Comparison of the sea level fluctuations in the Atlantic Ocean, Mediterranean and Black Seas for the last 100 years

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Introduction

There is no consensus about the mode by which sea level changed in the Black Sea during the Holocene (Yanko-Hombach, 2007). Some scientists (e.g., Balabanov, 2007; Yanko-Hombach, 2007) suggest that Black Sea level changes occurred in an oscillatory manner, while others (e.g., Pirazzoli, 1991; Brückner et al., 2010) challenge this. In their opinion, the sea-level changes in the Black Sea cannot be different from those that occurred in the World Ocean in general, and the Mediterranean Sea in particular.

This paper focuses on the comparison between sea-level fluctuations deduced from instrumental observations in the Atlantic Ocean, Mediterranean, and Black Sea during the last 100 years. The main goal is to show how (but not why!) the Black Sea level has behaved most recently. We understand perfectly that geological time is not comparable with that of the period of instrumental observations. However, it is probable that the behavior of the Black Sea level in recent time and in the geological past could show similar patterns but on a different scale.

Material and methods

Comparison of sea-level fluctuations was undertaken using sea-level stands in the NE part of the Atlantic Ocean (at the Brest site), the NW Mediterranean Sea (at the Marseille site), and the NW Black Sea (at the Odessa site). It is assumed that eustatic fluctuations of the Black Sea occur in synchrony along the entire coast of that water body (Reva, 1997), and therefore sea-level fluctuations at the Odessa site are characteristic of the entire basin.

Figure 1. Location of the Brest, Marseille, and Odessa sites.

Material and methods

Data from the Odessa site were collected by O.G. Likhodedova from various sources. Two others hav been obtained from the database of the Permanent Service for Mean Sea Level (PSMSL http://www.pol.ac.uk/psmsl/. The height of sea level at all three sites has been standardized to the zer position relative to the Odessa site. The latter is located at 5 m below the zero level of the Kronsta tide gauge.

The sea-level measurement series that we used for our study has different durations depending on th sites: Odessa-Brest, 1876–1991 (n=116); Odessa-Marseille, 1885–1991 (n=107); and Brest-Marseill 1885–2006 (n=122), where "n" is the number of observations. Further analysis of these series has bee considered for their common observation period: 1876–1991.

Data processing was accomplished by the use of Correlation, Harmonic, and Bivariate Spectr Analysis. The calculations were made using the applications of the STATISTICA 7 package.

Results

An average annual sea-level curve for the last 100 years for the Marseille, Brest, and Odessa sites i shown in Fig. 2. Slope coefficients of the linear trends for Marseille, Brest, and Odessa are 1.26, 1.2 and 1.59 cm/y, respectively. This means that change in sea level at Odessa occurred more intensel compared to that at Marseille and Brest, which have a similar range in their growth. Range of sea lev at Brest, Marseille, and Odessa is 22.6, 24.7, and 50.0 cm, respectively. This means that sea level i Odessa varied through a greater amplitude than that in Brest and Marseille.

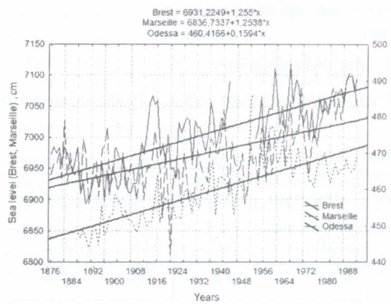

Figure 2. Average interannual sea-level stands at the Odessa (1), Brest (2), and Marseille (3) sites with plotted linear trends and their equations.

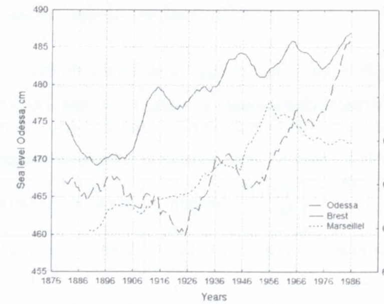

Figure 3. Rows of moving averages of interannual sea level stands smoothed to 11 years at the Bres Marseille, and Odessa sites.

Verification of the residues of the linear models with the help of the Durbin-Watson criterion show the presence of serial correlation in residues of regression models. This indicates a cyclical characte in the obtained trend. Low-frequency fluctuations are visible in the rows of moving averages smoothe to 11 years at the Brest, Marseille, and Odessa sites (Fig. 3).

Spectral analysis showed the presence of the following periods (Table 1). Periods with high spectra power are marked in bold.

Table 1. Periods (years) in long-term sea level changes.

Site	Period (years)
Brest	53.0, 35.3, 26.5, 21.2, 17.7, 15.1
Marseille	48, 24
Odessa	53.0, 35.3,26.5, 21.2, 17.7

Bivariate spectral analysis showed the presence of periods with a duration of 53.0, 35.3, 26.5, and 21. years in the compared time series.

The presence of low-frequency trends within the considered series largely masks the presence of the high-frequency components. Calculation of the difference between adjacent values reduces the impact of these trends, since the procedure actually corresponds to high-frequency filtering. Interannual changes in sea level at the Odessa, Brest, and Marseille sites are shown in Fig. 4.

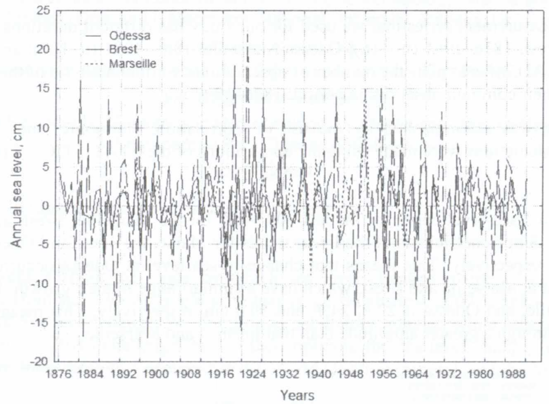

Figure 4. Interannual changes in sea level at the Brest, Marseilles, and Odessa sites.

Statistical characteristics of the interannual sea-level stands are shown in Table 2. It can be seen that they vary significantly in range and size dispersion.

Table 2. Statistical characteristics of interannual changes in sea levels.

	Valid N	Mean	Median	Minimum	Maximum	Range	Variance	Std.Dev.
Odessa	115	0.23	0.00	–17.0	22.0	39.0	67.0	8.2
Brest	106	0.20	0.65	–8.9	8.9	17.8	12.9	3.6
Marseille	102	0.24	0.15	–8.8	15.0	23.8	9.3	3.0

Bivariate Spectral Analysis of this time series showed high coefficients of coherence in the periods given in Table 3, providing information on the periods with coefficient of coherence above 0.6.

Table 3. Periods (years) of interannual sea level changes at Brest, Marseille and Odessa sites with cofficient of coherence > 0.6.

Site	Period (years)
Odessa-Brest	2.6, 3.5, 4.8, 5.0, 5.7, 10.4
Odessa-Marseille	2.3, 3.4–3.5, 3.7–3.9, 4.8, 11.8, 13.3
Brest-Marseille	2.1–2.4, 2.7–3.0, 4.8, 7.8, 8.3

Discussion

The above sites are located on the coast of the NE Atlantic Ocean, NW Mediterranean Sea, and NW Black Sea. These marine basins differ in their parameters (area, volume, etc.) and factors forming their hydrological regime. The Black Sea is much smaller compared to the two other basins and has a rather restricted water exchange with them. Its water balance is defined by the ratio between river discharge, precipitation, evaporation, and water exchange with the adjacent Sea of Marmara (Esin et al., 2010). At the same time, all three basins are exposed to common factors of a global nature. All this determines both the similarities and differences in sea-level fluctuation in each basin, which are especially pronounced on a scale from centuries to tens of thousands of years (Kalinin et al., 1975).

Despite the similarity in positive trend in sea-level change in all three basins, the Black Sea le behaves differently. It falls and rises with amplitudes two times higher than those observed in t Mediterranean Sea and Atlantic Ocean. The fact that the formation of sea levels impacts factors o global nature, is reflected in the similarity of their spectral structure, and the presence of simil periods with durations of 53.0, 35.3, 26.5, and 21.2 years. At the same time, these periods differ in t intensity of their manifestation and phase (Fig. 4, Table 1). This is understandable for the differe seas/oceans; because of their geological and climatic conditions, these factors will act differently.

For spectra of interannual sea levels, the presence of similar cycles that are common for components of the Black Sea water balance (Table 4) is characteristic (Al'tman, 1990).

Table 4. Periods (years) of water balance components in the Black Sea (Al'tman, 1990).

Component	Period (years)
River discharge	2.4, 3.5, 4.3, 13.2, 16.1
Precipitation	2.6, 3.2, 5.8, 11.0, 22.(
Evaporation	2.3, 3.2, 5.2, 19.4
Water exchange with the Sea of Marmara through the Bosphorus	2.1, 3.5, 6.1, 11.2

Attention should be paid to the matching between the selected periods in terms of water balan components. Based on the coefficients of coherence for the time series of compared sites, there is match between the selected periods in the water balance components of the levels of the Marseille ar Brest sites with those at the Black Sea site. The reason for this coincidence, we think, was formulat by Goryachkin et al. (2006): "Variability in the level of the Black Sea, Marmara, and Aegean seas connected not only with the exchange through the straits, but also with the ratio of the water balan for each basin at any given point in time. However, the basins are located virtually at the same clima zone and climatic region. Therefore, the seasonal variability of evaporation, precipitation and riv discharge is qualitatively similar in nature."

The oscillating character of sea-level fluctuations for the World Ocean was noted by Fairbridge (195 1960, 1961). Based on detailed observations off Western Australia, he drew together similar data fro elsewhere in the world. On the basis of this work, he formulated the hypothesis that sea levels ha been rising for the last 16,000 years and that the rise showed regular periodic oscillations of rise ar fall over the period. They show relatively rapid rises and falls of up to four meters over periods of n more than 10 or 20 years. In our case, it is 30 years.

Conclusions

Eustatic sea-level change in the Black Sea, Mediterranean Sea, and Atlantic Ocean during the last 10 years has been oscillatory in nature and has shown a unidirectional pattern with a positive trenc However, the amplitudes of the Black Sea level rise and fall are different. They are on average twic as high compared to those in the Mediterranean Sea and Atlantic Ocean. As such, the hypothesis abou eustatically oscillating sea level in the Black Sea cannot be disregarded as some scientists suggest.

Acknowledgments

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