



Water-Level Measurements in Dauphin Island, Alabama, From the 2013 Hurricane Season

By Patrick J. Dickhudt, Christopher R. Sherwood, and Nancy T. Dewitt

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
Pressure		
kilopascal (kPa)	0.0099	atmosphere, standard (atm)
kilopascal (kPa)	0.01	bar
kilopascal (kPa)	0.296	inch of mercury at 60°F (in Hg)
kilopascal (kPa)	0.145	pound-force per square inch (lbf/in ²)
kilopascal (kPa)	20.89	pound per square foot (lb/ft ²)
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

The SI unit for pressure is the pascal (Pa). 1 Pa = 0.0001 decibar (dbar) = 0.001 kilopascal (kPa).

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD83).

Elevation, as used in this report refers, to distance above the vertical datum.

Measurements in Dauphin Island, Alabama, From the 2013 Hurricane Season

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Abstract

This report describes the instrumentation, field measurements, and processing methods used by the U.S. Geological Survey to measure atmospheric pressure, water levels, and waves on Dauphin Island, Alabama, in 2013 as part of the Barrier Island Evolution Research project. Simple, inexpensive pressure sensors mounted in shallow wells were buried in the beach and left throughout the hurricane season. Additionally, an atmospheric pressure sensor was mounted on the porch of a private residence to provide a local atmospheric pressure measurement for correcting the submerged pressure records.

Introduction

The U.S. Geological Survey (USGS) measured atmospheric pressure, water levels, and waves on Dauphin Island, Alabama, from July 22 through November 20, 2013, as part of the Barrier Island Evolution Research (BIER) Project, which aims to assess the effects of individual, short-term storms on the historical and geological evolution of the coastal system. Barrier islands are dynamic systems that can experience substantial morphological change (erosion and deposition) during storms. Water levels around barrier islands are influenced by winds, waves, and atmospheric pressure during the passage of storms, and the morphological effects of storms depend, in part, on the magnitude of inundation and water-level gradients across the island. Direct water-level measurements on barrier islands during storms are somewhat uncommon because equipment is often lost, buried, or destroyed during these high-energy events.

This report describes the instrumentation, field methods, and data processing techniques used to measure water levels and waves with relatively inexpensive pressure sensors in a rapidly evolving barrier island system (fig. 1). These water-level and wave measurements can be used to validate numerical models and help interpret the morphological response of barrier islands to storms.

Instrumentation

RBR DR1060 Pressure Logger

The RBR DR1060 (fig. 2) is a small submersible pressure logger capable of recording more than 2 million samples at frequencies up to 1 hertz (Hz). These pressure loggers were temperature compensated and had pressure sensors with a depth rating of 10 meters (m). The manufacturer-specified accuracy was ± 0.05 percent of full scale (about 0.005-m water depth) and resolution was 0.001 percent of full scale (about 0.0001-m water depth). Each RBR DR1060 was mounted on a rigid metal rod connected to the cap of a buried well jetted into the beach (described in “Well Installation”). The RBR

DR1060s recorded pressure every 5 seconds. At this sample rate, the RBR DR1060s could sample for about 5 months before running out of memory.

RBR Virtuoso D|wave

The RBR Virtuoso D|wave (fig. 3) is a small submersible pressure logger capable of sampling continuously or in burst mode at speeds up to 6 Hz and can store 30 million individual readings. This unit was temperature compensated and had a pressure sensor with a depth rating of 10 m. The manufacturer-specified accuracy was ± 0.05 percent of full scale (about 0.005 m water depth) and resolution was 0.001 percent of full scale (about 0.0001 m water depth). The RBR Virtuoso D|wave was mounted on a rigid metal rod connected to the cap of a buried well jetted into the beach next to a piling of a residential porch (described in “Well Installation”). The well casing was secured to the porch piling with hose clamps and ratchet straps. The D|wave recorded pressure measurements continuously at 4 Hz from July 21, 2013, until its batteries died on October 24, 2013.

Onset Hobo U20 Water-Level Logger

The Onset Hobo U20 water-level logger (fig. 4) is a small submersible pressure logger capable of recording about 22,000 pressure and temperature samples at rates up to 1 Hz. Two models of Onset Hobo U20s were deployed: model U20–001–04 pressure sensors with ranges of 0 to 15 decibars (about 0–4 m water depth) were used as atmospheric and submersible sensors; and model U20–001–01 pressure sensors with ranges of 0 to 21 decibars (about 0–9 m water depth) were used as submerged sensors. The U20–001–04 sensor has a water-level accuracy of ± 0.075 percent of full scale (about 0.003 m water depth) and water-level resolution of 0.001 m water depth. The U20–001–01 used as a submerged sensor has a water-level accuracy of 0.05 percent of full scale (about 0.005-m water depth) and water-level resolution of 0.002 m water depth.

The U20–001–04 sensor used as an atmospheric sensor was mounted in a small white PVC tube with vents, and attached with hose clamps to the railing of a residential porch. The sensor was mounted about 4 m above ground level. The submerged Onset Hobo U20s were mounted on rigid metal rods connected to the cap of buried wells jetted into the beach (described in “Well Installation”). Each Onset Hobo U20 collected a pressure measurement every 600 seconds for the duration of the deployment. At this sample rate, the Onset Hobo U20s could sample for about 5 months before running out of memory.

Well Installation

The Onset Hobo and RBR DR1060 pressure sensors buried in the beach were encased in 4.8-centimeter (cm; outside diameter) schedule 80 polyvinyl chloride (PVC) slotted well screen. The RBR Virtuoso D|wave had a larger diameter and was encased in an 8.9-cm (outer diameter) schedule 80 PVC slotted well screen. The well casings were about 1.5 m long and were screened with 0.15-millimeter (mm)-wide slots along most of their length. A PVC well point with a 1.25 cm diameter hole drilled through its center (to allow a water jet to exit) was screwed on to the lower end of each well. Wells were installed by first digging a shallow hole (30 to 50 cm deep) and then using a 2.54-cm (1-inch) gasoline-powered water pump to jet the well into the sand until the top of the well was below the level of the beach (fig. 5). A pressure sensor was hung from a threaded rod attached to a PVC cap that screwed into the top of the well after jetting. The distance from the well cap to the pressure sensor is provided in table 1 and approximates the pressure-sensor depth below the sediment surface. Wells on the Gulf of Mexico side (mooring numbers 968, 970, and 971) were in an energetic surf zone setting (fig. 6A) and were

jettied into the beach next to the pilings of waterfront residences and secured to the pilings with hose clamps and ratchet straps (fig. 6A and B).

The elevation of the well cap was established using post-processed static Global Positioning System (GPS) data. A GPS base station was placed on the National Geodetic Survey (NGS) tidal benchmark PID BH1755 at the entrance into Fort Gains on the east end of Dauphin Island, and a GPS rover unit was used to survey the wells. The error between the base and the rover increased exponentially with distance from the base station (Waypoint Consulting Inc., 2005) as reflected by an increase in the root mean squared (RMS) error of the differentially corrected navigation data. All wells were within 12 kilometers of the base station.

The GPS base station and the rover were duplicate systems with Ashtech Z-Xtreme GPS receivers, internal data recorders, Thales choke-ring antennae, and tripods (fig. 7A). After the wells were installed, the GPS rover was positioned and referenced to a dimple on the well cap (fig. 7B). Both receivers recorded the 12-channel full-carrier-phase positioning signals (L1/L2) from the satellites and recorded their positions concurrently at 1-second (s) intervals for at least 30 minutes (min). This 30-min GPS static occupation session was repeated when the wells were recovered months later.

All GPS static sessions were processed using NovAtel GrafNet version 8.4 software, accounting for antenna height, antenna model, and GPS session type (rover or base). The NGS-published latitude, longitude, and ellipsoid height referenced to the North American Datum 1983 (NAD83) were transformed into World Geodetic System 1984 (WGS84; G1150) using the NGS Horizontal Time-Dependent Positioning (HTDP) version 3.2.3 utility for postprocessing purposes (table 2). The processed position heights were referenced to the top of the well cap and converted to NAD83 (CORS96) using the NGS HTDP utility. These processed heights were then processed through the NGS GEOID96 model to obtain geoid heights. The elevation of the pressure sensor was then determined by subtracting the distance from the well cap to the pressure sensor (table 1) from the cap elevation.

The uncertainty of the elevation of the water-level sensor was estimated by using the square root of the sum of the squared individual error terms. The individual error terms included difference in surveyed well cap heights as measured upon deployment and recovery, the estimated error in the length of the threaded rods the sensors were suspended from, and the standard deviation of the GPS elevation measurements for a particular well. In addition, for wells on the Gulf of Mexico side of Dauphin Island that were strapped to porch pilings, the error in the measured distance from the well cap to a surveyed mark on the porch was included. The estimated uncertainty in the water-level sensor elevations ranged from 0.008 to 0.036 m (table 1).

Site Description

Dauphin Island

Dauphin Island is a populated, low-lying barrier island in the northern Gulf of Mexico (fig. 1). It is bordered by Mobile Bay to the east, Mississippi Sound to the north and west, and the Gulf of Mexico to the south. Dauphin Island is frequently exposed to the force of hurricanes from the Gulf of Mexico, the most recent of which was Hurricane Katrina in 2005, which breached the western portion of the island.

Site 965

Site 965 was at a residence off St. Stephens Street. An Onset Hobo U20-001-04 atmospheric pressure sensor was mounted in a PVC tube that was hose clamped to the second floor porch railing of the residence.

Site 966

Site 966 was in a small channel in an empty lot on the Mississippi Sound side of the island about 200 m to the west of St. Stephens Street. An RBR DR1060 pressure sensor was mounted in a well buried in the beach.

Site 967

Site 967 was on the beach on the Mississippi Sound side of the island and to the north of the public parking lot at the western end of the island. An RBR DR1060 pressure sensor was mounted in a well buried in the beach. The sensor at site 967 could not be located for recovery, so the data were lost.

Site 968

Site 968 was on the Gulf of Mexico side of the island at a residence on Bienville Boulevard. An RBR Virtuoso D|wave was mounted in a well buried in the beach and strapped to a piling on the southeastern side of the residence. The piling the instrument was strapped to was in the swash zone of the beach at high tide when the instrument was deployed. About 0.6 to 0.8 m of sediment had accumulated at this site between deployment and recovery, completely burying the well (fig. 8) and making recovery difficult.

Site 969

Site 969 was on the Mississippi Sound side of the island in a small channel near Sam Houston Road. An Onset Hobo U20-001-01 pressure sensor was mounted in a well buried in the beach.

Site 970

Site 970 was on the Gulf of Mexico side of the island at a residence on Bienville Boulevard. An RBR DR1060 was mounted in a well buried in the beach and strapped to a piling on the southeastern side of the residence.

Site 971

Site 971 was on the Gulf of Mexico side of the island at a residence on Seneca Street. An RBR DR1060 was mounted in a well buried in the beach and strapped to a piling on the southwestern side of the residence.

Site 972

Site 972 was along the beach on the Mississippi Sound side of the island. An RBR DR1060 pressure sensor was mounted in a well buried in the beach.

Site 973

Site 973 was directly between sites 971 and 972 in the middle of the island. An Onset Hobo U20–001–04 pressure sensor was mounted in a well buried in the sand.

Site 974

Site 974 was in the middle of the island between sites 967 and 968 in a lot behind a home on Bienville Boulevard. An Onset Hobo U20–001–01 pressure sensor was mounted in a well buried in the sand.

Site 975

Site 975 was in the middle of the island in a channel in an empty lot just off St. Stephens Street and between sites 966 and 970. An Onset Hobo U20–001–04 pressure sensor was mounted in a well buried in the sand.

Site 976

Site 976 was along the beach on the Mississippi Sound side of the island very near the inlet of the canal next to St. Stephens Street. An Onset Hobo U20–001–01 pressure sensor was mounted in a well buried in the beach. Sometime before recovery, a large pile of sand (about 1 m high by 2 m in diameter) was placed over the sensor location and had to be removed so the instruments could be recovered.

Results

Atmospheric pressure data were collected continuously from July 22 to November 20, 2013, by the sensor mounted at site 965. The data appear to be of good quality but differ at times from data collected by the nearest land-based atmospheric pressure sensors. Specifically, the sensor at 965 shows larger variations in pressure than the sensors at National Oceanic and Atmospheric Administration (NOAA) gauge DPIA1, approximately 7 kilometers (km) east of site 965 (fig. 9). These pressure excursions may be real (for example, due to short-term pressure fluctuations caused by frontal passages) or they may be artifacts of sensor exposure to sun and wind. Figure 10 is a time-series plot of atmospheric pressure and temperature from site 965.

Pressure sensors encased in wells buried in the beach were deployed from July 2013 through November 2013 (table 1). All data from the wells were of very high quality with no evidence of error due to fouling or attenuation from burial. One sensor (at site 967) could not be located and was never recovered, so there are no data for that site. Three sensors stopped sampling early due to battery failure. The RBR D|wave sensor at site 968 stopped operating on October 24, the RBR DR1060 sensor at site 970 stopped operating on August 28, and the RBR DR1060 sensor at site 972 stopped operating on October 3.

Water levels were derived from the well pressure sensors by subtracting atmospheric pressure linearly interpolated (in time) from measurements taken every 60 minutes at NOAA gauge DPIA1. The corrected pressure data were converted from decibars to water depth using an assumed seawater density of 1022.3 kilograms per cubic meter (calculated from salinity of 34 practical salinity units and temperature of 26 degrees Celsius, a typical salinity and approximately the mean temperature) and

adjusted to a common datum (North American Vertical Datum of 1988 [NAVD88]) using the surveyed cap elevation and the measured distance from the cap to the pressure sensor (table 1). Time series plots of water-level data from the buried wells are shown in figures 11 through 20. In the water-level plots, the reported water level is NAVD88 orthometric height referenced to the NGS GEOID96 datum.

Data from all instruments were converted to standard format for USGS time series (Montgomery and others, 2009) and stored in network common data format (netCDF) files. NetCDF files store data and associated metadata in a format that is compact and machine-independent. Documentation of the USGS Oceanographic Time-Series Measurement Database can be found in Open-File Report 2007–1194 (<http://woodshole.er.usgs.gov/pubs/of2007-1194/>). Details of instrumentation used for measurement of water levels, atmospheric pressure, and temperature are provided in table 3.

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- Waypoint Consulting Inc., 2005, Static baseline accuracies as a function of baseline length, observation time and the effect of using the precise ephemeris: Waypoint Consulting Incorporated, 12 p., accessed September 2, 2014 at http://www.novatel.com/assets/Documents/Waypoint/Reports/Static_Accuracies.pdf.

Figures

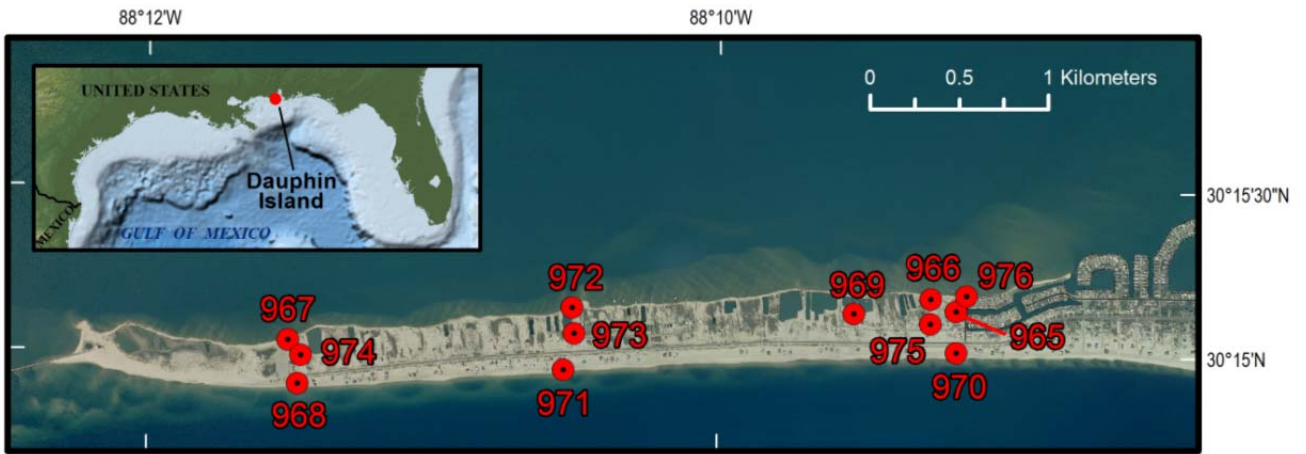


Figure 1. Locations of sites on Dauphin Island, Alabama, used to monitor water levels, atmospheric pressure, and temperatures from July 22 through November 20, 2013. Red dots on map indicate locations of sites. Inset base from the National Atlas of the United States, 2009. Aerial photo base from the U.S. Department of Agriculture, National Agricultural Imagery Program, 2011.



Figure 2. Photographs of RBR DR1060 pressure logger used on Dauphin Island, Alabama, in 2013. *A*, Close-up of RBR DR1060 pressure logger. *B*, RBR DR1060 pressure logger connected to well cap by threaded stainless-steel rod. The pressure sensor is inserted into well casing and cap is screwed onto top of well (fig. 5E).



Figure 3. Photograph of the RBR Virtuoso D|wave sensor used on Dauphin Island, Alabama, in 2013.



Figure 4. Photograph of one of the Onset Hobo U20 pressure loggers and threaded stainless-steel rod used on Dauphin Island, Alabama, in 2013.



Figure 5. Photographs illustrating the procedure for the installation of a buried well on Dauphin Island, Alabama, in 2013. *A–C*, well casing being jetted into the sand; *D*, well casing at the end of jetting; *E*, pressure sensor inserted into the casing; and *F*, completed installation with pressure sensor inserted and cap screwed into the well casing.

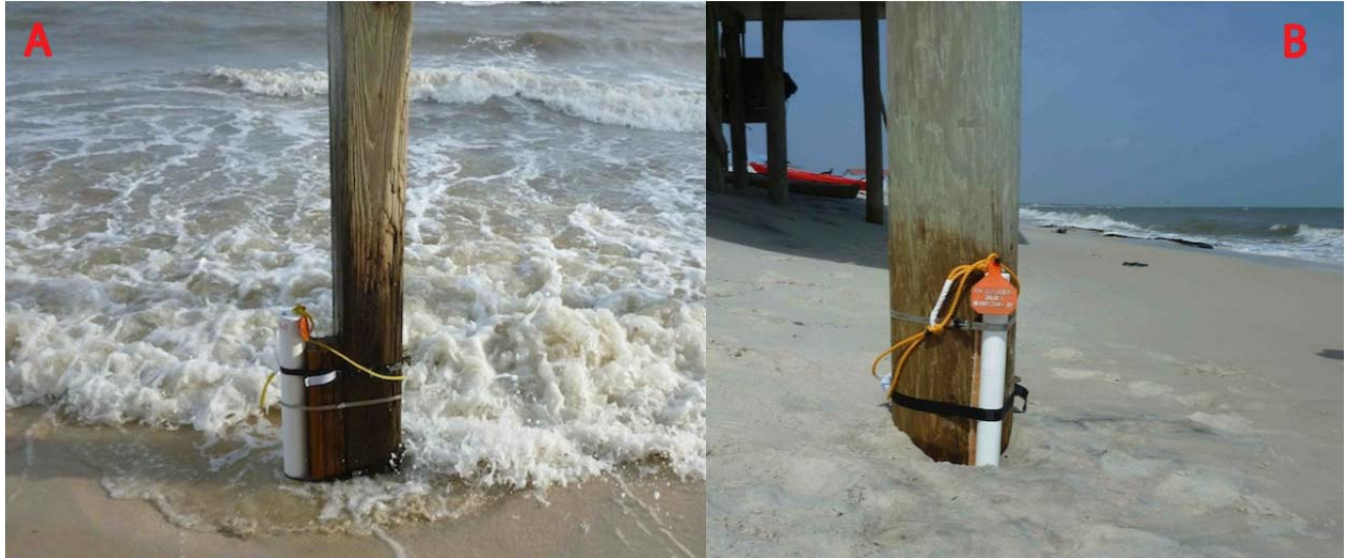


Figure 6. Photographs of well casings strapped to pilings of porches on Dauphin Island, Alabama, in 2013. *A*, The well casing at site 968 after being buried and strapped to a piling on the porch of a private residence. *B*, The well casing at site 971 after being buried and strapped to a porch piling.

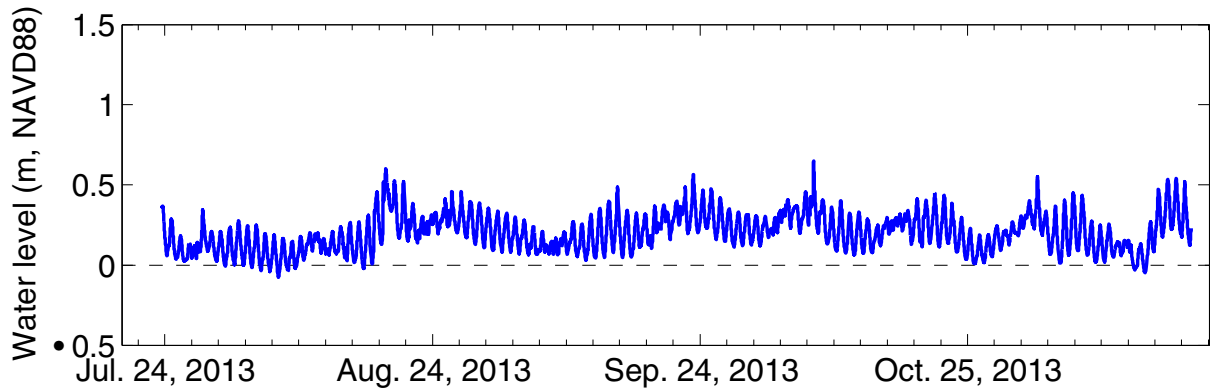


Figure 13. Water-level time series from an Onset Hobo U20 pressure logger mounted in a buried well at site 969 on Dauphin Island, Alabama, in 2013. m, meters; NAVD88, North American Vertical Datum of 1988.

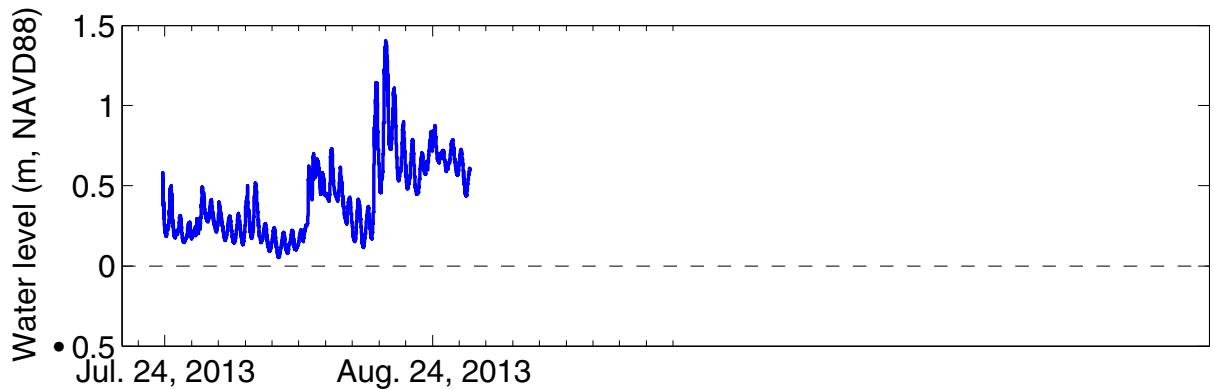


Figure 14. Water-level time series from an RBR DR1060 pressure logger mounted in a buried well at site 970 on Dauphin Island, Alabama, in 2013. m, meters; NAVD88, North American Vertical Datum of 1988.

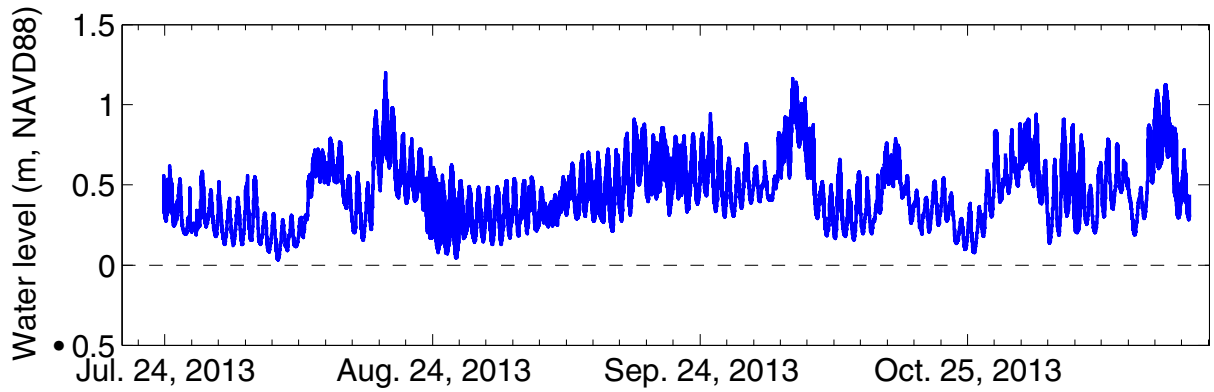


Figure 15. Water-level time series from an RBR DR1060 pressure logger mounted in a buried well at site 971 on Dauphin Island, Alabama, in 2013. m, meters; NAVD88, North American Vertical Datum of 1988.

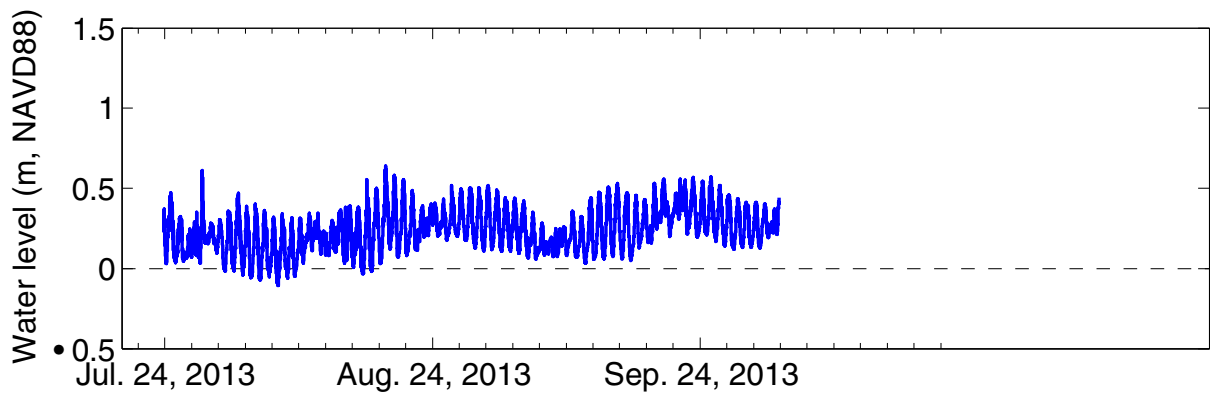


Figure 16. Water-level time series from an RBR DR1060 pressure logger mounted in a buried well at site 972 on Dauphin Island, Alabama, in 2013. m, meters; NAVD88, North American Vertical Datum of 1988.

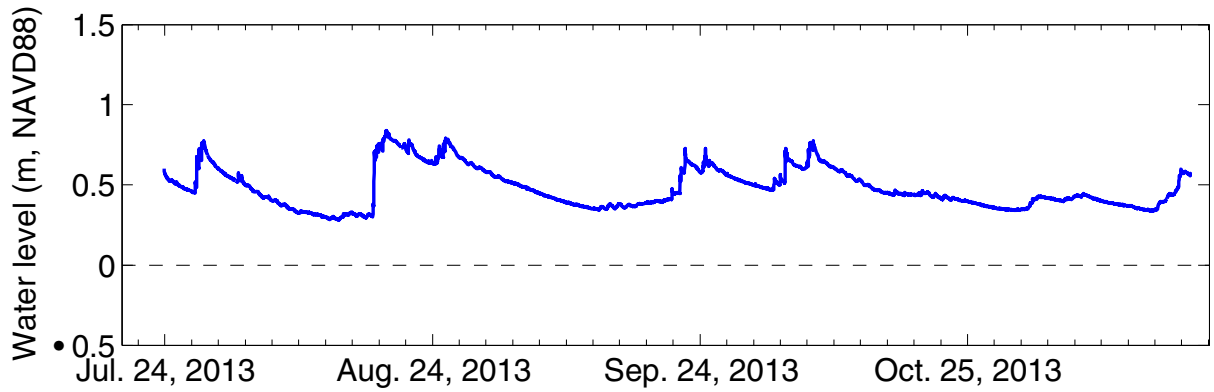


Figure 17. Water-level time series from an Onset Hobo U20 pressure logger mounted in a buried well at site 973 on Dauphin Island, Alabama, in 2013. m, meters; NAVD88, North American Vertical Datum of 1988.

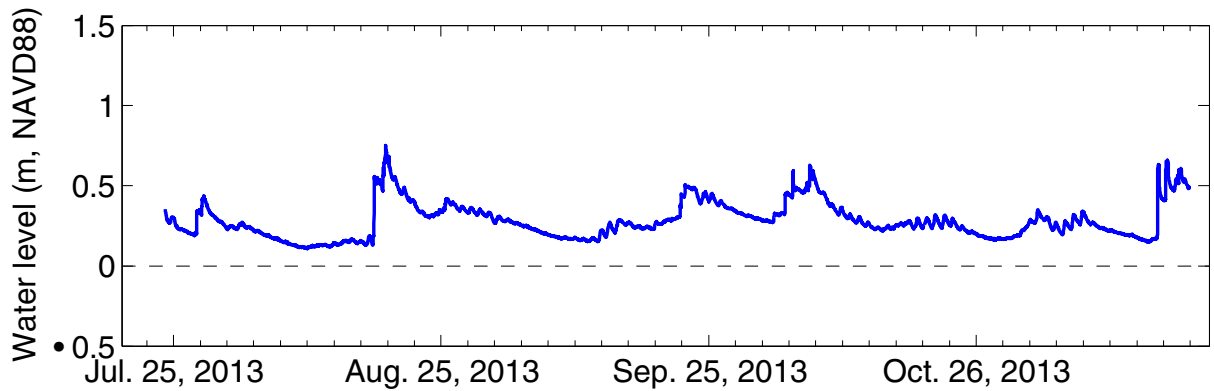


Figure 18. Water-level time series from an Onset Hobo U20 pressure logger mounted in a buried well at site 974 on Dauphin Island, Alabama, in 2013. m, meters; NAVD88, North American Vertical Datum of 1988.

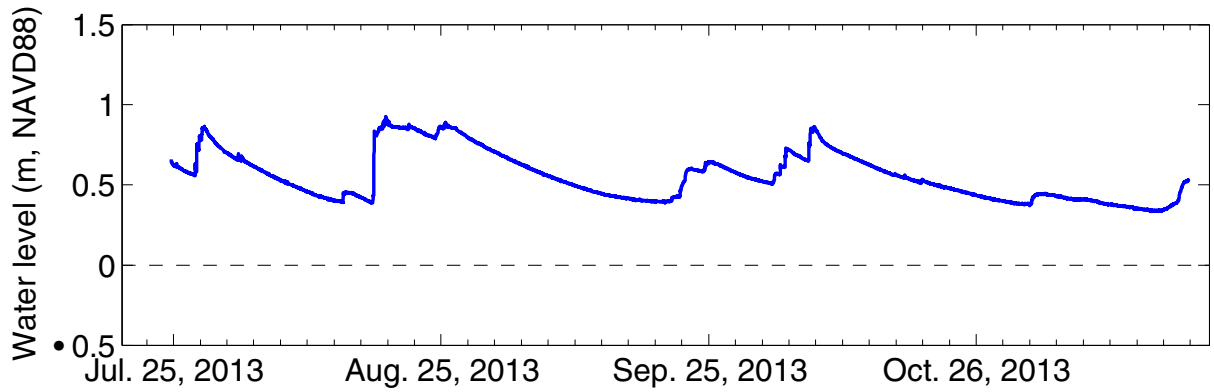


Figure 19. Water-level time series from an Onset Hobo U20 pressure logger mounted in a buried well at site 975 on Dauphin Island, Alabama, in 2013. m, meters; NAVD88, North American Vertical Datum of 1988.

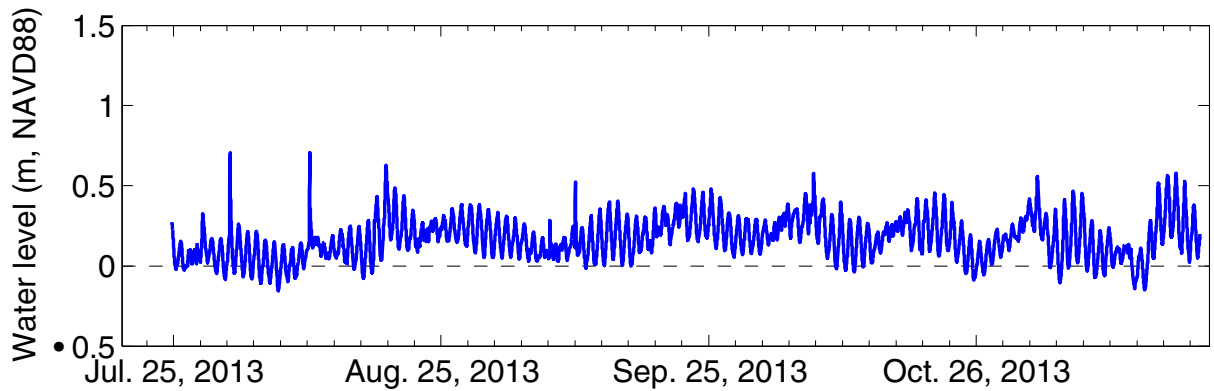


Figure 20. Water-level time series from an Onset Hobo U20 pressure logger mounted in a buried well at site 976 on Dauphin Island, Alabama, in 2013. m, meters; NAVD88, North American Vertical Datum of 1988.

Tables

Table 1. Mooring log sensor, location, and deployment information.

[NAVD88, North American Vertical Datum of 1988; m, meter; N, north; W, west; UTC, Coordinated Universal Time; NA, not available]

Sensor type	Serial Number	Site	Sensor elevation, in m above NAVD88	Sensor elevation uncertainty, in m above NAVD88	Distance from cap to sensor, in m	Latitude N	Longitude W	Time deployed, UTC	Time recovered, UTC
Onset Hobo U20-001-04	10125471	965	atmospheric, about 4 m	NA	NA	30.25229	88.15276	7/22/13 15:15	11/20/13 21:29
RBR DR1060	24101	966	-0.478	0.008	0.819	30.25289	88.15424	7/22/13 16:35	11/19/13 16:03
RBR DR1060	24032	967	-0.873	NA	0.816	30.25055	88.19177	7/22/13 21:10	Not recovered
RBR Virtuoso D wave	55033	968	-1.18	0.027	1.463	30.24834	88.19119	7/22/13 22:50	11/19/03 15:00
Onset Hobo U20-001-01	10313354	969	-0.269	0.014	0.678	30.25213	88.15872	7/23/13 16:08	11/19/13 22:00
RBR DR1060	24033	970	-0.477	0.031	1.435	30.25019	88.15273	7/23/13 17:00	11/19/13 16:46
RBR DR1060	24099	971	-0.490	0.014	1.43	30.24916	88.17568	7/23/13 20:15	11/19/13 17:02
RBR DR1060	24100	972	-0.496	0.036	0.819	30.25232	88.17518	7/23/13 21:25	11/19/13 19:25
Onset Hobo U20-001-04	10079949	973	-0.501	0.029	1.24	30.251	88.17506	7/23/13 21:45	11/19/13 19:32
Onset Hobo U20-001-01	10313355	974	-0.763	0.022	1.305	30.24978	88.19102	7/24/13 0:58	11/19/13 17:35
Onset Hobo U20-001-04	10079950	975	-0.585	0.014	1.287	30.25164	88.15425	7/24/13 17:40	11/19/13 15:05
Onset Hobo U20-001-01	10313353	976	-0.237	0.008	0.683	30.25306	88.15217	7/24/13 18:18	11/20/13 22:00

Table 2. National Oceanic and Atmospheric Administration benchmarks on Dauphin Island, Alabama.
 [Benchmarks are near the entrance of Fort Gaines on the eastern side of Dauphin Island. Benchmark BH1755 is in North American Datum of 1983 coordinate system and benchmark BH1755 is in World Geodetic System of 1984]

	Latitude	Longitude	Ellipsoid
BH1755	30 14 58.82004	88 4 33.67684	-25.167
BH1755	30 14 58.83945	88 4 33.70183	-26.586

Table 3. Instrumentation and data files for measuring water levels, atmospheric pressure, and temperature at Dauphin Island, Alabama.

[UTC, Coordinated Universal Time; NA, not available]

Sensor type	Serial Number	Site	Start of data record, UTC	End of data record, UTC	Data file name
Atmospheric pressure and temperature measurements					
Onset Hobo	10125471	965	7/22/13 15:20:00	11/20/13 21:20:00	9651hwl-a.nc
Water-level measurements					
RBR DR1060	24101	966	7/22/13 16:35:00	11/18/13 8:46:28	9661rb-a.nc
RBR DR1060	24032	967	NA	NA	NA
RBR D wave	55033	968	7/22/13 22:50:00	10/24/13 11:43:38	9681dw-a.nc
Onset Hobo	10313354	969	7/23/13 16:10:00	11/19/13 21:50:00	9691hwl-a.nc
RBR DR1060	24033	970	7/23/13 17:00:04	8/28/13 8:27:52	9701rb-a.nc
RBR DR1060	24099	971	7/23/13 20:25:08	11/19/13 17:01:56	9711rb-a.nc
RBR DR1060	24100	972	7/23/13 21:25:04	10/03/13 4:10:12	9721rb-a.nc
Onset Hobo	10079949	973	7/23/13 22:10:00	11/19/13 19:30:00	9731hwl-a.nc
Onset Hobo	10313355	974	7/24/13 01:00:00	11/19/13 17:30:00	9741hwl-a.nc
Onset Hobo	10079950	975	7/24/13 17:50:00	11/19/13 15:00:00	9751hwl-a.nc
Onset Hobo	10313353	976	7/24/13 18:30:00	11/20/13 21:50:00	9761hwl-a.nc

