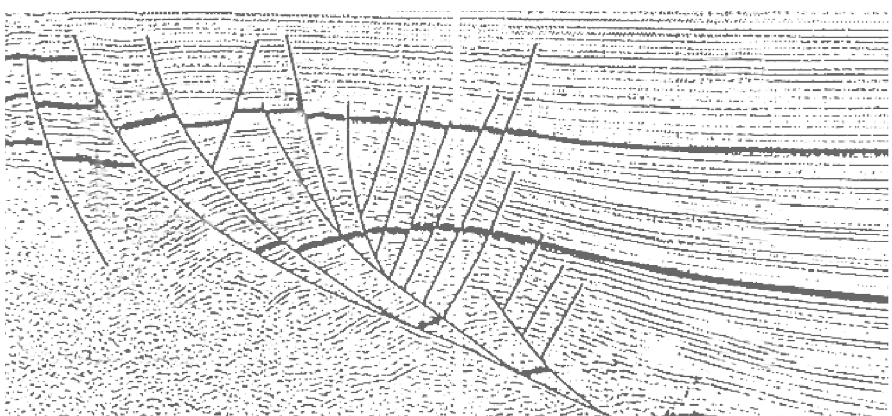
Houston Geological Society
and
Engineering, Science and Technology
Council of Houston

Coastal Subsidence, Sea Level and the Future of the Gulf Coast

A Conference to increase awareness of subsidence issues facing the Gulf Coast Region



November 3-5, 2005
Northwest Forest Conference Center
12715 Telge Road
Cypress, Texas

"Coastal Subsidence, Sea Level and the Future of the Gulf Coast"
a conference presented by the
Houston Geological Society (HGS), Continuing Education Committee
Engineering, Science and Technology Council of Houston (ECH)

November 3-5. 2005, Houston, TX

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Houston Geological Society and Engineering, Science and Technology Council of Houston Present:

"Coastal Subsidence, Sea Level and the Future of the Gulf Coast"

November 3-5, 2005
Northwest Forest Conference Center
12715 Telge Road
Cypress (NW Houston metropolitan area), Texas

Program Agenda:

Day 1 – SCIENTIC FINDINGS

7:30 - 8:30 A.M.	Registration and continental breakfast
8:30 - 8:40 A.M.	Welcome and introduction (Dave Rensink, President Houston Geological Society)
8:40 - 9:10 A.M.	Keynote 1: The Importance of Accurate Subsidence Network for the Establishment Vertical Control and Subsidence Rates (Dave Zilkoski, NGS/NOAA)

Historic subsidence rates along the Gulf Coast from benchmarks.

9:10 - 9:40 A.M.	Measurement, Methods, and Modern Subsidence: Definitions, Datums, and Disasters (RoyDokka, LSU)
9:40 - 10:00 A.M.	Break
10:00 - 11:00 A.M.	Rates of Vertical Displacement of Geodetic Benchmarks (Kurt Shinkle, NGS/NOAA)
11:00 - 12:00 Noon	Speaker Q & A.
12:00 Noon - 1:15 P.M.	Lunch - Guest Speaker: Sam Webb, Deputy Commissioner for Coastal Resources Program, Texas General Land Office Topic: "Coastal Subsidence: Finding Common Ground"

Causes of subsidence

1:30 - 2:00 P.M.	An Introduction to the Origin of the Gulf of Mexico and Its Role in Subsidence (Dave Rensink, HGS)
2:00 - 2:30 P.M.	Processes Resulting in Modern Subsidence Along Coastal Louisiana (Roy Dokka, LSU)

Causes of subsidence *(continued….)*

2:30 - 3:00 P.M.	Overview of Space Technologies for Subsidence Measurements (Ron Blom, Jet Propulsion Laboratory)
3:00 - 3:20 P.M.	Break
3:20 - 3:40 P.M.	Present-Day Tectonic Subsidence of New Orleans (Tim Dixon U. Miami) – substituted by Richard Carande
3:40 - 4:00 P.M.	Radar Interferometry and Houston Land Subsidence (Sean Buckley University of Texas)
4:00 - 4:20 P.M.	A Qualitative Analysis of Water-Level Change 1973–2005 and Measured Compaction 1973–2004 in the Chicot and Evangeline Aquifers, Harris and Galveston Counties, Texas (Mike Turco, USGS)
4:20 - 4:40 P.M.	Methods employed by HGSD for the detection and measurement of subsidence (Cliff Middleton, NGS)
5:00 - 5:30 P.M.	Panel discussion: Needs and future plans (Moderator: Glen Carlson)
7:00 – 10:00	**Dinner Banquet** – Guest Speaker: John Anderson, Rice University **Long-Term Subsidence Along the West Louisiana and East Texas Coast:** The meaning of old shorelines and basal peat ages as constraints to the average subsidence history of the western Louisiana and east Texas coast, from Calcasieu Lake to Corpus Christi

Day 2 - SOCIETAL AND PUBLIC POLCY IMPLICATIONS OF SUBSIDENCE

7:30 - 8:30 A.M.	Registration and continental breakfast.
8:30 - 8:40 A.M.	Welcome and Call to Order (Juan Moya)
8:40 - 9:10 A.M.	Keynote 2: Subsidence and Future Relative Sea Level Rise in the Gulf Coast (Virginia Burkett, USGS, Lafayette)
9:10 - 9:40 A.M	Using Holocene relative sea-level data for high-precision measurement of differential crustal movements in the Mississippi Delta (Torbjörn E. Törnqvist, Tulane University)
9:40 - 10:00 A.M.	Break
10:00 - 10:30 A.M.	Flooding and storm surge hazards of the Texas Coastal Plain (Steven Baig, National Hurricane Center/NOAA; Arthur E. Berman, speaker)

Societal And Public Polcy Implications Of Subsidence *(continued….)*

10:30 - 10:50 A.M.	Subsidence, Coastal Protection and Wetland Restoration in Louisiana: "A Levee Manager's Perspective" (Windell Curole, South La Fourche Levee District, Louisiana)
10:50 - 11:10 A.M.	Active faulting and impacts on the built environment (Richard Howe, Terrain Solutions, Inc.)
11:10 - 11:30 A.M.	Coastal Funding Programs at the Texas General Land Office (Juan Moya, Texas General Land Office)
11:30 - 12:00 A.M.	Height modernization in Texas (Gary Jeffress, Texas A&M University – Corpus Christi)
12:00 Noon - 1:30 P.M.	Lunch and review of posters

The Politics and Public Policy issues of subsidence

1:30 - 2:00 P.M.	The politics and public policy issues of subsidence (Ron Neighbors, Harris Galveston Subsidence District)
2:00 - 2:30 P.M.	Congressional report and legislation to Address Subsidence in Southern Louisiana (G."Ram" Ramachandran, Systems Research Int'l Inc., Destrehan, Louisiana)
2:30 – 4:00 Noon	Panel discussion on Practical impacts of subsidence

Day 3 - Field Trip - Carl Norman (UH), Richard Howe (Terrain Solutions) and Jace Houston (Houston Galveston Subsidence District)

"Ground Subsidence and Active Faults in the Houston Metropolitan Area**"**

Long-Term Subsidence Along the West Louisiana and East Texas Coast

John B. Anderson and Kristy Milliken
Department of Earth Sciences, Rice University, Houston, Texas 77251-1892.

Literally dozens of geological benchmarks exist along the west Louisiana and east Texas coast. These data include former shorelines and basal peats, both of which are considered reliable sea-level markers.

Using radiocarbon age constraints for these features the relative sea level rise for the past few thousand years can be constrained.

The east Louisiana shoreline is lined by virtually continuous beach ridges that include the Calcasieu and Sabine chenier plains. These were formed by storm waves and were formed within 2 meters of sea level. The ridges range in age from 2,800 to Present and indicate maximum subsidence rates of 5.4 cm/century.

From Sabine Pass to the West end of Galveston Island, the Texas data base consists of a number of beach ridges and basal peats whose ages have been recently constrained by AMS radiocarbon analysis. Beach ridges on Bolivar Peninsula range in age from 2,500 to modern and indicate subsidence rates of less than 4 cm/century. On Galveston Island, beach ridges date back to 5,500 years old. There are also a number of basal peat horizons in East Bay to Surfside Beach that have been dated and that yield similar subsidence rates.

Eustatic sea-level rise in the study area is well constrained and has been less than 0.05/century over the past 3,000 years. When the eustatic rise is subtracted from the relative rise that is indicated by geological benchmarks, the resulting subsidence ranges from 5 cm/century to 10 cm/century. This is in the range of subsidence rates for the past few hundred thousand years, based on stratigraphic studies of the continental margin. The rates for western Louisiana are far less that the rates derived from historical benchmark data (100 to 150 cm/century) reported by Dokka and Shinkle (2005). If these historical subsidence rates are valid, they imply much accelerated subsidence in recent decades, which can only be attributed to anthropogenic causes.

Flooding and storm surge hazards of the Texas Coastal Plain

Steven Baig, National Hurricane Center/NOAA

SLOSH (Sea, Lake and Overland Surges from Hurricanes) is a computerized model run by the National Hurricane Center (NHC) to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes. The model provides storm surge heights for a particular area in feet above the model's reference level, the National Geodetic Vertical Datum (NGVD), which is the elevation reference for most maps. The SLOSH model is generally accurate within plus or minus 20 percent.

SLOSH models were run for Galveston Island, the Bolivar Peninsula along the Texas coast of the Gulf of Mexico. A Category I hurricane moving 5 mph along a NNW track were considered for Galveston and Bolivar using both present geodetic benchmark elevations and using present elevations minus 2 feet, to account for relatively minor storm surge. In model runs using present elevations, Galveston

Island and the Bolivar Peninsula remained mostly above sea level. Model runs taking into account a 2 foot storm surge left both locations almost completely inundated.

Effects of a Category III hurricane were modeled for nearby Texas City. Assumptions were a northerly storm track moving at 10 mph. Results were essentially the same as with Galveston and Bolivar. Using present benchmark elevations, Texas City remained dry, but with a 2 foot storm surge, Texas City would be completely inundated.

SLOSH models graphically show that a relatively minor hurricane would create significant destruction along the Texas Coast; the effects of a storm larger than Category I would clearly be catastrophic. Considered differently, model results may be used to predict the probable inundation and disappearance of much of coastal Texas using accepted subsidence rates of approximately 2 feet per century, taking rising relative sea level into account.

Claims have recently been made that subsidence has been largely arrested on the Texas coastal plain through mitigation of ground water withdrawal and oil and gas production. These claims must be re-evaluated in light of SLOSH model results.

Overview of Space Technologies for Subsidence Measurements

BLOM, Ronald, Earth and Space Sciences, Jet Propulsion Lab/California Institute of Technology, M/S 300-233, 4800 Oak Grove Drive, Pasadena, CA 91109, ronald.blom@jpl.nasa.gov, FIELDING, Eric, Jet Propulsion Lab/California Institute of Technology, M/S 300-233, 4800 Oak Grove Drive, Pasadena, CA 91109, and IVINS, Erik, Jet Propulsion Lab/California Institute of Technology, M/S 300-233, 4800 Oak Grove Drive, Pasadena, CA 91109.

We present an overview of potential mapping and monitoring of subsidence phenomena using space based technologies. Key data include 1) image data (from various portions of the electromagnetic spectrum); 2) Global Positioning System (GPS) data, especially continuous data, and; 3). InSAR (Interferometric Synthetic Aperture Radar). In addition, these data can be used as input to geophysical modeling of subsidence phenomena. Such modeling may help in prediction of future subsidence, which requires understanding of complete process.

Use of various types of remote sensing imagery for mapping surface morphology related to subsidence, faulting, and other deformation phenomena is common. However, an up to date review of strengths and limitations of various available data types is warranted. For example, commonly available shorter wavelength radar systems image the vegetation canopy rather that a bald earth surface. Also of great interest are methods for directly detecting, mapping, and monitoring subsidence through use of continuously recording GPS receivers, and radar interferometry, or InSAR. The InSAR technique uses radar observations made over time to measure surface movement thru changes in the phase of the received signals. These data yield mm level precision maps of surface deformation. Opportunistic science observations from favorable environments show dramatic and often unexpected results. Otherwise unobserved phenomena include inflation/subsidence due to volcanic activity, aseismic fault creep, aseismic regional deformation, surface displacement due to changing groundwater levels, subterranean excavations, and other surface motions. Unfortunately existing InSAR capable satellites were not

designed for this application. In particular, these use short wavelengths (C-band, 5.8 cm) which neither penetrates vegetation, nor is free from decorrelation as scene details such as vegetation growth change over time, precluding generation of interferograms. While there are techniques which can overcome some deficiencies, a longer wavelength InSAR specific system as recommended in the Solid Earth Science Working Group report would enable high spatial and temporal resolution regional monitoring of defomation
(SESWG- http://solidearth.jpl.nasa.gov/PAGES/report.html). In addition, in warm, low elevation areas, the biggest InSAR errors come from varying moisture levels in the atmosphere. This is independent of the radar wavelength. Numerous observations mitigate the atmospheric errors by averaging.

We are investigating deriving atmospheric corrections for InSAR using dense GPS networks and optical satellite data It is also worth noting that C-band InSAR does work in urbanized areas where buildings provide unchanging scatterers. InSAR is complementary to continuous GPS measurements, in that GPS gives continuous sub-mm precision measurements of a point, while InSAR provides geographically continuous deformation maps derived from periodic observations.

Observations show that geographically comprehensive surface motion data is necessary to gain a complete picture of the geophysical processes. A key message in analysis of data from these technologies to date is that the Earth's crust is far more dynamic than appreciated, and often in unexpected ways. Finally, accurate prediction of future subsidence requires understanding of the partitioning of deformation between such phenomena as sediment loading, compaction, oxidation, faulting, and other causes. Modeling procedures developed for use with space based data have potential to contribute to understanding of regional, and even local, subsidence phenomena. This could be important for the Gulf Coast where loading related to sediment pulses of the last deglaciation has regional effects which are added to any local phenomena.

Radar Interferometry and Houston Land Subsidence

Sean M. Buckley, Center for Space Research at The University of Texas at Austin

Abstract

The use of synthetic aperture radar interferometry (InSAR) to measure Houston land subsidence was first demonstrated in the late 1990s. The objective of this study is to improve upon the limited deformation time series information gleaned from the first generation of Houston InSAR measurements. The approach taken here is to combine traditional radar interferometry processing with spatiotemporal filtering to separate Houston land subsidence from InSAR noise sources.

Standard InSAR data analysis utilizes two SAR images acquired over the same location to form a radar interferogram (see accompanying Houston interferogram). Current space-based radar systems provide monthly imagery over a given location spanning ~100 km by 100 km at a horizontal ground resolution of tens of meters. The resultant InSAR phase measurement is sensitive to the topographic height of the surface being imaged and any ground motion that occurred between the two radar acquisition dates. Under ideal conditions, InSAR can be used to measure sub-centimeter deformation along the radar line-of-sight. However, changes in the ground surface over time result in image areas that are uncorrelated and no reliable deformation measurement. The variability of the atmosphere over time and space poses additional problems. In the presence of these effects, an interferometry expert can identify centimeter-scale subsidence in a single interferogram.

The application of time series analysis techniques to tens of interferograms over the same location can aid in separating the topographic, deformation and atmospheric InSAR phase signatures. The final result is a time-ordered sequence of cumulative displacement maps at each of the radar image dates. With the elimination of the atmospheric noise signals, these products hold the possibility of revealing mm-level displacement of urban structures.

The Houston InSAR deformation measurements are found to be consistent with most but not all complementary deformation measurement techniques. A compelling example is the discrepancy between the ground motion observed in InSAR measurements near Seabrook and the lack of long-term subsidence recorded at a nearby extensometer through a portion of the 1990s.

The interferometry results also show greater spatial detail than provided by other deformation measurement techniques. For example, the evolution of centimeter-level differential subsidence across several Houston-area fault locations is clearly visible in the InSAR time series displacement maps.

To further extend radar interferometry deformation measurements in both time and space around Houston or other portions of the Gulf Coast requires support for regular radar acquisitions and a strategic plan to collect data in a single radar mode conducive for InSAR time series analysis.

Subsidence and Future Relative Sea Level Rise in the Gulf Coast

Virginia Burkett, U.S. Geological Survey

Coastal counties along the northern Gulf of Mexico shoreline contain 11% of the U.S. coastal population; this population roughly doubled over the past 50 years. Human development activities in the region have altered coastal landscapes and adjacent watersheds. Some of these activities, such as the dredging of waterways and the construction of reservoirs and levees along rivers that drain to the coast, have altered the natural processes that sustain coastal systems. Land surface subsidence is one consequence of human development in some Gulf Coast regions, but it is also a natural phenomenon in the Mississippi River deltaic plain. Regardless of the cause, as coastal landforms subside, they are more prone to storm surge flooding, shoreline erosion, and permanent inundation by the sea.

Sea level has risen approximately 120 m since the last glacial maximum about 20,000 years before present. Accelerated sea level rise is considered one of the most certain and most costly impacts of greenhouse gas enrichment and associated atmospheric warming. During the 21st century, the global average rate of sea level rise is expected to increase 2- to 4-fold over the 20th century rate (1-2 mm per year). The added stress of accelerated sea level rise on sinking coastal environments portends an increase in flood damages in the Gulf Coast that is greater than that projected for many other coastal regions. The relative rate of sea level rise along any coastal segment is dependent upon both the rate of sea level rise (which varies among ocean basins due to depth, basin geometry, and other factors) as well as the vertical motion of the land surface. Relative sea level rise can be monitored relatively easily. Projections of future subsidence and sea level rise are more challenging. New tools are being developed to assist coastal communities in understanding historical rates of sea level rise and in evaluating scenarios of future change.

Subsidence, Coastal Protection and Wetland Restoration in Louisiana
"A Levee Manager's Perspective"

Windell Curole
General Manager, South La Fource, Louisiana Levee District

South Louisiana communities support 30% of the lower 48 states fisheries, 25% of the U.S. oil needs, shipbuilding and the water borne trade of the mid west through ports along the Mississippi River. Subsidence is a threat to these communities and the services they perform for the nation.
Our goal has always been to integrate the needs of our wetland and flood protection. Both act as essential infrastructure on land which was created by the flow and sediments of the Mississippi River.
Due to subsidence and other factors new work has been necessary to protect our wetlands and our flood protection projects. Hurricanes Katrina and Rita, and Tropical Storm Cindy illustrate the challenges and risks to our communities.

Measurement, Methods, and Modern Subsidence: Definitions, Datums, and Disasters

Roy K. Dokka, Center for GeoInformatics and Department of Civil & Environmental Engineering, Louisiana State University, Baton Rouge, LA 70803.
Shinkle, K., National Geodetic Survey, National Oceanic and Atmospheric Administration, Jackson, MS

Modern subsidence of the Louisiana coast set the stage for the human and infrastructure devastation of Hurricanes Katrina and Rita by lowering the elevations of the land and surrounding levee defenses. As it plans and rebuilds, Society now requires reliable data and information on the amount and causes of subsidence, particularly in coastal areas. The most pressing questions are: What areas are subsiding, how much is occurring, why is subsidence occurring, and what will happen in the next 50-100 years? These questions demand answers based on: 1) spatially and temporally precise data appropriate to capture movements; and 2) understanding of the processes resulting in subsidence.
The measurement of any quantity requires a tool of known resolution and calibration. The former defines the precision of the measurement, and thus establishes the spatial and temporal limitations of questions can be addressed using the tool. The latter provides the means in which to compare the results against other similar measurements. If calibration is global in scope, the latter provides the means to assess accuracy.
The word, subsidence, can be defined as: the lowering of the surface of the Earth with respect to a datum. Lowering of the land surface implies that a change occurred in height with respect to a reference point or datum over a period of time. Thus, to measure subsidence at some point on the Earth requires:

• An appropriate measurement tool sensitive to resolve height change. The tool, e.g., a ruler, defines the precision of the measurement. Geodetic leveling is demonstrably the most accurate and precise method commonly used to measure modern subsidence, i.e., today ± human lifetime. Leveling can measure sub-millimeter vertical changes that occur over short periods, i.e., days, resulting in a resolution of mm per year. Furthermore, subsidence measured by leveling in the region has been independently validated by other methods (e.g., Shinkle and Dokka, 2004). In contrast, estimates based on peat chronostratigraphy average changes in position of a peat horizon over hundreds to thousands of years. Yearly to decadal changes such as measured by geodetic methods are beyond the resolution of peat chronostratigraphy methods. Furthermore, the accuracy of previous studies has not been verified independently using other methods of comparable or superior resolution. Previous studies using inland water level gauges failed to account for uncorrelated effects such as changes to the surface hydrology (e.g., canal building, drainage projects) and climatic changes to the watershed (freshwater input, wind patterns.
• A datum with which to reference measurements. A datum is a point, line, or surface that serves as a reference. If the datum is poorly chosen, then the accuracy of related measurements will be poor. An example of a precise datum is the North American Vertical Datum of 1988 (NAVD88), the current official vertical datum of the United States of America. It replaced National Geodetic Vertical Datum of 1929 (NGVD29). NAVD88 is a network of over 500,000 points spread over the continent whose exact spatial topology was known as of 1988. All previous attempts to measure subsidence in south Louisiana except Shinkle and Dokka (2004) employed an imprecise vertical datum to reference measurements. Unfortunately, failure to use a precise vertical datum such as NAVD88 has several unintended negative consequences. First, by using a datum that does not extend beyond the subsiding area to a point of vertical stability (or to a point of known motion), all measurements will be in error by the amount that the "reference" point is actually moving. Studies that use a local, informal datum will thus underestimate, or even neglect entirely any regional component. Second, the use of an areally restricted datum like sea level precludes users from defining the spatial limits of subsidence. If one cannot access the datum during measurement, no meaningful measurement can be made. Thus, studies using water level gauges or peat chronostratigraphy that rely on sea level as a datum were unable to detect subsidence in areas beyond the coast. In contrast, the use of NAVD88 explains why Shinkle and Dokka (2004) were able to measure subsidence of benchmarks well beyond the limits of the delta and alluvial valley of the Mississippi River. Finally, different areas with subsidence measurements based on locally contrived datums cannot be compared. Previous attempts to map subsidence regionally using disparate data have yielded unsatisfactory results (cf. Coast 2050 Report [1999] with Shinkle and Dokka [2004]). This statement also holds for studies that relied on sea level as a vertical datum to reference measurements, i.e., water level gauges and peat chronostratigraphy. It is now recognized that the elevation of sea level is not the same everywhere and that its position has changed globally over recent time (~2 mm/yr). Thus, any local measurement that is related to sea level is uncertain. Problems are compounded for studies using peat chronostratigraphy because this method relies on unconfirmed ancient positions of sea level.
• The ability to measure the time elapsed over which the change occurred. Because measurements are modern and recorded, we can measure the elapsed time in terms of days.

Here, our defined goal is to understand subsidence that has taken place in very recent past, i.e., 20th century, and hopefully, forecast the near future, i.e., 21st century. Clearly, geodetic methods (including GPS and InSar for future measurements) are superior to all others in accomplishing this narrow goal.

Processes Resulting in Modern Subsidence Along Coastal Louisiana

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Several natural and human-related processes are known or suspected to be causing subsidence in coastal Louisiana today and in the recent geologic past. Almost all previous studies, however, have provided qualitative insights rather than quantitative measurements of actually how much sinking has occurred. It can be said with reasonable certainty that modern subsidence is the integrated effect of multiple natural and anthropomorphic processes that operate at several different spatial and temporal scales. It follows that the motion at any point on the Earth's surface is thus dependent on a unique set of local and regional conditions. Therefore, to more fully understand subsidence, we must be able quantify the relative contributions of each process operating at a locality. Because these processes do not occur everywhere and at all times, hard evidence must be produced to rule in or rule out specific causes at any particular place. A list of processes proven or hypothesized to be active in the region is provided below:

- Natural processes
    - sediment compaction;
    - sediment consolidation;
    - compaction of semi-lithified rock
    - regional faulting associated with gravity spreading and/or salt evacuation;
    - sediment load-induced down-warping;
    - salt evacuation;
    - cap-rock collapse due to natural pressure reduction above salt domes.
- Human-induced processes
    - organic sediment decomposition due to drainage or agricultural projects;
    - groundwater extraction-compaction of shallow aquitards (clays);
    - groundwater extraction-compaction of shallow aquifers (sands);
    - oil/gas extraction related-compaction of aquitards (clays) – <u>unproven in Louisiana;</u> *theoretic models indicate that area of subsidence restricted to only the area of the oil/gas field;*
    - oil/gas extraction related-compaction of aquifers (sands) - <u>unproven in Louisiana;</u> *theoretic models indicate that area of subsidence restricted to only the area of the oil/gas field;*
    - fault motion-induced by shallow groundwater withdrawal*;*
    - cap-rock collapse due to induced pressure reduction above salt domes.

Present-Day Tectonic Subsidence of New Orleans

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Giovanni Sella
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The recent tragic flooding of New Orleans, Louisiana, associated with Hurricane Katrina on August 29, 2005, emphasizes the hazardous setting of this urban area. While it is generally known that New Orleans is a low lying area subject to flooding, there is much less appreciation of the primary reason for its low elevation, and the increasing flood risk associated with on-going subsidence. New GPS and leveling data suggest that New Orleans is subsiding rapidly because it is located in the hanging wall of an active listric normal fault system that accommodates southward motion of the Mississippi delta into the Gulf of Mexico. This location has focused Holocene sediment deposition. Averaged over the last decade, southward motion of this upper crustal block relative to the stable interior of North America occurs at a rate of 2.3 ±1.7 mm/yr. Leveling data suggest that the rate of motion may have been higher in the recent past. The average subsidence rate for GPS sites located on the delta is 5.2±2.3 mm/yr relative to Earths's center of mass, or about 7 mm/yr relative to mean sea level. Movement of the delta block on the listric fault is facilitated by underlying salt horizons. These horizons accommodate deformation via ductile flow at low temperatures, hence, there is little or no seismicity associated with faulting.

Active faulting and impacts on the built environment

Richard Howe, Terrain Solutions, Inc.

Geologic surface faults are found throughout the Gulf Coast of Texas and Louisiana. In Texas they range from south of Corpus Christi northward to the Sabine River. Currently, there are more than 450 identified surface faults along the Texas Gulf Coast and approximately 350 of these are found in the Houston Metropolitan Area.

Whereas there is controversy as to whether or not fault movement rates are influenced by subsurface fluid extraction, it is important to understand that their presence along with the continued ground motion associated with them is evidence of ongoing tectonic activity in the Gulf Basin.

Surface faults represent a natural hazard that has caused millions of dollars in damage to various engineered structures. Recognition and avoidance is the only form of risk management for this phenomenon. Detection and delineation of surface faults requires an understanding of the various types of surface expression associated with them. Where surface evidence is not sufficient to clearly identify a fault and delineate it, subsurface exploration is required, and this is accomplished via drilling and geophysically logging 300-foot boreholes – the only reliable subsurface exploration method for identifying and delineating surface faults.

HEIGHT MODERNIZATION IN TEXAS

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Texas A&M University-Corpus Christi in partnership with the National Geodetic Survey (NGS) has commenced the Texas Height Modernization project. The project is to enhance the vertical component of the National Spatial Reference System (NSRS) in Texas. The NSRS is a consistent national reference framework that specifies latitude, longitude, height (elevation), scale, gravity, and orientation throughout the United States. The vertical component of NSRS has been subject to movement since being established and is in need of modernization and ongoing maintenance. In coastal regions this movement is primarily the result of subsidence with the added effects of sea level rise. By re-observing coastal elevations using traditional leveling and GPS, coastal planners will be better prepared for coastal flooding due to tropical storm events.

The first year of funding will initiate the establishment of Texas Spatial Reference Center at Texas A&M-Corpus Christi. The Center will coordinate activity under the grant. The Center's primary role is to collect a continuous flow of elevation and terrestrial spatial data. Research will be continuously on going to analyze the data for determining how GPS is to be used for accurate elevation determination. Data collection procedures, development of algorithms and design of processes to make the height modernization process effective underlie this project. This research will be conducted in cooperation with the Geodetic Research group at NGS. The Center will develop an in-house expertise in geodetic leveling to NGS specifications. NGS will train Center personnel who will be responsible for coordinating and overseeing geodetic leveling statewide.

The Texas Spatial Reference will be housed in the Conrad Blucher Institute for Surveying and Science along with the Division of Nearshore Research that manages the Texas Coastal Ocean Observation Network (TCOON). TCOON provides near real-time water level observations from 34 active tide gauges along the entire Texas Gulf coast. Data from TCOON is providing valuable information on sea level rise due to the combined effects of subsidence and global sea level rise. The synergies between TCOON and Texas Height Modernization will be discussed.

Methods employed by HGSD for the detection and measurement of subsidence

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281-486-1105x321

The Harris Galveston Subsidence District (HGSD) with assistance from the U.S. Geological Survey (USGS) and the National Geodetic Survey (NGS) has employed Precise Differential Leveling, Extensometers, Global Positioning System (GPS) Technologies, LIDAR (Light Detection and Ranging) and INSAR (Interferometric Synthetic Aperture Radar) in the effort to measure and detect land subsidence.

Precise Differential Leveling is widely accepted as the most accurate method of determining heights and elevations. Precise Differential Leveling is accepted as being able to provide millimeter level precision/accuracy. In reality, the accuracy of differential leveling is a function of the total distance of the leveling route. For First Order Class 2 leveling, the tolerance specifications are 4 millimeters times the square root of the distance in Kilometers. When one considers the distance outside of the Houston area from which a releveling campaign must begin, the potential for accumulated error can be significant. The cost (currently about $2,000 per Kilometer) of major releveling campaigns is prohibitive and in the past could only be performed about every 8 to 10 years which leaves much to be desired. These leveling campaigns also consume a considerable amount of time (an experienced motorized leveling crew can make about 10 miles of progress per day).

Another drawback to leveling in a subsidence area is that once completed, the resulting elevations quickly become suspect. There are no benchmarks in the subsidence area which are unaffected by subsidence. The so called “Total Depth” Extensometers are designed to be unaffected by subsidence resulting from compaction and seasonal surface motion due to expansive soils, but they may be subject to other deeper seated subsidence. Nonetheless, the total depth extensometers are the best benchmarks in the Houston area, but they too are cost prohibitive.

Remote sensing technologies such as LIDAR and INSAR have shown promise but are also cost prohibitive to employ on a regular basis. An attempt was made over the previous leveling network to observe short term GPS at all of the stations but this proved to lack the desired resolution.

HGSD established a CORS (Continuously Operating Reference Station) and became one of the first NGS National CORS. It was established on an extensometer and 2 more have been established on additional extensometers. In addition to the CORS, 28 additional stations called PAMs (Port-a-Measure Stations) have been established which employ GPS and observe 24 hour datasets for a week at a time and each PAMs is occupied every 4 weeks. It is well documented that GPS has the capability for 2 centimeters of precision in the height component but as been seen CORS and other long term GPS sites, the vertical accuracy is more likely sub-centimeter.

There are a number of Vertical Datums commonly in use today but what is probably of the utmost concern to most people in the Houston area is their relationship to Sea

Level. Sea Level is a local phenomena and it is imperative that a CORS be established at an active tide station in Galveston and at as many as possible along the Texas Gulf Coast. The North American Vertical Datum of 1988 (NAVD88) elevation of a given point may not be as important as its relativity to sea level or a given flood plane, river stage or other vertical reference but it does provide for a National Datum which can link all of the datums in use if an adequate connection is made to it. Over the last 25 years since the inception of GPS there has been little advance in the methodologies or technologies of Differential Leveling that have resulted in improved accuracies. The GPS System on the other hand has seen vast improvement and there is every indication that these precisions and accuracies will continue to improve.

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Coastal Funding Programs at the Texas General Land Office

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The Texas General Land Office (GLO) is the steward of the following coastal programs: Texas Coastal Erosion Planning and Response Act Program (CEPRA), Coastal Management Program (CMP), Coastal Impact Assistance Program (CIAP), and Texas Coastal Ocean Observation Network (TCOON).

The CEPRA program works through collaboration between the GLO, federal and local governments, and the citizens of our coastal communities. CEPRA funds are used for projects such as: estuary programs, beach nourishment, dune restoration, shoreline protection, habitat restoration/protection, university research, non-profit groups and studies. The program was first authorized and funded by the 76th Texas Legislature. CEPRA gives Texans the tools to fight coastal erosion, as it continues to threaten our public beaches, marshes, homes and businesses, and public infrastructure. In the first three bienniums of the program, the CEPRA combined participation with local and federal entities has totalized more than $40 million in coastal projects.

The National Oceanic and Atmospheric Administration approved the Texas Coastal Management Program (CMP) in 1997. CMP brings approximately $2.2 million every cycle in federal funds to Texas state and local entities to implement projects and program activities. Texas is one of only a handful of coastal states that passes substantial amounts of CMP funds through to coastal communities for projects in the coastal zone. The CMP funds a wide variety of projects in coastal communities including: coastal natural hazards response, critical areas enhancement, shoreline access, waterfront revitalization and ecotourism development, permit streamlining/assistance and governmental coordination, information and data availability, public education and outreach, and water quality improvement.

For the CIAP program, as part of the General Appropriations Act of 2001, the U.S. Congress provided a one-time appropriation to NOAA of $150 million to be allocated to Texas and six other coastal states. The purpose was to assist these states in mitigating the impacts associated with outer continental shelf oil and gas production. Under this legislation, Texas was awarded $26,406,064. Management and supervision of these funds were divided between the state and 18 coastal counties. County CIAP funds were awarded directly by NOAA to the recipient counties. Based on the Governor's directives and in coordination with the Coastal Coordination Council, the GLO developed the Texas CIAP Plan for the state's portion of the award. Under this plan, state CIAP funds were managed and distributed by the Council and the GLO. The funds were divided into two pools -- $9,709,185 to be administered by the GLO and $7,454,756 to be administered by the Council. The funds were awarded to projects selected through a competitive grant process. Future CIAP funds are anticipated to be received in Texas by 2007.

Finally, for the TCOON program, in 1989 the Conrad Blucher Institute for Surveying and Science (CBI) at Texas A&M University-Corpus Christi commenced the installation of a modern state-of-the-art, water-level measurement system along the Texas coast. The first measurement systems installed by CBI were intended to provide real-time water-level and meteorological information to the City of Corpus Christi to assist local officials with preparations for incoming hurricanes and tropical storms. From this initial work, other state agencies such as the GLO and the Texas Water Development Board began contracting CBI to provide similar information for other areas along the Texas coast. Following a Texas Legislative mandate in 1991, this network of water level gauges became the Texas Coastal Ocean Observation Network (TCOON). As a result, TCOON expanded from an initial three stations in Corpus Christi in 1989 to over forty stations by 1992. TCOON provides information to private, academic, and public entities and tides and coastal inundation data.

The politics and public policy issues of subsidence

Ron Neighbors, General Manager
Harris Galveston Subsidence District
Fort Bend Subsidence District

In 1974, Houston and Harris County were in the throes of a huge economic bubble that showed no signs of bursting. Subdivisions were popping up like mushrooms, and the demand for water threatened to outstrip supply. Doomsayers predicted that the area was on a collision course with socio-economic disaster. Too many people, too much growth, too fast…and not enough natural resources to realistically sustain it into the future -- the basic "Sky is falling!" prophecy.

A decade earlier, experts had begun to link the increased frequency and severity of flooding to subsidence. In 1961, Hurricane Carla provided a dramatic wake up call when her swath of damage was far worse than anticipated…even from a category 4 storm. As a result, local area governments began to analyze the acute and very real impact subsidence could have on the area's potential economic growth and quality of life, and got serious about determining exactly what could be done about it.

In 1975, the 64th Texas Legislature created the Harris-Galveston Coastal Subsidence District -- the first of its kind in the United States. Authorized as a regulatory agency with a mission to "end subsidence" and armed with the power to restrict groundwater withdrawals, the District immediately went to work on a plan to positively impact the critical situation in the coastal areas. As part of the plan, industries on the Houston Ship Channel were converted to surface water supplied from the newly completed Lake Livingston reservoir, and subsidence in the Baytown-Pasadena area dramatically improved.

While subsidence was stabilizing in the coastal areas, groundwater levels in inland areas north and west of Houston were rapidly declining. As a result of the increasing threat subsidence posed to these areas, the HGSD adopted a series of regulatory plans to reduce groundwater pumpage, and ultimately mandated -- in the 1999 plan -- a reduction to only 20% reliance on groundwater by 2030. The North and the West teamed up to secure a fair and equitable contract with the City of Houston to supply surface water from Lake Houston, and new waterline infrastructure is well underway in both of these Authorities.

On the technical front, traditional systems on which we have relied to measure elevations for subsidence are being augmented by some high tech satellite help from space – from the Global Positioning System. Utilized by the new Texas Spatial Reference Center, rapidly emerging GPS technology will provide significant assistance to those in the fields of surveying, engineering, and construction – folks who have had a growing need for accurate and up-to-date elevation data for some time. This new tool will be especially important in analyzing flood zone data, and will be useful all the way down to the individual resident!

Like the Internet, this new system is not just one component, but rather a growing work in progress. It links together key pieces of the equation, with important benefits for many of the "players", including the Flood Control District, the City of Houston, the Highway Department, Universities, and even the National Geodetic Survey.

The Subsidence District has played an integral role over the past three decades in identifying and eliminating subsidence, and -- immune to the "Chicken Little" school of predicting the future -- the District will continue its mission and be an active participant in the technological evolution just ahead.

Congressional report and legislation to Address Subsidence in Southern Louisiana

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Wetland loss and coastal subsidence is a well known geologic fact in the Mississippi delta. Approximately thirty miles of shoreline retreat can be documented over a thirty-year period based on shoreline marsh flora at current water depths of 300. Causes for shoreline retreat and land loss include oil exploration, salt water intrusion, shore line earth quake, and alluvial deposit and cantilever reaction of two Pleistocene plateau.

Several field samples taken by LSU at the existing Highway system in south Louisiana indicate some tectonic activity mimicking earthquake activity due to alluvial deposits at the mouth of the Mississippi river. Air Line Highway, which runs through several river parishes including St Charles, has subsided approximately 3.4 feet from 1929 to 2004. Many survey markers are based on that reference for NGVD1929.

Congressional reports beginning in 1993 indicated that the vertical elevation data in Louisiana is inaccurate and obsolete. Survey markers are adjusted periodically to make measurements compatible with observed readings. USACOE is adjusting water elevations and river levels to be compatible with aerial surveys so that NAVD 88 is uniformly used on land masses. The spatial surveys using satellite-based vertical measurements will enable coastal areas to understand better the land subsidence and coastal erosion in absolute terms.

This is the only hope for city planners and public safety officials to plan for orderly evacuation routes for the citizenry. Accurate vertical elevations will help planned growth of sustainable communities and wetlands mitigation by using natural marsh lands to minimize effects of catastrophic events like Katrina. We introduced model legislation in our parish utilizing modern technology to control our growth using accurate vertical data measuring subsidence in absolute terms.

An Introduction to the Origin of the Gulf of Mexico and Its Role in Subsidence

David G. Rensink

The Gulf of Mexico opened during the early Jurassic, at approximately the same time as the Atlantic Ocean and its formation is a consequence of the opening of the Atlantic Ocean. However, while the Atlantic became an open ocean early in its life, the Gulf of Mexico originated as a rift valley with a restricted marine environment. Its origin and characteristics are very similar to the Red Sea. Water flowed in, but very little flowed out. The arid conditions prevailing at the time caused high evaporation rates, increased water salinity to near saturation levels, and resulted in the formation of evaporate deposits thousands of feet thick. The salt was subsequently covered by the upper Jurassic and Cretaceous clastics and carbonates. During the Paleocene, the basin began a period of rapid sediment influx along the western margin. The source of maximum sediment deposition has continued to move in clockwise direction around the basin through the Tertiary and Holocene to the current position of the Mississippi River.

The progressive deposition of clastic sediments along the margins of the basin triggered the movement of the Jurassic salt into the shallower section and pushed the salt further into the basin in a manner similar to pushing toothpaste from a tube. Salt movement is the primary cause of the growth fault dominated subsurface architecture present today. One of the consequences of the growth faulting is a mass movement of sediment basin-ward along glide planes that seem to be lubricated by salt off the Louisiana coast and by high pressured shale off much of the Texas coast. Mass sediment movement has a notable effect on seafloor subsidence near the shelf edge, but the effect it may have on subsidence near the shelf edge or surface subsidence onshore is not well defined.

This is a fairly simple model of sediment filling the available space, but it is complicated by basin subsidence resulting from the down warping due to the increasing sediment load and the thinning of the crust through basin expansion. Since the basin continues to fill with sediments and the Atlantic Ocean continues to widen through seafloor spreading, it is probably safe to assume that the Gulf of Mexico continues to sink. The rate of crustal subsidence can be estimated from the rate of sediment accumulation on the continental shelf, and these calculations seem to indicate that crustal subsidence is approximately a few millimeters per year. However these rates of subsidence are averaged over millions of years, and subsidence rates averaged over millions of years are only meaningful if the rates are constant throughout that period of time. If basin subsidence is episodic, these rates are not meaningful for making predictions over periods of time measured in decades.

In addition, the shallow sediments are compacting through dewatering. Subsidence through compaction is accomplished through both natural and artificial means. Gravity drives the natural process and water and hydrocarbon production is the artificial process. Compaction curves indicate that the effect of fluid withdrawal is greatest in the first few thousand feet of section where fluids provide some support of the overburden. Below about five thousand feet, the overburden is supported primarily by grain to grain contact. Therefore, oil and gas production at depth should have a negligible effect on surface subsidence. Subsidence through fluid withdrawal is well documented, but its effect is largely local and not regional in scale.

Surface subsidence is the result of multiple factors that are independent in rate and timing, and the only thing man can control is fluid withdrawal rates.

Rates of Vertical Displacement of Geodetic Benchmarks

Kurt D. Shinkle
National Geodetic Survey

We conducted this study to determine the rates of subsidence and the spatial extent of the vertical displacement in the lower Mississippi Valley and northern Gulf Coast regions. The primary data used in our analysis is 1st order geodetic leveling, the most precise vertical ground surface measurement information available. Throughout much of the 20th century, the U.S. Coast and Geodetic Survey, and later the National Geodetic Survey (NGS), conducted geodetic leveling surveys through the region to establish and extend the vertical control network. Occasionally, newer leveling surveys included lines of benchmarks established by previous surveys, thus providing two or more temporally separated measurements on a given point.

We used the long-term water level gauge at Grand Isle, Louisiana, as the starting point for our analysis. It has tracked the movement of “sea level” at that location since 1979. The trend of water level observations from the tide gauge contains two principle signals: the actual rise in global sea level, and the sinking of the land surface. From the water level trend, we extracted the rate of sinking of the tide gauge itself, and its adjacent benchmark, between the two times it was connected to the national leveling network by survey projects, i.e., 1982 and 1993. Thus, the rate of subsidence was established for one starting benchmark over one specific time interval. The 1993 height for the initial benchmark, at the end of the line near the tide gauge, was arbitrarily selected as the current published value. We used the rate of vertical displacement derived from the water level data to compute the height of that same mark in 1982. Then we used the corrected 1st order leveling observations, stored by the NGS, to compute observed heights at each benchmark along the chain for each of the two leveling runs. The difference in the computed height at any given benchmark between a later and an earlier leveling run, divided by the time elapsed between the two runs, is thus the rate at which the benchmark moved over that interval of time. The leveling measurements carry a precision of millimeters and the dates of the leveling runs are known to the month, so the derived rates can be reasonably stated in millimeters per year. Using this simple method, we assembled a network of benchmarks with measured rates of subsidence, as shown in the accompanying map.

From this study, we concluded that subsidence was a regional phenomenon. There is no such thing as a "stable" benchmark within the subsiding region. Elevation references within this region had been rendered inaccurate and unusable; new reference elevations would need to be brought in from other, more stable parts of the country. This approach of using geodetic survey measurements provides a common datum against which all measurements of elevation change throughout the region could be related and referred, as long as they can be connected to the fundamental vertical reference network.

Using Holocene relative sea-level data for high-precision measurement of differential crustal movements in the Mississippi Delta

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Due to the immense concern about wetland loss and coastal erosion in southern Louisiana, there is vigorous debate about the driving mechanisms that cause this environmental catastrophe. One frequently invoked component is tectonic subsidence of the Mississippi Delta and its surroundings as a consequence of lithospheric flexure due to ongoing sediment loading by the deltaic depocenter.

We have collected relative sea-level data covering the past 8500 years from three study areas in different sections of the Mississippi Delta, to assess whether significant differential crustal movements occur. Our sea-level index points were obtained from basal peat that accumulated during the initial transgression of the pre-existing, consolidated Pleistocene substratum, thus ruling out the role of compaction of Holocene strata. The study areas differ in their distance to the present shoreline. The rationale of our analysis is that given spatially uniform eustatic and glacio-hydro-isostatic signals, any difference between relative sea-level curves from the three study areas can be attributed to differential tectonic subsidence rates. The extremely favorable conditions for sea-level research on the US Gulf Coast (largely due to the low tidal range) and the long time span of observation allow us to calculate tectonic movements with exceptionally high accuracy and precision.

Our results show that differential crustal movements among the three study areas have been on the order of ~0.1 mm/yr only. We compare our new evidence with a recently published compilation of relative sea-level data from the Caribbean, to a large extent based on data from areas that are widely believed to be tectonically very stable (e.g., Florida, Bahamas, Belize). All our sea-level index points nearly coincide with the Caribbean data, showing that considerable parts of the Mississippi Delta are surprisingly tectonically stable. However, the well-documented high subsidence rates in and near the birdfoot of the Mississippi Delta indicate that different conditions prevail in that area. Nevertheless, we suggest that the rapid rates of coastal-wetland loss are to a large extent due to a combination of compaction of the thick Holocene strata, as well as human action, like the extraction of oil, gas, and groundwater.

A Qualitative Analysis of Water-Level Change 1973–2005 and Measured Compaction 1973–2004 in the Chicot and Evangeline Aquifers, Harris and Galveston Counties, Texas

By Mark C. Kasmarek[1], Matthew S. Milburn[2], and **Michael J. Turco[3] (Presenter)**

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Subsidence is a major concern in Harris and Galveston Counties in the Gulf Coast region of Texas. Subsidence can cause decreases in property values, changes in surface-water drainage patterns that lead to flooding, and large areas of inundation caused by tropical storm surges. In 1974 the U.S. Geological Survey (USGS), in cooperation with the Harris-Galveston Coastal Subsidence District and the City of Houston (COH) began an investigation into the processes that control subsidence in these counties (the study area). More recently, the Fort Bend Subsidence District and the Lone Star Groundwater Conservation District joined the USGS and the COH in this long-term cooperative effort.

The two primary water-yielding units (aquifers) of the Gulf Coast aquifer system in Harris and Galveston Counties are the Chicot aquifer (composed of Holocene- and Pleistocene-age sediments) and the Evangeline aquifer (composed of Pliocene- and Miocene-age sediments). The hydrogeologic units that compose these aquifers are laterally discontinuous, fluvial-deltaic deposits of gravel, sand, silt, and clay that dip and thicken from northwest to southeast. The clay layers in the Gulf Coast aquifer system are the primary units that compact. The sediments that compose the Chicot aquifer are geologically younger and have less overburden than the sediments of the Evangeline aquifer and are more susceptible to compaction.

Measured compaction data and water-level data were used to evaluate the association between water-level changes and compaction rates and long-term subsidence in the study area. Starting in 1962, 13 extensometers were installed at 11 sites at varying depths to measure the compaction of the material above the base of the extensometer (fig 1.). Currently (2005), the 13 extensometers are measured monthly and are part of a subsidence network that also includes 60 nested piezometers open to various depths for measuring water levels at the sites. Changes in water levels between 1977 and 2005, based in part on water levels measured from the subsidence network as well as about 300 other water levels measured annually, is shown in figure 1. Overall, water levels are rising in the eastern part of the study area where ground-water withdrawals have been decreasing since 1977, and declining in the western part of the study area where ground-water withdrawals have been increasing.

To evaluate historical subsidence in the area, geospatial techniques were used to estimate the amount of subsidence that has occurred in a small region in the eastern part of the study area (figure 2). Using a geographic information system, historical land-surface elevations from the earliest known topographic surveys in 1915–16 were compared with elevations derived from a Light Detection and Ranging (LIDAR) survey conducted as part of the Tropical Storm Allison Recovery Project of the Federal Emergency Management Agency and the Harris County Flood Control District in 2002. The LIDAR data were filtered to remove known anthropogenic structures and other recognizable anthropogenic features. In some isolated areas, it was estimated that as much as 12.8 feet of subsidence has occurred. As much as 10 feet of subsidence has been measured as a part of subsidence network monitoring (Gabrysch and Neighbors, 2005). This geospatial technique was a useful tool for evaluating the extent of subsidence and resulted in a more comprehensive depiction of overall subsidence in the area.

Based on nearly 30 years of compaction and water-level data that show a notable association between subsidence and water-level change, the authors conclude that the reduction of pore pressure within the clays of the Chicot and Evangeline aquifers caused by shallow fluid withdrawal (predominately ground water) is the primary cause of compaction and subsequent subsidence in the study area. The long-term compaction data from the 13 borehole extensometers indicates that in the early 1970s the compaction rates were much greater than the 2004 rates (fig. 3). Historic compaction rates have been as much as 0.3 feet per year at the Seabrook extensometer (LJ-65-32-625) and the deep Baytown extensometer (LJ-65-16-931). At the Northeast (LJ-65-14-746), Pasadena (LJ-65-23-322), and Texas City-Moses Lake (KH-64-33-920) extensometer sites, land-surface elevation has increased (rebounded) as much as 0.1– 0.2 feet associated with water-level rise in those areas (Kasmarek and Houston, 2005). Correlation tests and visual inspection of water-level hydrographs and compaction graphs indicate a correlation between compaction rates and water-level changes at nearly all extensometer sites. Although results vary at each extensometer site, approximately 92 percent of all piezometers show substantial water-level rises through time since the period of historical water-level lows in the late 1970s; and extensometers show corresponding decreases in rates of compaction.

The compaction rate of the Addicks extensometer was relatively constant and resulted in about 3.4 feet of compaction at the site during 1973–2004. The compaction data from this site also shows that since approximately mid-2003, compaction apparently has ceased and the land surface has rebounded slightly. This decrease in the rate of compaction was coincident with a large decrease in nearby ground-water withdrawals. Presently ground-water withdrawals in the area have resumed and compaction has begun again at a rate similar to the previous long-term average of about 0.1 feet per year.

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COASTAL SUBSIDENCE: FINDING COMMON GROUND

Sam Webb, Texas General Land Office

The Texas General Land Office (GLO) is the oldest state agency in Texas. Its core mission is the management of state lands and mineral-right properties, totaling over 20 million acres. This includes beaches, bays, estuaries and other submerged lands extending 10.3 miles into the Gulf of Mexico. Revenue generated from the lease of state land for oil and gas exploration is managed by the GLO and directed to the Permanent School Fund to support school districts on a per-pupil basis. In addition, the GLO administers the Texas Coastal Management Program, the Coastal Impact Assistance Program, and the Coastal Erosion Planning and Response Act Program, which have contributed millions in state and federal dollars to protect and enhance the coastal areas of Texas.

As a steward of the Texas coast, the GLO has a vested interest in protecting the state's coastal resources. Understanding and mitigating coastal subsidence is essential to maintaining the environmental and economic stability of the Gulf coast region, as well as the rest of the country. Never has that been clearer than after the devastating effects of Hurricanes Katrina and Rita.

The processes that drive coastal subsidence are controversial. Their impact, however, is commonly understood. Subsidence exposes communities to increased risk from storm activity and threatens ecologically and economically valuable habitat, vital infrastructure, and the public tax base. The GLO recognizes the importance of identifying the causes of subsidence, but must emphasize the determination of localized subsidence rates. Consistent, reliable velocity data is needed to ensure informed management of our coastal resources and the safety of our coastal communities.

The GLO is neither staffed nor equipped to quantify subsidence velocities. We must look to the National Geodetic Survey (NGS), the state NGS advisors, the U.S. Geological Survey, the Texas Bureau of Economic Geology, the Subsidence District, the burgeoning Spatial Reference Center at Texas A&M-Corpus Christi, and other state, federal, research, and university groups for guidance in assessing coastal subsidence.

The Importance of Accurate Subsidence Network for the Establishment Vertical Control and Subsidence Rates

David Zilkoski
National Geodetic Survey

Subsidence can severely damage property and infrastructure in a developed area. Typically when subsidence is human-induced, its prevention is expensive because conventional operations must be changed. Accurate monitoring of subsidence over time is vital to providing calibration data for modeling and prediction. Geodetic differential leveling, used previously to measure subsidence, was satisfactory but was expensive. The Harris Galveston Subsidence District (HGSD) and the National Geodetic Survey (NGS) measured subsidence using Global Positioning System (GPS) methods at a fraction of the cost of the previous method. Stable borehole extensometers equipped with GPS antennas provided a reference frame to measure subsidence in the area. These stations are known as local GPS continuously operating reference stations (CORS). It was also necessary to design and construct portable GPS measuring stations called Port-A-Measures (PAMS).

Dual-frequency, full-wavelength GPS instruments and geodetic antennas collect data at 30-second sampling intervals averaging 24 hours. The goal is to yield differential accuracy of less than 1 centimeter vertically in an automated mode. Data have been collected from three CORS sites and four PAMS for more than 4 years and three additional PAMS for 2 years. Results between CORS and PAMS indicate that some monuments are subsiding at rates of 7 cm per year and correlate well with extensometer data.

This report presents a brief summary of the CORS and PAMS results, discusses the use of GPS for assessing subsidence in the Houston-Galveston region Texas and estimating accurate North American Vertical Datum of 1988 heights.

Synthetic Aperture Radar for monitoring of Gulf Coast wetlands and subsidence

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Synthetic Aperture Radar (SAR) is a powerful remote sensing instrument that can make a number of unique measurements. The uniqueness comes from the ability of the radar to penetrate cloud cover providing extremely reliable imaging, and the coherent nature of the radar waves themselves. In this talk, we will examine through examples the ability of SAR to provide measurements relevant to wetlands. These include:

- monitoring wetlands water level and water flow using interferometric SAR
- detection of changes to wetlands (addition/deletion of land, water and/or vegetation), and
- measurements of ground motion near wetlands using differential interferometric SAR

The following specific examples will be presented:

Water level and flow were measured in the Everglades in the 1990's using interferometric SAR techniques. The derived water flow was in good agreement with in-situ point measurement gauges, but provided a much larger and synoptic view of the flow. These sort of measurements are critical to wetlands restoration programs.

Wetland changes from the recent Hurricane Katrina in and around New Orleans have been measured and will be presented. One advantage of using SAR for this measurement is its ability to see through any cloud cover producing a 100% useable image. Optical instruments invariably suffer from clouds and seeing conditions.

Obtaining ground motion measurements, including subsidence, from SAR is arguably the most powerful SAR application in use today. We review the 2-pass differential interferometric SAR technique, and present example measurements of subsidence and other ground motion. Finally, we present interesting measurements made from recent SAR acquisitions of New Orleans (post Katrina).