Southeast Texas Subsidence Adjustment Project (12029)

Davey EDWARDS and Ibraheem ALI, United States of America

Key words: geodetic, geomatics, survey, subsidence, vertical control, ellipsoid, geoid, spatial reference frame

SUMMARY

The United States of America is adopting a new spatial reference frame, North American Terrestrial Reference Frame of 2022, soon which will take our current datum from a static system to a dynamic system. This update to the system allows States to revise their respective coordinate systems to reflect an ability to create a low distortion projection which assist a seamless analysis of observations between geospatial information systems and reality in the field. This is especially important to large projects which require design across a large expanse such as transportation or utility routes.

Additionally, the United States will also adopt the North American-Pacific Geopotential Datum of 2022 which will provide more accurate orthometric heights related to the latest published Geoid models. Vertical datum is specifically important to maintaining base flood elevations for areas identified as flood inundation zones used for flood insurance rates and emergency management.

Recently, in the southeast region of Texas (USA), the National Geodetic Survey (NGS) suppressed vertical heights on published control due to irregularities in datum caused by subsidence. The Conrad Blucher Institute, with support and facilitation of the Texas Spatial Reference Center, initiated a campaign to occupy and observe primary control in areas identified by NGS. This work was done over a period of several months in late 2021 following a guideline to submit data to NGS for their use to update their model and release the suppressed vertical data.

This paper will cover a collaborated effort from state and local agencies alongside the private professional surveying industry to ensure geodetic datum accuracy for the protection of the safety and welfare of the public.

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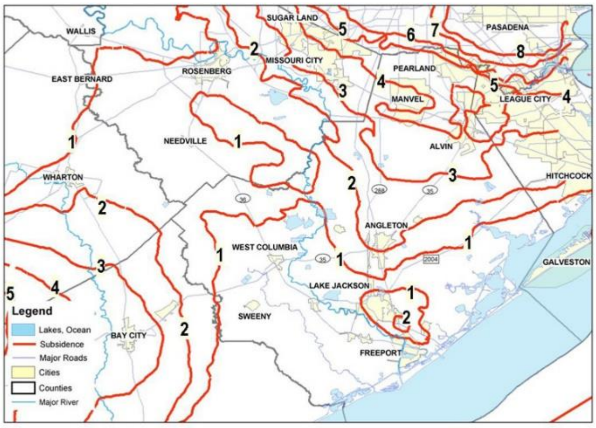
Southeast Texas Subsidence Rate

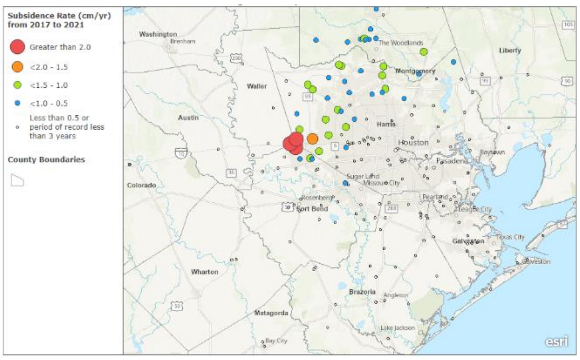
The southeast Texas region experiences an active and high rate of land subsidence activities. This subsidence in this region has negative consequences on the public, public safety, and the infrastructure. Some of the consequences are listed below:

- Reduces the water storage capacity in an aquifer.
- Submerges lands either completely or partially.
- Affect the public safety and the emergency management operations.
- Flood hazards. and changes the flow directions of creeks and bayous.
- Degrade the reliability of the horizontal and vertical geodetic network.
- Damages the community infrastructure as in roads, bridges, and building foundations.

The following images show the past and projected subsidence rate for southeast Texas region:



(BCGCD, n.d.)



(HGSD, n.d.)

NGS and Benchmarks

Due to the high rate of subsidence in southeast Texas, The National Geodetic Survey (NGS) analyzed the vertical control network in this region and identified the marks that have high residuals and were suspected of having moved significantly between the time they were first observed and established (leveled) and the time they were observed with GPS. Based on this analysis, only 28 of 7,500 published NAVD 88 marks in southeast Texas are considered valid (i.e., having a valid orthometric height). The rest of the marks were affected by the subsidence signature and their orthometric height was considered as invalid. These marks were flagged as suspect. As a result NGS suppressed the orthometric height on the datasheets for all the "suspect" vertical control network in southeast Texas.

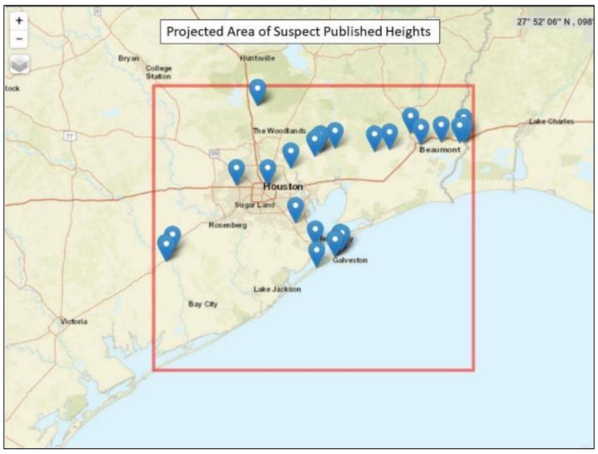
The Southeast Texas region extends south and west from the Texas-Louisiana border and includes the cities of Beaumont, Houston, Galveston, and Rosenberg. In order to re-establish and update the NAVD 88 heights for the suppressed marks, multiple major GNSS survey campaigns need to be conducted and multiple stakeholders and agencies need to be involved. The Conrad Blucher Institute, with support and facilitation of the Texas Spatial Reference Center, and in collaboration with National Geodetic Survey (NGS) and Texas Department of Transportation (TxDOT) initiated a GPS on Benchmarks (GPSonBM) campaign to occupy and observe primary vertical controls in the southeast Texas region and in areas identified by NGS.

The campaign was done over a period of several months in late 2021 following a guideline to submit data to NGS and update the geodetic coordinates and orthometric heights for the observed marks. This work included having two phases of GPS static observation which included observing more than 140 benchmarks, including 20 new TxDOT deep rod monuments, and integrated with the static data of six (6) TxDOT Real Time Network (RTN) stations and tied to the National Spatial Reference System (NSRS) by tying the project to 16 NGS CORS. Each of the two phases of this work included the following major steps:

1- GPS static observation on Benchmarks (The Field Campaign),
2- Session Processing and Least Squares Network Adjustment, and
3- Publishing the results to the NGS database.

The project, after being approved by the NGS, provided a densified and reliable geodetic network in the southeast Texas region with more marks that have valid and updated orthometric heights in NAVD 88. In addition, the GPSonBM data with published NAVD 88 heights will be used to create the transformation grids between NAVD 88 and the new "North American-Pacific Geopotential Datum of 2022 (NAPGD2022).

The image below shows the location of the 28 NGS only valid marks that were not suppressed.



OPUS Projects

For the GPS static data processing, OPUS Solution, QC/QA the acquired data, Least Squares Network Adjustment, and publishing the final results to the NGS database we used OPUS Projects. OPUS Projects (OP) is an NGS web-based geodetic application which enables the baseline processing of static GNSS observations that were observed at the same time (simultaneous GPS observation). These simultaneous GPS observations are called sessions in

OP. The session processing process in OP is followed by a least squares adjustment of the sessions. During the session processing and least squares adjustment certain and high quality Continuously Operating Reference Stations (CORS) are used as controls (Project CORS). The processing results are, therefore, tied to the National Spatial Reference System (NSRS). In addition to session processing and least squares adjustment, other metadata such as photos, mark descriptions, and a report are uploaded to the OP. The OP also has many additional functionalities to perform quality assurance and quality control on the collected survey data using its user-friendly graphic and map interface.

Field Campaign

In order to provide highly reliable and accurate data for this project, certain observation procedures, standards and specifications need to be followed during the data acquisition stage. Also, adhering to the NGS standards for GPS static observations, network adjustment, metadata requirements are crucial to the success of the OP project. Once all the data, metadata, adjustment results are reviewed and approved by NGS, the final NAVD 88 elevation will be published to the NGS database and will be available to the public.
In terms of field procedure, the following steps were followed to acquire the GPS data on each mark:

1. Two 6-hour GPS static sessions
2. Use 2-meter fixed height tripod
3. Acquire and submit multiple photos
4. Submit a detailed description
5. Continuous and correlated data observation during the field campaign in a staggering scheduling pattern

Accuracy Standards

This GNSS survey conforms to the FGCC standards for first-order GPS surveys according to the *Geometric Geodetic Accuracy Standards and Specifications for using GPS Relative Positioning Techniques*, version 5.0 with corrections, August 1, 1989, FGCC. Network design, field observations, and processing standards conformed to the specifications found in *Guidelines For Establishing GPS-Derived Ellipsoid Heights (Standards: 2cm and 5cm)*, NOAA Technical Memorandum NOS NGS 58 and *Guidelines for Establishing GPS-Derived Orthometric Heights*, NOAA Technical Memorandum NOS NGS 59 whenever possible. This geodetic network survey was performed to meet automated data recording, submittal, project review, and least squares adjustment requirements established by the Federal Geodetic Control Subcommittee (FGCS).

Observations

The observation guidelines under which this survey was conducted were a combination of NOS 58, OPUS Projects processing requirements, TxDOT and the Texas Spatial Reference Center (TSRC) specifications. They include mainly the following
<u>Equipment:</u>

- Equipment must be well maintained and properly calibrated.

- Uniform receivers and antennas are required for all observations. That is to say, the same manufacturer and model of equipment must be used for all observations.
- Receivers must collect dual-frequency GPS(L1/L2) full-wavelength carrier observables.
- Only antennas with calibrations accepted by the National Geodetic Survey (NGS) may be used. See http://www.ngs.noaa.gov/ANTCAL/ for a list of accepted antennas.
- Fixed height tripods will be required.

Procedures:

- The antenna's north reference point (NRP) shall be aligned oriented toward the true
- north direction as defined by NGS. See http://www.ngs.noaa.gov/ANTCAL/FAQ.xhtml#faq5 for additional details.
- The antenna must remain unmoved throughout the observing session.
- Only GPS observables will be processed.
- Elevation cut-off or mask angle shall not be set greater than 15°.
- Recording rates, or epochs, shall be set to 15 seconds or less.
- Data shall be collected as static observations.
- The assigned and provided station 4 Character ID (4 CHAR ID) and Station Serial Number (SSN) shall be used as the station identification for any field inputs prior to the commencement of the observation.
- A record of deviations from these instructions will be maintained and submitted to CBI at the conclusion of the project.

Session Parameters:

- Data will be collected in sessions. A minimum of four receivers will be required for every session. Each session will require a minimum of 6 hours of simultaneous observation (i.e., when all receivers are recording at the same time) and a minimum of 6.5 hours of individual observation (a specific receiver on a specific mark). If one surveyor is operating multiple receivers it is understood that there will be staggered start/stop times.
- One field surveyor may operate up to three receivers per session. Avoid using the same surveyor and equipment on redundant observations.
- Each station will be observed a minimum of two times. The observations associated with any one mark should be taken on different days. The time of redundant observation must be different than the other observation.
- 1st observation of mark ONE taken on day 001, session A (starts at 8:00 AM)
- 2nd observation of mark ONE taken on day 002, session B (starts at 11:00 AM)
- Sessions will be scheduled so that marks are observed in line, i.e., connected to their nearest neighbor in the session with alternate sessions overlapping previous sessions to tie the project together and to provide continuous and correlated observations.
- NGS Field log sheets will be required for each observation/occupation.
- NGS mark designation will be used.
- Cross out any incorrect entries and replace with the appropriate correction as one would do with traditional survey field notations.

- Fixed height metric unit to the Antenna Reference Point (ARP) will be used.
- ARP height will be recorded in meters.
- Record comments about potential issues such as inclement weather or potential obstructions nearby.

Available resources in terms of manpower, equipment, and time may result in slight deviations regarding the session attributes.

Deep Rod Monuments – Texas Department of Transportation

Texas Department Of Transportation (TxDOT) – Houston District has integrated a number of their existing and new deep rod monuments into this project. The locations of the TxDOT monuments are carefully selected to be located close to and paired with the TxDOT Real Time Network stations (RTN) and\or to provide better area coverage for the SE TX Subsidence Project. These deep rod monuments (Existing and New) will be similarly observed with two 6-hour static sessions and have the same metadata collected during the field survey activities. Also, these monuments will be processed and adjusted in OPUS Projects, and they will be shared and published with NGS.

OPUS Projects Settings and Parameters

For the OPUS project, the following setting and parameters have been set to process the collected static GPS data, see the following table:

Precise Ephemeris:	Best Available
Minimum ARP Height (m):	0
Maximum ARP Height (m):	3
Minimum Observations Used (%):	70
Minimum Ambiguities Fixed (%):	70
Maximum Solution RMS (m):	0.03
Maximum Height Uncertainty (m):	0.04
Maximum Latitude Uncertainty (m):	0.025
Maximum Longitude Uncertainty (m):	0.025
Output Ref Frame:	Let OPUS Choose
Output Geoid Model:	Let OPUS Choose
GNSS:	GPS Only
Tropo Model:	Piecewise Linear
Tropo Interval (s):	7200
Elevation Cutoff (deg):	15
Constraint Weights:	Normal
Minimum Data Duration (s):	1800
Minimum Session Overlap Multiplier:	0.5
Maximum Position Difference (m):	1

Accuracy Standards

This GNSS survey conforms to the FGCC standards for first-order GPS surveys according to the *Geometric Geodetic Accuracy Standards and Specifications for using GPS Relative Positioning Techniques*, version 5.0 with corrections, August 1, 1989, FGCC. Network design, field observations, and processing standards conformed to the specifications found in *Guidelines For Establishing GPS-Derived Ellipsoid Heights (Standards: 2cm and 5cm)*, NOAA Technical Memorandum NOS NGS 58 and *Guidelines for Establishing GPS-Derived Orthometric Heights*, NOAA Technical Memorandum NOS NGS 59 whenever possible.

Project Metadata and Marks Description

Marks' description for this project have been entered and verified through "WINDESC". WINDESC is a stand alone NGS application that the user can utilize to enter, edit, and verify the marks' description. The process of verifying the marks and their description is listed in the following:

Neighbor for all marks

Each mark was evaluated in "neighbor" functionality using a radius of 10 meters. All of the stations being claimed as observed were confirmed.

Discrepancies for all PIDs

All discrepancies were reviewed and evaluated to identify and address any significant differences between the mark attributes being submitted and those found in the NGS iIntegrated Database (IDB). None was found.

Recovery dates for all marks

There were no duplicate recovery dates associated with this project.

Spell check all descriptions

Spell check was run on all descriptions. Corrections were applied where necessary.

Error file

The error file was evaluated. All errors were corrected. The remaining warnings were determined to be acceptable.

Photos

Photos are being submitted for every mark. They have been checked and verified as being a correct representation of the marks observed. The photos were uploaded to the OP Project directly.

Network Adjustment

The network adjustment involves a full cycle of horizontal and vertical adjustments. It includes the Horizontal Free, Horizontal Constrained, Vertical Free, Vertical Constrained adjustments. The following sections discuss each of the adjustment's components and their results.

The SE TX Subsidence project has been conducted in two phases (Phase I and Phase II). Each phase was adjusted and run through OP independently. The following solution shows the network adjustment results for Phase I and Phase 2

<u>Phase I Network Adjustment:</u>

Horizontal Free Adjustment

Solution date: 2021-11-13t13:07:59 utc
Standard error of unit weight: 1.000
Total number of observations: 9378763
Total number of marks: 99
Constrained marks: 1 horizontal, 0 vertical

Horizontal Constrained Adjustment

Solution date: 2021-11-16t11:44:25 utc
Standard error of unit weight: 1.050
f statistic test: pass (1.10 < 1.13 f critical @ 99% confidence)
Total number of observations: 9378763
Total number of marks: 99
Constrained marks: 24 horizontal, 0 vertical

Constrained Marks and CORS

There were a total of 24 marks constrained in the Horizontal Constrained adjustment, 7 of them were CORS.

Vertical Free Adjustment

Solution date: 2021-11-20t11:43:26 utc
Standard error of unit weight: 1.001
Total number of observations: 9378763
Total number of marks: 99
Constrained marks: 1 horizontal, 1 vertical

Vertical Constrained Adjustment

Solution date: 2021-12-14t11:30:18 utc
Standard error of unit weight: 1.042
f statistic test: pass (1.09 < 1.13 f critical @ 99% confidence)

total number of observations: 9378763
Total number of marks: 99
Constrained marks: 1 horizontal, 25 vertical

Phase II Network Adjustment:

Horizontal Free Adjustment

Solution date: 2022-08-09t18:45:29 utc
Standard error of unit weight: 1.000
Total number of observations: 11353186
Total number of marks: 92
Constrained marks: 1 horizontal, 0 vertical

Horizontal Constrained Adjustment

Solution date: 2022-08-10t13:04:14 utc
Standard error of unit weight: 1.059
F statistic test: pass (1.12 < 1.12 f critical @ 99% confidence)
Total number of observations: 11353186
Total number of marks: 92
Constrained marks: 45 horizontal, 0 vertical

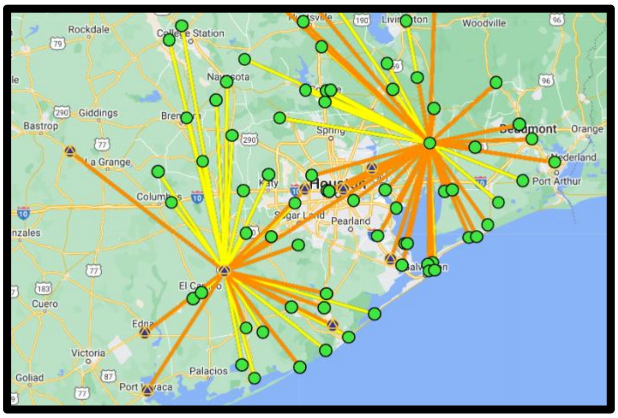
Vertical Free Adjustment

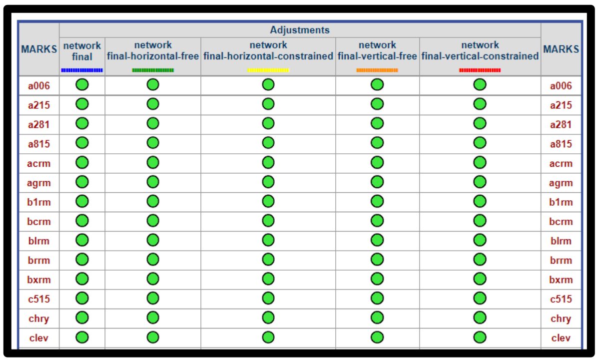
Solution date: 2022-08-10t13:35:18 utc
Standard error of unit weight: 1.000
Total number of observations: 11353186
Total number of marks: 92
Constrained marks: 1 horizontal, 1 vertical

Vertical Constrained Adjustment

Solution date: 2022-08-22t11:59:56 utc
Standard error of unit weight: 1.031
F statistic test: pass (1.06 < 1.12 f critical @ 99% confidence)
Total number of observations: 11353186
Total number of marks: 92

Constrained marks: 1 horizontal, 41 vertical

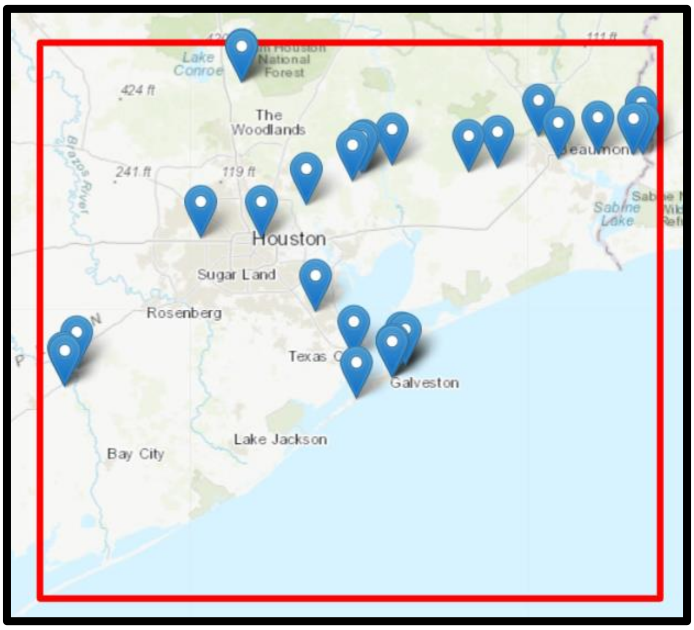




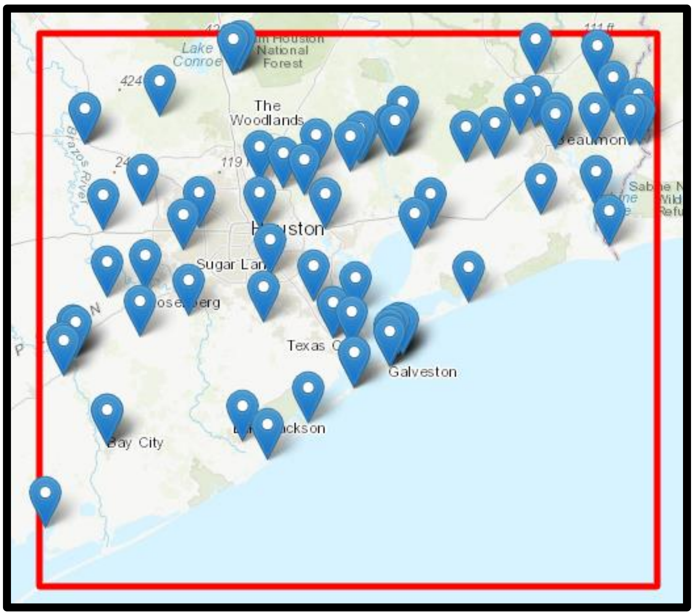
MARKS	Adjustments					MARKS
	network final	network final-horizontal-free	network final-horizontal-constrained	network final-vertical-free	network final-vertical-constrained	
a006	●	●	●	●	●	a006
a215	●	●	●	●	●	a215
a281	●	●	●	●	●	a281
a815	●	●	●	●	●	a815
acrm	●	●	●	●	●	acrm
agrm	●	●	●	●	●	agrm
b1rm	●	●	●	●	●	b1rm
bcrm	●	●	●	●	●	bcrm
blrm	●	●	●	●	●	blrm
brrm	●	●	●	●	●	brrm
bxrm	●	●	●	●	●	bxrm
c515	●	●	●	●	●	c515
chry	●	●	●	●	●	chry
clev	●	●	●	●	●	clev

The two images above show the OPUS Projects Graphic and Map Interface for the SE TX subsidence project, Marks, baseline, observations, and network adjustment

The image below shows the status of the vertical network in SE TX before conducting the project. The image shows only 28 marks that have valid NAVD 88 orthometric height and the rest of the marks in the vertical network were suppressed by NGS.



The next image shows the status of the vertical network after conducting the SE TX subsidence adjustment project, Phase I. The image shows that more than 70 marks were added to the network with valid orthometric height.



The last image shows the results after conducting and publishing the SE TX subsidence adjustment project, Phase II. The image shows that more than 140 marks were added to the network with valid orthometric height (NAVD 88 elevation).

CONCLUSION

In conclusion, the southeast Texas region suffers from high rate of earth surface deformation, particularly subsidence activities. The subsidence rate reaches to 2cm/yr in certain areas in the region. This high rate of subsidence has affected the vertical and horizontal geodetic network in southeast Texas. As a consequence of this degradation, National Geodetic Survey (NGS) has suppressed the NAVD 88 orthometric height for all but 28 benchmarks in the region. A major, urgent, and collaborative work was required to re-observe and update the NAVD 88 heights for the suppressed marks. Conrad Blucher Institute in collaboration with Texas Department of Transportation, and NGS conducted a major GPS on Benchmark (GPSonBM) static survey campaign with two phases. The campaign consists of stringent field requirements combined with rigorous analysis and network adjustment and finally publishing the adjusted data to the NGS database. The two phases of this campaign were conducted successfully, and the results were verified, approved, and published by NGS. This campaign managed to add more than 100 marks with valid orthometric heights to the vertical geodetic network. These 100 marks are added to the original 28 valid marks. Adding these marks densifies the geodetic vertical network and improves its quality. Improving the geodetic network benefits the Public and private sectors as well as the whole surveying and geospatial community.

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BIOGRAPHICAL NOTES

Davey Edwards, PhD, PLS LSLS CFedS

Davey Edwards is a professional land surveyor in Texas and Oklahoma, a Texas licensed state land surveyor, and a U.S. Federal land surveyor. He is currently the Director of Surveying for Baseline | DCCM.

Davey has his BS degree in Biomedical Science from Texas A&M University in College Station, MS degree in Geospatial Surveying Engineering from Texas A&M University in Corpus Christi, and Doctorate degree in Geosciences from the University of Texas in Dallas. His studies concentrated on land administration systems and riparian boundary morphology.

Davey continues to teach various professional continuing education courses on boundary surveying. He was an adjunct professor in geology at Weatherford College Wise County and professional assistant professor in surveying at Texas A&M University – Corpus Christi. He has served on the advisory committee for the Geographic Information Science program at Texas A&M University – Corpus Christi.

Davey is the current president-elect of the National Society of Professional Surveyors and a past president of the Texas Society of Professional Surveyors. He is the 2006 recipient of the TSPS Young Surveyor of the Year award and the 2007 recipient of the TSPS Chapter President of the Year award. He is currently serving as a survey emeritus member of the Texas Board of Professional Engineers and Land Surveyors and a member of the survey advisory committee. He has served as public member of the Texas Board of Architectural Examiners and as a licensed state land surveyor member of the Texas Board of Professional Land Surveying. He is a former chair of the City of Decatur's planning and zoning commission. He is the former director of the Texas Spatial Reference Center.

Ibraheem Ali, MS, CP CMS-RS

Ibraheem Ali is an experienced geodesist and geoscientist. Mr. Ali is an ASPRS Certified Photogrammetrist (CP), and a Certified Mapping Scientist-Remote Sensing (CMS-RS). Ibraheem holds a Master of Science degree in Earth Science and a Bachelor of Science degree in Surveying Engineering. He has more than 25 years of experience in geodesy, surveying, remote sensing, Geographic Information System (GIS) and the Global Navigation Satellite System (GNSS).

During his career, Ibraheem has worked in a variety of industries and organizations such as government bodies, academic institutes, the oil and gas industry and construction and engineering consulting firms.

He recently worked with the CBI, Texas Spatial Reference Center (TSRC), TxDOT, NGS, and other stakeholders on the Southeast Texas Subsidence Area Adjustment Project. He was also involved in the development of the Low Distortion Projection (LDP) Coordinate System for the state of Texas as part of the new State Plane Coordinate System of 2022 (SPCS 2022).

CONTACTS

Dr. Davey Edwards, PLS LSLS CFedS
Baseline | DCCM
1750 Seamist Dr., Ste. 160
Houston, Texas 77008
UNITED STATES of AMERICA
Tel. 1 (940) 393-0820
Email: wedwards@baselinesurveyors.net
Web site: www.baselinesurveyors.net

Ibraheem Ali, MS, CP CMS-RS
S.I. Geomatics, LLC
2614 Kimbleton Ct.
Houston, TX, 77082
UNITED STATES of AMERICA
Tel. 1 (832) 291-6996
Email: si.geomatics.llc@gmail.com