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HARMONIC ANALYSIS OF TIDES IN ADMIRALTY BAY*

1. BRIEF CHARACTERISTIC OF DYNAMIC VARIATIONS RELATED TO TIDES IN THE REGION OF ADMIRALTY BAY AND THE SOUTH SHETLANDS

Admiralty Bay, on King George Island, has been the area of oceanographic surveys carried out by Polish scientific expeditions based in the Arctowski Station since 1977. During the Antarctic summer of 1977/78, comprehensive studies were conducted in part of Admiralty Bay (Ezcurra Inlet) including meteorological conditions, currents, sea level oscillations, salinity and temperature [7]. Investigations of salinity and temperature showed that the value of the density of the water is very uniform throughout the entire vertical profile. Except for cases where desalinated water occurs near the surface, the relative density $\delta_t = 27.3 \pm 0.2$ in the entire water column (Fig. 1) [7].

The characteristics of water flows, determined on the basis of current measurements in two vertical profiles, each series of two-week duration has been published in [5]. The dependence between sea level oscillations (tides) and currents was observed in two vertical pro-

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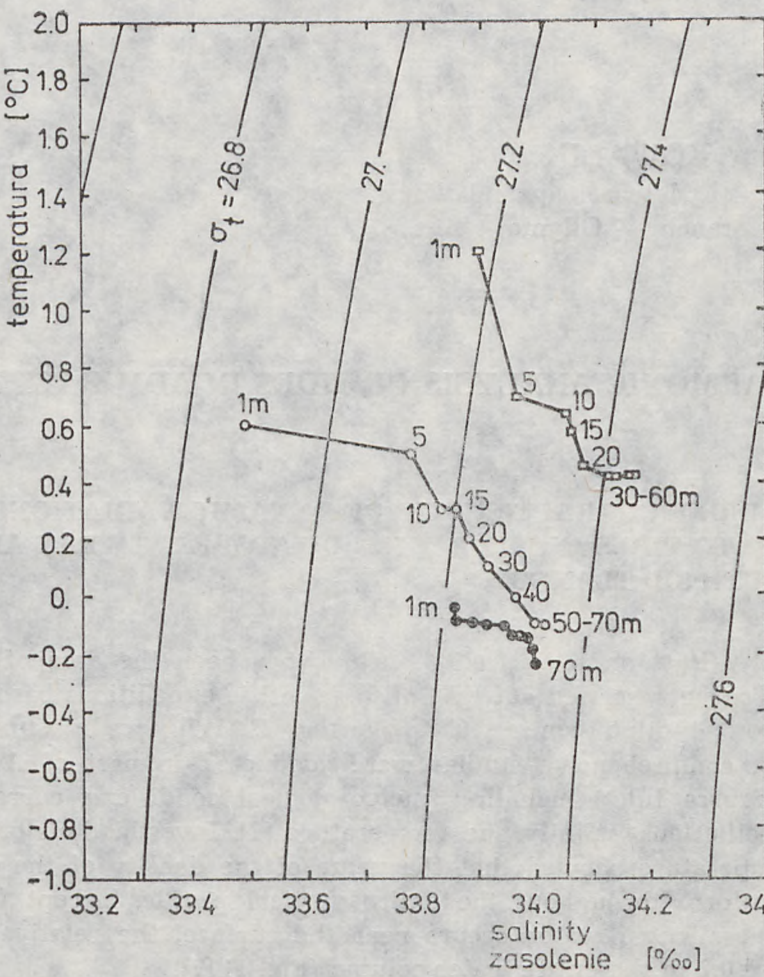

Fig. 1. T-S diagrams for Ezcurra Inlet waters with relative density isolines included δ_t (according to Dera [7])

Rys. 1. Diagramy T-S dla wód fiordu Ezcurra na tle izolinii gęstości umownej δ_t (na podstawie Dery [7])

files in the bay. Spectral analysis of the currents (utilizing FFT algorithm) enabled the amplitudes of tidal currents for these profiles to be determined. The maximum values of amplitudes of diurnal and semi--diurnal tidal currents are equal to 5—6 and 2—3 cm/s, respectively. The vertical profiles of current velocity are relatively uniform (proving that the tides are barotropic) in contrast to the horizontal profiles, for which the amplitudes of tidal currents near the inlet of the bay are twice as high as in the inner part. The water flow occurs along the axis of the bay due to convenient connection of this basin with the ocean.

In addition, a spectral analysis of the currents, utilizing the method of rotational components, was performed for the two profiles mentioned above [5].

The characteristics of rotational components comprising: total spectrum, spectrum for clockwise rotation components (negative spectrum), rotation coefficient and orientation of the main axis of the current ellipse in relation to the direction 330° (along the axis of the fiord), are shown in Figs 2 and 3. The analysis demonstrated that the maximum ki-

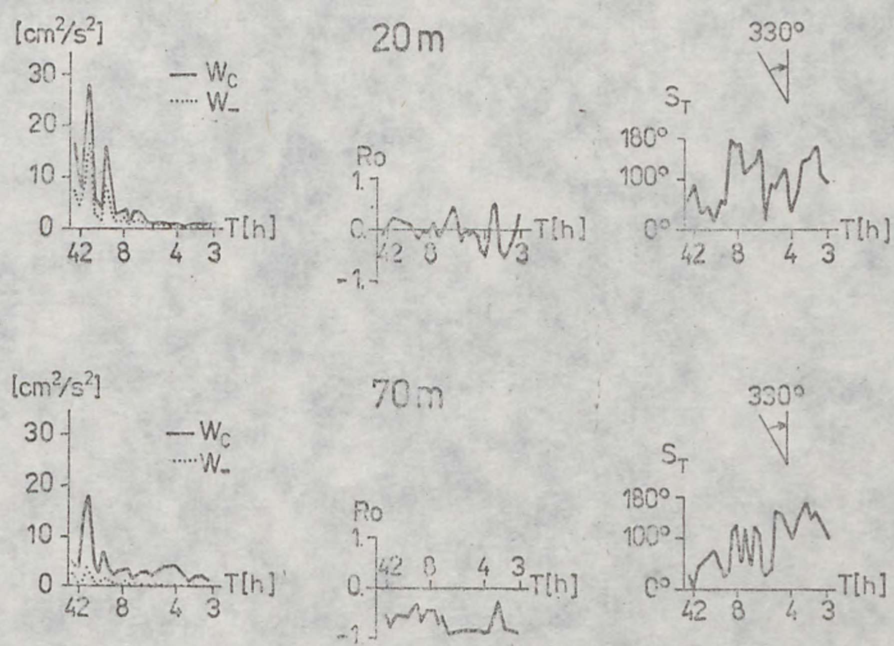

Fig. 2. Rotation spectrum W, rotation coefficient R_o, and orientation of the main axis of current ellipse S_T at point I at depths 20 and 70 m

Rys. 2. Widmo rotacji W, współczynnik rotacji R_o, orientacja osi głównej elipsy prądów S_T w punkcie I na głębokości 20 i 70 m

netic energy is associated with the period corresponding to currents with the components $K1$, $O1$. The domination of the diurnal period in the current spectrum results from the superposition of the measurement period with spring tides, which have a distinct influence on the diurnal components. The rotation coefficient and orientation of the main axis of current ellipses both indicate that the water flow occurs along the axis of the bay. The rotation coefficient R_o=O results from similar contributions of energy to both spectra, characteristic for clockwise and counterclockwise rotations (negative and positive). The direction of the main axis of the tidal currents ellipse agrees with that of the axis of the basin.

Sea levels were recorded in the region of the Arctowski Station at 1-hour intervals [15]. Sea level oscillations in February 1978 are shown in Fig. 4. It follows from Fig. 4 that these variations represent the tidal phenomena with a predominance of semi-diurnal tides. Further in this paper the type of tides in Admiralty Bay was accurately determined by means of harmonic analysis.

The grid of long-period measurements of sea level oscillations and currents is poorly developed in the region of the Antarctic studied. Tidal waves are generally formed in the central part of the ocean, between latitudes 40°S and 40°N, subsequently propagating north- and southward

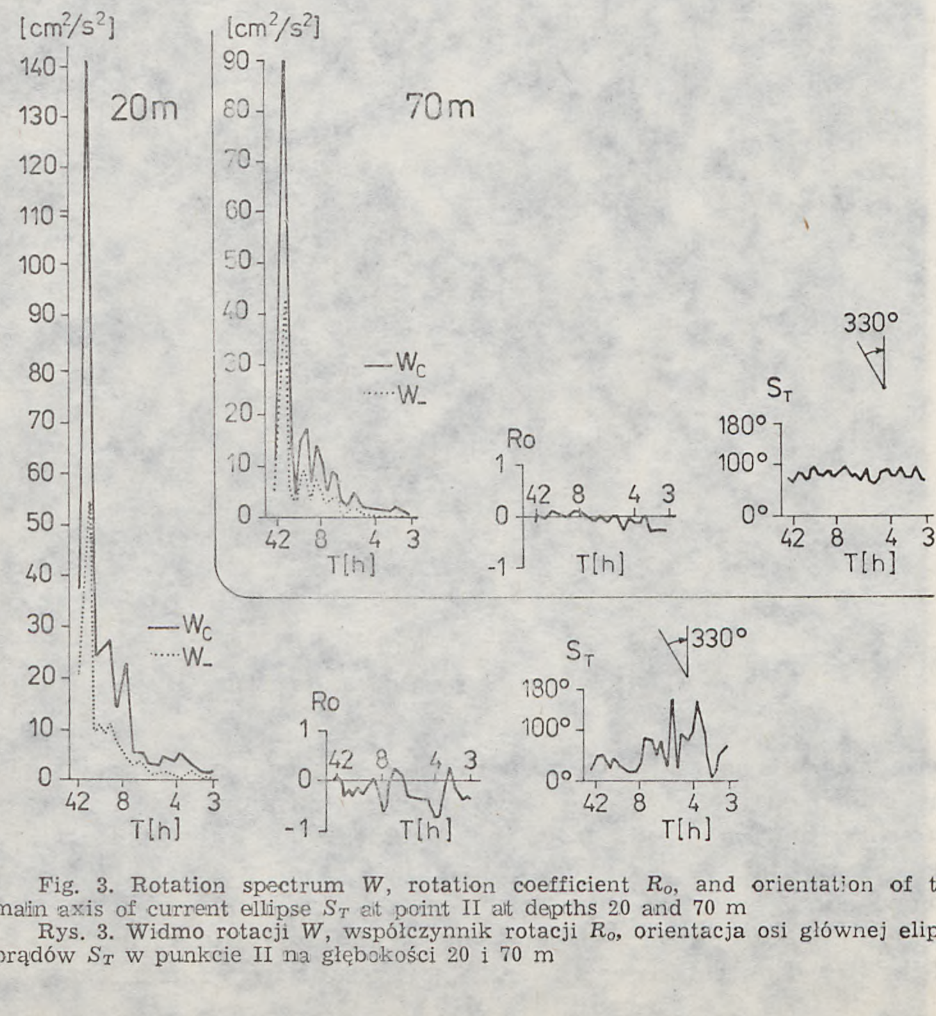

Fig. 3. Rotation spectrum W, rotation coefficient R_o, and orientation of the main axis of current ellipse S_T at point II at depths 20 and 70 m

Rys. 3. Widmo rotacji W, współczynnik rotacji R_o, orientacja osi głównej elipsy prądów S_T w punkcie II na głębokości 20 i 70 m

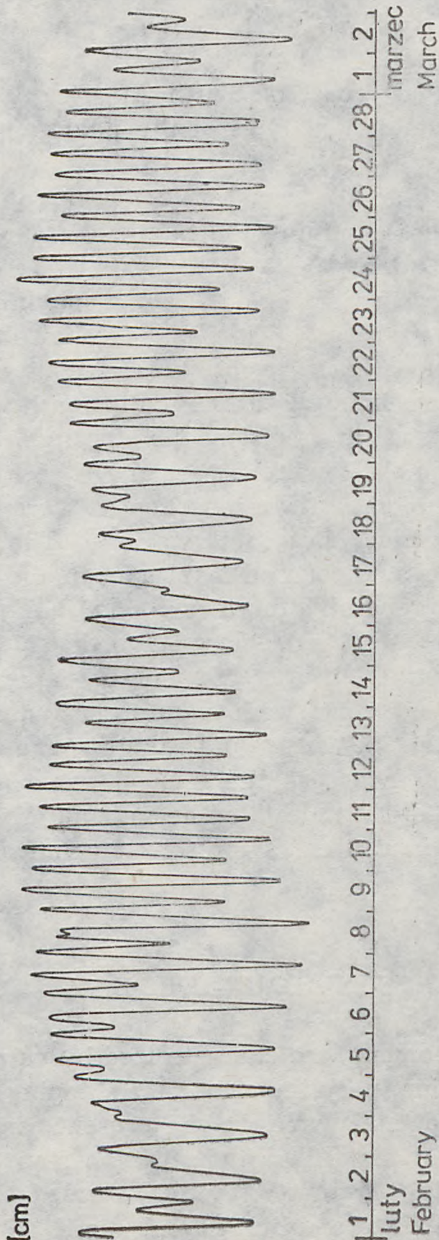

Fig. 4. Sea level oscillations in Admiralty Bay in February 1978
Rys. 4. Wahania poziomu morza w Zatoce Admiralicji w lutym 1978 r.

[4]. These waves have considerable effect on the character of tides in the Antarctic region. In addition to the large amphidromic system (latitude ca. 40°S) this character is also influenced by a smaller system located east of the south-east coast of South America. This influence is particularly marked in the cotidal lines of the tidal components *M*2, *S*2 [3].

In recent years, much new information has been contributed by studies of dynamics of waters adjoining the South Shetlands, especially in Drake Passage [2, 11, 12, 13].

In the current spectra in this region, distinct maxima corresponding to the periods of tides are observed. Tidal and inertial phenomena dominate in the range of periods from several hours to one day. The 14-day variation of currents associated with the half-monthly tide (MSF) is also distinctly marked [2, 11]. In addition, the amplitude of semi-diurnal tidal currents is higher in the northern part of Drake Passage [13]. The characteristics of tidal currents at various depths were determined during the investigations carried out in this region. The *M*2 component predominates at all levels studied. The main axes of the current ellipses for this component are generally directed along the NE-SW line, the direction of the main axes thus being parallel to that of the propagation of the tidal wave. Maximum velocities of tidal currents for the *M*2 component do not exceed 5—7 cm/s with counterclockwise motion of the current vectors [13]. The *M*2 tidal wave in Drake Passage generally propagates along the meridian, whereas the diurnal wave (*O*1+*K*1) in the direction of the parallel of latitude [2]. The maximum values of amplitudes are equal to 4—6 and 3 cm/s for semi-diurnal and diurnal currents, respectively.

2. TIDAL CONSTANTS IN ADMIRALTY BAY

Tides, as periodical phenomena, are characterized by values of amplitude and phase. Tidal prediction, very important for shipping, is based on the harmonic analysis of the tidal wave. In the present case, 29-day recordings of sea level oscillations with a quantization step of $\Delta t = 1$ hr, taken in the vicinity of the Arctowski Station, formed the basis for the determination of the values of amplitudes and phases (H and g) of twenty five harmonic constants. An algorithm, based on Horn's formulas and employed in practice by Noye and Easton [10], was used for the calculations.

The sum of tidal waves consists of many harmonic components of the character [8]:

$$R = \cos / qt - \xi /$$

where: R — amplitude of wave,

q — angular velocity of wave,

ξ — wave phase.

The amplitude and phase of a tidal wave can be expressed in the form:

$$R = fH$$

$$-\xi = / v_0 + u / - g$$

where f and $(v_p + u)$-g are variables depending on astronomic conditions.

Knowing sea level oscillations at a given point, one can determine the amplitude and phase of particular tidal waves by means of harmonic analysis. The height of a wave in its general form can be represented as [8, 9, 10]:

$$h = A_0 + \sum_i R_i \cos / q_i t - \xi_i /$$

where A_o is he average sea level.

Using denotations $R_i \cos \xi_i = A_i$ and $R_i \sin \xi_i = B_i$, the height of a tidal wave becomes:

$$h = A_0 + \sum_{i=1}^{KL} / A_i \cos q_i t + B_i \sin q_i t /$$

$i = 1, ..., KL$ — the number of tidal components.

The method of least squares was used to determine coefficients A and B [8, 10]. Knowing the values of A and B for each tidal component, it is possible to calculate the tidal constants (H and g) from the formula:

$$H = \frac{1}{f} R \quad \text{and} \quad g = \xi + / v_0 + u /$$

$$\text{where: } R = \sqrt{A^2 + B^2} \quad \text{and} \quad \xi = \text{arctg} \frac{B}{A}$$

Phases of the tidal components will be determined relative to the culmination on the Greenwich meridian.

The tidal constants (H, g) for Admiralty Bay calculated on the basis of water level recordings in February 1978 are given in Table 1 (central value 46.30 for Feb. 16, 1978; $A_0 = 482.4$ cm).

It follows from this Table, that the four principal tidal components: $M2$, $S2$, $K1$, $O1$ predominate. The substantial contribution of the half--monthly tidal component (MSF) with the corresponding value of am-

Table 1. Tidal constants of Admiralty Bay

Component	Amplitude H [cm]	Phase g [°]	Period [hrs]
MSF	9.3	50.7	354.367
SG1	1.6	81.2	27.848
Q1	7.2	338.3	26.868
O1	32.1	23.3	25.819
M1	2.6	358.5	24.841
K1	29.4	90.9	23.934
J1	2.7	120.6	23.098
001	5.3	337.8	22.306
MU2	1.0	15.5	12.872
N2	6.1	209.4	12.658
M2	48.2	256.0	12.421
L2	2.6	307.9	12.192
S2	30.6	344.5	12.000
2SM2	0.7	232.2	11.607
2MK3	0.7	193.6	8.386
M3	0.3	231.1	8.280
MK3	1.4	282.8	8.177
MN4	0.3	251.6	6.269
M4	0.7	338.4	6.210
MS4	0.2	13.4	6.103
2MN6	0.6	133.1	4.166
M6	0.1	301.4	4.140
MSN6	0.4	151.9	4.118
2MS6	0.9	292.6	4.092
2SM6	0.1	57.4	4.046

plitude $H=9.3$ cm should be noted. The values of H and g shown in Table 1 are consistent with those published by Bogdanov [3, 4].

Using the same algorithm, the tidal constants for Admiralty Bay were calculated on the basis of mareographic data recorded in January 1979. The values obtained were similar to the constants listed in Table for the four principal tidal components, especially in the relation to phase shifts.

For January 1979, the amplitudes and tidal phases were equal to:

Component	H [cm]	g [°]
O1	29,5	20,1
K1	35,5	81,6
M2	46,1	258,4
S2	24,6	339,2

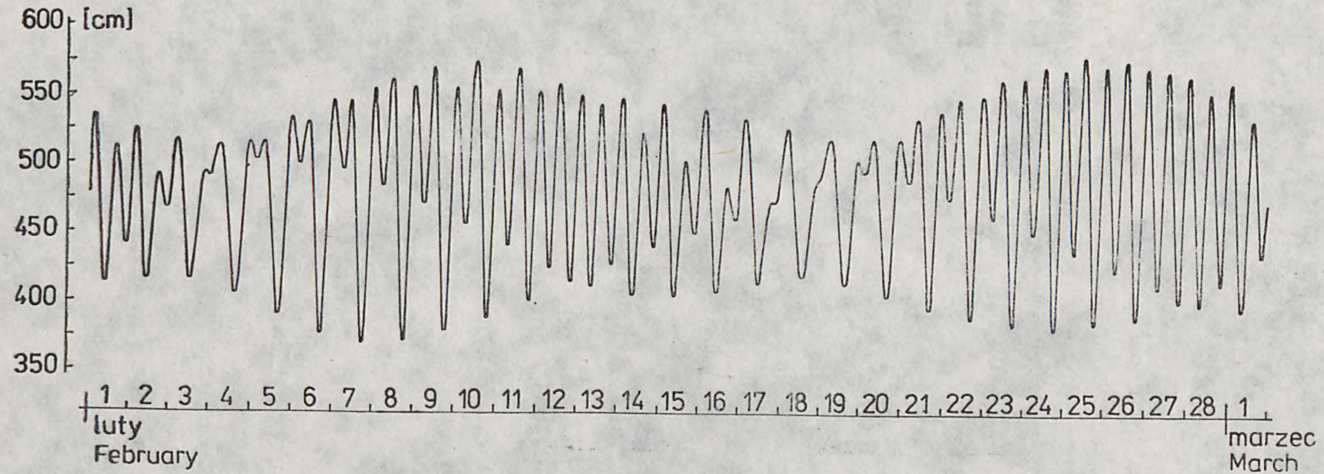

Fig. 5. Predicted sea level oscillations in Admiralty Bay in February 1978
Rys. 5. Przewidywane wahania poziomu morza w Zatoce Admiralicji w lutym 1978 r.

In addition, the components $Q1$ (H=7.2 cm) and $N2$ (H=6.1 cm) contribute considerably to diurnal and semi-diurnal waves, respectively. In contrast with the tidal components discussed above, the shallow water components do not influence the type of tide in this region.

In order to verify the values of the tidal constants given in Table, predicted sea level oscillations in Admiralty Bay were calculated for February 1978 (Fig. 5). It follows from Fig. 5 that the predicted course closely resembles the sea level oscillations observed. The differences in the sea level oscillations shown in Figs. 4 and 5 may result from not having taken into account luni-solar semi-diurnal declinational $K2$ and diurnal principal solar $P1$ components in calculations of the predicted sea level. Assuming that the tidal constants of these waves can be expressed as [9]:

$$H_{K2} = \frac{1}{3.67} H_{S2} \qquad g_{K2} = g_{S2} - 0{,}081 / g_{S2} - g_{M2} /$$

$$\text{and} \quad H_{P1} = \frac{1}{3} H_{K1} \qquad g_{P1} = g_{K1} - 0{,}075 / g_{K1} - g_{O1} /$$

one obtains the tidal constants of these components

$K2$	H=8.0 cm	and	g=337.3°,
$P1$	H=9.7 cm	and	g= 85.8°.

The type of tide dominating in Admiralty Bay was determined on the basis of the magnitude of amplitudes of the four principal tidal components [6]:

$$F = \frac{K1 + O1}{M2 + S2}$$

The F value was equal to 0.78 and 0.91 for February 1978 and January 1979, respectively.

For $0.25 < F \leqslant 1.5$ it is assumed that the tide is of a mixed type — semi-diurnal, irregular. In such case, so-called two low and two high waters with large differences in heights occur.

In addition, the average heights of semi-diurnal and diurnal tides were determined:

for February 1978

$$2(M2+S2)=158 \text{ cm},$$
$$2(K1+O1)=123 \text{ cm};$$

for January 1979

$$2(M2+S2)=142 \text{ cm},$$
$$2(K1+O1)=130 \text{ cm}.$$

The type obtained above predominates in the region of the Antarctic waters [6]. According to the classification of Duwanin [8], the type of tide can be expressed in the form of $(K1+O1)/M2$. According to this classification, a mixed irregular semi-diurnal tide, for which the F value varies from 0.5 to 2.0, dominates in the region. On the tide map tidal type (0.5—2.0) predominates in the greater part of the western Antarctic [3]. In the future, having an annual series of mareographic recordings, it will be possible to determine 49 components of the tide in Admiralty Bay more accurately.

A new Soviet scientific station Bellingshausen was founded in 1968 in the south-west part of King George Island, in Ardley Bay [14]. Harmonic constants of the components *M2, S2, K1, O1, P1, Q1, N2, K2* were determined there for five various periods in 1968. The values of amplitudes undergo slight variations over the year (with the maximum in winter). The F value, characterizing the type of tide, varies from 0.68 in summer to 0.83 in winter. The amplitudes of spring and neap tides amount to 146 and 42 cm, respectively [14]. Spring tides influence diurnal components very distinctly, particularly in the case of superposition of syzygy with the maximum lunar declination.

The amplitude and phase of the four principal components at several points of the South Shetlands region are given in *Admiralty Tide Tables* [1]. The components have been determined by the so-called admiralty method. For example, for two points located on King George Island the constants equal:

Point	φ	λ	*M2*		*S2*		*K1*		*O1*	
			g	*H*	*g*	*H*	*g*	*H*	*g*	*H*
Admiralty Bay	62°03'S	58°24'W	218	40	274	26	39	19	17	27
Potter Cove	62°14'S	58°40'W	187	45	243	28	14	21	352	35

Taking into account the amplitude values from last Table, the type of tide can be estimated ($F=0.70$ and 0.77).

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ANALIZA HARMONICZNA PŁYWÓW W ZATOCE ADMIRALICJI

Streszczenie

Składowe pływów w Zatoce Admiralicji wyznaczono po przeprowadzeniu analizy harmonicznej zarejestrowanych oscylacji poziomu morza w ciągu 29 dni.

Stwierdzono, że przeważały tu cztery główne składowe pływów: $M2$, $S2$, $K1$, $O1$. Ponadto wyróżniono półmiesięczne pływy (MSF). Pływy w zatoce tej wykazują zróżnicowany typ: półdobowy, nieregularny. Przeciętna wysokość półdobowych pływów 2 ($M2+S2$) równa się 158 cm, podczas gdy pływu dobowego 2 ($K1+O1$) dochodzi do 123 cm.

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