Modelling wind-wave in the Venice Lagoon from 1611 to present: relationship with salt-marsh lateral erosion rate

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ABSTRACT

Wind-wave attack promote marsh erosion in estuaries and lagoons worldwide, we analysed the spatial distribution of wave power density in the last four centuries and the relationship between incident wave power density and salt-marsh erosion rate.

1 INTRODUCTION

Salt marsh loss is driven by relative sea level rise, land subsidence, ship wakes along the main channels and wind-wave attack along the marsh boundaries. However among these the wind-wave attack is one of the main mechanisms and includes both the removal of small size particles and the sudden detachment of marsh-edge portions [1, 2].

Recent studies have demonstrated the existence of a direct linear relationship between wave power density and salt-marsh lateral retreat on theoretical and empirical grounds [1, 3, 4, 5], less attention has been directed to the temporal evolution of wave power density.

In this work, considering the study case of the Venice Lagoon (IT), we aim at evaluating, through the application of a two-dimensional Wind Wave Tidal Model (WWTM), the effects of wave action on marsh boundaries and how the wind-wave field has changed through time.

To this end, we first analysed the spatial distribution of wave power density during the last four centuries from the 1611 to the present configuration of the Venice Lagoon and then we investigated the relationship between the incident wave power density and salt marsh volumetric erosion rate.

2 MATERIALS AND METHODS

We applied the fully coupled WWTM [6, 7] to six different configurations of the Venice Lagoon (namely 1611, 1810, 1901, 1932, 1970 and 2012). The WWTM describes the hydrodynamic flow field and the wind-wave generation and propagation by solving the 2D shallow water equations and the wave-action conservation equation. The model has been widely tested by comparing model results to hydrodynamic and wind-wave data collected in the Venice Lagoon and others lagoon wordwide [e.g., 7, 8]. The model was forced with a one-year-long record of water levels, wind speeds and directions collected in the Venice Lagoon in 2005, a representative year in terms of wind forcings.

The determination of the hydrodynamics and wind-wave field within the Lagoon allowed us to compute the power density, P, in the entire basin:

$$P = \frac{\gamma c_g H^2}{8} \tag{1}$$

where H is the wave height and c_g the wave group celerity. The wave power density for the six different configurations was averaged over the one-year-long simulations.

In order to obtain a map of the eroding margins we used two sets of aerial photographs, acquired in 1970 and 2010, whose georeferencing and superimposition together with the bathymetric information allowed us to calculate the volumetric erosion rate in the southern portion of the Venice Lagoon. (Fig. 1a).

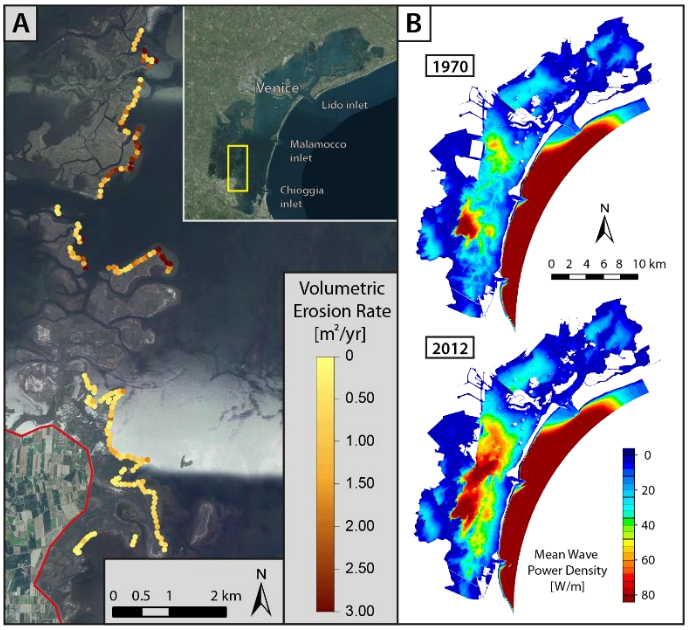

Figure 1. Volumetric erosion rate in the southern portion of the Lagoon (A) and the spatial and temporal variation of the mean power density in 1970 and 2012.

3 RESULTS AND DISCUSSION

Fig. 1b shows two examples (1970 and 2012) of the spatial distribution of the mean wave power density (MWPD) evaluated for all the six configurations of the Venice Lagoon.

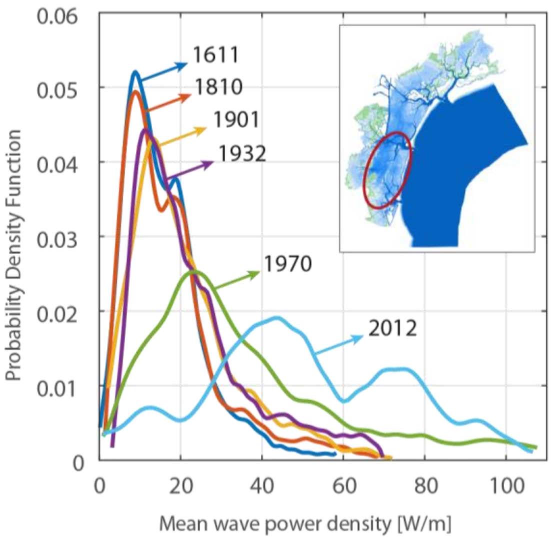

Figure 2. Probability density function of the mean wave power density in the central southern of the lagoon basin.

The probability density functions (Fig. 2) evaluated for the southern portion of the lagoon show that the MWPD increased over the last four centuries due to the evolution of the Lagoon morphology and bathymetry. The power density has not significantly changed from 1611 to 1932. However, in the last century a rapid increase in wave power densities was observed due to the larger depths and fetches that characterize the more recent Lagoon configurations. In particular, in the central-southern part of the Lagoon the wind forcing can easily generate fetch unlimited conditions and the resulting wave field produces higher power densities.

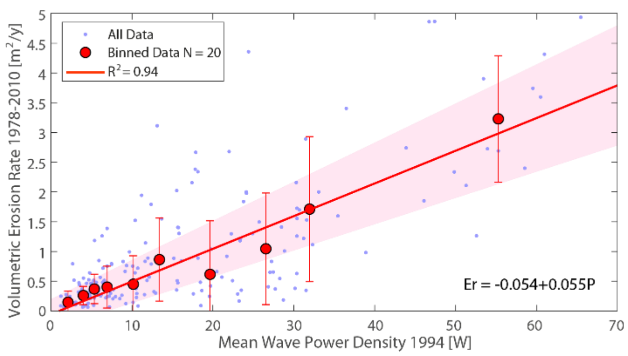

Figure 3. Probability density function of the mean wave power density in the central southern of the lagoon basin. Red circles indicate values obtained by averaging data points over intervals of 20 data of MWPD to emphasize the overall linear trend. The pink area is the uncertainty of the prediction of Er over a range of coefficients with 95% bounds.

The volumetric erosion rate (computed between 1978 and 2010 using the aerial photographs) was associated to the MWPD estimated for the 1994 (R^2= 0.94) by linear interpolation of the 1970 and 2012 wave fields (Fig. 3). The relationship between the erosion rate and the MWPD was observed to be linear. In addition considering the intermediate MWPD of 1994 we are able to accounts for the changes in the bathymetry that occurred between 1970 and 2012.

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