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Invited review

Dynamic interactions between coastal storms and salt marshes: A review

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ABSTRACT

This manuscript reviews the progresses made in the understanding of the dynamic interactions between coastal storms and salt marshes, including the dissipation of extreme water levels and wind waves across marsh surfaces, the geomorphic impact of storms on salt marshes, the preservation of hurricanes signals and deposits into the sedimentary records, and the importance of storms for the long term survival of salt marshes to sea level rise. A review of weaknesses, and strengths of coastal defences incorporating the use of salt marshes including natural, and hybrid infrastructures in comparison to standard built solutions is then presented.

Salt marshes are effective in dissipating wave energy, and storm surges, especially when the marsh is highly elevated, and continuous. This buffering action reduces for storms lasting more than one day. Storm surge attenuation rates range from 1.7 to 25 cm/km depending on marsh and storms characteristics. In terms of vegetation properties, the more flexible stems tend to flatten during powerful storms, and to dissipate less energy but they are also more resilient to structural damage, and their flattening helps to protect the marsh surface from erosion, while stiff plants tend to break, and could increase the turbulence level and the scour. From a morphological point of view, salt marshes are generally able to withstand violent storms without collapsing, and violent storms are responsible for only a small portion of the long term marsh erosion.

Our considerations highlight the necessity to focus on the *indirect* long term impact that large storms exerts on the whole marsh complex rather than on sole after-storm periods. The morphological consequences of storms, even if not dramatic, might in fact influence the response of the system to normal weather conditions during following inter-storm periods. For instance, storms can cause tidal flats deepening which in turn promotes wave energy propagation, and exerts a long term detrimental effect for marsh boundaries even during calm weather. On the other hand, when a violent storm causes substantial erosion but sediments are redistributed across nearby areas, the long term impact might not be as severe as if sediments were permanently lost from the system, and the salt marsh could easily recover to the initial state.

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1. Introduction

1.1. Changing storm activity

Many coastal areas are experiencing a change in both extreme and mean storm conditions as a consequence of a changing climate (e.g. Zhang et al., 2000; Webster et al., 2005; Bacmeister et al., 2016). For example, according to the Intergovernmental Panel on Climate Change (e.g. Meehl et al., 2007; Pachauri et al., 2014) it is virtually certain (99–100% probability) that the intensity of cyclone activity has increased in the North Atlantic since 1970, even if there is low confidence that the long term changes are robust. In terms of extremes, it is likely (66–100% probability) that extreme sea levels such as the ones experienced during storm surges have increased since 1970 on a global average. The latter trend has been mainly attributed to an increase in mean sea level even if more studies are necessary to fully separate the effect of global mean sea level rise from the effects of more local modifications to the coastal systems (e.g. Pachauri et al., 2014).

Evaluations of future increases in storms and hurricanes activity are complex, and with large uncertainties. For example, a statistical correlation has been found between the power dissipation index of hurricanes (i.e. an index combining intensity, frequency and duration of hurricanes) and Atlantic Sea Surface Temperature (SST) (e.g. Vecchi et al., 2008). Based on this relationship and taking into account hurricanes activity since 1950, as well as future SST projection, there should be a 300% increase in hurricanes activity by the late 21st century. However, a statistical correlation has been also found between the power dissipation index and the Atlantic sea surface temperature relative to the Tropical mean sea temperature; if the latter relationship is considered, the projected change in hurricane activity by 2100 would be around 25%, which is modest with respect to the estimation above (Vecchi et al., 2008). Projections about the future of hurricanes activity might get even more complicated when looking at the longer term. Mean air temperature, Atlantic SST and the unadjusted hurricanes count all show a marked increase since the late 1800; however, when the raw hurricane count is adjusted for the storms which were not counted during the pre-satellite era due to technology, and ship track density limitations, no significant increase is observed (e.g. Vecchi et al., 2008).

Generally, according to the IPCC (Meehl et al., 2007), it is likely that there will be an increase in peak wind intensities, and near storm precipitations in future cyclones, with an increased occurrence of violent storms in spite of the likely decrease in the total number of storm.

Fig. 1 illustrates model results in relation to the 21st century changes in Emmanuel's (1995) wind maximum potential intensity (MPI_V), the increase of which is generally associated with an increase in storms activity and intensity (Vecchi and Soden, 2007). Results refer to the IPCC-AR4 Scenario A1B for the period from June–November. The MPIv index increases over most of the northern hemisphere and tropical zone of the southern hemisphere, but there are also large areas particularly in the southern hemisphere indicating decreases. The regions where the MPI_V decreases are associated with a relative minimum in SST (e.g. Sobel et al., 2002).

On a regional scale, by using a barotropic type surge model and global conditions representative of the IPCC A2 SRES scenarios between 1961–1990 and 2071–2100, it was shown that storm surge extremes may significantly increase along most of the North Sea coast towards the end of this century (Woth et al., 2006). Ensemble simulation runs using Regional Climate Models for various locations in the United States (Jiang et al., 2016) also support the hypothesis of variations in future storm pattern; specifically, they predict shorter storm durations, longer inter-storms periods, and higher storms intensities.

In spite of the abundance of studies in relation to climatic projections and past trends, many challenges are still present, especially for the monitoring of coastal zones, due to limitations of some current modelling and field practice frameworks. For instance, the retrieval of waves and winds in the coastal areas is not yet as mature as sea level measurements, and the development of a wider applicability of altimetry techniques could be relevant for the simultaneous monitoring of wave height, wind speed and sea levels. In this context, Liu et al., 2012 showed the potential usefulness of the 1-Hz along-track altimetry data for the description of shelf areas, and Passaro et al., 2015 showed that estimations of wave height form ALES (Adaptive Leading Edge Subwaveform retracker) were better correlated to buoy data than processed products. Such techniques could be coupled to standard modelling, and field data approach to build a more comprehensive and homogeneous database for the study of these coastal ecosystems.

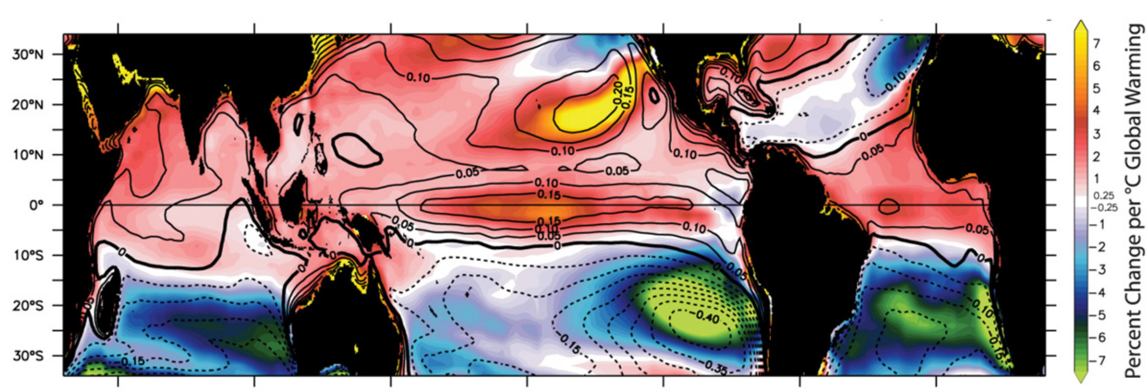

Fig. 1. Percentage changes in Emmanuel's (1995) wind maximum potential intensity (MPI_V) per degree increase in global surface air temperature. Large values of MPIv values are generally associate to enhanced tropical storms activity, and intensity.
(Adapted from Vecchi and Soden, 2007.)