Quaternary Geochronology 42 (2017) 130–143

Contents lists available at ScienceDirect

Quaternary Geochronology

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

Millennial-scale variability in the local radiocarbon reservoir age of south Florida during the Holocene

Lauren T. Toth [a,*], Hai Cheng [b,c], R. Lawrence Edwards [b], Erica Ashe [d], Julie N. Richey [a]

[a] U.S. Geological Survey, St. Petersburg Coastal and Marine Science Center, 600 Fourth Street South, Saint Petersburg, FL 33701, USA
[b] Department of Earth Sciences, University of Minnesota, Minneapolis, MN 55455, USA
[c] Institute of Global and Environmental Change, Xi'an Jiaotong University, Xi'an 310049, China
[d] Department of Statistics and Biostatistics, Rutgers University, 110 Frelinghuysen Rd., Piscataway, NJ 08854, USA

ARTICLE INFO

Article history:
Received 23 February 2017
Received in revised form
27 July 2017
Accepted 27 July 2017

Keywords:
ΔR
Radiocarbon
Holocene
Circulation
Western Atlantic
Upwelling
Groundwater

ABSTRACT

A growing body of research suggests that the marine environments of south Florida provide a critical link between the tropical and high-latitude Atlantic. Changes in the characteristics of water masses off south Florida may therefore have important implications for our understanding of climatic and oceanographic variability over a broad spatial scale; however, the sources of variability within this oceanic corridor remain poorly understood. Measurements of ΔR, the local offset of the radiocarbon reservoir age, from shallow-water marine environments can serve as a powerful tracer of water-mass sources that can be used to reconstruct variability in local-to regional-scale oceanography and hydrology. We combined radiocarbon and U-series measurements of Holocene-aged corals from the shallow-water environments of the Florida Keys reef tract (FKRT) with robust statistical modeling to quantify the millennial-scale variability in ΔR at locations with ("nearshore") and without ("open ocean") substantial terrestrial influence. Our reconstructions demonstrate that there was significant spatial and temporal variability in ΔR on the FKRT during the Holocene. Whereas ΔR was similar throughout the region after ~4000 years ago, nearshore ΔR was significantly higher than in the open ocean during the middle Holocene. We suggest that the elevated nearshore ΔR from ~8000 to 5000 years ago was most likely the result of greater groundwater influence associated with lower sea level at this time. In the open ocean, which would have been isolated from the influence of groundwater, ΔR was lowest ~7000 years ago, and was highest ~3000 years ago. We evaluated our open-ocean model of ΔR variability against records of local-to regional-scale oceanography and conclude that local upwelling was not a significant driver of open-ocean radiocarbon variability in this region. Instead, the millennial-scale trends in open-ocean ΔR were more likely a result of broader-scale changes in western Atlantic circulation associated with an increase in the supply of equatorial South Atlantic water to the Caribbean and shifts in the character of South Atlantic waters resulting from variation in the intensity of upwelling off the southwest coast of Africa. Because accurate estimates of ΔR are critical to precise calibrations of radiocarbon dates from marine samples, we also developed models of nearshore and open-ocean ΔR versus conventional ^{14}C ages that can be used for regional radiocarbon calibrations for the Holocene. Our study provides new insights into the patterns and drivers of oceanographic and hydrologic variability in the Straits of Florida and highlights the value of the paleoceanographic records from south Florida to our understanding of Holocene changes in climate and ocean circulation throughout the Atlantic.

1. Introduction

The oceanic corridor between the Florida Keys and Cuba, known as the Straits of Florida, provides a critical connection between the tropical and high-latitude western Atlantic (Fig. 1; Hall and Bryden, 1982; Schmitz and Richardson, 1991; Schmitz and McCartney, 1993; Lee et al., 1995; Lund and Curry, 2004; Lynch-Stieglitz et al., 2009; Schmidt et al., 2012). Flow through the Straits of Florida occurs via the Florida Current, which is formed by the confluence of the Gulf of Mexico Loop Current and the eastward extension of the Yucatan

* Corresponding author.
E-mail address: ltoth@usgs.gov (L.T. Toth).

http://dx.doi.org/10.1016/j.quageo.2017.07.005
1871-1014/Published by Elsevier B.V.

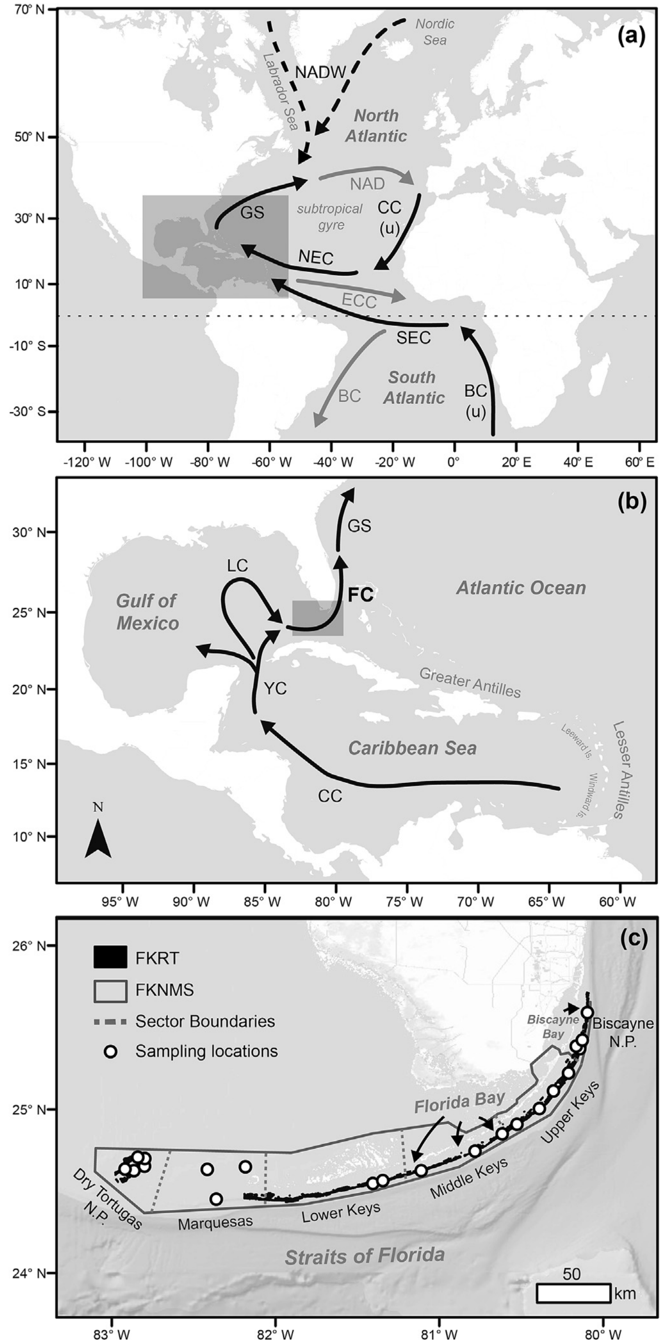

Fig. 1. (a) Generalized depiction of the major currents of the Atlantic (solid lines): Gulf Stream (GS), North Atlantic Drift (NAD), Canary Current upwelling system (CC(u)), North Equatorial Current (NEC), Equatorial Counter Current (ECC), South Equatorial Current (SEC), Benguela Current upwelling system (BC(u)), and Brazilian Current (BC). The locations of North Atlantic Deepwater Formation (NADW) in the Labrador and Nordic Seas are indicated by dashed lines. The currents not discussed specifically in the text are in gray. The shaded rectangle in (a) indicates the bounds of (b), the location of the study area in relation to the major currents of the Caribbean: Caribbean current (CC), Yucatan current (YC), Loop Current (LC), Florida Current (FC), and Gulf Stream (GS) drawn after Gyory et al. (2013). The shaded rectangle in (b) indicates the location of the study, (c). Sampling locations along the FKRT (black shading; from the benthic habitat maps derived by Florida Fish and Wildlife Conservation Commission-Fish and Wildlife Research Institute, National Oceanic and Atmospheric Administration Coastal Services Center, Dade County, FL (http://ocean.floridamarine.org/metadata/custom/SECOORA/south_fl_coral_reefs.htm) are indicated by white circles. Dashed lines within the FKNMS show the boundaries between subregions of the FKRT (after Klein and Orlando, 1994). Black arrows indicate locations where water flows from Florida and Biscayne Bays onto the reef.

Current from the southern Caribbean (Fig. 1b; Schmitz and Richardson, 1991; Lee et al., 1995). The Florida Current is situated at the origin of the Gulf Stream, which is the primary mechanism of heat and salt transport to the North Atlantic (Hall and Bryden, 1982; Schmitz and McCartney, 1993; Lee et al., 1995; Lund and Curry, 2006). Variations in the sources and character of the Florida Current may, therefore, have important implications for Atlantic Ocean circulation and regional climate variability (Lynch-Stieglitz et al., 1999; Lund and Curry, 2006; Came et al., 2008; Schmidt et al., 2012).

Recent studies have demonstrated that there were considerable changes in the hydrography (Lund and Curry, 2004, 2006; Lynch-Stieglitz et al., 2009; Schmidt et al., 2012) and geostrophic flow through the Straits of Florida during the Holocene (Lund et al., 2006; Lynch-Stieglitz et al., 2009). These changes have been linked to large-scale climate phenomena including solar forcing (Lund and Curry, 2004, 2006; Lynch-Stieglitz et al., 2009; Schmidt et al., 2012), meridional shifts in the position of the inter-tropical convergence zone (Lund and Curry, 2004; Lund et al., 2006; Lynch-Stieglitz et al., 2009), Atlantic Meridional Overturning Circulation (AMOC; Lynch-Stieglitz et al., 2009; Came et al., 2008), and the El Niño–Southern Oscillation (Schmidt et al., 2012); however, the local-to regional-scale oceanographic responses to climate forcing and the role of ocean circulation in determining the characteristics of the Florida Current are less clear.

Radiocarbon (^{14}C) variability in shallow-water environments can provide a powerful tracer of changes in ocean circulation through space and time (Broecker et al., 1960; Druffel, 1997b). The ^{14}C content of the oceanic mixed layer reflects variability in both atmospheric ^{14}C production and exchange with ^{14}C-depleted sources (Broecker et al., 1960; Stuiver et al., 1986; Reimer and Reimer, 2001). On a global scale, mixing with ^{14}C-depleted deepwater produces a significant offset between the ^{14}C of the atmosphere and marine surface-water, known as the global marine radiocarbon reservoir age, R, which is modeled over time by the marine calibration curve (e.g., Reimer et al., 2013). Local-to regional-scale oceanographic or hydrologic variability can, however, produce significant local deviations from this globally-averaged value (e.g., Druffel and Linick, 1978; Druffel, 1997a; Reimer and Reimer, 2001; Guilderson et al., 2004; Kilbourne et al., 2007; Druffel et al., 2008; Wagner et al., 2009; Dewar et al., 2012; Toth et al., 2015a, b). The local offset of the radiocarbon reservoir age at any given location is known as the local reservoir age correction, ΔR (Stuiver et al., 1986; Reimer and Reimer, 2001).

At present, the most significant source of local oceanographic variability in the Straits of Florida is upwelling of intermediate water as the result of cyclonic gyres and offshore meanders of the Florida Current (Klein and Orlando, 1994; Lee et al., 1995; Leichter and Miller, 1999; Davis et al., 2008, Fig. 1c). From Dry Tortugas N.P. to the Lower Keys (Fig. 1c), periodic formation of large, slow-moving cyclonic gyres is an important inter- and intra-annual driver of water-column mixing (Klein and Orlando, 1994; Lee et al., 1995). Similarly, high-frequency, but short-lived upwelling is a persistent feature in the Upper Keys where the Florida Current flows closest to the reef tract (Klein and Orlando, 1994; Leichter and Miller, 1999). The upwelling regime of south Florida over longer timescales is unknown, but significant changes in the intensity or frequency of upwelling should be reflected in ΔR variability. Because ΔR is a function of mixing, upwelling results in surface-waters with depleted ^{14}C and elevated ΔR, and the opposite occurs where there is strong water-column stratification or downwelling (Broecker et al., 1960; Key et al., 2004a,b; Reimer and Reimer, 2001).

Terrestrial influences from the Florida platform are another potential source of local-scale ΔR variability in the Straits of Florida. Terrestrially-derived sediments, runoff of meteoric waters, and