tide gauges are shown in tab. 1. Feature of Tatar Strait is strong variability of amplitudes of annual and semi-annual harmonics both along of Primorie and Sakhalin coasts. Along the western coast of the strait the amplitude of an annual harmonic in the beginning approximately in 1.5 times decreases from Rudnaya Pristan up to Cape Zolotoy. Then amplitude increases in northern direction, the maximum was found in De-Kastri.

Amplitude of annual harmonic decreases southward along the Sakhalin coastline. Maximal values were found at Alexandrovsk, minimal values are occurred at Chechov, Kholmsk and Nevelsk. On the southwestern coast of Sakhalin Island amplitudes of annual and semi-annual harmonics are close. The second maximum is occurred here in December-January. The winter sea level maximum is produced under influence of Okhotsk Sea.

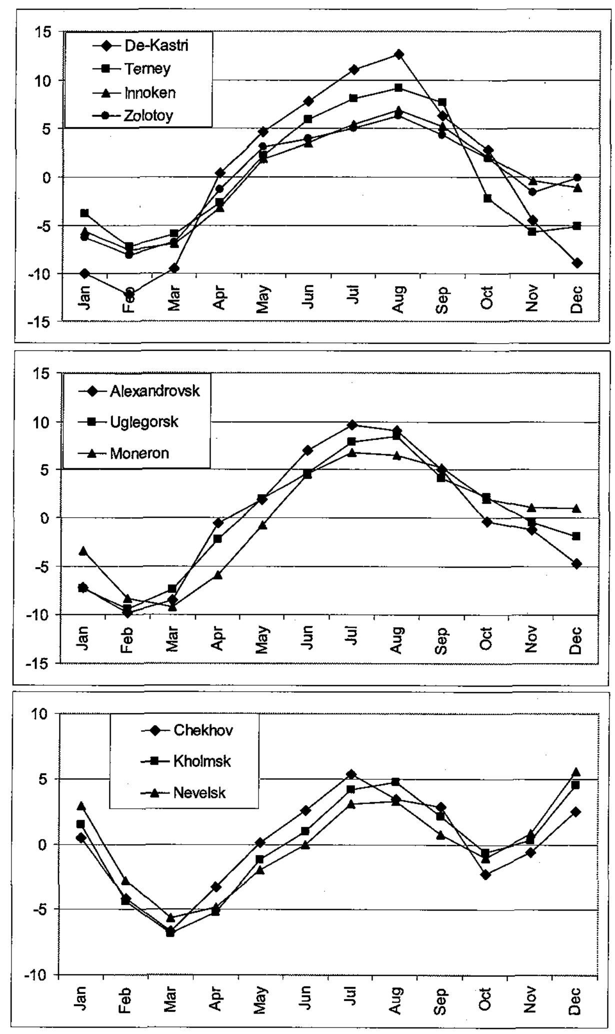

Figure 2. Average monthly sea levels for the coastal stations.

The amplitude of an annual harmonic according to satellite altimetry data is essentially less, than according to coastal stations. Probably, it is connected adjusted for atmospheric pressure. On measurements on a meteorological station Uglegorsk, atmospheric pressure has well expressed maximum in February and a minimum in July. The amplitude of an annual harmonic due to this amendment decreases approximately on 2 cm. In northern part of the Tatar Strait parameters of an annual harmonic did not calculated because of significant gaps in winter caused by an ice cover. But the summer maximum of a level is expressed better, than on a track 138. It is connected to influence of southern winds that prevailing in summer.

Table 1

Amplitudes (A, cm) and phases (g, °) of annual and semi-annual harmonics for coastal stations and TP spots..

station	A_1	g_1	A_2	G_2	A_2/A_1
Rudnaya	9	190.8	2.2	26.8	0.24
Terney	9.4	199.4	1.7	313.2	0.18
Zolotoy	6.3	201.8	1.4	266.7	0.22
Innoken	6.6	208.2	1	290.9	0.15
S. Gavan	6.7	197.5	0.6	321	0.09
De-Kastri	11.6	189	0.4	223.2	0.03
Alexandr	9.4	199.4	1.7	313.2	0.18
Uglegorsk	7.6	202.3	1.2	289.2	0.16
Moneron	7.1	220.3	2.5	317.4	0.35
Chekhov	3.5	216.6	3	333.4	0.86
Kholmsk	3.9	240.7	3.2	335.5	0.82
Nevelsk	3	262.9	3.3	337.5	1.10
TP ascending track 203					
812	3.9	242.5	0.6	242.9	0.15
822	3.7	241.1	0.3	289.5	0.08
832	4	229.8	0.9	329.5	0.23
842	3.7	241.7	0.4	310.3	0.11
851	2.4	257.8	2.4	2.9	1.00
TP descending track 60					
852	1.6	257.7	1.2	347.3	0.75
860	2.6	223	0.9	14.2	0.35
868	3.9	231.6	0.8	323.2	0.21
876	6.7	236.8	0.9	66.8	0.13
TP descending track 136					
877	2.2	246.9	1.1	125.8	0.50
885	2.8	236.6	0.4	90.6	0.14
893	3.4	233.6	1.5	333.5	0.44
901	2.4	267.1	1.9	346.4	0.79

ALONG TRACK SEA LEBEL SLOPES

Let's consider of a sea level slopes along sub-satellite tracks for various seasons. We shall most carefully study three tracks in northern part of Tatar Strait.

To study the sea surface slopes, the average values of a average monthly levels were collected for each spots of sub-satellite track. Along a descending track 60 in the spring (May) is observed smooth sea level lowering, the total difference of heights is about 3 cm (fig.5). It is unexpected result because in May Tsushima Warm Current is already enough active, and it was possible to expect higher values of a level at coast of Japan. But in the summer when Tsushima Warm Current reaches the maximal activity, on 6 eastern spots the significant gradient of a level is observed – the difference of heights reaches 4 cm (totally along track - about 7 cm). In the autumn (October) along track sea level variations are smooth and monotonous, Tsushima Warm current is expressed weaker than in the summer, but still far from being has lost the influence.

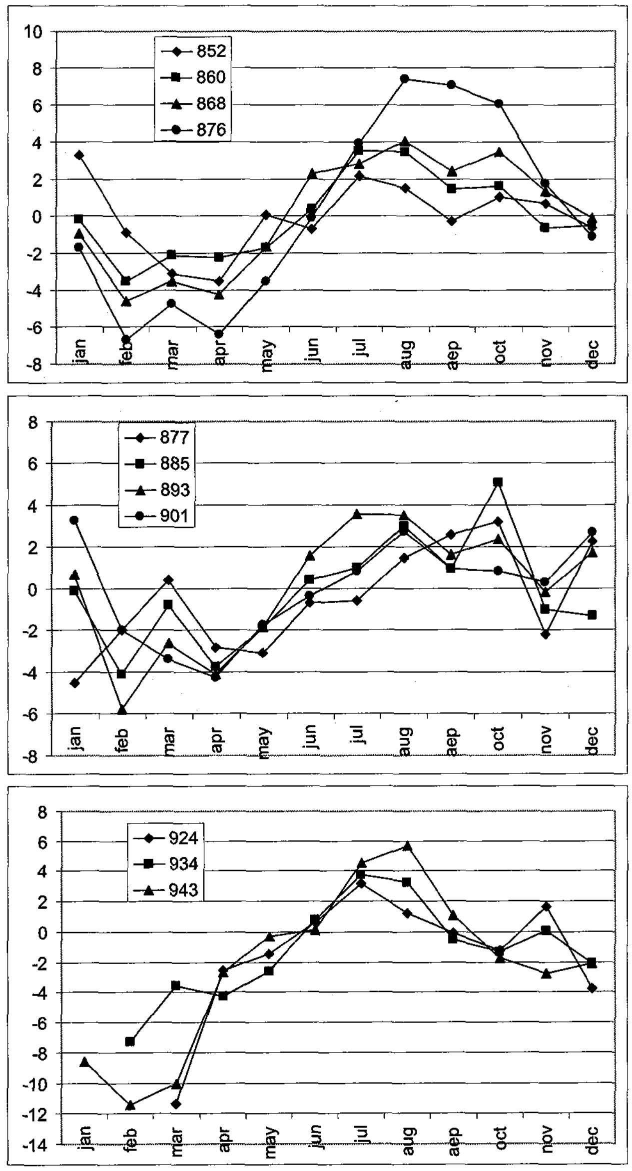

Figure 3. Average monthly sea levels for the spots of TP descending tracks 60, 136 and 212.

On the following descending track 136 in the spring and summer sea level variations are approximately identical and rather insignificant - the total differences of heights are about 3 and 2 cm correspondingly (fig.4).

In the autumn the situation essentially changes, and starting from a point 890 there is the significant sea level lowering to Sakhalin (about 4 cm). Probably, it is connected to an autumn intensification of south-directed West Sakhalin Cold Current.

It is rather remarkable lengthways track variability of a level on most northern of descending tracks 212. In the spring the level goes down from Asia coast to the central part of the strait, and then again smoothly grows in a direction of Sakhalin. It answers a stream the south along western and on the north along east coast of researched pool that will be coordinated to known circuits of currents in northern part of the Tatar Strait [Sea of Japan]. The total difference of heights is rather insignificant, that specifies moderate intensity alongshore current.

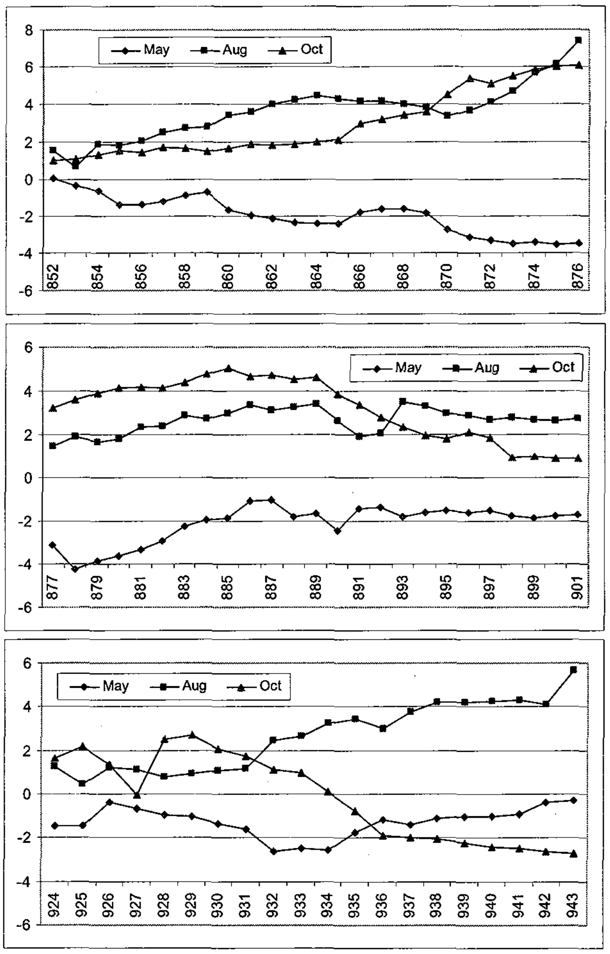

Figure 4. Sea level slopes along TP descending tracks 60, 136 and 212 for different seasons.

In the summer time the level variations are similar. However in the autumn the situation changes sharply. In the area adjacent to Sakhalin coast we found sea level lowering. It means change of the alongshore current direction on opposite in comparison with the warm season. Pronanly the cause of south-directed alongshore current is a northwesterly winds that dominate in autumn. This result is very important - in known summary review [Sea of Japan] this difference between summer and autumn currents is not shown.

In the western part of a track strong variations of a sea level are observed. We found south-directed alongshore current near Asia coat and north-directed current near the shelf edge.

We found the similar picture of the long track sea level variations on the ascending track 212.

We also analysed water temperature, salinity and density data on two standard sections for different seasons. In the spring and winter we found less density water near Asia (less salinity) and Sakhalin coasts (more warm water). So we see typical picture with southward current along Asia and northward current along Sakhalin cost. In fall season we found well-expressed wind-induced upwelling event near Sakhalin coast. Cold and salt waters are occurred in the upper layer, they flow southward.

CONCLUSION

On the main of Tatar Strait well-expressed annual fluctuations with a maximum in July - August and a minimum in February were found. Exception is made with spots of sun-satellite tracks which located close to southwest coast of Sakhalin. Semi-annual fluctuations with two maxima in the winter and summer are occurred in this area. Winter sea level maximum is caused by the Okhotsk Sea influence.

The analysis of the satellite altimetry data has allowed us to find a change of sea level slope in area adjacent to western coast of Sakhalin Island in the autumn in comparison with spring and in the summer. It means change of alongshore currents in northern part of Tatar Strait from northward to southward. It is the new result which has been not described earlier in the scientific literature. This result agrees with result of temperature and salinity data analysis on standard sections.

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