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Surface deformation in Houston, Texas using GPS

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ABSTRACT

Surface deformation in the Houston area has been quantified by using a variety of methods including LIDAR, InSAR, extensometers, drilling (to approximately 100 m), and Ground Penetrating Radar. In this paper we report on GPS data acquired during the period between 1995 and 2005 that found evidence of ongoing subsidence (up to −56 mm/year) in northwestern Houston and of possible horizontal surface movement towards the Gulf of Mexico (up to 6 mm/year). We describe the methods of data-processing used in the study and speculate on the possibility that the active elevation of salt domes, mainly at the south and east of the city, may indirectly influence other surface movements including fault movements and subsidence over areas >1 km^2. Making use of our observations and analysis could help in natural hazard mitigation in the Houston area and possibly also indicate approaches to surface subsidence study that might be used in other urban areas.

1. Introduction

The city of Houston lies within the wide coastal shelf margin of the Gulf of Mexico small ocean basin in a region in which extension over the future site of the Gulf began with Triassic rifting (approximately 230 Ma to 200 Ma, Salvador, 1991) and reached a peak in a brief episode of sea-floor spreading during the Middle to Late Jurassic (between approximately 160 Ma and 145 Ma, Bird et al., 2005). Subsequent sediment deposition on the northwestern Gulf Coast has resulted in the progradation of a continental margin sedimentary wedge into the Gulf of Mexico basin throughout the Latest Jurassic, Cretaceous, and Cenozoic (since approximately 150 Ma, Winker, 1982). Paleogene (approximately 65 Ma to 22 Ma) deposition on the margin was predominantly in South Texas, but Neogene deposition (since approximately 22 Ma) has been concentrated in East Texas and Southern Louisiana. Regions of most active growth faulting around the Gulf of Mexico typically occur near the currently prograding shelf margins. The area in which Houston is located lay near the then prograding shelf margin during the Oligocene (approximately 34 to 22 Ma) but active fault movement occurs in Houston today. In this paper we address this anomalous behavior and phenomena related to it. GPS observations in other areas have been used successfully to measure and monitor displacement/subsidence (e.g., Teatini et al., 2005, Tosi et al., 2009).

Repeat-pass Interferometric Synthetic Aperture Radar (InSAR) provides for detailed mapping of the vertical component of deformation, but does not address the horizontal (Williams, 2001). InSAR measurements yield phase differences, which, after unwrapping, provide a measure of vertical deformation. Using InSAR Buckley et al., 2003 have shown strong linear interference fringes along the Long Point Fault. These fringes result from interactions between the fault and the Jersey Village subsidence depression (Buckley et al., 2003). Buckley et al (2003) also observed a similar linear phase signature associated with faults of the Addicks Fault System. However, there do not appear to be clear interferogram signals associated with the other faults.

2. Active geological structures of the Houston area

2.1. Houston faults

Houston faults are part of a population of hundreds of faults that cut Pleistocene and Holocene sediments on the Texas coastal plain between Beaumont and Victoria (Verbeek, 1979) (Fig. 1 inset). Paine (1993) considered that regional subsidence has been active along the Texas coast at least since the Pleistocene and Verbeek (1979) estimated that more than 10% of the faults between Beaumont and Victoria were active during the 20th century. Active surface faults in the Houston area have been mapped by many workers (Clanton and Amsbury, 1975; Verbeek, 1979; O'Neill and Van Siclen, 1984; Shaw and Lanning-Rush, 2005; Engelkemeir and Khan, 2008). Fig. 1 shows active surface faults that have been mapped using LIDAR data (as red lines, Engelkemeir and Khan, 2008). Because there are no recorded earthquake epicenters in the Houston area, fault motion is considered to occur by aseismic creep. Faults in the metropolitan Houston area have exhibited both spatial and temporal variabilities in movement

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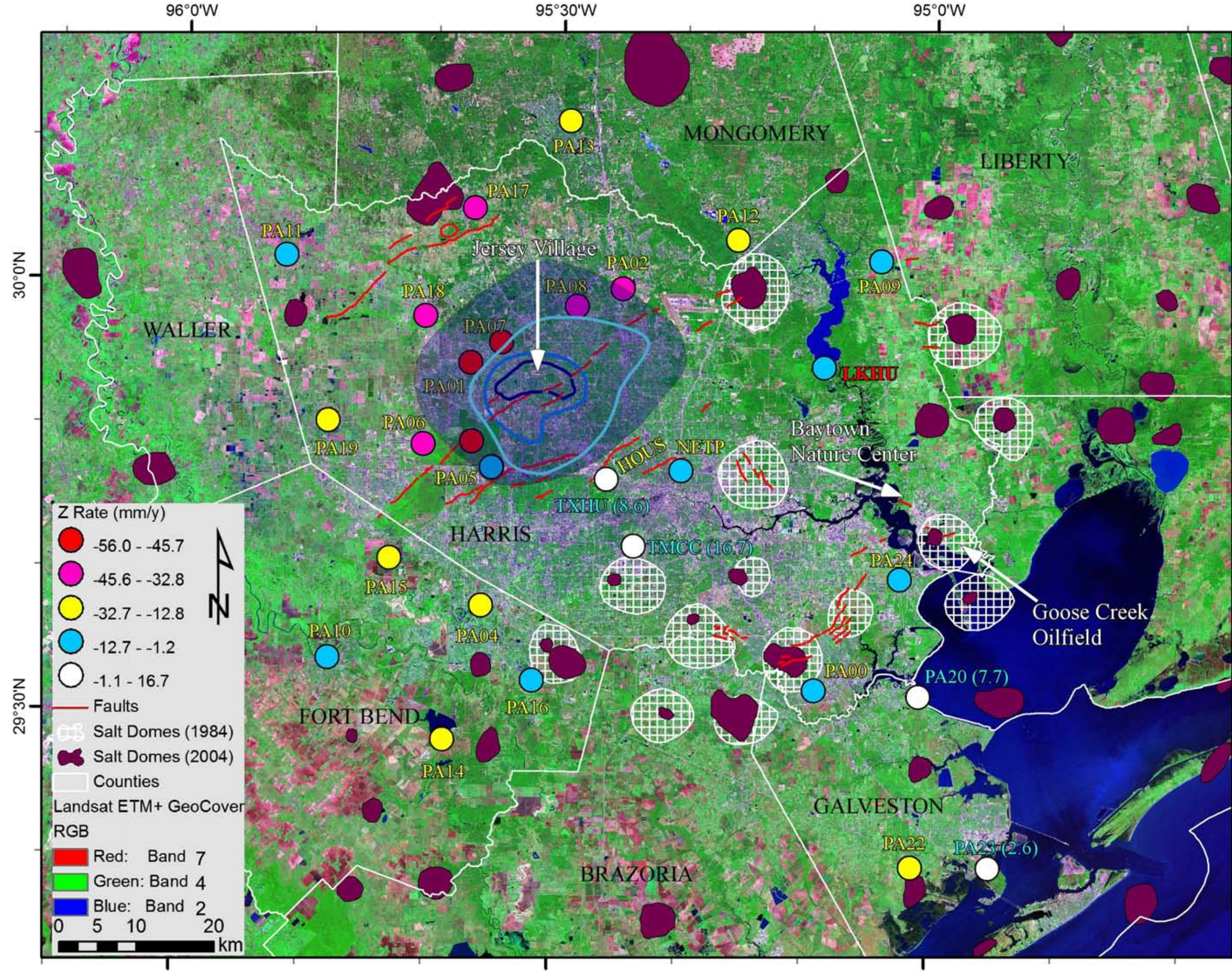

Fig. 1. Rates of vertical motion observed in this study. The Lake Houston site (LKHU), shown in bold red, is the base station for processing. Sites with high error rates (Table 1) are not shown here. Faults are from Engelkemeir and Khan (2008) and are for Harris County only. There are two versions of the salt domes, illustrating the ambiguity of their extent. The older salt dome data are from are from O'Neill and Van Siclen (1984), while the recent salt dome data are from Huffman et al. (2004) Contours for the Jersey Village subsidence depression for the period 1978 thru 1995 are also shown. PA07 is located in Jersey Village. The contour interval is 30 cm, with the outer contour corresponding to subsidence of 0 cm. This study covers 1995 to 2005 and indicates the (50 km × 20 km) depression 30 km northwest of downtown Houston is expanding to the northwest.

(Mastroianni, 1991). Movement on active faults has caused damage to structures including buildings, pipelines, and roads. Fault locations have, in some cases, remained unknown until accumulated slip has resulted in significant damage, but ongoing maintenance has in other cases minimized damage to structures from active faults. Rates of movement on individual faults have been reported to have been as high as 3 cm/year (Buckley et al., 2003; Norman, 2005).

Many of Houston's surface faults have been linked to the abundant subsurface faults well known in petroleum exploration (Van Siclen, 1967), which show evidence of increasing throw with depth. Faults that show evidence of increasing throw with depth are called “growth faults” because they are interpreted to have moved, continuously or episodically, while deposition was in progress. Movements during deposition result in a greater thickness of sediment on the down-thrown side of the fault (Hardin and Hardin, 1961). “Down to the basin” faults, generating extension toward the Gulf of Mexico basin, dominate in the Houston area (Sheets, 1971). Accommodation of extension in the hanging walls of those faults is expressed in either or both of antithetic faults and rollover anticlines (Ellis and McClay, 1988; Xiao and Suppe, 1992). Antithetic surface faults in Houston have been reported from opposite the most active sections of the primary faults (Norman, 2005), and at least 11 of those faults are currently active. Similar faults have been studied in Louisiana (Gagliano et al., 2003). Dokka (2006) mapped active boundaries of a rapidly moving block approximately ~60,000 km^2 in area in and offshore Louisiana. Active blocks of this extent have been inferred to have existed in the Houston area when it was closer to the continental margin (see for example Fig. 1 in Rosenfled and Pindell, 2003) but such large scale active blocks are not considered now to exist in the Houston area today, which is presently much further from its active continental margin.

2.2. Subsidence

Surface subsidence in Houston may be related to a variety of causes including fluid withdrawal, sediment compaction, and surface faulting. Houston area surface fault activity has been attributed to subsidence resulting from fluid (usually water, but in some cases oil and gas) withdrawal. One of the recognized associations of faulting with fluid withdrawal was in the vicinity of the Goose Creek Oil Field (Pratt and Johnson, 1926). The interaction between Houston surface faults and subsidence is complex and not well understood, although