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Sea level change along the Black Sea coast from satellite altimetry, tide gauge and GPS observations

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ABSTRACT

Sea level change affects human living conditions, particularly ocean coasts. However, sea level change is still unclear along the Black Sea coast due to lack of in-situ measurements and low resolution satellite data. In this paper, sea level change along the Black Sea coast is investigated from joint satellite altimetry, tide gauge (TG) and Global Positioning System (GPS) observations. The linear trend and seasonal components of sea level change are estimated at 8 TG stations (Amasra, Igneada, Trabzon-II, Sinop, Sile, Poti, Tuapse, and Batumi) located along the Black Sea coast, which are compared with Satellite Altimetry and GPS. At the tide gauge stations with long-term records such as Poti (about 21 years) and Tuapse (about 19 years), the results obtained from the satellite altimetry and tide gauge observations show a remarkably good agreement. While some big differences are existed between Satellite Altimetry and TG at other stations, after adding vertical motion from GPS, correlation coefficients of the trend have been greatly improved from 0.37 to 0.99 at 3 co-located GPS and TG stations (Trabzon-II, Sinop and Sile).

1. Introduction

With global warming and climate change recently, sea level change is affecting our human living conditions [1]. Sea level change contains two main causes: (1) volume change due to density changes of sea waters, and (2) mass change due to water exchange with atmosphere and land through precipitation, evaporation, river runoff and ice melting [2,3]. Thus, sea level change is not geographically uniform [4]. Therefore, accurate estimations of sea level change are important to estimate and predict its impacts on coastal and island regions. Since late 1992, satellite altimetry has nearly provided global measurements of absolute sea and lake level changes [5,6]. On the other hand, global sea level change has been measured from numerous networks of coastal tide gauges around the world since the 18th century [7]. However, as tide gauge measurements are made with respect to a local

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fixed reference level on land, the tide gauge data reflect the relative sea level change [8]. If there is vertical land motion at the tide gauge location, the tide gauge record is a combination of the local sea level change and the vertical land motion. Therefore, in order to obtain absolute coastal sea level change, the vertical land motion at tide gauge location should be added, such as from levelling and GPS observations.

The Black Sea is an inland sea and filled with salty water by sea level rise at the end of the last glacial period when it was a freshwater body [9]. Today, the Black Sea exchanges water with the Mediterranean Sea only through the Bosphorus and Dardanelles Straits. On the other hand, the north-western shelf of the Black Sea receives the discharges from the Europe's largest rivers. Using satellite altimetry data [10] reported that the Black Sea basin shows an increase in sea level with around 0–5 mm/yr from January 1993 to December 2014. Ref. [11] also pointed out that due to the cyclonic Rim Current intensification the Black Sea level was rising at 8–9 mm/yr in the coastal areas of the Black Sea basin that exceeded in the offshore by 1.5–2 times (4.5–6 mm/yr) for the period of 1992–2005. Thus, estimation of the Black sea level change has large uncertainty.

In this study, sea level changes along the Black Sea coast are estimated from tide gauge and multi-mission satellite altimetry data as well as GPS. Because of some problems in tide gauges, such as poor spatial distribution along the Black Sea, less tide gauge data and short overlapping period, we concentrate only on the analysis of sea level change at 8 tide gauge stations along the eastern and southern coasts of the Black Sea (Fig. 1). Because each tide gauge station has different data period, the satellite altimetry time series has been analyzed at the same time period (Table 1). Moreover at 3 stations with co-located GPS and TG, the sea level change is analyzed and compared.

2. Data and method

2.1. *Satellite altimetry data*

For this study, gridded daily sea level anomalies maps with spacing of 1/8° × 1/8° are provided from the French Archiving, Validation and Interpretation of the Satellite Oceanographic Data (AVISO; http://www.aviso.altimetry.fr/en/data.html).

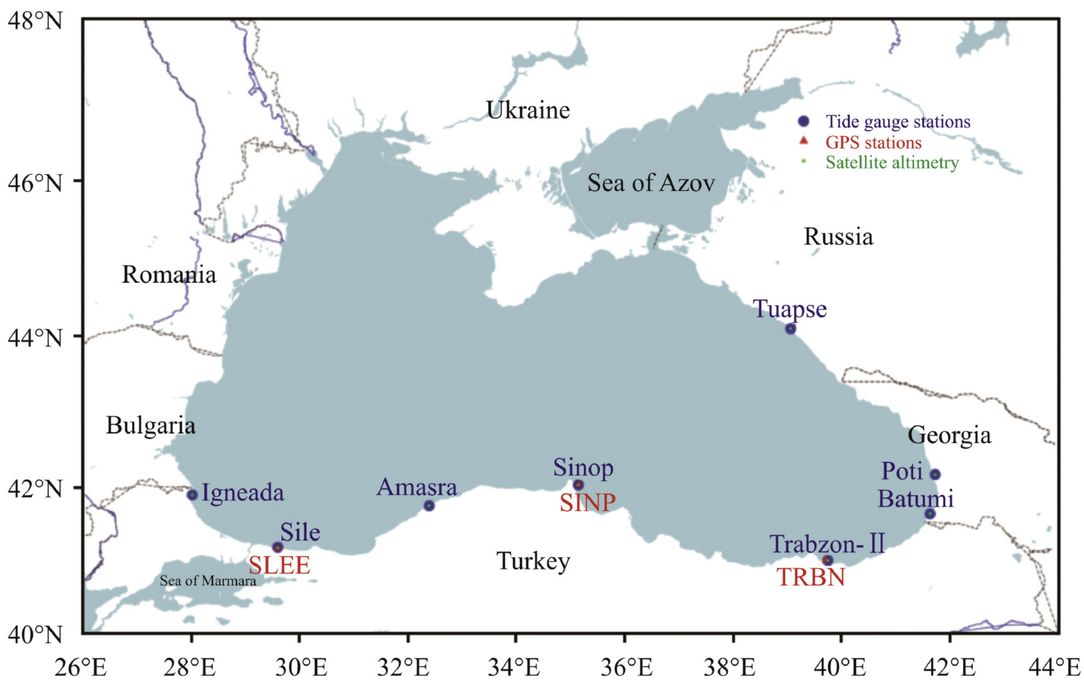

Fig. 1 – The locations of observation stations used in the study.

Table 1 – Trends of sea level change from satellite altimetry and tide gauge data at the same observation period.

Tide gauge station	Location		Distance (km)	Time span	Trend (mm/yr)	
	Latitude	Longitude			Satellite altimetry	Tide gauge
Poti	42°10″N	41°41″E	2.4	Jan. 1993–Dec. 2013	3.45 ± 0.78	4.13 ± 0.78
Tuapse	44°06″N	39°04″E	4.2	Jan. 1993–Dec. 2011	3.42 ± 0.86	4.30 ± 0.88
Batumi	41°38″N	41°42″E	6.2	Sep. 2003–Dec. 2013	1.38 ± 2.29	3.47 ± 2.56
Amasra	41°45″N	32°24″E	7.9	June 2001–Dec. 2012	0.95 ± 1.72	0.07 ± 1.45
Igneada	41°53″N	28°01″E	7.9	July 2002–Dec. 2014	2.19 ± 1.66	6.74 ± 2.08
Trabzon-II	41°00″N	39°45″E	8.6	July 2002–Dec. 2014	−0.38 ± 1.65	2.33 ± 1.76
Sinop	42°01″N	35°09″E	6.0	June 2005–Dec. 2014	7.05 ± 2.48	0.43 ± 2.88
Sile	41°11″N	29°36″E	5.5	July 2008–Dec. 2014	3.61 ± 4.57	5.03 ± 4.84