A Tale of Two Storms: Surges and Sediment Deposition from Hurricanes Andrew and Wilma in Florida's Southwest Coast Mangrove Forests

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Hurricanes can be very different from each other. Here we examine the impacts that two hurricanes, Andrew and Wilma, had in terms of storm surge and sediment deposition on the southwest coast of Florida. Although Wilma was the weaker storm, it had the greater impact. Wilma had the higher storm surge over a larger area and deposited more sediment than did Andrew. This effect was most likely due to the size of Wilma's eye, which was four times larger than that of Andrew.

Introduction

Hurricanes can be as different from each other as people are. Some hurricanes are small and compact; wound up tight, they are lean, mean, fighting machines. Others are big and wide; you could almost call them portly. Hurricane Andrew in August 1992 was the former, and Hurricane Wilma in October 2005 was the latter. Andrew was a category 5 storm at landfall, the highest category, but its eye was surprisingly small, only some 20 mi (32 km) across. Wilma was a category 3 at landfall but had an eye over 80 mi (128 km) wide, four times the size of Andrew's eye. The storms came from opposite directions, and both impacted important resources along Florida's southwest coastline (fig. 1).

This coastal area has large tracts of mangrove forests. These forests are to south Florida what salt marshes are to the northern Gulf of Mexico and Atlantic coasts. Mangroves provide habitat for endangered species such as roseate spoonbills (*Ajaia ajaja*) and American crocodiles (*Crocodylus acutus*). Mangroves are the food base that supports important commercial and recreational fisheries including snook (*Centropomus undecimalis*), tarpon (*Megalops atlanticus*), mangrove snapper (*Lutjanus griseus*), and red drum (*Sciaenpos ocellatus*). The thick root systems of mangrove forests trap and bind sediment, thus aiding in stabilizing shorelines. Mangrove ecosystems clearly provide goods and services to human society (Ewel and others, 1998; Gilbert and

Janssen, 1998). Unfortunately, throughout most of the world, mangrove forests are being cleared for a variety of coastal developments including ports, housing, and aquaculture ponds (Valiela and others, 2001).

The passage of two such large hurricanes in a relatively short time span (13 years) allows scientists to begin asking questions concerning their multiple effects or cumulative impacts. Additionally, we know that sea level is rising in south Florida (Maul and Martin, 1993). Thus we have the opportunity to study the interactions between disturbance and sea-level change. People cannot manage what they do not understand; therefore, proper management of these valuable forests is dependent on a sound scientific understanding of their ecology, including how mangrove forests respond to natural disturbances such as hurricanes.

Studying Hurricane Impacts

We began intensive research in the southwest coastal Everglades immediately after Hurricane Andrew in August 1992. The Mangrove Hydrology Sampling Network was initiated following Andrew as part of the South Florida Global Climate Change project (Smith, 2004). By the time of Wilma, hydrologic monitoring stations had been set up at a number of sites (fig. 1). At these sites we have hydrology-monitoring wells for both surface and ground water, sediment surface elevation tables (SETs), marker horizons, and permanent vegetation plots (see Ward and Smith, this volume).

The hydrology stations employ standard U.S. Geological Survey (USGS) methods and equipment for measuring water elevation and conductivity. Changes in sediment-surface elevation have been measured with sediment SETs, simple devices that can accurately measure relative changes in elevation over time (Boumans and Day, 1993). Sediment marker horizons have been established that allow us to measure deposition of sediment in the forest. Marker horizons are simply a layer of colored material (e.g., sand or brick dust) that is placed on the sediment surface (Wood and others, 1989); as material is deposited on top of the marker horizon, it can be easily measured.

Following the passage of tropical storms or hurricanes, we conduct rapid assessments to ascertain impacts. For many storm systems these impacts are hardly perceptible. For example, after Hurricane Katrina (a weak category 1 system when it was in Florida) passed over our study sites, we determined negligible impacts on the environment (although one hydrology station was damaged and one in northeast Florida Bay was destroyed). Experience told us that as Wilma approached, however, things would be different. Immediately after this storm we resampled our sediment SETs, conducted surveys of storm surge, and measured sediment deposition. These data gave us a chance to compare Andrew and Wilma and also to begin examining the cumulative impacts of large hurricanes on mangrove forests.

Storm surge is the water that is pushed towards the shore by storm-related winds. The surge combines with tides and may reach levels of 15–20 ft (4.6–6 m) or more above normal levels. Storm surge is the greatest threat to human life during hurricanes (see *http://www.nhc.noaa.gov/HAW2/english/storm_surge.shtml* to learn more about storm surges). Storm surges carry material as they move inland, and this material includes sediment. Sediment is often deposited in recognizable layers that scientists can find years after the storm has passed and use to assess hurricane impacts (Kang and Trefy, 2003).

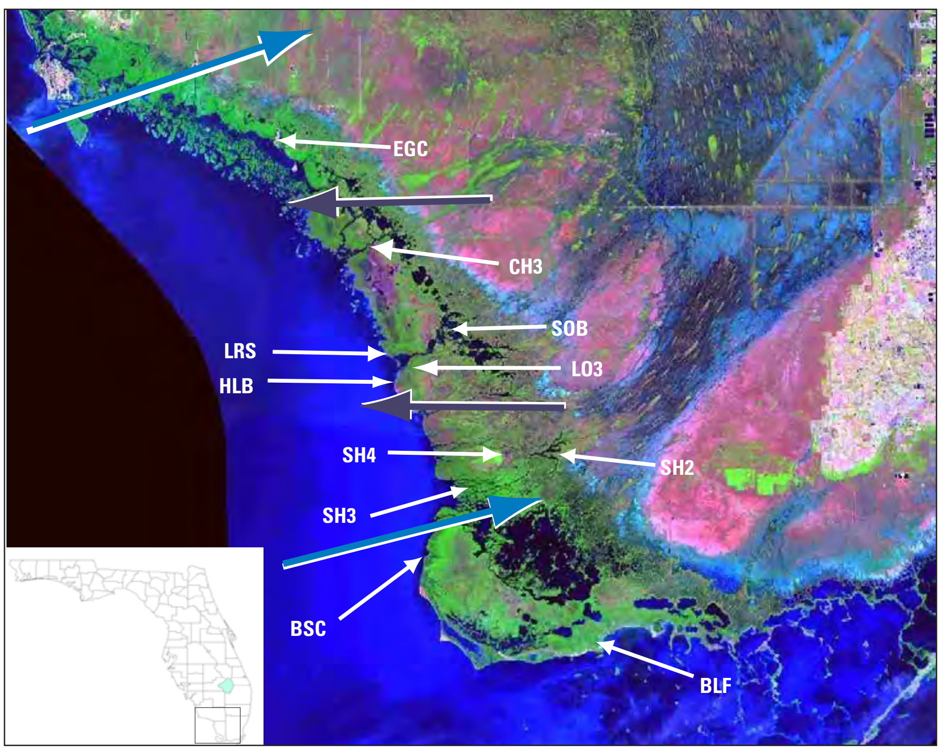

Figure 1. The southwest Florida coast is shown in this satellite mosaic from 1994. The approximate positions of the northern and southern eyewalls of Hurricane Andrew (1992) (purple arrows) and Hurricane Wilma (2005) (blue arrows) are shown. Abbreviations for locations mentioned in the text are as follows from north to south: EGC, Everglades City; CH3, Chatham River 3; SOB, Second Onion Bay; LRS, Lostmans River Ranger Station; LO3, Lostmans River 3; HLB, Highland Beach; SH4, Shark River 4; SH2, Shark River 2; SH3, Shark River 3; BSC, Big Sable Creek; and BLF, Black Forest.

Comparing Andrew and Wilma

Storm Surge from Andrew

Rappaport (1993) reported that, as Andrew exited the southwest coast of Florida, storm surges of 4–5 ft (1.2–1.5 m) were observed at Flamingo (near Black Forest (BLF in fig. 1)) and of 6–7 ft (1.8–2.1 m) at Everglades City (EGC in fig. 1). Mayfield and others (1994) estimated a storm surge of 5–7 ft (1.5–2.1 m), along a very short segment of coast, as Andrew exited southwest Florida. There were no hydrologic monitoring stations present on the southwest coast at the time of Andrew, so Mayfield's estimates are based on the results of hydrological models.

Storm Surge from Hurricane Wilma

In contrast, we estimate that storm surge from Wilma was in excess of 15 ft (4.6 m). We know this fact based on observations of debris found stranded in the mangrove forests that Wilma flooded. At Big Sable Creek (BSC in fig. 1), debris was found 10 ft (3 m) up in the remains of the mangrove forest canopy (fig. 2). No evidence of storm surge was found at this site following Andrew. Weight of the logs had bent the stems upon which they rest, so our estimates are most likely low. Some 15 mi (24 km) to the north, at Highland Beach (HLB) we found entire trees suspended in the remains of the mangrove forest canopy, approximately 9–15 ft (2.7–4.6 m) above the soil (fig. 3).

At the nearby Lostmans River 3 hydrology station (LO3), we found sediment deposited on the top of the box housing the destroyed instruments, an elevation of 8 ft (2.4 m). At the Lostmans River Ranger Station (LRS), debris was observed 8–10 ft (2.4–3 m) high in the mangrove forest. The ranger station itself was a wooden structure on low pilings that survived the leading and trailing eyewalls of Hurricane Andrew. The building sat on a barrier beach some 15 ft (4.6 m) above sea level. It was entirely swept away by the surge from Wilma (fig. 4).

Further north at EGC, National Park Service personnel reported a storm surge of 6–7 ft (1.8–2.1 m). At BLF, our southernmost site (located 1.5 mi (2.4 km) inland from the coast), sediment stains on vegetation indicated flooding of 2 ft (0.6 m).

Our stage height gages revealed that a clear gradient is from north to south along the coast with the three southern stations being overtopped by the storm surge and lost (fig. 5). Data from just prior to instrument failure, however, indicate just how quickly water levels were rising. At BSC the water level went from -4.665 to 2.515 ft (-1.422

Figure 2. Debris pile (purple arrow) some 10 ft (3 m) above the forest floor at Big Sable Creek (BSC), Fla., after Hurricane Wilma in 2005. The weight of the debris bent down the stems on which it came to rest (blue arrow).

Figure 3. This photograph was taken in the Highland Beach (HLB), Fla., permanent vegetation plot, some 12 mi (19.2 km) north of Big Sable Creek (BSC), Fla., after Hurricane Wilma in 2005. Entire trees have been washed from the barrier dune and swept into the mangrove forest where they were stranded in the remains of the canopy. Tree trunks have been deposited some 15 ft (4.6 m) (blue arrow) and 9 ft (2.7 m) (purple arrow) above the forest floor.

Figure 4. Lostmans River Ranger Station (LRS) in Florida in January 1998 (*A*), well after Hurricane Andrew (which hit in 1992), and in October 2005 (*B*), just after Hurricane Wilma.

to 0.767 m), the last recorded data point, in 3 hours (the minus signs indicate that water levels were below mean sea level). A gradient is also seen in the reduction of the surge as it propagated upstream in the Shark River (stations BSC and SH2–SH4 in figs. 1 and 6). The two downstream stations were lost, but the recovered data indicate the rapid increase in stage. At Shark River 4 (SH4), 12 mi (19.3 km) upstream from the gulf, the peak water level was approximately 3.3 ft (1.0 m), and at Shark River 2 (SH2), 16.5 mi (26.5 km) upstream, the peak was reduced to only 1.2 ft (0.4 m) (fig. 6).

Sediment Deposition

Risi and others (1995) conducted a detailed survey of sediment deposition following Andrew. They found storm deposits distributed from Highland Beach south to Shark Point, an 8-mi (13-km) length of coastline. Deposits from Andrew did not reach further than 6.25 mi (10 km) inland. By our estimates, deposits from Andrew influenced 44 mi^2 (114 km^2) of mangrove forest. Following Wilma, we found little or no sediment deposition at sites immediately adjacent to the shoreline (BSC, HLB, LRS). In fact, resampling of our SETs at the BSC site revealed that erosion of the mudflats had occurred that was equal to the previous 7 years.

Deposition from Wilma (fig. 7) was found along the Lostmans River (LO3), in Second Onion Bay (SOB), south to the Shark River and along all the tidal rivers in between. Deposits were maximal (2–6 inches (5–15 cm)) from 1 to 3 mi (1.6 to 4.8 km) upstream and then decreased until they terminated some 8 mi (13 km) upstream from the Gulf of Mexico. The total area impacted by Wilma's storm deposits was 110 mi^2 (285 km^2), 2.5 times larger than the area affected

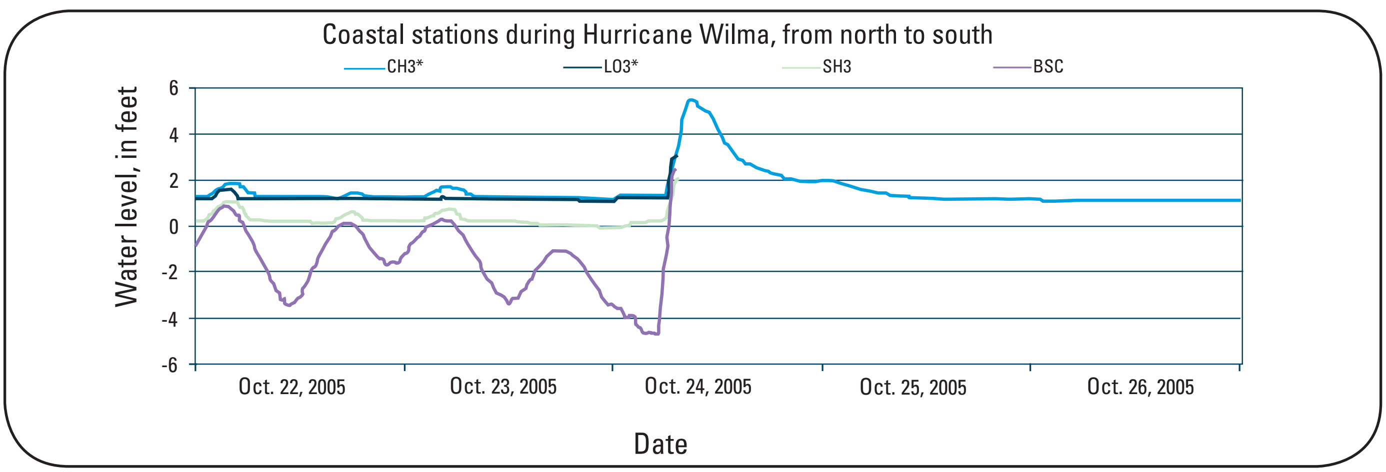

Figure 5. Data recovered from four coastal stations in the Mangrove Hydrology Sampling Network. From north to south they are Chatham River 3 (CH3); Lostmans River 3 (LO3); Shark River 3 (SH3); and Big Sable Creek (BSC) and cover a distance of 25 mi (40 km). BSC is located in a tidal creek some 50 yd (46 m) away from the spot where the photograph in figure 2 was taken. Data for SH3 and BSC are referenced to the North American Vertical Datum of 1988 (NAVD88) in which zero (0.0) is approximately mean sea level. (*Data from CH3 and LO3 have not yet been converted to NAVD88.)

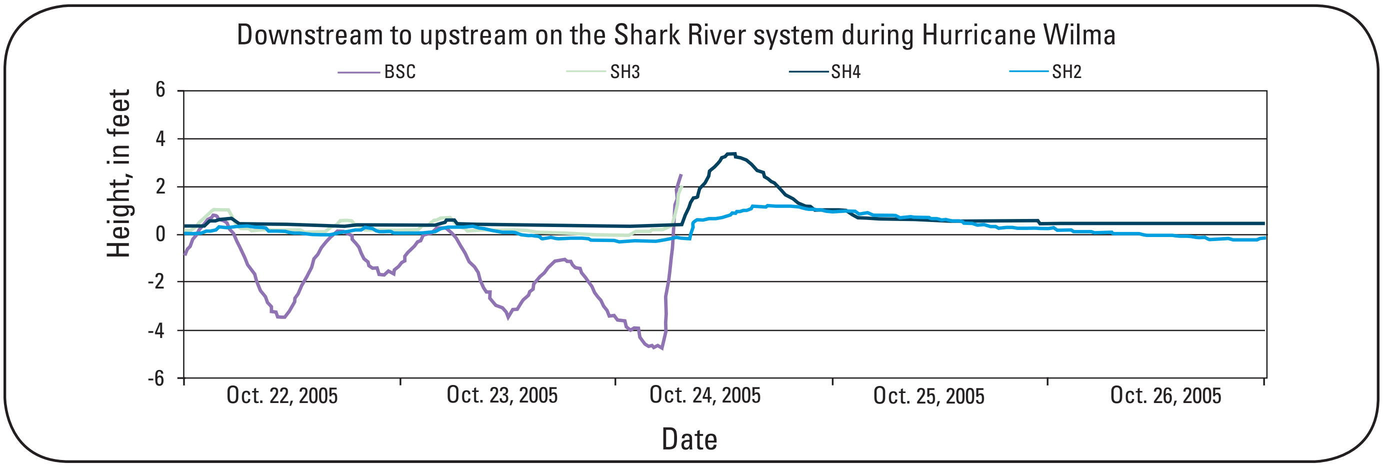

Figure 6. Additional data from stations in the Mangrove Hydrology Sampling Network. These four stations make up a downstream (Big Sable Creek (BSC)) to upstream (Shark River 2 (SH2)) gradient in the Shark River drainage system of the Everglades, Fla. Stations SH2–SH4 are in vegetated wetlands adjacent to tidal rivers. All data from these stations are referenced to the North American Vertical Datum of 1988 (NAVD88).

by Andrew. Although the deposition of 3–6 inches (7.6–15 cm) of sediment does not sound like much, when the volume of this thin layer is calculated for the large area over which it was deposited, the result is approximately 2.1 million dump truck loads, a lot of sediment.

Weaker Storm with Bigger Impacts

Our preliminary findings clearly indicate that Wilma, a category 3 storm, had a greater impact on the southwest Florida mangrove coastline than did Andrew, a category 4 storm when it exited the coast (Landsea and others, 2004). As indicated earlier, storms are different. As Andrew crossed the south Florida Peninsula and exited into the Gulf of Mexico, it was losing strength (Landsea and others, 2004). As Wilma approached the coastline, it was gaining strength over the warm gulf waters (Pasch and others, 2006). Also, the eye of Wilma was over four times the size of Andrew's eye, so destructive winds and surge were much more widespread.

Field observations and data collection will continue in our pursuit of a greater understanding of hurricane impacts on important coastal ecosystems.

Figure 7. Sediment deposition at site Shark River 3 (SH3) in Florida. The white marker horizon (purple arrow) was laid down approximately 8 months prior to Hurricane Wilma. The blue arrow points to a layer of mangrove leaves that was deposited first and then covered by mud (green arrow) that was swept in and dropped by the storm surge. Leaves from all three Florida mangrove species (*Avicennia germinans*, *Laguncularia racemosa*, and *Rhizophora mangle*) are present in the leaf layer.

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