Global Positioning System Surveys of Storm-Surge Sensors Deployed During Hurricane Ike, Seadrift, Texas, to Lake Charles, Louisiana, 2008

Data Series 435

U.S. Department of the Interior
U.S. Geological Survey

Front cover: Photographs at Freeport, Texas, benchmark location during 2008 Hurricane Ike Global Positioning System (GPS) surveys of storm-surge sensors showing (clockwise from bottom left) brass U.S. Geological Survey marker; various types of waterfowl; and GPS unit (Ashtech Geodetic IV rev. A without groundplane).

Back cover: Photograph of alligator along coast south of Beaumont, Texas, during 2008 Hurricane Ike GPS surveys of storm-surge sensors.

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By Jason D. Payne, Brenda K. Woodward, and John B. Storm

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KEN SALAZAR, Secretary

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Conversion Factors and Datums

Inch/Pound to SI

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Global Positioning System Surveys of Storm-Surge Sensors Deployed During Hurricane Ike, Seadrift, Texas, to Lake Charles, Louisiana, 2008

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Abstract

The U.S. Geological Survey installed a network of pressure sensors at 65 sites along the Gulf Coast from Seadrift, Texas, northeast to Lake Charles, Louisiana, to record the timing, areal extent, and magnitude of inland storm surge and coastal flooding caused by Hurricane Ike in September 2008. A Global Positioning System was used to obtain elevations of reference marks near each sensor. A combination of real-time kinematic (RTK) and static Global Positioning System surveys were done to obtain elevations of reference marks. Leveling relative to reference marks was done to obtain elevations of sensor orifices above the reference marks. This report summarizes the Global Positioning System data collected and processed to obtain reference mark and storm-sensor-orifice elevations for 59 storm-surge sensors recovered from the original 65 installed as a necessary prelude to computation of storm-surge elevations. National Geodetic Survey benchmarks were used for RTK surveying. Where National Geodetic Survey benchmarks were not within 12 kilometers of a sensor site, static surveying was done. Additional control points for static surveying were in the form of newly established benchmarks or reestablished existing benchmarks. RTK surveying was used to obtain positions and elevations of reference marks for 29 sensor sites. Static surveying was used to obtain positions and elevations of reference marks for 34 sensor sites; four sites were surveyed using both methods. Multiple quality checks on the RTK-survey and static-survey data were applied. The results of all quality checks indicate that the desired elevation accuracy for the surveys of this report, less than 0.1-meter error, was achieved.

Introduction

As Hurricane Ike approached the Gulf Coast of Texas and Louisiana in September 2008, the U.S. Geological Survey (USGS) installed a network of pressure sensors at 65 sites along the coast (56 in Texas and 9 in Louisiana) to record the timing, areal extent, and magnitude of inland storm surge and coastal flooding. The sensor network extended from Seadrift, Tex., northeast to Lake Charles, La., and was centered on the forecasted track of the hurricane. The HOBO® pressure sensors used were installed on barrier islands, on beaches, in river channels, and on the inland side of bays. The sensors internally log water or barometric pressure and temperature at a set time interval. Some sensors measured water pressure and others barometric pressure.

After the storm, a Global Positioning System (GPS) was used to obtain elevations of reference marks (RMs) near each sensor in meters above the North American Vertical Datum of 1988 (NAVD 88). A combination of real-time kinematic (RTK) and static GPS observations were used to survey the RMs. Leveling relative to RMs was done to obtain elevations of sensor orifices in meters above the RMs. Continuous water pressure recorded by the sensors before, during, and after the hurricane, corrected for barometric pressure and salinity, was converted to elevation of water in meters above sensor orifices. For each sensor, elevation of an associated RM, elevation of the sensor orifice above the RM, and elevation of water above the orifice could then be summed to obtain elevation of storm surge above NAVD 88 at each site, as documented in East and others (2008)[1].

This report summarizes the GPS data collected and processed to obtain RM and storm-sensor-orifice elevations for 59 of the 65 storm-surge sensors installed along the Texas and Louisiana coast (fig. 1). Sensors from six sites were not recovered and thus not surveyed. The report describes the application of RTK GPS surveying and static GPS surveying, how each type of data is processed, and the accuracy of the data.

Global Positioning System Surveys

GPS is a constellation of navigation satellites that are used in conjunction with ground receivers to provide precise elevation and horizontal location (position). Elevation and horizontal position are determined when a ground receiver can correctly determine the time of travel of the microwave signals

[1] East and others (2008) uses inch/pound units of measure rather than metric units, as used in this report.

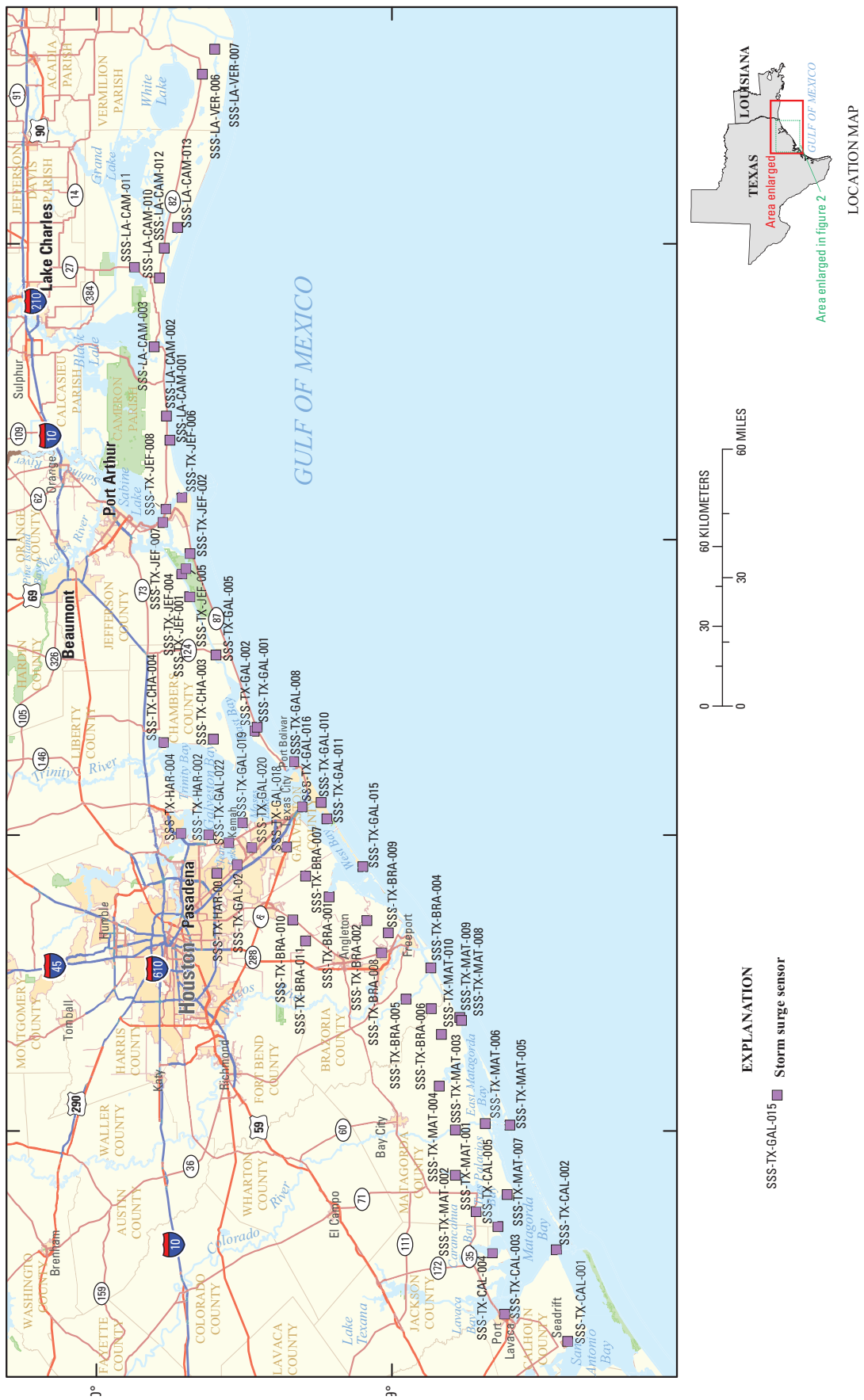

Figure 1. Locations of sensor sites from which storm-surge data were collected before, during, and after Hurricane Ike, Seadrift, Texas, to Lake Charles, Louisiana, 2008.

between the satellite and the receiver and relate this to distance to each of the GPS satellites observed (Bogan, 1998). Even though the position of a receiver can be determined by communicating with a minimal number of satellites (less than six), additional information is needed when very accurate horizontal and vertical positions are required. This additional information comes from setting at least one receiver, referred to as a base station, on a known point, referred to as a benchmark, during the survey. The receiver calculates position in relation to the satellites and then uses the known position to calculate errors in time of travel (attributed to ionospheric and tropospheric interference) that affect the message from the satellites. These calculated corrections can then be applied to other data points that were collected with other receivers in the area during the same period to reduce the error in position. GPS positions calculated from distance to each satellite are in the form of latitude, longitude, and ellipsoidal heights. However, most surveyors are interested in orthometric heights (elevations above NAVD 88), which can be calculated from ellipsoidal heights by applying the gravitational model Geoid03 (National Geodetic Survey, 2003).

For the surveys of this report, an elevation accuracy of less than 0.1 meter (including error associated with the Geoid03 model) was desired to accurately document storm surge along the coast. Therefore, benchmarks were required to establish base stations for the survey. If available, National Geodetic Survey (NGS) first-order benchmarks were used (fig. 2); NGS second- and third-order benchmarks were not used. NGS benchmarks were used for RTK surveying. Where NGS benchmarks were not available (not within 12 kilometers of the sensor site), static surveying was done. Additional control points (points for which elevations were obtained) for static surveying were in the form of newly established benchmarks or reestablished existing benchmarks (existing benchmarks for which elevations were reestablished during RTK or static surveys).

Along the Texas coast, a number of continuously operating reference stations (CORS) are maintained by the NGS (National Geodetic Survey, 2008a) and Texas Department of Transportation. Three CORS were included in the static surveys (fig. 2) as control checks, although the data collected from them were not directly used for obtaining elevations of sensor RMs, and thus sensor elevations. (Also included in RTK-survey data collection, but not for the purpose of obtaining elevations of sensor reference marks, were seven USGS real-time gages [table 1].)

Real-Time Kinematic Surveys

If NGS benchmarks were within 12 kilometers of sensor sites, the base stations could transmit correction information to receivers by way of radio signal, and corrections were applied in real time to measurements made at sensor RMs. RTK surveying is a carrier-phase-based, relative-positioning technique that uses two or more receivers simultaneously tracking the same satellites (Texas Department of Transportation, 2008). Normally the base receiver remains stationary over a known point and is attached to a radio transmitter. A rover receiver is attached to a radio receiver and is positioned at an unknown or known point. The base receiver GPS measurements and coordinates are transmitted to the rover receiver through a radio link. The software in the rover receiver combines and processes the GPS measurements collected at the base and the rover receivers to obtain the rover coordinates.

A modified RTK technique was used to reduce the baseline lengths between the rover and base station and allow for a more centralized base-station location. This technique is similar to a set of differential levels because the base station is set over a point of unknown coordinates. Instead of inputting its location, the base station “fixes” its first reading from Wide Area Augmentation System (WAAS)-generated coordinates (Federal Aviation Administration, 2009). This reading would be considered the height of the instrument in differential leveling. This reading does not improve or degrade over time because it is fixed. All rover measurements are then made relative to the fixed base station with measurements on control points considered backsights and measurements on unknown points (storm-surge sensors) considered foresights. This technique allowed the selection of the best location possible for the base station without the requirement to set up over a known benchmark that could have obstruction or stability issues, or long base lines.

A diagram showing the RTK GPS configuration and photographs of base-station and rover setups are shown in figure 3. Equipment for the base station and the rovers include a fixed-height tripod and bipod, respectively, each set at 2 meters for consistency. While the base station (a Trimble Zephyr Geodetic) runs continuously, each rover (two Trimble 5800s) occupies a location for a minimum of 3 minutes (180 epochs at a 1-second logging interval) to compute a final elevation. The rover is then inverted until communication with the satellites and the base station is lost. To ensure quality in the data, the rover is then reset over its original point and allowed to reinitialize and regain all communications to establish a second fixed solution. This is done because the GPS solution occasionally is in error (known as an integer ambiguity error), and a second measurement can be compared to the first to ensure that the error is not affecting the reading. If the maximum allowable difference of 0.02 meter between the first and second solutions is not met, the same procedures for reinitialization are followed, and a third measurement is taken. Quality-control parameters such as vertical precision (generally within 0.03 meter at 95-percent confidence) and position-solution standard deviation root mean square (RMS) spread of results are noted and checked to indicate whether a solution should be removed because of poor quality; if not, all solutions are kept for a final average. RMS values generally were kept within 0.01 meter. In addition surveyors kept baseline lengths under 12 kilometers and Position Dilution of Precision (a unitless measure that indicates when satellite geometry will provide the most accurate results) less than 3. Multipath

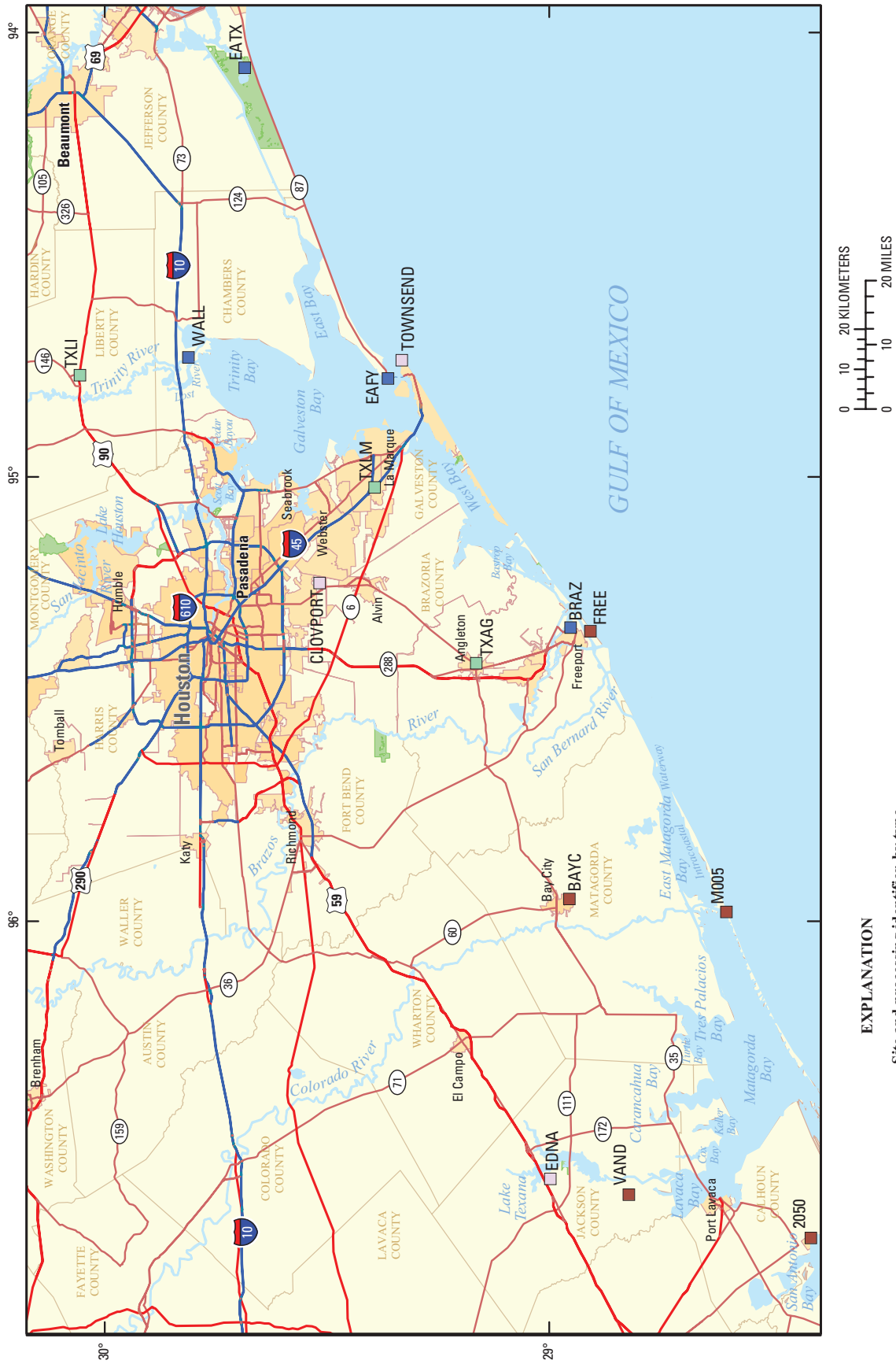

Figure 2. Locations of National Geodetic Survey benchmarks, newly established benchmarks, reestablished benchmarks, and continuously operating reference stations surveyed after Hurricane Ike, Seadrift, Texas, to Lake Charles, Louisiana, 2008.

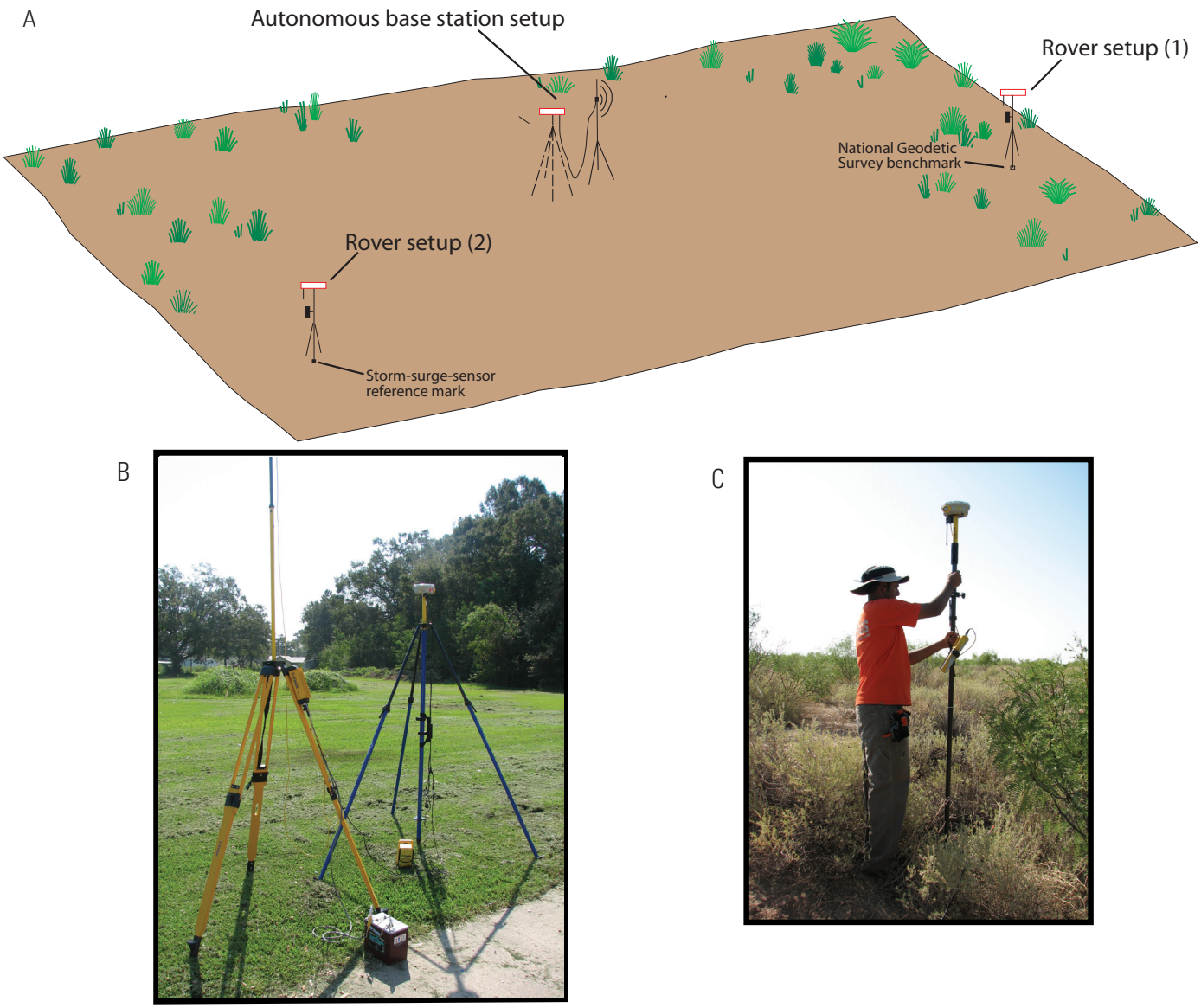

Figure 3. (A) Diagram showing real-time kinematic Global Positioning System configuration used during surveys of storm-surge sensors, Seadrift, Texas, to Lake Charles, Louisiana, 2008; (B) photograph showing base-station setup; and (C) photograph showing rover setup.

conditions were observed and noted before collecting GPS data, and rover elevation masks were set between 12 and 15 degrees (that is, only satellites above 12–15 degrees in the sky are used in solutions) to avoid atmospheric delay and refraction.

To ensure quality in the data, as many control points as possible were included with each base-station setup. Three control points were considered ideal, but in some cases only one was available. At each base-station setup, the RTK-derived elevations at the control points were compared to the published NGS elevations (National Geodetic Survey, 2009) and the difference applied to the RTK-derived elevation for each unknown RM. If the differences between the NGS-published elevations and RTK-derived elevations based on the WAAS starting position for the base receiver were not consistent among all the control points, an average difference was computed and applied to the RTK-derived elevation at each unknown RM. Horizontal positions were not corrected on the basis of known locations; instead the average of the RTK positions based on the WAAS starting position for the base receiver was used.

Table 1 shows positions and elevations for RMs for 29 storm-surge-sensor sites (and one reestablished U.S. Army Corps of Engineers [USACE] benchmark [Bolivar Ferry, EAFY] used as control for the static survey; and seven real-time gages surveyed only because it was convenient).

Table 1. Positions and elevations for 29 storm-surge-sensor reference marks, one reestablished benchmark, and seven real-time gages from real-time kinetic Global Positioning System surveys, Seadrift, Texas, to Lake Charles, Louisiana, 2008.

[RM, reference mark; UGSG, U.S. Geological Survey; UTM, Universal Transverse Mercator zone 15; --, not applicable; Leveled, diffential levels run]

Sensor identifier (fig. 1) (RM surveyed)	Reestablished benchmark identifier (processing identifier)	USGS real-time gage name (site number)	Average northing (UTM-meters)	Average easting (UTM-meters)	Elevation (meters above NAVD 88)
SSS–TX–GAL–001 (1)	--	--	3259393.790	341307.112	2.220
SSS–TX–GAL–002 (1)	--	--	3260739.121	340179.312	1.053
SSS–TX–GAL–008 (3)	--	--	3246279.927	330411.550	.996
SSS–TX–GAL–010 (1)	--	--	3235870.783	317530.346	2.019
SSS–TX–GAL–011 (1)	--	--	3233986.352	310982.148	1.140
SSS–TX–GAL–016 (1)	--	--	3243233.990	314915.637	2.109
SSS–TX–GAL–018 (1)	--	--	3249136.936	301994.609	5.196
SSS–TX–GAL–019 (1)	--	--	3265678.548	310235.824	2.912
SSS–TX–GAL–020 (1)	--	--	3260400.032	301383.807	1.510
SSS–TX–GAL–021 (3)	--	--	3266699.943	296077.239	1.619
SSS–TX–GAL–022 (1)	--	--	3270884.886	303813.956	1.154
SSS–TX–HAR–002 (3)	--	--	3278372.587	306539.645	2.080
SSS–TX–HAR–003 (3)	--	--	3275462.814	293882.055	6.684
SSS–TX–HAR–004 (1)	--	--	3288636.344	307162.724	2.502
SSS–TX–JEF–002 (1)	--	--	3283406.396	398978.972	1.471
SSS–TX–JEF–004 (1)	--	--	3287058.471	392356.714	1.25
SSS–TX–JEF–005 (1)	--	--	3285179.619	395517.37	1.091
SSS–TX–JEF–006 (1)	--	--	3287117.076	416793.650	1.523
SSS–TX–JEF–007 (1)	--	--	3294223.145	408978.910	2.094
SSS–TX–JEF–008 (1)	--	--	3293081.792	413173.301	.695
SSS–LA–CAM–001 (1)	--	--	3291343.787	435825.473	1.538
SSS–LA–CAM–002 (1)	--	--	3292537.349	443665.646	1.942
SSS–LA–CAM–003 (1)	--	--	Leveled	Leveled	1.417
SSS–LA–CAM–010 (1)	--	--	3295083.463	488872.255	1.561
SSS–LA–CAM–011 (1)	--	--	3304438.553	492300.693	1.419
SSS–LA–CAM–012 (1)	--	--	3293360.582	498556.651	2.922
SSS–LA–CAM–013 (1)	--	--	3286353.669	531281.033	1.913
SSS–LA–VER–006 (1)	--	--	3279197.192	555379.982	1.149
SSS–LA–VER–007 (1)	--	--	3274907.662	563652.688	1.714
--	Bolivar Ferry (EAFY)	--	3249438.106	327407.307	1.368
--	--	La Marque levee pump station near La Marque, Tex. (08077740)	3247949.053	309422.862	5.827
--	--	Taylor-Alligator Bayou pump station near Port Arthur, Tex. (08042522)	3303892.179	404276.722	4.864
--	--	Neches River saltwater barrier at Beaumont, Tex. (08041780)	3336295.382	392567.783	2.594
--	--	Pine Island Bayou above BI Pump Plant, Beaumont, Tex. (08041749)	3339205.671	385481.166	4.169
--	--	Moses Lake-Galveston Bay near Texas City, Tex. (08077650)	3258847.090	314018.739	5.157
--	--	Clear Lake second outflow channel at Kemah, Tex. (08077637)	3271046.925	304165.267	1.770
--	--	Buffalo Bayou at Turning Basin, Houston, Tex. (08074710)	3293194.999	278404.346	5.428

Figure 4. Static Global Positioning System equipment used during surveys of storm-surge sensors, Seadrift, Texas, to Lake Charles, Louisiana, 2008.

Appendix 1 shows the complete data used to derive location and elevation of each RM surveyed and the control data used, organized by RTK base-station setup.

Static Surveys

If NGS benchmarks were not within 12 kilometers of a sensor site, static surveys were done. Static surveys consisted of three GPS receivers recording data at 15-second intervals over known benchmarks (NGS benchmark, reestablished benchmark, or newly established benchmark) that formed a triangle (from about 32 to 64 kilometers on each side) around several sensor sites. While all three base stations were collecting data, GPS receivers (fig. 4) were set over the RMs for sensors enclosed within the triangle formed by benchmarks to record GPS data at 15-second intervals for about 3 to 6 hours. These data were then post-processed to relate base-station correction information to the data collected at sensor RMs through baseline processing and network adjustment. GPS antennas used in static surveys included three Sokkia GSR 2700 IS (L1/L2), three Ashtech Geodetic IV rev A without groundplane, two Trimble 5800s, and a Trimble Zephyr Geodetic.

Static surveying was used to obtain positions and elevations of RMs for 34 sensor sites (35 sensors total because two RMs were associated with one site (SSS–TX–GAL–002). Static surveys involved five newly established benchmarks (one of which is an RM [M005] coincident with a sensor site [SSS–TX–MAT–005]), four reestablished benchmarks, and three NGS benchmarks (table 2). Static surveying began on October 2, 2008, and was completed on October 8, 2008. New benchmarks were established at Vanderbilt (VAND), Bay City (BAYC), and Freeport (FREE), by drilling a small hole into concrete and placing on the concrete a brass USGS marker secured with epoxy glue (fig. 5). The new benchmark established at sensor site SSS–TX–MAT–005 (M005) is a square chiseled in concrete. The new benchmark established at Seadrift (2050) is a USGS Nebraska Water Science Center survey cap attached to an approximately 1-meter rod with extendable underground anchors that hold the rod in place. Benchmarks were reestablished at the USGS real-time gage 08067252 Trinity River at Wallisville (WALL), at the USGS real-time gage 08079120 Old Brazos River near Freeport (BRAZ), at the USACE benchmark Bolivar Ferry (EAFY), and at Sea Rim State Park (EATX); all those are brass caps that were resurveyed.

Processing of the static GPS surveys was completed in two different network adjustments. Network 1 comprised the five newly established benchmarks (2050, VAND, BAYC, FREE, and M005), three of the four reestablished benchmarks (EAFY, EATX, and WALL), the three NGS benchmarks (EDNA, CLOVPORT, and TOWNSEND) used as control for positions and elevations, and the three CORS used as control checks but not directly for obtaining sensor RMs (CORS site identifiers TXLI, TXLM, and TXAG [not in table 2]) for a total of 14 control points. Network 2 comprised all the control points in Network 1 plus reestablished benchmark BRAZ plus all 35 sensor RMs for a total of 49 control points (not 50 because benchmark M005 is coincident with a sensor site).

A number of steps were taken to process the static GPS survey data in Trimble Geomatics Office (TGO) (Trimble, 2008). First, data observation files were imported with the antenna type, antenna height, and site name information. Network 1 contained 37 observations and Network 2 contained 75 observations. Then baselines were processed to determine the exact x,y,z difference between each pair of observations; 72 baselines were processed in Network 1 and 324 in Network 2. All three-sided loops were evaluated to determine whether errors in loop closures could be reduced by identifying and removing inconsistent baselines or duplicate baselines that conflicted with one another. The inconsistent or duplicate baselines were removed from the survey networks, leaving Network 1 with 55 baselines and Network 2 with 219 baselines.

Once all loops closed within acceptable standards—the least-accurate loops in the surveys closed vertically within 0.06 meter and horizontally within 0.04 meter—a minimally constrained adjustment was processed. The minimally constrained adjustment was completed for both networks with just one control point, the NGS benchmark Townsend, held constant (fixed). The Townsend benchmark was used because it was a first-order vertical and horizontal NGS benchmark in the center of the survey area. Prior to adjusting, all known control points are set by entering into TGO the known positions and elevations. This allows the surveyor to evaluate the adjustment by reviewing how far each known point has been shifted. During the minimally constrained adjustment, error estimates are scaled to better identify the error in baseline processing. The minimally constrained adjustment also helps to identify any data outliers that do not fit within the overall network. Reports on the minimally constrained adjustments for both networks are in appendix 2.

After the minimally constrained adjustment was made and evaluated, several known control points were fixed, the Geoid03 model was applied, and a fully constrained adjustment was made on each survey network. Quality checks such as evaluation of shifts in elevation and position applied to non-fixed control points (table 3), 95-percent confidence limits in the accuracy of measurements of each position, and parts per million (PPM) errors in baselines (appendix 2) were done for each network. The PPM error is a calculation of error based on the length of the baseline. The largest shift in elevation of a non-fixed control point in Network 2 was 0.093 meter. Errors in orthometric heights were estimated by adding the average error in the Geoid03 model of 0.020 meter (National Geodetic Survey, 2003) to the estimated error in ellipsoid heights as determined by TGO. If errors were acceptable, then the position and elevation calculated by the fully constrained adjustment was accepted as the final position and elevation of each control point. Reports on the fully constrained adjustment for both networks are in appendix 3. The final positions and elevations for all control points in Network 2 are listed in table 4.

As another quality check, all newly established benchmarks and three of the four reestablished benchmarks were surveyed on several different dates and were processed through the NGS Online Positioning Users Service (OPUS) (National Geodetic Survey, 2008b) in addition to processing with TGO. OPUS processing of static GPS data collected on one benchmark on different dates resulted in differences in orthometric height of as much as 0.043 meter (Freeport benchmark on October 4 and 6, 2008) (table 5). The greatest difference in ellipsoid height between the two processing methods was 0.096 meter (Vanderbilt benchmark).

During processing of static survey data, multiple observations give the surveyor more opportunities to find and eliminate poor data and allow for the position to be determined with multiple satellite geometries, which yields a more reliable outcome. Multiple observations were made on RMs associated with three sensors (SSS–TX–MAT–003, SSS–TX–MAT–006, SSS–TX–BRA–005), and these data were incorporated into the surveying database (table 2).

In addition, two RMs (RM 1, RM 2) associated with one sensor site (SSS–TX–GAL–002) were surveyed to assess how the difference in elevation computed from static GPS measurements for the two RMs compared to the difference obtained by

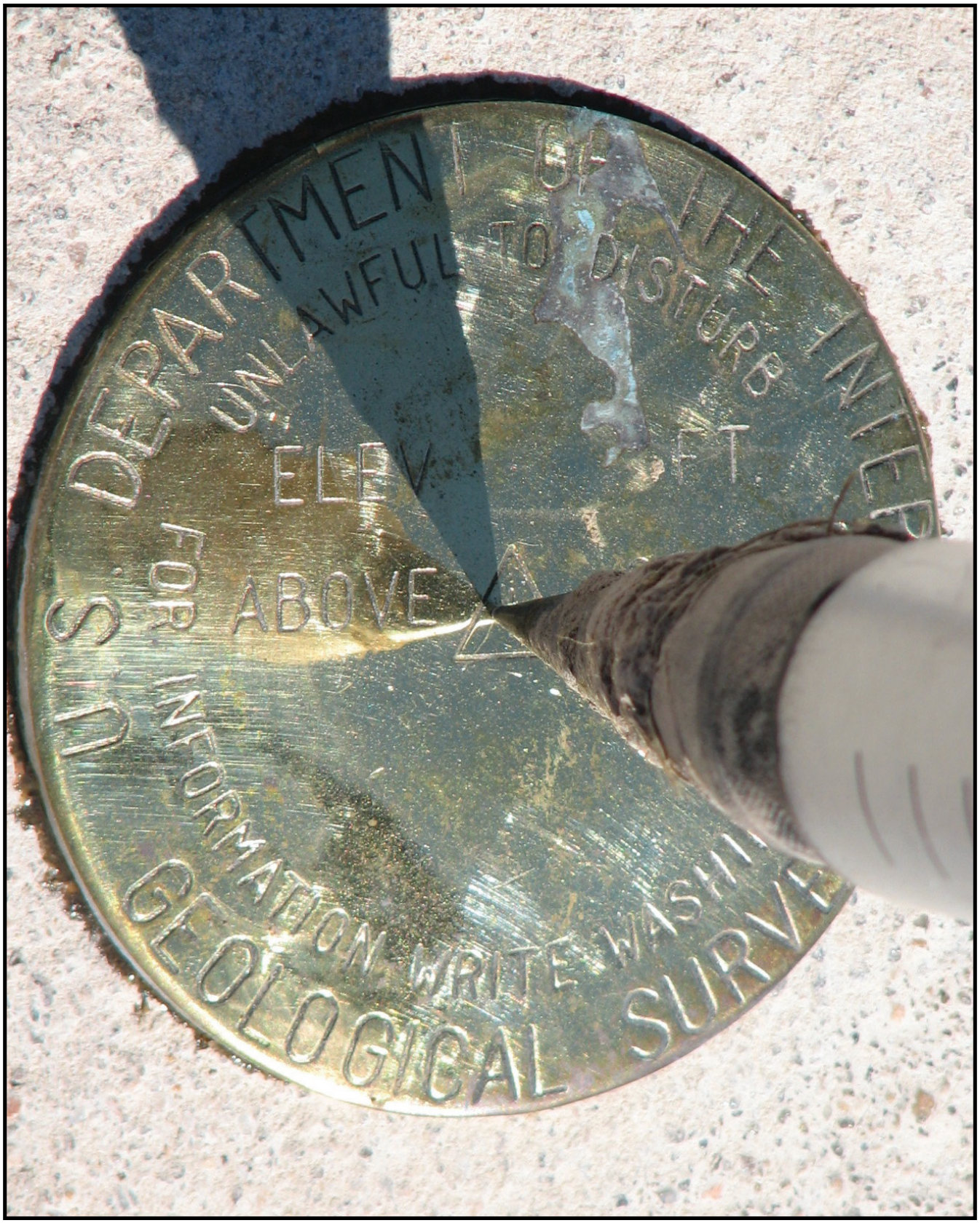

Figure 5. Benchmark (brass U.S. Geological Survey marker) established during static Global Positioning System surveys of storm-surge sensors, Seadrift, Texas, to Lake Charles, Louisiana, 2008.

Table 2. Data from static Global Positioning System surveys of storm-surge-sensor reference marks, Seadrift, Texas, to Lake Charles, Louisiana, 2008.

[NGS, National Geodetic Survey; RM, reference mark; --, not applicable; PID, primary identifier; USGS, U.S. Geological Survey]

Date	Newly established or reestablished benchmark identifier (processing identifier shown in fig. 2)	NGS benchmark identifier	Sensor identifier (fig. 1) and RM used	Processing identifier	Total survey time (hours:minutes: seconds)
10/2/2008	Seadrift	--	--	2050	7:14:45
10/2/2008	Bay City	--	--	BAYC	4:59:00
10/2/2008	--	NGS EDNA PORT PID:AN2051	--	EDNA	8:28:15
10/2/2008	Freeport	--	--	FREE	7:51:50
10/2/2008	M005	--	SSS–TX–MAT–005 RM 3	M005	11:51:30
10/2/2008	Vanderbilt	--	--	VAND	7:14:15
10/3/2008	Seadrift	--	--	2050	9:54:45
10/3/2008	M005	--	SSS–TX–MAT–005 RM 3	M005	3:29:00
10/3/2008	M005	--	SSS–TX–MAT–005 RM 3	M005	10:13:15
10/3/2008	Vanderbilt	--	--	VAND	10:16:30
10/3/2008	--	--	SSS–TX–CAL–001 RM 1	CA001	2:38:45
10/3/2008	--	--	SSS–TX–CAL–002 RM 1	CA002	4:56:45
10/3/2008	--	--	SSS–TX–CAL–003 RM 2	CA003	4:09:45
10/3/2008	--	--	SSS–TX–CAL–004 RM 1	CA004	2:47:45
10/3/2008	--	--	SSS–TX–CAL–005 RM 1	CA005	2:37:30
10/3/2008	--	--	SSS–TX–MAT–001 RM 1	M001	3:24:15
10/3/2008	--	--	SSS–TX–MAT–007 RM 2	M007	3:37:15
10/4/2008	Bay City	--	--	BAYC	3:21:30
10/4/2008	Bay City	--	--	BAYC	6:44:40
10/4/2008	Freeport	--	--	FREE	7:33:45
10/4/2008	M005	--	SSS–TX–MAT–005 RM 3	M005	13:03:45
10/4/2008	--	--	SSS–TX–MAT–002 RM 1	M002	2:43:45
10/4/2008	--	--	SSS–TX–MAT–003 RM 1	M003	3:44:30
10/4/2008	--	--	SSS–TX–MAT–003 RM 1	M003	3:19:15
10/4/2008	--	--	SSS–TX–MAT–006 RM 1	M006	3:33:45
10/4/2008	--	--	SSS–TX–MAT–006 RM 1	M006	2:59:15
10/4/2008	--	--	SSS–TX–MAT–008 RM 1	M008	2:59:00
10/4/2008	--	--	SSS–TX–MAT–009 RM 2	M009	3:00:00
10/5/2008	Bay City	--	--	BAYC	10:36:30
10/5/2008	Freeport	--	--	FREE	10:36:45
10/5/2008	M005	--	SSS–TX–MAT–005 RM 3	M005	12:16:15
10/5/2008	--	--	SSS–TX–BRA–004 RM 2	B004	5:59:45
10/5/2008	--	--	SSS–TX–BRA–005 RM 1	B005	3:08:45
10/5/2008	--	--	SSS–TX–BRA–006 RM 1	B006	3:02:00
10/5/2008	--	--	SSS–TX–MAT–004 New	M004	3:00:30
10/5/2008	--	--	SSS–TX–MAT–010 RM 3	M010	3:06:00
10/6/2008	Bay City	--	--	BAYC	3:35:30
10/6/2008	--	NGS CLOVPORT AZ MK 1987 PID: AW5550	--	CLOVPORT	9:47:00
10/6/2008	Freeport	--	--	FREE	6:35:00
10/6/2008	Freeport	--	--	FREE	4:26:45
10/6/2008	--	NGS TOWNSEND PID: AW7078	--	TOWNSEND	8:45:15
10/6/2008	--	--	SSS–TX–BRA–001 RM 1	B001	5:33:15
10/6/2008	--	--	SSS–TX–BRA–002 RM 2	B002	4:58:30
10/6/2008	--	--	SSS–TX–BRA–005 RM 1	B005	3:29:00
10/6/2008	--	--	SSS–TX–BRA–007 RM 3	B007	5:28:30
10/6/2008	--	--	SSS–TX–BRA–008 RM 2	B008	3:11:45
10/6/2008	--	--	SSS–TX–BRA–009 RM 1	B009	2:59:15
10/6/2008	--	--	SSS–TX–BRA–010 RM 1	B010	4:06:15
10/6/2008	--	--	SSS–TX–BRA–011 RM 3	B011	4:06:30

Table 2. Data from static Global Positioning System surveys of storm-surge-sensor reference marks, Seadrift, Texas, to Lake Charles, Louisiana, 2008—Continued.

Date	Newly established or reestablished benchmark identifier (processing identifier shown in fig. 2)	NGS benchmark identifier	Sensor identifier (fig. 1) and RM used	Processing identifier	Total survey time (hours:minutes: seconds)
10/6/2008	USGS real-time gage Old Brazos River near Freeport, Tex. (08079120)	--	--	BRAZ	2:59:30
10/6/2008	--	--	SSS–TX–GAL–015 New	GA15	3:18:15
10/7/2008	Bolivar Ferry	--	--	EAFY	7:12:15
10/7/2008	Sea Rim State Park	--	--	EATX	7:47:15
10/7/2008	USGS real-time gage Trinity River at Walllisville, Tex. (08067252)	--	--	WALL	8:09:00
10/8/2008	Bolivar Ferry	--	--	EAFY	9:01:45
10/8/2008	Sea Rim State Park	--	--	EATX	9:40:00
10/8/2008	USGS real-time gage Trinity River at Walllisville, Tex. (08067252)	--	--	WALL	9:48:15
10/8/2008	--	--	SSS–TX–CHA–003 RM 2	C003	4:07:00
10/8/2008	--	--	SSS–TX–CHA–004 RM 1	C004	4:05:30
10/8/2008	--	--	SSS–TX–GAL–001 RM 1	G001	5:06:30
10/8/2008	--	--	SSS–TX–GAL–002 RM 1	G0021	3:57:30
10/8/2008	--	--	SSS–TX–GAL–002 RM 2	G0022	3:56:29
10/8/2008	--	--	SSS–TX–GAL–005 RM 1	G005	6:10:45
10/8/2008	--	--	SSS–TX–JEF–001 New	J001	6:12:45
10/8/2008	--	--	SSS–TX–JEF–004 RM 1	J004	4:02:45
10/8/2008	--	--	SSS–TX–JEF–005 RM 1	J005	4:03:45

Table 3. Shifts in position and elevation applied to non-fixed control points of static Global Positioning System surveys, Seadrift, Texas, to Lake Charles, Louisiana, 2008, during the final adjustment of Network 2.

[Δ, change in location from initial network adjustment; UTM, Universal Transverse Mercator zone 15]

Processing identifier (fig. 2)	Δ Northing (UTM-meters)	Δ Easting (UTM-meters)	Δ Height (meters)
WALL	-0.001	0.002	0.012
EATX	-.005	.006	.025
BAYC	.008	-.004	-.003
M005	.008	-.007	-.010
VAND	.015	-.005	-.007
2050	.013	-.010	-.021
FREE	.003	-.004	-.002
TXAG	-.004	.028	-.093
TXLM	.013	.024	-.052
TXLI	.022	.019	-.017
EAFY	-.003	.000	.012

Table 4. Final positions and elevations for statically surveyed newly established benchmarks, reestablished benchmarks, National Geodetic Survey benchmarks, continuously operated receiver stations, and storm-surge-sensor reference marks (all control points in Network 2), Seadrift, Texas, to Lake Charles, Louisiana, 2008.

[UTM, Universal Transverse Mercator zone 15; N, north; W, west; shaded rows indicate control positions (National Geodetic Survey benchmarks) fixed in the network adjustment]

Processing identifier	Latitude (degrees, minutes, decimal seconds)	Latitude error	Longitude (degrees, minutes, decimal seconds)	Longi-tude error	Ellipsoid height (meters)	Ellipsoid height error (meters)	Northing (UTM-meters)	Easting (UTM-meters)	Elevation (meters above NAVD 88)
WALL	29 48 43.16443N	0.004	94 43 52.61468W	0.004	-23.577	0.016	3299209.530	332695.050	3.803
EATX	29 41 07.33034N	.004	94 04 45.75110W	.004	-26.273	.015	3284409.777	395566.758	.688
BAYC	28 57 14.89738N	.003	95 57 00.04042W	.003	-13.479	.012	3206489.927	212474.392	13.346
M005	28 36 01.32589N	.003	95 58 42.54370W	.003	-25.209	.020	3167337.537	208715.453	1.284
VAND	28 49 13.56849N	.004	96 36 55.01308W	.004	-16.364	.014	3193462.874	147138.788	10.856
2050	28 24 30.03152N	.004	96 42 49.54181W	.004	-24.430	.024	3148053.740	136098.884	2.511
EDNA	28 59 50.58839N	0	96 34 47.30629W	0	-9.179	0	3212982.664	151197.120	18.151
FREE	28 54 24.68734N	.002	95 20 49.01511W	.002	-24.806	.014	3199932.608	271168.398	1.510
CA002	28 26 41.39552N	.005	96 24 09.25267W	.005	-25.206	.025	3151197.404	166726.846	1.506
CA001	28 24 24.14115N	.006	96 42 42.10225W	.006	-25.566	.027	3147866.012	136295.934	1.372
CA004	28 39 38.72794N	.005	96 24 42.73486W	.005	-25.266	.021	3175167.586	166497.608	1.627
CA003	28 37 09.13179N	.005	96 37 11.55699W	.005	-25.343	.023	3171158.534	146011.462	1.701
M001	28 43 14.90328N	.005	96 16 25.04709W	.005	-25.497	.023	3181447.265	180201.896	1.362
CA005	28 38 31.78188N	.009	96 19 24.96860W	.009	-24.771	.059	3172861.845	175073.551	2.051
M007	28 36 38.85394N	.006	96 12 54.05552W	.006	-25.171	.026	3169092.812	185601.936	1.565
M006	28 40 59.94118N	.004	95 58 30.94286W	.004	-21.758	.023	3176525.950	209259.863	4.861
M003	28 47 14.77100N	.004	95 59 46.08822W	.004	-20.432	.021	3188120.665	207509.574	6.295
M002	28 47 11.71570N	.005	96 09 01.26222W	.005	-26.285	.027	3188416.017	192444.226	.556
M008	28 45 51.14133N	.005	95 37 37.50865W	.005	-24.421	.025	3184693.138	243494.880	1.948
M009	28 46 15.35494N	.005	95 36 59.93953W	.005	-25.659	.022	3185416.254	244530.607	.709
B004	28 52 07.06590N	.004	95 26 54.94842W	.004	-24.414	.018	3195895.920	261166.820	1.923
B005	28 56 57.68898N	.004	95 33 20.41524W	.004	-24.686	.017	3205065.033	250912.383	1.844
B006	28 52 00.01108N	.005	95 35 15.14681W	.005	-25.415	.028	3195966.542	247604.830	1.054
M010	28 50 10.60696N	.005	95 40 06.94023W	.005	-22.416	.025	3192772.962	239619.851	4.094
M004	28 50 19.87388N	.005	95 51 10.29541W	.005	-23.049	.026	3193476.672	221639.827	3.601
B008	29 02 07.46031N	.004	95 23 55.56364W	.003	-20.526	.014	3214282.478	266403.501	6.032
TXAG	29 09 50.97299N	.003	95 25 08.42428W	.003	-14.569	.012	3228594.481	264725.176	12.157
TXLM	29 23 31.98626N	.002	95 01 25.23873W	.002	-16.093	.009	3253143.836	303621.337	10.766
B002	29 05 05.25615N	.003	95 17 17.07791W	.003	-24.870	.015	3219542.424	277292.113	1.712
B009	29 00 48.60783N	.004	95 19 46.99888W	.004	-24.148	.017	3211719.906	273081.388	2.348
BRAZ	28 57 04.80254N	.005	95 20 19.46172W	.005	-21.106	.023	3204846.531	272066.449	5.285
B001	29 12 42.53459N	.003	95 12 30.76428W	.003	-25.175	.012	3233473.418	285299.778	1.544
B007	29 17 12.18320N	.003	95 07 51.51276W	.003	-21.228	.011	3241635.821	292993.413	5.554
GA15	29 05 10.83505N	.003	95 07 04.85849W	.003	-25.379	.014	3219404.564	293852.094	1.108
J001	29 41 05.74030N	.004	94 11 33.51917W	.004	-24.818	.014	3284468.464	384606.327	2.202
G005	29 35 37.70342N	.004	94 23 22.93715W	.004	-24.347	.014	3274583.343	365416.903	2.596
J004	29 42 32.38264N	.004	94 06 46.12012W	.004	-25.764	.015	3287058.477	392356.716	1.263
J005	29 41 32.32296N	.005	94 04 47.85592W	.004	-25.904	.015	3285179.612	395517.369	1.072
G0021	29 27 57.34015N	.004	94 38 52.78191W	.004	-25.818	.014	3260738.905	340199.072	.996
TXLI	30 03 21.18020N	.003	94 46 15.68037W	.003	-9.784	.022	3326299.520	329271.131	17.748
G001	29 27 14.11497N	.004	94 38 10.94626W	.004	-24.622	.013	3259392.365	341307.389	2.162
G0022	29 27 57.29251N	.004	94 38 53.50516W	.004	-25.613	.014	3260737.714	340179.567	1.202
TOWNSEND	29 19 53.61285N	0	94 44 14.27179W	0	-25.203	0	3245973.441	331316.602	1.397
CLOVPORT	29 31 00.65288N	0	95 14 20.13235W	0	-15.681	0	3267339.763	282993.841	11.374
B010	29 20 10.31979N	.004	95 17 03.50705W	.004	-18.371	.012	3247401.548	278201.611	8.524
B011	29 17 48.37226N	.004	95 21 24.00177W	.005	-18.493	.027	3243170.440	271085.624	8.388
EAFY	29 21 44.17782N	.004	94 46 41.10181W	.004	-25.341	.012	3249436.696	327407.589	1.343
C004	29 46 22.73903N	.008	94 41 09.38399W	.008	-24.082	.027	3294821.423	337014.156	3.250
C003	29 36 15.10400N	.008	94 40 32.11090W	.008	-25.683	.028	3276100.592	337744.199	1.400

Table 5. Positions and heights computed for newly established benchmarks and selected reestablished benchmarks using National Geodetic Survey Online Users Positioning Service and Trimble Geomatics Office to process static Global Positioning System survey data, Seadrift, Texas, to Lake Charles, Louisiana, 2008.

[OPUS, Online User Positioning System; --, not applicable; TGO, Trimble Geomatics Office]

Newly established or reestablished benchmark identifier	Processing identifier	Processing method and survey date	Latitude (degrees, minutes, decimal seconds)	Latitude error (meters)	Longitude (degrees, minutes, decimal seconds)	Longitude error (meters)	Orthometric height (meters)	Orthometric height error (meters)	Ellipsoid height (meters)	Ellipsoid height error (meters)	Ellipsoid height difference (meters)
Seadrift	2050	OPUS 10/2/2008	28 24 30.03129	0.004	96 42 49.54164	0.012	2.42	0.074	-24.522	0.038	--
Seadrift	2050	OPUS 10/3/2008	28 24 30.03106	.007	96 42 49.54173	.016	2.423	.07	-24.519	.028	--
Seadrift	2050	OPUS Average	28 24 30.03118	--	96 42 49.54169	--	2.422	--	-24.521	--	--
Seadrift	2050	TGO	28 24 30.03152	.004	96 42 49.54181	.004	2.511	.044	-24.43	.024	**0.091**
Bay City	BAYC	OPUS 10/2/2008	28 57 14.89726	.013	95 57 00.04014	.005	13.31	.068	-13.514	.024	--
Bay City	BAYC	OPUS 10/4/2008	28 57 14.89716	.009	95 57 00.03982	.011	13.305	.066	-13.519	.015	--
Bay City	BAYC	OPUS 10/5/2008	28 57 14.89745	.004	95 57 00.04009	.016	13.283	.066	-13.541	.016	--
Bay City	BAYC	OPUS 10/6/2008	28 57 14.89734	.004	95 57 00.03983	.012	13.283	.073	-13.541	.034	--
Bay City	BAYC	OPUS Average	28 57 14.89730	--	95 57 00.03997	--	13.295	--	-13.529	--	--
Bay City	BAYC	TGO	28 57 14.89738	.003	95 57 00.04042	.003	13.346	.032	-13.479	.012	**.05**
Bolivar Ferry	EAFY	OPUS 10/7/2008	29 21 44.17798	.02	94 46 41.10121	.016	1.347	.067	-25.337	.019	--
Bolivar Ferry	EAFY	OPUS 10/8/2008	29 21 44.17809	.017	94 46 41.10112	.005	1.325	.065	-25.359	.012	--
Bolivar Ferry	EAFY	OPUS Average	29 21 44.17804	--	94 46 41.10117	--	1.336	--	-25.348	--	--
Bolivar Ferry	EAFY	TGO	29 21 44.17782	.004	94 46 41.10181	.004	1.343	.032	-25.341	.012	**.007**
Sea Rim State Park	EATX	OPUS 10/7/2008	29 41 07.33114	.015	94 04 45.75024	.02	0.714	.066	-26.228	.017	--
Sea Rim State Park	EATX	OPUS 10/8/2008	29 41 07.33124	.006	94 04 45.75080	.033	0.747	.075	-26.195	.039	--
Sea Rim State Park	EATX	OPUS Average	29 41 07.33119	--	94 04 45.75052	--	0.731	--	-26.212	--	--
Sea Rim State Park	EATX	TGO	29 41 07.33034	.004	94 04 45.75110	.004	0.688	.035	-26.273	.015	**.061**
Freeport	FREE	OPUS 10/2/2008	28 54 24.68742	.014	95 20 49.01464	.002	1.489	.065	-24.827	.012	--
Freeport	FREE	OPUS 10/4/2008	28 54 24.68766	.008	95 20 49.01441	.018	1.459	.085	-24.857	.057	--
Freeport	FREE	OPUS 10/5/2008	28 54 24.68770	.012	95 20 49.01421	.002	1.465	.072	-24.851	.034	--
Freeport	FREE	OPUS 10/6/2008	28 54 24.68745	.011	95 20 49.01445	.001	1.502	.068	-24.814	.023	--
Freeport	FREE	OPUS 10/6/2008	28 54 24.68738	.024	95 20 49.01478	.015	1.502	.067	-24.814	.021	--
Freeport	FREE	OPUS Average	28 54 24.68752	--	95 20 49.01450	--	1.483	--	-24.833	--	--
Freeport	FREE	TGO	28 54 24.68734	.002	95 20 49.01511	.002	1.51	.034	-24.806	.014	**.027**
M005	M005	OPUS 10/2/2008	28 36 01.32565	.003	95 58 42.54335	.015	1.218	.08	-25.274	.048	--
M005	M005	OPUS 10/3/2008	28 36 01.32600	.003	95 58 42.54330	.01	1.217	.067	-25.275	.021	--
M005	M005	OPUS 10/4/2008	28 26 01.32570	.003	95 58 42.54313	.011	1.232	.076	-25.26	.041	--
M005	M005	OPUS 10/5/2008	28 36 01.32580	.003	95 58 42.54319	.015	1.237	.066	-25.255	.015	--
M005	M005	OPUS Average	28 36 01.32579	--	95 58 42.54324	--	1.226	--	-25.266	--	--
M005	M005	TGO	28 36 01.32589	.003	95 58 42.54370	.003	1.284	.04	-25.209	.02	**.057**
Vanderbilt	VAND	OPUS 10/2/2008	28 49 13.56824	.004	96 36 55.01328	.005	10.772	.075	-16.448	.039	--
Vanderbilt	VAND	OPUS 10/3/2008	28 49 13.56833	.002	96 36 55.01304	.01	10.748	.073	-16.472	.035	--
Vanderbilt	VAND	OPUS Average	28 49 13.56829	--	96 35 55.01316	--	10.76	--	-16.46	--	--
Vanderbilt	VAND	TGO	28 49 13.56849	.004	96 36 55.01308	.004	10.856	.034	-16.364	.014	**.096**
USGS real-time gage Trinity River at Walllisville, Tex. (08067252)	WALL	OPUS 10/7/2008	29 48 43.16688	.07	94 43 52.61612	.135	3.802	.236	-23.575	.227	--
USGS real-time gage Trinity River at Walllisville, Tex. (08067252)	WALL	OPUS 10/8/2008	29 48 43.16520	.005	94 43 52.61432	.006	3.816	.066	-23.561	.015	--
USGS real-time gage Trinity River at Walllisville, Tex. (08067252)	WALL	OPUS Average	29 48 43.16604	--	94 43 52.61522	--	3.809	--	-23.568	--	--
USGS real-time gage Trinity River at Walllisville, Tex. (08067252)	WALL	TGO	29 48 43.16443	.004	94 43 52.61468	.004	3.803	.036	-23.577	.016	**.009**

Table 6. Elevations of the same reference mark obtained using real-time kinetic and static Global Positioning System surveying for reference marks at four storm-surge-sensor sites, Seadrift, Texas, to Lake Charles, Louisiana, 2008.

[RM, reference mark; N, north; W, west; RTK, real-time kinetic]

Survey method	Sensor identifier and RM surveyed	Latitude (degrees, minutes, decimal seconds)	Longitude (degrees, minutes, decimal seconds)	Ellipsoid height (meters)	Elevation of RM (meters)	Difference in RM elevation (meters)
Static	SSS–TX–GAL–002 RM 1	29 27 57.34015N	94 38 52.78191W	-25.818	0.996	
RTK	SSS–TX–GAL–002 RM 1				1.053	
						-0.057
Static	SSS–TX–GAL–001 RM 1	29 27 14.11497N	94 38 10.94626W	-24.602	2.162	
RTK	SSS–TX–GAL–001 RM 1				2.22	
						-.058
Static	SSS–TX–JEF–004 RM 1	29 42 32.38264N	94 06 46.12012W	-25.764	1.263	
RTK	SSS–TX–JEF–004 RM 1			-25.769	1.25	
						.013
Static	SSS–TX–JEF–005 RM 1	29 41 32.32296N	94 04 47.85592W	-25.904	1.072	
RTK	SSS–TX–JEF–005 RM 1			-25.865	1.091	
						-.019

Table 7. Elevations above North American Vertical Datum of 1988 of 59 storm-surge-sensor orifices from real-time kinetic and static Global Positioning System surveys, Seadrift, Texas, to Lake Charles, Louisiana, 2008.

[RM, reference mark; no shading indicates static survey method used; light shading indicates both methods used for RM associated with sensor; dark shading indicates real-time kinetic (RTK) survey method used]

Sensor identifier[1]	RM surveyed (method if both used)	Elevation of RM (meters above NAVD 88)	Height of sensor orifice above RM (meters)	Elevation of sensor orifice (meters above NAVD 88)
SSS–TX–BRA–001	1	1.544	-0.847	0.697
SSS–TX–BRA–002	2	1.712	-.923	.789
SSS–TX–BRA–004	2	1.923	-1.519	.404
SSS–TX–BRA–005	1	1.844	-1.351	.493
SSS–TX–BRA–006	1	1.054	-.565	.489
SSS–TX–BRA–007	3	5.554	-4.847	.707
SSS–TX–BRA–008	2	6.032	-5.329	.703
SSS–TX–BRA–009	1	2.348	-1.67	.678
SSS–TX–BRA–010	1	8.524	-8.589	-.065
SSS–TX–BRA–011	3	8.388	-3.931	4.457
SSS–TX–CAL–001	1	1.372	-.779	.593
SSS–TX–CAL–002	1	1.506	-.956	.55
SSS–TX–CAL–003	2	1.701	-1.427	.274
SSS–TX–CAL–004	1	1.627	-.962	.665
SSS–TX–CAL–005	1	2.051	-1.594	.457
SSS–TX–CHA–003	1	1.4	-.594	.806
SSS–TX–CHA–004	1	3.25	-2.816	.434
SSS–TX–GAL–001	1 (RTK)	2.22	.175	2.395
SSS–TX–GAL–001	1 (Static)	2.162	.175	2.337
SSS–TX–GAL–002	1 (RTK)	1.053	-.56	.493
SSS–TX–GAL–002	1 (Static)	.996	-.56	.436

Table 7. Elevations above North American Vertical Datum of 1988 of 59 storm-surge-sensor orifices from real-time kinetic and static Global Positioning System surveys, Seadrift, Texas, to Lake Charles, Louisiana, 2008—Continued.

Sensor identifier[1]	RM surveyed (method if both used)	Elevation of RM (meters above NAVD 88)	Height of sensor orifice above RM (meters)	Elevation of sensor orifice (meters above NAVD 88)
SSS–TX–GAL–002	2 (Static)	1.202	-0.623	0.579
SSS–TX–GAL–005	1	2.596	-2.283	.313
SSS–TX–GAL–008	3	.996	-1.978	-.982
SSS–TX–GAL–010	1	2.019	-.671	1.348
SSS–TX–GAL–011	1	1.14	.132	1.272
SSS–TX–GAL–015	New	1.108	-.903	.205
SSS–TX–GAL–016	1	2.109	-1.432	.677
SSS–TX–GAL–018	1	5.196	-4.461	.735
SSS–TX–GAL–019	1	2.912	-2.817	.095
SSS–TX–GAL–020	1	1.51	-.073	1.437
SSS–TX–GAL–021	3	1.619	-.7	.919
SSS–TX–GAL–022	1	1.154	-.35	.804
SSS–TX–HAR–002	3	2.08	-1.123	.957
SSS–TX–HAR–003	3	6.684	-5.854	.83
SSS–TX–HAR–004	1	2.502	-1.772	.73
SSS–TX–JEF–001	New	2.202	-1.614	.588
SSS–TX–JEF–002	1	1.471	.289	1.76
SSS–TX–JEF–004	1 (Static)	1.263	-1.057	.206
SSS–TX–JEF–004	1 (RTK)	1.25	-1.057	.193
SSS–TX–JEF–005	1 (Static)	1.072	-.974	.098
SSS–TX–JEF–005	1 (RTK)	1.091	-.974	.117
SSS–TX–JEF–006	1	1.523	-1.358	.165
SSS–TX–JEF–007	1	2.094	-1.98	.114
SSS–TX–JEF–008	1	.695	-.391	.304
SSS–TX–MAT–001	1	1.362	-1.001	.361
SSS–TX–MAT–002	1	.556	-.659	-.103
SSS–TX–MAT–003	1	6.295	-5.622	.673
SSS–TX–MAT–004	New	3.601	-4.189	-.588
SSS–TX–MAT–005	3	1.284	-.794	.49
SSS–TX–MAT–006	1	4.861	-4.499	.362
SSS–TX–MAT–007	2	1.565	-1.279	.286
SSS–TX–MAT–008	1	1.948	.343	2.291
SSS–TX–MAT–009	2	.709	-.101	.709
SSS–TX–MAT–010	3	4.094	-3.268	.826
SSS–LA–CAM–001	1	1.538	.227	1.765
SSS–LA–CAM–002	1	1.942	.472	2.414
SSS–LA–CAM–003	1	4.65	-.984	3.666
SSS–LA–CAM–010	1	1.561	-.974	.587
SSS–LA–CAM–011	1	1.419	-1.45	-.031
SSS–LA–CAM–012	1	2.922	-1.979	.943
SSS–LA–CAM–013	1	1.913	.209	2.122
SSS–LA–VER–006	1	1.149	-.607	.542
SSS–LA–VER–007	1	1.714	-.832	.882

[1] East and others (2008, table 1) reports storm-surge data for the same 59 sensors listed in this table, with two exceptions: (1) Sensor SSS–LA–CAM–013 (this table) is not in East and others (2008, table 1), and (2) sensor SSS–TX–JEF–009 (East and others, 2008, table 1) is not in this table.

leveling. Static-GPS-measured elevation at RM 2 was 1.202 meters above NAVD 88 and at RM 1 was 0.996 meter above NAVD 88, which indicates RM 2 to be 0.206 meter above RM 1. Leveling between RM 1 and RM 2 indicates RM 2 to be 0.209 meter above RM 1.

The match between elevations at the same RM from the two surveying methods was assessed for RMs associated with several sensor sites (SSS–TX–GAL–001, SSS–TX–GAL–002, SSS–TX–JEF–004, and SSS–TX–JEF–005). The greatest (absolute) difference in estimated elevation between the two methods was 0.058 meter for the RM associated with SSS–TX–GAL–001 (table 6). The results of all quality checks indicate that the desired elevation accuracy for the surveys of this report, less than 0.1-meter error, was achieved.

Final Sensor Elevations and Positions

RTK and static GPS surveys were done to establish monumentation on permanent structures near the sites of storm-surge sensors to obtain elevations of RMs in meters above NAVD 88 associated with sensor sites. Because GPS could not be used to collect data directly over each sensor, leveling was done to obtain elevations of sensor orifices in meters above the RMs. Elevations above NAVD 88 of orifices of 59 (of the original 65) sensors are listed in table 7.

Summary

The U.S. Geological Survey installed a network of pressure sensors at 65 sites along the Gulf Coast from Seadrift, Tex., northeast to Lake Charles, La., to record the timing, areal extent, and magnitude of inland storm surge and coastal flooding caused by Hurricane Ike in September 2008. A Global Positioning System (GPS) was used to obtain elevations of reference marks (RMs) near each sensor in meters above NAVD 88. A combination of real-time kinematic (RTK) and static GPS surveys were done to obtain elevations of RMs. Leveling relative to RMs was done to obtain elevations of sensor orifices above the RMs. For each sensor, elevation of an associated RM, elevation of the sensor orifice above the RM, and elevation of water above the orifice (computed from water pressure recorded by the sensors) could then be summed to obtain elevation of storm surge above NAVD 88 at each site. This report summarizes the GPS data collected and processed to obtain RM and storm-sensor-orifice elevations for 59 storm-surge sensors recovered from the original 65 installed.

National Geodetic Survey (NGS) benchmarks were used for RTK surveying. Where NGS benchmarks were not within 12 kilometers of a sensor site, static surveying was done. Additional control points for static surveying were in the form of newly established benchmarks or reestablished existing benchmarks. For the surveys of this report, an elevation accuracy of less than 0.1-meter error (including error associated with the Geoid03 model) was desired to accurately document storm surge.

RTK surveying was used to obtain positions and elevations of RMs for 29 sensor sites. Static surveying was used to obtain positions and elevations of RMs for 34 sensor sites (35 sensors total because two RMs were associated with one site); four sites were surveyed using both methods. RMs (one per sensor site except two for sensor site SSS–TX–GAL–002) were surveyed within base-station triangles composed of five newly established benchmarks (one of which is an RM coincident with a sensor site), four reestablished benchmarks, and three NGS benchmarks.

Quality checks on the RTK-survey data included reinitializing and taking multiple observations on each RM; ensuring final positions and elevation solutions were within acceptable quality-control limits—vertical precision generally within 0.03 meter at 95-percent confidence and position-solution standard deviation root mean square values generally within 0.01 meter; and observations of multiple known benchmarks with the majority of base-station setups.

Quality checks on the static-survey data during post-processing included evaluation of shifts in elevation and position applied to non-fixed control points, 95-percent confidence limits in the accuracy of measurements of each position, and parts per million errors in baselines. As another quality check, all newly established benchmarks and three of the four reestablished benchmarks were surveyed on several different dates and were processed through the NGS Online Positioning Users Service in addition to processing with Trimble Geomatics Office and the results were compared.

In addition, two RMs associated with one sensor site were surveyed to assess how the difference in elevation computed from static GPS measurements for the two RMs compared to the difference obtained by leveling; the difference in elevation computed using the two methods is 0.003 meter. The match between elevations at the same RM from the two surveying methods was assessed for RMs associated with several sensor sites; the greatest (absolute) difference in estimated elevation between the two methods was 0.058 meter. The results of all quality checks indicate that the desired elevation accuracy for the surveys of this report, less than 0.1-meter error, was achieved.

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