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An Investigation of Sea Level Fluctuations in Varna and Bourgas

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Introduction

The sea level variations under low-tidal range conditions, such as conditions in the Western part of the Black Sea, are generally formed under influence of the wind energy upon the sea surface, oscillations of atmospheric pressure and planetary forces (R o z h d e s t v e n s k i, 1964; V e s s e l i n o v, M u n g o v, 1998).

In the presented paper the main results of investigation of sea level variations for 53 years series in the Varna and Bourgas bays are shown.

Archive sources of the Institute of Oceanology, BAS over the period 1928 - 1987 were used as the main data source to perform the statistical and correlational analyses.

The next results are presented: investigation of trend of series, intra-annual and inter-annual sea level variations as well as ensure function of extremal sea levels.

Input data

Main Administration for Geodesy and Cartography maintains four sea level gauges at the Bulgarian Black sea coast – Varna, Bourgas, Ahtopol and Irakli. Two of them – Varna and Bourgas were built in 1928. The series in Ahtopol and Irakli starts later, therefore in the present investigation they are not taken into account. Monthly averaged sea level series as well as monthly maximal and minimal records from Varna and Bourgas are used in present investigation.

Investigation of trend

The trend investigation of long-year series has specifically significant in condition of sea level increasing. For example, to these series for Black Sea basin could be series from Sevastopol and Odesa (beginning in 1875), Poty (1874), Batumi (1882) (Z i l b e r s t e i n, T i k h o n o v a, 2000). In the investigation of Z i l b e r s t e i n and T i k h o n o v a (2000) are indicated value of trend for sea level gauges in former USSR: Odesa, Nikolaev, Sevastopol, Anapa, Novorossijsk, Tuapse, Sukumi, Poty and Batumi. The linnear trend values are limited between 0.2 - 0.6 cm per year.

M a l c i u and D i a c o n u (2000) are present linnear trend in Constantza Port for the period 1933 - 1998. The trend value is 0.128 cm per year.

The value of trend in the present investigation is obtained for Varna – 1.074 cm per year and for Bourgas – 0.734 cm per year. It is clear, that there is vertical movement of the Earth core (sinking of a pegel). M a r k o v (1970) make approximate estimation of vertical movement range. For more detail sea level trend investigation it is necessary to take data for levelling of pegel points with points from the inland, as well as their changes in the time. Results of trend investigation are shown in fig. 1.

Seasonal sea level variations

The seasonal sea level variability is mostly

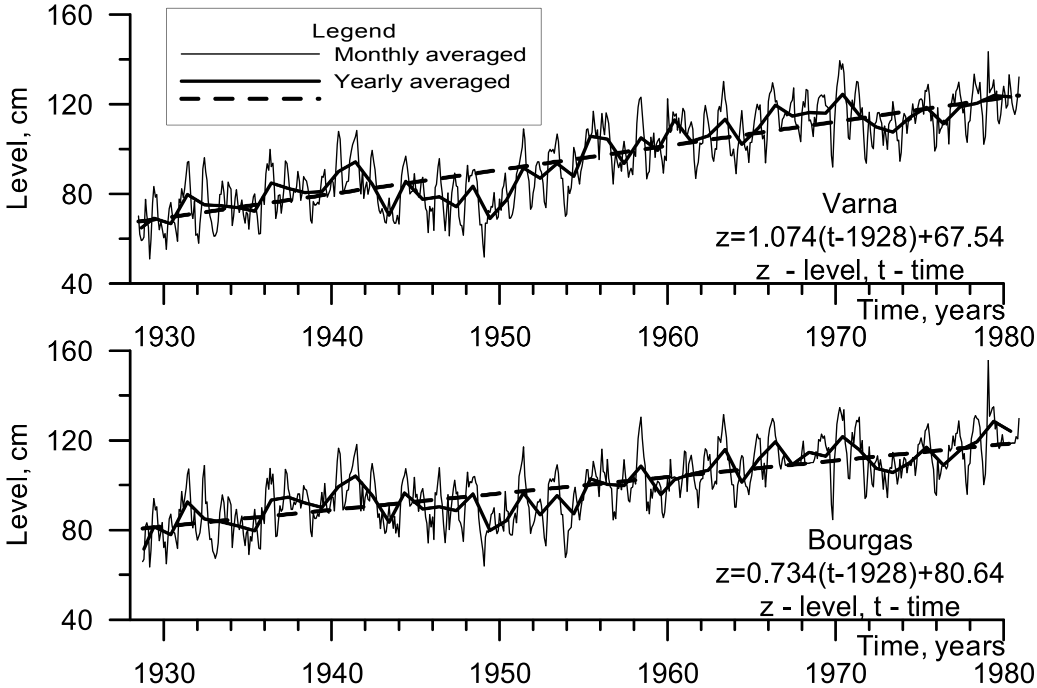

Fig. 1. Investigation of trend for Varna and Bourgas

caused by the seasonal variability of water balance (A l t m a n, 1991). The river runoff is the essential part of incoming part of the water balance of the Black sea – typical estuarine basin. About 60 % of river runoff is due to the Danube discharge. That is why the sea level variations are closely depends of Danube discharge variability. The annual sea level variations in Varna bay are object of investigation of R o z h d e s t v e n s k i (1964), Z j u m b j u l e v a (1973, 1977), V e s s e l i n o v, M u n g o v (1998). R o z h d e s t v e n s k i (1964) obtains that the amplitude of variations is 16.1 cm, where the maximal value is in May, and minimal in October. Z j u m b j u l e v a (1973, 1977) on the example of Varna station, shows by means of the correlation principle that the continental discharge is the main factor determining the seasonality of the yearly sea level motion. In the research work of V e s s e l i n o v and M u n g o v is shown that the maximal levels can be observed during Spring-Summer period and minimal levels can be observed most often in October. M a l c i u and D i a c o n u (2000) show that the annual evolution of the sea level at Constanza and the Danube discharge are identical.

Our results are similar. By averaging of sea level values for all months with equal names is obtained seasonal component of sea level variations. The seasonal variations for Varna and Bourgas are shown in fig. 2.

Maximal levels in May-June are associated with maximal values in river runoff, flowing in the Black Sea and forming incoming part of Black sea water balance. During July-August the level decreases, that is connected not only with decreasing of river runoff, but with increasing of evaporation, that forms outgoing part of water balance. The typical feature of Black sea level intra-annual variability – the period of subside (July-September) is essentially shorter than the increasing period (December-April) can be seen in the intra-annual Danube discharge too (M a l c i u, D i a k o n u, 2000). The minimal sea level values are observed in October and November and absolute minimum is in October. The time of Danube discharge maximum occur – April-

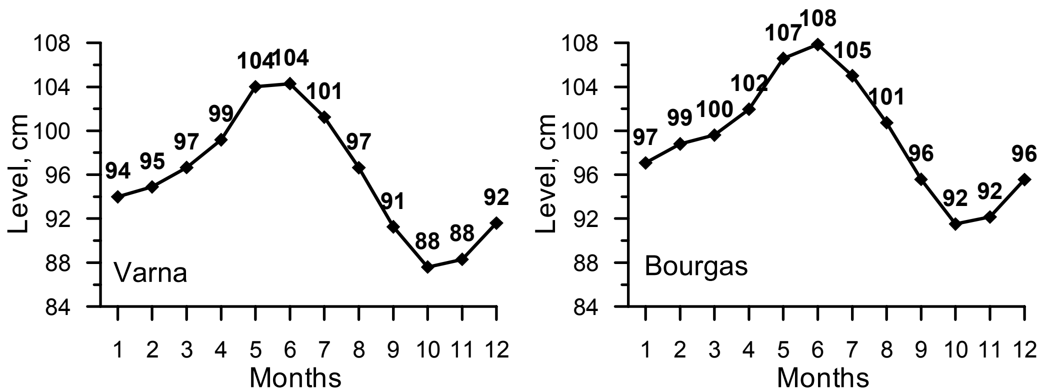

Fig. 2. Seasonal sea level variations for Varna and Bourgas

May (absolute maximum in May), Constanza maximum level – May-June (absolute maximum in May), Varna maximum level – May-June (the level values in May and June are equal), Bourgas maximum level – May-June (absolute maximum in June). Detailed analysis of data, presented by M a l c i u and D i a k o n u (2000), and our results allows us to make the following conclusion: there is a defazation between occur time of maximum in Danube discharge, and annual seal level maximum in Constanza, Varna and Bourgas.

Inter-annual sea level variations

In order to obtain the period and the amplitude of large-scale inter-annual sea level variations, it is necessary to exclude the trend, shown in fig. 1, and the seasonal variations, shown in fig. 2. The running average is used for processing of residual. The results of calculation for Varna and Bourgas bays are depicted in fig. 3. The river discharge variations as whole and, in particular, the Danube discharge variations influence over intra-annual and inter-annual sea level variations (B e r e n b e i m, 1959; A l t m a n, 1991; V e s s e l i n o v, M u n g o v, 1998; M a l c i u, D i a k o n u, 2000; Z i l b e r s t e i n, T i k h o n o v a, 2000). The most typical feature of the inter-annual sea level variation is the cyclic recurrence. The cycles with periods 2 - 3, 4 - 5, 9 - 17 and 25 - 30 are discribe by F o m i c h e v a, R a b i n o v i c h, D e m i d o v (1991); Z i l b e r s t e i n, T i k h o n o v a (2000). From fig. 3 is clearly seen the presence of inter-annual sea level variability with period about 30 years. Two maximums – in 1936 and 1965 - 1966 and one minimum – in 1948 are outlined during the period of investigation. Variability with similar cyclic recurrence are registered from V e s s e l i n o v and M u n g o v (1998) and shown that a synchrony between the sea level variations and the Danube discharge exists.

Maximum and minimum sea levels

Maximal sea levels are especially important for the purpose of coastal construction design and coastal protection. Minimal sea levels are important too, because of maintenance of port and harbor aquatories and navigation channels.

Analysis of the published information (B e l b e r o v et al., 1982; K o s t i c h k o v a, B e l b e r o v, 1985) ascertained that a main omission in research of the maximal sea level in the Bourgas bay was using the sea level variation series excluding extreme high levels during catastrophic storm on 16 - 22 of February, 1979. The main reason for this was that the sea level gauge in the port Bourgas did not register this phenomenal sea level rise due to comparatively low elevation of the gauge "zero" and consecutive reduction in the registration range of the maximum levels. In the same period, 16 - 22 of February 1979, the sea level gauges in Irakly and Ahtopol, at a higher zero of the gauge registered a sea level increase about 1.40 m. This extreme event is due to the continued wind influence for more than 78 hours at a speed of 20 - 28 m/s with a dominating NE direction. The combination between mentioned extreme increase (with 200 years return period) and wind waves is the reason for catastrophic damages. For the

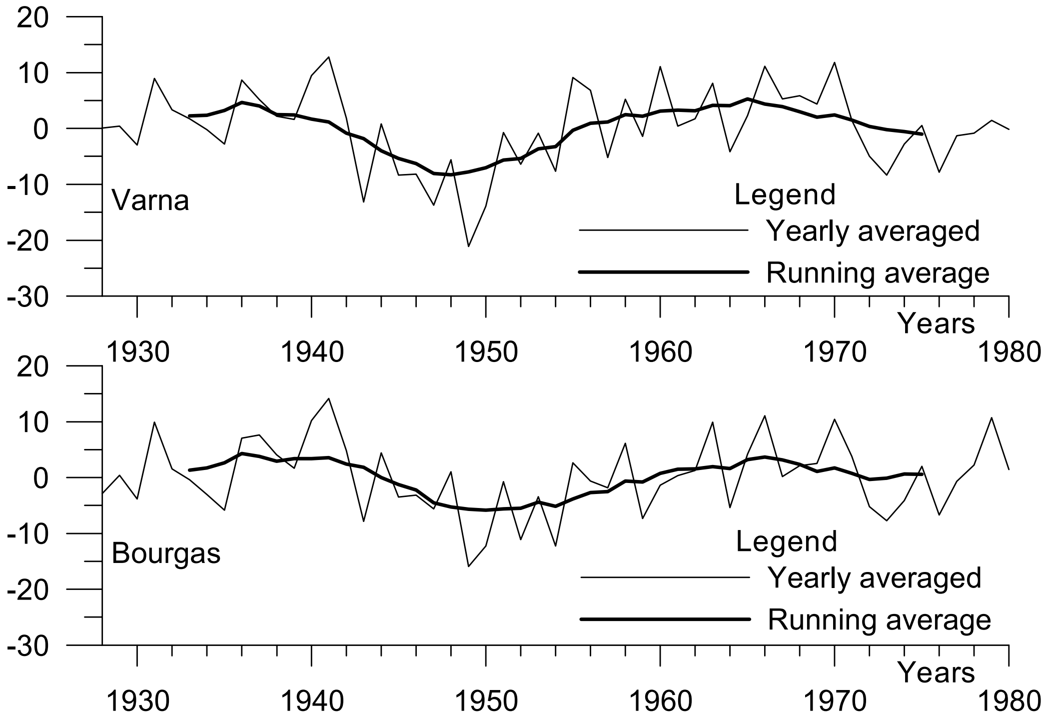

Fig. 3. Inter-annual sea level variations for Varna and Bourgas

additional statistical and correlation analysis, are used the data of the sea-level gauges in Varna, Bourgas, Ahtopol and Irakly (K o s t i c h k o v a et al., 2001).

The statistical theory for extreme sea level values gives possibility to calculate the extremums with rare repetition on the base of existing observations. The method for estimating extreme sea levels is based on the asymptotic theory of extremums (G e r m a n, 1971) and it includes: excluding the tendencies (trends) in the extreme sea level series; take an account of the unrepresentative extreme sea level series (building on the regional distribution functions); approximation and extrapolation of the regional distribution functions on the basis of the assessment of the parameters at the boundary distribution of the extremums; calculation of the extreme levels and assessment of their punctuality of occurrence.

The statistics of the extreme values is based on double exponential low. It is based on the assumption of the independence of the observer, which holds rare in reality. Such assumption limits the theory for the extreme values. The theory agrees with the results, such as it reflects just the asymptotic behavior of the exit distribution.

$$y = -\ln(-\ln P), \qquad (1)$$

were $P = \exp(-e^{-y})$, the distribution function for the extreme values of the sea level substituting P with its value, expressed by return period $P = \frac{T-1}{T}$, we obtain,

$$y = -\ln\ln\left(\frac{T}{T-1}\right) \qquad (2)$$

Since maximal annual height series of the level are unsteady in most of the cases, the input data for calculating the distribution functions are given by the formula

$$h_{\max} = H_{\max} - \overline{H}, \qquad (3)$$

where $h_{\max}$ – maximal annual diversion,
$H_{\max}$ – maximal annual sea level heights,
$\overline{H}$ – average annual sea level heights.

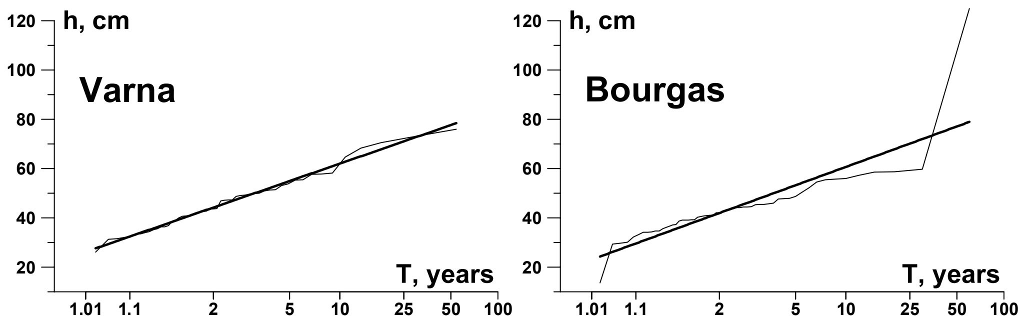

Fig. 4. Ensure function of the maximal diversions h_{max} for Varna and Bourgas

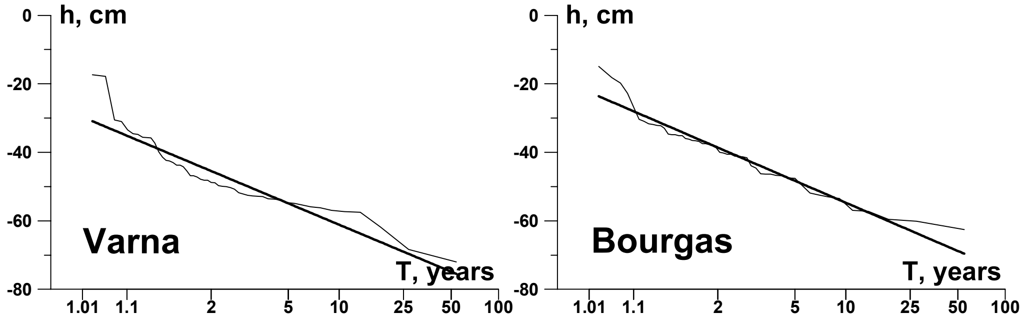

Fig. 5. Ensure function of the minimal diversions h_{min} for Varna and Bourgas

After statistical analysis of the annual diversions $h_{\max}$ of the maximal annual levels $H_{\max}$ (1928 - 1987) in fig. 4 are presented the regime functions of the maximal diversions h_{max} towards the average longyears level $\overline{H}$ (-0.28 m by Baltic zero) for the Bourgas and Varna bays. The analysis of minimal diversion h_{min} is performed by analogical way, as well as the maximal diversions. In fig. 5 are presented the regime functions of the minimal diversions $h_{\min}$ towards the average longyears level $\overline{H}$ for the Bourgas and Varna bays.

The results from the investigations are presented in the tables 1 and 2.

Conclusions

As final results of presented paper could be pointed, that:

- In order to obtain "real" sea level trend in

Table 1. Repetition of the maximal diversions h_{max} for Varna and Bourgas bays

Return period [year]	1	2	5	10	25	50	100
Varna h_{max}[cm]	26.24	44.19	54.93	62.04	71.02	77.69	84.30
Bourgas h_{max}[cm]	23.11	41.96	53.23	60.69	70.12	77.12	84.06

Table 2. Repetition of the minimal diversions h_{min} for Varna and Bourgas bays

Return period [year]	1	2	5	10	25	50	100
Varna h_{min}[cm]	-29.72	-45.48	-54.89	-61.13	-69.01	-74.85	-80.65
Bourgas h_{min}[cm]	-22.45	-38.63	-48.30	-54.71	-62.80	-68.80	-74.76

Varna and Bourgas bays it is necessary to determine rates of vertical land movement at sites where the gauges are situated;
- The seasonal sea level variations are about 15 cm, minimal value is in October, and maximal in May-June;
- The time for setting in the sea level maximum delays with increasing the distance form the Danube delta;
- The period of inter-annual (inter-decadal) sea level variations is about 30 years;
- The ensure function of extremal (maximal and minimal) sea level values was obtained in the result of the asymptotic theory applying.

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Изследване на изменението на морското ниво във Варна и Бургас

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(Резюме)

В настоящата статия са представени основните резултати, които са получени при изследване на данни за морското ниво във Варна и Бургас за периода от 1928 до 1980 г. Използвани са три редици данни: максималните, минималните и средномесечните значения за двата пункта.

За Варна и Бургас са получени стойностите на сезонните съставляващи на колебанията, както и трендът, обусловен не само от повишението на нивото на Световния океан, но и от вертикалните движения на сушата.

След елиминирането на тренда и сезонната съставляваща, остатъчният член е осреднен с бягащото средно. Представените резултати ясно сочат наличието на междугодишни колебания на морското ниво с период около 30 години.

Статистическата теория на максималните нива, основаваща се на асимптотичната теория на екстремумите, е използвана при обработката на редиците с екстремални стойности (максимални и минимални). Получени са функциите на обезпеченост за максималните и минималните морски нива във Варна и Бургас. Резултатите са представени и в табличен вид.