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Occurrence of energetic extreme oceanic events in the Colombian Caribbean coasts and some approaches to assess their impact on ecosystems

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ABSTRACT

Above-normal meteorological and oceanographic conditions that generate damage on coastal ecosystems and associated human communities are called extreme oceanic events. Accurate data are needed to predict their occurrence and to understand their effects. We analyzed available data from four localities in the Colombian Caribbean to study the effect of wave-related extreme events (hurricanes, surges) in three coastal ecosystems, i.e., mangroves, beaches, and reefs. Three localities were continental (Portete Bay mangroves at the Guajira Peninsula, Bocagrande Public Beach at Cartagena City, Tayrona Natural Park reefs near Santa Marta City), and one was oceanic (Old Providence Island reefs in the San Andres and Old Providence Archipelago, SW Caribbean). We gathered data on ocean surface winds (1978–2011) for the four locations, then modeled significant wave heights, then identified extreme events, and finally tried to identify effects on the ecosystems, directly or from published literature. Wave-related extreme surges were also compiled from Colombian press news (1970–2008). Modeled wave maximums (>5 m significant wave height) and press-reported events coincided with hurricanes, extreme dry season, mid-summer drought and northern hemisphere winter cold fronts, with neither a relationship to ENSO events, nor a temporal trend of increase, excepting Portete Bay, with a marked increase after 1995. Changes in Portete Bay mangroves were analyzed from aerial photographs before and after Tropical Storm Cesar (1996). In the 38 years before Cesar there was mangrove inland colonization, with some loss associated to beach erosion, while during the 8 years following the storm there were localized retreats and important changes in vegetation composition related to the falling of large trees and subsequent recolonization by species that are faster colonizers, and changes in soil composition brought about by inundation. Cartagena's Bocagrande Beach was followed between 2009 and 2011 by video, and two events of strong retreat were observed in 2010, one associated to the arriving of cold fronts in March, and the other to the passing of Hurricane Tomas in November–December. Together, they produced >90 m beach retreat. We identified modeled wave maximums during Hurricane Lenny (1999) at Santa Marta city, and hurricane Beta (2005) at Old Providence Island, both of which, according to the literature, had transient minor effects on local coral reefs, which had been more affected by diseases and bleaching.

1. Introduction

An extreme oceanic event occurs when the meteorological and oceanographic conditions exceed their normal levels (typically, and depending on the variable, the 90th, 95th or 99th percentile, from a probability density function estimated from existing observations); it is not predictable and has an impact on marine ecosystems and on the coast. Among the most recognized events are sea temperature rises above the seasonal maximums, sediment outpourings, storms, tropical cyclones (called hurricanes in the Atlantic), and storm surges. Long-term climatic conditions (from El Niño, Southern Oscillation, ENSO, to global climate change) are linked to the frequency and intensity of extreme oceanic events, but in some regions this relationship is not fully understood (IPCC, 2012).

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The nature and severity of the impacts of extreme events on the ecosystems depend not only on the events themselves, but also on the exposure and vulnerability of the ecosystems. In turn, the events affect future ecosystem vulnerability by changing their resilience and adaptation capacity (IPCC, 2012). Coastal ecosystems such as reefs, sea grass beds, mangroves, and beaches, are directly exposed to the impacts of extreme oceanic events. Although they may have a degree of adaptation to them, with current human pressure and global climate change they may be seriously threatened (Hughes, 1994; Wilkinson, 2008). Evidence for the change in the extremes in global and local climate is available only after about 1950. Thus, confidence in observed trends depends on the amount and quality of data, and on the availability of studies analyzing them, which vary greatly for different regions and types of events.

To face the social and ecological challenge that involves new trends in extremes over a region, it is necessary to understand the association between physical processes (threats) and ecosystem responses (vulnerability). Identifying and understanding the extremes of physical processes are a complex task, requiring knowledge on the average conditions and observations lasting long enough to record events with large recurrence times. Similarly, ecosystems are complex and in order to understand their responses and vulnerability, it is also required to know their average behavior. Furthermore, knowledge about the characteristics and impact on marine ecosystems of one forcing is not enough; it is necessary to address synergistic effects (The MerMex Group, 2011).

In an attempt to improve the understanding of the energetic extreme oceanic events and their impact on the ecosystems, this paper illustrates some cases of ecosystems affected by storm surges and hurricanes in the Colombian Caribbean at different timescales. It begins with a brief overview of extreme oceanic events and their impacts on mangroves, beaches, and reefs. Then, an analysis of the occurrence of physical extremes over the Colombian Basin is presented. Finally, their possible influence on the ecosystems is examined in four locations where some evidence is available. Three continental and one oceanic location were studied; in each, a particular ecosystem where data are available was examined. Continental: mangroves in Portete Bay in La Guajira Peninsula, beaches in Cartagena City, and reefs at Tayrona National Natural Park near de city of Santa Marta. For the oceanic location, the reefs of Old Providence in the Colombian San Andres Archipelago in the SW Caribbean were chosen (Fig. 1). Some ecological cases (mangroves, beaches) contain new evidences and data, but others (reefs) were taken from published information. Each case begins with a short area description, followed by an explanation of the methodology, and ends with results and discussion. Final remarks and recommendations are made in the conclusions section.

2. Overview of extreme oceanic events and impact on coastal ecosystems

For the near future, a considerable increase in the frequency and magnitude of weather extremes has been predicted over a broad range of ecosystems. In particular, the maximum wind speed, the intensity and the duration of hurricanes have increased during the last few decades (Jentsch and Beierkuhnlein, 2008; Webster et al., 2005; Emanuel, 2005).

In addition, Webster et al. (2005) found no global trend in the total number of tropical storms and hurricanes between 1970 and 2004. Only the North Atlantic showed a statistically significant increase in hurricanes, which started in 1995. However, they found that the strongest hurricanes (categories 4 and 5) have almost doubled in number and proportion in all of oceanic basins in the last decade compared to the 1970s. For the Caribbean Sea, this behavior has been reported by Montoya (2013), who showed an important trend in the number of Category 4 and 5 hurricanes (+4.2 hurricanes/century) for the last decades (1979–2011). Nevertheless, this increase was not accompanied by an increase in the intensity of the most intense hurricanes: The maximum intensity has remained static over the past 35 years.

However, an index of the potential destructiveness of tropical cyclones based on the total dissipation of power integrated over its lifetime (Emanuel, 2005) has increased markedly since the mid-1970s. The record of net cyclone power dissipation is highly correlated with tropical sea surface temperature (SST), following multi-decadal oscillations in the North Atlantic and North Pacific, and reflecting global warming. But only part of the observed increase in tropical cyclone power dissipation is directly due to increased SSTs; the rest can be explained by changes in other factors such as vertical wind shear or temperature distribution of the upper ocean. There is some indication that sub-surface temperatures have also been increasing, thereby reducing the negative feedback from storm-induced mixing (Emanuel, 2005).

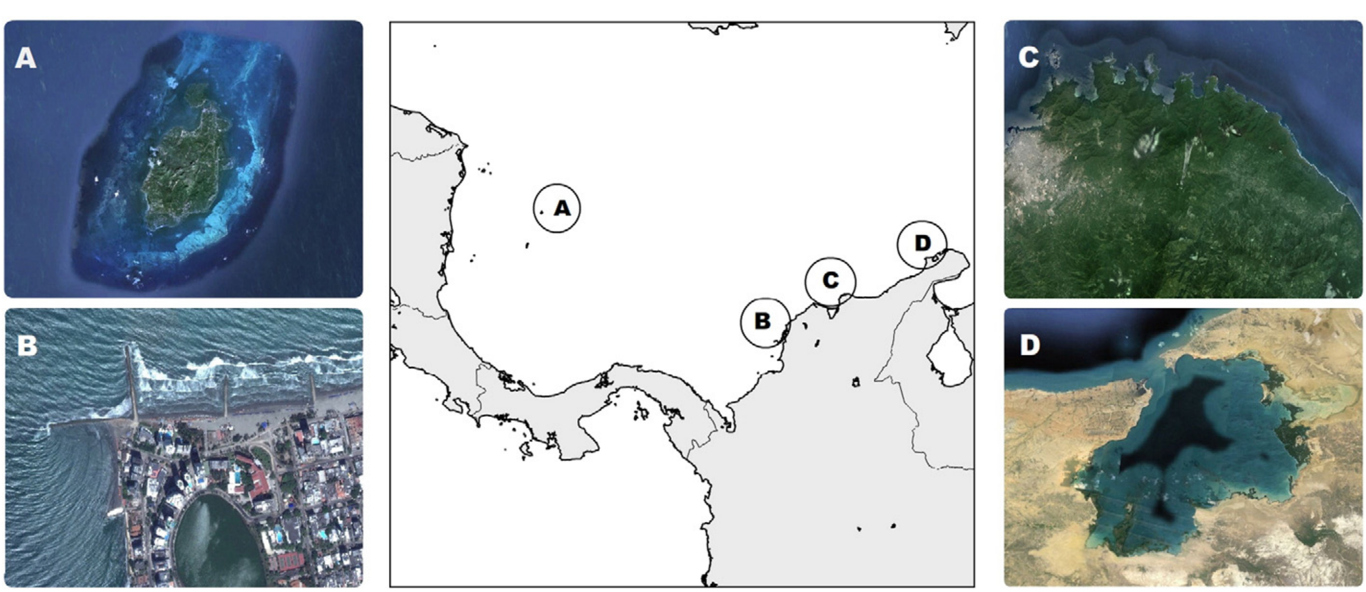

Fig. 1. Location of the cases presented. A: San Andres and Old Providence Archipelago reefs in the SW Caribbean (Old Providence Island, PR). B: Cartagena City beaches (Bocagrande, BG). C: Santa Marta area reefs (Tayrona National Natural Park, TY). D. Guajira Peninsula mangroves (Portete Bay, PO).