

# OCENA SPREMINJANJA NIVOJA MORSKE GLADINE IN FIZIKALNIH POJAVOV V BALTSKEM MORJU

# ASSESSMENT OF THE DYNAMICS OF SEA LEVEL AND PHYSICAL PHENOMENA IN THE BALTIC SEA

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## IZVLEČEK

*Povprečne spremembe morske gladine so v neposredni povezavi s fizikalni pojavi, kot so spremembe temperature, slanosti, kar hkrati povzročata spremembe v gostoti morske vode. Analiza sprememb nivoja morske gladine se pogosto uporablja kot sredstvo za raziskovanje obalne črte in podnebnih sprememb. Zvišanje ali znižanje temperature ter slanosti vode Baltskega morja lahko pomembno vpliva na ekosistem. Cilj raziskave je uporaba sezonskih kazalcev za oceno dinamike sprememb morske gladine in samih fizikalnih pojavov, ki močno vplivajo na te spremembe. V raziskavi smo uporabili podatke satelitske altimetrije in podatke satelitske misije GRACE (angl. Gravity Recovery and Climate Experiment). Opravili smo analizo sezonskih sprememb mesečnih časovnih vrst v obdobju januar 2010–december 2014. Podatki so bili s petih postaj na Baltskem morju. Absolutni in relativni kazalniki so pokazali, da so vrednosti danih fizikalnih pojavov, kot posledica vpliva sezonskih dejavnikov, manjši ali večji od ocenjenih z linearno funkcijo trenda. Slanost je največja jeseni in pozimi ter najmanjša poleti. Rezultati so koristni za prepoznavanje sprememb morske gladine, temperature in slanosti morske vode ter so lahko podlaga za nadaljnja opazovanja in raziskave teh dejavnikov.*

## KLJUČNE BESEDE

GRACE, nivo gladine morja, slanost, satelitska altimetrija, temperatura vode, Baltsko morje

## ABSTRACT

*The average sea level fluctuations are connected with the occurrence of physical phenomena, such as changes in temperature and salinity, which influence the changes in water density. The sea level change modelling is used widely to evaluate and study shoreline and climate changes. An increase or decrease in water temperature and salinity may have a very important effect on the ecosystem of the Baltic Sea. The aim of the paper is to use the seasonal indicators to estimate the dynamics of changes of sea level and the physical phenomena that have a substantial influence on this changes. Data from satellite altimetry and GRACE (Gravity Recovery and Climate Experiment) satellite mission were used in the research. The analyses of seasonal fluctuations were made for time series for every month in the period between January 2010 and December 2014 in five stations of the Baltic Sea. The absolute and relative indicators showed that, as a consequence of the influence of seasonal factors, the values of the given phenomenon are lower or higher than those estimated with the linear trend function. Salinity is the highest in autumn and winter months but it is the lowest in summer months. The results are useful to identify the changes of sea level, water temperature and salinity and can serve as a basis for further improvement and development of tools and methodologies for monitoring these factors.*

## KEY WORDS

GRACE, sea level, salinity, satellite altimetry, water temperature, Baltic Sea

## 1 INTRODUCTION

The Baltic Sea is located in the northern part of the European continent. It is a shallow sea and its average depth is about 50 meters; its surface is about 415,000 km<sup>2</sup> (BACC, 2008). The Baltic Sea is cold, the water temperature and salinity depends on the latitude. It is an inland sea that is connected with the neighbouring North Sea only through narrow and shallow straits that hinder the flow of salty ocean water (Winsor et al., 2001). That aspect has the main influence on the salinity of the sea, which is rather low, in comparison to the ocean salinity (the average salinity amounts to only 7.4 ‰ (Janssen et al., 1999)). The Baltic Sea salinity is controlled by river runoff, net precipitation and water exchange through the North Sea (Meier, 2006). An essential feature of the Baltic Sea water is its stratification. There are two main strata: surface water and groundwater. Surface water has low salinity, it is well-mingled and oxygenated. Its temperature fluctuates depending on a season, from 0°C to 20°C. The temperature of the surface layer in the Baltic Sea varies essentially on the annual scale. The surface layer responds quickly to changes of the local atmospheric conditions (Stigebrandt and Gustafsson, 2002). Groundwater with the salinity of 12–22‰ has the almost stable temperature of 4–6 °C. In the halocline (at the depth of 40–80 m), there is a sudden increase in salinity and at the same time in water density. The temperature of the southern part of the Baltic Sea varies from 0°C (winter) to 8°C (summer), however, the average temperature in the bays is +22°C (Helsinki Commission, 2013). Surface water in the summer has on average between 15°C and 23°C, however, it is below 0°C in winter. Those and other physical phenomena have a great influence on sea level changes. The whole average change in the Baltic Sea level is connected with the consequences of post-glacial rebounds, the growth of global ocean mass mainly due to the melting of glaciers, the thermal expansion of sea water and regional factors (Peltier, 1998).

To determine the changes in sea level and water temperature, salinity and mass variations, statistical methods based on linear regression or multinomial regression are mainly used (Kryński and Zanimon-skiy, 2004). In the analyses of changes in sea level, water temperature and salinity, one can apply the ratio method. In the method, the seasonal indicators for particular phases of cycles are determined. If the fluctuation amplitudes, defined as differences between the real values and theoretical values gained from calculations of the linear trend estimation in analogical phases of the cycles, are more or less the same, then they are the absolute constant fluctuations. However, if the height of the amplitudes changes in some almost equal proportion, then those are the relative constant fluctuations (Issahaku et al., 2016; Australian Bureau of Statistics).

In the article the authors made the analysis of seasonal fluctuations in the Baltic Sea level and the physical phenomenon – water temperature, salinity and equivalent water height in selected stations distributed in various parts of the Baltic Sea. The main aim of the analysis was to estimate the parameters of the model of developing variables and the evaluation of the precision of the models fitting to empirical data with the use of the seasonal indicators method.

## 2 DATA SETS

The analysis was made between 2010 and 2014 and it concerned: water temperature, salinity, sea level anomaly (SLA) and equivalent water height (EWH). The spatial scope of the research engaged five selected stations in the Baltic Sea region as presented in Figure 1.

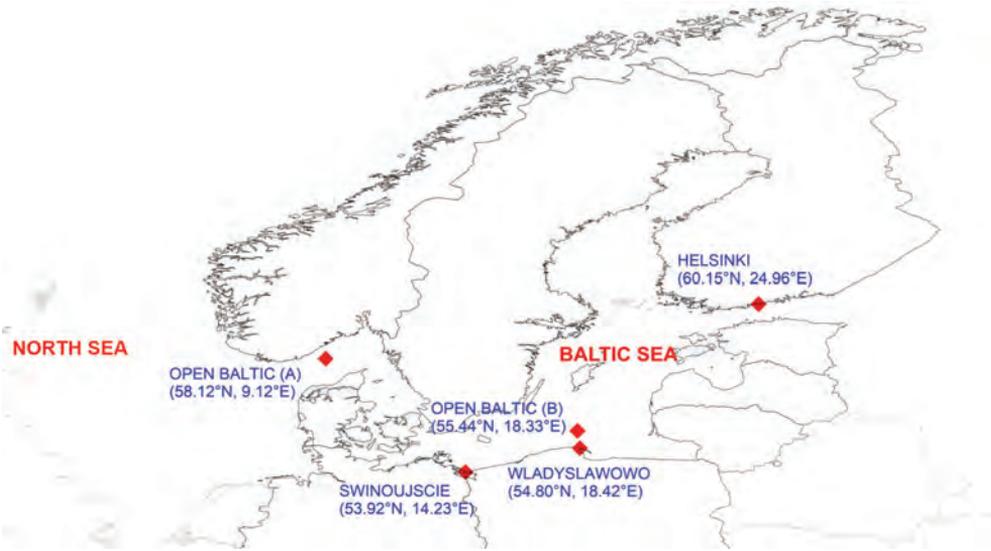


Figure 1: Spatial distribution of station in the Baltic Sea region (OPEN BALTIC A, OPEN BALTIC B, SWINOUJSCIE, WLADYSLAWOWO, HELSINKI).

The data used in the research on sea level changes are sea level anomaly (SLA) that were collected by satellite altimetry (Antonov et al., 2002). The altimetry data set used for this study are daily sea level anomalies provided by the Copernicus Marine and Environment Monitoring Service (CMEMS) (<http://marine.copernicus.eu>). This data set, a combined solution from the multi-mission, covers over a 20-year period from January 1993. Altimeters emit signals toward the Earth, and receive the echo from the sea surface, after the reaction. The sea surface height is obtained from the difference between the satellite's position relative to the reference ellipsoid and the satellite distance from the sea surface (range) (AVISO). The altimetric measurements are corrected for atmospheric effects (ionospheric delay and dry/wet tropospheric effects) and geophysical processes (solid, ocean, and pole tides, loading effect of the ocean tides, sea state bias, and the Inverted Barometer response of the ocean). Detailed information of the corrections can be found at the AVISO website [www.aviso.oceanobs.com](http://www.aviso.oceanobs.com) and [www.marine.copernicus.eu](http://www.marine.copernicus.eu). In this paper we used the data sets concerning water temperature and salinity that was also provided by the Copernicus Marine and Environment Monitoring Service (CMEMS).

The GRACE (Gravity Recovery and Climate Experiment) was the second data set in the research. The Gravity Recovery and Climate Experiment (GRACE), is a joint USA and German satellite mission launched in 2002 (Tapley et al., 2004, Sakumura et al., 2014). The primary objective of the mission is to monitor gravity field variations (Tapley et al., 2004). Three centers are part of the GRACE Ground System and generate Level-2 data (spherical harmonic fields): CSR (U. Texas/Center for Space Research); GFZ (GeoForschungsZentrum Potsdam); and JPL (Jet Propulsion Laboratory).

Each global and regional change of gravity is caused by the Earth's mass variations. The mass variations occur due to processes in the interior of the Earth and on its surface (Wahr et al., 2006). Because the effects of the pole tide, the solid earth tide, and the ocean tide have been removed from the GRACE gravity field model, the GRACE solutions can reflect changes of continent water storages and ocean

water mass (Han et al., 2005; Kusche, 2007; Zhou et al., 2006; Eshagh et al., 2013). The mass changes can be expressed in terms of equivalent water height (EWH) (Wahr et al., 1998; Schrama et al., 2007). The GRACE data are widely used to estimate the mass changes in the global and regional scale, such as monitoring the terrestrial water changes in the Baltic Sea.

Their output include spherical harmonic coefficients of the gravity field and of the dealiasing fields used to compute them. For the purpose of the test RL05, product computed and processed by CSR center was used. GRACE ocean data were processed by Chambers, supported by the NASA MEaSUREs Program, and are available at <http://grace.jpl.nasa.gov> (Chambers, 2010; Chambers and Bonin, 2012).

### 3 METHODOLOGY

There are three groups of reasons that influence level changes in different types of phenomena in time:

- main reasons – they work permanently with constant intensity, they mark the main directions of changes (i.e. trends or linear trend estimation),
- seasonal reasons (temporary) – they work regularly but in short cycles; they are connected with the specificity of the researched phenomenon, they determine seasonal fluctuations,
- random reasons – they work irregularly, they are unpredictable considering both direction and force, they express the activity of random factors and they determine random fluctuations.

During the analysis of time ranges often, apart from determining the linear trend, seasonal fluctuations are identified (cyclical, temporary, short-time), i.e. changes in the intensity of the analysed phenomenon that repeat in a time interval (Eurostat, 2007). The four components of a time series (t: trend, s: seasonal, c: cyclical, r: random) can be combined in different ways. Accordingly, the time series model used to describe the observed data (Y) can be additive and multiplicative:

$$y_{ij} = t_{ij} + s_{ij} + c_{ij} + r_{ij} \tag{1}$$

$$y_{ij} = t_{ij} \times s_{ij} \times c_{ij} \times r_{ij} \tag{2}$$

where  $i = 1, 2, \dots, 12$  indicates the months and  $J = 1, 2, \dots, n$  the years. If the trend is linear, these two models look as follows:

$$y_{ij} = (a + bt) + s_{ij} + c_{ij} + r_{ij} \tag{3}$$

$$y_{ij} = (a + bt) \times s_{ij} \times c_{ij} \times r_{ij} \tag{4}$$

In an additive model the seasonal, cyclical and random variations are absolute deviations from the trend (they do not depend on the level of the trend). In a multiplicative model the seasonal, cyclical and random variations are relative (percentage) deviations from the trend (the higher the trend, the more intensive these variations are). Though in practice the multiplicative model is the more popular, both models have their own merits and, depending on the nature of the time series to be analysed, they are equally acceptable. In this paper we used additive and multiplicative model (Fase et al., 1973). The reasons for the occurrence of seasonal fluctuations are mostly natural. It means that their occurrence is closely connected with the course of the following seasons and also with changes in climate conditions.

The choice of a given method for distinguishing seasonal fluctuations, first of all depends on the course of the general linear trend estimation (particularly on the type of function that describes the tendency) and types of seasonal fluctuations (Australian Bureau of Statistics). There are two types of fluctuations (Ostasiewicz et al., 2008):

1. Absolute fluctuations, when the fluctuation amplitudes in corresponding phases of a cycle are more or less the same (additive model).
2. Relative fluctuations, when the heights of the fluctuation amplitudes change more or less in the same ratio in the corresponding phases of a cycle (multiplicative model).

In a ratio analysis, one can distinguish four stages of work:

- The selection of the linear trend estimation of the analysed phenomena (the linear trend model).
- The selection of seasonal fluctuations with the elimination of the linear trend estimation from the time series.
- In the case of the additive model, it is achieved by estimating the difference between the empirical value of the analysed variable and the theoretical value gained from the linear trend estimation model.
- In the case of the multiplicative model, by estimating the quotient of the empirical value of the analysed variable to theoretical values gained from the linear trend model. The gained values are independent of trends but they contain seasonal and random fluctuations.

In this paper, we estimated indigenous seasonal indicators for the investigation of the dynamics of changes of sea level and physical phenomena. For the purpose of seasonal adjustment, the time series was assumed to be observed monthly and consisted of distinct elements: the trend, the seasonal, cyclical and irregular components. In this paper, the objective of seasonal adjustment was to identify and estimate the seasonal effects, and to remove them from the time series. At the end of our investigation we estimated values in particular stations of the Baltic Sea for the random component, the coefficient of residual variation, the coefficient of convergence and the coefficient of determination for the additive model and multiplicative model.

## 4 RESULTS

In order to determine the pace and direction of changes in the average water temperature, salinity, sea level anomaly (SLA) and equivalent water height (EWH) in all the analysed station of the Baltic Sea in the years 2010–2014, the linear trend function was determined. The change in water temperature is above zero, the salinity trend decreases or slightly increases, the sea level anomalies (SLA) trend grows in all the analysed stations of the Baltic Sea, equivalent water heights (EWH) trend decreases, with the exception of OPEN BALTIC B point, where the trend increases. Table 1 presents all the data.

Additionally, at each researched point, the correlation coefficient for trend between the different phenomena was computed (Jöreskog, 1978). The trends of salinity and water temperature are consistent with a correlation of  $-0.62$ . The correlation of trend from water temperature and sea level anomaly is  $-0.59$ . However, there is a very high linear correlation between equivalent water height (EWH) and water temperature ( $0.66$ ). The trends of equivalent water height (EWH) and sea level anomaly had a very low a linear correlation of  $-0.09$ . The correlation between the trend for salinity and sea level anomaly is only  $0.33$ . Figure 2 shows the correlations for trend between salinity, water temperature, equivalent water height (EWH) and sea level anomaly (SLA) results.

Table 1: The trend value of water temperature, salinity, sea level anomalies and equivalent water heights in all the analysed station in the Baltic Sea; units are [°C] for water temperature, [‰] for salinity, [cm] for SLA, [cm] for EWH; data span January 2010–December 2014.

Point	Trend/year			
	Temperature	Salinity	EWH	SLA
OPEN BALTIC A	0.70	-0.10	-0.34	0.71
OPEN BALTIC B	0.72	-0.01	1.57	0.87
SWINOUJSCIE	0.77	0.13	-0.46	0.43
WLADYSLAWOWO	0.55	-0.01	-0.24	0.52
HELSINKI	0.36	0.27	-1.69	1.02

Additionally, at each researched point, the correlation coefficient for trend between the different phenomena was computed (Jöreskog, 1978). The trends of salinity and water temperature are consistent with a correlation of  $-0.62$ . The correlation of trend from water temperature and sea level anomaly is  $-0.59$ . However, there is a very high linear correlation between equivalent water height (EWH) and water temperature ( $0.66$ ). The trends of equivalent water height (EWH) and sea level anomaly had a very low a linear correlation of  $-0.09$ . The correlation between the trend for salinity and sea level anomaly is only  $0.33$ . Figure 2 shows the correlations for trend between salinity, water temperature, equivalent water height (EWH) and sea level anomaly (SLA) results.

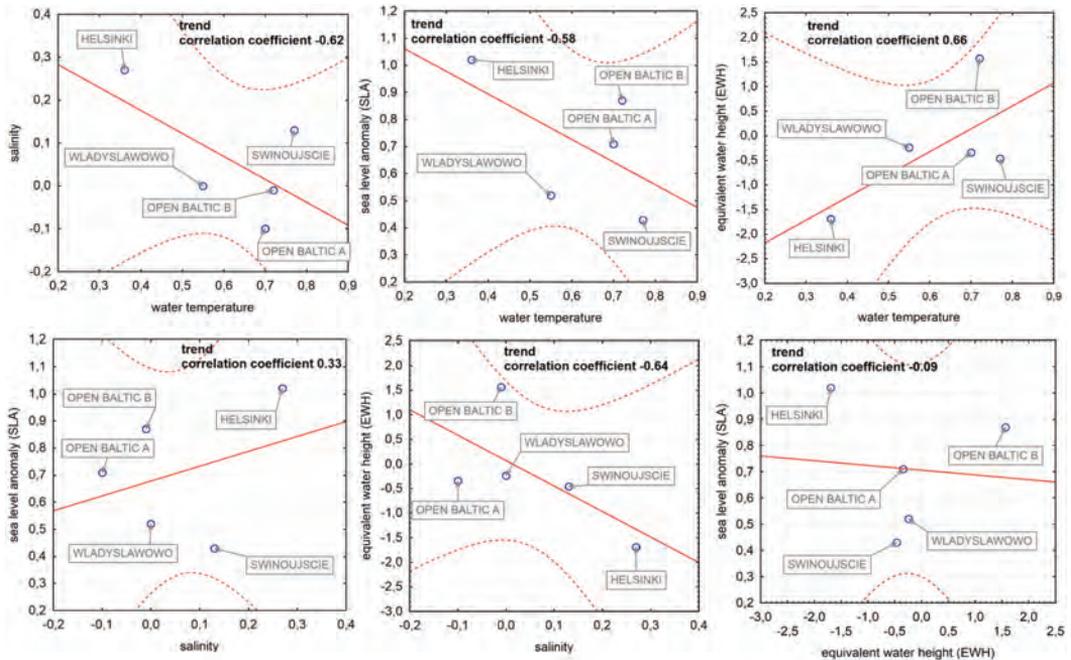


Figure 2: Correlation coefficients between for trend between salinity, water temperature, equivalent water height (EWH) and sea level anomaly (SLA).

#### 4.1 Absolute fluctuations

The next step of the analysis was the estimation of the absolute seasonal indicators for a particular physical phenomenon in the selected stations of the Baltic Sea. The absolute indicators and the sum of all seasonal indicators were estimated. In the case of the absolute indicators, the sum coincided with the expected value, i.e. it was 0 (Ostasiewicz et al., 2008). Figure 3 presents the calculated seasonal indicators in relation to the estimated trend value. The indicators in the additive model show how much the level of the phenomenon is higher or lower in a given month than the estimated trend function.

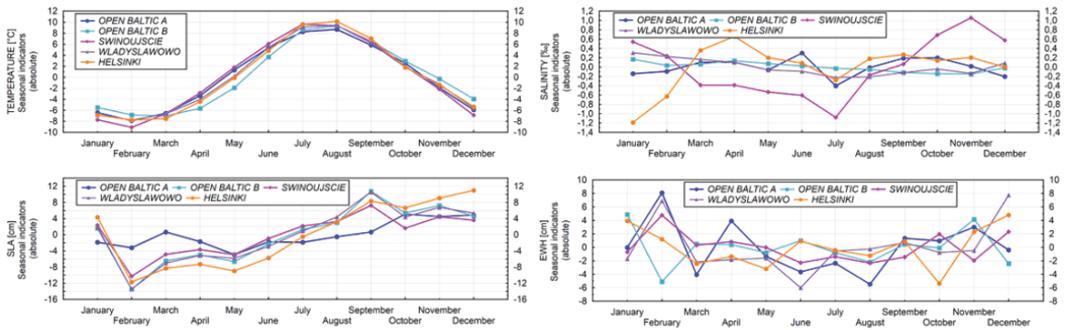


Figure 3: The graphs presents of seasonal indicators (absolute) of water temperature, salinity, sea level anomaly (SLA) and equivalent water height (EWH) in five researched station of the Baltic Sea.

From the estimated pure seasonal indicators (Figure 3) one can draw conclusions that as a result of the activity of seasonal factors, water temperature is the highest (it is higher than the value estimated with the linear trend function by about  $7^{\circ}\text{C}$ – $10^{\circ}\text{C}$ ) in July and August, however, it is the lowest in February. Salinity is (Figure 3), however, is usually the highest in November and January, and the lowest in July. In OPEN BALTIC A point, salinity is the highest in June and it is higher than the values estimated with the linear trend function, and it is the lowest in July. In HELSINKI point, there is also a change in salinity. The most significant changes occur in April and the least in January. In September and October (about 5–10 cm) sea level anomalies (SLA) (Figure 3) are the highest (they are higher than the estimated trend function) as a result of seasonal indicators activity. They are the lowest in February (about 10–13 cm) almost in all researched station of the Baltic Sea. In OPEN BALTIC A, SLA is the highest in May (about 5 cm), and the lowest in October. Equivalent water height (EWH) (Figure 3) in OPEN BALTIC A point is the highest in February (higher by about 8 cm than the estimated trend function) and the lowest (about 5.5 cm) in August. In OPEN BALTIC B point, EWH is the highest in January (about 5 cm higher than the linear trend function) and the lowest in February (about 5 cm). EWH in SWINOUJSKIE point is the highest in February (about 5 cm) and the lowest (about 2 cm) in August. In WLADYSLAWOWO point, the most significant changes in EWH occur in December (about 8 cm), and the least in June (about 6 cm). In HELSINKI point, EWH in the highest in December (about 5 cm) and the lowest in October (about 6 cm).

The next step of the analysis was the calculation of the theoretical values which include the linear trend estimation and seasonal fluctuations. Having added proper seasonal indicators, the theoretical values were estimated. The calculated values considered both the trend and their seasonality.

$$\hat{y}_{ij} = \hat{y}_{ij} + s_j \tag{5}$$

where,  $\hat{y}_{ij}$  is the linear trend and  $s_j$  is the seasonal fluctuations, which was calculated using the formula:

$$s_j = \frac{1}{n_i} \sum_1^{n_i} (y_{ij} - \hat{y}_{ij}) \tag{6}$$

where,  $y_{ij}$  is the real values,  $\hat{y}_{ij}$  is the linear trend and  $n_i$  is the number of observations.

The last element of the analysis was the calculation of the random component ( $S_\epsilon$ ) and the coefficient of residual variation ( $v_\epsilon$ ) which indicates random changes. The random component ( $S_\epsilon$ ) and the coefficient of residual variation ( $v_\epsilon$ ) were calculated using the formula:

$$S_\epsilon = \sqrt{\frac{\sum (y_{ij} - \hat{y}_{ij})^2}{n - 2}} \tag{7}$$

where,  $y_{ij}$  is the real values,  $\hat{y}_{ij}$  is the theoretical values and  $n$  is the number of observations.

$$V_\epsilon = \frac{S_\epsilon}{\bar{y}} \cdot 100 \tag{8}$$

where  $S_\epsilon$  is the random component and  $\bar{y}$  is the average for the each time series.

The coefficient of variation (the coefficient of convergence) is a measure of fit ( $\varphi^2$ ), which informs if the researched changes are explained by the changing in time (linear trend function) and by seasonal, and another factor. The coefficient of variations was calculated using the formula:

$$\varphi^2 = \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y}_i)^2} \tag{9}$$

where  $y_i$  is the real values,  $\hat{y}_i$  is the theoretical values and  $\bar{y}_i$  is the average for the each time series.

The last measure of fit is the  $R^2$  coefficient which informs if the changes are explained by the changes in time and seasonality, which was calculated using the formula:

$$R^2 = 1 - \varphi^2 \tag{10}$$

All estimations are presented in Table 2.

Table 2: The table presents the estimated values in a particular station of the Baltic Sea for the random component, the coefficient of residual variation, the coefficient of convergence and the coefficient of determination for the additive model; units are [°C] for water temperature, [‰] for salinity, [cm] for SLA, [cm] for EWH; data span January 2010–December 2014.

Point	Temperature				Salinity				SLA				EWH			
	$S_\epsilon$	$V_\epsilon$	$R^2$	$\varphi^2$												
OPEN BALTIC A	1.78	0.20	0.92	0.08	1.81	0.06	0.02	0.98	3.46	0.63	0.49	0.51	6.23	4.61	0.27	0.73
OPEN BALTIC B	0.98	0.10	0.97	0.03	0.11	0.02	0.44	0.56	11.48	3.42	0.26	0.74	4.09	1.23	0.32	0.68
SWINOUJSKIE	1.07	0.11	0.98	0.02	1.18	0.22	0.23	0.77	8.42	2.49	0.26	0.74	4.91	2.36	0.32	0.68
WLADYSLAWOWO	1.11	0.12	0.97	0.03	0.26	0.04	0.30	0.70	11.54	3.32	0.26	0.74	5.44	3.89	0.11	0.89
HELSINKI	1.17	0.15	0.97	0.03	0.62	0.13	0.50	0.50	12.23	3.45	0.30	0.70	5.60	1.26	0.20	0.80

The analysis of seasonal fluctuations showed (Table 2) that the observed changes in water temperature (real) differ from those estimated with the use of linear trend function and the relative seasonal indicator in a particular station of the Baltic Sea by between 0.98°C and 1.78°C. The significance of random fluctuations is moderate, only about 10% to 20%. The coefficient of variation showed that the changes in water temperature are not explained by time changes (linear trend function) and seasonality, but by other factors. It means that only a couple percent of fluctuations in water temperature are caused by other factors. The R2 coordinate, i.e. a measure of fit, showed that 92%–98% of changes in water temperature are explained by time changes and seasonality.

The observed changes in salinity (real) differ from those estimated with the use of linear trend function and relative seasonal indicators by between 0.11‰ and 1.81‰. Random variation of salinity in the Baltic Sea is low, between 2%–22%. The coefficient of variation, however, showed that changes in salinity are not explained by time changes (linear trend function) and seasonality, but they are caused by other factors. The R2 coordinate, i.e. a measure of fit, showed that in OPEN BALTIC A only 2% of water temperature changes are explained by time changes and seasonality. In OPEN BALTIC B station there are only 44%, in SWINOUJSKIE 23%, WLADYSLAWOWO 30% and HELSINKI it is 50%.

There is a great importance of random fluctuations in the analysis of sea level anomaly (SLA). Changes in SLA differ from the estimated ones by 3.46 cm–12.23 cm. The coefficient of variation is several dozen percent and it results from the fact that changes in SLA are caused by other factors; however, only between 26% and 49% of the changes are explained by time changes and seasonality. Changes in equivalent water height (EWH) differ from the estimated ones by 4.09 cm–6.23 cm. There is a great importance of random fluctuations. The coefficient of variation showed that in several dozen percent changes in EWH are caused by other factors; between 11% and 32% of the changes in EWH are explained by time changes and seasonality.

### 4.2 Relative fluctuations

The next step of the analysis was the estimation of the relative seasonal indicators for a particular physical phenomenon in a selected station of the Baltic Sea. The relative indicators and the sum of all seasonal indicators were estimated. In the case of the relative indicators, the sum of the seasonal indicators equals 12 as monthly data were researched in a year (Ostasiewicz et al., 2008). Figure 4 presents the calculated seasonal indicators in relation to the estimated trend value.

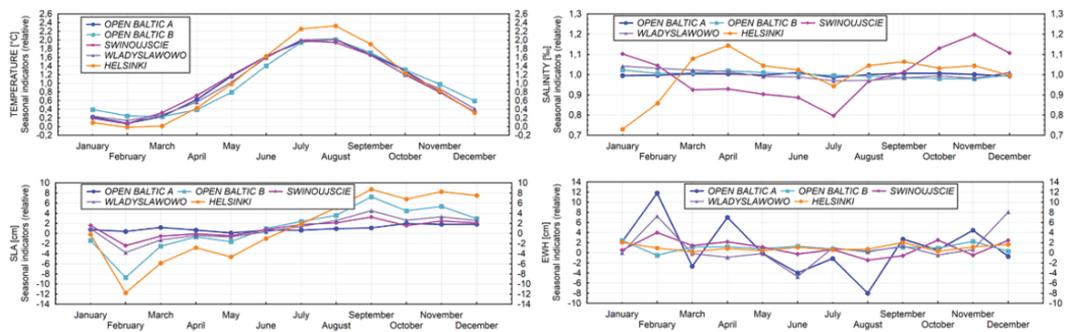


Figure 4: The graphs presents of seasonal indicators (relative) of water temperature, salinity, sea level anomaly (SLA) and equivalent water height (EWH) in five researched station of the Baltic Sea.

Seasonal indicators in the multiplicative model show by what percentage the level of the phenomenon in a given phase of the cycle is higher or lower than the level that would be reached if there were no fluctuations and the development occurred according to the trend. According to the estimated seasonal indicators, one can assume that as a consequence of seasonal factors, water temperature is the highest in July and August (about 100% higher than the average temperature); however, in February it is the lowest (about 90% lower than the average). Water salinity is usually higher than the average salinity in November, December and January, but it is the lowest in July. In September and October, as a consequence of the occurrence of seasonal factors, sea level anomalies (SLA) are higher than the average, however, they are the lowest in February. Equivalent water heights (EWH) are usually the highest in December, January and February, but they are the lowest in August.

The next step of the analysis was the calculation of the theoretical values that contained the development tendency and seasonal fluctuations that considered both the trend and seasonality. In order to fit the function that includes both the trend and seasonality, the random component ( $S_e$ ), the coefficient of residual variation ( $V_e$ ), the coefficient of variation ( $\varphi^2$ ) and the coefficient of determination  $R^2$  were estimated and presented in Table 3. All values were calculated similarly to additive variations, only seasonality indicators were calculated with a different formula, using the equation:

$$s_j = \frac{1}{n_i} \sum_1^{n_i} \left( \frac{y_{ij}}{\hat{y}_{ij}} \right) \tag{11}$$

where  $y_{ij}$  is the real values,  $\hat{y}_{ij}$  is the linear trend and  $n_i$  is the number of observations.

Table 3: The table presents the estimated values for a particular station of the Baltic Sea: the random component, the coefficient of residual variation, the coefficient of convergence and the coefficient of determination for the relative model; units are [°C] for water temperature, [‰] for salinity, [cm] for SLA, [cm] for EWH; data span January 2010–December 2014.

Point	Temperature				Salinity				SLA				EWH			
	$S_e$	$V_e$	$R^2$	$\varphi^2$	$S_e$	$V_e$	$R^2$	$\varphi^2$	$S_e$	$V_e$	$R^2$	$\varphi^2$	$S_e$	$V_e$	$R^2$	$\varphi^2$
OPEN BALTIC A	0.12	0.01	0.99	0.01	0.60	0.02	0.90	0.10	0.13	1.36	1.00	0.00	1.85	0.63	0.94	0.06
OPEN BALTIC B	0.09	0.01	0.99	0.01	0.04	0.01	0.93	0.07	2.57	0.06	1.00	0.00	0.19	0.77	0.99	0.01
SWINOUJSKIE	0.13	0.01	0.99	0.01	0.05	0.01	0.99	0.01	0.91	0.19	0.99	0.01	0.39	0.27	0.99	0.01
WLADYSLAWOWO	0.06	0.01	0.99	0.01	0.08	0.01	0.92	0.08	2.76	0.78	0.96	0.04	1.09	0.79	0.97	0.03
HELSINKI	0.05	0.01	0.99	0.01	0.13	0.03	0.98	0.02	1.78	0.57	0.98	0.02	2.51	0.50	0.82	0.18

In the multiplicative model, the authors noticed that water temperature changes (real) differ from those estimated with the use of linear trend function and relative seasonal indicator in a particular station of the Baltic Sea by the range of 0.05 °C–0.13 °C. The significance of random fluctuations is moderate, only 1%–3%. The coefficient of variation showed that water temperature changes are not connected with time changes (linear trend function) and seasonality, but they are caused by other factors. In other words, water temperature changes are influenced by other factors only in a couple percent. The  $R^2$  coefficient, i.e. a measure of fit showed that in all the analysed stations, 99% of water temperature changes are caused by changes in time and seasonality.

Changes in salinity (real) differ from the estimated ones by 0.04‰–0.60‰. Random variation of the Baltic Sea salinity is really low (1%–3%). The coefficient of variation showed that changes in water salin-

ity are not explained by time changes and seasonality, but by other factors. The  $R^2$  coefficient showed that in more than ninety percent, the changes in salinity are explained by time changes and seasonality.

Sea level anomaly (SLA) differs from the estimated values by an average of 0.13 cm–2.76 cm. The significance of random fluctuations is moderate to high (27%–79%). The coefficient of variation showed that between 1% and 4% changes in SLA are caused by other factors and almost 100% of changes in SLA are caused by time changes and seasonality.

Changes in equivalent water heights (EWH) differ from the estimated ones by an average of 0.19 cm–2.51 cm. The significance of random factors is very high. The coefficient of variation showed that between 1% and 18% changes in equivalent water heights (EWH) are caused by other factors. 18% to 99% changes in EWH are caused by time changes and seasonality.

## 5 DISCUSSION

One of the major concerns associated with global climate changes are future sea level variations. They may have a strong impact on coastal areas, ecosystems and human societies. At the regional scale the sea-level rise is determined largely by the heat up-take by the ocean, changes in salinity and changes in wind driven ocean circulation and water temperature. Therefore, a detailed understanding of the physical factors that contribute to the observed variability of sea level is necessary for a complete assessment of possible future sea-level changes.

Most of the studies of the Baltic Sea focus on its limited regions. For instance Ekman (e.g. 2003 and references therein) and Andersson (2002) based their studies on the 200-year long Stockholm sea level record, pointing out that the winter climate, in particular wind, plays the central role for the Baltic Sea level variations. Rak and Wieczorek (2012) argue in their studies that changes in the basic physical properties of selected areas of the Baltic Proper were analysed on the basis of the results of a 12-year series. In their study they focused on the seasonal to long-term variability of temperature and salinity in three basins of the southern Baltic: the Bornholm Deep, the Słupsk Furrow and the Gdańsk Deep. They observed that positive temperature trends of 0.11 and 0.16°C year<sup>-1</sup> were observed in the surface and deep layers respectively. The salinity trend was also positive. From the modelling study of Meier and Kauker (2003), the volume-average salinity in the Baltic Basin is 7.4 ‰, with decadal variations of the order of 1‰. It is very important check to dynamic of sea level changes and physical phenomena and thus still monitoring. In our paper we estimated of indigenous seasonal indicators to investigation this dynamics of changes. The aim of this paper was to remove the seasonal components from the time series. Many approaches of removing the seasonal variations can be taken. We used the seasonal indicators to estimate the dynamics of changes of sea level and physical phenomena.

Two different types of models have been used, namely the additive model and the multiplicative model. For each time series considered it was therefore necessary to clarify which of the two models described the data in the best way. In the additive model, the seasonal variation is independent of the absolute level of the time series, but it takes approximately the same magnitude each year.

In the multiplicative model, the seasonal variation takes the same relative magnitude each year. This means that the seasonal variation equals a certain percentage of the level of the time series. The amplitude of the

seasonal factor varies with the level of the time series. When comparing the absolute coefficients and the relative seasonal coefficients, one can state that the development tendency and relative seasonal indicators show the real situation in a better way. One may suggest that we have the multiplicative seasonality. The observations of the graphs prove that the authors gained the best fitting from the linear trend function and relative seasonal indicators.

The graphs in Figures 5, 6, 7, 8 show the fitted linear trend function with the absolute (additive model) and relative (multiplicative model) seasonality factors.

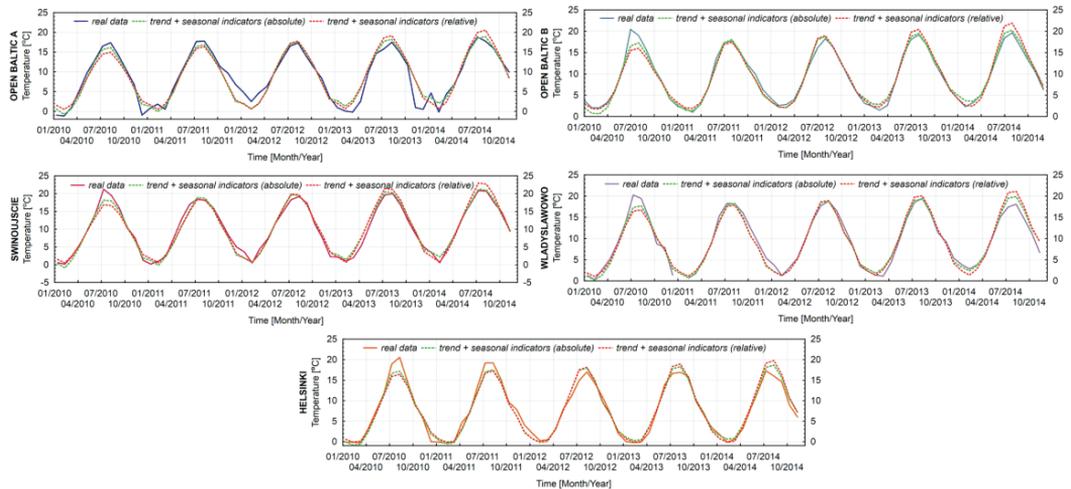


Figure 5: The graphs presents of the linear trend function with fitted absolute (additive model) and relative (multiplicative model) seasonal indicators for water temperature in five researched stations of the Baltic Sea: OPEN BALTIC A, OPEN BALTIC B, SWINOUJSCIE, WLADYSLAWOWO, HELSINKI.

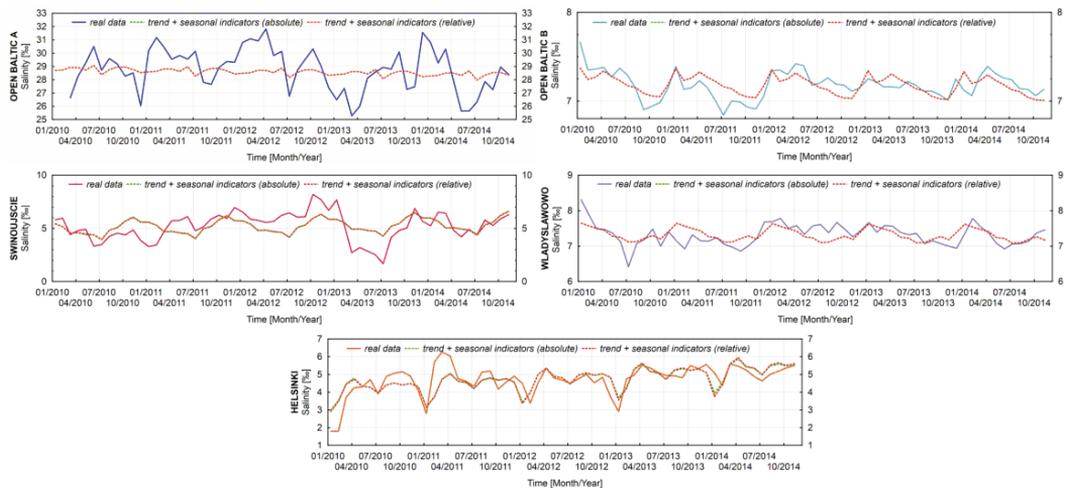


Figure 6: The graphs presents the linear trend function with fitted absolute (additive model) and relative (multiplicative model) seasonal indicators for salinity in five researched stations of the Baltic Sea: OPEN BALTIC A, OPEN BALTIC B, SWINOUJSCIE, WLADYSLAWOWO, HELSINKI.

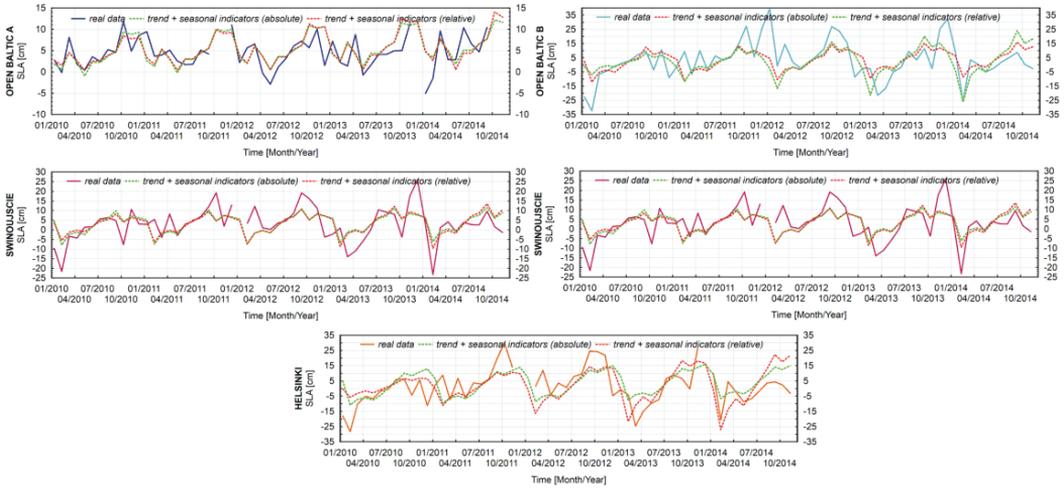


Figure 7: The graphs presents the linear trend function with fitted absolute (additive model) and relative (multiplicative model) seasonal indicators for sea level anomalies (SLA) in five researched stations of the Baltic Sea: OPEN BALTIC A, OPEN BALTIC B, SWINOUJSCIE, WŁADYSŁAWOWO, HELSINKI.

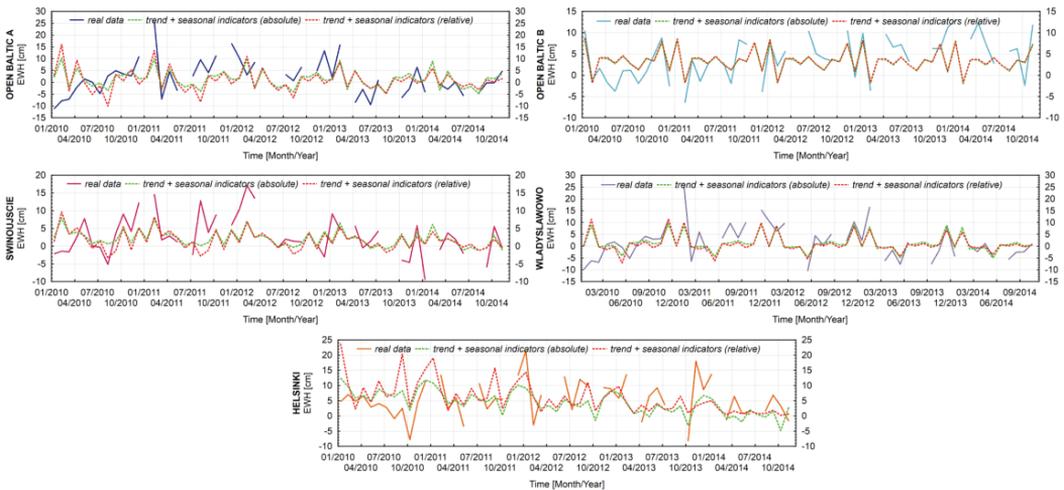


Figure 8: The graphs presents the linear trend function with fitted absolute (additive model) and relative (multiplicative model) seasonal indicators for equivalent water heights (EWH) in five researched stations of the Baltic Sea: OPEN BALTIC A, OPEN BALTIC B, SWINOUJSCIE, WŁADYSŁAWOWO, HELSINKI.

## 6 CONCLUSION

On the basis of the conducted analyses and investigations (the results were presented in diagrams and tables), the following main conclusions were drawn. The linear trend estimation of the researched phenomena was distinguished. The trend indicated that water temperature increases annually, salinity decreases or has the same level, sea level anomalies have an increasing tendency and EWH has a decreasing tendency (only in OPEN BALTIC B point the trends definitely grow).

We think that the complexity of the influence of the water temperature and salinity on changes in the sea level enable the water change during both a year period and during long-standing periods. The absolute and relative indicators showed that, as a consequence of the influence of seasonal factors, the water temperature in summer is the highest, whereas it is the lowest in February. Salinity is the highest in autumn and winter months but it is the lowest in summer months. In general, during winter-early spring (February) there is a significant monthly agreement between the decrease of water temperature and decrease of sea level. Baltic Sea level shows a mean annual cycle that usually peaks in the autumn-winter months (September–December) and attains its minimum in end winter-early spring (February). The equivalent water height is the highest in February, while it is the lowest in summer. The coefficient of determination of the models and the coefficient of convergence showed that the multiplicative model has the best-fitted function.

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