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Seasonal Baltic Sea level change from altimetry data

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Abstract. Regional sea level changes occur at different time scales. Global warming of the oceans, glacial and polar ice melting and meteorological or hydrological factors are major contributors to long-term sea level rise. In the recent years, a lot of attention has been paid to research concerning sea level change and seasonal fluctuations.
The main objective of this paper was to determine the seasonal variability in the Baltic Sea level using satellite altimetry data for the period 1 January 2010 – 31 December 2014. The ANOVA analysis of variance was used in the research in order to estimate seasonal fluctuations.
This study focused on investigate the monthly and annual amplitude in sea level anomalies over a given time period.
The results from research showed that the amplitudes of fluctuations are the highest in winter and the smallest in summer in three analyzed points of the Baltic Sea.
The results can bring valuable information about ongoing aspects in sea level changes, as a way of tracking climate change.

Keywords: Sea level change, SLA, Seasonal, Satellite Altimetry.

Conference topic: Technologies of Geodesy and Cadastre.

Introduction

In the recent years, a lot of attention has been paid to research concerning sea level anomalies (SLA) (Rahmstorf 2007; Horton *et al.* 2008), and seasonal fluctuations (Stramska *et al.* 2013). Global warming influences sea level and ocean level. The reasons for that are inter alia the rise in water volume with the increase of temperature and glaciers melting. The results of water level measurements, both those direct and satellite, show that the average ocean level rises. The increase of water level is not a phenomenon that equally occurs all over the world. Measurements made in different time and in different places give disparate results. Water level may significantly change not only on short terms, as a result of wind direction change, undulation, rising tides or changes in air pressure, but it can have long-term changes as well depending on the ocean currents or subsidence. In various regions, the trends may be different. Water level may rise for many years in one place and it may be small in the other (Church *et al.* 2010). The trend of the Baltic Sea level is about 2.15 m per year (Pajak, Birylo 2016). A trend is, besides cyclical fluctuations, seasonal fluctuations and random fluctuations, one of the elements of a function that analyze the phenomenon level (StatSoft).

The main aim of the article is to analyze sea level seasonal fluctuations. The data used in the article are satellite altimetry data and they are time series for sea level anomalies (SLA) in the period of 2010–2014, in three selected points of the Baltic Sea (e.g. see Fig. 1).

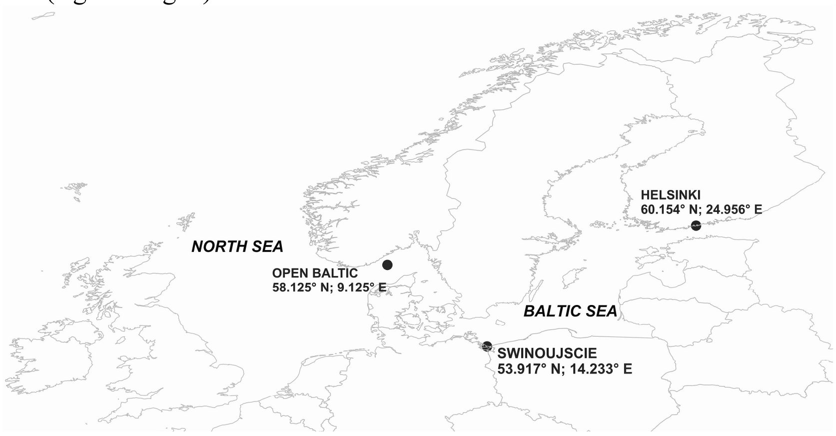


Fig. 1. Map showing the geographical positions corresponding to the various time series data used in this study (HELSINKI, SWINOUJSCIE, OPEN BALTIC)

The seasonality of sea level changes is an inequality which occurs in sea level anomalies (SLA) due to seasons in which various phenomena that have an essential influence on the changes appear. By distinguishing the influence of seasonal fluctuations on the course of changes in sea level, one can gain more precise prognosis, and the time series free from seasonal fluctuations is necessary for short-term analyses.

Seasonal changeability of the sea is connected mainly with meteorological factors (atmospheric pressure, wind, evaporation and falls), water balance (rivers runoff), evaporation and changes in sea topography or changes in water density. The Baltic Sea level has been observed carefully for many years (Ekman 2009). Numerous researches on the Baltic Sea level are based on mareographs (Kowalczyk 2006; Poutanen, Kakkuri 2000), (Ekman, Makinen 1996; Donner *et al.* 2012). It has been stated in many studies that a one-year cycle is characterized by maximum sea level in winter months and minimal sea level in spring and summer. There are researches that show that the amplitude of the cycle increased in the XX century (Ekman, Stigebrandt 1990; Plag, Tsimplis 1999; Hunicke, Zorita 2008; Ekman 2009). It is essential to constantly check and control seasonal fluctuations of sea level.

Methodology and data sets

There are two types of time series: additive time series and multiplicative time series. The types depend on the relation that occurs between particular components. The type of time series depends on mutual relations of the series' components, so also on the way they influence the variable. The additive model concerns time series in which the value of the dependent variable is the sum of series' components, i.e. the trend value is increased or decreased by constant seasonal factors values. The components in the additive series are independent and there is no interaction between them. Additive fluctuations are characterized by constant fluctuations amplitude and they do not depend on the level of the phenomenon in time. Each element in the additive model is presented in the same units. During conducting the time series decomposition, seasonal fluctuations, as well as random fluctuations, are the deviation from the trend or from the average variable level. In the case of the multiplicative models, the original time series is presented as a product of its components. It means that the trend value is decreased or increased in direct proportion by proper seasonality measurement. The expected value of the random component in the multiplicative model is 1. Multiplicative fluctuations have a changeable amplitude and theirs impact depends on the changes of the phenomenon in time. The ANOVA analysis of variance was used in the research in order to estimate seasonal fluctuations (StatSoft).

The data used in the work constitute of three time series of sea level anomalies that are satellite altimetry data. The data product is available at AVISO (www.aviso.oceanobs.com and www.marine.copernicus.eu). The details of standard processing applied to satellite altimetry data are available at www.aviso.oceanobs.com and www.marine.copernicus.eu.

Results

In order to distinguish seasonal fluctuations and analyze the dynamics of change in sea level, a linear trend estimation was determined. It is presented in e. g. see Figure 2. The author made a preliminary analysis of time series graphs, i.e. they analyzed the shape and course of the series.

Figure 2 shows a marked five-year daily and monthly cycle of sea level anomalies (SLA) used in the research with the linear trend function. Time series include SLA in OPEN BALTIC and two points near the coast (SWINOUJSCIE and HELSINKI). It was stated that one of the components of time series is a trend and it increases as the values of sea level anomalies (SLA) increase year by year in all of the analyzed points of the Baltic Sea. The greatest fluctuations occur in time series for the inshore points (SWINOUJSCIE and HELSINKI), however, data collected in the open point of the Baltic Sea have smaller fluctuations.

The fluctuations of values that are in all probability seasonal fluctuations as annually in the same points one can observe increase and decrease of the phenomenon. More precise visual analyses can be seen on the diagrams (e.g. see Fig. 3, Fig. 4, Fig. 5) on which sea level anomalies (SLA) are presented in relation to seasons, between 2010 and 2014. It is vivid that fluctuation amplitudes are the highest in winter and the smallest in summer in all of the analyzed points of the Baltic Sea, and every year fluctuation amplitudes are different. They vary from each other to a large extent.

Before the analysis of seasonal fluctuations, the trend was eliminated in two ways – by subtracting the trend value from the empirical series and by presenting the relation of the trend value to the theoretical trend function value in percent. The hypothesis of the essence of seasonal fluctuations that occur in time series was verified. The analysis of variance was made and the absolute and relative seasonality indicators were estimated with the use of one-way analysis of variance (ANOVA). All the analyses of variance and seasonal coefficients are presented in Table 1.

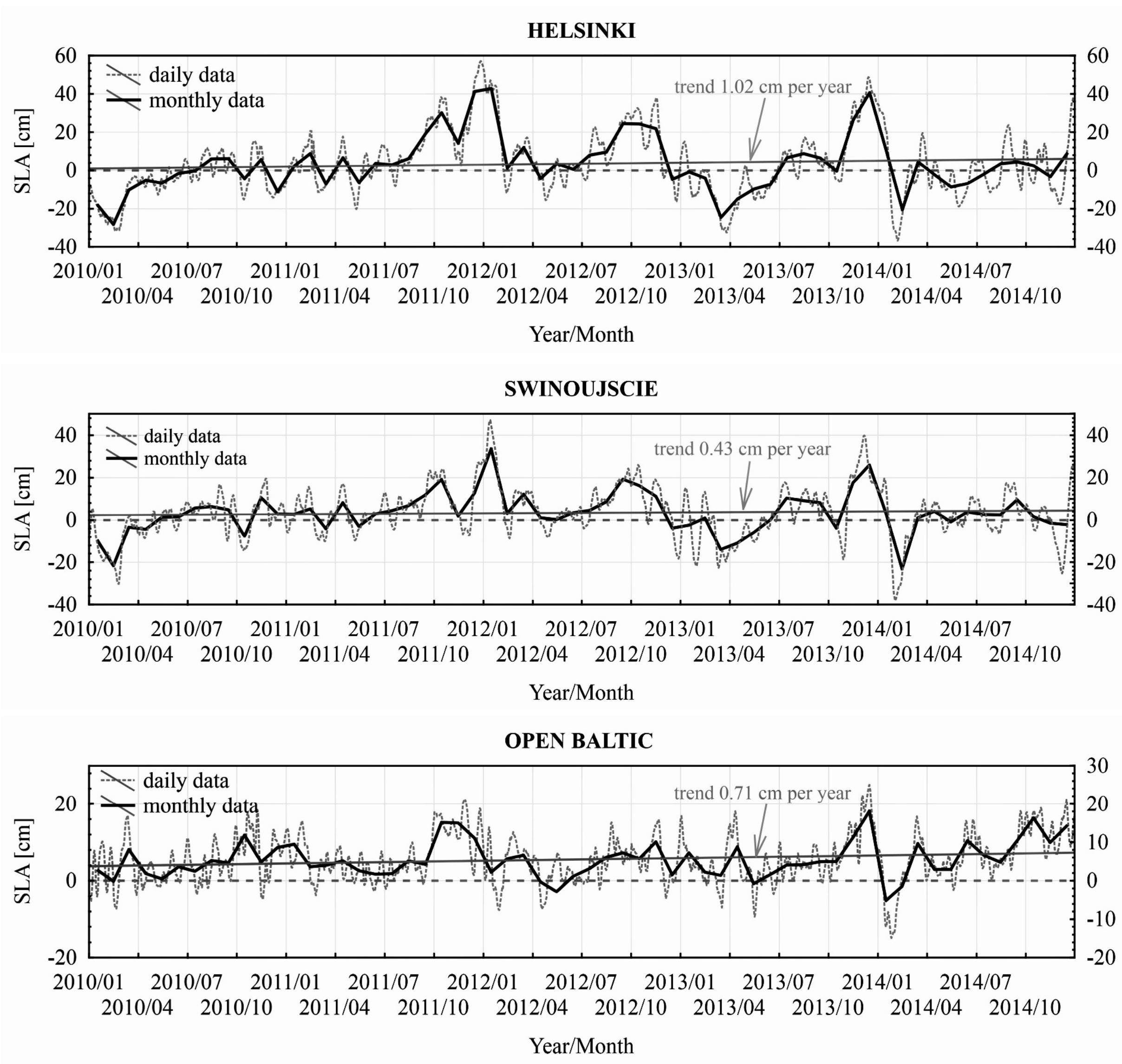


Fig. 2. Time series in five-year daily (solid line) and monthly (broken line) sea level anomalies (SLA) used in the analysis with marked linear trend function.
Data for OPEN BALTIC, SWINOUJSCIE and HELSINKI are based on satellite altimetry.

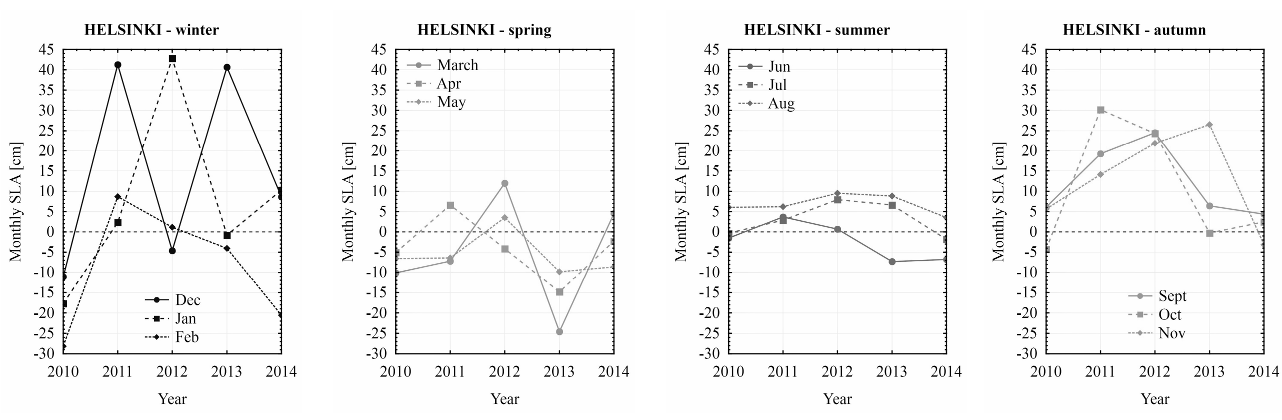


Fig. 3. The diagrams presents fluctuation amplitudes of sea level anomalies (SLA) in HELSINKI point in four seasons: winter, spring, summer and autumn

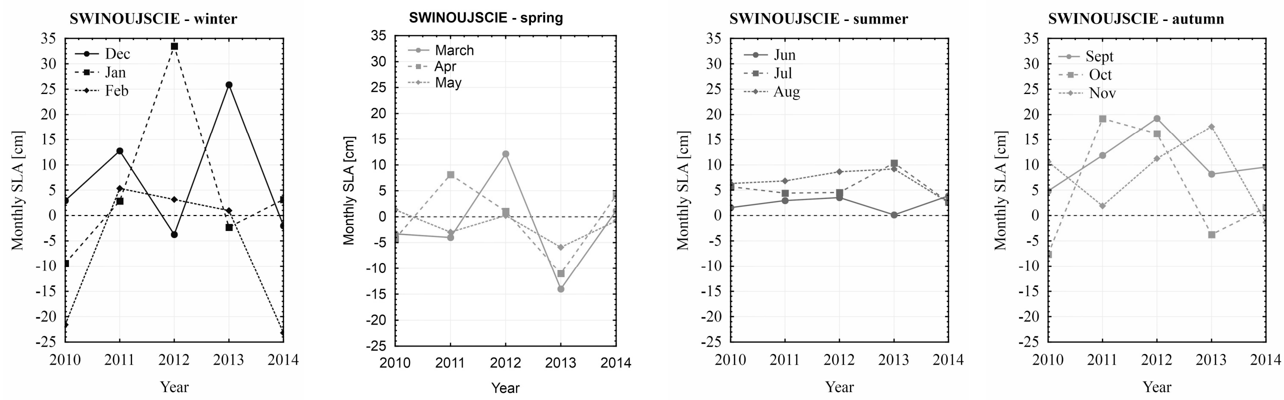
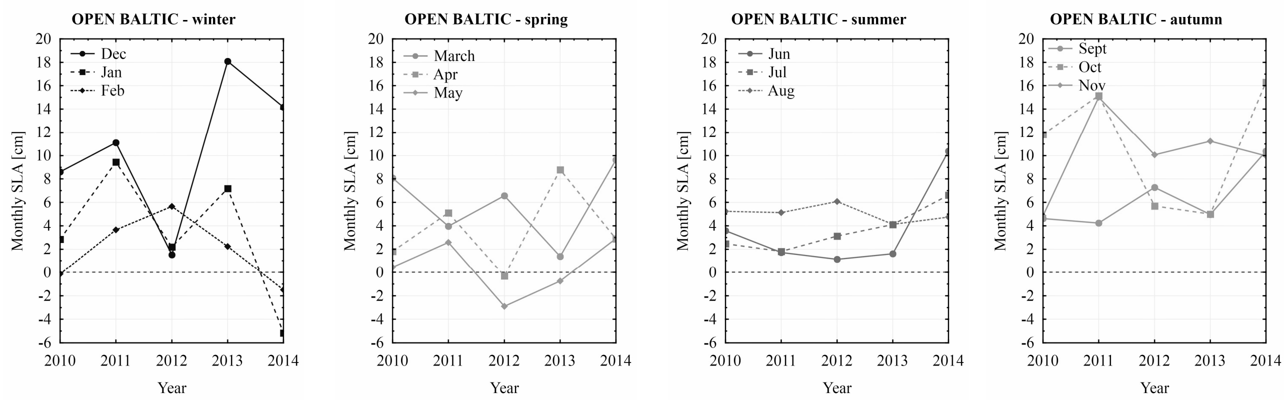


Fig. 4. The diagrams presents fluctuation amplitudes of sea level anomalies (SLA)



in SWINOUJSCIE point in four seasons: winter, spring, summer and autumn

Fig. 5. The diagrams presents fluctuation amplitudes of sea level anomalies (SLA) in OPEN BALTIC point in four seasons: winter, spring, summer and autumn

Table 1. The table presents the results of the analysis of variance and values of absolute and relative seasonal indicators in HELSINKI, SWINOUJSCIE and OPEN BALTIC points; units are [cm] for seasonal indicators (absolute, relative); data span January 2010 – December 2014

Month	HELSINKI		SWINOUJSCIE		OPEN BALTIC	
	Analysis of variance p=0.0008, F=3.68	Analysis of variance p=0.0117, F=2.58	Analysis of variance p=0.0009, F=3.62	Analysis of variance p=0.0006, F=3.77	Analysis of variance p=0.0006, F=3.75	Analysis of variance p=0.0004, F=3.96
	Seasonal indicators (absolute)	Seasonal indicators (relative)	Seasonal indicators (absolute)	Seasonal indicators (relative)	Seasonal indicators (absolute)	Seasonal indicators (relative)
Dec	10.97	7.50	3.59	2.04	4.90	1.82
Jan	4.33	–0.20	2.36	1.54	–1.85	0.75
Feb	–11.74	–11.76	–10.28	–2.32	–3.23	0.40
March	–8.31	–5.87	–4.86	–0.50	0.66	1.17
Apr	–7.28	–2.83	–3.67	–0.10	–1.67	0.68
May	–8.98	–4.66	–4.93	–0.42	–4.93	0.08
Jun	–5.74	–1.01	–0.95	0.79	–1.77	0.64
Jul	–0.51	1.92	2.14	1.78	–1.88	0.63
Aug	3.17	5.07	3.27	2.11	–0.50	0.95
Sept	8.38	8.74	7.27	3.14	0.67	1.10
Oct	6.64	6.81	1.62	1.49	5.11	1.98
Nov	9.07	8.29	4.44	2.45	4.49	1.80

The analysis of variance showed that p value (statistical significance) is smaller than 0.05, and F–test statistic is more than 2, the results are statistically significant. It means that the average deviations from trends in particular months differ significantly, so in the analyzed time series there are seasonal fluctuations. The values of seasonal fluctuations, as absolute and relative seasonal coefficients, were estimated and then presented in Table 1. It was claimed that in November and December, sea level anomalies (SLA) in HELSINKI point are higher that it would result from the linear trend function. The greatest deviations in minus occur in February. In SWINOUJSCIE point, the greater changes in SLA occur in November and December as well, than it would result from the linear trend function. The greatest deviations in minus occur also in February. In OPEN BALTIC point, it was stated that in October the changes are the greatest, however, the greatest deviations in minus occur in February. The percentage seasonal coefficients prove the results (Table 1).

In order to analyze the divergence between the minimal and maximal sea level anomalies (SLA) for each month of the years 2010–2014, the diagrams for the data devoid of the trend for all months were prepared. (e.g. see Fig. 6).

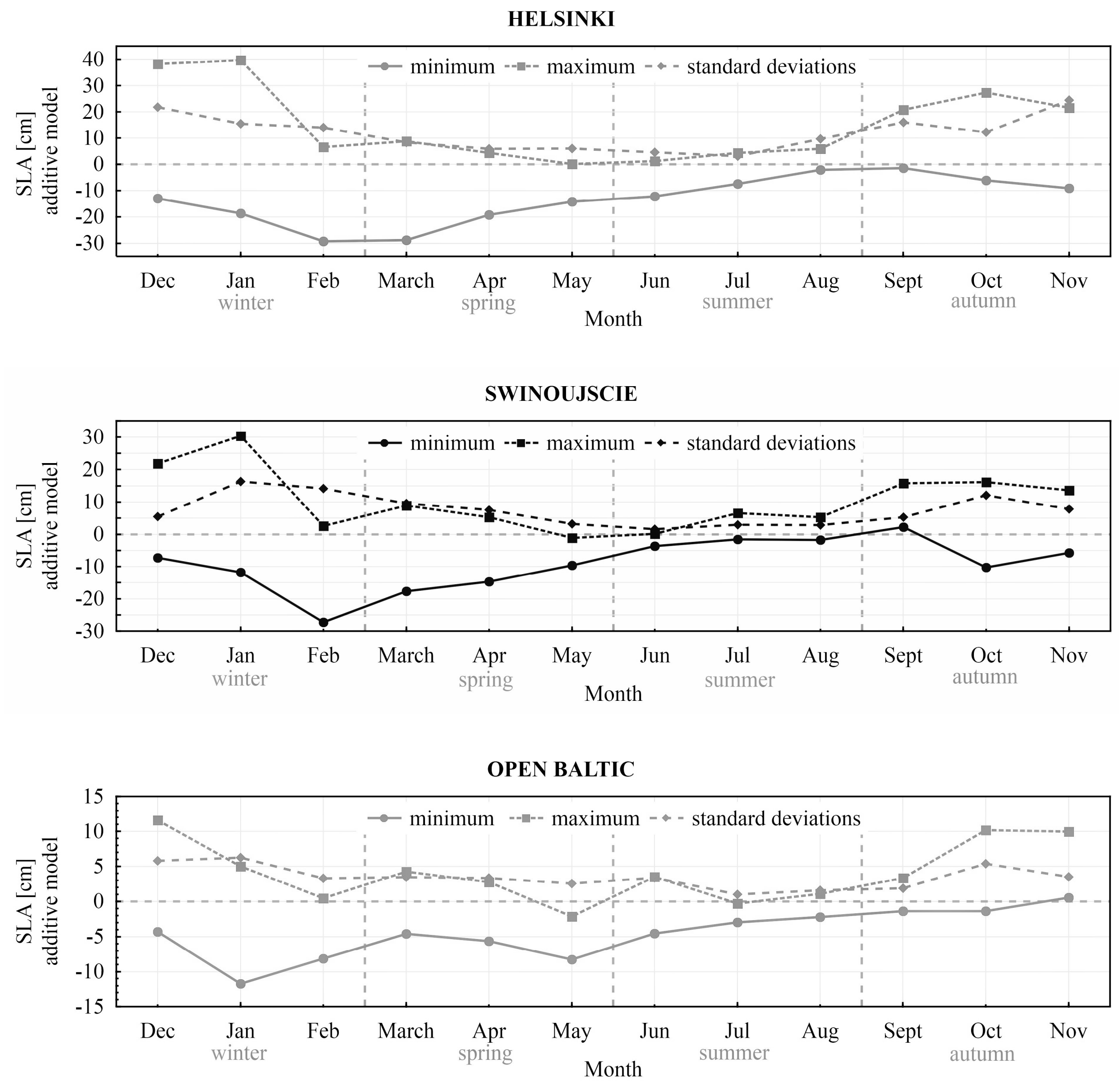


Fig. 6. The diagrams present minimal and maximal divergence, and standard deviation of sea level anomalies (SLA) for the additive model in all months

In the additive model, the greatest amplitudes of fluctuations occur in winter months, the smallest in summer months. The same conclusions can be drawn for all the analyzed time series in HELSINKI, SWINOUJSCIE and OPEN BALTIC points. The diagrams present also standard deviation of SLA. The greatest standard deviation in

HELSINKI point occur in November and December, the smallest in June. In SWINOUJSCIE point, the greatest standard deviation is in January and the smallest in June. The greatest value of standard deviation in OPEN BALTIC point occurs in January and the smallest in July.

In the multiplicative model, the greatest amplitudes of fluctuations occur in winter months and the smallest in summer months for all of the analyzed time series in HELSINKI, SWINOUJSCIE and OPEN BALTIC points (e.g. see Fig. 7).

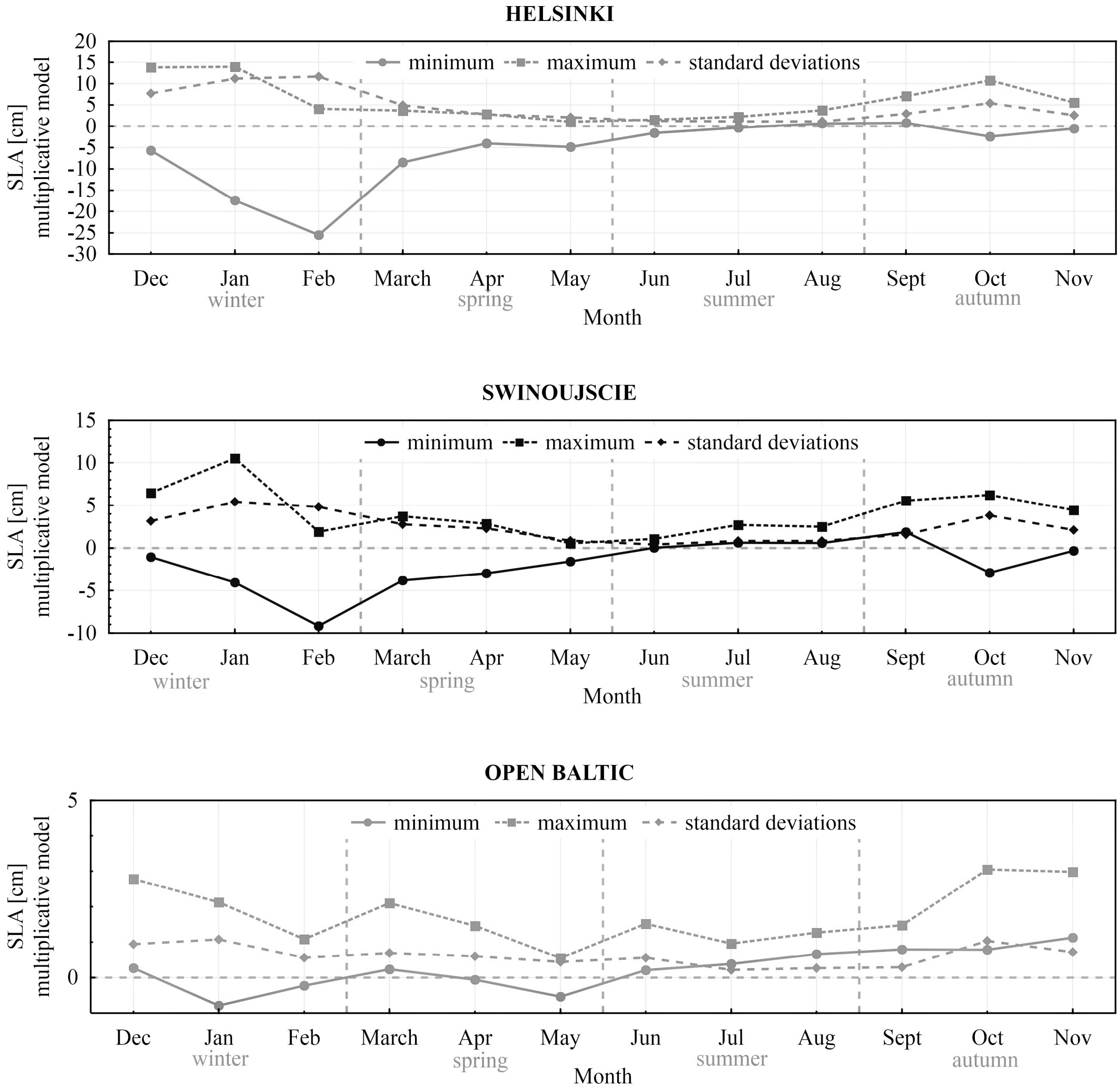


Fig. 7. The diagrams present minimal and maximal divergence, and standard deviation of sea level anomalies (SLA) for the additive model in all months

In the multiplicative model, the highest value of standard deviation of sea level anomalies (SLA) in HELSINKI point occurs in January and February and the smallest in June and July. In SWINOUJSCIE point, the greatest standard deviation occurs in January and the smallest in June. The highest values of standard deviation in OPEN BALTIC point is in January and the smallest value is in July.

Conclusions

The possibility to observe and measure sea level changes that occur in time allows for indicating the reasons that shape the changes, and for using the information in further research and prognosis.

The aim of the article was to analyze seasonal fluctuations of sea level anomalies (SLA) of the Baltic Sea. All the analyses were made on time series for three points of the Baltic Sea, one was located in the open Baltic Sea and the two points were inshore. The analyses were conducted during 5 years, from 2010 to 2014. The used data were satellite altimetry data. Having made the estimations and analyses, one stated that one of the factors of the time series in three locations is a trend and it is increasing as the values of sea level anomalies (SLA) grow year by year. While analyzing the seasonality phenomenon, one is looking for given regularities that repeat in the same periods, in this case – a year. In a year there are four seasons during which great changes in sea level anomalies (SLA) were observed. All the analyses indicate that the increases in sea level anomalies (SLA) occur in winter months, and the decreases occur in summer months.

The seasonality of changes in the sea level that occur in the Baltic Sea is connected with all types of factors, including meteorological ones, and other phenomena that occur in given season. In the Baltic Sea, the amplitudes of fluctuations are the highest in winter and the smallest in summer, which was noticed in all three locations: HELSINKI, SWINOUJSCIE and OPEN BALTIC. Year by year, the amplitudes differ from each other and in each year there are other values. The author stated that for three locations, having estimated the absolute coefficient, in October, November and December the changes in sea level are higher than it would result from the linear trend function. The greatest deviation in minus occurs in February. Having conducted the analyses, one stated that the time series free from seasonal fluctuations is necessary for all types of analyses.

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References

Church, J. A.; Woodworth, P. L.; Aarup, T.; Wilson, W. S. (Eds.). 2010. Understanding sea-level rise and variability. Wiley-Blackwell, Chichester, Oxford, Hoboken. 456 p. https://doi.org/10.1002/9781444323276

Donner, R. V.; Ehrcke, R.; Barbosa, S. M.; Wagner, J.; Donges, J. F.; Kurths, J. 2012. Spatial patterns of linear and nonparametric long-term trends in Baltic sea- level variability, *NonlinearProc.Geoph*. 19(1): 95–111.

Ekman, M. 2009. *The changing level of the Baltic Sea during 300 years: a clue to understanding the Earth*. Summer Inst. Histor. Geophys, Åland Islands, p. 168.

Ekman, M.; Makinen, J. 1996. Mean sea surface topography in the Baltic Sea and its transition area to the North Sea: a geodetic solution and comparisons with oceanographic models, *Journal of Geophysical Research: Oceans* 101(C5): 11993–11999. https://doi.org/10.1029/96JC00318

Ekman, M.; Stigebrandt, A. 1990. Secular change of the seasonal variation in sea level and of the pole tide in the Baltic Sea, *Journal of Geophysical Research: Oceans* 95(C5): 5379–5383. https://doi.org/10.1029/JC095iC04p05379

Horton, R.; Herweijer, C.; Rosenzweig, C.; Liu, J.; Gornitz, V.; Ruane, A. C. 2008. Sea level rise projections for current generation CGCMs based on the semi- empirical method, *Geophysical Research Letters* 35(2). https://doi.org/10.1029/2007GL032486

Hunicke, B.; Zorita, E. 2008. Trends in the amplitude of Baltic Sea level annual cycle, *Tellus A* 60(1): 154–164. https://doi.org/10.1111/j.1600-0870.2007.00277.x

Kowalczyk, K. 2006. New model of the vertical crustal movements in the area of Poland, *Geodezija ir Kartografija* 32(4): 83–87.

Pajak, K.; Birylo, M. 2016. Evaluation of the Baltic Sea Basin using satellite altimetry data, in *16th International Multidisciplinary Scientific GeoConference SGEM 2016*, SGEM2016 Conference Proceedings, 28 June – 6 July 2016, Book3, 1: 297–304. ISBN 978-619-7105-61-2 / ISSN 1314-2704.

Plag, H. P.; Tsimplis, M. N. 1999. Temporal variability of the seasonal sea-level cycle in the North Sea and Baltic Sea in relation to climate variability, *Global and Planetary Change* 20(2–3): 173–203. https://doi.org/10.1016/S0921-8181(98)00069-1

Poutanen, M.; Kakkuri, J. 2000. The sea surface of the Baltic – a result from the Baltic Sea Level Project (IAG SSA 8.1). Geodesy Beyond 2000 – The Challenge of the First Decade. K. P. Schwarz (Ed.). IAG General Assembly, 19–30 July 1999, Birmingham, IAG Symp. Vol. 121, Springer, p. 289–294.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea level rise, *Science* 315(5810): 368–370. https://doi.org/10.1126/science.1135456

Statsoft Electronic Statistics Textbook [online], [cited 02 January 2017]. Available from Internet: http://www.statsoft.pl/textbook/stathome.html

Stramska, M.; Kowalewska-Kalkowska, H.; Świrgoń, M. 2013. Seasonal variability in the Baltic Sea level, *Oceanologia* 55(4): 787–807. https://doi.org/10.5697/oc.55-4.787