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Research paper

Reconstructing the accumulation history of a saltmarsh sediment core: Which age-depth model is best?

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ABSTRACT

Saltmarsh-based reconstructions of relative sea-level (RSL) change play a central role in current efforts seeking to quantify the relationship between climate and sea-level rise. The development of an accurate chronology is pivotal, since errors in age–depth relationships will propagate to the final record as alterations in both the timing and magnitude of reconstructed change. A range of age-depth modelling packages are available but differences in their theoretical basis and practical operation mean contrasting accumulation histories can be produced from the same dataset.

We compare the performance of five age-depth modelling programs (Bacon, Bchron, Bpeat, Clam and OxCal) when applied to the kinds of data used in high resolution, saltmarsh-based RSL reconstructions. We investigate their relative performance by comparing modelled accumulation curves against known age–depth relationships generated from simulated stratigraphic sequences. Bpeat is particularly sensitive to non-linearities which, whilst maximising the detection of small rate changes, has the potential to generate spurious variations, particularly in the last 400 years. Bacon generally replicates the pattern and magnitude of change but with notable offsets in timing. Bchron and OxCal successfully constrain the known accumulation history within their error envelopes although the best-fit solutions tend to underestimate the magnitude of change. The best-fit solutions of Clam generally replicate the timing and magnitude of changes well, but are sensitive to the underlying shape of the calibration curve, performing poorly where plateaus in atmospheric ^{14}C concentration exist.

We employ an ensemble of age-depth models to reconstruct a 1500 year accumulation history for a saltmarsh core recovered from Connecticut, USA based on a composite chronology comprising 26 AMS radiocarbon dates, ^{210}Pb, ^{137}Cs radionuclides and an historical pollen chronohorizon. The resulting record reveals non-linear accumulation during the late Holocene with a marked increase in rate around AD1800. With the exception of the interval between AD1500 and AD1800, all models produce accumulation curves that agree to within ~10 cm at the century-scale. The accumulation rate increase around AD1800 is associated with the transition from a radiocarbon-based to a ^{210}Pb-dominated chronology. Whilst repeat analysis excluding the ^{210}Pb data alters the precise timing and magnitude of this acceleration, a shift to faster accumulation compared to the long-term rate is a robust feature of the record and not simply an artefact of the switch in dating methods. Simulation indicates that a rise of similar magnitude to the post-AD1800 increase (detrended increase of ~16 cm) is theoretically constrained and detectable within the radiocarbon-dated portion of the record. The absence of such a signal suggests that the recent rate of accumulation is unprecedented in the last 1500 years. Our results indicate that reliable (sub)century-scale age-depth models can be developed from saltmarsh sequences, and that the vertical

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uncertainties associated with them translate to RSL reconstruction errors that are typically smaller than those associated with the most precise microfossil-based estimates of palaeomarsh-surface elevation.

1. Introduction

Constructing an accurate accumulation history is a vital but non-trivial component of most sediment-based palaeoenvironmental reconstructions (Telford et al., 2004; Blaauw and Heegaard, 2012). This is exemplified by the current generation of 'high resolution' relative sea-level (RSL) studies seeking to employ saltmarsh sediments as late Holocene 'tide gauges' (see Barlow et al., 2013). In this approach the age and altitude of palaeomarsh-surfaces (PMS) (Fig. 1a) are combined with estimations of the height above sea level at which they formed (Fig. 1b) in order to reconstruct the RSL change experienced at a study site (Fig. 1c). Microfossils such as foraminifera are used to infer PMS height whilst age control is provided by AMS radiocarbon dating of saltmarsh plant remains. Whilst some microfossil samples are directly dated, the age of others must be inferred by interpolation between dated horizons. Although this situation is not unique to RSL reconstruction, establishing an accurate age—depth relationship is particularly important for saltmarsh-based studies since it directly impacts the magnitude of the reconstructed change as well as determining its timing (see Fig. 1c and d). As core collection typically targets high marsh environments, the resulting RSL reconstruction is primarily controlled by the sediment accumulation history (Edwards, 2007).

In recent years, several software tools have been developed to assist in the process of chronology construction. Whilst some packages employ classical statistical methods to develop age-depth models (e.g. Clam: Blaauw, 2010), the use of Bayesian statistics has become increasingly common (Parnell et al., 2011; Parnell and Gehrels, 2015). Variations in underlying theory and its practical application mean that each model handles data differently and, in this way, a single dataset can produce a diversity of accumulation histories. In fact, Blaauw and Heegaard (2012) note that model choice is the greatest source of uncertainty in age-depth modelling. Previous work highlights that each modelling approach has particular strengths and weaknesses, with no single model out-performing all others in every situation (Parnell et al., 2011). Consequently, comparative assessment of model performance using simulated and real data is an important step to ensure that informed choices are made during chronology construction (e.g. Telford et al., 2004; Blockley et al., 2007). Furthermore, since inaccurate accumulation histories can give rise to spurious RSL signals, it is important to ensure that any inferred rate changes are not simply artefacts of the calibration process or switches between dating method (Gehrels et al., 2005; Barlow et al., 2013).

In this paper we present a new, well-dated saltmarsh sediment core from Connecticut, USA, covering the last 1500 years which is typical of sequences targeted in 'high resolution' RSL studies (e.g. Kemp et al., 2011, 2013). We use a suite of simulations to evaluate the performance of five age-depth modelling packages (Bacon, Bchron, Bpeat, Clam and OxCal) in order to address the following questions: 1) Do age-depth models introduce spurious accumulation rate changes?; 2) Can we tell if recent accumulation rates are without precedent given down-core changes in dating approach and resolution?

2. Saltmarsh core and age data

A 1.82 m-thick sequence of high saltmarsh peat was recovered from Pattagansett River marsh in Connecticut, USA (Fig. 2). Twenty-six samples for AMS radiocarbon dating were collected at 6 cm intervals below 29 cm depth to produce a 1500 year-long record with an average of one radiocarbon date every 60 calendar years (Fig. 3, Table B.1). This radiocarbon-based chronology was supplemented by pollen and short-lived radionuclide data from the upper 64 cm of the sequence (Fig. 4, Table 1, Table B.2).

An initial manual wiggle-match of the radiocarbon data to the calibration curve (van de Plassche et al., 2001) confirms the predominantly linear nature of the age-depth profile and the absence of significant hiatuses (Fig. 3). This is supported by the lithostratigraphy (Fig. 2c) which indicates consistent accumulation within a high marsh environment (abundant *Spartina patens* rhizomes with uniform $\delta^{13}C$ signatures (Table B.1)). The resulting late Holocene accumulation rate of 1.1 mm/yr matches estimates of the underlying rate of glacio-isostatic adjustment (GIA) for the region (1.0 ± 0.2 mm/yr, Donnelly et al. (2004); 1.1 ± 0.1 mm/yr, Engelhart et al. (2009)), implying that the effects of sediment compaction in this shallow core are negligible. Forward extrapolation of this long-term rate fails to intersect with the modern surface by ~13 cm (Figs. 3b and 4f), indicating that an increase in accumulation rate must have occurred in the most recent portion of the record. This inference is confirmed by both a simple linear interpolation from the core top to the *Ambrosia* chronohorizon (mean accumulation rate of 1.7 mm/yr since AD1650) or from the ^{210}Pb and ^{137}Cs data (mean accumulation rates of 2.1 mm/yr since AD1850 or 2.6 mm/yr since AD1963). The local rate of RSL rise recorded by the tide gauge at New London is 2.3 mm/yr since AD1938.

Whilst this simple approach of comparing linear trends is sufficient to identify the existence of a recent acceleration in saltmarsh accumulation rate, it cannot reliably quantify it given the range of possible rates (1.6 mm/yr − 2.8 mm/yr), or unequivocally date the timing of its onset. More importantly it is unable to address the question of whether a change of similar magnitude occurred in the earlier, radiocarbon-dated portion of the record, which is masked within the larger age error envelope.

Age-depth modelling has been used to refine the timing and significance of recent changes identified in RSL records and to decrease the magnitude of age error envelopes by considering the stratigraphic ordering of dates within a sediment core (e.g. Kemp et al., 2011). However, given the differences in performance and underlying theory, it is unclear which approach will produce the most precise and accurate accumulation history for a particular sediment core. In the following section, we use simulations to produce a series of known accumulation histories against which we can evaluate the performance of the different age-depth modelling packages. Whilst numerous permutations of synthetic data are possible (e.g. uneven sampling intervals, varying age precision etc), the characteristics of the simulated dataset will influence relative model performance. Consequently, we develop a series of synthetic dates that emulate the sampling resolution and dating precision of the Pattagansett core chronology.