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Tidal changes in a heavily modified coastal wetland

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ABSTRACT

Changes in tidal regime in the heavily modified Venice Lagoon, Italy, are investigated using long-term observations and numerical modelling. The amplitudes of the major tidal constituents exhibit a significant increase over the last century. Analysis of tide gauge data in the adjacent Adriatic Sea reveals that these changes could be only partially attributed to the rise of the mean sea level. Numerical experiments confirm that natural and anthropogenic morphological changes are responsible for the alteration of tidal regime inside the lagoon. Temporal and spatial changes in tidal asymmetry highlight the complex impacts of human interventions on tidal changes and long-term morphodynamics. Our results suggest that over time the lagoon became more and more an ebb-dominant system. Moreover, in Venice the tidal modulations are significantly impacting the frequency with which high water level thresholds are exceeded. Occurrence of flooding events is therefore influenced by sea level rise and secondarily by the increase in amplitude of principal tidal waves.

1. Introduction

Changes in tidal regime have been reported for several parts of the world by several authors (see Woodworth (2010) and references therein). Along the coast, regional effects, like seasonal ocean stratification (Müller, 2012) and morphological modifications (Picado et al., 2010; Song et al., 2013; Pelling et al., 2013), can strongly influence the amplitudes and phases of tide. This is especially true for tidal wetlands which are dynamic systems in an ephemeral equilibrium.

Coastal wetlands are highly valuable features of the Mediterranean Sea, with crucial ecological, historical, economical and social relevance (Pérez-Ruzafa et al., 2011). Hydromorphological responses of coastal wetlands to natural processes and human interventions are extremely complex. Use of coastal wetlands may change the internal balance between accretion and erosion, either by accelerating the rate of sediment infill or by inducing erosion (Duck and da Silva, 2012).

Venice Lagoon (Fig. 1), with its century-long (millennium) tradition of human modifications, is an ideal case for studying changes in the tidal regime. Starting from the 10th century, Venetians have modified the lagoon in an attempt to preserve Venice's economic interests and defence (Ravera, 2000). Tidal flow through the inlets ensures water exchange with the North Adriatic Sea (Gačić et al., 2004), flushing the lagoon from pollutants and supplying oxygen and nutrients (Ravera, 2000). Moreover, tidal forcing is one of the main factors that influences the long-term morphological evolution of this coastal system (Ferrarin et al., 2008).

The city of Venice is located in the centre of the lagoon and is composed of more than a hundred islands linked by bridges. The elevation of these islands is extremely low, subjecting them to flooding during storms, which in turn threatens the unique cultural heritage of this city and affects its everyday life. It is therefore of crucial importance for the management of this environment to understand the factors affecting tidal propagation and their eventual impacts on extreme high water levels.

The aims of the research reported here were to (i) identify tidal changes in Venice Lagoon over the last 70 years due to natural and anthropogenic factors (Section 4.1), (ii) examine changes in tidal asymmetry and their relationships with long-term morphodynamic patterns (Section 4.2) and (iii) investigate if the tidal changes exacerbated the extreme high water levels (Section 4.3). The applied methodology comprises of a combination of long-term time-series analysis and numerical modelling (Section 3).

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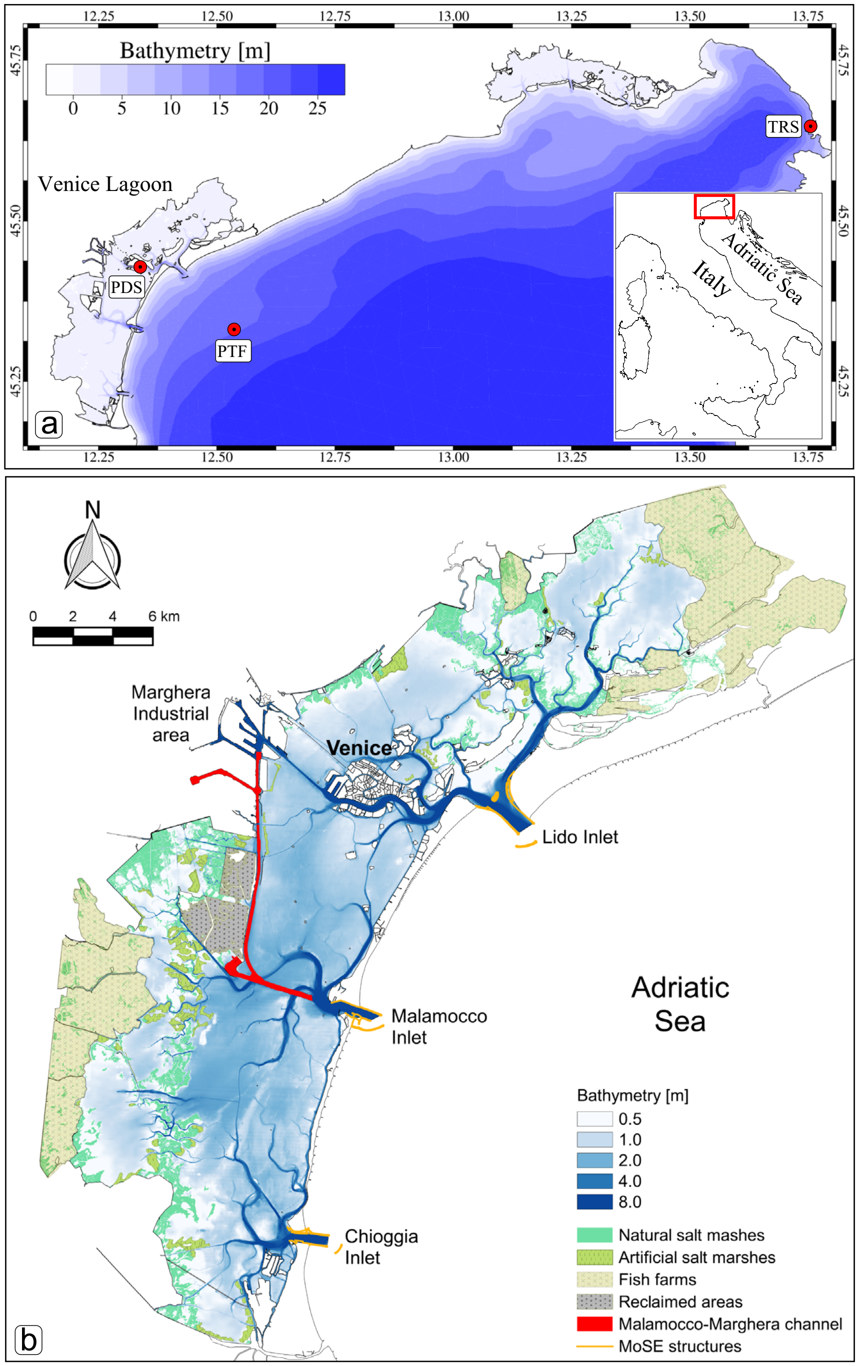

Fig. 1. (a) Bathymetry of the North Adriatic Sea with locations of the considered tide gauges (PDS, Venice - Punta della Salute; TRS, Trieste; PTF, Piattaforma Acqua Alta). (b) Bathymetry of the Venice Lagoon with major morphological types (channels and salt marshes) and modifications since the 1930s (artificial salt marshes, fish farms, reclaimed areas, Malamocco-Marghera channel and MoSE structures at the inlets).

2. Study site

Venice Lagoon (Fig. 1) is the largest Mediterranean lagoon (area of 500 km^2). It is characterised by a complex network of channels ranging in depth from a few cm of tidal creeks to more than 15 m of larger tidal collectors. The drainage system cuts across a large extension of shallow water (with an average depth of about 1 m), mud flats and salt marshes. Three inlets, Lido, Malamocco and Chioggia, allow water exchanges with the open sea. They are from 500 to 1000 m wide and up to 25 m deep.

The main historical human interventions in Venice Lagoon were the diversion outside the lagoon of its most important tributaries (from the XV to the XVII century), the protection of the barrier islands from storm waves with seawalls (1740–1782) and the construction of jetties at the inlets (1808–1927) (Ravera, 2000; Madricardo and Donnici, 2014). During the last century, the lagoon was subjected to several man-made transformations, the most significant of which was: separation of fish farming areas from the rest of the lagoon (1928); removal of a vast extents of salt marsh areas (1927–1960) for the construction of Porto Marghera industrial zone, Venice airport, and the urban development of the city of Mestre; increased subsidence due to groundwater and natural gas extraction (9 cm from 1930 to 1970); dredging of the Malamocco-Marghera navigation channel in the central part of the