Evidence for Rapid Coastal Changes during the Holocene: The Roles of Climate, Sea Level and Thresholds

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NC CGC North Carolina Coastal Geology Cooperative

Abstract and Introduction

The Outer Banks barrier islands and adjacent estuarine system of North Carolina contain a geologic record which demonstrates that rapid coastal reorganization has occurred in the past. Rapid reorganization is likely the result of a combination of changing sea level, variations in storm patterns, and threshold-crossing accompanied by positive feedbacks. Time slice reconstructions of coastal environments, based upon paleontological, sedimentological, geophysical, geomorphic and geochronologic data reveal at least three episodes of major coastal reorganization along the NC coast during the last 4500 years, which were marked by significant changes in barrier continuity and dynamics. These episodes occurred at ca. 5000-3500 yBP, 1200 yBP (the Medieval Warm Period - MWP) and ca. 500 yBP (the Little Ice Age - LIA). Normal marine salinity units occur in Pamlico Sound, suggesting barrier island collapse. Data also indicate shoreface ravinement several kilometers landward of the modern shoreline between 5-3.5 ka. Sediment accumulation rates within the estuaries increase by a factor of four to six at this time, suggesting a rapid sea-level rise, or a greatly modified tidal regime. Regressive systems above the shoreface ravinement surface suggest an ensuing sea-level fall, or a major increase in sediment flux. Comparison to climate proxy data indicates that this event occurred during a period of rapid climate change and a possible sea-level oscillation. Barrier and estuarine facies associated with the MWP and the LIA have been imaged using geophysical techniques, and cored and dated using radiocarbon and optically stimulated luminescence techniques (OSL). OSL data indicate the occurrence of numerous inlets and wide-spread flood-tide delta formation during both time intervals, suggesting elevated storm conditions (relative to today). Comparison to proxy climate and storm data suggests that inlet activity during the MWP responded to intensified hurricane impacts, while elevated inlet activity during the LIA was likely in response to increased extratropical (nor'easter) storm activity. A general decrease in storminess at mid-latitudes in the North Atlantic over the last 300 years has allowed the system to evolve into a more continuous barrier with few inlets; however, projections of sea-level change and hurricane impacts suggest that the current geomorphic condition is likely to change rapidly.

Figure 1. The northeast NC coastal system is a 300 km long microtidal, wave-dominated barrier island coast that is fundamental to North Carolina's economy. The astronomical tidal range within the APES is approximately 10 cm as a result of the continuous barrier island chain (the Outer Banks) fronting the system. The lack of significant astronomical tides has a profound effect on the coastal morphology and ecosystems (terrestrial and estuarine).

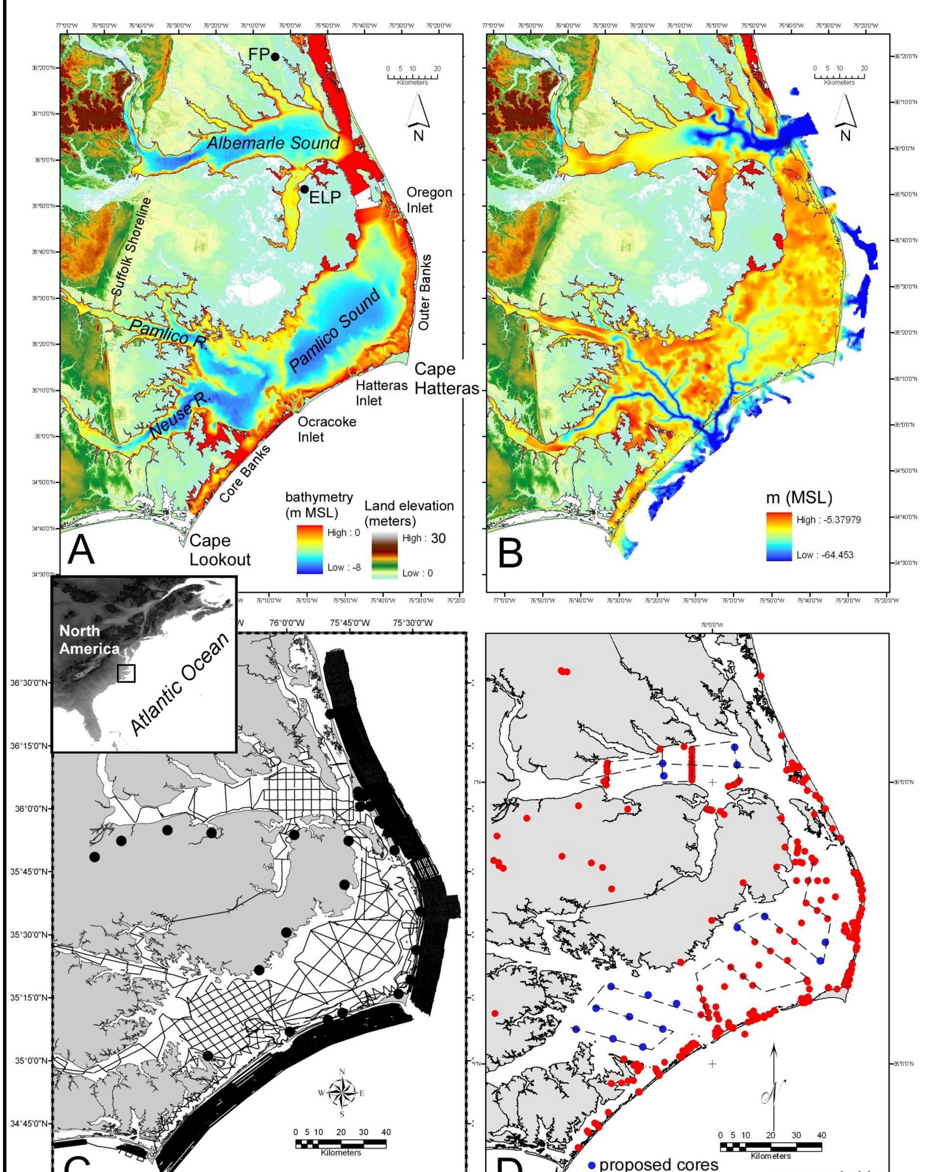


Figure 2. The North Carolina Coastal Geology Cooperative (NCCGC – includes ECU, USGS, NCGS, U. Delaware, U. Penn., VIMS) has a substantial geological database within the coastal system (maps to the left), including (A) the modern bathymetry, (B) the Last Glacial Maximum unconformity (based upon seismic data), (C) 3000 km of seismic data, and (D) >100 cores. These data enable us to reconstruct paleobathymetry, paleoenvironment, and geomorphology during specific timeslices over the last c. 10,000 years.

Late Holocene Changes in Coastal Morphology and Processes

Geologic data reveal two units within Pamlico Sound which contain foraminifera indicating normal marine salinity conditions under the influence of Gulf Stream derived waters (Figs. 3, 4 and 5). These two units date to c. 5000-3750 cal yr BP, and 1200-550 cal yr BP. Additional data show a very high rate of sediment accumulation rates between 5000 and 3500 cal yr BP (Fig. 6), as well as shoreface ravinement landward of the present shoreline (Mallinson et al., 2008; Timmons et al., 2010). Seismic data show a significant erosional surface behind the barrier islands, with scours to nearly 20 meters below sea-level (Fig. 7) which is filled with normal marine salinity units that date to c. 1000 cal yr BP. Together these data indicate a widespread barrier breakdown ("collapse") in the Ocracoke region between approx. 5000-4000 cal yr BP and 1100 to 550 cal yr BP (Fig. 8) (Culver et al., 2007).

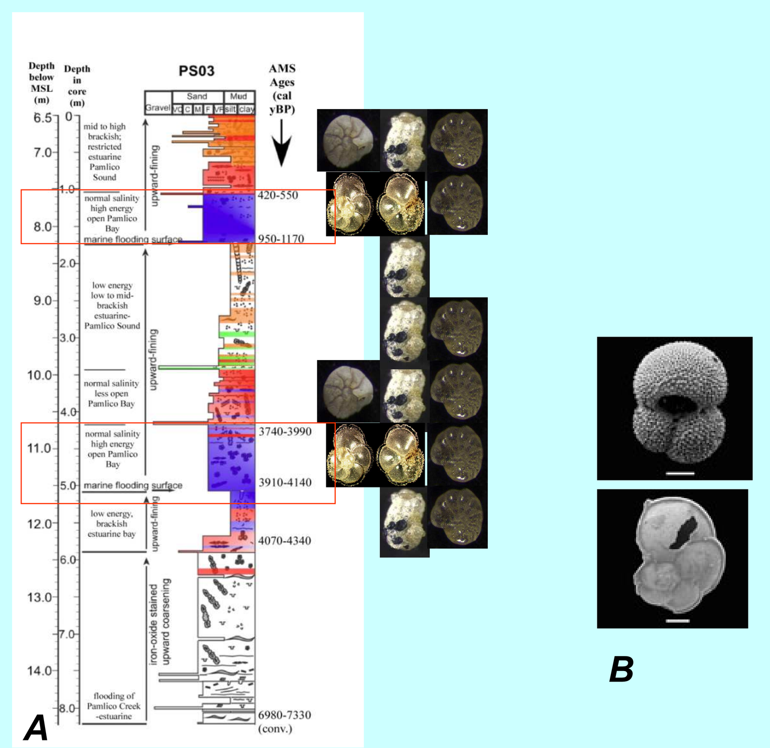


Figure 3. A) Foraminifera assemblages indicate normal marine salinity conditions and widespread open connections to the open ocean at c. 5000 to 3740 cal yr BP, and 1100 to 500 cal yr BP (red boxes). B) The two most abundant planktonic taxa: Globigerinoides ruber (to) and Globorotalia menardii (bottom). These are tropical and subtropical indicators of Gulf Stream influence, and are found within two units within cores of the Pamlico Sound.

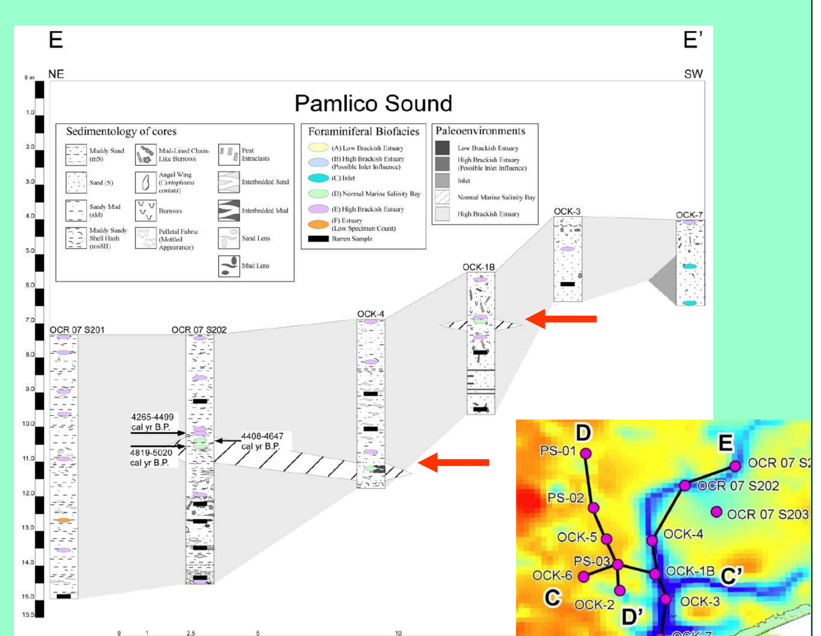


Figure 5. Geologic cross-section (see E-E' on inset map) showing the two units (cross-hatched and indicated by red arrows) within Pamlico Sound (from Metger, 2008).

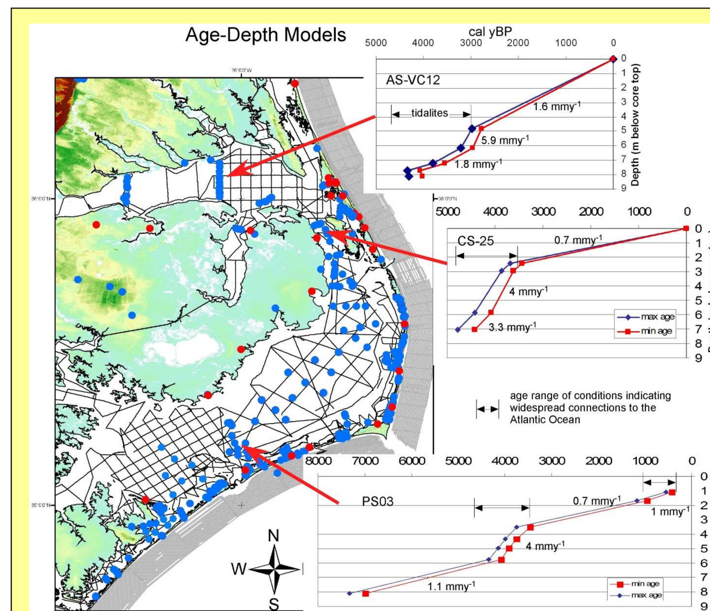


Figure 6. High accumulation rates occurred within the sounds between c. 5000 and 3000 cal yr BP, suggesting a very different hydrodynamic regime, or rapid sea-level rise.

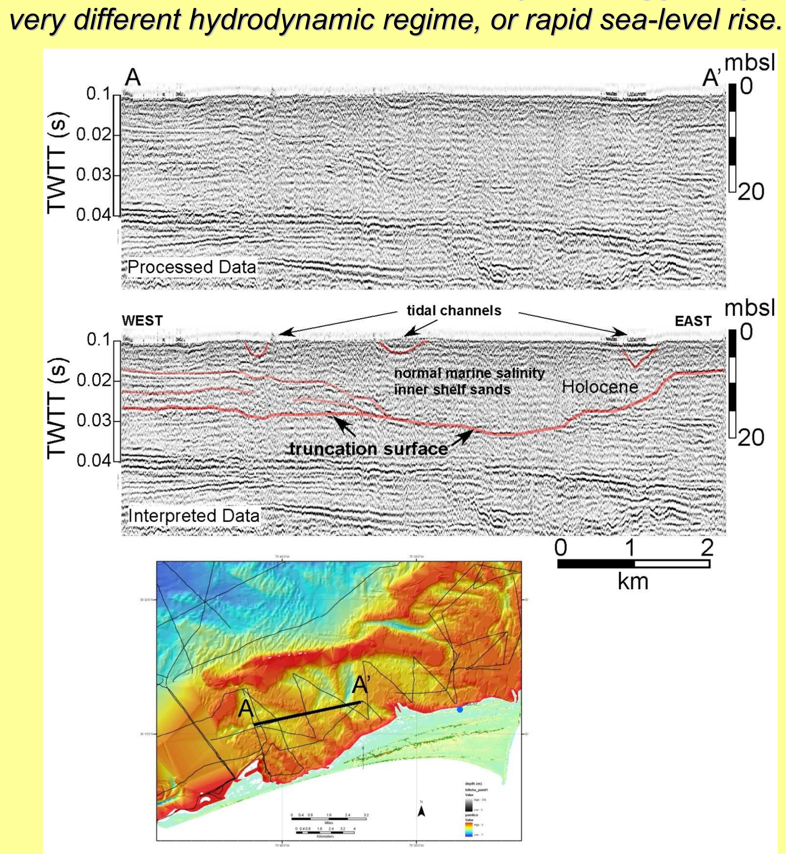
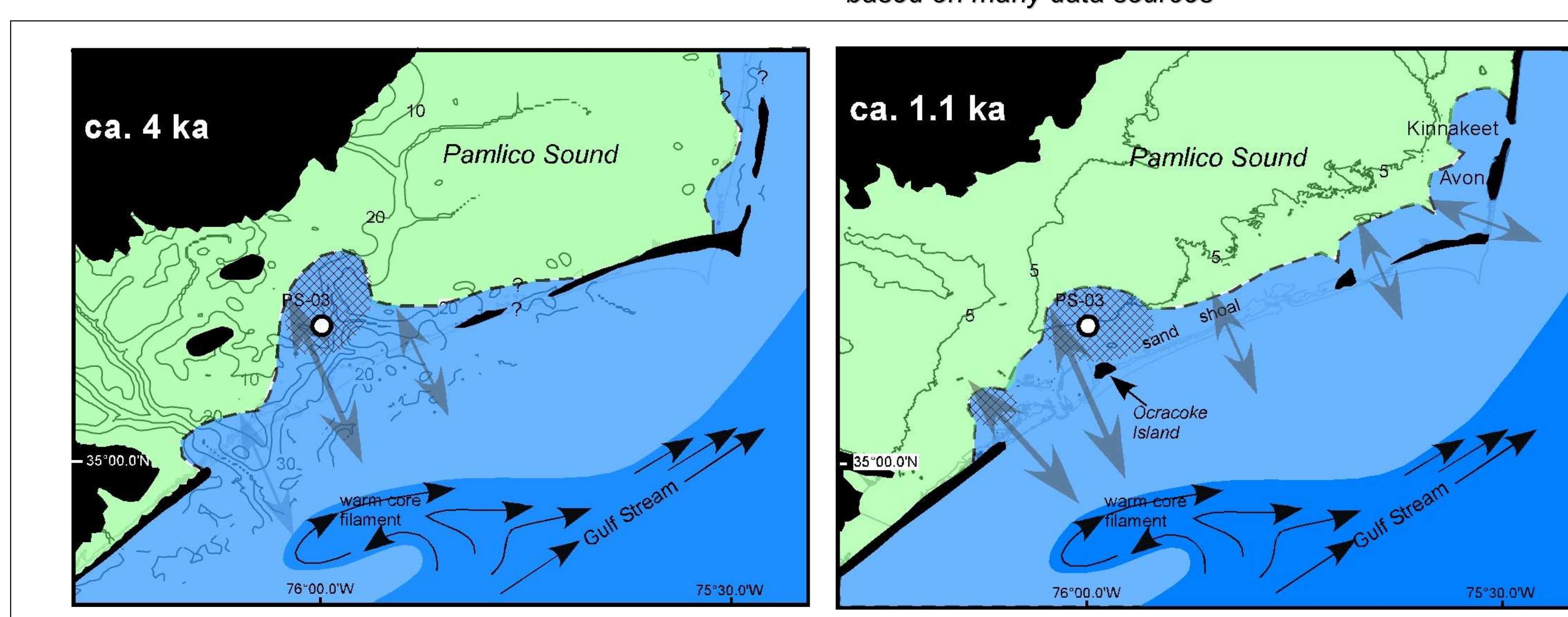


Figure 7. Boomer seismic profile well behind Frisco-Hatteras Village area showing cut-and-fill patterns to nearly 20 mbsl, filled with Holocene normal marine salinity sands dated to c. 1000 cal yr BP.

Figure 8. Time slice reconstructions of paleoenvironment and geomorphology at 4 ka and 1 ka based on many data sources



Research and Management Considerations

Why, when and how rapidly do changes in tidal regime and coastal morphology occur?

How will future changes impact coastal evolution in NC?

To answer these questions:

We are using observations of coastal stratigraphy and paleobathymetry as input to a circulation model to understand past changes of the coastal system in response to storms and sea-level change.

Input from Geologic Constraints

bathymetric models: constrained by core data; seismic data; GPR data;

Paleoenvironment: determined using sediments and microfossil assemblages,

Age: using radiocarbon and optically-stimulated luminescence techniques

Modeling Uses Delft3D software

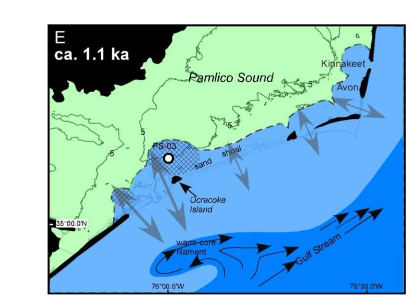
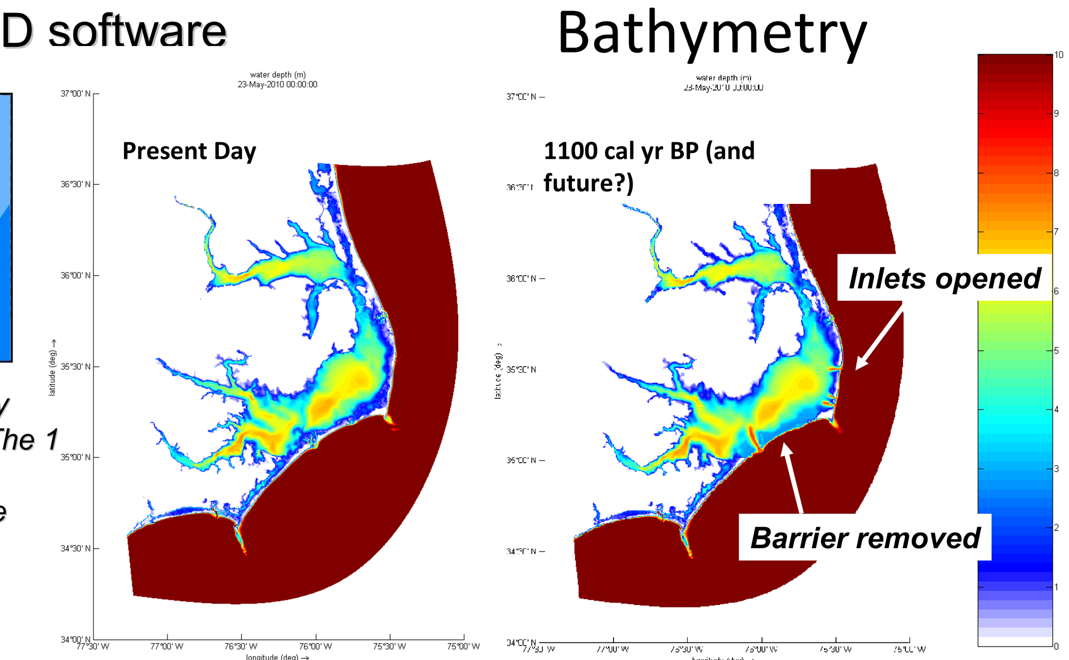


Figure 9. The modern bathymetry was input to test model results. The 1 ka paleoenvironmental scenario (above) was superimposed on the modern bathymetry.

Bathymetry



Model Results

The model outputs (below), based on geologic constraints for the 1100 yBP time slice, indicate that collapse of the Ocracoke Island region, and opening of new inlets through Hatteras Island result in an increase in tidal amplitude of c. 45 cm in northern Pamlico Sound, and a large-scale increase in currents within the system that should greatly modify sediment erosion, transport, and deposition causing rapid morphodynamic readjustment.

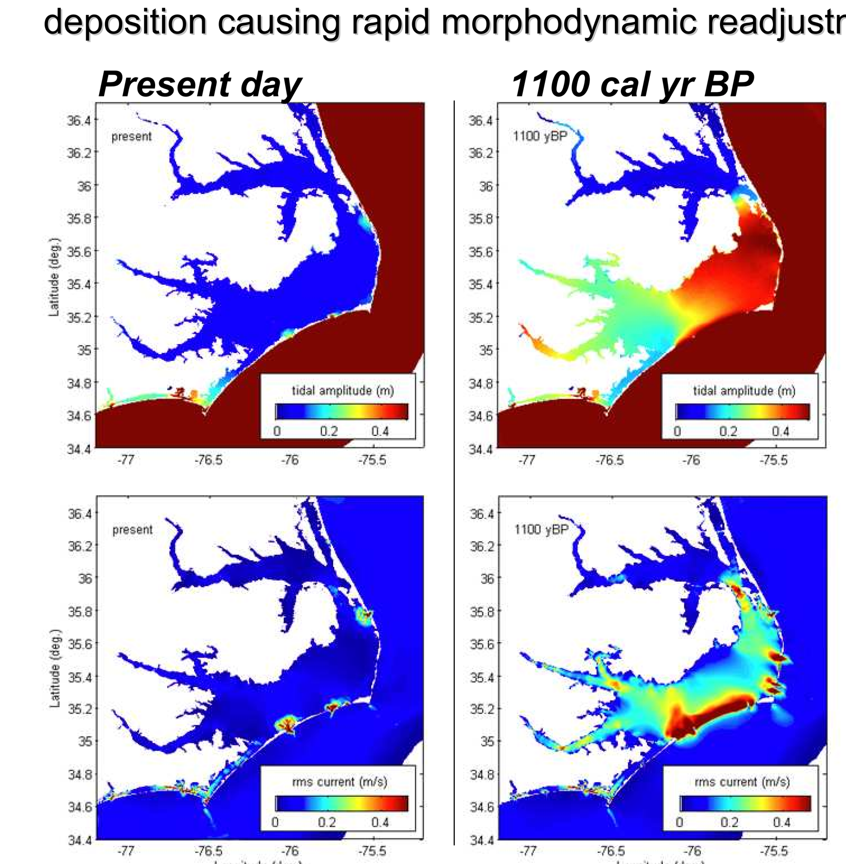


Figure 10. The modern tidal amplitude and currents are reproduced by the model (left-top and bottom respectively) and are reproduced. Modifying the morphology greatly increases the tidal amplitude and currents (right – top and bottom).

Ebb Currents:

Hatteras to Ocracoke

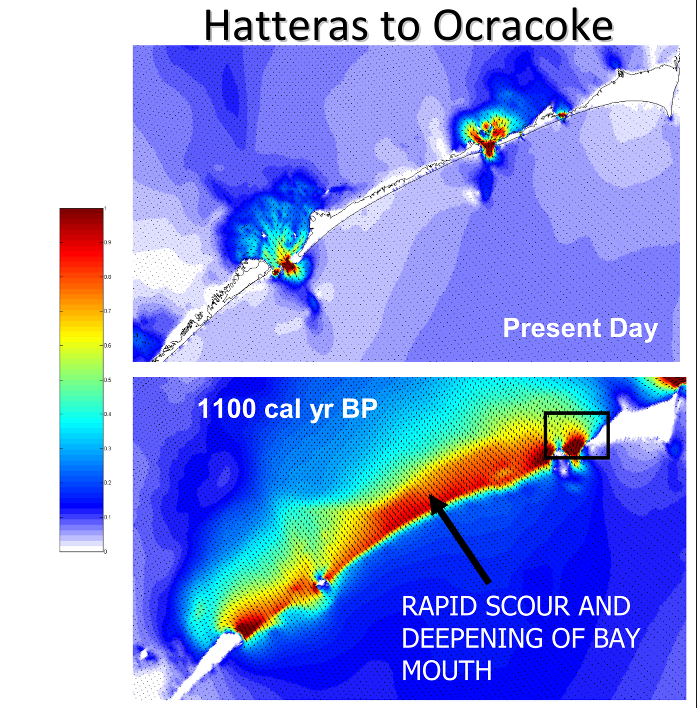


Figure 11. High current velocity over the Ocracoke shoals should scour the area until a new morphodynamic equilibrium is attained. ***The scour shown in Figure 7 may be the "smoking gun".***

Application can give us some idea of the magnitude of change to be expected in different areas, including: Shoreline erosion; Expansion of the intertidal zone; Ecosystem migration; Salinity changes; Residence time changes; Sediment transport and deposition

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