Interconnection between Winds and Sea Level in the Western Black Sea Based on 10 Years Data Analysis from the Climate Change Perspective *(Maria-Emanuela Mihailov, Luminița Buga, Alina-Daiana Spînu, Lucian Dumitrache, Laurențiu-Florin Constantinoiu, Maria-Ionela Tomescu-Chivu)*	"Cercetări Marine" Issue no. 48 Pages 171-178	2018

INTERCONNECTION BETWEEN WINDS AND SEA LEVEL IN THE WESTERN BLACK SEA BASED ON 10 YEARS DATA ANALYSIS FROM THE CLIMATE CHANGE PERSPECTIVE

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ABSTRACT

The relationship between the annual wind records from Romanian shore weather station and annual mean sea level, is examined using observations covering period 2006 - 2016. It is demonstrated that even such a relatively short record is sufficient for finding a convincing relationship. Using measured data from a weather station is found to give a slight improvement over reanalysis data, but for both the correlation between annual mean sea level and wind energy in the west–east direction is high. Supplementary data from a numerical hydrodynamic model are used to illustrate the regional variability in annual mean sea level and its interannual variability at a high spatial resolution. Recent climate change and land uplift are causing changes in sea level. This study implies that climatic changes in the strength of winds from a specific direction may affect local annual mean sea level quite significantly. Water levels at a particular location are not only affected by the local air pressure but also by other factors, so this simple correlation is rarely observed. Using 10 years (2006 - 2016) of Constanta - Romania coastal sea-level observations, we examine the contribution of these latter processes to long-term sea-level rise, which, to date, have been relatively less explored. A specific analysis and to evidence the correlation between wind pattern and sea level, the 2014 is chosen due to the frequent western winds that occurred during January and August in the Romanian Black Sea coast.

Key-Words: sea level, wind, climate change, coastal area, Black Sea

AIMS AND BACKGROUND

Evidence of climate change from atmosphere and seas observations has increased significantly in recent years. At the same time, new improved ways to characterize and quantify uncertainty have highlighted the remaining challenges for developing climate and long-term data recordings. At present, the atmosphere and sea observations indicate the following modifications: the composition of the atmosphere, the radiation budget, water and air temperature in the hydrological cycle, extreme events, and thus sea wind driven circulation that induce the sea surface circulation. It is found that wave contributions can strongly dampen or enhance the effects of thermal expansion and land ice loss on coastal water-level changes at interannual-to-multidecadal timescales (Melet et al., 2018).

According to the IPCC report (2014) is almost certain that the averaged sea level, increased at an average rate between 1900 and 2010 with 1.7 [1.5-1.9] mm / year and 3.2 [2.8 to 3.6] mm / year between 1993 and 2010. This assessment is based on several studies using different methods, as well as independent observation systems (digital gauges and altimetry) from 1993 - present. Although vertical local movement can cause even higher rates of sea level rise (or decrease) than the coastline, it is very likely that this does not affect global averages (IPCC, 2014).

Change in the mean Black Sea level is the sum of global, regional and local effects. Globally, communities are threatened by sea-level changes operating at various spatial scales. From global to regional the sea level variations are associated with glacier and ice sheet loss and ocean thermal expansion. Referring to coastal-scale variations the associated causes are complemented with atmospheric surges and waves.

The most direct measurement of relative sea level is from tide gauges. Relative sea level represent the height of the sea surface relative to the sea floor, and thus to land, at a given location, and is estimated using tide gauges or sea level reconstructions using information from the geological record (Hünicke et al, 2015).

In contrast to global studies, only a few studies for the Black Sea region have so far (to 2018) used wind datasets together with tide gauge readings to address different research questions (such as: for the Romanian Black Sea coast: Malciu V, 2013; and for the Black Sea basin: Avsar et al., 2015; Aksoy, 2017; Aydin et al., 2016; Vigo et al., 2005).

For an overall study and a proper understanding of the interaction between two coupled and interactive environments: sea - atmosphere but also dynamic processes on the marine basin, we considered in this paper: the knowledge of historical data - analysis and interpretation of data; assessing the current state and determining the trends of atmospheric and sea dynamic parameters.

EXPERIMENTAL

Establishing long-term evolution and the different ranges of main physical parameters (sea level, wind) and their assessment based on the values determined during the study period, 01.01.2006-31.12.2016, were determined based on historical Romanian Black Sea data of the *National Institute for Marine Research and Development "Grigore Antipa"* (sea level) and *National Meteorological Administration - Regional Meteorological Centre of Dobrogea* (wind field: speed and direction).

Sea level. For the globally sea level are used data from Global Mean Sea Level (GMSL) generated from the Integrated Multi-Mission Ocean Altimeter Data for Climate Research is used for global sea level with respect to climate change. The GMSL is a 1-dimensional time series of globally averaged Sea Surface Height Anomalies (SSHA) from TOPEX/Poseidon, Jason-1 and OSTM/Jason-2 (https://sealevel.nasa.gov). It starts in September 1992 to present, with a lag of up to 4 months. All biases and cross-calibrations have been applied to the data so SSHA are consistent between satellites. Data are reported as changes relative to January 1, 1993 and are 2-month averages. Glacial Isostatic Adjustment (GIA) has been applied (Beckley et al., 2017),

Sea level data used for analysis on the Western Black Sea coast are originated from NIMRD database. The database is updated periodically with sea level data from monitoring stations along Romanian Black Sea coast. The systematic recording of sea level started in Romania as early as 1933, by installing a mechanical level recorder, the maregraph (see Malciu V., 2013). Along with these devices, a hydrometer is also installed, performing visual measurements three times a day, for the apparatus control. The accuracy of measurements, which results in a continuous curve on a gridded paper diagram, is 1 mm. After 1990, at Constanta Harbour a digital sea level recorder with a Pressure Sensor Paroscientific Intelligent Instrument was installed, functional and currently included by UNESCO / IOC as part of the international tsunami observation / alerting network (http://www.ioc-sealevelmonitoring.org/station.php?code=csta).

Wind. Meteorological data (on wind speed and direction, by National Meteorological Administration) were recorded in the weather stations, (component to the national weather stations network): Constanta station (44013' N, 28038' E) is located on the coast, at a height of 12.8 meters from the sea level. Gloria station (44031' N, 29034' E) was installed on the oil offshore platform in 1976 and it is 70 km from the coast (Fig. 1a). The automatic station measures the observations regarding wind direction and speed at Constanta station, while at Gloria measurements are realized by anemograph (42 m from the sea level). Wind speed values are mediated on two minutes.

Plots and maps. In this paper the graphics are realized with specialized software: Golden Software - Grapher and OriginLab.

RESULTS AND DISCUSSION

Climate change has many elements, sea level and storm activity are the most significant. Increasing global temperatures are resulting in the melting of the large areas of previously permanent ice. Increasing global temperatures are also raising the temperature of the water in the sea. This increased temperature increases the volume of the sea resulting in sea level rise. These are the eustatic changes.

The bias of the sea level, compared to other climate variables, tend to be relative to natural variability. Nonetheless, changes in ocean dynamics, density, and wind can cause substantial sea level variability in some regions, at interannual timescales.

According to Global Mean Sea Level (GMSL) a rate of 3.2 (± 0.4) mm/yr (Fig. 1) is tracked which reflect the sea level variations and changes, since 1993 as observed by satellites (Table 1, Beckley et al., 2017, Nerem et al., 2010). Globally, is accepted the fact that the main factors that are responsible for the sea level rise with respect to climate change are: the oceans warm due to an increasing global temperature – expansion of the seawater and the melting of ice over land – additional water. The conclusion of Fig. 1 and Table 1 after comparison of results from a variety of approaches is that the human-caused climate change is the main contributor of the global mean sea level rise since 1901.

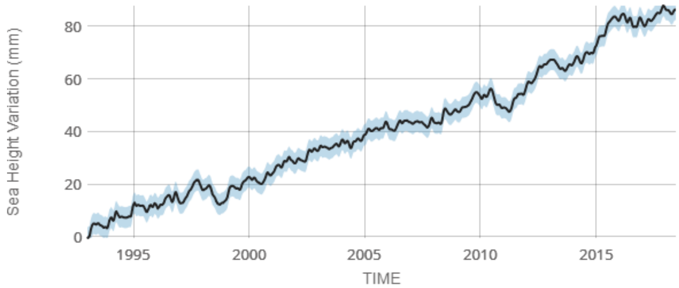

Fig. 1. Global trend of the sea height variation from satellite sea level observations, 1993 – to present (https://sealevel.nasa.gov, Beckley et al., 2017).

Table 1. Global Sea Level estimation (according to bibliography, https://sealevel.nasa.gov/understanding-sea-level/by-the-numbers, accessed in **13.10.2018**)

Period	Estimate (mm/yr)	Uncertainty (+- mm/yr)	Reference	Measurement / Forecast Model
1993 - 2014	2.6-2.9	0.4	Watson et al., 2015	Satellite altimetry and tide gauges
1993 - 2010	**3.2**	0.4	Nerem et al., 2010	Satellite altimetry
1901 - 2010	1.7	0.2	Church and White, 2011	Tide gauge reconstruction
1993 - 2010	2.8	0.5	Church and White, 2011	Tide gauge reconstruction

Sea level in the Black Sea basin. Sea level is a dynamic parameter with the determining influence on local coastal dynamics. Changes to the hydrological cycle are difficult to assess at this stage, but some traces become obvious. The general trend of the Black Sea level is risen (Table 2), with an estimated rate in the Western Black Sea of approx. 1.37 mm/yr (at Constanta - Romania) and in the Eastern Black Sea corner with 6.68mm/yr (Poti – Georgia), and maintaining this would lead to an increased average levels of about 0.8m in 50 years or 1.7m in the next 100 years.

Table 2. Black Sea seasonal average sea level (mm/year), (http://www.psmsl.org, accessed in 13.10.2018).

Water Level (mm/year)															
Station	Time period	Relative sea level trend (mm/an)	Month	1	2	3	4	5	6	7	8	9	10	11	12
Constanta (Romania)	1933 - 1997	1.37	Water Level	-0.008	0.006	0.025	0.04	0.071	0.068	0.041	-0.002	-0.054	-0.076	-0.071	-0.041
			Upper95%	0.033	0.048	0.066	0.081	0.112	0.109	0.082	0.039	-0.013	-0.035	-0.03	0.001
			Lower95%	-0.049	-0.035	-0.016	-0.001	0.03	0.027	0	-0.043	-0.095	-0.117	-0.112	-0.082
Varna (Bulgaria)	1929 - 1996	1.22	Water Level	-0.018	-0.009	0.009	0.034	0.073	0.074	0.053	0.006	-0.044	-0.072	-0.069	-0.037
			Upper95%	0.021	0.03	0.048	0.072	0.111	0.112	0.091	0.044	-0.006	-0.033	-0.03	0.002
			Lower95%	-0.056	-0.047	-0.03	-0.005	0.034	0.035	0.014	-0.033	-0.082	-0.11	-0.107	-0.075
Bourgas (Bulgaria)	1929 - 1996	1.91	Water Level	-0.026	-0.004	0.008	0.032	0.073	0.083	0.063	0.016	-0.046	-0.076	-0.076	-0.048
			Upper95%	0.015	0.037	0.049	0.073	0.114	0.125	0.104	0.057	-0.004	-0.035	-0.035	-0.007
			Lower95%	-0.067	-0.045	-0.033	-0.009	0.031	0.042	0.022	-0.025	-0.087	-0.117	-0.117	-0.089
Batumi (Georgia)	1882 - 2015	1.96	Water Level	-0.021	-0.01	-0.017	0.01	0.046	0.074	0.076	0.036	-0.025	-0.068	-0.067	-0.034
			Upper95%	0.005	0.016	0.009	0.036	0.073	0.1	0.102	0.062	0.001	-0.042	-0.041	-0.008
			Lower95%	-0.047	-0.036	-0.044	-0.016	0.02	0.048	0.05	0.01	-0.051	-0.094	-0.093	-0.06
Poti (Georgia)	1874 - 2015	6.68	Water Level	-0.032	-0.027	-0.015	0.025	0.075	0.109	0.095	0.044	-0.036	-0.088	-0.092	-0.059
			Upper95%	-0.011	-0.006	0.007	0.047	0.097	0.131	0.117	0.066	-0.015	-0.067	-0.07	-0.038
			Lower95%	-0.054	-0.049	-0.036	0.004	0.054	0.088	0.074	0.023	-0.057	-0.11	-0.113	-0.08
Sevastopol (Ukraine)	1910 - 1994	1.26	Water Level	-0.019	-0.013	-0.007	0.029	0.08	0.095	0.072	0.024	-0.043	-0.089	-0.085	-0.045
			Upper95%	0.024	0.03	0.036	0.072	0.122	0.138	0.114	0.067	0	-0.046	-0.043	-0.003
			Lower95%	-0.061	-0.056	-0.049	-0.014	0.037	0.053	0.029	-0.018	-0.085	-0.131	-0.128	-0.088
Tuapse (Russia)	1917 - 2016	2.46	Water Level	-0.011	-0.002	-0.006	0.016	0.058	0.084	0.087	0.041	-0.043	-0.092	-0.088	-0.043
			Upper95%	0.014	0.022	0.019	0.041	0.083	0.109	0.112	0.066	-0.018	-0.068	-0.064	-0.018
			Lower95%	-0.036	-0.027	-0.031	-0.008	0.033	0.059	0.062	0.017	-0.068	-0.117	-0.113	-0.068

For the Western Black Sea at Constanta, the rise of the sea (0.15cm/yr) has increased the eustatism of the Danube River, whose flow rate is decreasing (-0.27km^3/yr), if taken into account the time interval of the measurements, as is shown in Fig. 2 (1959-2005).

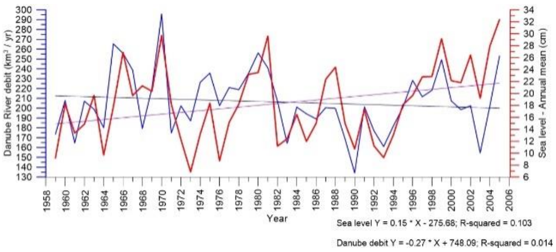

Fig. 2. Yearly mean of the Sea level at Constanta (red line) and Danube River debit - Ceatal Ismail (blue line), period 1959 - 2005.

Sea level analysis at Constanta – Romania during 2006 – 2016. To understand the effects of the wind-stress on the regional patterns of sea level in the Western Black Sea coast, we analyse the interannual variations in sea-level and in wind speed, as observed (Fig. 3). This suggests that the wind variations are largely responsible for the positive sea level trends in the north-western Black Sea coast.

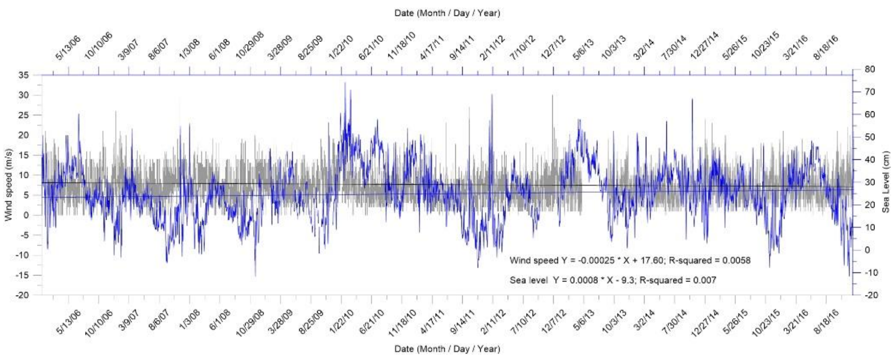

Fig. 3. Sea level (blue) and wind speed (dark grey) daily evolution at Constanta, during

analysed. **period (2006 – 2016)**

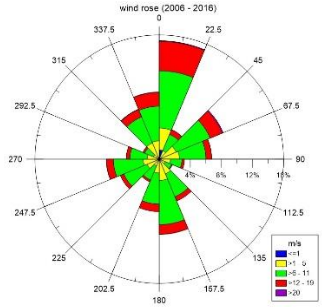

Fig. 4. Wind rose for Constanta recorded at the meteorological station, period 2006 - 2016.

Our analysis confirms previous results (Malciu V., 2013) that the northern and north-eastern winds regime leads to increased levels during the analysed period (Fig.4). For the analysed decade, the sea level continue to raise with 0.12cm relative to natural variability and under anthropogenic factors.

2014 year - Study case. For the western Black Sea, compared with the 1965-2000 (Fig. 2) and the period 1971 - 2010, the wind direction in 2014 (Fig. 5) is represented by all 16 directions, but a higher frequency of the winds in the E, ESE and SSW.

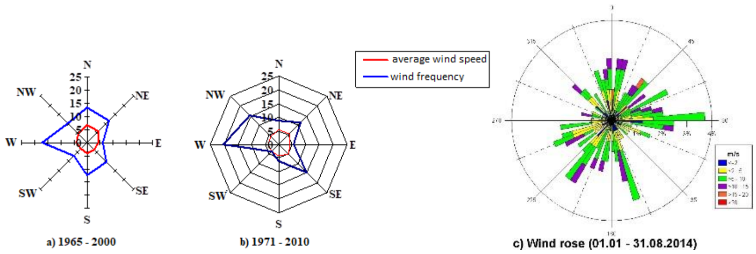

Fig. 5. Constanta wind direction of average frequency and speed distribution wind rose during a) 1965 – 2000, b) 1971 – 2010 and c) January - August 2014.

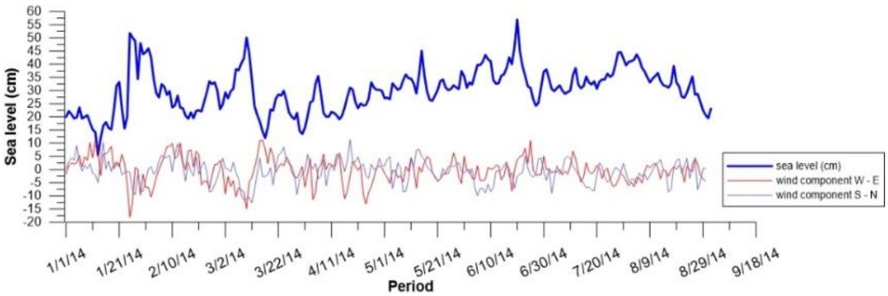

Fig. 6. Sea level and wind components (W-E and N-S) distribution at Constanta, 01.01-31.08.2014 period.

The wind fields were decomposed in u and v vectors using formula: ***u = ws * cos(θ)*** and ***v = ws * sin(θ)***, were **θ** is the wind direction using "math" direction, and **ws** is the wind speed (the magnitude of the wind vector).

The sea level is strongly influenced by the wind vector components (u, v) and, therefore, is dependent on the season: trends are negative for the W-E component in winter (January) and equal to the N – S wind component (Fig. 6). As shown in Fig. 6, it can be seen that due to the level configuration of the sea coast, high values are recorded when the wind is prevailing in the eastern sector. The predominant wind from the western sector determines low sea level.

CONCLUSIONS

The impacts of sea-level rise induced by global warming and anthropogenic factors on global and local scale are assessed. Global eustatic sea level is accelerated during 20th Century with a rate of 1.7 mm/yr and since 1993 the rise is continuing with a globally rate of 3.2 (± 0.4) mm/yr.

From identified sea level data sources, for the Black Sea, level rise with different rates along the basin: approx. 1.37 mm/yr at Constanta (Romania), at Varna (Bulgaria) with 1.22 mm/yr, Bourgas (Bulgaria) a rate of 1.91 mm/yr, Batumi (Georgia) with 1.96 mm/yr, with 6.68mm/yr at Poti (Georgia), in Sevastopol (Ukraine) with 1.26 mm/yr and at Tuapse (Russia) with 2.46 mm/yr.

To identify the regional patterns and the main driven factor of the sea level change we analysed the in-situ sea level data from NIMRD database compared with wind field from NMA database. From our analysis, the sea level continue to raise in the Western Black Sea coast with a trend of 0.12cm/period. To highlight the regional patterns of sea level variation, the wind was decomposed in u and v vector components. The north to south coastal configuration of the Romanian Black Sea coast, the sea level rise when the wind prevails from the eastern sector and predominant westerly winds determines low values.

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