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Rapidly installed temporary gauging for hurricane waves and surge, and application to Hurricane Gustav

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ABSTRACT

Hurricanes can produce extreme nearshore waves and surge, but permanent gauging stations are often much sparser than is desired. This paper describes the rationale behind and outline for rapidly installed temporary coastal gauges, and presents results during Hurricane Gustav (2008). Within 48 h prior to landfall, twenty self-recording pressure gauges were deployed in depths of 1.4–23 m over more than 700 km of coastline, using helicopters to cover the large distances. Results showed a complex picture that was strongly dependent on location. East of the Mississippi Delta, open coast waves were large, and surge reached 3.8 m NAVD88 in marshes. West of the delta but near landfall, waves and surge were generally smaller as the river levees blocked flow from East to West. West of landfall, both waves and surge were very small and the most prominent feature was a water level drawdown that reached 1.5 m. Wave spectra varied strongly depending both on location and time from landfall.

This type of rapid gauging program is straightforward to duplicate: with multiple localized deployment centers to ensure coverage, dense nearshore hurricane wave and surge records could increase substantially in the future.

1. Introduction

During Hurricane Katrina, no tidal stations in the most affected areas survived to provide time series of the largest surge ever seen in the United States. Similarly, aside from buoy NDBC 42040 east of the Mississippi Delta, there were no complete wave records in the most impacted areas. This and similar data gaps during other severe hurricanes create difficulties in determining the precise forcing causing coastal erosion and structural damage. Maximum water level information can be obtained to some degree through high water marks taken after the storm, although the interpretation of what is measured is often not clear (Rogers and Houston, 1997). However, even when records do survive, coastal wave gauges, in particular, are sparsely distributed. All of this increases uncertainty in determining exactly what took place during past storms, which in turn increases the difficulty in predicting accurately the effects of future storms.

Effects of this uncertainty are significant. Everything from predictions of 100 year inundation regions and the associated damage, to levee heights, to estimates of future morphological changes, to determination of safe evacuation routes, to disputes over insurance claims, would be improved by nearshore time series of waves and surge.

The optimal solution would be to have hardened permanent wave and water level stations at short intervals along the coast. However, permanent hardened stations are expensive and although considerable progress has been made; it does not appear likely that the number will be sufficient to match the demand for wave and surge time series during landfalling hurricanes. All of this provides impetus for the program described here. The remainder of the paper describes efforts over 2006–8 to measure tropical cyclone wave and surge characteristics near the shoreline. Because there are many thousands of kilometers in the US, where cyclones may make landfall, a rapid deployment program was implemented, in which a small team of investigators traveled to the expected landfall area two days in advance of the storm and deployed wave and surge-measuring instruments from helicopters several kilometers offshore of a long stretch of coastline. Instruments were then retrieved post-hurricane.

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This strategy of rapidly installed temporary gauging has been employed in wind engineering for the past decade (Masters et al., 2004), and is also beginning to take root with onshore surge measurements (Berenbrock et al., 2008). The main benefits of this approach are the ability to cluster instruments in areas, where storm effects are predicted to be the most severe, and in the relatively small number of mobile instruments required.

Records obtained from the present study are of use not only by themselves, but as part of a larger scale ocean observing system, complementing in situ ocean gauges, numerical forecasts and hindcasts, permanent and temporary shore-based systems, satellite and airplane-based remote sensing systems, and post-storm damage assessments. The sum of all measurements, predictions, and post-storm observations can then give a much better overall picture of the system than may be found from its individual components. Although the system described here focuses on the use of self-recording pressure sensors to measure surge and non-directional wave spectra, it is straightforward to extend the rapid response concept to include other properties, such as directional waves and currents, temperature, salinity and, possibly, suspended sediment concentrations.

The remainder of this paper gives details of the rapidly installed temporary gauging program, with representative results. Section 2 describes the instruments, deployment and retrieval strategy, while Section 3 relates results from field deployments with concentration on Hurricane Gustav in 2008. Finally, Section 4 assesses the program, discusses future work, limitations, and concludes the paper.

2. Instruments, deployment, and retrieval

The major goal of this program was to collect as much wave/surge data as possible in the path of a landfalling hurricane, almost anywhere along the east and gulf coasts of the USA, in depths of 10–15 m. The major constraint was a relatively limited budget. Within these goals and constraints, a combined instrument/deployment/retrieval plan was adopted and refined over 2006–2008. Its major features are

- instruments consisting of self-recording pressure sensors taking continuous measurements at 1 Hz for 11 days, or 2 Hz for 5.5 days, etc.,
- bottom-mounted, low-profile steel bases, with acoustic beacons to aid in retrieval,
- centralized instrument storage, with instruments and bases driven to the landfall area,
- helicopter deployment several kilometers offshore of up to 20 gauges approximately two days before landfall,
- boat and diver retrieval post-storm.

The instrument type was strongly constrained by the relatively short lead time to deploy instruments and by the limited budget. Directional wave and current measurements from, for example, an Acoustic Doppler Current Profiler (ADCP) would be very useful, but costs would have been prohibitive for deployments of 10–20 instruments. Because of this, inexpensive pressure sensors were used with the added feature that shallowly buried instruments would continue to produce useful measurements. Similarly, self-recording bottom-mounted instruments are orders of magnitude cheaper than any conceivable real-time transmissions for rapidly deployable ocean wave and surge gauges. Helicopter deployment was driven by both the large uncertainty in hurricane tracks several days before landfall, necessitating blanket coverage of a coastline, and by dangerous boating conditions prior to a hurricane. From the centralized storage facility in Gainesville, Florida (and in Morehead City, NC for 2008), all mainland US hurricane landfall locations could be reached in less than one day's drive, with the exception of the far northeastern United States. The most hurricane-prone areas (Mississippi Delta, South Florida, Outer Banks of North Carolina) could all be reached in less than 12 h.

2.1. Self-recording, bottom-mounted pressure gauges

All wave and surge gauges were custom-built around a low power Onset Tattletale TFX-11v2 data-logger with 2 MB of non-volatile memory. At 2 bytes per record, this permitted continuous 1 Hz wave measurements for over 11 days. The other major components of the wave gauge were the 100 PSI absolute (689 kPa) piezoelectric silicon pressure sensor, and the datalogger interface board. All instruments were laboratory-calibrated against a Paroscientific quartz oscillation transducer, and resulted in typical linear regression coefficients over the useful range of $(1-r^2)=O(1\times10^{-5}\text{–}1\times10^{-6})$. For 100 PSI (689 kPa) sensors and a 12 bit A/D converter, this gave a resolution equivalent to 1.7 cm of seawater (0.7 in). Noise in the circuitry measured from short term apparent pressure fluctuations in still air gave a standard deviation of around 0.8 cm of seawater, which is less than the measurement resolution. Power was supplied by either three or four primary 3.6 V AA-size lithium thionyl chloride non-rechargeable cells.

Instrument housings were semi-disposable and were built around commercial 1.5 in (3.8 cm) Schedule 40 PVC pipe. At one end, the pressure sensor was threaded through a machined PVC end cap with an o-ring seal. The other end of the housing was left open until deployment, when it was glued shut using a commercial PVC end cap. Instruments were cut open after deployment to access the electronics, and the same, but shorter, pressure housing could be reused several times before the electronics was transferred into a new housing. For instruments that would probably be deployed only one or two times, this was a simpler solution than producing machined reusable end caps. The finished instruments were less than 30 cm (12 in) in length.

2.2. Instrument bases

Base design changed somewhat throughout the program, ending with a simple low-profile armored base made from 3 in (7.6 cm) steel channel arranged into a 15 in (38 cm) square. Instrument packages fit inside two channels placed back to back, as shown in Fig. 1. Instruments in this configuration were completely armored by the base and were not exposed to potential waterborne debris. An acoustic beacon was also placed into the instrument cavity, and a small string of floats aided in retrieval. Instrument masses were increased to around 25 kg (55 lbs), using additional weights.

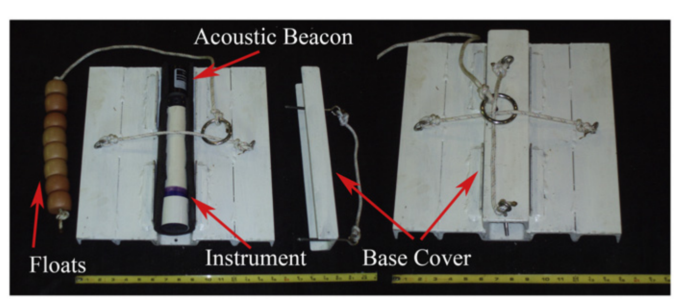

Fig. 1. Instrument package with base open to show instruments and closed for deployment.