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Coastal Impact Underestimated From Rapid Sea Level Rise

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A primary effect of global warming is accelerated sea level rise, which will eventually drown low-lying coastal areas, including some of the world's most populated cities. Predictions from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) suggest that sea level may rise by as much as 0.6 meter by 2100 [*Solomon et al.,* 2007]. However, uncertainty remains about how projected melting of the Greenland and Antarctic ice sheets will contribute to sea level rise. Further, considerable variability is introduced to these calculations due to coastal subsidence, especially along the northern Gulf of Mexico (see http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml).

Scientists and policy makers may be underestimating the impacts of sea level rise by placing too much emphasis on magnitudes of rise and too little emphasis on rates of rise. Most impact scenarios rely on inundation models, where the landscape elevation is simply flooded as the sea rises (e.g., http://www.epa.gov/climatehange/effects/coastal/slrmaps.html). But past coastal response to rising sea level shows that shoreline evolution is far more complicated to predict because coastal inundation varies spatially and temporally due to differences in subsidence rates and in rates of sediment accumulation. This balance between subsidence and global sea level rise is called relative sea level rise, and when the rate of relative rise exceeds sediment accumulation rates, widespread coastal flooding occurs, even when the magnitude of rise is minimal. For example, in southern Louisiana, increased subsidence and decreased sediment supply has resulted in unprecedented flooding and irreversible coastal change [*Blum and Roberts,* 2009].

Perhaps a better approach involves examining coastal change during times when sea level was rising at rates similar to those of model predictions. Doing this requires careful study of long-term records of sea level rise, derived from radiometrically dated benchmarks for past sea level such as barrier reefs and former shorelines that were submerged by the rising sea. Examining robust sea level curves from the northern Gulf of Mexico (Figure 1) reveals that the current rate of sea level rise worldwide, which averages 3.3 millimeters per year and ranges between 2 and 4 millimeters per year [*McCarthy,* 2009], is about 6 times the average rate (0.6 millimeter per year) for the past 4000 years in the northern Gulf [*Tornqvist et al.,* 2004; *Milliken et al.,* 2008]. According to model projections, the global rate will at least double by the end of this century, exceeding the highest average rate of rise (5 millimeters per year) in the Gulf for the past 7500 years.

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Complex Patterns in Sea Level Signatures From the Gulf of Mexico

During the overall rise of the past 9000 years, the east Texas and western Louisiana coasts experienced episodes of stability and growth followed by rapid shoreline retreat of up to 20 meters per year, while the central Texas coast remained relatively stable [*Rodriguez et al.,* 2004]. Most modern barrier islands and peninsulas of the east Texas coast formed in the past 5500 years, after the rate of sea level rise decreased from an average of 5 to 2 millimeters per year (Figure 1). The oceanfront shorelines of these barriers are now experiencing rapid retreat, but the rate of retreat varies by an order of magnitude along the coast. These differences reflect variations in rates of sediment supply and subsidence, which vary along the coast. If current rates of shoreline movement along the east Texas coast are used to project the shoreline position from when coastal barriers initially formed to today, then the shoreline would be located kilometers landward of its current location. Thus, current rates of shoreline movement are unprecedented and are likely driven by accelerated sea level rise over the past few decades in addition to direct human modifications.

Because ice sheet retreat is governed by several factors that vary spatially and temporally, it is reasonable to assume that overall sea level rise after the Last Glacial Maximum (~20,000 years ago) was episodic and likely punctuated by short-lived (decadal- to century-scale) increases of a few decimeters [*Vaughan et al.,* 2007]. Such events could have profoundly affected low-gradient coasts. Yet teasing out signatures of these events has proven difficult. Even the most detailed sea level curves for the northern Gulf of Mexico are accurate to within only a couple of meters. Further, the offshore record of shoreline migration is largely removed as waves erode deeply into the retreating shoreface. Modern bays have not been subject to the same erosive forces and thus contain a more complete and detailed sedimentary record of their response to rising sea level. The dramatic response of Gulf Coast bays to short-lived and modest increases in rates of relative sea level rise can be seen by examining the evolution of these bays during the past 10,000 years.

Record of Punctuated Sea Level Rise From Gulf Coast Bays

Results from recent studies of the evolution of Gulf Coast bays (Mobile Bay, Calcasieu Lake, Sabine Lake, Galveston Bay, Matagorda Bay, and Corpus Christi Bay) provide a basis for examining how these bays responded to variable rates of sea level rise and sediment supply [*Anderson and Rodriguez,* 2008]. The bays were studied using similar methodologies to obtain comparable results. First, seismic data, sediment cores, and engineering borings were used to construct a detailed map of each bay's bathymetry, which revealed that they are flooded paleovalleys. Next, high-resolution seismic data helped to characterize seismic units and map bounding surfaces. These results were combined with sedimentological and paleontological analysis of drill cores to reconstruct paleoenvironments and to examine their up-valley migration through time. In each bay the succession of sedimentary deposits resulting from flooding of the valley represents, from bottom to top, fluvial, bay-head delta, middle-bay, and tidally influenced lower-bay environments (see colored deposits in Figure 2).

These results reveal that deltas that occupied the upper portions of the bays (bay-head deltas) experienced abrupt landward shifts indicating times when rates of sediment accumulation were exceeded by the rate of sea level rise. These events are conspicuous in sediment cores as bay mud with oyster shells overlying organic-rich mud with shells of the *Rangia* species, a mollusk that today lives only in bay-head deltas. Seismic records show that the contact between bay and bay-head delta deposits is a prominent surface that can be traced for kilometers up and down the axis of each bay. These are considered flooding surfaces because they reflect an overall deepening of the bay. The timing and duration of individual flooding events recorded by these flooding surfaces are constrained to within one to two centuries using radiocarbon ages above and below these surfaces at two or more locations along the axis of each bay (Figure 2). The underlying assumption is that flooding events that are correlative between bays, and therefore regional in extent, were caused by accelerated sea level rise, whereas more localized flooding events are attributed to reductions in sediment supply or differences in the size and shape of the valley being flooded. The latter effect is constrained using detailed maps of the valleys that were flooded.

Of the six bays investigated, Mobile Bay has had the most unique evolution, having experienced rapid inundation around 8200 years ago and relatively stable conditions since that time. Mobile Bay differs from the other bays in that it occupies a more deeply incised paleoriver valley and therefore represents a higher-gradient system that is less prone to flooding by more subtle sea level events.

Louisiana and Texas bays, which occupy low-gradient valleys, experienced frequent and rapid change from the time of their initial formation, between about 9800 and 9500 years ago, until about 7500 years ago (Figure 2). During these events, there were landward shifts of bay-head deltas of as much as a few tens of kilometers in two to three centuries, with maximum rates of bay-head delta migration of about 150 meters per year. Several flooding events appear to have been contemporaneous, having occurred about 9800–9500, 8900–8500, 8400–8000, 7900–7500, and 7400–6800 years ago (Figure 2). Hence, these events are interpreted as having been caused by episodes of rapid sea level rise. In fact, the event of 8400–8000 years ago has been observed globally and is believed to have been caused by mass wasting of the Laurentide Ice Sheet [*Kendall et al.*, 2008]. The other flooding events have gone largely unrecognized.

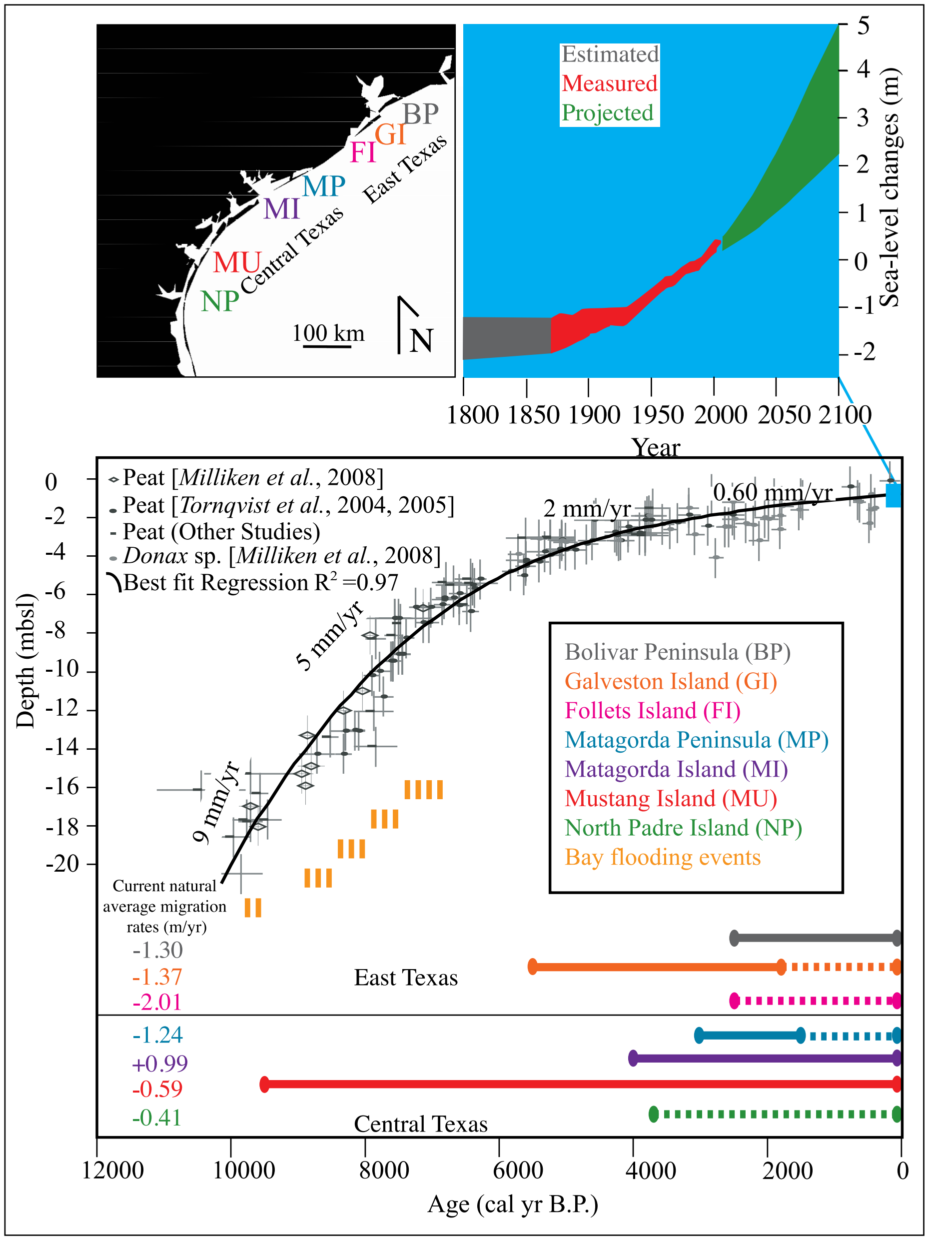

Fig. 1. Coastal evolution in western Louisiana and Texas relative to sea level rise. The location of barrier islands is depicted at top left. The composite sea level curve for the northwestern Gulf of Mexico, based on radiocarbon dates from peat samples taken at different depths (denoted by meters below sea level (mbsl)), is from Milliken et al. *[2008]. Error bars are noted. Historic sea level records (1800 to present) and projected future ranges are also shown, at top right (from* Bindoff et al. *[2007],* Rahmstorf *[2007], and* Pfeffer et al. *[2008]). The dashed orange vertical lines (bottom) represent periods of rapid flooding of Texas and Louisiana bays that are believed to have been caused by short-lived rapid sea level rises, perhaps a few decimeters in magnitude. Colored horizontal bars denote previously established coastal barrier island histories, with dashed lines representing retreat and solid lines representing stability. Note Mustang Island's long history of stability, in contrast to barrier islands of the upper Texas coast that formed after sea level rise rates slowed to 2 millimeters per year or less. Ages are in calibrated years before present. (cal yr B.P.). Current natural (not of clear anthropogenic influence) rates of shoreline migration (from Texas Bureau of Economic Geology) are shown to the left of each barrier island.*

Implications for Coastal Change in the 21st Century

The use of inundation models to portray future coastal change conveys a message to the public and to policy makers that the impact of accelerated sea level rise is uncertain and will not occur for decades. These models place too much emphasis on large magnitudes of sea level rise and largely ignore other factors such as subsidence and sediment supply. In fact, the low-gradient Louisiana and Texas coasts are currently experiencing unprecedented change in some areas that is due to the inability of sedimentation to keep pace with accelerating sea level rise.

This case study of northern Gulf of Mexico bays provides documentation that dramatic change in these environments occurred at times when the rate of sea level rise was in the range that is predicted for this century. This suggests that more widespread coastal change will occur as the rate of sea level rise continues to increase. Further, inundation models should be used with caution because they underestimate the timing and extent of coastal change.

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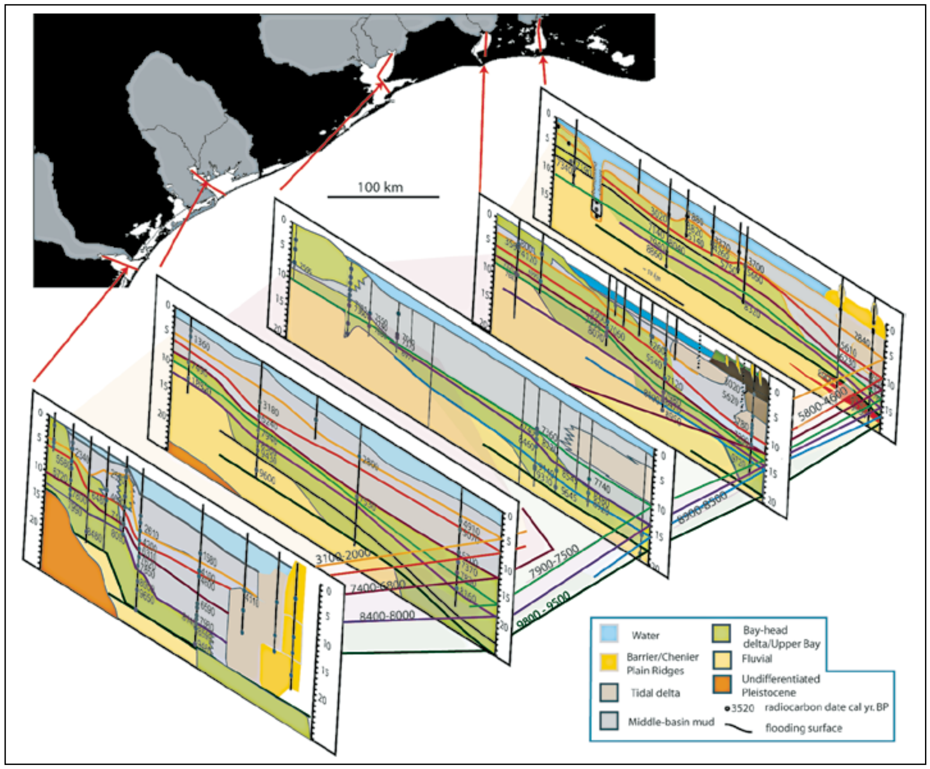

Fig. 2. Geological cross sections of five Gulf Coast bays, with submarine sedimentary layers marked as different colors. Also shown are flooding surfaces that mark abrupt changes in bay environments. Major flooding surfaces are designated with bold colored lines along with the ages of these surfaces. Flooding events that occurred around 9800–9500, 8900–8500, 8400–8000, 7900–7500, and 7400–6800 years ago appear to correlate across the region and most likely were formed by rapid sea level rises. The dark vertical lines designate drill cores acquired along the axis of each valley, with radiocarbon ages provided. Depths are in meters.

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