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Supplemental Material

Increasing the Probability of Detecting Storms

Nine back-barrier or coastal salt marshes were selected for reconnaissance gouge augering in hopes of finding an extensive record of storm deposition. These localities were chosen because they potentially contained a long, stratigraphically complete storm record within the strata (not in proximity to modern or known prehistoric inlets) and they were close enough to Onslow Bay to receive marine sediments during large storms. Nine total sites were cored to a depth of auger refusal and the sediments were analyzed to detect sandy layers that may represent storm deposits.

Based on the depth of successful coring and the sandy layers present, three localities were selected for more extensive coring and more detailed sedimentalogical and micropaleontological analysis: Tar Bay Landing, Alligator Bay, and Oak Island (although only the first two localities clearly had downcore sandy deposits enriched with marine foraminifers). A total of seventeen additional cores were recovered from these three marshes. These localities were also selected because they represented three different latitudes from within Onslow Bay, offering a better probability to detect different hurricane strikes or perhaps correlate hurricane deposits between marshes. The intended goal of this project was to use the methodology previously published for successful paleostorm detection in South Carolina (discrete sandy layers of sediment enriched with offshore-indicative foraminifers interbedded in marsh strata) (Hippensteel and Martin, 1999, 2000; Hippensteel et al., 2005) to create several similar storm records for the marshes along Onlsow Bay.

Seven auger cores were recovered to refusal from the high marshes of Tar Bay Landing and Alligator Bay, and three auger cores were recovered from Fort Caswell Beach.

Sedimentological analysis was conducted on the strata from these seventeen cores while detailed foraminiferal analysis was conducted on four cores from Tar Bay Landing and Alligator Bay and two cores from Fort Caswell Beach.

The high marsh subenvironment was selected for coring because bioturbation has been demonstrated to be lower in the high marsh subenvironment when compared to low and intermediate marsh environments (Hippensteel and Martin, 1999, 2000). In all cases the gouge auger core reached a minimum depth of 3 m. Cores were divided into 30-cm lengths and returned to UNC Charlotte in plastic bags to prevent drying prior to sedimentological and micropaleontological analysis. Surface (0-2 cm) sediment samples were also taken from each of the following subenvironments to aid in downcore paleoenvironmental interpretations: Beach/Dune, Extreme High Marsh (high marsh/mainland fringe), High Marsh, Low Marsh, Extreme Low Marsh (low marsh/estuary or tidal creek transition), Estuary (tidal creek).

Identification of Storm Deposits

Modern and downcore samples were wet-sieved using 1-mm, 0.5-mm, and 0.074-mm screens. Grain-size distribution was measured for each sample to facilitate comparison between modern and buried samples. The 0.5-mm and 0.074-mm screenings were analyzed for microfossil content while the samples were still wet. Cores were sampled at 1-cm increments for the upper 3-m of the cores and two 1-cm^3 subsamples were cut from the center of each gouge-auger sample for foraminiferal analysis. This high resolution sampling interval provided 6000 samples for analysis. As with the modern foraminiferal assemblages, foraminifers were picked from the downcore samples and all micropaleontological analysis was conducted while the samples were wet.

Samples were also sieved to measure the percent by volume of sediment that was coarser than 0.5 mm. The modern marshes in this region are composed of primarily mud with less than 20% by volume medium (or coarser) sand, although most marshes appeared to have a higher sand content closer to the high marsh fringe/mainland transition. The beaches, dunes, and modern overwash deposits, however, are nearly entirely composed of medium or medium-coarse, well-sorted sands.

Downcore washover or storm deposits in the marsh strata were identified based on sedimentological criteria (increase in grain size of the samples) and changes in the microfossil assemblage (offshore-indicative taxa present). Benthic marine taxa typical of the inner shelf in this region include *Elphidium* spp., *Ammonia* spp., *Hanzawaia stratoni, Nonionella atlantica*, and *Buccella inusitata* and the planktonic taxa *Globigerinoides ruber* and *Globorotalia menardii* (Culver et al., 2006). Initial analysis of the reconnaissance cores also revealed the presence of the offshore taxa *Quinqueloculina* spp. and *Rosalina* spp. Marsh deposits are characterized by agglutinated taxa including *Trochammina inflata, Miliammina fusca, Tiphotrocha comprimata, Jadammina macrescens, Arenoparrella mexicana,* and *Haplophragmoides wilberti.*

Geochronology of the cores was established using seven radiocarbon dates of in situ mollusk shells and halophyte remains. The Radiocarbon analysis was conducted by the Center for Applied Isotope Studies at the University of Georgia (Table 1). Four dates were obtained for samples from the marsh cores from Tar Bay Landing and the other three dated samples came from Alligator Bay.

Hurricane Irene

Atmospheric and Oceanic Observations

The atmospheric and oceanic observations analyzed in this study were collected between 26 and 29 August as Irene approached and passed just east of Onslow Bay. During this period, Irene was moving slowly north-northeast at ~7 knots with tropical storm force winds extending over 200 km from the storm center.

The National Data Buoy Center (NDBC) Beaufort (BFTNY) and Wrightsville Beach (JMPN7) tidal stations were selected to characterize the atmospheric and surge conditions during the passage of Irene through the core site study area, while the Onslow Bay (41036), Frying Pan Shoals (41013), and Masonboro Inlet (41110) buoys were selected to characterize the offshore and near-shore wave conditions. These observations were supplemented with rainfall data from nearby NOAA Automated Surface Observing System (ASOS) stations at Morehead City (KMRH) and Wilmington (KILM). The locations were selected due to their close proximity and continuous hourly data records throughout the 3-day period. Additional atmospheric and oceanic observations from sites elsewhere along the Carolina coast were analyzed and simply reaffirm the presented data. Detailed information on platform configuration, sensor descriptions and accuracy, data acquisition, and quality control is available at the NDBC (http://www.ndbc.noaa.gov/) and NOAA (http://www.nws.noaa.gov/asos/) websites.

Selection of Storm Deposit Sampling Locations

Sampling locations were selected with similar geomorphological characteristics to minimize the effects of species specific biogeographic variation and subenvironmental preference. In other words, the low marsh subenvironment sample at Alligator Bay, for example, was taken from a site with approximately the same elevation and vegetation as the other three low marshes. Each of the four marshes in this study was primarily vegetated by *Spartina alterniflora* in the Low Marsh and Extreme Low Marsh subenvironments and *Juncus roemerianus* in the High Marsh subenvironment. The shore-perpendicular sampling transect extended from the shallow subtidal to the high marsh and is typical of sampling strategies used in sea level studies from North Carolina (Culver and Horton, 2005). Sampling was also conducted at approximately the same time of year in each marsh to minimize seasonal changes in foraminifer populations or subenvironment preference.

Collection and Analysis of Foraminiferal Data

To assess the changes in foraminiferal populations before and after Hurricane Irene, surface (0-2 cm) samples were taken during the late spring and summer of 2011. Samples were taken from four marshes along Onslow Bay from the following subenvironments: High Marsh, Low Marsh, Extreme Low Marsh (low-marsh/tidal-creek transition) and Tidal Creek (at the sediment/water interface; 0.5 m water depth). Subenvironments were determined based on elevation above mean-high tide and halophyte distribution.

A 2 cm^3 sediment sample was taken from four locations with each subenvironment at each marsh yielding 64 samples (four samples from each subenvironment at each of four subenvironments at each of four marshes). Samples were wet-sieved using 1-mm, 0.5-mm, and 0.074-mm screens and all foraminifers from within the 0.5-mm and 0.074-mm screenings were wet-picked and identified. Samples were not allowed to dry.

This identical sampling protocol was followed in the same marsh subenvironments immediately after Hurricane Irene's landfall. This second sampling took place on September 2 and 3, 2011, within a week after the hurricane passed through Onslow Bay. The negligible time period between landfall and sampling diminished post-storm alteration of foraminiferal populations, as well as changes to the assemblages from bioturbation or taphonomic loss.

Supplemental Table 1. Details of the radiocarbon analyses used to establish the geochronology of the paleostorm record from Tar Landing Bay (TLB) and Alligator Bay (AB). The uncalibrated dates have been given in radiocarbon years before 1950 (years BP), using the ^{14}C half-life of 5568 years. The error is quoted as one standard deviation and reflects statistical and experimental errors. AMS ^{14}C age estimates calibrated using CALIB REV 6.0.0 (Stuiver and Reimer, 1993) with calibration data from Reimer et al., 2009.

Location (depth)	UGAMS#	Sample ID	Material	δ13C‰	^{14}C age years, BP	±	pMC	±	2-σ age range cal BP
TLB (0.80 m)	6564	FMAC 06-02	plant	-16.2	360	3	95.64	0.30	316 - 499
TLB (0.95 m)	6563	FMAC 06-01	plant	-17.1	540	25	93.46	0.30	516 - 629
TLB (1.15 m)	6958	FMAC 09-02	shell	-0.1	800	20	90.55	0.25	148 - 489
TLB (1.20 m)	6959	FMAC 09-03	shell	0.0	850	20	89.96	0.25	264 - 502
AB (2.15 m)	5959	ABAC 04-02	plant	-27.6	1700	50	80.90	0.53	1422 - 1729
AB (2.20 m)	6953	ABAC 09-01	shell	-0.3	1640	20	81.54	0.23	938 - 1247
AB (2.70 m)	6568	ABAC 05-02	shell	0.4	1520	25	82.73	0.28	791 - 1141
FC (0.90 m)	6955	FCAC 02-06	plant	-26.6	760	20	90.94	0.25	671 - 724
FC (1.30 m)	6558	FCAC 02-01	plant	-27.1	1180	25	86.34	0.28	1008 - 1175
FC (1.80 m)	6559	FCAC 02-02	plant	-28.7	1240	25	85.66	0.27	1081 - 1263

Supplemental Table 2. Previous paleotempestology studies.

1) Central and Southwestern ME, (Buynevich et al., 2004)
2) Little Sippewissett Marsh, MA (Madsen et al., 2009)
3) Mattapoisett Marsh, MA (Boldt et al., 2010)
4) Western Long Island, NY (Scileppi and Donnelly, 2007)
5) Brigantine, NJ (Donnelly et al., 2004)
6) Whale Beach, NJ (Donnelly et al., 2001)
7) Central DE (Maurmeyer and John, 1979)
8) Onslow Bay, NC (Hippensteel and Garcia, 2013)
9) Masonboro Island, NC (Hosier and Cleary, 1977)
10) Murrells Inlet, SC (Collins et al., 1999)
11) Prices Inlet, SC (Collins et al., 1999)
12) Folly Island, SC (Hippensteel and Martin, 1999)
13) Wassaw Island, GA (Kiage et al., 2011)
14) West Central FL (Sedgwick and Davis, 2003)
15) Apalachee Bay, FL (Lane et al., 2011)
16) Eastern and Western Lake, FL (Das et al., 2013)
17) Western Lake, FL (Liu and Fearn, 2000; Lu and Liu, 2005)
18) Little Lake, AL (Liu et al., 2008)
19) Dauphin Island, AL (Froede, 2006)
20) Ocean Springs, MS (Horton et al., 2009)
21) Pearl River Marsh, MS/LA (Reese et al., 2008)
22) Constance Beach, LS (Williams and Flanagan, 2009)
23) Clam Lake, TX (Williams, 2010)
24) Laguna Madre, TX (Wallace and Anderson, 2010)
25) Big Culebrita Salt Pond, PR (Donnelly, 2005)
26) Laguna Playa Grande, PR (Woodruff et al., 2008)