Modeling of centennial Black Sea level changes as a basis for forecasting

Likhodedova O.[1], *Konikov E.G.*[2]

[1,2]Department of Engineering Geology and Hydrogeology, I.I. Mechnikov Odessa National University, 2, Shampanskij Per., Odessa 65058, Ukraine, [1]branz@list.ru, [2]konikov2006@mail.ru

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Main goal

This study aims to: 1) reveal the patterns of sea-level regime in the northwest region of the Black Sea, and 2) define the factors, which determine sea-level changes at different process scales.

Methods

The statistical parameters that characterize sea-level regime along the NW Black Sea have been calculated and analyzed. Monthly and yearly averages of sea level position for the 1876-2002 observation period (Odessa station) were used to study fluctuations in sea level. We performed spectral (Fourier Transform) and frequency-temporal (Wavelet) analyses of time domains, which characterize the level changes in the study region. The cross-correlation analysis of sea-level regime and water balance was also included in the study. We compared the low-frequency elements of water-level regime with factors that characterize climate changes in the Northern Hemisphere in the 20th century.

Wavelet analysis provides wide possibilities for investigating time-domain periodicity. The basis of this method was generated in the mid 1980s by Grossman and Morle as an alternative to Fourier transform to be used for temporal/spatial domains with expressed heterogeneity. Wavelet transform divides the analyzed process into its constituent waves and components of various scales, and also provides time-specific process information.

Results and discussion

Fourier transform analysis of time domains that characterize inter-annual and mean annual incremental sea-level rise showed presence of a trend, which can be viewed as a fragment of low-frequency constituent (possibly characterizing a centennial cycle) and periodic constituents of 2-5, 10-14, and 20-30-year clusters. However, Fourier transform does not account for the fact that frequency may evolve with time. The result of the wavelet-transform of a one-dimensional sequence is a two-dimensional massive of wavelet-transform amplitudes – the coefficient values W (a, b). The spatial distribution of these values (a, b) = (time scale, time localization) provides information about the evolution of the relative contribution of components of various scales in time. It is called a wavelet-transform coefficient spectrum, time-scale spectrum, or wavelet-spectrum (as opposed to a single spectrum of Fourier). Spectrum W (a, b) of the one-dimensional signal represents a surface in a three-dimensional space. This surface can be projected onto a plane (a, b). Fig. 1a shows wavelet-transform coefficients of sea-level in the projection onto the plane (a, b). A clearer picture was obtained by analyzing the mean monthly values (Fig. 1b).

In Fig. 1a (scale up to 32 years), there is a well expressed series of various components, which can be grouped into the following periodicities: 1-7, 8-14, 15-20, 21-29, and 29-32. It follows from Fig.1 that the above components evolve with time, especially in the upper part of the Fig.1, where the scale corresponds to long-period constituents. The lower part of the Fig. 1b reveals a light swath that corresponds to seasonal components (scale 6-12 months). As a whole, the components with a scale up to 60 months have sufficiently regular appearance.

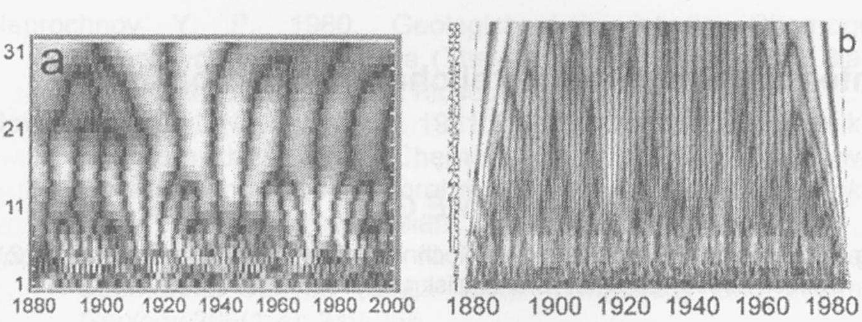


Fig. 1. Wavelet-transform coefficients W (a, b). a – sequence of inter-annual sea-level rise; b – sequence of mean monthly values. X-axis – time, Y-axis – time-domain scale.

High-frequency fluctuations (2-5 years) are characterized by substantial amplitude and are present along essentially the entire observation interval (Fig. 1a). To a large degree, they are influenced by the changes in the freshwater input into the Black Sea and are related to the elements of the water balance, the primary of which are river discharge, precipitation, and evaporation over the Black Sea basin. The values of the cross-correlation coefficients of the inter-annual sea-level change, precipitation, and river input are 0.35 and 0.79, respectively (observation period 1921-1986). Correlation of period spectrograms of the inter-annual incremental sea-level rise, Dnieper and Danube discharge, and precipitation (Fig. 2) are supported by the influence of the water balance on 2-5-year periodicity.

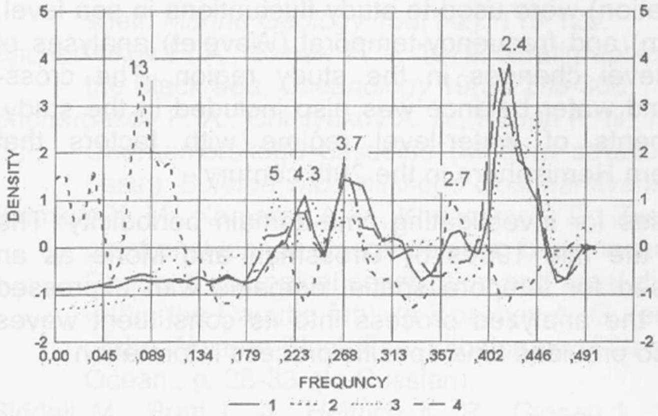
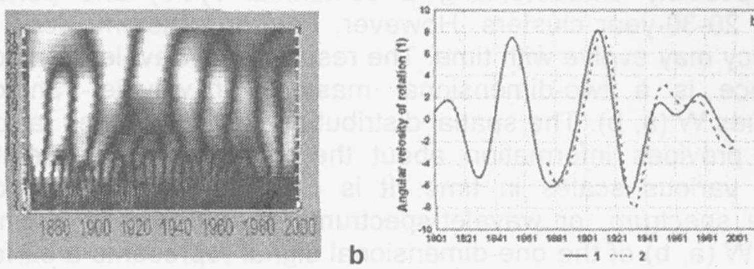


Fig. 2. Spectrogram correlation: 1-inter-annual sea-level rise, 2-precipitation, 3-Dnieper discharge, 4-Danube discharge. Spectral values are numbered.

The picture of wavelet-coefficients in Fig. 1a is qualitatively similar with the corresponding wavelet-coefficient scheme of the time sequence of changes in daily duration (Fig. 3).



a b

Fig. 3. Correlation of wavelet coefficients of the changes in Earth's velocity: (a) and inter-annual sea-level rise (b) at the 32-year scale.

For the scales (periods) exceeding 20 years, we observe a high correlation of wavelet-coefficient changes in the rotation speed and inter-annual incremental sea-level rise. A characteristic feature of the changes in mean annual water level values for the period of 1876-1991 is the transition from the decrease to an increase of sea level, which occurred during 1920s. According to observations at the Odessa station during 1876-1921, the sea level fell by 22 cm, but from 1921 to 1991 it rose by 49 cm (compared to the benchmark). The average rate of sea-level fall during the first period was 0.48 cm/year and the rate of rise during the latter period was 0.70 cm/year. The changes during the 1920s were affected by the changes in circulation epochs and to a large degree had a global character. Fig. 4

shows Black Sea level changes with boundaries of circulation epochs according to Girs (1971).

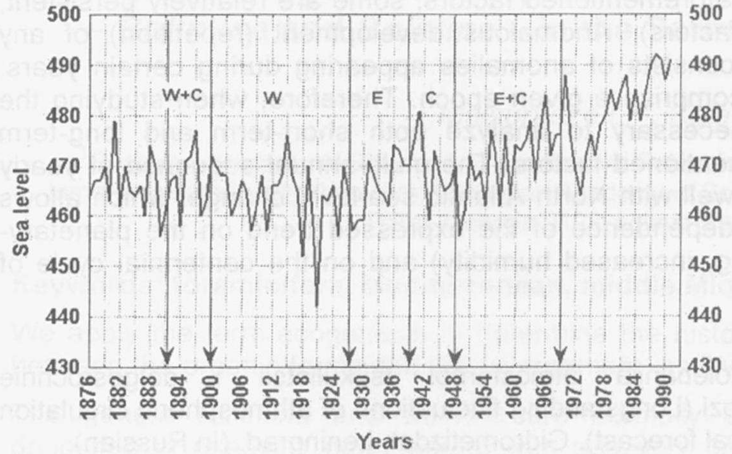


Fig. 4. Changes in the mean annual Black Sea level showing the boundaries of circulation epochs.

The shift from westerly to easterly circulation in the Northern Hemisphere, followed by the shifts to meridional and easterly-meridional, was reflected in the climatic and hydrogeological setting at both global and regional scales (Fig. 5). Globally, there is a warming and eustatic sea-level rise (Fig. 5a). Regionally, there was an increase in precipitation, atmospheric pressure, and river discharge (Fig. 5b).

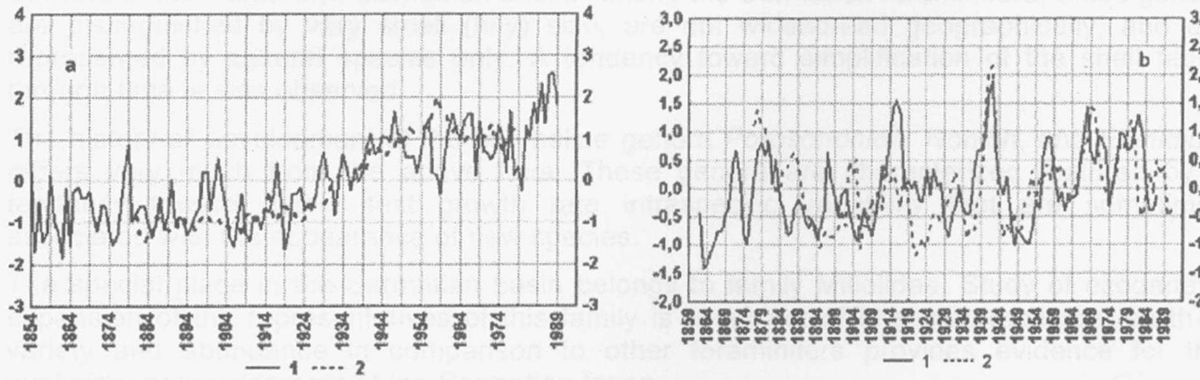


Fig. 5. a – global temperature and eustatic sea-level changes; b – Danube discharge, Odessa regional precipitation. Three-year smoothing has been applied. The sequences are numbered.

The change of circulation epochs is reflected in sea-level fluctuations in the Mediterranean. During the westerly circulation epoch, fluctuations of sea-level were around a mean value were characteristic, with a tendency to decrease during the first half (prior to 1910). For the epochs of easterly and meridional circulation, a rise in Mediterranean Sea level was more characteristic, which was reflected in Black Sea level changes.

Conclusions

The results of statistical modeling reveal intra-annual cycles (2-6 months), stages of circulation epochs (2-6 years) and of circulation epochs (10-30 years). All these are stages of one process – the process of general atmospheric circulation – and thus they always exist in tight interconnection and interdependence. Therefore, the methods of long-range forecasting must be built on common principles and must take into account the interconnection of stages with variable temporal scales. General atmospheric circulation and its development are defined by a large number of interacting factors, the role of which changes with time. The principal of these factors should be considered: 1) latitudinal heterogeneity of solar energy distribution; 2) Earth rotation speed; 3) heterogeneous distribution and heating of land and water, and orographic characteristics of the underlying surface; 4) cyclonic activity along tropospheric fronts, and 5) solar activity and other orbital and geophysical factors. Among the aforementioned factors, some are relatively persistent, recurring from year to year (1-3 factors). Anomalous development (repetition) of any processes over the years (epochs) consists of anomalies appearing during certain years, seasons, months, and days, which comprise a given epoch. Therefore, when studying the origin of circulation epochs it is necessary to analyze both short-term and long-term (background) influence of the aforementioned factors. The multi-annual sequence of yearly means of the Black Sea level agree well with North Atlantic sea-level change, which allows us to make a conclusion about the dependence of the expressed trend on the planetary-scale climatic factors (global warming, increased humidity) and on the centennial cycle of solar activity as a whole.

References

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