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Critical storm thresholds for significant morphological changes and damage along the Emilia-Romagna coastline, Italy

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ABSTRACT

The definition of storm morphological thresholds along the coast of the Emilia-Romagna Region strictly depends on its configuration and variability. The region is located in northern Italy, facing the Adriatic Sea. The coastline is characterised by very different levels of economic development, ranging from natural zones with dunes to highly developed stretches protected by breakwaters and groynes. The Integrated Coastal Zone Management effort is mainly concentrated on preserving urban areas that generate significant income for the regional economy. Natural areas, while small in comparison to the urbanised zone, are important for environment preservation. Because of such a multiplicity of issues at stake, it was decided to produce two different thresholds: one for the morphological impact on natural sectors and another for inundation and damage to structures along urbanised zones.

The "forcing" component of the threshold definition for natural areas was calculated by summing the effects of surge + tide + waves (run-up elevation) to find the Maximum Water Level (MWL) reached by the sea during one, ten and one-hundred year storm return periods. For urbanised zones, historical storm information was collected starting from the 1960s in order to identify the forcing conditions causing real damages. Each storm was classified in terms of wave height, period, direction and surge level. Morphological information were obtained from Lidar flights performed in 2003 and 2004 and from direct surveys undertaken in September 2008 and February 2009 as part of the monitoring programme for the MICORE Project.

The computed MWL for each return period was then compared to beach elevations along natural areas in order to calculate the Dune Stability Factor (DSF), an index that accounts for the eroded sediment volume above the MWL during a storm. Based on analysis along 41 profile lines at a 500 m spacing, it was found that the 1-in-1 year return period wave height + 1-in-1 year return period surge are able to erode and/or overwash 2/3 of the dunes.

The historical storm hydrodynamic information was used to estimate which wave and surge conditions are able to inundate at least 2/3 of the beach profiles. The MWL was again compared to beach elevations, this time along 63 anthropogenic profiles spaced 500 m apart (or 1/3 of the urbanised coastline). It was found that a wave heights >= 2 m and surge + tide levels >= 0.7 m are able to flood between 18% and 36% of the built-up coast.

The defined thresholds are related to the present coastal characteristics and are not "static", meaning that they are likely to change according to future evolution of the coastline. They are very important because they can be used as thresholds to issue warnings and alert the Civil Protection. Moreover they are the first thresholds defined for the Emilia-Romagna coastline and will be used as starting values to generate "dynamic" thresholds based on numerical model predictions of morphological change for a given wave and surge level.

1. Introduction

The evaluation of inundation risk generated by marine storm events along coastal areas is becoming increasingly important worldwide in terms of coastal planning and civil protection. In the context of climate change, governments of many countries around the world are facing unsustainable costs in restoring areas affected by extreme storms (Pompe and Rinehart, 2008) as they have to cope

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with the consequences of environmental and social disasters (e.g. Hurricane Katrina, New Orleans).

The EU Directive (2007/60/EC) states that each EU country will by 2015 have to produce regulations and laws to manage natural risks (e.g. landslides, river floods, coastal erosion and inundation) that include the vulnerability of coastal areas. EU countries will have to create new civil protection schemes able to both counteract climate change and prevent risky conditions for the population, while at the same time preserving human and natural assets. An historical "storm" database is one of the instruments indicated inside the EU Directive as a means of assessing the areas that are most frequently impacted by storms. Regarding Italy, there are already historical databases on seismic, hydrogeological and hydraulic events (Cipolla et al., 1999; Guzzetti, 2000; Guzzetti et al., 2002). The collection and analysis of information of historical marine storms in Italy however has never been conducted.

As a result of the increasing interest worldwide in environmental issues and in the significant effects of storms along coastlines, a specific European project MICORE (Morphological Impact and COastal Risks induced by Extreme storm events) has been financed within the VII Framework Programme (www.micore.eu). MICORE intends to evaluate the risks from coastal erosion and flooding, with its final goal being to create warning systems to prevent disasters for the population living and working along coastlines and to preserve human and natural assets within close proximity to the sea. This approach is no longer unique to Europe — authorities on the west coast of the USA are developing comparable warning systems based on ensembles of regional wave models and local morphological models (Barnard et al., 2009).

In order to produce reliable warning systems and optimise their speed in obtaining coastal erosion forecasts, critical thresholds for the forcing agents (e.g. waves, current, tides) must first be identified and the factors specific to the particular coastal segment (e.g. wave exposure, sedimentological/geomorphological characteristics, presence of coastal structures etc.) accounted for. Most of the work present in the literature deals with the impact of hurricanes, for recent papers see Wang et al. (2006), Robertson et al. (2007), Stockdon et al. (2007), Houser and Hamilton (2009) and Plant et al. (2010). Notable exceptions that concentrate on storms are the "beach erosion potential" of Zhang et al. (2001) and the seminal work of Sallenger (2000) in producing a storm impact scale specific for dunes and barrier-islands. On a strategic level, future coastal planning will have to take into account the occurrence of flood events and erosion, so that many authors have mapped maximum run-up levels which can be useful to delimit set-back lines (Benavente et al., 2006; Ferreira et al., 2006; Ciavola et al., 2007a).

The application of storm indexes to highly developed Mediterranean coastlines remains very limited and largely confined to the Western Mediterranean (Mendoza and Jimenez, 2004, 2006). Recently Jiménez et al. (2009) concluded that both Mediterranean and northern Adriatic beaches have common vulnerabilities, a result of the low beachface gradients and exposure to storm inundation in both regions. Despite the high level of occupation of Italian beaches, the issue of storm damage to developed coastlines has been neglected.

The definition of storm thresholds at a regional scale for the Emilia-Romagna coast must account for its peculiar configuration and level of human development. The coastline is characterised by very different levels of modification, ranging from natural zones with dunes to highly developed stretches of intense development. These developed stretches

Fig. 1. (A) View of the beach in the Rimini area, Emilia Romagna Region. To note the intense urbanisation and occupation of the beach by tourist activities during the summer season (from the internet: http://xoomer.virgilio.it/hotel-rimini/Vacanze-Rimini-Riccione-Estate.jpg); (B) example of artificial sand embankment built by beach users to serve as flood protection (November 2008); (C) the sand is bulldozed back to the lower beach at the beginning of the bathing season (May 2008). This creates unnatural beach slopes.