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A long-term trend and temporal fluctuations of the sea level at the Polish Baltic coast

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Abstract

The analysis of sea level record series along the Polish coast is presented. The main aim was to identify linear trends in the sea level changes at the coastal (Świnoujście, Kołobrzeg, Ustka, Łeba, Władysławowo, Hel, Gdynia, Gdańsk), lagoonal (Trzebież, Tokmicko) and riverine (Szczecin) gauge stations. The analysis showed individual coastal stations to differ in the rate of sea level changes. During 60 years of continuous observations (1947–2006), the differences varied from 1.0 (the western part of the coast) to 2.5 mm year⁻¹ (the eastern part of the coast). The longest, more than 100-yr-long data series showed the sea level rise in Świnoujście and Kołobrzeg to be about 0.5 mm year⁻¹; 1.57 mm year⁻¹ being revealed in Gdańsk. Spectral analysis applied to the data showed numerous fluctuations and cyclicity in changes of the annual mean sea level at the Polish coast. A distinct, major 3-year cycle was revealed. In addition, three secondary cycles of 4.6, 6.7, and 8.6 years were present in the data, more or less clearly identifiable at individual stations.

INTRODUCTION

Fluctuations in the sea level present an important geophysical, oceanographic, and climatologic problem. Sea level fluctuations change the water depth and substantially affect the location of important shore components, and thus may contribute to the coastal erosion and the landward shift of the shoreline. A considerable part of sedimentological effects on the shore is generated by long-term (on the scale of years or decades) changes in the sea level. It is of utmost importance to monitor the sea level fluctuations, so that processes and effects in the coastal zone are understood, their adverse consequences are adequately forecast, and if possible appropriate preventive measures are to be taken (Cyberski, Wróblewski 1999), (Majewski 1986), (Girjatowicz 2008), (Wiśniewski, Wolski 2009), (Wiśniewski et al. 2009).

The aim of the study was to elucidate secular trends in the mean sea level in Świnoujście (1811–2006), Kołobrzeg (1901–2006), and Gdańsk (1886–2006). In addition, an attempt was made to identify trends in the sea level changes at 11 stations distributed along the entire Polish coast during the same 60-year period (1947–2006) of water gauge and mareograph records. The obtained trend results were compared to the forecasted sea level treated as a reference in the Polish coastal protection strategy (Cieślak 2005).

As proposed in the current climatological literature, the global climate is rapidly warming, and effects are made to pinpoint anthropogenic effects (the increased atmospheric concentration of CO₂ and other glasshouse gases via fossil fuel combustion) as the underlying causes. Evidence of the changes is sought also in areas other than the global atmospheric temperature increase; a rise in the sea level being used as additional support. The report

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published by the Nongovernmental International Panel on Climate Change (NIPCC 2008) has summarized opinions on the causes of the sea level rise presented by the four IPCC reports of 1990, 1995, 2001, and 2007. All those reports refer to melting of mountain glaciers, small and gigantic icecaps of Greenland and the Antarctic, as well as thermal expansion. The reports contain the following, gradually decreasing, maximum estimates of the sea level rise by 2100: 367 (IPCC of 1990), 124 (IPC of 1995), 77 cm (IPCC of 2001), and 59 cm (IPCC of 2007) (Fig. 1). The 1990 IPCC report predicted that by 2030, thermal expansion would account for about 55% of the sea level rise, while icecap melting provides explanation for the remaining part of the increase. However, as shown by the data in the 1990 IPCC report, some sources regarded glaciers and icecaps as being responsible for 77% of the sea level rise. Additionally, the 2007 IPCC report put forth a prediction of a sea level rise caused by melting of the Greenland icecap (IPCC A4 2007).

The Commission on Sea Level Changes and Coastal Evolution of the International Union for Quaternary Research (INQUA) has presented different forecasts of changes in the sea level. As shown by measurements taken in Europe, the sea level was rising by 1.1 mm year^{-1} between 1850 and 1940, but the increase stopped after 1940, and by 2100 the sea level may increase by 5–10 cm (Morner 2004).

In his report on the Strategy of coastal protection, Cieślak (2005) wrote that, according to the forecast for the next 100 years, the sea level rise (SLR) of 0.3 m (SLR 0.3, optimistic scenario), 0.6 m (SLR 0.6, most probable scenario) and 1.0 m (SLR 1.0, pessimistic scenario), poses a new threat to the coast and its low-lying hinterland, and that the following scenarios can be envisaged for the mean sea level rise during the next 50 years:

	SLR 0.3	SLR 0.6	SLR 1.0
after 10 years	2 cm	4 cm	7 cm
after 25 years	8 cm	16 cm	28 cm
after 50 years	15 cm	30 cm	50 cm

Cieślak (2005) drew such conclusions from his analysis of forecasts put forth by the Intergovernmental Panel on Climate Changes (IPCC) and natural conditions driving the changes in the Polish coastal zone.

Consequently, a question arises as to which scenario is the closest one to the hitherto known sea level records from the Polish coast. To address this question, the present authors made an attempt to identify trends in multi-annual and secular changes in the mean sea level; the results were used to verify the SLR scenarios for the Polish coast.

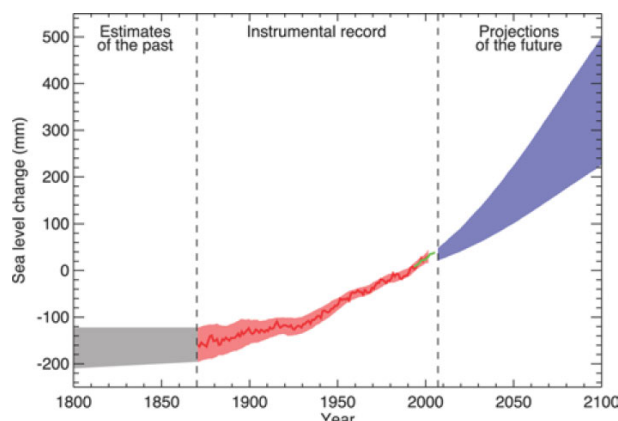


Fig. 1. Changes in the world ocean level as estimated for the 19th century, recorded at present and predicted to occur by 2100 (source: ICCP AR4 2007).

MATERIALS AND METHODS

Long-term series of data, applicable to the analysis of secular trends, were obtained from the measurement stations in Świnoujście, Kołobrzeg, and Gdańsk. In order to compare more locations at the coast and, at the same time, to maintain the comparability of the measurement data, the analysis covered the period of 1947–2006. Uniform series of data on the sea level, used in this work, were collected at the Polish coastal water gauge stations in Świnoujście, Kołobrzeg, Ustka, Łeba, Władysławowo, Hel, Gdynia, and Gdańsk. Additionally, the analysis includes data from the shore stations in the lagoons (Tolkicko in the Vistula Lagoon and Trzebież in the Szczecin Lagoon) and from Szczecin, as changes in the water level at those stations may be associated with effects of the sea level variability.

The analysed data consisted of monthly mean sea levels in 1947–2006 extracted from the data published in the Baltic Hydrological Sea Annals (1947–1970), Marine Hydrological-Meteorological Bulletins (1961–1990) and Environmental Conditions in the Polish Zone of the Southern Baltic (1986–2001), as well as from data sets purchased from the Institute of

Meteorology and Water Management (IMWM) for the research project "Extreme meteorological and hydrological events in Poland" (Project No. PBZ-KBN-091/PO4/2004; data sources: 22-25).

For the purpose of this work, the data were standardized to a single water-level gauge datum, i.e. -500 cm N.N. for the Polish coast.

The data were processed with the least squares method associated with the linear regression analysis, and Fourier spectral analysis was used to find out if any cyclic signals were embedded in the water level data.

Linear regression analysis and the least squares method

The least squares method is used to identify the trends in multi-annual variability of the sea level explored with the aid of the linear regression analysis. The regression line summarizes the relationship between the two sets of data. It can be used to calculate the most probable value of one variable when the value of the other variable is known, as there is no single value of the first variable that has to be associated with a defined value of the other variables. Because the relationship between the two variables can be described by many different lines, there has to be found a line producing the best fit to the data, i.e. a line that best approximates the relationship between the two variables. In order to produce a regression line by calculations, the sum of squares of deviations of individual observations should be minimized. This condition can be written as:

$$S = \sum_{i=1}^n (y - y_i)^2 = \text{minimum} \quad (1)$$

The regression line will make it possible to identify a trend of changes in the mean sea/water level at the stations where observations were collected (Wiśniewski 1978).

The regression fit to the data was verified by calculating the coefficient of determination, computed as the squared Pearson correlation coefficient (r^2). The latter is expressed as:

$$r = \frac{\sum_{i=1}^n x_i y_i - \sum_{i=1}^n x_i \sum_{i=1}^n y_i}{\sqrt{\left[\sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2 \right] \left[\sum_{i=1}^n y_i^2 - \left(\sum_{i=1}^n y_i \right)^2 \right]}} \quad (2)$$

The obtained correlation coefficients were assumed to be statistically significant when the significance level (p) was lower than $\alpha = 0.05$.

Fourier spectral analysis

Spectral analysis is used to explore the harmonic structure of a time series. It decomposes a complex time series containing cyclic components into a number of basic sine and cosine functions with defined wavelengths (frequencies) in order to identify those particularly strong or important. The sine and cosine functions are independent of each other (orthogonal); therefore in order to obtain a periodogram, squared coefficients for each frequency (period) can be added. Values of the applied periodogram were calculated as follows:

$$P_k = \sin_k^2 \times \cos_k^2 \times \frac{N}{2} \quad (3)$$

where: P_k is a value of the periodogram at frequency k and N is the length of the series.

Individual values of the periodogram usually vary substantially and randomly. A more distinct pattern of periodicity is frequently observed when analyzing the spectral density, i.e. when looking for frequency areas, which most contribute to the total harmonic structure of the series. Therefore, spectral density was determined in this work by smoothing out the periodogram values using the moving weighted average. The analysis employed the so-called Hamming window in which weights of the moving weighted averages for each frequency (period) were calculated as follows:

$$w_j = 0.54 + 0.46 \times \cos\left(\frac{\pi j}{p}\right) \text{ (for } j \text{ from } 0 \text{ to } p) \quad (4)$$

$$w - j = w_j \text{ (for } j \neq 0) \quad (5)$$

where:

$$p = \frac{m - 1}{2} \quad (6)$$

m is the width of the data window = 5

The following Hamming weights were used: 0.0357, 0.2411, 0.4464, 0.2411 and 0.0357. Those values were used in the analysis of spectral density for each coastal and lagoonal station. The analysis was preceded by the elimination of the linear trend and the arithmetic mean from the observation series, as the two effects, potentially strong, might have masked the more interesting periodic changes.

RESULTS AND DISCUSSION

Secular sea level trends in Świnoujście, Kołobrzeg, and Gdańsk

The secular trend in changes and fluctuations of the sea level at the Polish coast is well represented in a series of annual mean sea levels in Świnoujście over 1811–2006. It is the longest series of observation data at the Polish coast. Secular trends can be identified at other stations as well, but they are based on shorter observation data series.

This work shows secular trends in changes of annual mean sea levels in Świnoujście (1811–2006), Kołobrzeg (1901–2006) and Gdańsk (1886–2006) (Figs. 2–4). The value of the sea level rise is $0.45 \text{ mm year}^{-1}$ in Świnoujście, 0.5 mm year^{-1} in Kołobrzeg and 1.6 mm year^{-1} in Gdańsk. The obtained trends turned out to be a half, or even one-sixth of the optimistic scenario of the coastal protection strategy developed for the Polish coast (Cieślak 2005).

In addition to the differences in the magnitude of the increase, the appearance of cyclic fluctuations in the sea levels is interesting, observed with 11-yr moving averages assigned to the consecutive terms of the observation series of the annual mean sea levels. In Fig. 2 appeared cycles 1820–1878 year, 1878–1927 year and 1927–1986 year. The cycle 1927–1986 year appeared on all three stations (Figs. 2–4). This cycle is clearly coherent based on the probable common reason, i.e. climatic changes (Fig. 5). The results shown in Fig. 2 for Świnoujście may also be interpreted differently: the >100-yr cycle of 1820–1927 is more important and it may be repeated in 1927–2034, but the confirmation is postponed until the 2030s.

Sea level trends at the Polish coast in 1947–2006

The analysis of mean annual sea levels during the observation period of 1947–2006 made it possible to include data for more stations along the Polish coast (Table 1 and in Figs. 6–9).

Values of the linear trend in the mean annual sea level for the recent 60 years show that the level has risen by 0.8 mm year^{-1} (8 cm per 100 years) in Szczecin to 2.5 mm year^{-1} (25 cm per 100 years) in Gdańsk. Generally, the results support the finding known from the literature about a slightly accelerated mean sea level rise along the southern Baltic coast in the second half of the 20th century. However, the obtained trend magnitudes proved to be lower than those forecasted by the optimistic scenario for the

coastal protection strategy, defined as 30 cm per 100 years (Cieślak 2005). Interestingly, the 11-yr moving averages show a tendency for the mean annual sea level to rise at all the stations until 1986, the tendency is disappearing afterwards.

To illustrate the discrepancies in the linear trend estimates and to show how a selected period of time affects those estimates, also the results for the recent 30 years (1977–2006) are presented in this paper (Table 1). The data could have allowed picking out another period of observations with a clearly increasing trend, but its statistical significance would have been low. It is therefore important that when identifying the trends, the longest possible observation series are analyzed rather than periods of a few or several years.

It is proposed to estimate secular and multi-annual trends also for the maximum and minimum annual sea levels. When the available data from the extreme sea levels are taken into account, the longest data series available is that for Kołobrzeg (1867–2006), followed by stations located in the major Polish ports: Gdańsk (1886–2006) and Świnoujście (1901–2006). The results are shown in Fig. 10. With respect to the maximum annual sea level, the changes range from $+0.62 \text{ mm year}^{-1}$ (Kołobrzeg) to $+2.27 \text{ mm year}^{-1}$ in Gdańsk, the changes in the minimum annual sea levels vary from $-0.44 \text{ mm year}^{-1}$ (Świnoujście) to $1.56 \text{ mm year}^{-1}$ (Gdańsk).

The analysis of the relatively long observation series on the annual extreme sea levels in Świnoujście, Kołobrzeg and Gdańsk showed the amplitude between the maximum and minimum annual sea levels. In addition, in the recent 60 years (1947–2006), the rate of changes in the maximum sea level clearly accelerated: linear trends of the maximum annual sea level at those stations ranged from 4.5 mm year^{-1} (Świnoujście) to 5.7 mm year^{-1} (Gdańsk), which results from an increasing number and intensity of storm surges (Wiśniewski, Wolski 2009; Wiśniewski, Musielak, Wolski 2009).

The results obtained in this study supplement the estimates of trends in the sea level changes reported by other authors, as summarized in Table 2 based on the example of analyses of data collected in Świnoujście.

The notion of eustatic nature of changes in the sea level (changes in the budget of water exchange between the atmosphere, hydrosphere, and lithosphere), which has been assumed by climatologists as the major cause underlying the global sea level changes, is not borne out by the

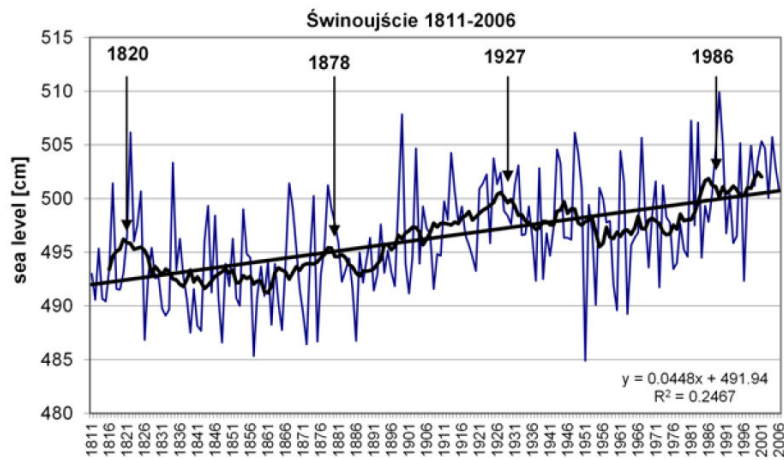


Fig. 2. Changes of the mean sea level in Świnoujście in 1811-2006 (the straight line represents the linear trend; the curve represents the 11-yr moving average).

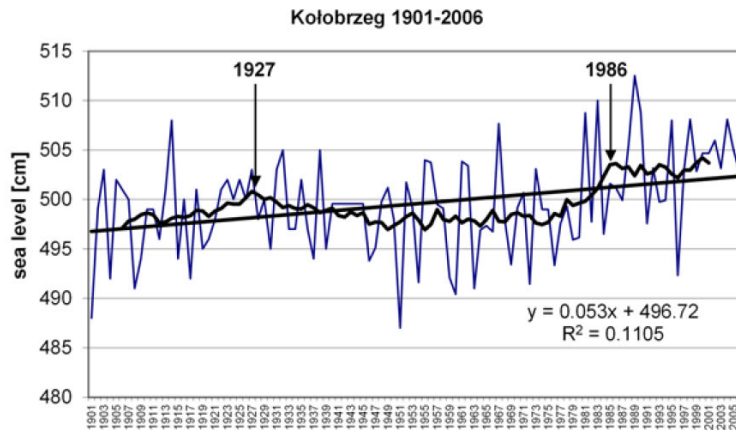


Fig. 3. Changes of the mean sea level in Kołobrzeg in 1901-2006 (the straight line represents the linear trend; the curve represents the 11-yr moving average).

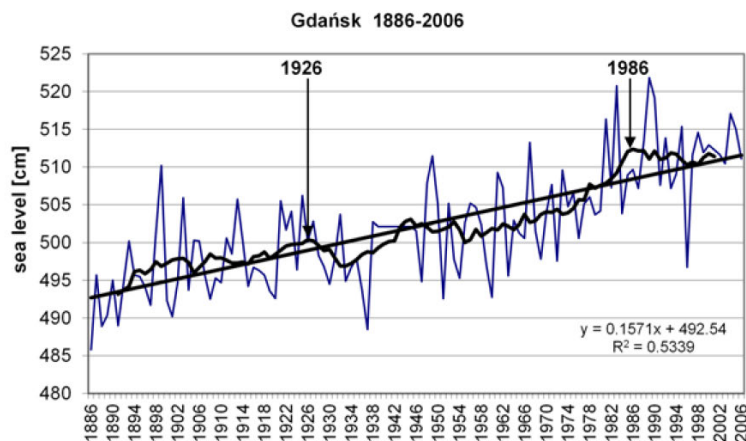


Fig. 4. Changes of the mean sea level in Gdańsk in 1886-2006 (the straight line represents the linear trend; the curve represents the 11-yr moving average).

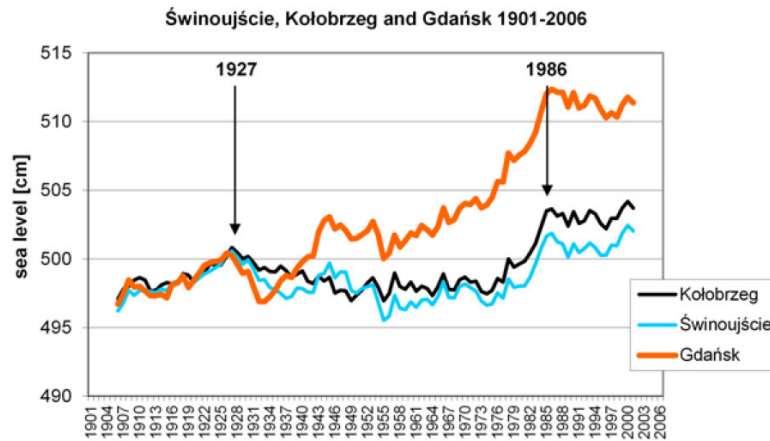


Fig. 5. Changes of the mean sea level (the 11-yr moving average) in Świnoujście, Kołobrzeg and Gdańsk in 1901-2006.

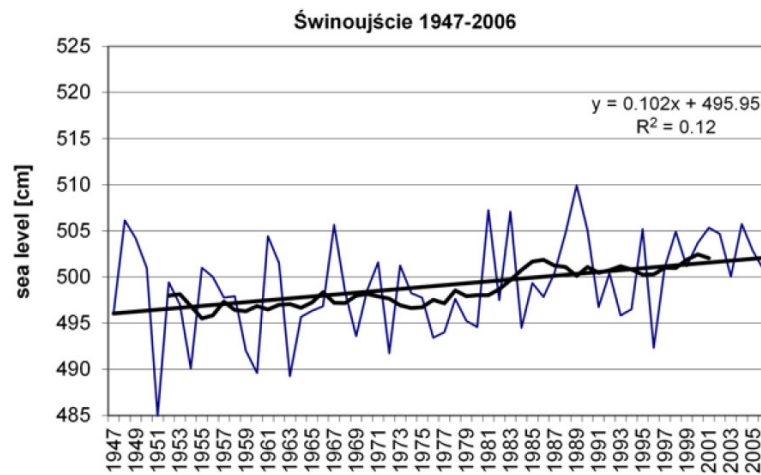


Fig. 6. Changes of the sea level in Świnoujście in 1947-2006 (the straight line represents the linear trend; the curve represents the 11-yr moving average).

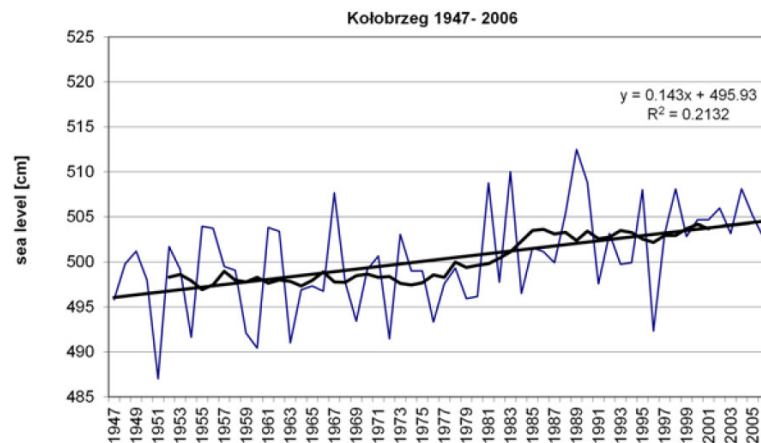


Fig. 7. Changes of the mean sea level in Kołobrzeg in 1947-2006 (the straight line represents the linear trend; the curve represents the 11-yr moving average).

Table 1

Magnitudes of trends in the homogenous observation series of 1947-2006 at the major observation stations of the Polish coast.

Station	1947-2006		1977-2006	
	Magnitude of trend	Mean increase/ decrease of sea level (cm)	Magnitude of trend	Mean increase/ decrease of sea level (cm)
Szczecin	+0.8 mm year ⁻¹ (+8 cm per 100 years)	510.2 → 515.2	0.0 mm year ⁻¹ (0 cm per 100 years)	514.3 → 514.3
Trzebież	+1.1 mm year ⁻¹ (+11 cm per 100 years)	503.2 → 509.6	+0.4 mm year ⁻¹ (+4 cm per 100 years)	507.8 → 509.0
Świnoujście	+1.0 mm year ⁻¹ (+10 cm per 100 years)	496.0 → 502.1	+1.8 mm year ⁻¹ (+18 cm per 100 years)	498.1 → 503.3
Kołobrzeg	+1.0 mm year ⁻¹ (+14 cm per 100 years)	496.1 → 504.5	+1.8 mm year ⁻¹ (+18 cm per 100 years)	500.0 → 505.3
Ustka	+1.4 mm year ⁻¹ (+14 cm per 100 years)	497.1 → 505.6	+0.9 mm year ⁻¹ (+9 cm per 100 years)	502.5 → 505.1
Łeba	+1.0 mm year ⁻¹ (+10 cm per 100 years)	500.3 → 505.9	+1.2 mm year ⁻¹ (+12 cm per 100 years)	503.2 → 506.7
Władysławowo	+1.9 mm year ⁻¹ (+19 cm per 100 years)	496.4 → 507.8	+1.7 mm year ⁻¹ (+17 cm per 100 years)	503.2 → 508.1
Hel	+1.5 mm year ⁻¹ (+15 cm per 100 years)	498.8 → 507.5	+1.2 mm year ⁻¹ (+12 cm per 100 years)	504.0 → 507.3
Gdynia	+2.0 mm year ⁻¹ (+20 cm per 100 years)	499.0 → 511.0	+1.6 mm year ⁻¹ (+16 cm per 100 years)	506.0 → 510.6
Gdańsk	+2.5 mm year ⁻¹ (+25 cm per 100 years)	499.1 → 514.0	+1.8 mm year ⁻¹ (+18 cm per 100 years)	508.3 → 513.4
Tolkmicko	+1.7 mm year ⁻¹ (+17 cm per 100 years)	499.3 → 509.6	+1.9 mm year ⁻¹ (+19 cm per 100 years)	504.6 → 510.0

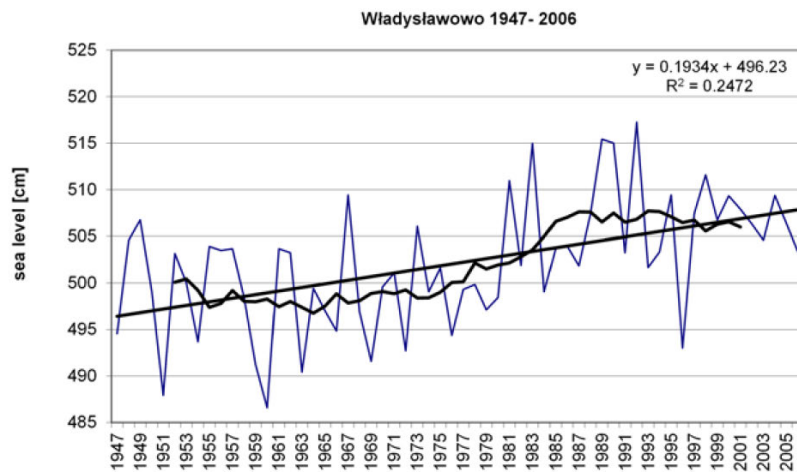


Fig. 8. Changes of the mean sea level in Władysławowo in 1947-2006 (the straight line represents the linear trend; the curve represents the 11-yr moving average).

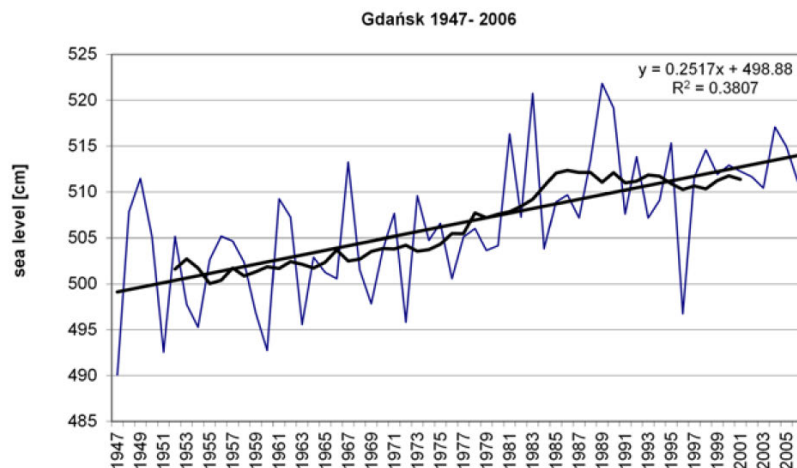


Fig. 9. Changes of the mean sea level in Gdańsk in 1947-2006 (the straight line represents the linear trend; the curve represents the 11-yr moving average).

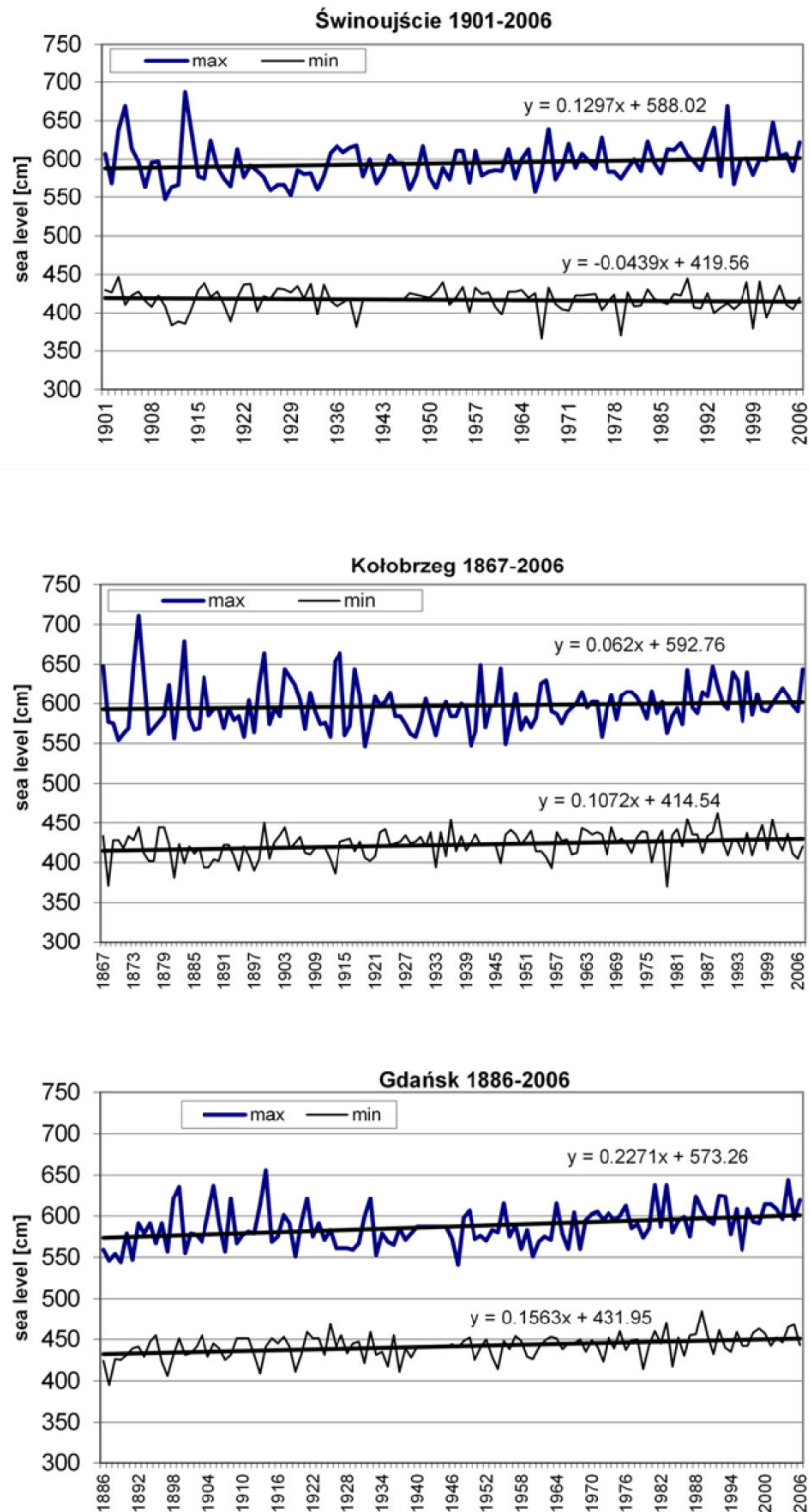


Fig. 10. Maximum and minimum annual sea levels in Świnoujście (1901-2006), Kołobrzeg (1867-2006) and Gdańsk (1886-2006).

Table 2

Results of some estimations of trends in the annual Baltic Sea level in Świnoujście.

Authors	Data	Trend (cm year ⁻¹)
Dziadziuszko and Jednorat (1988)	1811-1985(HSR ^a)	0.07 ±0.1
Dziadziuszko (1993)	1951-1985 (HSR)	0.14
Kałas (1993)	1947-1991 (HSR)	0.9
Wróblewski (1992)	1947-1991 (HR MAX ^b)	0.5
Wróblewski (1994)	1901-1990 (HSR)	0.12 ±0.02
Kożuchowski, Stolarczuk and Wiśniewski (1996)	1811-1990 (HSM ^c)	0.048
Rotnicki and Borzyszkowska (1999)	1951-1990 (HSM)	0.2
Authors of the present publication	1811-2006 (HSR)	0.045
	1901-2006 (HR MAX)	0.13
	1901-2006 (HR MIN ^d)	-0.04
	1947-2006 (HSR)	0.10
	1947-2006 (HR MAX)	0.43
	1947-2006 (HR MIN)	-0.15

^a HSR - annual mean water level

^b HR MAX - maximum annual water level

^c HSM - monthly mean water level

^d HR MIN - minimum annual water level

Table 3

Significant periodicity in sea/water level changes at the Polish gauge stations, as determined for the 1947-2006 observation series.

Station	Periodicity (years)	Station	Periodicity (years)
Coastal stations			
Świnoujście	3	Władysławowo	3
	6.7		4.6
			8.6
Kołobrzeg	3	Hel	3
	4.6		4.6
Ustka	3	Gdynia	3
	8.6		4.6
Łeba	3	Gdańsk	3.0
	8.6		4.6
			5.4
			8.6
Riverine and lagoonal stations			
Szczecin	3	Trzebież	3
	4.6		4.6
	6.7		8.6
	7.5		
Tolkmicko	3		
	4.6		

Table 4

Periodicity of changes in the Baltic Sea level, as reported by different authors (Kowalik, Wróblewski 1973), (Wróblewski 1974), (Wiśniewski 1978), (Wróblewski 1992), (Kozuchowski et al. 1994), (Kozuchowski et al. 1996).

Authors	Data (annual mean sea level)	Periodicity (years)
Kowalik and Wróblewski (1973)	Świnoujście (1811-1970) HSR ^a	3
		5-6
		11
		15.6 23-28 ~80
Wróblewski (1974)	Świnoujście (1811-1970) Kołobrzeg (1868-1970) HSR	3
		5-6 11
Wiśniewski (1978)	23 Baltic stations (different periods) HSR	3
		5
		7-8
		11 19
Wróblewski (1992)	Świnoujście (1811-1985) HR MAX ^b	3 5-6 8
Kozuchowski, Stolarczuk and Wiśniewski (1994)	Świnoujście (1811-1990)	HM MIN ^c
		2.1
		2.3
		2.9
Kozuchowski, Stolarczuk and Wiśniewski (1996)	Świnoujście (1811-1990) HSM ^e	HSR
		90
		HM MAX ^d
		6.4
Authors of the present publication	Świnoujście (1811-2006) HSR	1
		2.95
		90?
	Świnoujście (1947-2006) HSR	3
		6.3
		11 98
	Kołobrzeg (1901-2006) HSR	3
		3
	Gdańsk (1886-2006) HSR	3
		4.6 8.6

a) HSR - annual mean water level

b) HR MAX - maximum annual water level

c) HM MIN - minimum monthly water level

d) HM MAX - maximum monthly mean water level

e) HSM - monthly mean water level

results obtained in this study. The Baltic is a semi-enclosed sea, for which reason the observed secular changes are dependent on the Baltic's connection with the Atlantic. In addition to the global warming effect on the sea level, the latter may also be affected by changes in the Earth's geoid, global isostasy, rotational mass distribution in the Earth's interior and in the world's oceans, extensive fluctuations in

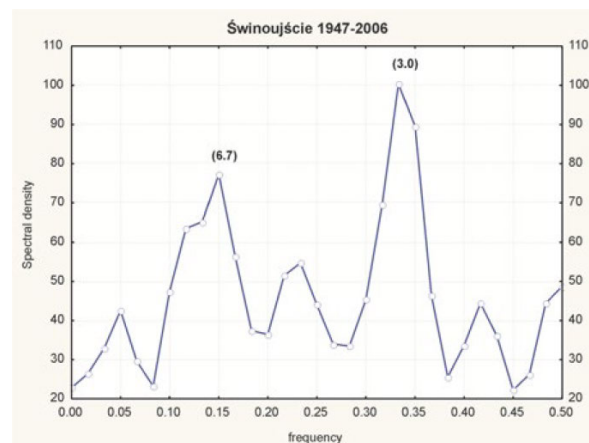


Fig. 11. Spectral analysis of annual mean sea levels in Świnoujście in 1947-2006; values in parentheses denote the length (years) of significant cycles.

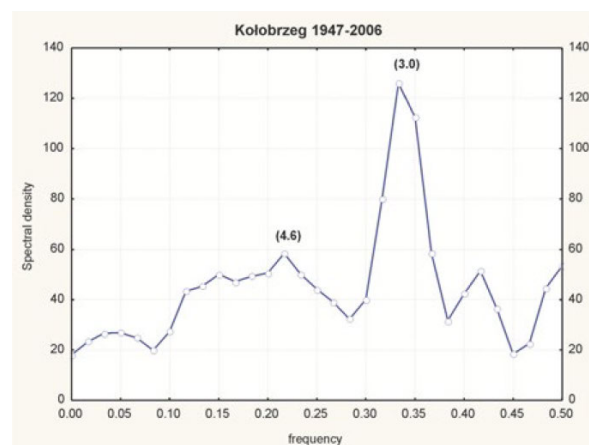


Fig. 12. Spectral analysis of annual mean sea levels in Kołobrzeg in 1947-2006; values in parentheses denote the length (years) of significant cycles.

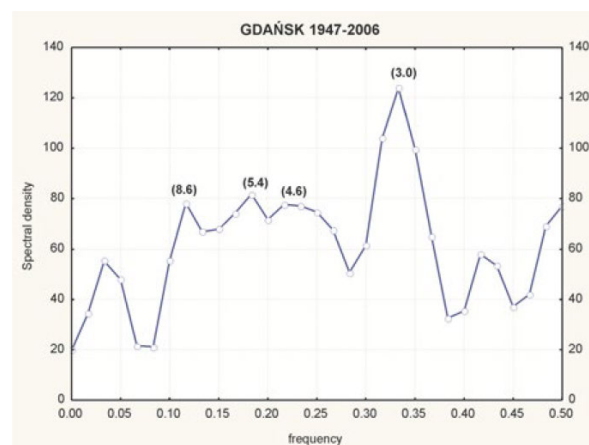


Fig. 13. Spectral analysis of annual mean sea levels in Gdańsk in 1947-2006; values in parentheses denote the length (years) of significant cycles.

oceanic currents, sedimentation in the oceans, etc. In addition, local vertical movements of the Earth's crust at the coast may have also affected the trends observed.

Significant cycles in sea level changes at the Polish coast

As already mentioned, the cyclicity in the sea level changes along the Polish coast was explored with Fourier spectral analysis. Significant periodicities in the water/sea level in 1947–2006 at the observation stations are shown in Table 3 and, at the selected stations, in Figs. 11–13.

As demonstrated by spectral analysis, all the gauge stations at the Polish coast show a single distinct 3-yr cycle, as well as secondary cycles (of 4.6, 6.7, and 8.6 years), which are more or less clearly visible at different stations. Thus, the results of the analysis evidence the fluctuations in the long-term sea level data series, which change the nature of the long-term trend. The frequencies of the identified cycles are consistent with the cyclicity of changes in the Baltic Sea level reported by other authors and summarized in Table 4.

SUMMARY

1. The observation series of the annual mean sea levels in Świnoujście, the longest one at the Polish coast, shows that the secular trend for 1811–2006 amounts to $0.44 \text{ mm year}^{-1}$, i.e. the sea level was rising by about 4.5 cm per 100 years. In Kołobrzeg, the secular linear trend of the mean annual sea level was $0.53 \text{ mm year}^{-1}$ in 1901–2006, and in Gdańsk during 1886–2006 – it was $1.57 \text{ mm year}^{-1}$.
2. The analysis of the relatively long observation series on the annual extreme sea levels in Świnoujście, Kołobrzeg and Gdańsk showed that the amplitude between the maximum and minimum annual sea levels has increased; the increase of the secular linear trend of the maximum sea level ranged from 0.6 to 2.3 mm year^{-1} .
3. The Polish Baltic coast is characterized by the variability in the rate of sea level changes. In the recent 60 years of continuous observations (1947–2006), the differences between the rates determined for different parts of the coast ranged from 1.0 (the western part) to 2.5 mm year^{-1} (the eastern part). The attempt at predicting the sea

level changes during the next 100 years suggests a sea level rise by 10 to 25 cm. The attempt at finding out how the mean sea level at the Polish coast might change during the next 100 years showed that most probably the sea level will rise from 10 to 25 cm, i.e. less than the rise assumed by the optimistic scenario in the coastal protection strategy (Cieślak 2005).

4. The variability in the rate of sea level changes at the Polish coast is also evidenced by the 11-yr moving average (which follows a cycle of rise and drop) and by the spectral analysis revealing considerable fluctuations and cyclicities: a distinct 3-yr cycle and somewhat weaker cycles of 4.6, 6.7, and 8.6 years; perhaps also a half-century and 100 yr+ cycles occur.

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