Holocene sea-level changes: Implications for current rates of sea-level rise

Benjamin P. Horton, Simon Engelhart & Andrew Kemp

Department of Earth and Environmental Science

University of Pennsylvania

Penn
University of Pennsylvania

IUGS UNESCO IGCP

IGCP 495 Quaternary Land-Ocean Interactions: Driving Mechanisms and Coastal Response

- Employ a standardized approach of RSL data collection and analysis to facilitate collaborations
- Develop high-resolution (centimeter to meter scale vertical resolution and annual to centennial scale age resolution) records of RSL

Key Processes

$$\Delta\xi rsl(\tau,\varphi) = \Delta\xi eus(\tau) + \Delta\xi iso(\tau,\varphi) + \Delta\xi tect(\tau,\varphi) + \Delta\xi local(\tau,\varphi)$$

$\Delta\xi_{rsl}(\tau,\varphi)$ = RSL at time τ and location φ

$\Delta\xi_{eus}(\tau)$ = time-dependent eustatic function

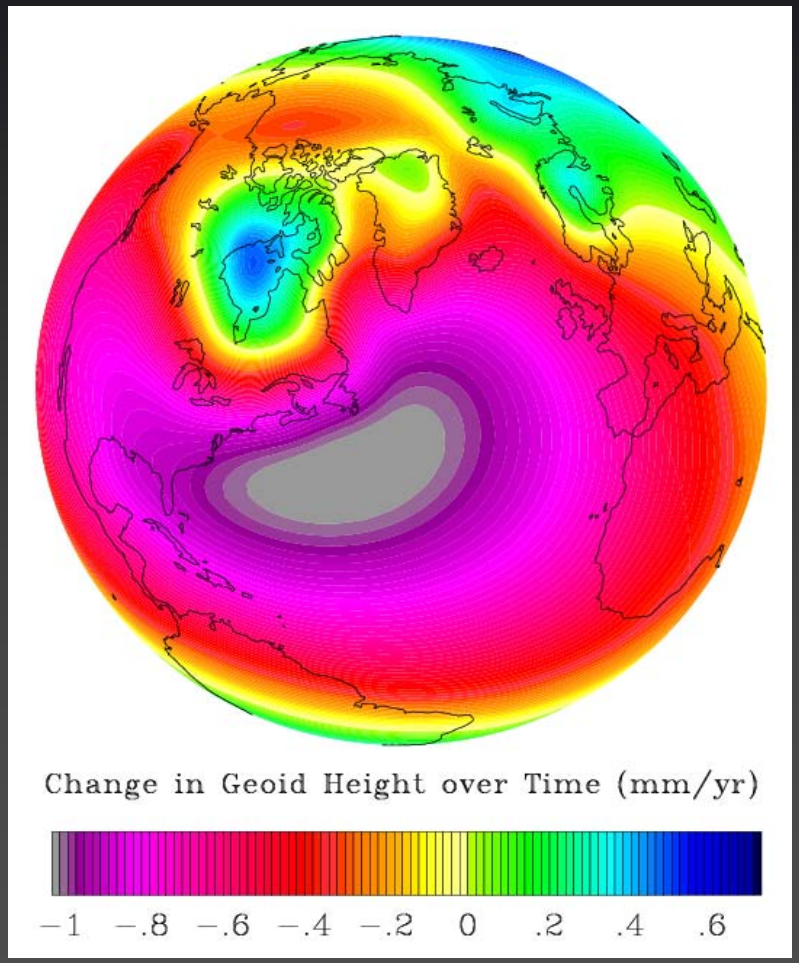
$\Delta\xi_{iso}(\tau,\varphi)$ = total isostatic effect of the glacial rebound process (glacio and hydro isostacy)

$\Delta\xi_{tect}(\tau,\varphi)$ = total isostatic effect of tectonic process

$\Delta\xi_{local}(\tau,\varphi)$ = total effect of local processes

Glacial Rebound along the Atlantic East Coast

- Dipolar variation between Hudson Bay and offshore of the northeastern United States
- Accurate models of the GIA process has become acute for the credibility of Gravity Recovery and Climate Experiment (GRACE) dual satellite measurement system

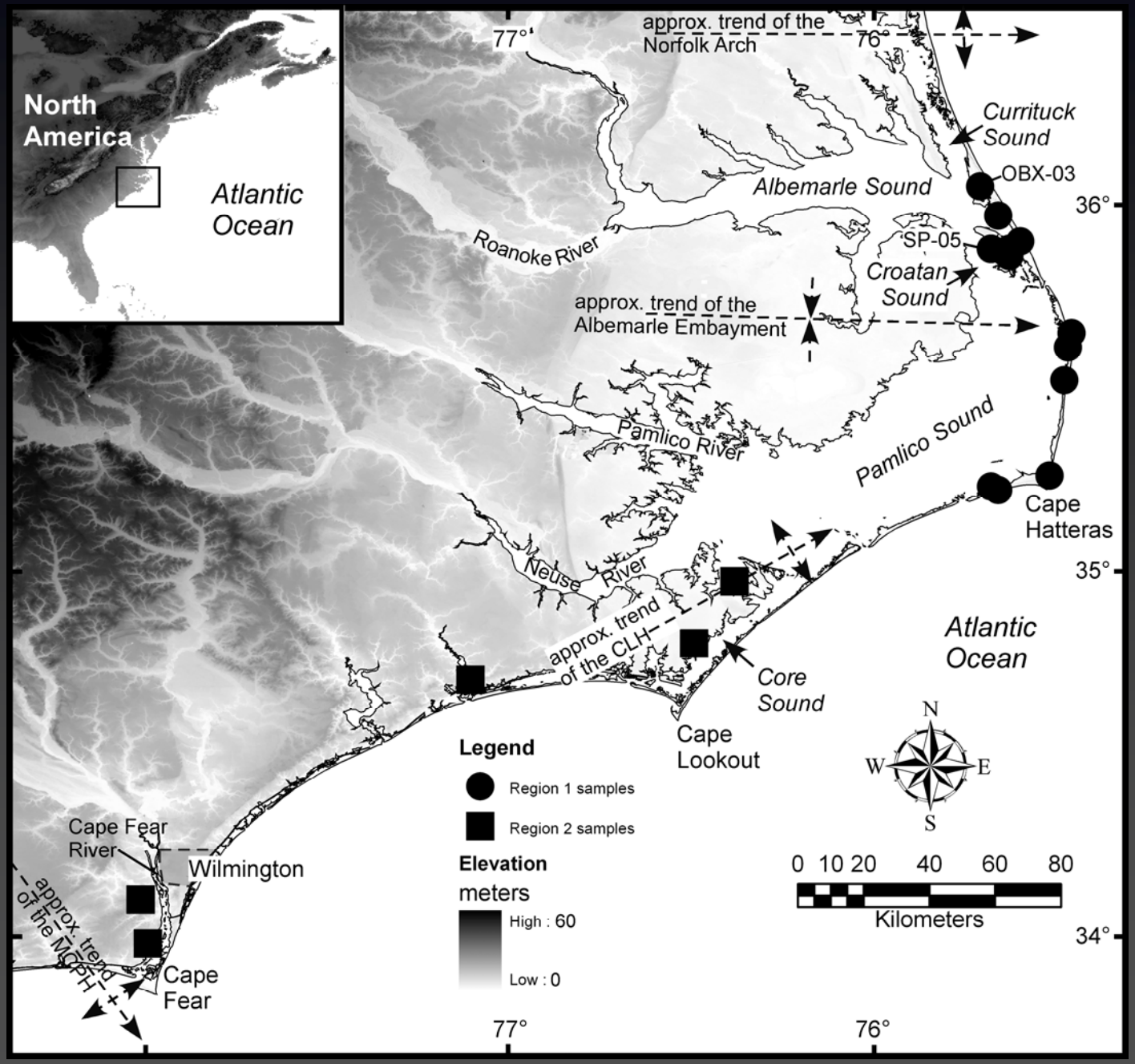


Prediction from the ICE-4G(VM2) model

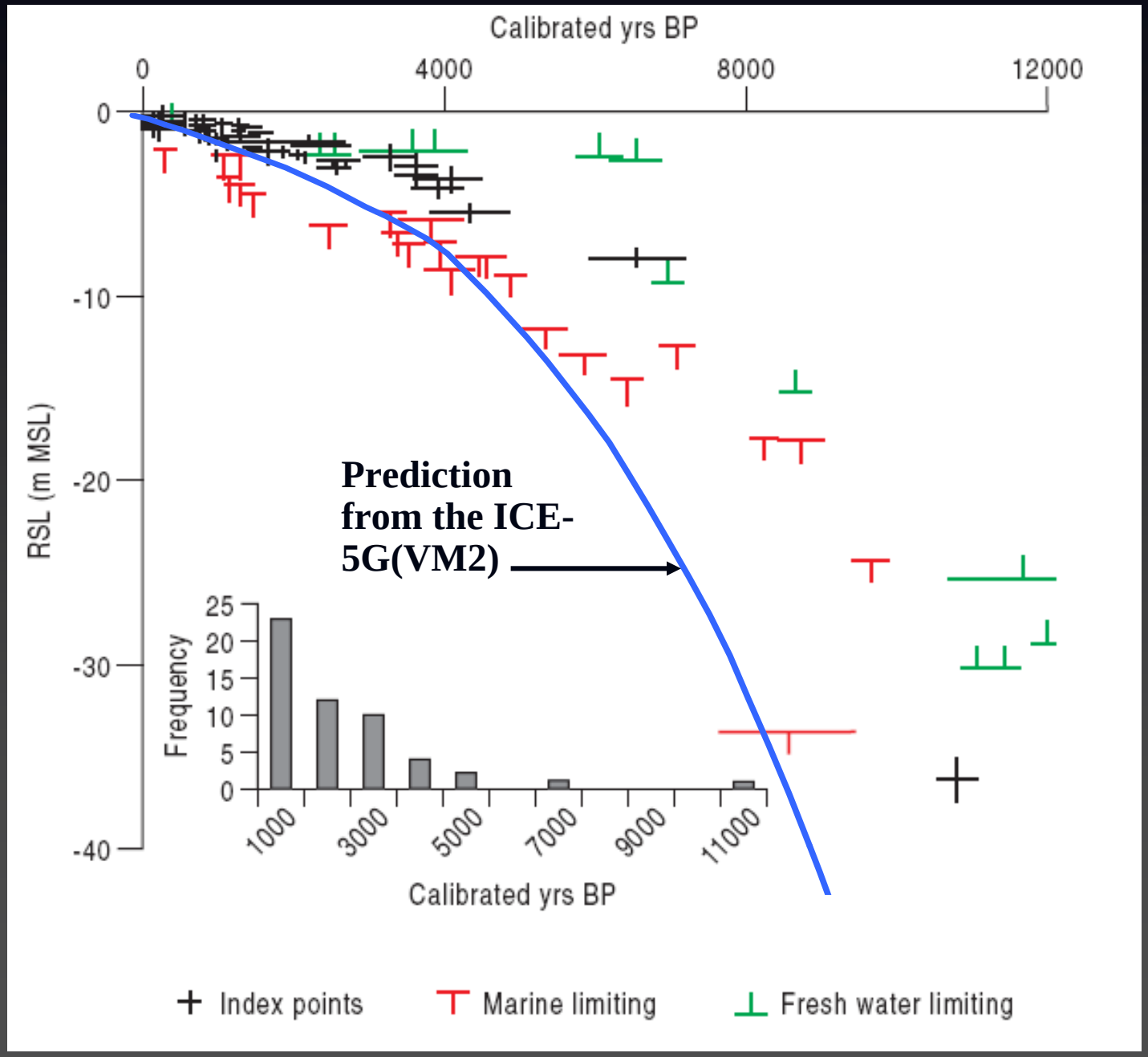
(1) Employ a standardized approach of RSL data

- **Location**: the geographical coordinates of the sample site.
- **Age**: calibrated calendar date calculated using IntCal04. In instances where marine samples (such as shells and foraminifera) have been dated, the dataset Marine04 and an appropriate marine reservoir correction will be used.
- **Elevation**: To measure RSL change, it is necessary to establish the relationship of the sample to a tidal level. The relationship of a sample to a tide level, and hence sea level, is called the ‘indicative meaning’.

Case study: North Carolina



Holocene RSL data vs. GIA model

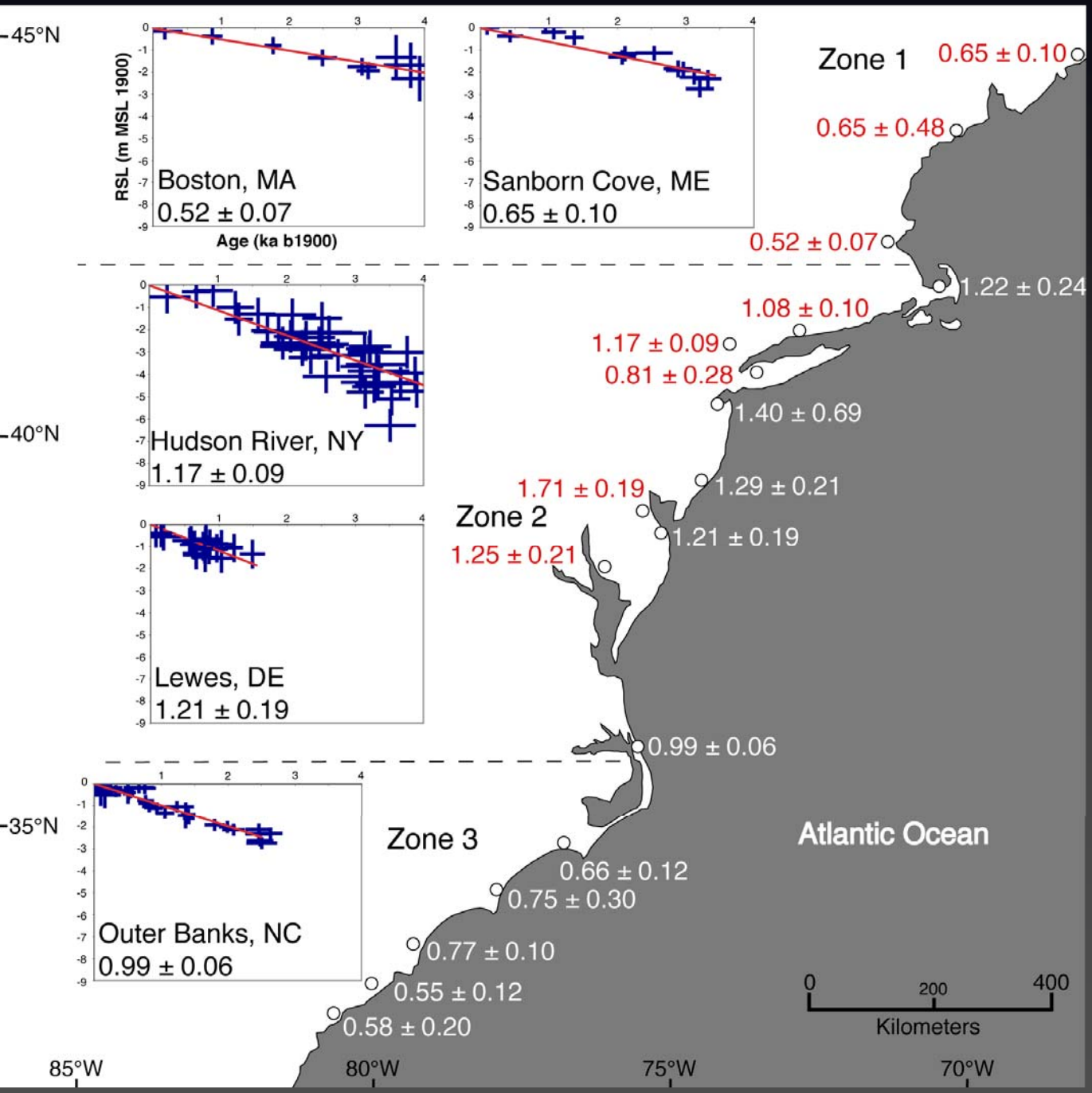


Late Holocene

$$\Delta\xi_{rsl}(\tau,\varphi) = \Delta\xi_{eus}(\tau) + \Delta\xi_{iso}(\tau,\varphi) + \Delta\xi_{tect}(\tau,\varphi) + \Delta\xi_{local}(\tau,\varphi)$$

- Zero meltwater input ($\Delta\xi_{eus}$) over the last 4 ka
- Zero tectonic ($\Delta\xi_{tect}$) influence for the Atlantic Coast
- Compaction errors minimized by basal peat ($\Delta\xi_{local}$)
- Last 4 ka is an indicator of isostatic adjustment due to the melting of the Laurentide Ice Sheet ($\Delta\xi_{iso}$)
- Correct tide gauge records of 20th century RSL with these baseline rates

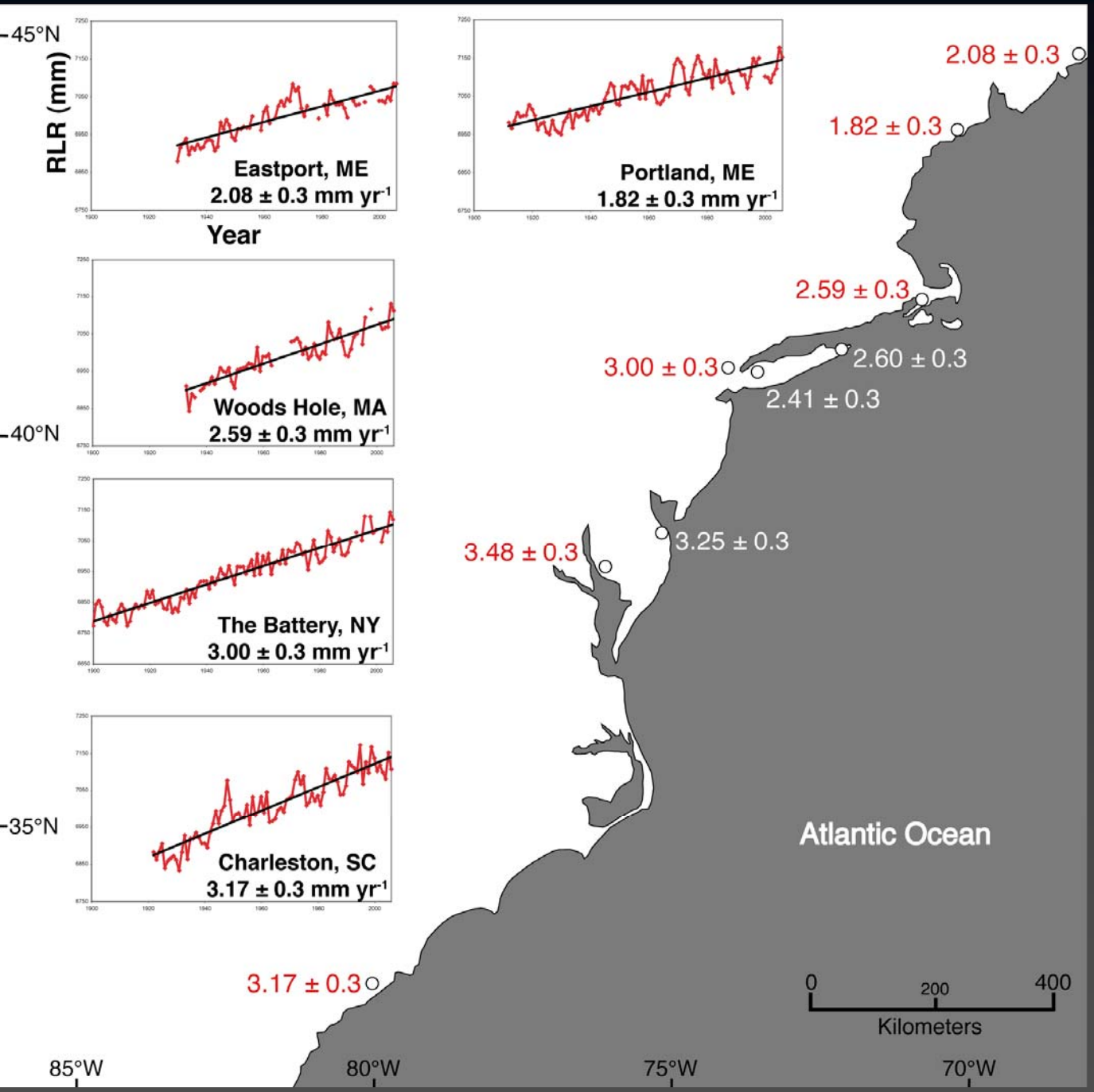
Late Holocene sea-level change



- Zone 1: 0 - 1 mm/yr
- Zone 2: 1-2mm/yr
- Zone 3: 0-1 mm/yr

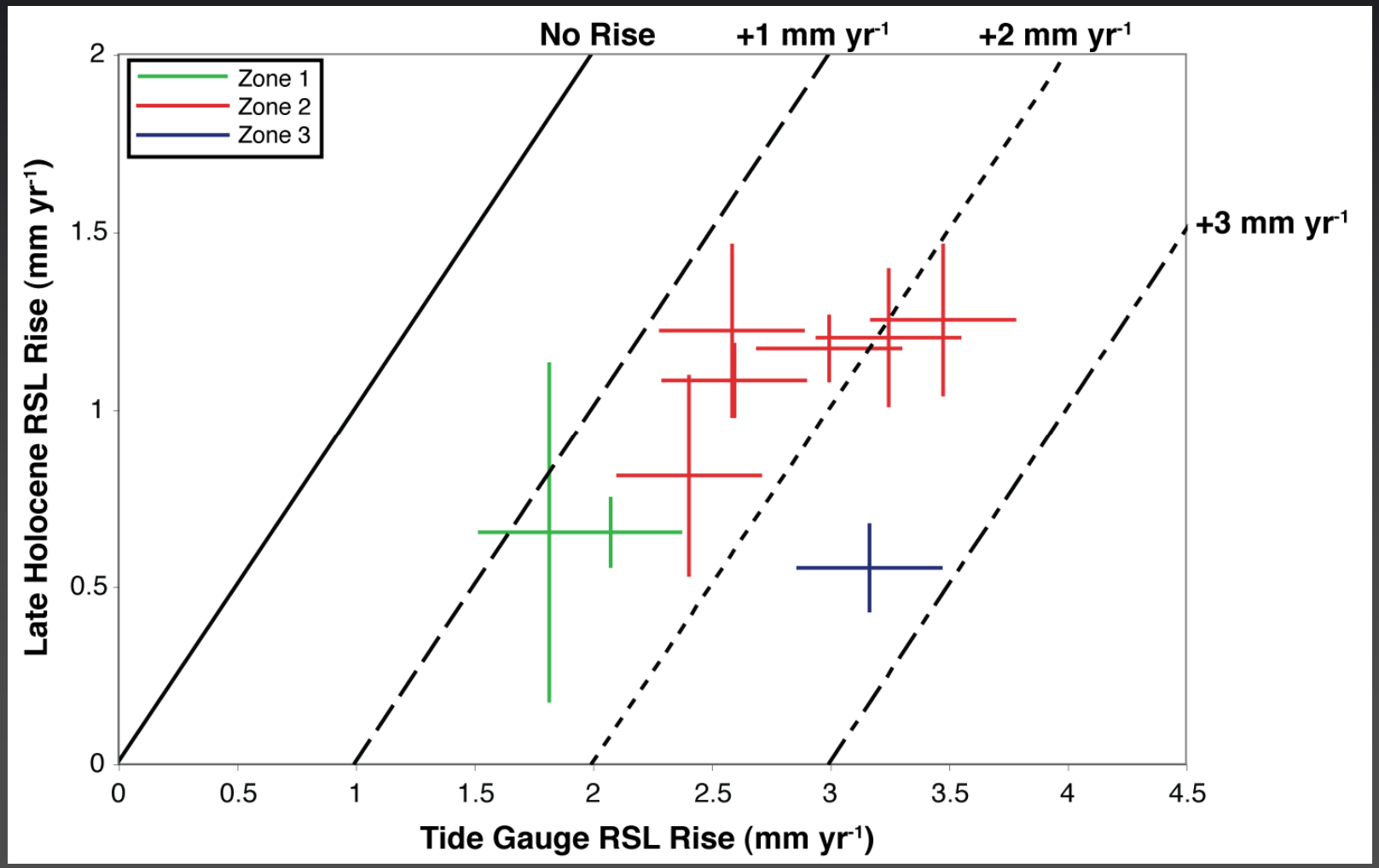
- NO DATA: New Hampshire, Rhode Island, Virginia, Georgia, Florida

Tide Gauges



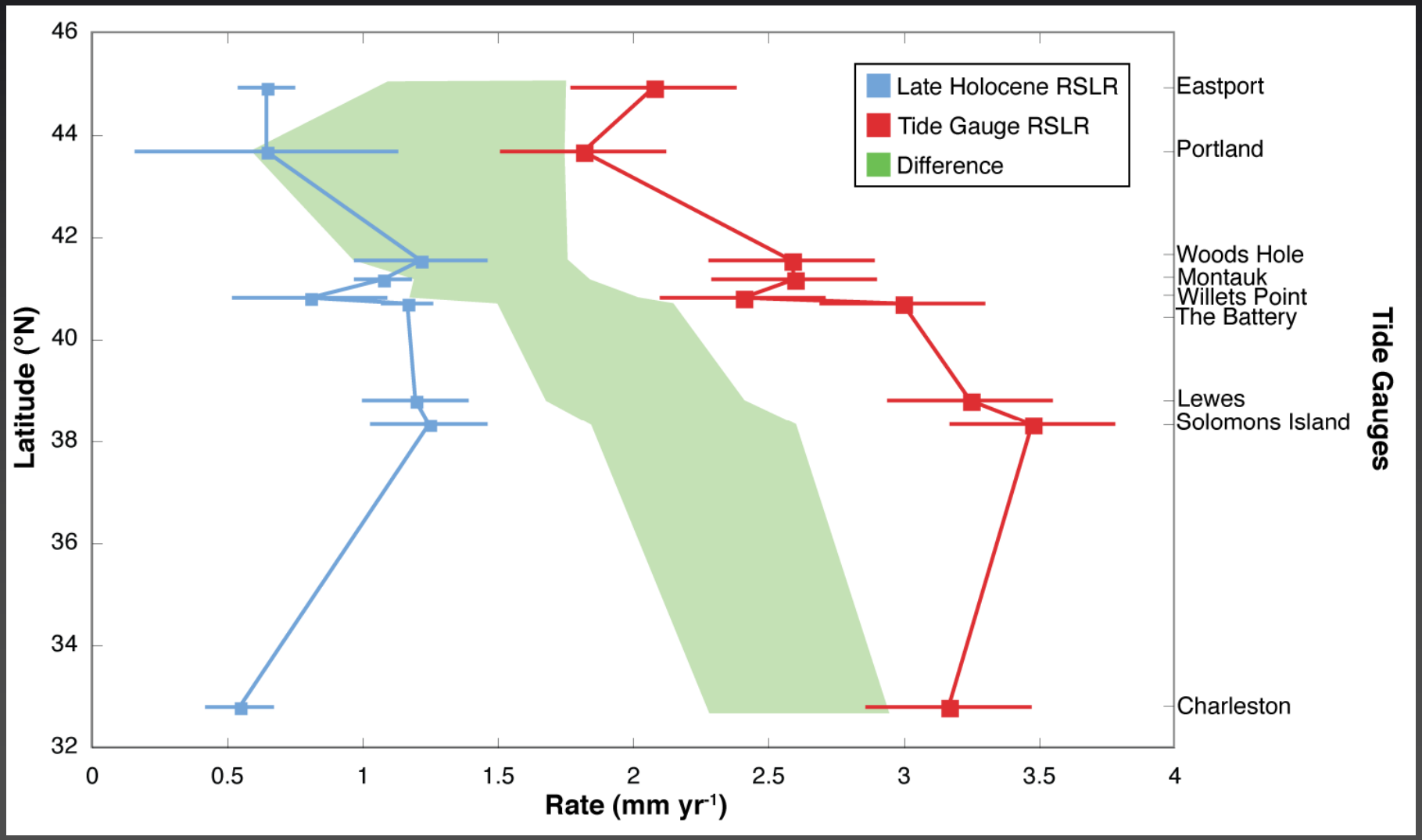
- Only use tide gauges > 50 years to minimize effects of decadal variability
- Tide gauges with significant non-GIA affects are disregarded

20th Century Sea Level Acceleration

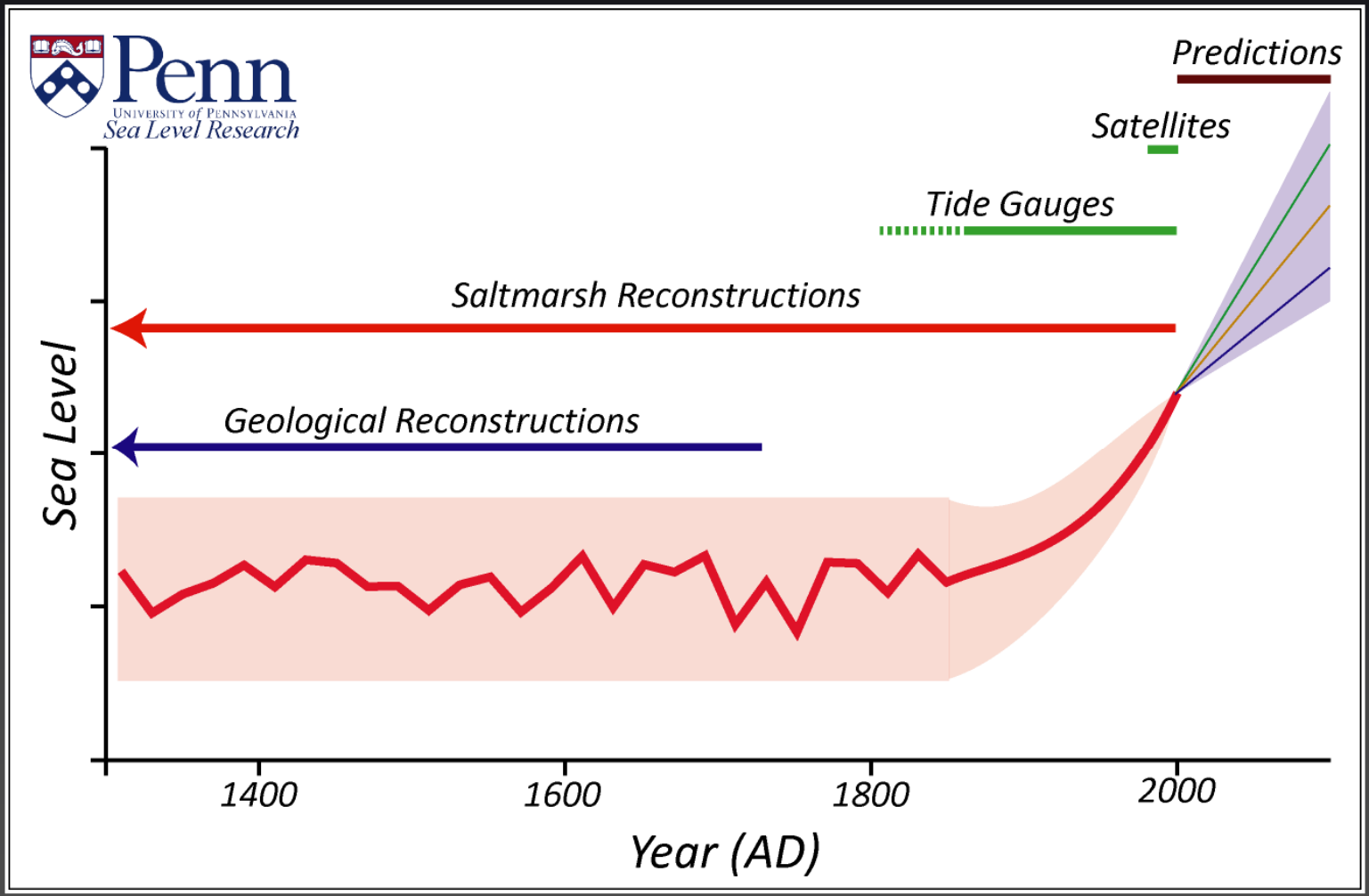


1.8 ± 0.2 mm yr^{-1}

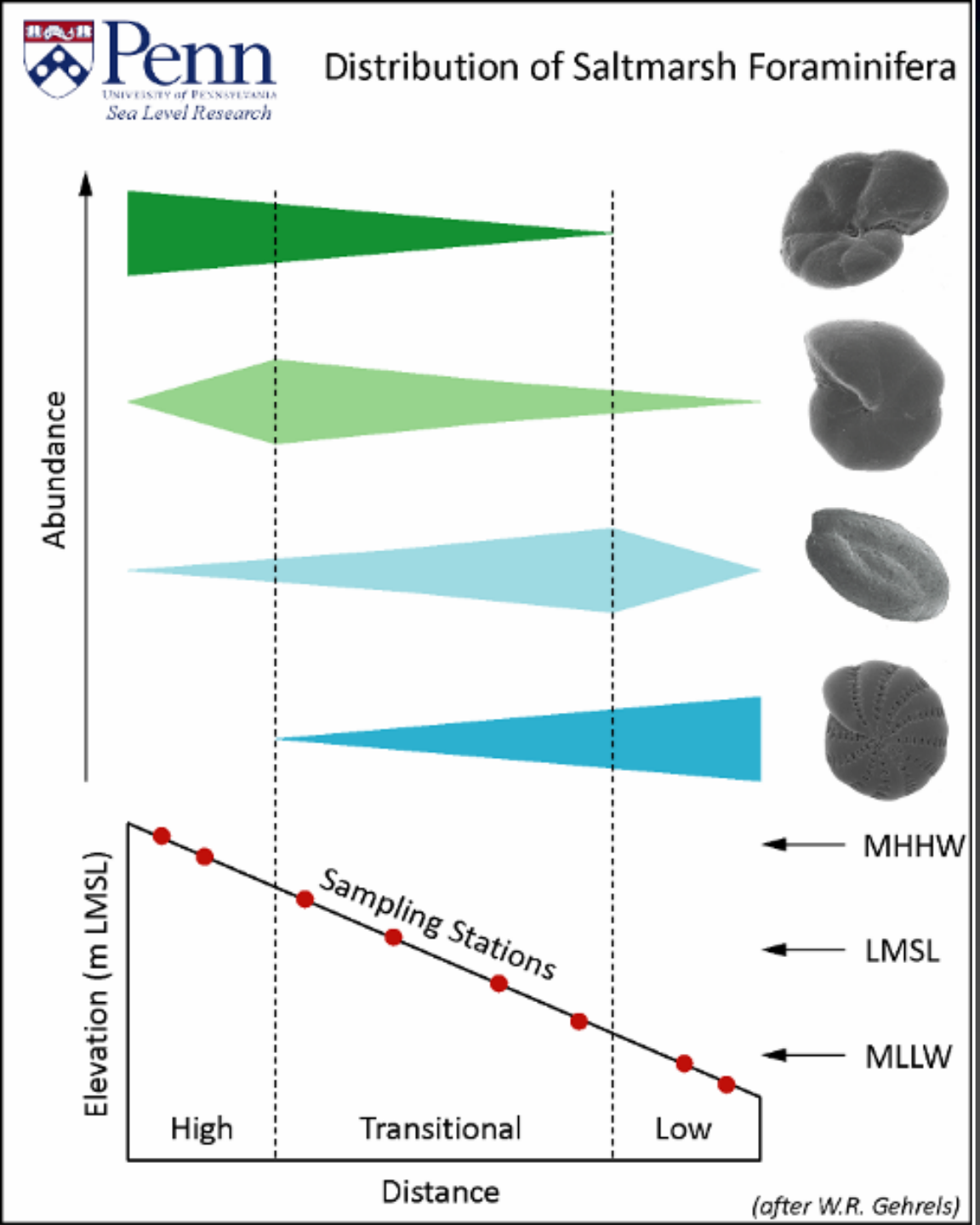
20th Century Sea Level Rise Trend



(2) High-resolution records of RSL

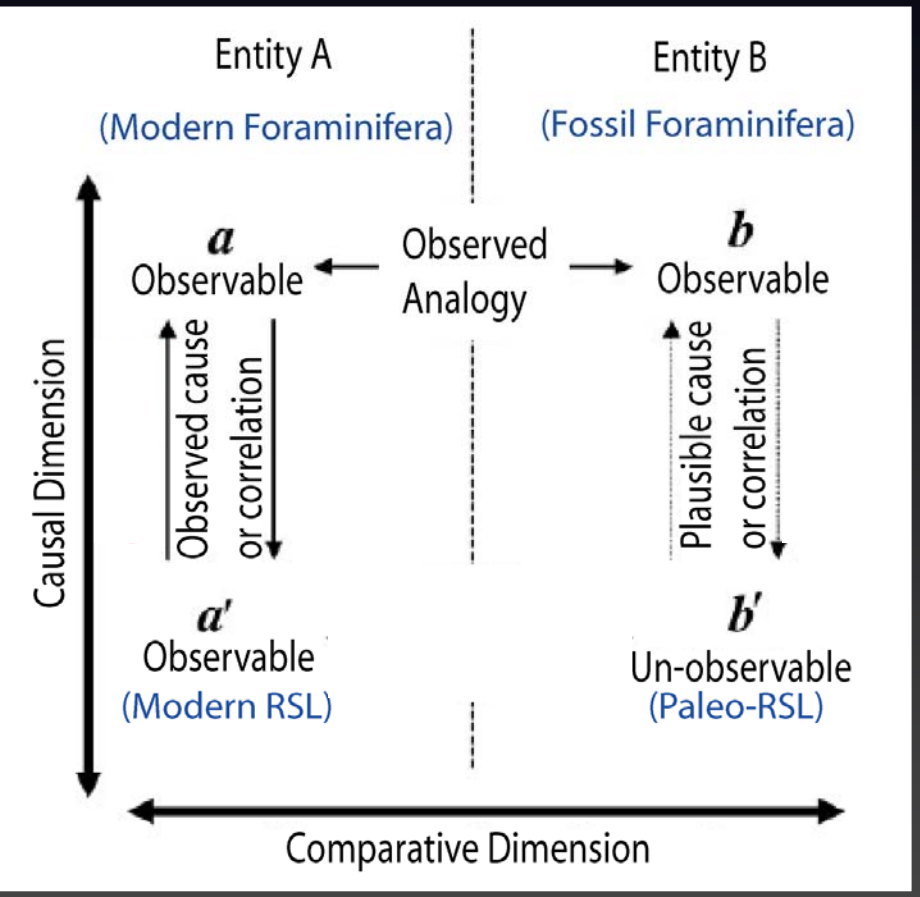


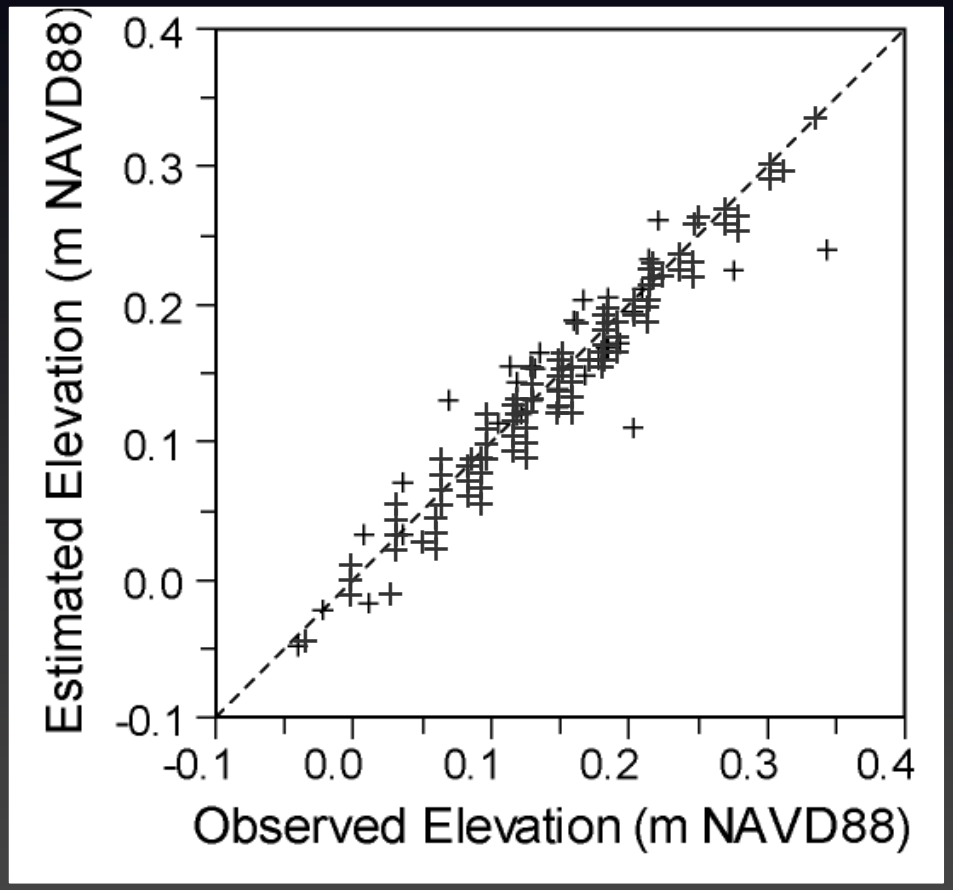
High resolution salt marsh reconstructions can bridge the gap between spatially limited instrumental data and imprecise geological records of RSL change.



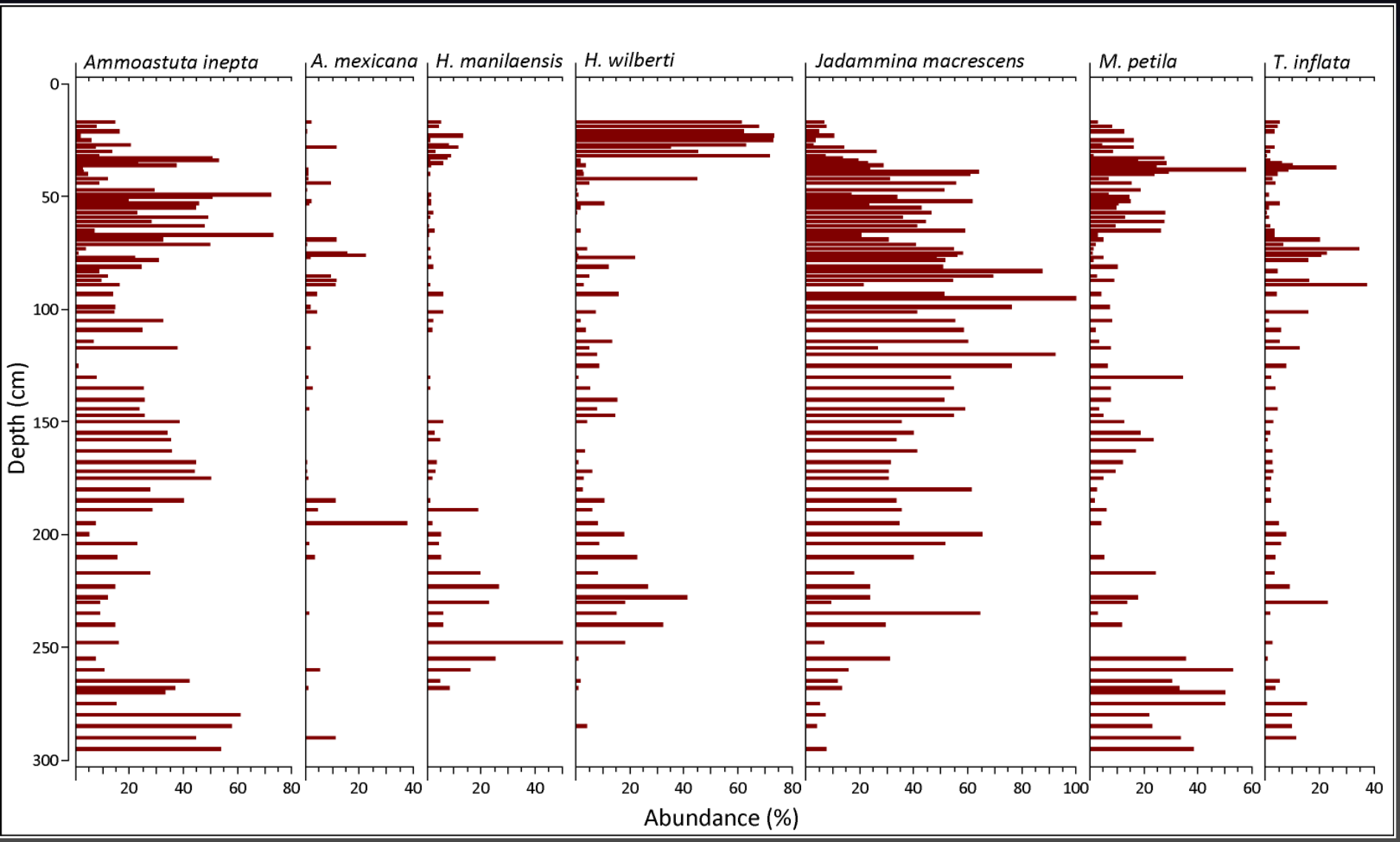
Saltmarsh proxy: forams

- Foraminifera assemblages are vertically zoned
- These modern relationships can be quantified
- They are representative of past conditions encountered in Holocene salt-marsh sedimentary sequences

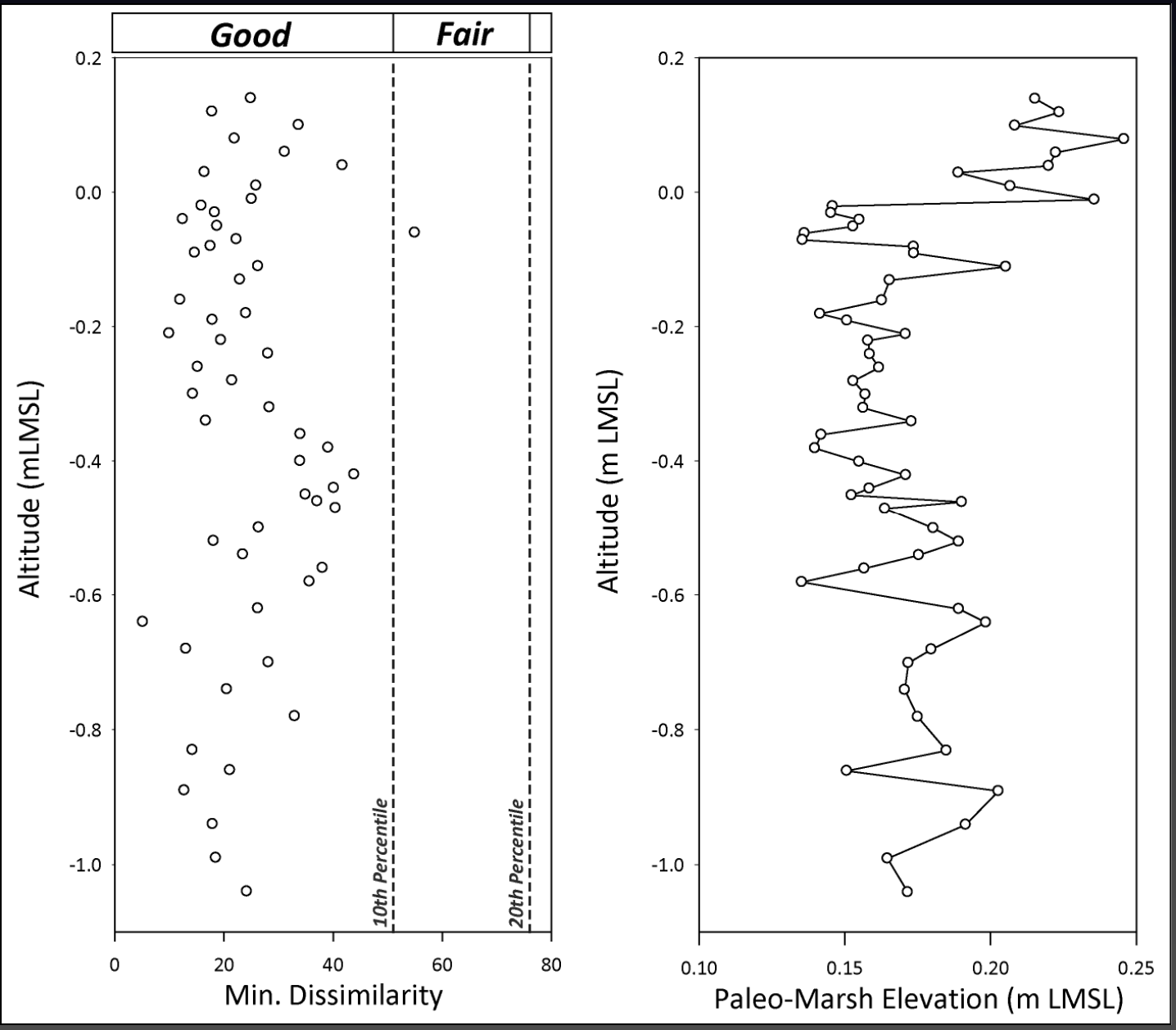




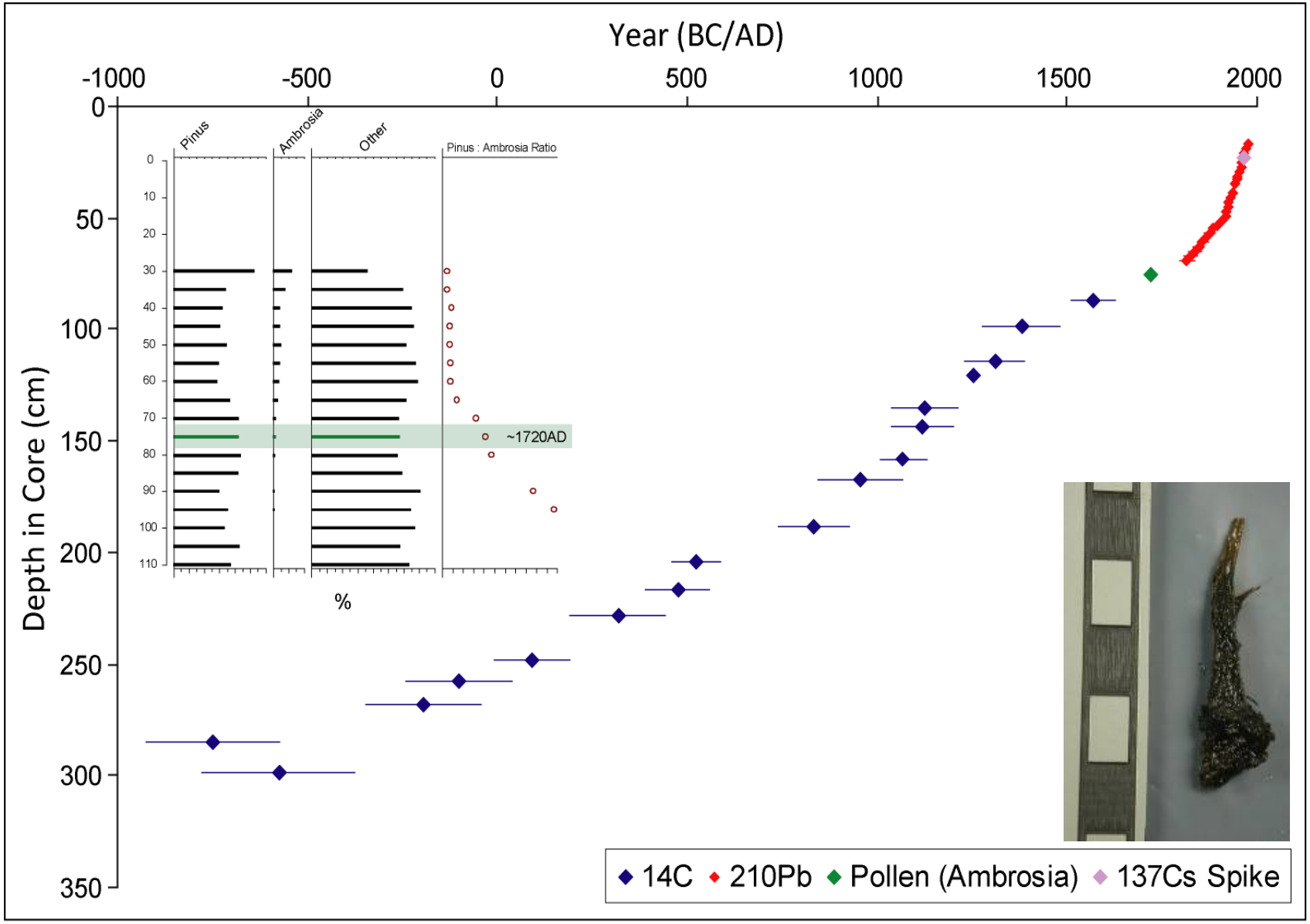
- Transfer functions are empirically derived equations for calculating quantitative, estimates of past environmental conditions from fossil biological data.
- This is an example from modern transects on the Outer Banks of North Carolina. r = 0.9, RMSE = 0.04m (potential precision).



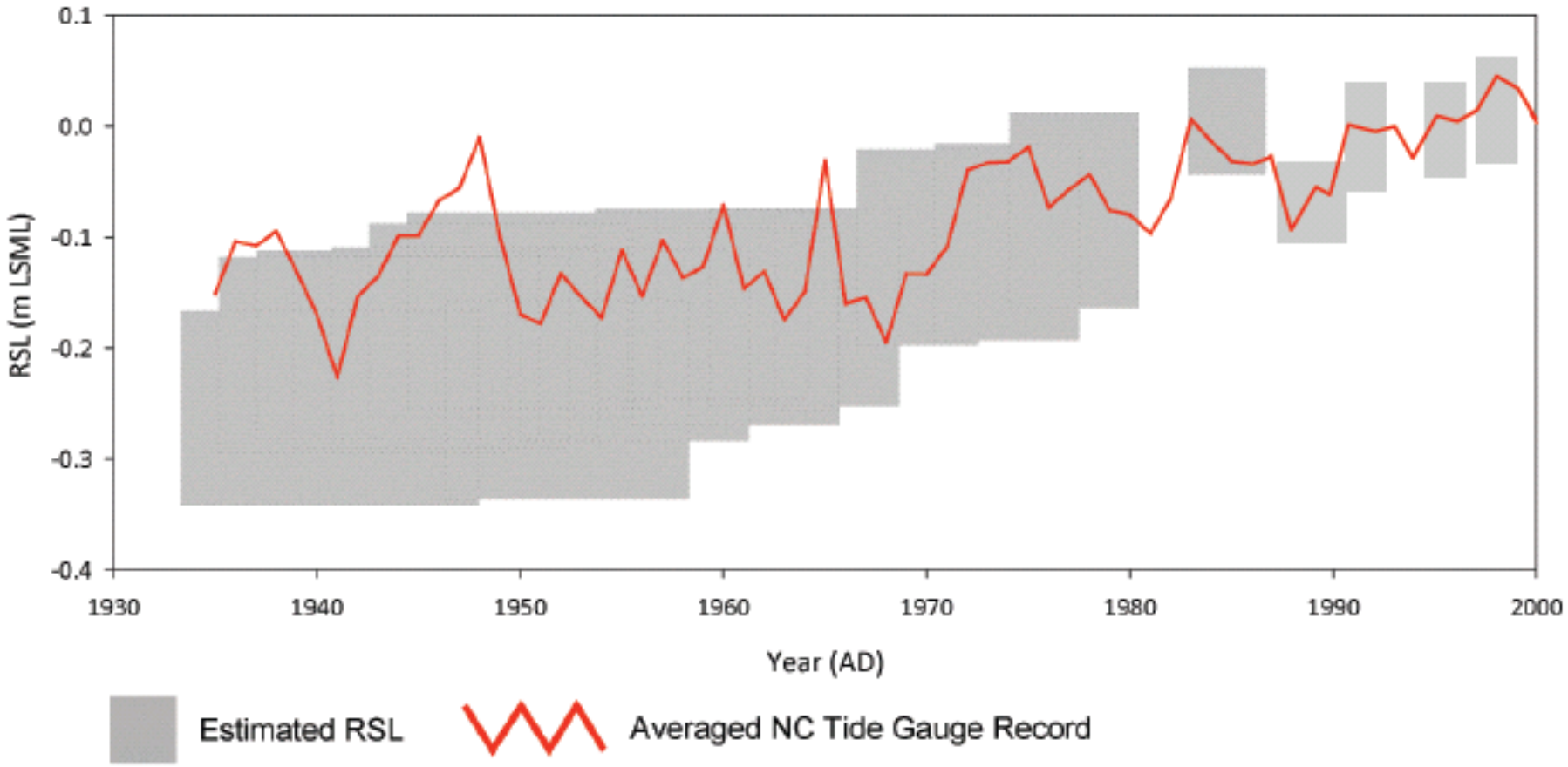
Foraminifera are well preserved in saltmarshes and are counted down core at high resolution. These '*fossil*' foraminifera will provide estimates of former sea levels. This is an example from Sand Point on Roanoke Island, North Carolina.



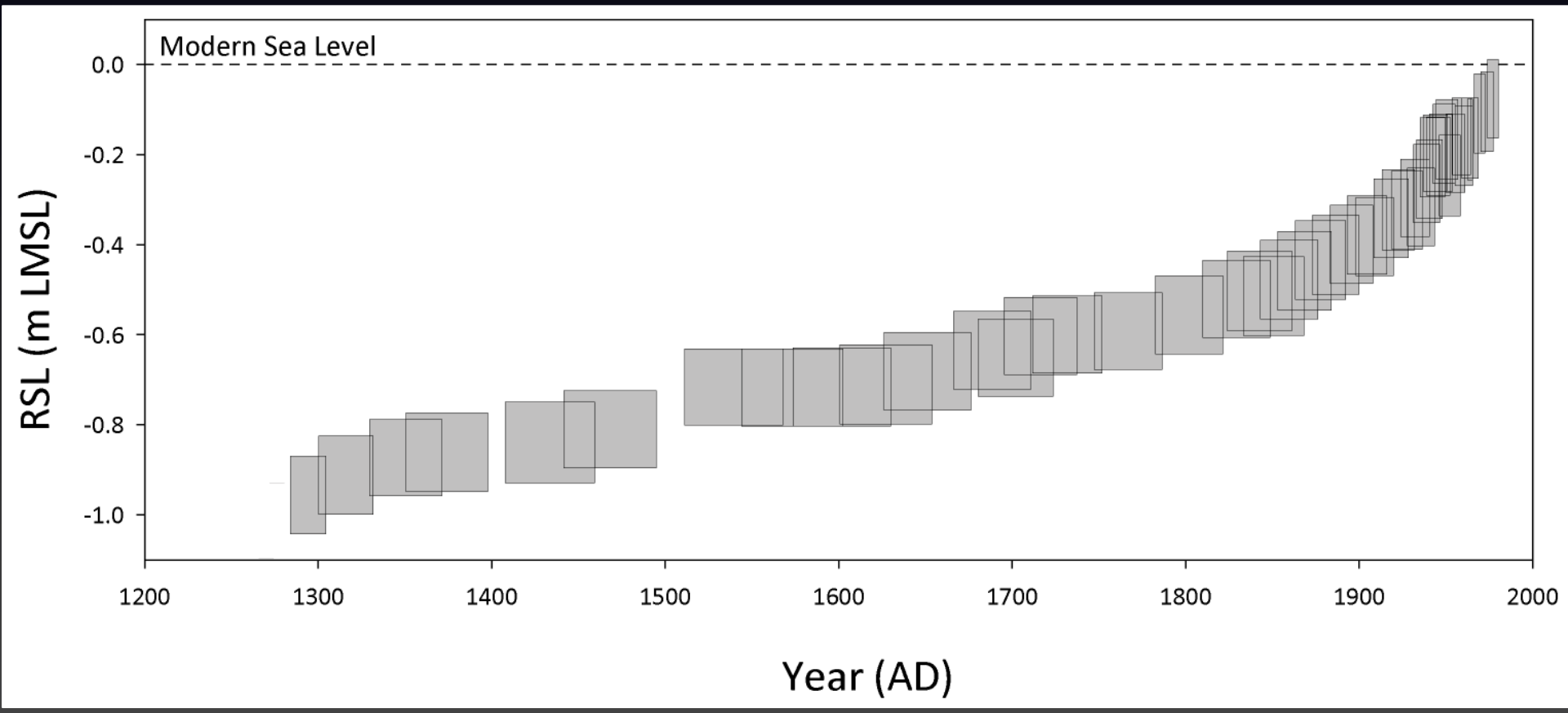
- Application of the transfer function to fossil foraminifera provides estimates of Paleo-Marsh Elevatio).
- Their reliability can be judged using the analogy between modern and fossil samples



Sediments are dated using radiocarbon for the period prior to ~1600AD. Recent parts of the record can be dated using pollen chrono-horizons, 210Pb and 137Cs dating and bomb-spike radiocarbon.



Reconciliation of tide gauge records with RSL estimates from saltmarsh sediments provides a means to validate the methodology and provide confidence in reconstructions of RSL for the period prior to tide gauge records.



- RSL is reconstructed at high resolution to elucidate timing and magnitude of historical accelerated RSL rise.
- Sand Point, NC shows RSL rise accelerate from 0.8 $mmyr^{-1}$ (1300 – 1800 AD) to 1.7 $mmyr^{-1}$ (1800 - 1900 AD) to 4.2 $mmyr^{-1}$ (1950 - 2000 AD). The nearest tide gauge (Duck) shows a comparable rate of 4.27 $mmyr^{-1}$.

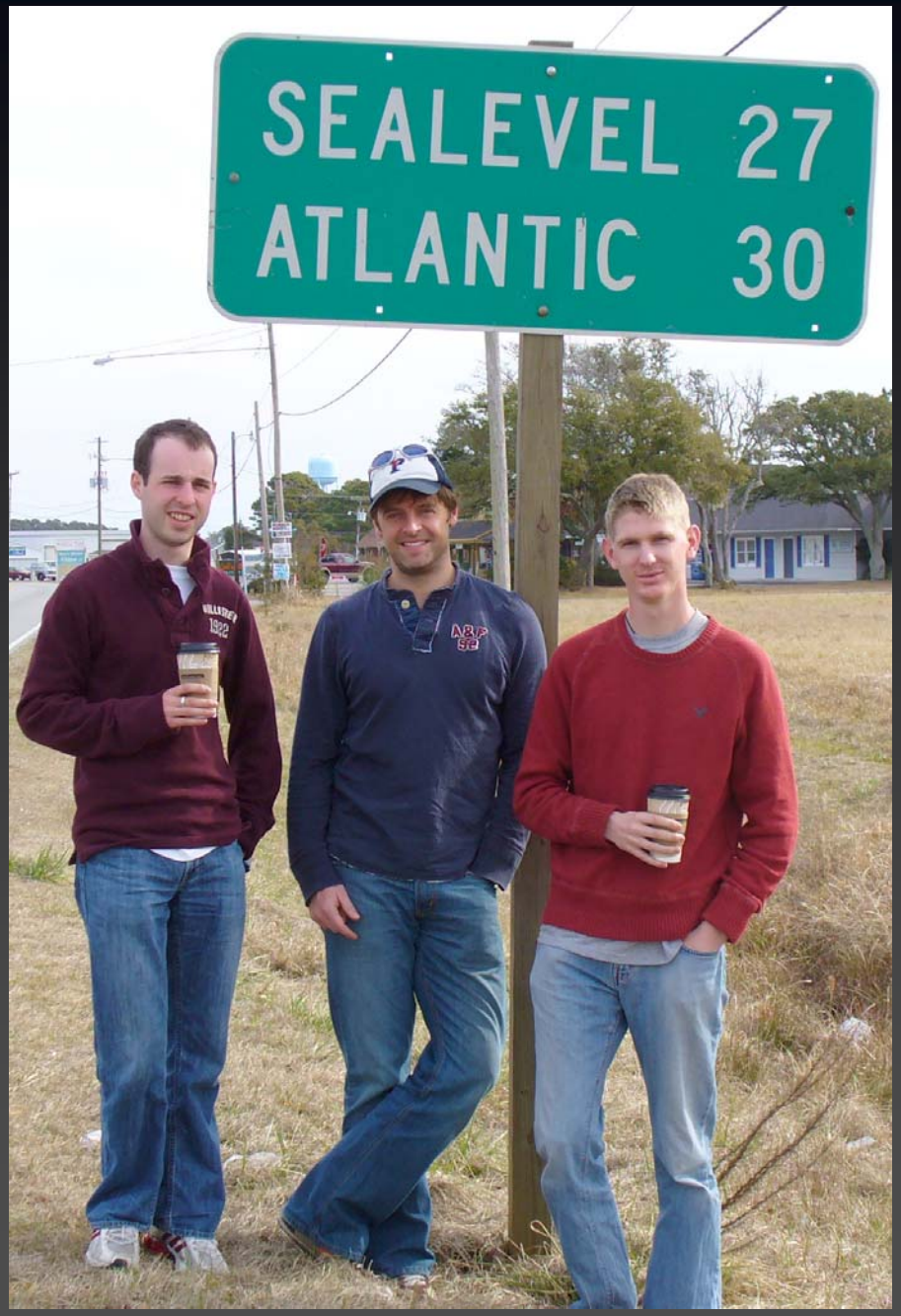
Conclusions

Established methodology

- Holocene RSL observation show a significant misfit with GIA model
- Sea level along the US Atlantic Coast rose at 1.8 ± 0.2 mm yr^{-1} during the 20th century with a is distinct spatial variability from north to south along the coastline

New high resolution techniques

- RSLR accelerating during the 19th and 20th Centuries



North Carolina vs. Delaware