ANALYSIS OF MONTHLY SEA LEVEL DATA FROM VARNA TIDE GAUGE STATION

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Abstract. Climate changes and global warming are assume for main reasons of constant sea level rise. Survey methods such as altimetric measurements are essential for determining global processes related to sea level change, but the regional and local changes are also important. In this paper regional sea level changes at tide gauge station Varna at Black sea coast are analyzed. Single spectrum analysis is use to analyze the monthly sea level data for the period 1929-2019. The sea level trend, long term tidal constituents - amplitudes and phases, are estimated. The results clearly indicate positive mean sea level trend with value of 1.2 ±0.1mm/yr.

Key words: mean sea level, tide gauge, radar

Introduction

Climate changes and global warming are the cause of sea level rise during the 20th century of about 2 mm per year. The sea level researches are useful not only to forecast cataclysms and sea level rising, but also in connection with interdisciplinary studies exploring the causes of this change. Climate changes and global warming are supposed to be the main reasons of the constant sea level rise. The regional sea level changes are determine by tide gauge measurements and satellite altimetry is use to investigate global sea level changes. Mean sea level changes are important for geodesy and geophysics. The mean sea level for a long time periods was used in the past to define the height systems. It is an important component in determining the geoid. Tide gauge measurements are important for realizing the worldwide Unified Global Height System (UGHS) of the Global Geodetic Observing System (GGOS) initiative.

Methods and Theory

In this study, monthly sea level data from Varna tide gauge at the Northern Black Sea coast is used. The data period coverers the time interval from year 1929 to year 2019 and the daily registrations are aggregate in average monthly sea level values. The methods used to analysis of Time series are Single Spectrum Analysis (SSA), regression and Fourier analysis. The method used for decomposition the time series to trend, periodic components and noise is call Single Spectrum Analysis. The method involves two stages: decomposition and restoration of the time series. The decomposition of the time series involves two sub-stages - the construction of a trajectory matrix and the Singular Value Decomposition (SVD) - the decomposition of single vectors and the restoration of the time series - grouping and diagonal averaging (Golyandina, et al., 2001). Regression analysis is use to solve for the mean sea level and trend and the Fourier analysis - to solve for the periodical constituents.

Data processing

The observations of sea level at tide gauge station Varna has started in 1928. From 1928 until 2013 the tide gauge was of mechanical type - stilling well gauges „A.Ott" Kempten. In 2013 a new radar tide gauge, type Vega Puls S60, is installed above water level in the draw well (Fig. 1). The new radar tide gauge system emits short microwave pulses with frequencies about 18 – 27 GHz in the direction of the surface water, they are reflected and received back. Accuracy of measurements is about 5mm and observations interval is set to one second.

Fig. 1. Radar Tide gauge Vega plus from Varna tide station

Observations are stored in a signal conditioning instrument and can be shown in a web browser in a real time (http://niggg.bas.bg/wp-content/uploads/2014/02/mare/text.html). The two data sets are brought to one and the same "zero" point by precise levelling through the Tide Gauge Bench Mark. Data gaps (missing observations) are filled in with the Caterpillar SSA MV software using PI Projection method with sequential filling (Golyandina, and Osipov, 2007).

All data are corrected for the vertical crustal motion obtained by repeated levelling measurements started in 1928. Old data are converted to European Vertical Reference System (EVRS), EVRF2007 (Earth Vertical Reference Frame 2007). The average monthly sea level values are analyzed by the SSA method. The time series are decomposed into separate sub-series, which represent the influence of mean sea level, trend and tidal influences. Significant harmonic constituents are determined by spectrogram analysis. A model comprising the above-mentioned parameters is compiled. The values obtained from the model are compared with the measurements. The residuals of the model are examined for autocorrelation and spectral analysis of the model residuals is performed. The resulting amplitude – Arms, is determined and is used to calculate the Signal to Noise Ratio (SNR). Significant tidal effects are supposed to be these with SNR > 2.

The mean sea level and trend are determined by regression analysis of the time series determined by the previous SSA analysis. The Fourier analysis is used to determine the amplitudes and phases of all significant tidal influences from the model determined by SSA analysis. The mean sea level, trend and long term tidal constituents, amplitudes and phases, are estimated. The results clearly indicates positive mean sea level trend with value of 1.2 ± 0.1mm/yr. Figure 2 shows the mean sea level and the model. Gray curve shows the average monthly sea level values, black curve is shown the model and the trend is represented by the line. The resulting average sea level for the period 1929 - 2019 is 2.8 ± 0.1 cm in EVRF2007.

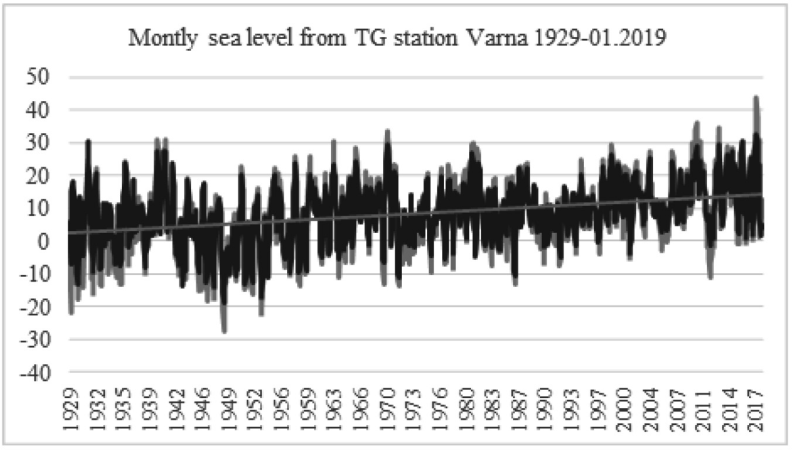

Fig. 2. Monthly seal level data for period 1929-2019 (gray sea level, black model, line is trend)

The model residuals are plotted on Fig. 3. Residual data of the harmonic constituents are analyzed by Fourier analysis. The harmonic influences with major impact at residuals series are given in Table 1. In the table are presented ten of them with the highest amplitudes. The resulting amplitude calculated with the coefficients specified in the table is 0.7 cm, the mean value of the order of the residuals is 0.45 cm and the standard deviation - 3.4 cm. The resulting amplitudes of the residuals series and Signal to Noise Ratio (SNR) coefficients are computed and shown in Table2. SNR is computed as a square of amplitudes ratio first from signal and second from noise – Arms. The annual and semi-annual variations, as expected, have the greatest impact with amplitudes of 6.7 cm and 1.4 cm. Table 2 shows also a tide with a periodicity close to 18.6 years with amplitude of 1.3 cm. The value of the tide with period of 14.4 is similar to that of the nodal tide.

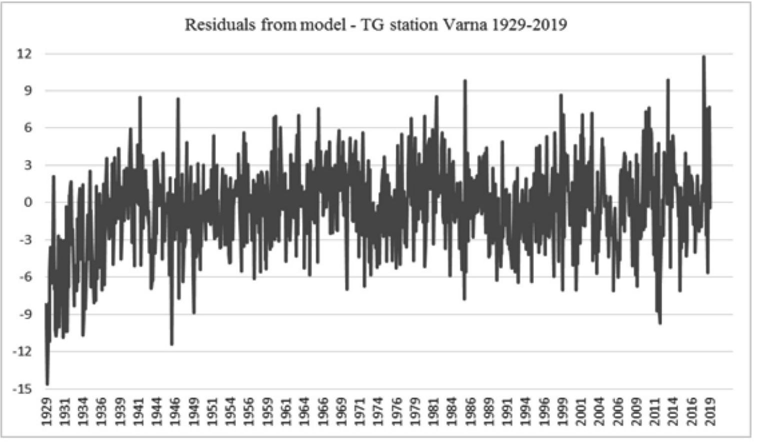

Fig. 3. Residuals from analysis

Table. 1. Harmonic influences with major impact at residuals series.

Frequency	Period [mont]	Cosine coef [cm]	Sine coef [cm]	Amplitudes [cm]
0.0009	1080.0	-1.0	0.7	1.23
0.0056	180.0	-0.5	-0.8	0.98
0.0037	270.0	-0.7	-0.1	0.70
0.0639	15.7	-0.4	-0.4	0.58
0.0046	216.0	0.1	-0.5	0.52
0.0306	32.7	0.2	-0.5	0.52
0.0028	360.0	-0.5	-0.1	0.52
0.0120	83.1	-0.3	-0.4	0.47
0.0213	47.0	0.2	-0.4	0.46

Table. 2. Solved for parameters from the model.

Frequency	Period [mont]	Cosine coef [cm]	Sine coef [cm]	Amplitudes [cm]	Phases [°]	SNR
0.08333	12.0	-3.42	5.76	6.70	300.67	91.5
0.16667	6.0	1.30	-0.49	1.39	159.42	3.9
0.08426	11.9	-0.75	-0.97	1.22	232.25	3.1
0.02222	45.0	1.30	0.55	1.41	23.01	4.1
0.02315	43.2	-1.31	0.24	1.33	349.64	3.6
0.06944	14.4	-0.92	0.77	1.20	320.32	2.9
0.01667	60.0	-0.94	0.62	1.12	326.65	2.6
0.00429	233.0	-1.26	0.47	1.34	339.37	3.7

Conclusions

The analysis of tide gauge data for 90 years clearly indicates annual, semiannual and decadal variations of the mean sea level. The estimated mean sea level is 2.8 ± 0.1 cm with trend of 1.2 ± 0.1mm/yr. The SSA analysis is helpful to identify and allocate the mean sea level, trend and harmonic influences in the monthly data. Five long term periodical variations with amplitudes greater than 1 cm are observed in the time series data. The annual and semi-annual variations, as expected, have the greatest impact with amplitudes of 6.7 cm and 1.4 cm. The long period variation of about 233 months (19.4years) can be associated with the nodal tide with period (18.61 years) in the mean sea level. The tide gauge registration from the radar equipment will give the opportunity to resolve the short term harmonic constituents and the relatively long 90 years data will be valuable contribution for realizing the Unified Global Height System.

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Анализ на средномесечни стойности на морското ниво от мареографна станция Варна

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Резюме. Предполага се че климатичните промени и глобалното затопляне са основните причини за покачването на морското ниво. Методи за наблюдения като алтиметричните измервания са от изключително значение за определяне на глобалните процеси свързани с изменението на морското ниво, но регионални и локални изменения също са много важни. В тази статия са анализирани регионални изменения на морското ниво от мареографна станция Варна на Черноморското крайбрежие. Използван е анализ на единичния спектър за средномесечни стойности за периода 1929 – 2019 година. Определени са трендът на морското ниво, сезонни вариации и дългопериодични влияния, амплитуди и фази. Резултатите показват положителен тренд на средното морско ниво със стойност от 1.2 ± 0.1 mm/y.