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Sea-level rise and potential drowning of the Italian coastal plains: Flooding risk scenarios for 2100

F. Antonioli [a, *], M. Anzidei [b], A. Amorosi [c], V. Lo Presti [a], G. Mastronuzzi [d], G. Deiana [e], G. De Falco [f], A. Fontana [g], G. Fontolan [h], S. Lisco [d], A. Marsico [d], M. Moretti [d], P.E. Orrù [e], G.M. Sannino [a], E. Serpelloni [b], A. Vecchio [i]

[a] ENEA, SSPT, Roma, Italy
[b] Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy
[c] Dipartimento di Scienze Biologiche, Geologiche e Ambientali, University of Bologna, Italy
[d] Dipartimento di Scienze della Terra e Geoambientali, University "Aldo Moro", Bari, CONISMA, Italy
[e] Dipartimento di Scienze Chimiche e Geologiche, University of Cagliari, CONISMA, Italy
[f] IAMC-CNR Oristano, Italy
[g] Dipartimento di Geoscienze, University of Padova, Conisma, Italy
[h] Dipartimento di Matematica e Geoscienze, University of Trieste, CONISMA, Italy
[i] Lesia Observatoire de Paris, Section de Meudon 5, France

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ABSTRACT

We depict the relative sea-level rise scenarios for the year 2100 from four areas of the Italian peninsula. Our estimates are based on the Rahmstorf (2007) and IPCC-AR5 reports 2013 for the RCP-8.5 scenarios (www.ipcc.ch) of climate change, adjusted for the rates of vertical land movements (isostasy and tectonics). These latter are inferred from the elevation of MIS 5.5 deposits and from late Holocene sea-level indicators, matched against sea-level predictions for the same periods using the glacio-hydro-isostatic model of Lambeck et al. (2011). We focus on a variety of tectonic settings: the subsiding North Adriatic coast (including the Venice lagoon), two tectonically stable Sardinia coastal plains (Oristano and Cagliari), and the slightly uplifting Taranto coastal plain, in Apulia. Maps of flooding scenarios are shown on high-resolution Digital Terrain Models mostly based on Lidar data. The expected relative sea-level rise by 2100 will change dramatically the present-day morphology, potentially flooding up to about 5500 km^2 of coastal plains at elevations close to present-day sea level.

The subsequent loss of land will impact the environment and local infrastructures, suggesting land planners and decision makers to take into account these scenarios for a cognizant coastal management. Our method developed for the Italian coast can be applied worldwide in other coastal areas expected to be affected by marine ingression due to global climate change.

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1. Introduction

Instrumental and observational data show that in the past two centuries global sea level has risen at faster rates than in the last two or three millennia (Veermer and Rahmstorf, 2009; Church et al., 2010; Church and White, 2011; Kemp et al., 2011), with values up to 3.2 mm/yr in the last decades (Meyssignac and Cazenave, 2012; Mitchum et al., 2010; Jevrejeva et al., 2008, 2014; Wöppelmann and Marcos, 2012).

The recent report on global climate change (Church et al., 2013) warned countries on the risk induced by sea-level rise (Fig. 1). This warning must be seriously considered for the assessment of coastal vulnerability and flooding hazard in response to the fast retreat of the coastline (Schaeffer et al., 2012; Rahmstorf et al., 2011). In addition, natural or anthropogenic coastal subsidence at rates of several mm/yr may represent a critical factor for accelerating local coastal changes, especially when in combination with sea-level rise (Carbognin et al., 2004; Syvitski et al., 2009; Karim and Mimura, 2011; Anzidei et al., 2016).

In Europe, about 86 million people (19% of the entire population) are estimated to live within 10 km from the coastline (Carreau

* Corresponding author.
E-mail address: fabrizio.antonioli@enea.it (F. Antonioli).

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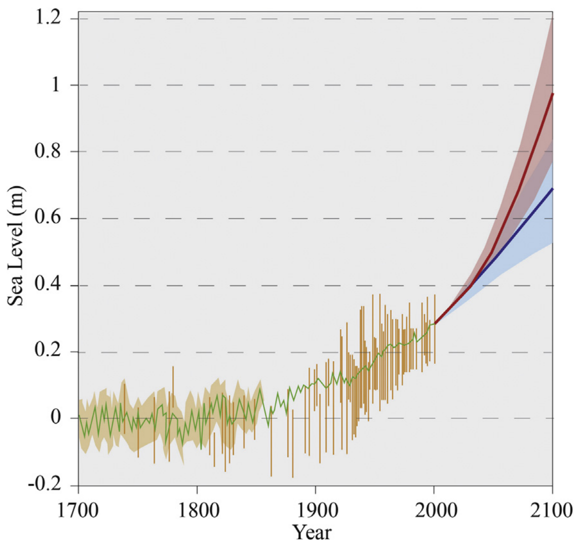

Fig. 1. Projection of global sea-level rise from 1700 to 2100, based on IPCC AR5 report on temperature projections for different emission scenarios (www.ipcc.ch, 2013). Past and future sea levels: for the past periods, proxy data are shown in light brown, for the future, the IPCC projections are reported for two different emissions: very high (red, scenario RCP8.5) and very low emissions (blue, RCP 2.6 scenario). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and Gallego, 2006) in contrast, most of the Mediterranean population (about 75%) lives in coastal areas. In Italy, where coasts are stretching for more than 7500 km, this value is up to 70% (annuario.isprambiente.it). Here, rapid urbanization started after the 60s of the 20th century, leading to the uncontrolled expansion of coastal settlements, today exposed to increasing coastal hazard (Sterr et al., 2003). In addition, the Italian coasts, which are often characterized by natural heritage sites, host important urban and industrial installations and continuously growing tourist activities (D'Alessandro et al., 2002).

Though several studies attempted to predict global sea-level change at 2100 (Church et al., 2010, 2013; Rahmstorf, 2007; Galassi and Spada, 2014; Kopp et al., 2016) (Table 1) or even up to 2200 (Zecca and Chiari, 2012), in few cases only sea-level rise projections were used in combination with high-resolution Digital Terrain Models (DTM) and with geological and geomorphological landscape changes for long to middle term trends derived from local field data to draw detailed maps of expected coastal flooding.

DTMs have provided crucial advancements in topographic measurements, improving significantly the spatial resolution available to Earth scientists in different environments (Achilli et al., 1998; Pesci et al., 2007; Hengl and Reuter, 2009; Fabris et al., 2010; Baiocchi et al., 2007; Baltsavias et al., 2001). From the widely used 90-m resolution global DEM produced by the Shuttle Radar Topography Mission (Farr et al., 2007), now DTMs with considerably higher (better than 1 m) resolution are available from LiDAR surveys. Therefore, the analysis of 3-D high-resolution topography is significantly enhancing coastal studies to estimate future landscape changes through time in relation to sea-level rise (Anzidei et al., 2016; Antonioli et al., 2002; https://coast.noaa.gov/digitalcoast/tools/slr.html).

Among the pioneering studies that considered the contribution of land subsidence to flooding hazard, we recall Bondesan et al. (1995), who applied 66 cm of sea-level rise for the North Adriatic coast of Italy. While Karim and Mimura (2011) estimated the impact of sea-level rise and flooding induced by cyclones storms, in western Bangladesh; in North America, Strauss et al. (2012) highlighted that half West and East coasts of the U.S. are at high or very high risk of sea-level rise. Using a tidally adjusted approach, they estimated that 3.7 million of people living in 2150 coastal cities placed at about 1 m above sea level have some degree of exposure to sea flooding. Rosenzweig et al. (2011) realized detailed flooding maps for New York and the surrounding coastal areas, for minimum and maximum values of expected sea-level rise for 2100, at 22 and 58 cm, respectively (Church et al., 2008). These results were used to propose an adaptation plan that included a storm surge barrier placed in the near offshore, facing the coast of New York City, although vertical land movements have not been considered in the relative sea level rise scenarios.

In the Mediterranean, many coasts are presently submerging or expected to flood in consequence of sea-level rise, storm surge and tsunamis, as inferred from seismic, geodetic, geological and archaeological evidence (Anzidei et al., 2014). The most critical areas include the coasts of Turkey (Anzidei et al., 2011), the northern Adriatic (Antonioli et al., 2007; Lambeck et al., 2011), the Aeolian islands (Anzidei et al., 2016), the coast of central Italy (Aucelli et al., 2016) and eastern Morocco (Snoussi et al., 2008). For the Italian region, Lambeck et al. (2011) provided a sea-level rise projection for 2100, using an extensive database that included the isostatic and tectonic contribution to the IPCC, 2007 (https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4_wg2_full_report.pdf) and Rahmstorf (2007) climatic models. Results have shown that, assuming a minimum of 18 cm and a maximum of 1400 mm of sea-level rise projections for 2100, respectively, 33 coastal zones may become at risk of marine inundation (Fig. 2).

In this research we provide a high resolution upgrade to estimate the expected effects of sea-level rise by 2100 for selected zones of the Italian coasts. Our scenarios are based on the last IPCC report (Church et al., 2013) and Rahmstorf (2007) projections, high-resolution DTMs and rates of vertical land movements, including the glacio-hydro-isostatic model of Lambeck et al. (2011).

We focused on four coastal plains (the wide North Adriatic coastal plain, Taranto in Apulia, Cagliari and Oristano in Sardinia Fig. 2) that cover a wide spectrum of vertical tectonic phenomena, being located in stable (Sardinia), slightly uplifting (Apulia) and subsiding (North Adriatic) tectonic settings, respectively. These coastal plains are highly sensitive to sea-level rise in terms of dynamic geomorphological response, landscape modifications and rapid environmental changes.

Table 1
Predicted sea level scenario for 2100, from Kopp et al. (2016) all values are computed without vertical movements.

Scenario	IPCC 2013 min max mm	Kopp et al., 2016 min max mm	Mengel et al., 2016 min max mm	Horton et al., 2014 min max mm	Rahmstorf 2007 Scenario mm
RCP 2.6	280–600	240–610	280–560	250–700	–
RCP 4.5	350–700	330–850	370–770	n.a.	–
RCP 6.0	390–730	–	–	–	
RCP 8.5	530–970	520–1310	570–1310	500–1500	500–1400