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Sea level rise sedimentary record and organic carbon fluxes in a low-lying tropical coastal ecosystem

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ABSTRACT

Sea level rise, one of the most evident effects of recent climate change, is already impacting coastal ecosystems. Because of its low relief, population increase and economic development during the last century, the Celestun lagoon is highly vulnerable to global change, including sea level rise. Here, we study a sediment core from a tropical saltmarsh to evaluate the impact of sea level rise on sediment accretion and carbon fluxes. Some geochemical indicators in a ^{210}Pb dated sediment core showed clear signals of marine influence. This was reflected on increased accretion rates, from 0.3 ± 0.1 mm yr^{-1} in $\approx$ 1941 to 2.9 ± 1.2 mm yr^{-1} in 2012. These accretion rates were similar to eustatic sea level rise, and mean acceleration ranged from 0.037–0.22 mm yr^{-2}, implying a SLR by 2100 ranging from 14 to 86 cm. The one-century (1917–2013) organic carbon stock in sediments was calculated to be 10.1 ± 0.2 Mg C ha^{-1}. During the same period, the organic carbon flux, corrected for organic carbon degradation, increased from 7 ± 3 g C m^{-2} yr^{-1} to 73 ± 26 g C m^{-2} yr^{-1}, attributed to the impact of sea level rise in this ecosystem. This work shows that tropical saltmarshes may provide useful information on sea level rise, and the presented methodology may be used where instrumental records do not exist or they are too short.

1. Introduction

Sea level rise is threatening coastal ecosystems, reducing ecosystem services (e.g. storm protection, niche for species larval stage) and may, in the long term, cause profound socio-economic changes (SLR; Stocker et al., 2013). Low-lying coastal ecosystems are the most vulnerable ones to recent SLR. The Ría Celestún (Celestun coastal lagoon, Gulf of Mexico) is located in the northwestern Yucatan peninsula and encompasses a large diversity of ecosystems and species, some of which are endangered. It is inhabited by almost 7000 people, > 25% living in extreme poverty (SEDESOL, 2016). The main economic activities in the area are fishing, salt extraction and tourism (UNESCO, 2016). The maximum altitude of the Celestun Biosphere Reserve is only 3 m above local mean sea level, so it is highly vulnerable to SLR and extreme climatic events, such as tropical storms and hurricanes.

Although recent eustatic SLR, mainly caused by continental ice melting and seawater thermal expansion, is rather well known and thoroughly studied, specific ecosystem and socio-economic impacts will

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be caused by local SLR, i.e. eustatic SLR corrected for vertical movements of the earth's crust and by long-term changes of atmospheric pressure, ocean currents and temperature (e.g. Nicholls and Cazenave, 2010; Wu et al., 2010).Therefore, in order to propose scientifically sound adaptation and mitigation strategies, long-term sea level time series are needed. However, for most of the world's coastal regions these are inexistent, too short or too sparse to obtain sound information. Near the Celestun coastal lagoon (90 km NE), the Servicio Mareográfico Nacional (Universidad Nacional Autónoma de México) manages a tide gauge in Progreso de Castro (Yucatan State), which has provided a rather continuous time series of tidal elevation during the period 1946–1985, partial records during 1994, and the continuous record was reestablished in 2012 (SMN, 2017). For the period 1953–1992, the estimated SLR rate in Progreso is 2.5 ± 1.2 mm yr^{-1} (Zavala-Hidalgo et al., 2010). Recently, eustatic SLR rate is estimated to be 2.8 ± 0.8 mm yr^{-1} during the period 1993–2009 (Church and White, 2011).

In the absence of long term tide gauge records, the only option to reconstruct the SLR trends within the past century may be ^{210}Pb dated sediment cores from coastal ecosystems, under the assumption that, to be preserved, the accretion rates in these environments are at least equivalent to the SLR elevation. Tropical saltmarshes (locally known as *marismas*) are usually found along semi-sheltered low-energy coastlines, protected from the open ocean, located behind the mangrove fringe in the highest topographic position within the tidal range, so they are intermittently inundated by medium to high tides. High evaporation and relatively infrequent flooding favor the formation of hypersaline soils that can be colonized by halophyte “glassworts”, vegetation (i.e. *Batis maritima* and *Salicornia pacifica*) that can tolerate inundation with seawater and high soil salinity (Costa et al., 2009; Ruiz-Fernández et al., 2016) or remain non-vegetated. When sediment supply is sufficient, saltmarshes are able to keep pace with SLR (Nolte et al., 2013), so the sedimentary record can provide useful information on local SLR (e.g. Lynch et al., 1989; Parkinson et al., 1994; Sanders et al., 2010a; Ruiz-Fernández et al., 2016).

In this work, we study the geochemical signals of SLR in a ^{210}Pb dated sediment core collected from a tropical saltmarsh in Celestun, a low-lying coastal lagoon in the southern Gulf of Mexico, and compare sediment accretion rates with eustatic SLR and with a nearby tide gauge station. It is expected that this information will help to better protect and plan sound adaptation and mitigation strategies for this important protected area.

2. Methods

2.1. Study site

The Yucatan Peninsula is a large karstic platform with mangrove forests and wetlands along its coastline. About 80% of the soils are shallow (leptosols; Bautista-Zúñiga et al., 2003) and lie on a highly permeable substrate, dominated by carbonates. Due to intense weathering, these soils are rich in insoluble oxides (Herbilion and Nahon, 1988).

The Celestun coastal lagoon (Fig. 1) is located on the northwestern side of the peninsula (20° 45′ N; 90° 23′ W). Ground water discharge to the lagoon induces a salinity and temperature gradient due to mixing with Gulf of Mexico seawater (Perry et al., 2009). The northern part of the Yucatan Peninsula is under a tropical wet/dry “AW” climate, according to the Köppen classification (Wilson, 1980). The mean annual rainfall is 760 mm, and climate shifts from warm medium-dry from March until May, to rainy from June to October, and to windy (strong winds locally known as “nortes”) from November to February. The Celestun coastal lagoon is narrow, approximately 22 km long and 2 km wide at its widest point. The vegetation is dominated by *Rhizophora mangle*, *Avicennia germinans* and *Laguncularia racemose* (Stalker et al., 2014).

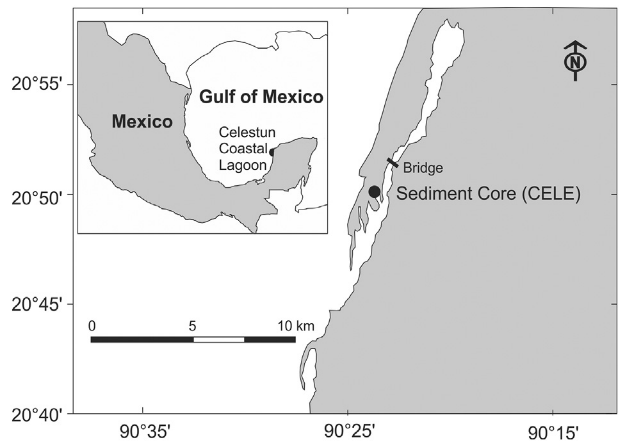

Fig. 1. Location of the Celestun coastal lagoon and location of the CELE sediment core.

The coastal plain in the Celestun region is bounded by the Ticul Fault, a karstic structure composed primarily of Early and Late Tertiary limestone platforms with a band of Quaternary beach and lagoon deposits (Pope et al., 1993). The aquifer is mostly unconfined, except near the coast where an impermeable caliche has formed near the fresh water discharge, which has migrated inland with rising Holocene sea level (Pope and Duller, 1989).

2.2. Sampling and analysis

Sampling was carried out in a non-vegetated area of a tropical saltmarsh, where a clear tidal influence was observed (Fig. 1). The sampling site height and location were measured with a Leica GS10 receiver and a Leica AS10 geodesic antenna, with a nominal vertical precision of 3.5 mm. Levelling was achieved with a Leica DNA03 digital level. The orthometric height was 0.302 m, i.e. close to the mean sea level.

The sediment core was collected on April 25th 2013 with a split push corer (PVC tube, inner diameter = 10 cm, length = 50 cm) and showed no compression. It was cut onsite into 1 cm sections, and samples were stored in air tight and acid cleaned plastic containers. Back to the laboratory, samples were freeze-dried. For grain size analysis (Table 1), samples were sieved through a 63 μm mesh, digested with 30% H_2O_2 and analyzed by laser diffraction with a Malvern Mastersizer 2000. The classifications reported were 0.1–2 μm (clay), 2–63 μm (silt) and 63–1000 μm (sand). Mineralogical analysis (halite and gypsum) was performed with a Siemens D5000 X-Ray diffractometer on a well-mixed sample.

Section aliquots were carefully ground with an agate mortar. Elemental composition was determined by X-ray fluorescence (XRF) spectrometry with a SPECTRO Xepos-3 system, calibrated with 34 reference materials. Analytical quality was monitored through the analysis of certified reference materials (IAEA-158 and PACS2). For OC analysis, inorganic carbon was removed by carefully adding by drops 5 mL of a HCl 1 N solution, which was left to react over two days. Acid was removed by diluting the sample to 40 mL with MilliQ water, centrifuged during 15 min at 3500 rpm, frozen for one day and freeze-dried for three days. The washing procedure was repeated until acid was fully removed. Organic carbon (OC) and total nitrogen (N) were determined with a CE Instruments Flash EA 1112 Element Analyzer and reported as % of the total dry weight. For quality assurance, the Calibration Sample (soil LECO Lot 10002, Part number 502-309) was measured every ten analyses. Recoveries (n = 12) were 102 ± 3% for N and 99 ± 1% for OC. $\delta^{13}C$ of organic matter was analyzed using an Elementar Vario Micro Cube™ elemental analyzer coupled to an Isoprime100™ isotope ratio mass spectrometer in continuous flow mode. The values are reported relative to VPDB (± 0.1‰ at 1σ) and the variation coefficient