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Relative sea-level change in Connecticut (USA) during the last 2200 yrs

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ABSTRACT

We produced a relative sea-level (RSL) reconstruction from Connecticut (USA) spanning the last ~2200 yrs that is free from the influence of sediment compaction. The reconstruction used a suite of vertically- and laterally-ordered sediment samples ≤2 cm above bedrock that were collected by excavating a trench along an evenly-sloped bedrock surface. Paleomarsh elevation was reconstructed using a regional-scale transfer function trained on the modern distribution of foraminifera on Long Island Sound salt marshes and supported by bulk-sediment δ^{13}C measurements. The history of sediment accumulation was estimated using an age-elevation model constrained by radiocarbon dates and recognition of pollution horizons of known age. The RSL reconstruction was combined with regional tide-gauge measurements spanning the last ~150 yrs before being quantitatively analyzed using an error-in-variables integrated Gaussian process model to identify sea-level trends with formal and appropriate treatment of uncertainty and the temporal distribution of data. RSL rise was stable (~1 mm/yr) from ~200 BCE to ~1000 CE, slowed to a minimum rate of rise (0.41 mm/yr) at ~1400 CE, and then accelerated continuously to reach a current rate of 3.2 mm/yr, which is the fastest, century-scale rate of the last 2200 yrs. Change point analysis identified that modern rates of rise in Connecticut began at 1850–1886 CE. This timing is synchronous with changes recorded at other sites on the U.S. Atlantic coast and is likely the local expression of a global sea-level change. Earlier sea-level trends show coherence north of Cape Hatteras that are contrasted with southern sites. This pattern may represent centennial-scale variability in the position and/or strength of the Gulf Stream. Comparison of the new record to three existing and reanalyzed RSL reconstructions from the same site developed using sediment cores indicates that compaction is unlikely to significantly distort RSL reconstructions produced from shallow (~2–3 m thick) sequences of salt-marsh peat.

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1. Introduction

Common Era relative sea-level (RSL) reconstructions characterize natural variability, provide a long-term perspective against which to compare recent trends, and capture multiple phases of climate and sea-level behavior for model calibration. Along the U.S. Atlantic coast, these reconstructions are primarily produced from cores of salt-marsh sediment and demonstrate that sea level departed positively and negatively from a stable mean, most noticeably since the onset of historic rates of rise (e.g. Kemp et al., 2011).

In high salt-marsh ecosystems on the U.S. Atlantic coast, RSL rise creates accommodation space that is filled by *in-situ* accumulation of peat. Through this response, salt-marshes preserve their elevation in the tidal frame and the salt-marsh surface tracks rising RSL (e.g. Bloom, 1964; Redfield and Rubin, 1962). Conse-

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quently, sequences of high salt-marsh peat are valuable archives from which RSL is reconstructed using proxies for tidal elevation (termed sea-level indicators) and a dated history of sediment accumulation. Foraminifera and plants are sea-level indicators because their distribution on modern salt marshes reflects the varied preferences and tolerances of species to inundation, which is primarily a function of tidal elevation (e.g. Scott and Medioli, 1978). Sequences of salt-marsh sediment are usually recovered as a single core that is processed to provide vertically-ordered samples for reconstructing the tidal elevation at which each sample was originally deposited (termed paleomarsh elevation, PME). A limitation of this approach is that thickening of the sequence as sediment accumulates may cause compaction of underlying material and post-depositional lowering of samples, resulting in an overestimation of the amount and rate of RSL rise (Bloom, 1964; Brain et al., 2012). RSL can also be reconstructed from discrete basal samples that minimize the influence of compaction, but do not provide a continuous record of Common Era RSL change (e.g. Redfield and Rubin, 1962). In Connecticut (and similar regions) it is possible to produce a continuous and basal RSL reconstruction using salt-marsh sediment that accumulated on top of incompressible bedrock or glacial erratics. Ice retreat from the modern Connecticut coast by ∼18,000 yrs before present (Balco et al., 2009) exposed bedrock that was later transgressed by salt-marshes because Common Era RSL rose due to ongoing glacio-isostatic adjustment (GIA; e.g. Engelhart et al., 2011). The salt-marsh sediment deposited in contact with bedrock did not experience post-depositional lowering and preserves a compaction-free history of RSL change (Donnelly et al., 2004; Nydick et al., 1995).

We reconstruct RSL change during the last ∼2200 yrs in Connecticut from salt-marsh sediment in direct contact with bedrock to answer two questions: (i) did persistent sea-level trends occur in Connecticut during the Common Era? and (ii) does sediment compaction materially alter patterns of RSL change reconstructed from cores of salt-marsh sediment? Samples from the sediment-bedrock contact were recovered by excavating a trench along the downward slope of a granite outcrop. Foraminifera and bulk sediment δ^{13}C values were used as sea-level indicators and sediment accumulation was dated using radiocarbon and regional pollution markers. The resulting RSL record was combined with instrumental measurements to identify positive and negative Common Era sea-level trends in Connecticut. Comparison with other RSL reconstructions from East River Marsh (Nydick et al., 1995) indicates that stratigraphies with intercalated peats are susceptible to compaction, but this compaction does not materially distort reconstructed RSL trends.

2. Study site

East River Marsh (Fig. 1) is typical of salt marshes in the northeastern United States (e.g. van de Plassche, 1991). Low-salt marsh environments are vegetated by *Spartina alterniflora* (tall form) and characterized by muddy sediment. This laterally-narrow floral zone exists between mean tide level (MTL) and mean high water (MHW). The high salt-marsh platform is found between MHW and mean higher high water (MHHW). It is vegetated by a mixed meadow of the C_4 plants *Spartina patens*, *Distichlis spicata*, and *Spartina alterniflora* (short form) and comprises most of the salt marsh by area. The transition between salt-marsh and freshwater ecosystems occurs between MHHW and highest astronomical tide (HAT). This zone is vegetated by the C_3 plants *Phragmites australis* and *Iva fructescens* at East River Marsh, but may also be characterized by sedges (e.g. *Schoenoplectus americanus*). The great diurnal tidal range at the site (mean lower low water, MLLW to MHHW) was estimated as 1.73 m using the NOAA vertical datum transformation tool for coastal regions (VDatum), compared to 1.74 m measured by the NOAA tide gauge in Guilford Harbor (∼1.5 km away; Fig. 1b).

3. Materials and methods

3.1. Site selection and trench sampling

East River Marsh was selected because granite bedrock outcrops above the salt-marsh surface and salt-marsh sediment is in direct contact with bedrock. We selected a location where the bedrock sloped evenly at ∼30° to a depth of ∼2.4 m below the modern marsh surface (Fig. 2a). Assuming that GIA caused ∼1.0 mm/yr of Common Era RSL rise in southern Connecticut (e.g. Donnelly et al., 2004; Engelhart et al., 2009; Peltier, 1996), we anticipated that the selected location would provide a continuous sequence of compaction-free sediment spanning the entire Common Era. A trench was excavated to expose the bedrock-sediment contact (Fig. 2). The basal sediment was segmented at slight changes in bedrock slope and recovered as a series of adjacent blocks. Sample elevations were measured by leveling the four corners of each block in contact with bedrock to a temporary benchmark, the elevation of which was established (relative to NAVD88) by real time kinematic satellite navigation. Each block was wrapped in plastic, labeled to preserve its original orientation, and refrigerated. The blocks were subsequently cut into 1-cm thick basal samples representing 1-cm increments of elevation (Fig. 2b). This approach created a suite of vertically- and laterally-ordered sediment samples that were deposited ≤2 cm above the bedrock surface. The position of each sampled is expressed in a two-dimensional (depth and distance) co-ordinate system where the top of the trench (1.01 m above MTL) is the origin. Sample positions discussed in the text and presented on figures use this reference frame. All subsequent analyses (radiocarbon and pollution dating, foraminiferal counts, and δ^{13}C measurements) were performed on this set of samples that we consider to be free from the effects of sediment compaction. In most cases a thin (<2 mm) mat of fine roots was removed from the bottom of each sample and discarded after inspection. This mat formed by the growth of roots from younger plants at the surface along the sediment-bedrock interface.

3.2. Modern foraminifera

At 12 salt marshes we established transects across the prevailing elevation and environmental gradient to describe the modern distribution of foraminifera (Fig. 1a). These sites represent the spatial, ecological, and geomorphological range of salt marshes on the north coast of Long Island Sound and complement the distribution of existing modern datasets. At East River Marsh we sampled two parallel transects (Fig. 1c) that included highest-marsh environments where the shallow, amorphous sediment overlying bedrock is analogous to the basal sediment that accumulated in the trench. Similar highest salt-marsh sediments and environments were also sampled at other sites. We combined the new dataset of modern foraminifera with those summarized by Wright et al. (2011) to produce a regional training set consisting of 254 modern foraminifera samples from 16 sites on the north coast of Long Island Sound (Fig. 1) including 92 samples from four Connecticut sites that were reported in published literature (Edwards et al., 2004; Gehrels and van de Plassche, 1999). The new modern foraminifera data are presented in the supporting appendix.

3.3. Reconstructing paleomarsh elevation

A weighted-averaging transfer function with inverse deshrinking (WA-inv) was developed to quantify the relationship between

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