Mexico City’s subsidence has been recognized for over 100 years, after the first well battery was drilled to supply water to the rapidly growing city at the end of the 19th century. The relationship between water extraction and subsidence, however, was not realized until the 1940s. Consequences of the subsidence process are costly. Water sewage works must be constantly upgraded due to loss of gradient, and transitional areas between lacustrine beds and slope deposits are prone to severe differential subsidence, damaging infrastructure. However, the regional extent and spatial variation of subsidence, and seasonal and longer-term variations, are not well monitored, hampering effective mitigation. The economic consequences of subsidence are generally factored into yearly maintenance budgets rather than accounting for them as a unique or single natural hazard. It has thus become increasingly important to assess the extent and magnitude of damage due to ground subsidence in the Mexico City metropolitan area.

Interferometric Synthetic Aperture Radar (InSAR) and GPS measurements including data from an eight-site permanent GPS network show land subsidence in Mexico City at rates as high as 380 mm/yr, with a relatively constant rate over the last ten years and no discernible seasonal variations. This rate of subsidence is close to the historical maximum levels of the mid 20th century, when local government enforced strong mitigation efforts to reduce damage to the downtown colonial buildings. However, the locus of maximum subsidence has shifted eastwards over the last decades from downtown into the lacustrine plains of old Lake Texcoco, where intense urban development has also taken place, increasing the vulnerability of the city to a large-scale, slowly occurring natural disaster. Correlation of InSAR-GPS results with lithostratigraphic mapping and analytical models relating surface subsidence to groundwater levels indicate that subsidence is primarily controlled by compaction of Quaternary lacustrine clays and silts. This process represents a natural hazard and imposes serious constraints to the maintenance and future development of the city.

Related References


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Biomass Characterization from Microwave Attenuation Using Ground-Based GPS Receivers

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Soil moisture is a key parameter for understanding Earth’s climate and the global water and energy cycle. Numerous experiments have demonstrated that L-band (~1.4 GHz) radiometry is the ideal approach for measurements of this key parameter from space (Jackson, 1993). Nevertheless microwave emissions are highly sensitive to variations in vegetation transmissivity especially at biomass quantities greater than about 5 kg m\(^{-2}\) (pasture or mature row crop). Unfortunately, there is little knowledge about the spatial-temporal variability of vegetation properties to develop appropriate attenuation and scattering correction procedures for soil moisture retrieval algorithms.

A rather large body of literature exists concerning the propagation and interaction of electromagnetic waves in vegetation as applied to telecommunications and remote sensing. However, there are no definitive methods relating radio frequency propagation to generalized quantities such as biomass. The objective of this study was to assess the potential of using radio frequency attenuation and multipath scattering from GPS signals to detect differences in vegetation biomass and obtain a preliminary assessment of its sensitivity.

Ground-based GPS observations were made beneath vegetation canopy with a Trimble NetRS Reference Station and Trimble Zephyr Geodetic antenna. L1 and L2 carrier frequency signals were obtained in fields of corn and cotton and beneath deciduous and pine forest canopies. Concurrent control observations with an unobstructed view of the sky were made nearby using a second receiver and antenna. We also placed the antenna and receiver beneath single tree specimens to quantify the spatial attenuation characteristics.

The GPS receivers were able to track significant numbers of satellites from beneath vegetation canopies. The signal to noise ratio (SNR) as a function of incidence angle is different for each vegetation type and differs from unobstructed SNRs by as much as 10 dBHz. For row crops there is no detectable difference in SNRs for obstructed and unobstructed antennas at 90° incidence. As the incidence angle increases, however, the SNR difference also increases (Figure 1). In forests, the SNR difference is quite variable at all incidence angles and only slightly greater at lower angles (Figure 2). L2 data are compared in the same manner with L1. Data are being filtered to isolate contributions from multipath scattering.

Clearly, there is a strong relationship between signal attenuation and scattering and biomass. This relationship is, however, very specific to vegetation type insofar as scattering is a direct function of plant architecture. Sensitivity to small changes in biomass under forest canopy is demonstrated by slight changes observed in the L1 SNR data as the leaves dropped from the trees during the fall (Figure 3).
Remote Detection of Water Surface Elevations in the Peace-Athabasca Delta, Alberta, Canada

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River discharge and terrestrial storages of water in lakes, reservoirs, and wetlands are critical components of the global water balance yet are poorly observed in many high-latitude environments (Shiklomanov et al., 2002). Space-based remote sensing offers a powerful and attractive tool for tracking the boreal hydrologic cycle. It is essential, however, to obtain extensive ground-based data on a variety of hydrologic variables including river and lake depth, flow direction and velocity, sediment transport, and inundated area in order to develop reliable techniques for remote sensing of northern wetlands. The Peace-Athabasca Delta (PAD) of Northern Alberta (Figure 1), among the world’s largest freshwater deltas, is an ideal area in which to collect such data due to its complex hydraulic characteristics, its extremely low relief, and, compared to other large northern wetlands, its relative ease of access (Prowse et al., 2006).

During the summer 2006 field season, we deployed 32 pressure-transducer water level loggers throughout the PAD to acquire the ground data necessary for developing satellite-derived area-stage relationships as well as to examine flow dynamics in low-relief wetland systems. To compare water surface elevations among logger locations, we installed elevation benchmarks throughout the PAD using differential GPS equipment and then surveyed water levels from these benchmarks several times during the field season. We combined these water elevations (Figure 2) with data on flow direction, wind speed, rainfall, and other pertinent variables. Preliminary results suggest that sustained winds and variations in discharge from rivers flowing into the Delta have large effects on water level, while direct precipitation plays a minimal role in summertime water level variability. ASTER and MODIS imagery will be used in combination with our ground-based datasets to determine to what extent water level variability in the PAD can be tracked remotely.

References:
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Figure 1: The Peace-Athabasca Delta, located in Northern Alberta. Water surface elevations were calculated every 15 minutes at 32 points within the Delta.

Figure 2: Examples of water surface elevation time series at 15 locations in the Peace Athabasca Delta from Summer 2004. Summer 2006 data will be available at an additional 17 locations.
GPS Monitoring of Dynamic Deformations of Flexible Civil Engineering Structures

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RTK-GPS has been introduced for the structural monitoring and identification of dynamic characteristics of major flexible civil engineering structures such as cable bridges, antennas, and other structures (Nickitopoloulou et al., 2006; Pytharouli et al., 2006). However, very little is known about the characteristics of structures or the accuracy range that can be surveyed. To overcome this problem, we made systematic experiments in which oscillations of known, computer-controlled characteristics were recorded by GPS and subsequently analyzed using filtering and spectral analysis software based on least squares mostly to account for outliers and discontinuous data sets (Pytharouli and Stiros, 2007). Experiments were limited to linear oscillations with frequency and amplitude within the range 0.05 to –4 Hz and 0.5 to 3cm. Our analysis revealed that the potential of GPS to record oscillations depends on the trade-off between amplitude and frequency of the oscillation (Figure 1a; Psimoulis and Stiros, 2006), and that frequencies up to 4 Hz can accurately be determined (Figure 1b).

Moreover, field measurements in real structures were made to permit a further refinement of techniques for the analysis of data and to overcome problems such as the multipath and the changing satellite geometry effects. When possible, GPS measurements were supplemented by recordings of robotic theodolites (RTS). Results are very promising. For instance, the analysis of the response of a historical short-span bridge (single span opening 30 m; Figure 1c) to passing trains permitted measurement of its dominant frequency (Figure 1d).

References:

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**Measurement Of Land Subsidence Based On GPS And Historical Geodetic Data**

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Ground subsidence is a major problem in many areas, leading to serious damage in infrastructure (Kontogianni et al., in press) and loss of land in Greece (Figure 1; Stiros, 2001) and other countries including the U.S. A main problem in some cases is to identify the extent and causes of the effect and separate anthropogenic contributions (mainly due to pumping) from natural effects. For this reason data covering greater than 30 to 40 year time periods are necessary. Comparison of historical leveling and triangulation data with GPS data, corrected for geoid undulations, appears to be the most promising way. Figure 2 summarizes the results of such a comparison in the Thessaloniki plain where subsidence rates up to 10 cm/yr have been measured (Stiros, 2001; Psimoulis et al., in press). These data indicate that subsidence is a basin-wide, long-term natural effect, and only locally subsidence due to pumping is superimposed. This result is extremely important, especially since pumping by the Water Authority is blamed for all damage observed. Except for the Thessaloniki Plain, measurements have also been made in the Thessaly Plain, central Greece. A future task is to refine and extend measurements with the support of UNAVCO.

**Figure 1:** Electricity poles offshore indicate loss of land due to land subsidence in the Kalochori area (Thessaloniki, Northern Greece)

**References:**
Kontogianni, V., Pytharouli, S. and Stiros, S. Ground subsidence, Quaternary faults and vulnerability of utilities and transportation networks in Thessaly, Greece, Environmental Geology, in press.
Psimoulis, P., Ghilardi, M., Fouache, E., Stiros, S. Subsidence and evolution of the Thessaloniki Plain, Greece, based on historical leveling and GPS data. Engineering Geology, in press.

This work was supported by Patras University and the Greek Secretariat for Research and Technology.

**Figure 2:** Contours of subsidence (in m) in the wider Thessaloniki (Northern Greece) plain in the last 50 years based on a comparison of historical leveling and GPS data (triangles). Amount of subsidence is maximum, >4m in the Kalochori area partly due to water pumping (after Psimoulis et al., in press).
Since 2001, our sea-level research in the Mississippi Delta has been carried out in close cooperation with UNAVCO, Inc. One of the premier objectives of these studies is to quantify rates of long-term vertical crustal movements with the highest attainable accuracy and precision. The rationale of this work (Törnqvist et al., 2004) is to use indicators of sea-level positions over the past 8000 years, and to measure their vertical displacement relative to one another in order to infer differential tectonic movements. The sea-level indicator used is basal peat—mostly salt-marsh peat that accumulates on the consolidated Pleistocene basement as a result of sea-level rise—that is widely present in the subsurface. Because our study areas are as much as 100 km apart, it is challenging to determine accurate elevations of sea-level indicators with reference to a common geodetic datum. This challenge is partly due to uncertainties about the quality of National Geodetic Survey benchmarks in this region, which is widely believed to be highly unstable. GPS presents an opportunity to obtain independent elevation data, and thus is critical to these investigations. The main finding so far (Törnqvist et al., 2006) is that the Pleistocene basement underneath the Mississippi Delta is much more stable than what has been commonly postulated.

Our latest field campaign, completed in July 2006, aims at measuring the subsidence rate of the New Orleans metropolitan area. Results of this study are expected in 2007. Figure 1 summarizes the present state of understanding of long-term subsidence rates in various sections of the Mississippi Delta.

Figure 1. Map with areas experiencing coastal wetland loss in green. The study areas analyzed so far are indicated with approximate rates of subsidence of the Pleistocene basement, expressed in mm yr⁻¹, after Törnqvist et al. (2002, 2004, 2006). Although such data are not yet available from the New Orleans metropolitan area, it appears likely that subsidence rates there are roughly of the same order of magnitude.

References


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Publications:


Related Science

Formation of Pools in Marshes of the Plum Island Sound Estuary

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Pools are prevalent features on tidal marshes of New England and elsewhere. Their characteristics and distribution may hold clues to the development and maintenance of these marshes in the face of sea level rise. We examined pool and drainage network (i.e., natural channels and human-made ditches) patterns and elevation characteristics in selected interfluvial high marsh areas of the Plum Island Sound estuary in northeastern Massachusetts using geographic information systems and global positioning technologies.

From the early 1950s to 2001, the number and extent of pools increased greatly throughout the study area. Pool density, mean pool size, and pool-to-marsh surface area ratio are 5, 23, and 5 times greater, respectively, in the area with lower drainage density. Pools and pannes exist on relatively flat, topographically high, interior marsh platforms, which are approximately 10 to 20 m from an adjacent creek. In this paper, we describe a process under which pools and pannes can form on a mature marsh platform and we pose questions regarding the implications of pool formation and creation.