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Sea-level change during the last 2500 years in New Jersey, USA

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ABSTRACT

Relative sea-level changes during the last ~2500 years in New Jersey, USA were reconstructed to test if late Holocene sea level was stable or included persistent and distinctive phases of variability. Foraminifera and bulk-sediment $\delta^{13}C$ values were combined to reconstruct paleomarsh elevation with decimeter precision from sequences of salt-marsh sediment at two sites using a multi-proxy approach. The additional paleoenvironmental information provided by bulk-sediment $\delta^{13}C$ values reduced vertical uncertainty in the sea-level reconstruction by about one third of that estimated from foraminifera alone using a transfer function. The history of sediment deposition was constrained by a composite chronology. An age–depth model developed for each core enabled reconstruction of sea level with multi-decadal resolution. Following correction for land-level change (1.4 mm/yr), four successive and sustained (multi-centennial) sea-level trends were objectively identified and quantified (95% confidence interval) using error-in-variables change point analysis to account for age and sea-level uncertainties. From at least 500 BC to 250 AD, sea-level fell at 0.11 mm/yr. The second period saw sea-level rise at 0.62 mm/yr from 250 AD to 733 AD. Between 733 AD and 1850 AD, sea level fell at 0.12 mm/yr. The reconstructed rate of sea-level rise since ~1850 AD was 3.1 mm/yr and represents the most rapid period of change for at least 2500 years. This trend began between 1830 AD and 1873 AD. Since this change point, reconstructed sea-level rise is in agreement with regional tide-gauge records and exceeds the global average estimate for the 20th century. These positive and negative departures from background rates demonstrate that the late Holocene sea level was not stable in New Jersey.

1. Introduction

Late Holocene (last ~2500 years) sea-level reconstructions with decimeter vertical and multi-decadal temporal resolution provide important information for investigating the relationships between sea-level change and temperature. Such data calibrate and test the validity of models that predict sea-level changes under scenarios of global climate evolution (e.g. Rahmstorf, 2007; Bittermann et al., 2013). Instrumental measurements of sea level (tide gauges and satellites) are too short to capture pre-anthropogenic trends and the long-term (100s–1000s of years) response of sea level to temperature variations. This time-series limitation hinders the development of predictive models and is a motivation for reconstructing late Holocene sea-level changes. Proxy-temperature data show distinct climate phases during the late Holocene such as the Medieval Climate Anomaly, Little Ice Age, and 20th century warming (e.g. Moberg et al., 2005; Mann et al., 2008; Ahmed et al., 2013; Thompson et al., 2013). In contrast, relatively little is known about sea level during this period, although there is some evidence that persistent positive and negative departures from regional, linear background rates (driven primarily by glacio-isostatic adjustment; GIA) occurred prior to the onset of modern sea-level

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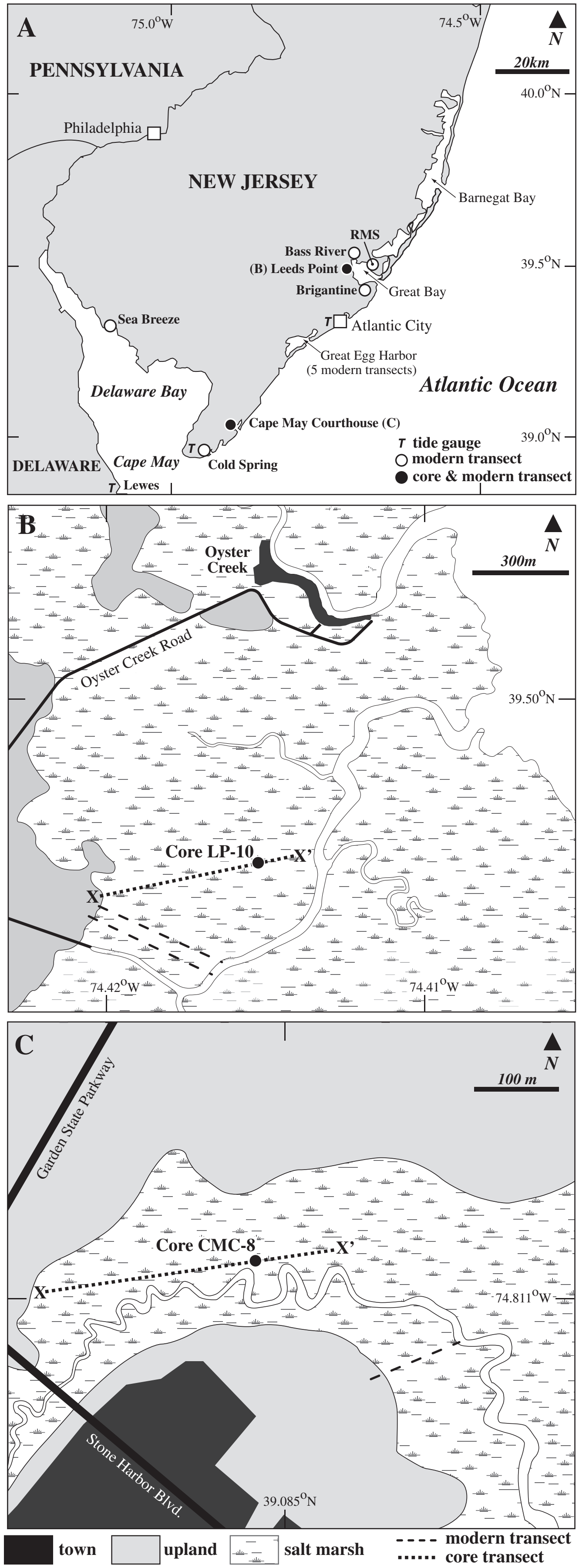

Fig. 1. Location of study sites in New Jersey, USA (**A**). Distribution of modern foraminifera was documented at 12 sites (open circles (Kemp et al., 2013)), including five around Great Egg Harbor. Location of tide gauges at Cape May, NJ, Atlantic City, NJ, and Lewes, DE is denoted by T symbols. RMS = Rutgers Marine Station. Cores for sea-level reconstruction (filled circles) were collected at Leeds Point in the Edwin Forsythe National Wildlife Refuge (**B**) and at Cape May Courthouse (**C**).

rise in the late 19th or early 20th centuries (e.g. Gehrels, 2000; van de Plassche, 2000; Sivan et al., 2004; González and Törnqvist, 2009; Kemp et al., 2011).

Salt-marsh sediment is one of the most important archives for reconstructing relative sea level (RSL) during the late Holocene. Under regimes of RSL, rise salt marshes accumulate sediment to maintain their elevation in the tidal frame (Morris et al., 2002). The resulting sequences of salt-marsh sediment accurately preserve the elevation of past RSL, which is the net result of all driving mechanisms. The vertical precision of RSL reconstructions is maximized by employing sea-level indicators that differentiate among salt-marsh sub-environments to estimate the tidal elevation where the sediment was originally deposited (paleomarsh elevation; PME). Salt-marsh foraminifera are sea-level indicators because their distribution is controlled by the frequency and duration of inundation, which is principally a function of tidal elevation (e.g. Scott and Medioli, 1978; Horton and Edwards, 2006). Foraminifera are abundant in salt marshes where they form assemblages occupying narrow elevational ranges making them suitable for quantitative and precise PME reconstructions. Bulk sediment geochemistry can also be employed as a sea-level indicator. In regions where salt marshes are dominated by C_4 plants such as the mid-Atlantic and northeastern U.S., measured $\delta^{13}C$ values readily identify sediment of salt-marsh origin (e.g. Middleburg et al., 1997; Wilson et al., 2005; Tanner et al., 2010). RSL reconstructions also require the timing of sediment deposition to be estimated. Sediment that accumulated under low-energy conditions on salt marshes is often undisturbed and well suited to developing detailed chronologies. Radiocarbon is the principal means to date late Holocene salt-marsh sediment, but alternatives are necessary for the period since approximately 1650 AD because of a plateau on the calibration curve (e.g. Reimer et al., 2011). Age–depth models developed from composite chronologies incorporating radiocarbon dates and age markers of pollution and land-use change enable RSL to be reconstructed with the multi-decadal precision necessary to describe small (decimeter) RSL changes (e.g. Marshall et al., 2007). The resulting RSL reconstructions filter out short-lived (annual to decadal) sea-level variability because of the time-averaging effect of sedimentation and sampling. The resulting records are analyzed using numerical tools to identify and quantify the timing and magnitude of persistent (decadal to centennial) phases of sea-level evolution.

Relative sea-level changes in New Jersey over the past ~2500 years were reconstructed to determine how and when persistent sea-level trends deviated from background rates. Reconstructions were developed from salt-marsh sediment at two sites (Leeds Point and Cape May Courthouse; Fig. 1) using foraminifera and stable carbon isotopes ($\delta^{13}C$) as sea-level indicators and age–depth models constrained by composite chronologies of radiocarbon, ^{137}Cs activity, and pollen and pollution chrono-horizons. Change point analysis identified four persistent periods of sea-level behavior during the last 2500 years that mark positive and negative departures from a linear background rate. The new reconstructions demonstrate that the rate of sea-level rise since ~1850 AD exceeds any previous persistent rate in the late Holocene.