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Discussion on sea level fluctuations along the Adriatic coasts coupling to climate indices forced by solar activity: Insights into the future of Venice

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Abstract

The North Atlantic Oscillation (NAO), which is a dominant circulation pattern in Northern Hemisphere winter, is known to affect sea-level variability in the Mediterranean Sea mainly through the hydrostatic response of water masses to pressure anomalies and changes in evaporation/precipitation budgets. In this study the influence of the NAO on sea levels along the Adriatic coasts is re-assessed in the attempt to uncover the potential causes of the observed high sensitivity of the northern basin to NAO fluctuations. The investigation is focused on the role of the NAO as forcing factor of the winds blowing in the area and of the freshwaters input from the Po River, both of which influence the hydrodynamics of the Northern Adriatic. In addition, some insights into the future of Venice are discussed on the basis of the hypothesis that NAO phases are modulated by the varying solar activity through the intensity of the Earth's geomagnetic activity.

Keywords: Venice; Adriatic Sea; sea levels; NAO; Po River; solar forcing

1. Introduction

Climate changes impact coastal zones in many ways, including changes in water levels, wave climates and in the magnitude of storm surges. The rise in the global mean sea level, which results from thermal expansion of upper ocean waters and increased melting of glaciers and ice caps, is indexed as the primary influence for water level changes along marine coasts (Church et al., 2001). However, from an impact perspective it is local changes in sea levels that are important, and these can differ significantly from global changes.

The Venice lagoon (Italy), which is situated along a low-lying coast in the Northern Adriatic (see Fig. 1) and is the largest Mediterranean lagoon, is an emblematic case of local features affecting coastal vulnerability. The most debated symptom of the vulnerability of Venice is the periodic 'acqua alta' phenomenon (excessive high tides with water at flood level) that affects the downtown: in this low-lying area storm surges with comparatively small amplitudes (about 1 m above the mean sea level) can cause flooding and damages to the historical center.

In recent decades an increase of the city's susceptibility to these high tides and flooding events was

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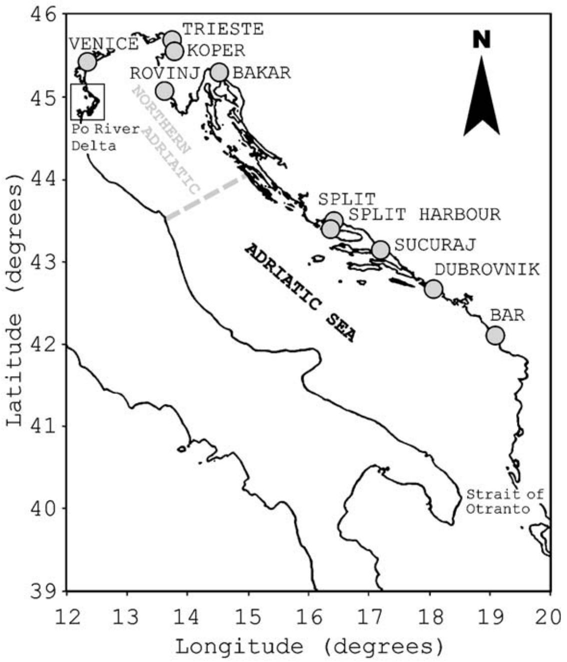

Fig. 1. Map of the Adriatic Sea with the location of the ten tide gauges used in this study; the area of the Po River delta is evidenced.

observed (Canestrelli et al., 2001), as a result of the combined effect of natural and anthropogenic subsidence (Teatini et al., 1995; Carminati et al., 2003), changes in the global mean sea-level (that is expected to lead to progressively higher background water levels in the lagoon) and intervention in the morphology of the lagoon such as the deepening of navigation channels (Pirazzoli and Tomasin, 2002).

The astronomical tidal dynamics in the Adriatic are of mixed diurnal/semidiurnal type (Malačič et al., 2000; Cushman-Roisin and Naimie, 2002; Wakelin and Proctor, 2002) and the tides range between 25 and 80 cm. The highest tides are generated along the northern coasts of the Adriatic because the semidiurnal tides rotate around an amphydromic point in the middle of the basin and diurnal tides propagate from the eastern to the western coast. Nevertheless, astronomical tides alone are still unable to endanger Venice, so that most of the flooding events in the lagoon are the result of severe meteorological conditions (such as a 'Scirocco' windstorm or the passage of a low pressure system) coupled with a high tidal peak. Scirocco, which is a south-easterly wind mostly dominated by synoptic-scale events, couples with the cold katabatic 'Bora' wind to characterize the climate along the eastern coast of the Adriatic from October to January. As a consequence, surges in the Venice lagoon are a typical phenomenon of autumn.

Large-scale patterns of climate variability can therefore affect the interannual variability of sea levels through the aperiodic forcing of meteorological processes. The principal mode of climate variability in the Northern Hemisphere is the Arctic Oscillation (AO) (Thompson et al., 2000), whose regional manifestation is the North Atlantic Oscillation (NAO). The NAO is a fluctuation in the sea level pressure difference between the Arctic and the subtropical Atlantic. It is often defined by an index of normalized, time-averaged pressure difference between stations representing its two centres of action (Hurrell, 1995). NAO anomalies are associated to changes in mean circulation patterns over the North Atlantic and to pronounced shifts in the storm tracks that drive the synoptic eddy activity over the Euro-Mediterranean area (Marshall et al., 2001; Quadrelli et al., 2001). The NAO is associated with other teleconnection patterns such as the East Atlantic–West Russian (EA-WR) (Wallace and Gutzler, 1981) and the Polar-Eurasia (POL) (Barnston and Livezey, 1987).

Tsimplis and Baker (2000) and Tsimplis and Rixen (2002) found a link between the NAO and the sea-level variability in the Mediterranean, due to the combined effect of changes in evaporation/precipitation budgets and hydrostatic response of water masses to atmospheric pressure anomalies. According with Woolf and Tsimplis (2003), the influence of the NAO in the Mediterranean is remarkably homogenous, though the sensitivity is stronger in the Northern Adriatic (defined as the shallow area of the Adriatic Sea lying north of the 100-m isobath).

More recently, Fagherazzi et al. (2005), who investigated the influence of climatic oscillations on the flooding of Venice, found that winter tides are negatively correlated with AO, NAO and EA-WR, and that during the fall season there is mainly a relatively strong dependence between high tides, and the AO and EA-WR, whilst the NAO has only a limited impact.

In addition to the hydrostatic effects and to the upwelling caused by wind stress curl, the NAO may influence sea levels in the Adriatic Sea by modulating the riverine freshwater input through the control of rainfalls in the bordering regions. The Po River is the major contributor of freshwater runoff in the basin and it strongly influences the Northern Adriatic. Ursella and Gačić (2001) observed that during the stratified season sudden increases in Po discharge (pulses) generate waves along the Italian coast, which induce coastal