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Late Holocene sea- and land-level change on the U.S. southeastern Atlantic coast

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ABSTRACT

Late Holocene relative sea-level (RSL) reconstructions can be used to estimate rates of land-level (subsidence or uplift) change and therefore to modify global sea-level projections for regional conditions. These reconstructions also provide the long-term benchmark against which modern trends are compared and an opportunity to understand the response of sea level to past climate variability. To address a spatial absence of late Holocene data in Florida and Georgia, we reconstructed ~1.3 m of RSL rise in northeastern Florida (USA) during the past ~2600 years using plant remains and foraminifera in a dated core of high salt-marsh sediment. The reconstruction was fused with tide-gauge data from nearby Fernandina Beach, which measured 1.91 ± 0.26 mm/year of RSL rise since 1900 CE. The average rate of RSL rise prior to 1800 CE was 0.41 ± 0.08 mm/year. Assuming negligible change in global mean sea level from meltwater input/removal and thermal expansion/contraction, this sea-level history approximates net land-level (subsidence and geoid) change, principally from glacio-isostatic adjustment. Historic rates of rise commenced at 1850–1890 CE and it is virtually certain ($P = 0.99$) that the average rate of 20th century RSL rise in northeastern Florida was faster than during any of the preceding 26 centuries. The linearity of RSL rise in Florida is in contrast to the variability reconstructed at sites further north on the U.S. Atlantic coast and may suggest a role for ocean dynamic effects in explaining these more variable RSL reconstructions. Comparison of the difference between reconstructed rates of late Holocene RSL rise and historic trends measured by tide gauges indicates that 20th century sea-level trends along the U.S. Atlantic coast were not dominated by the characteristic spatial fingerprint of melting of the Greenland Ice Sheet.

1. Introduction

Relative sea level (RSL) is the net outcome of several simultaneous contributions including ocean mass and volume, the effect changing ice sheet mass on geoid and crustal height, ocean dynamics, and glacio-isostatic adjustment (GIA; e.g. Shennan et al., 2012). During the late Holocene (last ~2000–3000 years), RSL change along the passive U.S. Atlantic margin was dominated by spatially-variable land subsidence and geoid fall. The primary driver of these two processes was (and continues to be) GIA caused by the retreat of the Laurentide Ice Sheet and the collapse of its pro-glacial forebulge (e.g. Peltier, 2004). However, other processes such as dynamic topography caused by mantle flow associated with plate tectonic motion (e.g. Rowley et al., 2013) and sediment compaction (Miller et al., 2013) also contribute to long-term RSL trends through vertical land motion. For convenience we use the term "land-level change" to refer to the net effect of GIA-induced geoid change and vertical land motion from all sources (Shennan et al., 2012). To isolate climate-related sea-level trends and compare reconstructions from different regions, it is necessary to quantify rates of land-level change (e.g. Church and White, 2006). These estimates are important for coastal management and planning because in many regions subsidence will be a principal reason for regional

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modification of global sea-level projections (e.g. Kopp et al., in press; Nicholls and Cazenave, 2010). Approaches to estimate the contribution of land-level change to past and projected RSL include:

i. Earth-ice models that assume no meltwater input during the late Holocene and attribute predicted RSL trends solely to GIA (Peltier, 2004);
ii. Permanent global positioning stations (GPS) that directly measure net vertical motion from GIA and other processes (e.g. Sella et al., 2007; Woppelmann et al., 2009). The short time series of measurements currently causes large (but decreasing) uncertainties in estimated land-level trends. GPS measurements do not incorporate GIA-induced changes in the geoid;
iii. Paired satellite altimetry and tide-gauge datasets;
iv. Basal RSL reconstructions that assume late Holocene meltwater input was negligible (like Earth-ice models) until ~1850 CE and attribute RSL trends solely to land-level change (e.g. Engelhart et al., 2009), thereby also capturing land-level changes from processes other than GIA.

Earth-ice models predict that the contribution of GIA to RSL varies systematically with distance away from the former centers of glaciation. Along the east coast of North America this pattern is clear in RSL reconstructions, which show that the rate of late Holocene subsidence is greatest along the U.S. mid-Atlantic coast (up to 1.4 mm/year in New Jersey and Delaware) with decreasing rates to the north and south (Engelhart et al., 2009, 2011a, 2011b). However, the absence of RSL reconstructions prevented estimation of subsidence rates in Florida and Georgia. It is important to constrain the late Holocene RSL history of this region to support coastal planning, to provide geological data for testing Earth-ice models, and to fill the spatial gap between the existing RSL datasets that are available for the U.S. Atlantic coast (Engelhart and Horton, 2012) and Caribbean (Milne et al., 2005; Milne and Peros, 2013).

Detailed reconstructions of late Holocene RSL allow investigation of the response of sea level to climate variability (e.g. the Medieval Climate Anomaly and Little Ice Age) and show that historic sea-level rise (either reconstructed or measured by tide gauges) exceeds the background rate that persisted for several previous centuries or longer (e.g. Donnelly et al., 2004). Existing reconstructions from the Atlantic coast of North America indicate that RSL departed positively and negatively from a linear trend at intervals during the last 2000 years and prior to the onset of historic rates of rise (Gehrels, 2000; Gehrels et al., 2005; Kemp et al., 2011a, 2013a). Spatial differences in the timing, sign, and magnitude of these trends may be indicative of the mechanisms causing RSL change (e.g. Clark and Lingle, 1977; Mitrovica et al., 2009; Yin et al., 2010).

To estimate the rate of late Holocene land-level change and describe sea-level trends in northern Florida (Fig. 1) we reconstructed RSL change during the past ~2600 years using plant macrofossils and foraminifera preserved in a dated core of salt-marsh sediment from Nassau Landing. We estimate the rate of late Holocene (pre-1800 CE) RSL rise using noisy-input Gaussian process regression and compare it to historic tide-gauge measurements from Fernandina Beach and reconstructions from elsewhere on the U.S. Atlantic coast. We evaluate the possible role of GIA and ocean dynamics as drivers of past, present, and future RSL change in the southeastern United States.

2. Study area

We used sediment recovered in gouge cores to investigate the stratigraphy underlying numerous salt marshes between Jacksonville, FL and St. Mary's, GA (Fig. 1). Nassau Landing had the thickest and most complete sequences of high salt-marsh peat that we identified in the region.

We selected core NLM2 from Nassau Landing for detailed analysis because it included a 1.0 m thick unit of salt-marsh peat with abundant

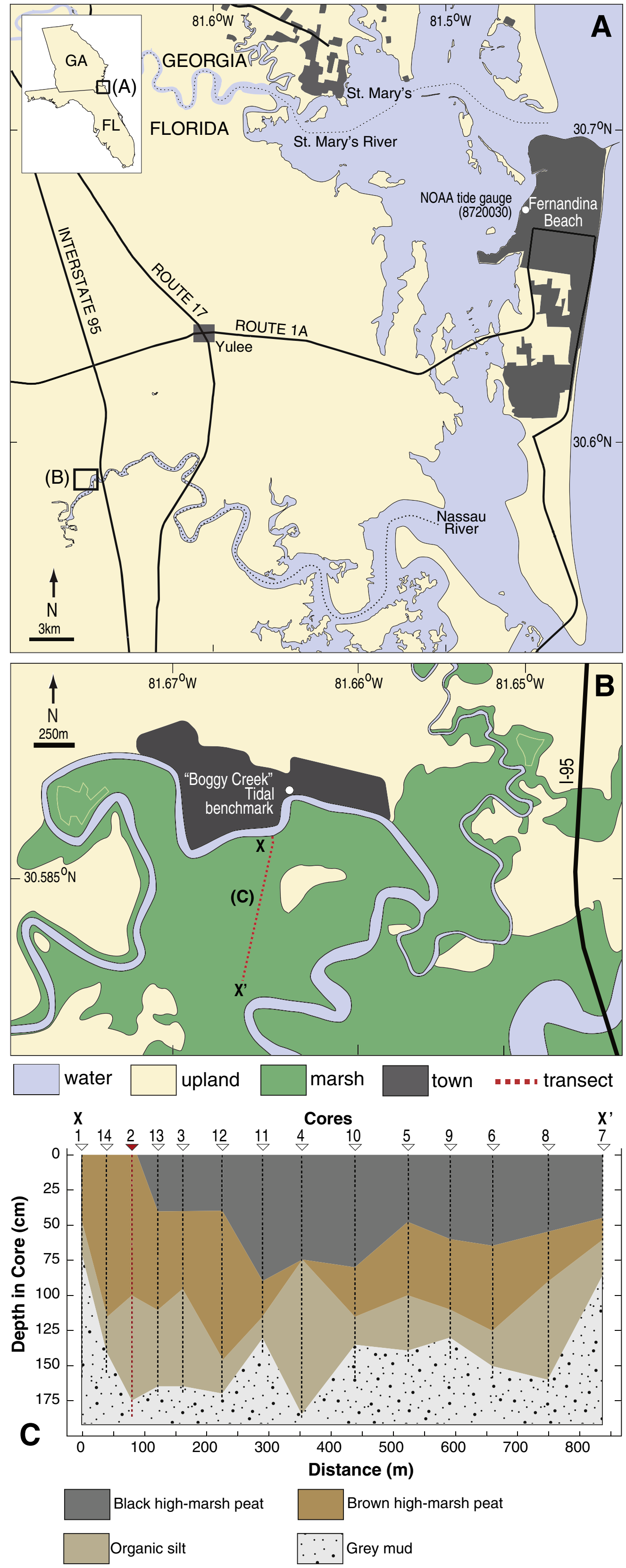

Fig. 1. (A) Location of study area on the Nassau River in northeastern Florida. (B) Location of coring transect (X–X′), and tidal benchmark at the Nassau Landing site. (C) Stratigraphy described in the field from gouge cores collected along transect X–X′. Core NLM2 (in red) was selected for detailed analysis and collected using a Russian corer.