THE SOLAR SEMIANNUAL TIDE IN THE OCEAN

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Abstract

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I. V. MAKSIMOV

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The question of tides and tidal phenomena produced in the ocean by long-period variations of the tide-generating force is of considerable interest ([2,3,9]). Especially important is the study of the semiannual solar tide. The force exciting this tide is well known. The oscillations of the mean level surface of the World Ocean produced by it can be clarified in sufficient detail by using the harmonic constants of the semiannual wave, obtained from the analysis of numerous annual series of observations of sea-level oscillations in almost all parts of the World Ocean.

The potential of the semiannual part of the tide-generating force of the Sun is given by the equation:

$$W_{SS_a} = 0.03644\, G_0 (1 - 3\sin^2\varphi)\cos 2h,$$

where h is the mean longitude of the Sun and $G_0 = 26\,160$ cm^2/sec^2 is the gravitational coefficient according to A. Doodson.

For the height of the static tide relative to the solid Earth, the equation

$$H = \frac{W}{g}(1 + h - K),$$

is valid, where W is the potential of the disturbing force and $(1 + h - K)$ is a factor expressing the elastic properties of the Earth' s crust.

Taking $(1 + h - K) = 0.67$, one can obtain the following distribution of the heights of the static semiannual solar tide at different latitudes of the Earth:

Latitude	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
Amplitude, mm	6.5	5.9	4.2	1.6	−1.6	−5.0	−8.1	−10.7	−12.4	−13.0

Let us consider what the solar semiannual tide in the World Ocean actually is. To study the solar semiannual tide we used the results of an analysis of long-term observations of tides at 234 stations on the shores of the World Ocean ([7,10]). The harmonic constants of the semiannual tide at these stations were distributed by oceans and by different latitudinal zones of the ocean and averaged (see Table 1). Figure 1 presents a diagram of the phases of the semiannual tide in the northern part of the Atlantic Ocean, and Fig. 2 shows the distribution and change with latitude of the mean amplitudes of the semiannual tide in the Atlantic, Indian, and Pacific Oceans.

From the data presented it is evident that the semiannual tide in the World Ocean is indeed a planetary standing wave, with antinodes near the Earth' s poles and nodal lines located, as observations show, in the middle latitudes of the Earth.

This is clearly revealed when comparing the values of the phases of the planetary wave in different latitudinal zones of the Earth and at longitudes opposite one another. We shall give the mean values, calculated from the data of Table 1, of the phase of the wave φ and the phase shifts $\Delta\varphi$, characterizing the lag of the wave relative to the phase of the force.

Table 1

Mean values of the harmonic constants of the solar semiannual wave in the World Ocean

Latitude	Number of observation stations	S_{sa}		
		A, mm	φ	$\Delta\varphi$*
Atlantic Ocean				
North of 60° N	18	53	228°	+48°
40–60° N	63	39	258	+78
20–40° N	25	52	66	+66
0–20° N	4	45	90	+90
0–20° S	–	–	–	–
20–40° S	7	36	246	+66
Indian Ocean				
20–40° N	16	49	150°	+150°
0–20° N	29	58	102	+102
0–20° S	3	56	90	+90
Pacific Ocean				
40–60° N	19	46	264°	+84°
20–40° N	28	42	312	+132
0–20° N	5	72	114	+114
0–20° S	3	22	114	+114
20–40° S	9	36	300	+120

Latitude	Number of observation stations	$S^{\cdot}_{sa}$		
40–60° S	5	32	264	+84

* $\Delta\varphi$ is the lag of the semiannual wave in the ocean relative to the wave of the semiannual static tide.

	φ	$\Delta\varphi$
Atlantic Ocean, between 40 and 70° N, 81 observation stations	243°	+63°
Atlantic Ocean, between 20° S and 40° N, 29 observation stations	78	+78
Atlantic Ocean, between 20 and 40° S, 7 observation stations	246	+66
Indian Ocean, between 20° S and 40° N, 48 observation stations	114	+114
Pacific Ocean, between 20 and 40° N, 8 observation stations	288	+108
Pacific Ocean, between 20° S and 20° N, 8 observation stations	114	+114
Pacific Ocean, between 20 and 60° S, 14 observation stations	282	+102

On average for the World Ocean we obtain the following phase relation of the semiannual wave:

World Ocean	φ	$\Delta\varphi$
North of 40° N	252°	+72°
Between 20° S and 20° N	102	+102
South of 40° S	264	+84

For the different longitudinal waves of the World Ocean we have:

	Atlantic Ocean φ	Indian Ocean φ	Pacific Ocean φ
North of 40° N	243°	–	264°
Between 20° S and 20° N	90	96°	114
South of 20° S	246	–	264

The data presented show that the general character of the semiannual oscillations of the mean level of the World Ocean fully corresponds

···the principal features of the distribution over the Earth' s surface of the semiannual component of the tide-generating force of the Sun. Therefore this wave may be defined as a wave of the semiannual solar tide S_{sa}.

In all the cases studied, the phase of the wave was noticeably shifted relative to the phase of the force. The mean value of the phase shift characterizing the semiannual wave proved to be 86°, or 1.4 months.

(Figure: Fig. 1)

Fig. 1. Phase diagram of the solar semiannual tide in the northern part of the Atlantic Ocean. The points denote the end of the phase vector of the semiannual wave at the observation station.

The dimensions of the wave exceeded those predicted for it by static theory. The value of the ratio $m = A_{\text{obs}}/A_{\text{stat}}$ was found from the harmonic constants of the semiannual wave, published by E. Lisitsina ([9]) for many stations on the coasts of the World Ocean, from which the following mean values were obtained: in the Atlantic and Pacific oceans (north and south of 40° N and S latitude), data from the processing of 1917 annual cycles of observations of level oscillations at 82 stations on the ocean coasts: $m = 4.73$; in the Atlantic, Indian, and Pacific oceans (between 20° N and 634 annual cycles of observations at 77 stations on the ocean coasts: $m = 6.64$. Thus, on average for the entire ocean the ratio is $m = 5.69$, i.e., the real semiannual tide in the World Ocean is approximately 5–6 times larger than the value predicted for it by static theory. It should be noted, however, that the theory of long-period tides allows for the possibility that, in forced tidal waves, there may arise a phase shift between the wave and the force, and that the actual oscillations in the real ocean may also fail to correspond to their theoretical magnitude ([1]).

(Figure: Fig. 2)

Fig. 2. Mean values of the amplitudes of the semiannual solar tide in the Atlantic (*a*), Indian (*b*), and Pacific (*v*) oceans.

In the middle latitudes of the ocean, the existence of a semiannual tidal wave must naturally give rise to semiannual tidal currents. Semiannual astronomical currents are in fact observed in the ocean.

It was noted earlier ([4]) that semiannual currents in the middle latitudes of the ocean are not only noticeable, but are also clearly expressed in many regions of the ocean' s middle latitudes. In the Arctic Ocean the maximum velocity of the semiannual current was found to be 3 cm/sec, in the Southern Ocean 3.2 cm/sec. Data from long-term observations of currents in the Tsushima Strait gave a value of 12.8 cm/sec. In the Gulf Stream zone the velocity of a current of this kind was 2.8 cm/sec. Thus, further study of semiannual rhythmicity in the activity of ocean currents is an interesting and important task of dynamical oceanography.

Thus, the data from the study of semidiurnal oscillations of the level of the World Ocean do not confirm the hypotheses of R. Eyselin ([8]) and K. N. Fedorov ([5]) on the meteorological origin of the semiannual rhythm in the ocean; on the contrary, they compel one to believe that the semiannual oscillations of mean sea level and the semiannual variations of sea currents have a simpler explanation –namely, they are produced by the semiannual solar tide.

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REFERENCES

[1] G. Lamb, *Hydrodynamics*, Moscow-Leningrad, 1947. [2] I. V. Maksimov, *Scientific Notes of the Leningrad Higher Engineering Maritime School named after Admiral Makarov*, vol. 13 (1959). [3] I. V. Maksimov, *Problems of the Arctic and Antarctic*, No. 3 (1960). [4] I. V. Maksimov, *Oceanology*, vol. 2 (1962). [5] K. N. Fedorov, *Bulletin of the Academy of Sciences of the USSR, Geographical Series*, No. 4 (1959). [6] A. Doodson, *Proc. Roy. Soc.*, A, 100, No. 704 (1921). [7] International Hydrographic Bureau, Special Publication, No. 26, *Tidal Harmonic Constants*, Monaco, 1930-1940. [8] C. O' D. Iselin, *Papers in Physical Oceanography and Meteorology Published by Massachusetts Institute of Technology and Woods Hole Oceanographic Inst.*, 8, No. 1 (1940). [9] E. Lisitzin, *Extr. du Bul. d' Inform du Comité Central d' Oceanographie et d' Etude des Côtes*, 8, 8 (1956). [10] P. A. Schuremann, *Manual of the Harmonic Analysis and Prediction of Tides*, Washington, 1924.

Note: Figure translations are in progress. See original paper for figures.