Quaternary Science Reviews 68 (2013) 142–153

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Reconstruction of paleostorms and paleoenvironment using geochemical proxies archived in the sediments of two coastal lakes in northwest Florida

Oindrila Das [a,b,*], Yang Wang [a,b], Joseph Donoghue [a], Xiaomei Xu [c], Jennifer Coor [a], James Elsner [d], Yingfeng Xu [a,b]

[a] Department of Earth, Ocean, and Atmospheric Science, Florida State University, Tallahassee, FL, USA
[b] High National Magnetic Field Laboratory, Tallahassee, FL, USA
[c] Keck Carbon Cycle AMS Facility, University of California, Irvine, CA 92697-3100, USA
[d] Department of Geography, Florida State University, Tallahassee, FL, USA

ARTICLE INFO

Article history:
Received 18 June 2012
Received in revised form
30 January 2013
Accepted 8 February 2013
Available online 16 March 2013

Keywords:
Paleotempestology
Paleoenviroment
Stable carbon isotope
Stable nitrogen isotope
Radiocarbon dating

ABSTRACT

Late Holocene paleoclimate records from coastal regions are important for understanding long-term variability of hurricane activity. Here we present a nearly 4000-year record of severe storm landfalls and environmental changes based on organic geochemical proxies (OGPs) preserved in sediment cores from two coastal lakes in northwest Florida. Our analysis shows that there are significant variations in $\delta^{13}C$, $\delta^{15}N$, C%, N% and C/N with depth, reflecting changes in lake environment, which in turn affected the processes delivering water and sediment to the lake as well as biological productivity within the lake. Isotopic signatures of modern organic materials in the lakes and their surrounding areas show that the major sources of sedimentary organic matters in the lakes are aquatic and terrestrial C_3 vegetation. C_4 grasses do not contribute significantly to the sedimentary organic matters in the lake, although they can be found in the mostly forested watershed. Thus, the positive C and N isotopic shifts, concurrent with negative shifts in C/N ratios, most likely indicate shifts to a marine-like environment in coastal lakes following the influx of marine water and nutrients and marine biota associated with major storm events. Some of these isotopic shifts observed in the sediment cores correspond to visible sand layers presumably representing overwash deposits associated with severe storm events. Radiocarbon dating of bulk sediment organic matters, wood fragments and shells indicates that the sediment in these cores was deposited over the last 3000–4000 years. Based on our age model and OGP interpretation, Eastern Lake data suggest that the recurrence interval of severe storms (i.e., large enough to cause seawater flooding of the lakes) is approximately 84 years over the last 2900 years, whereas Western lake data suggest an average recurrence interval of 86 years in the past 3900 years.

1. Introduction

In recent years, several tropical systems struck the U.S. Gulf Coast, causing considerable damage to property and loss of human life in densely populated cities along the Gulf Coast. A general trend towards increasing hurricane activity and intensity has been observed since 1923 (Goldenberg et al., 2001; Grinsted et al., 2012). A number of scientists have recently suggested the observed trend toward increasing tropical system intensity can be correlated with increases in ocean surface temperature (Elsner et al., 1999, 2008; Enfield et al., 2001; Emanuel, 2005; Trendberth, 2005; Webster et al., 2005; Landsea et al., 2006; Wang and Lee, 2010; Grinsted et al., 2012). These scientists argue that as oceans warm, more kinetic energy is available to be converted to tropical cyclone wind and thus may provide more favorable conditions for developing stronger storms (Elsner et al., 2008).

Historical records reveal that hurricane activities vary widely on interannual and multidicadal time scales, which may be directly or indirectly correlated to several climatic phenomena such as Atlantic Multi-decadal Oscillation (AMO), temporal shifts in the position of the Bermuda high and El Nino-Southern Oscillation (ENSO) (Elsner and Kara, 1999). For example, the more southwesterly position of the Bermuda High would result in more hurricane landfalls on the Gulf of Mexico Coast instead of the Atlantic Coast (Liu and Fearn, 2000). Although, the frequencies of major hurricanes are not directly correlated with AMO, it has been suggested that the number

* Corresponding author. Department of Earth, Ocean, and Atmospheric Science, Florida State University, Tallahassee, FL 32306-4100, USA. Tel.: +1 850 644 2816; fax: +1 850 644 0827
E-mail addresses: odas@magnet.fsu.edu, od07@my.fsu.edu (O. Das).

0277-3791/$ – see front matter
http://dx.doi.org/10.1016/j.quascirev.2013.02.014

of minor hurricanes of category 1 and 2 is increased during the warm phase of AMO than in the cool phase (Chylek and Lesins, 2008). However, significant variations in both hurricane activity and ocean surface temperature on long time scales make it difficult to establish any long-term trend with certainty (Elsner et al., 1999, 2000; Trendberth, 2005; Webster et al., 2005; Landsea et al., 2006; Vecchi and Soden, 2007; Emanuel et al., 2008; Wang and Lee, 2010). Unfortunately, the 100 to 150-year long instrumental record is too brief to detect long-term trends or to clearly distinguish between natural and human induced effects on tropical cyclones (Elsner et al., 1999; Trendberth, 2005; Landsea et al., 2006). Therefore, reconstructing a reliable paleostorm history has been recognized as important to understanding the possible link between future climate change and increasing storm intensity and frequency (Emanuel, 2006; Landsea et al., 2006; Emanuel et al., 2008).

Proxy-based paleostorm reconstruction has a number of advantages over the instrumental record as it allows reconstruction of storm activities on millennial or longer time scales and thus can provide a longer record of storm activities (Chappell et al., 1983; Liu and Fearn, 1993; Elsner et al., 2000; Donnelly et al., 2001a, b; Liu et al., 2001; Donnelly et al., 2004; Donnelly and Webb, 2004; Lambert et al., 2008). Long-term records of storm activities can help constrain models in predicting recurrence interval of landfalling large storms in coastal areas in the near future (Liu and Fearn, 1993, Elsner et al., 2000, Frappier et al., 2007).

In this study, three sediment cores from two coastal lakes in northwest Florida were analyzed for their organic geochemical signatures including their carbon (C) and nitrogen (N) isotopic compositions, C%, N% and C/N ratios. Radiocarbon ages of selected sediment, wood and shell samples were also determined in order to establish a chronological framework for the interpretation of the geochemical data. In addition, the C and N isotopic compositions of plants and soils from the lake areas as well as dissolved organic matter and particulate organic matter in the lakes were analyzed. The data were used to reconstruct a record of changes in lake environment and paleostorm activity over the last ~3900 years in the area.

2. Background and paleostorm records for the Gulf of Mexico Coast

The most common method for reconstructing the frequency of landfalling paleohurricanes is to identify and count overwash sand deposits in coastal lakes or ponds (Liu and Fearn, 1993; Liu et al., 2008). According to Liu and Fearn (2000), each sand layer deposited by overwash process represents a storm event. They postulate that the size and thickness of an overwash sand layer is proportional to the storm intensity. Thus, larger storms (i.e., category 4–5) produce larger overwash deposits, resulting in thicker sand layers in the sedimentary record (Liu and Fearn, 2000).

This method has been applied to two coastal lakes along the northern Gulf Coast: Lake Shelby in Alabama and Western Lake in northwest Florida, with the interpretations of these studies suggesting a recurrence interval of 600 years and 280 years for major storms for these two lake areas, respectively (Liu and Fearn, 1993; 2000). The underlying assumptions associated with this method are: (1) sand layers are derived exclusively from the Gulf of Mexico during storms; (2) sand layer distance from the lake shoreline is proportional to the storm intensity, and (3) radiocarbon dates bracketing the sand layers (and uncorrected for reservoir effects) yield a reliable chronology. The validity of these assumptions is, however, difficult to evaluate without a good understanding of the lake setting and dynamics and in particular the nature and spatial distribution of the lake sediments (Otvos, 1999; 2002). A recent study found substantial ^{14}C deficiencies in Lake Shelby, highlighting the problem of reservoir effects on ^{14}C dating of coastal lake sediments (Aharon and Lambert, 2009). Thus, recurrence intervals based on uncorrected ^{14}C dates on coastal lake sediments are not accurate if the reservoir effect is a significant factor as observed in Lake Shelby.

Recent studies have demonstrated that geochemical proxies, including $\delta^{13}C$ and $\delta^{15}N$ in lacustrine sediments, $\delta^{18}O$ in tree rings, or $\delta^{18}O$ in speleothems, provide a valuable tool for reconstructing high-resolution paleostorm records (Lambert et al., 2003; Lambert et al., 2008; Frappier, 2009; Miller et al., 2006). Lambert et al. (2008) used organic geochemical proxies (OGPs) in sediment cores from Lake Shelby, to reconstruct a millennia-long record of landfalling severe storms that inundated the coastal lake with marine water. The Lambert et al. (2008) study suggested a recurrence interval of ~62 years over the past millennia, which is an order of magnitude greater than the ~600 year recurrence interval proposed by the overwash sand layer record by Liu and Fearn (1993). To increase sensitivity and confidence in paleostorm identification, Lambert et al. (2008) considered positive shifts in $\delta^{13}C$ and $\delta^{15}N$ in lake sediments as indicative of seawater inundation during catastrophic storm surge, because organic matters of marine origin are generally more enriched in the heavy isotopes ^{13}C and ^{15}N than those of freshwater origin or those derived from terrestrial plants (Lambert et al., 2008). Proxy records based on overwash deposits likely only record very large hurricanes of category 4 or larger while the OGPs appear to have recorded severe storms that were large enough to cause seawater flooding of the coastal lake (Lambert et al., 2008). Although the OGPs are likely a more sensitive indicator of storm events than overwash deposits and can detect storms where overwashed sand is not visible, the method has not been further tested or applied to similar coastal lakes.

In this study, the OGPs approach (Lambert et al., 2008) was applied to sediment cores from Eastern Lake and Western Lake on the Gulf Coast of northwest Florida in an effort to reconstruct the paleostorm history for the area. The results are compared with those from the traditional method used previously for Western Lake (Liu and Fearn, 2000).

3. Study sites

3.1. Eastern Lake

Eastern Lake (30°18′41.857″ N, 86°5′35.647″ W) is located within 200 m of the NW Gulf Coast of Florida (Fig. 1). The lake occupies 20.8 ha. The average water depth of the lake is approximately 3 m (Florida Lakewatch, 2008). The lake is stratified throughout the year. From 2001 to 2008, the average salinity of the lake water was 12.9 ppt at the bottom and 10.6 ppt at the surface, and the average pH was 7.5 (Florida Lakewatch, 2008). For brief periods of time the lake has been connected to the Gulf of Mexico through a small outlet following large storms. The Eastern Lake shoreline is moderately developed. The lake area has relatively flat topography. A small highway bridge separates the lake into north and south lake segments. The most abundant plant species in the lake shore area is black needlerush. Other plants found in or around the lake are widgeon grass, cordgrass, saltbush, water-pennywort, big rose mallow, green algae, salt marsh fringerush and giant bulrush (Florida Lakewatch, 2008).

3.2. Western Lake

Western Lake (30°19′37″ N, 86°9′4″ W) is located in Grayton Beach State Park, along the northwest Gulf Coast of Florida (Fig. 1). The lake covers ~37.6 ha and is separated from the Gulf of Mexico by 150–200 m wide, well-developed sand dunes, as much as 9.3 m