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Potential use of Subsidence Rates Determined From GPS-Based Height Modernization Measurements of NGS Benchmarks in Southeast Texas for Flood Risk Planning

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Abstract

This study determines the rates of subsidence or uplift in coastal areas of SE Texas by comparing recent GNSS measurements to the original orthometric heights of 340 previously installed National Geodetic Survey (NGS) benchmarks. Understanding subsidence rates in coastal areas of SE Texas is critical when determining its vulnerability to local sea level rise and flooding, as well as for accurate elevation control for flood risk maps. The study area includes major metropolitan and industrial areas as well as more rural areas at risk for flooding and hurricane storm surge. The resurveying methods used in this RTK GNSS study allow a large area to be covered relatively quickly with enough detail to determine subsidence rates that are averaged over several decades, and identify at-risk regions that can be monitored more closely with permanent or campaign-style measurements. Overall, vertical rates vary from -6 to -15 mm/yr subsidence in Port Arthur, Nederland, and other areas of Jefferson County, as well as in areas northwest of Beaumont, Texas. Other areas with subsidence rates between -10 and -4 mm/yr include parts of the Bolivar Peninsula in Galveston County, northeastern Chambers County, and the Mont Belvieu area just east of Houston. Current benchmark elevations were as much as -0.86 m lower than the original, illustrating the need for height modernization surveys in the area. Surprisingly, areas of uplift, with rates as great as +5 mm/yr, were found in some parts of the study area. Several of the counties in the study area are experiencing inundation and erosion from global sea level rise, with local subsidence exacerbating the problem. Many of the counties in the study area were also affected by the storm surge from Hurricane Ike and flooding from Hurricane Harvey. Understanding the current elevation in these areas, as well as the rates of change in elevation, is critical for creating updated flood plain maps and surge inundation models, as well as planning how these maps and models will likely change in the future. Understanding how rapidly the elevations are changing is also critical for planning and maintaining flood and surge protection infrastructure projects such as levees, dune restoration, marsh restoration, and raising of structures to prevent flooding well into the future.

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ABSTRACT   Paper Number NH31E-0896

This study determines the rates of subsidence or uplift in coastal areas of SE Texas by comparing recent GNSS measurements to the original orthometric heights of 340 previously installed National Geodetic Survey (NGS) benchmarks. Understanding subsidence rates in coastal areas of SE Texas is critical when determining its vulnerability to local sea level rise and flooding, as well as for accurate elevation control for flood risk maps. The study area includes major metropolitan and industrial areas as well as more rural areas at risk for flooding and hurricane storm surge. The resurveying methods used in this RTK GNSS study allow a large area to be covered relatively quickly with enough detail to determine subsidence rates that are averaged over several decades, and identify at-risk regions that can be monitored more closely with permanent or campaign-style measurements.

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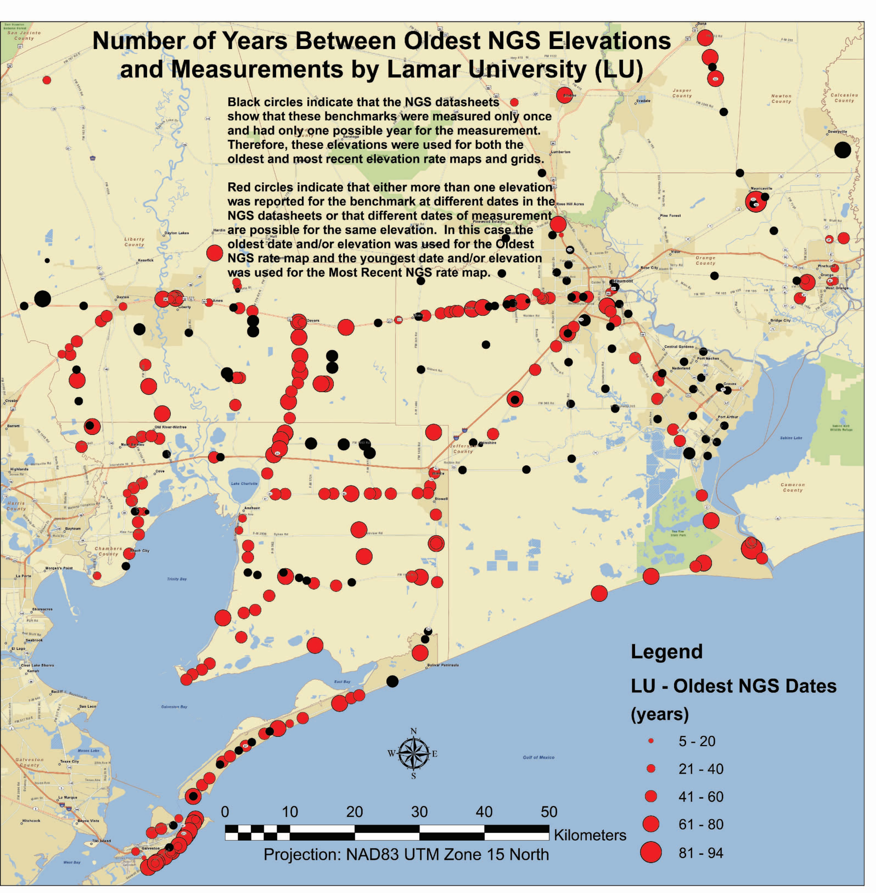
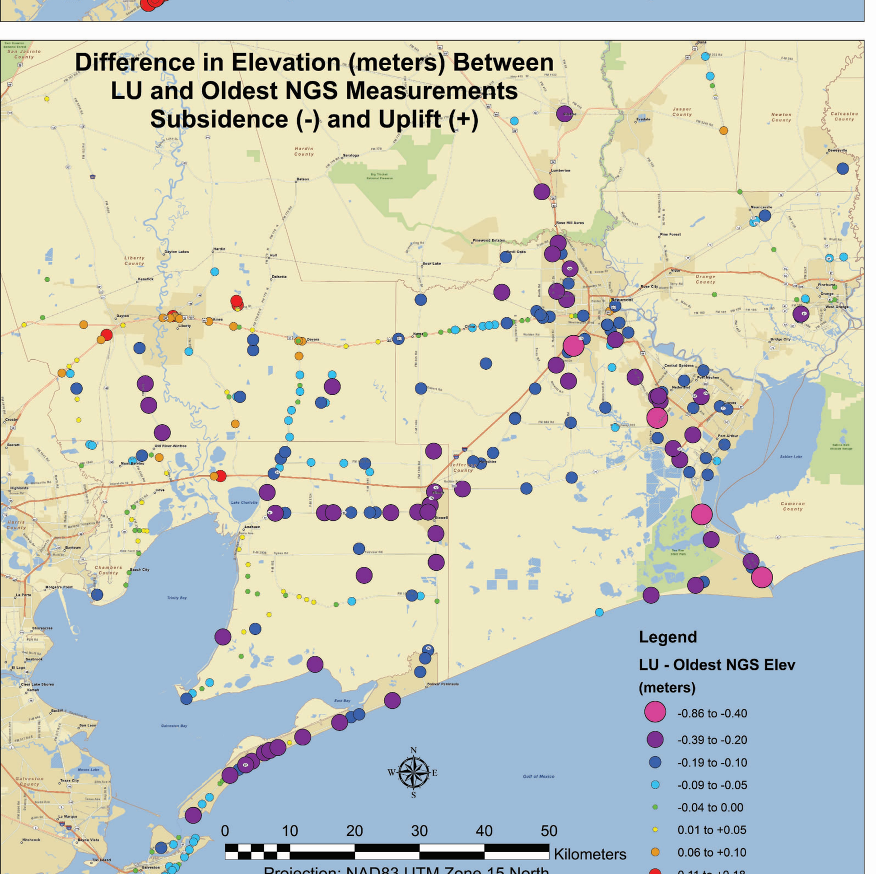
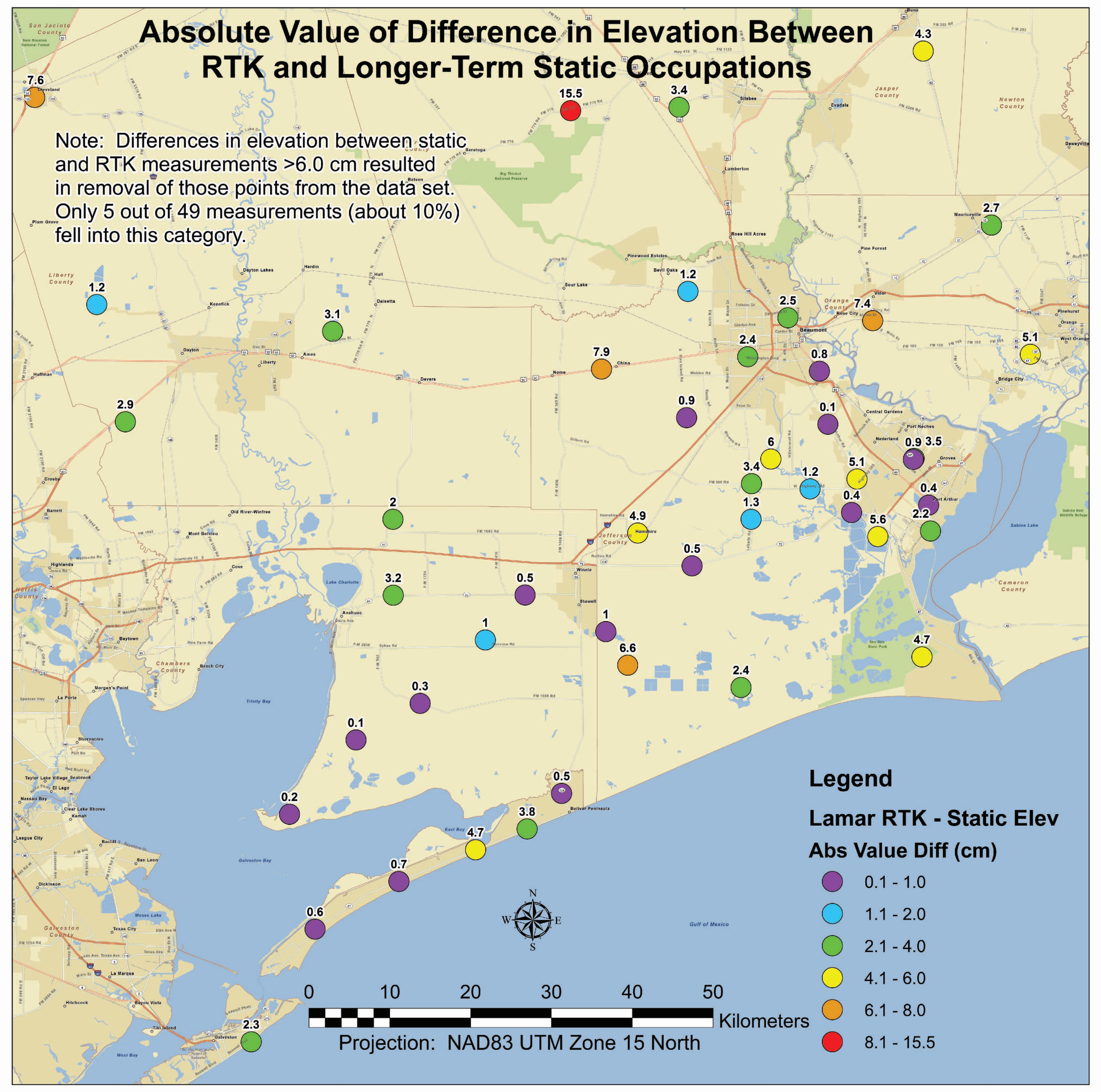
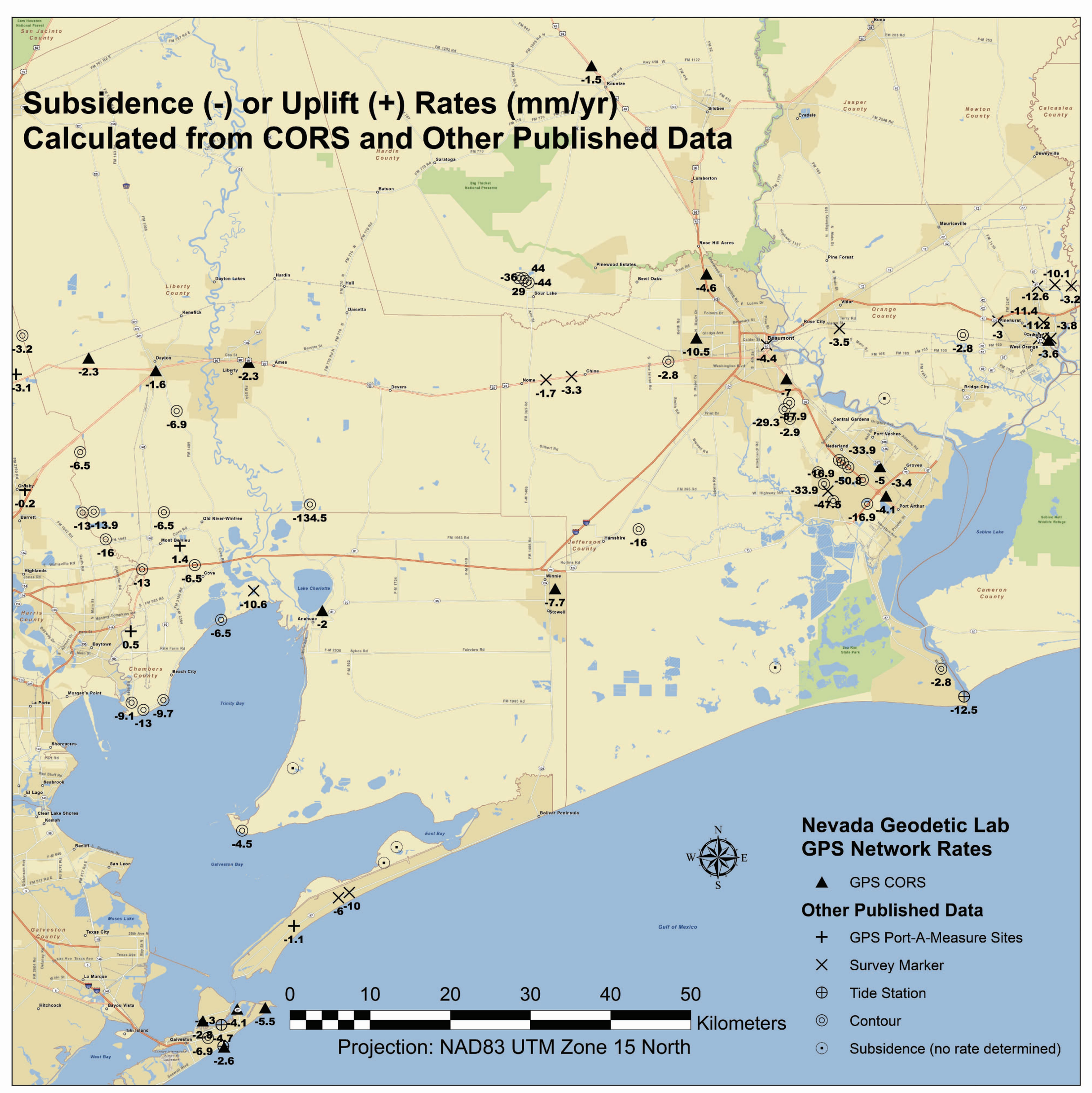
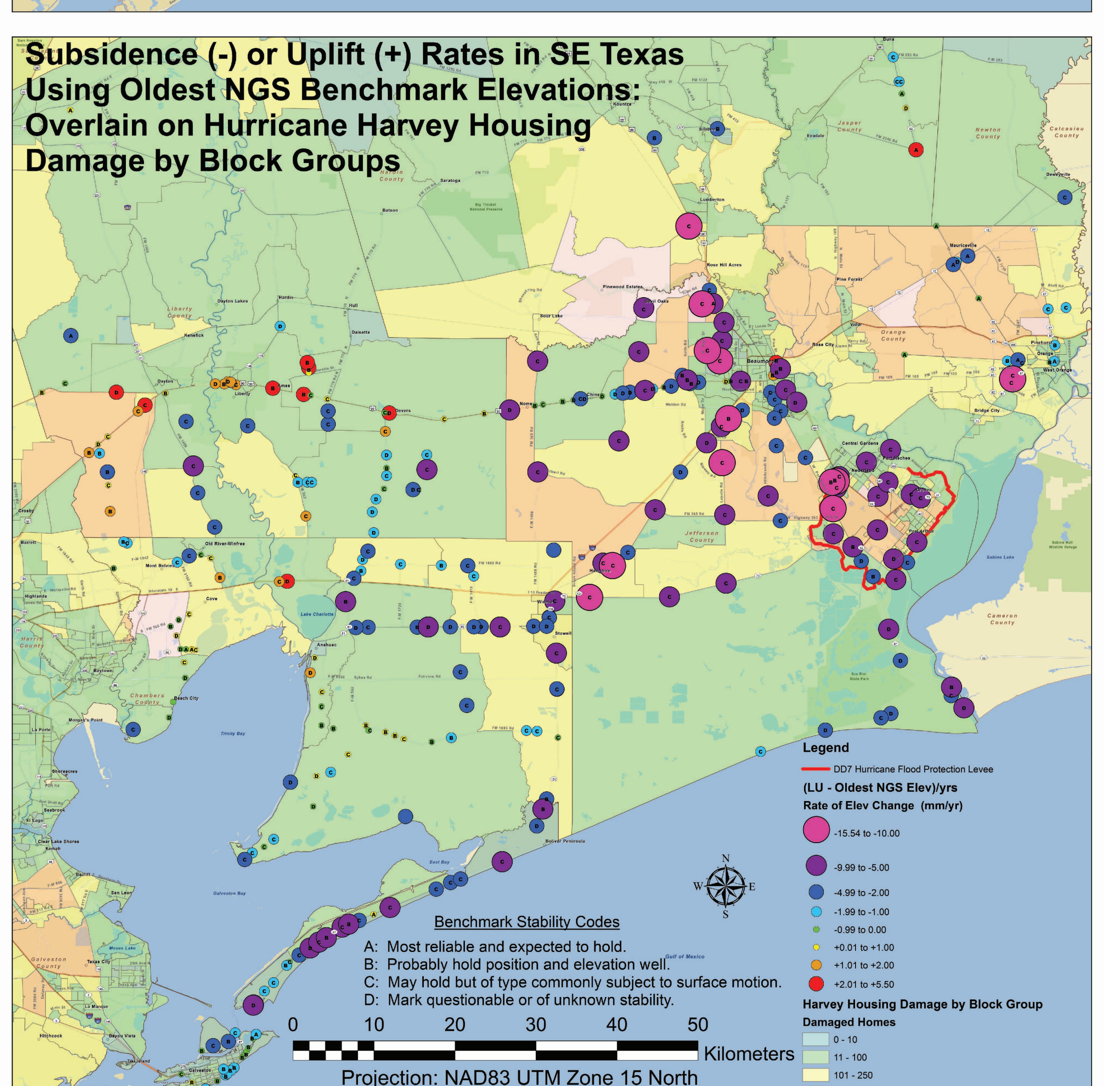
Left: Student measuring a benchmark using the Trimble R8 GNSS GPS.
Right: Examples of benchmarks used in survey.

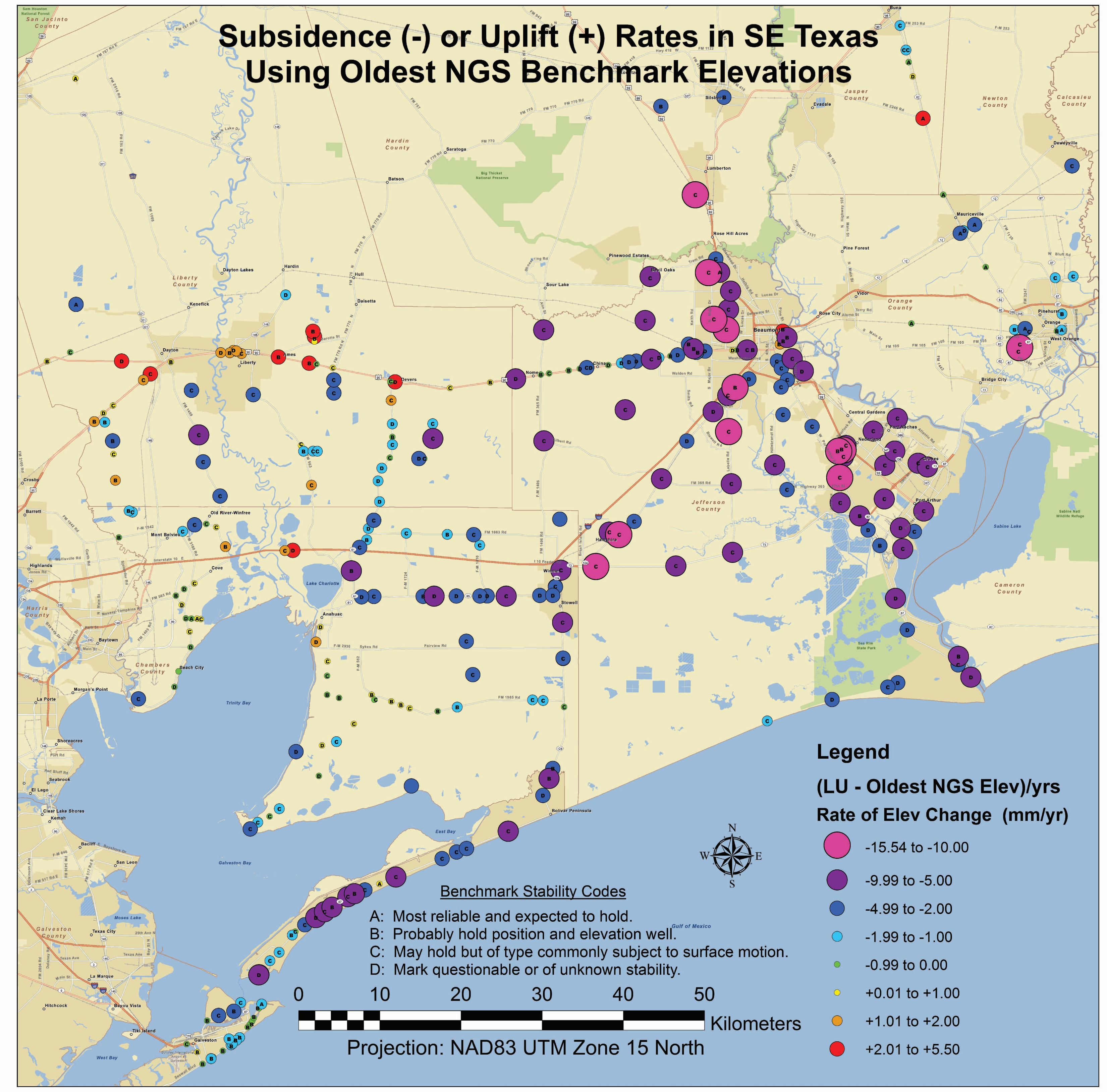


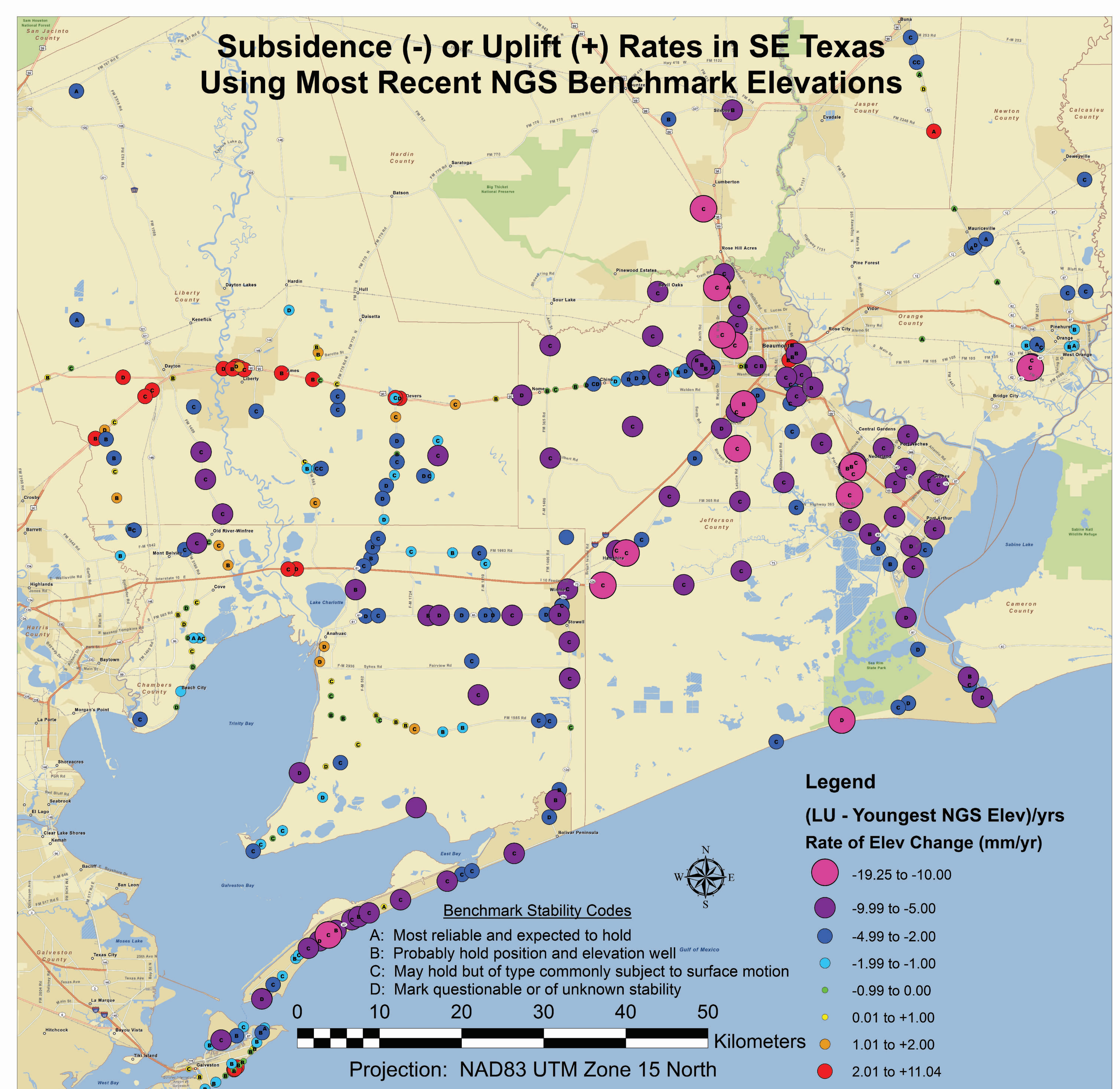


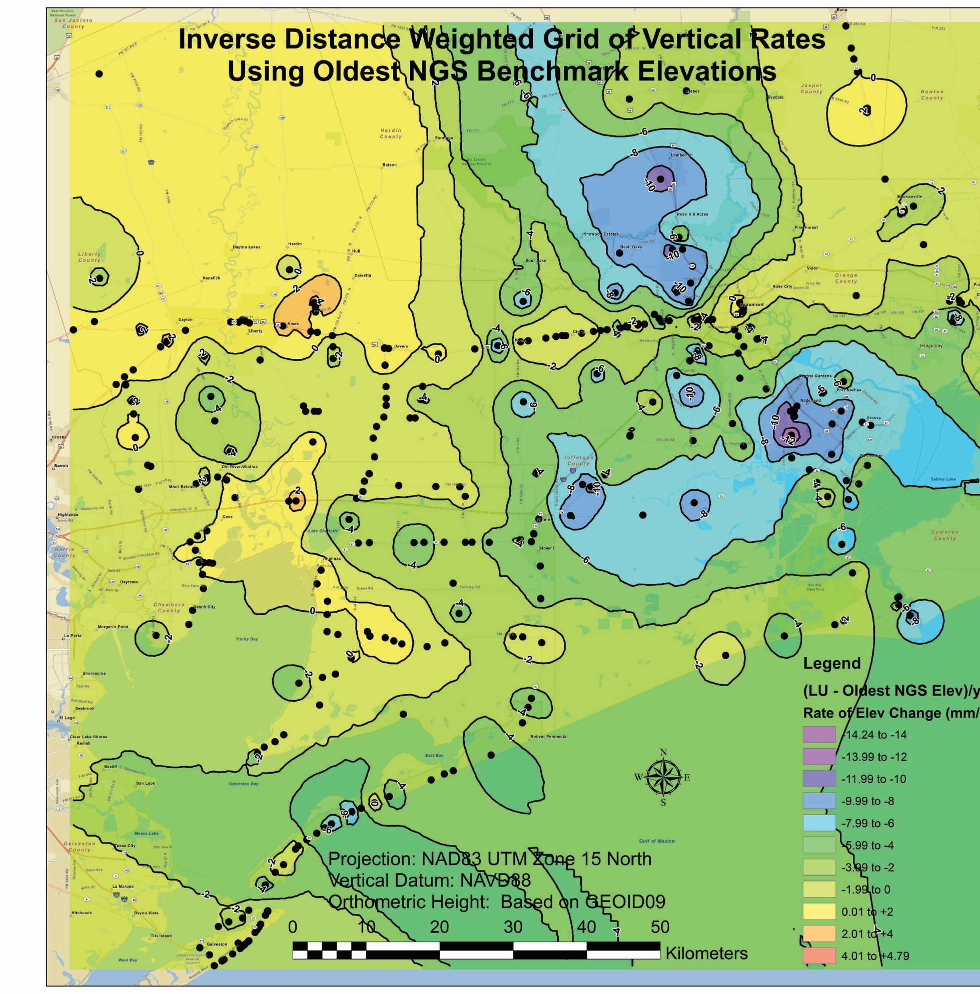


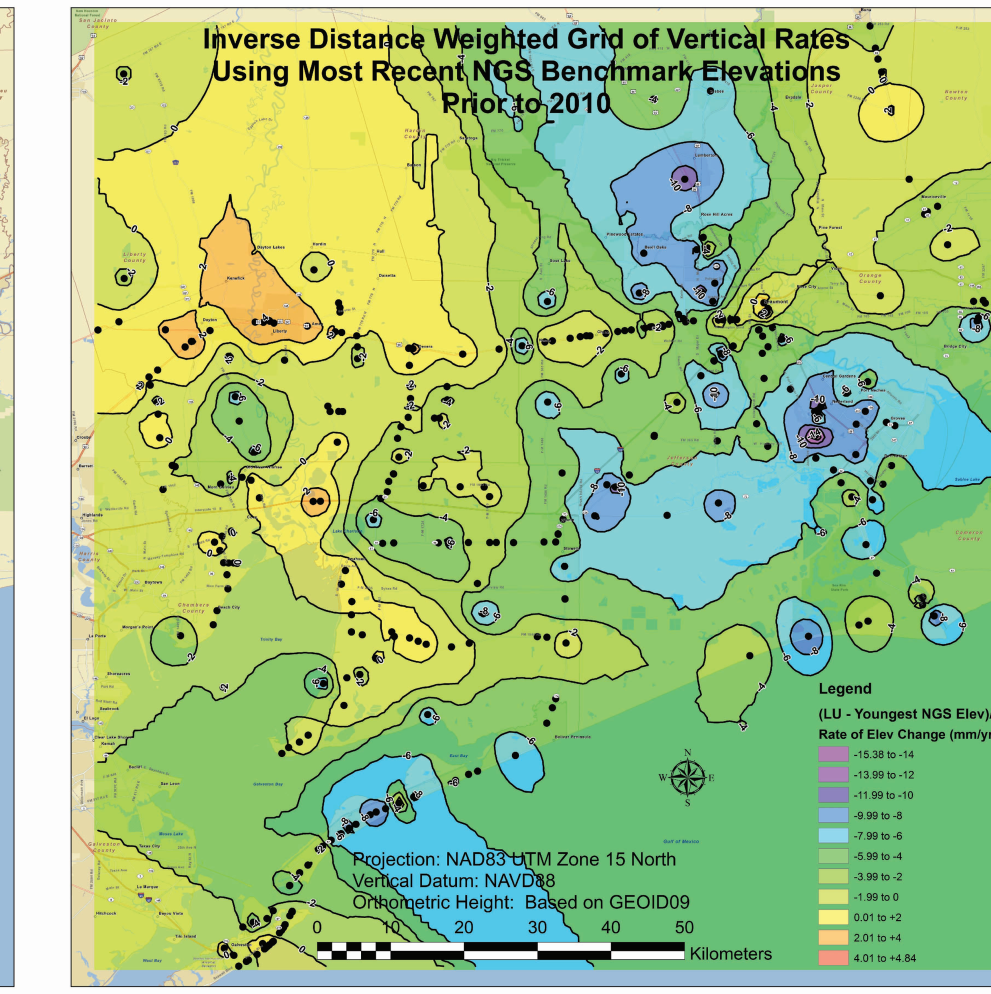


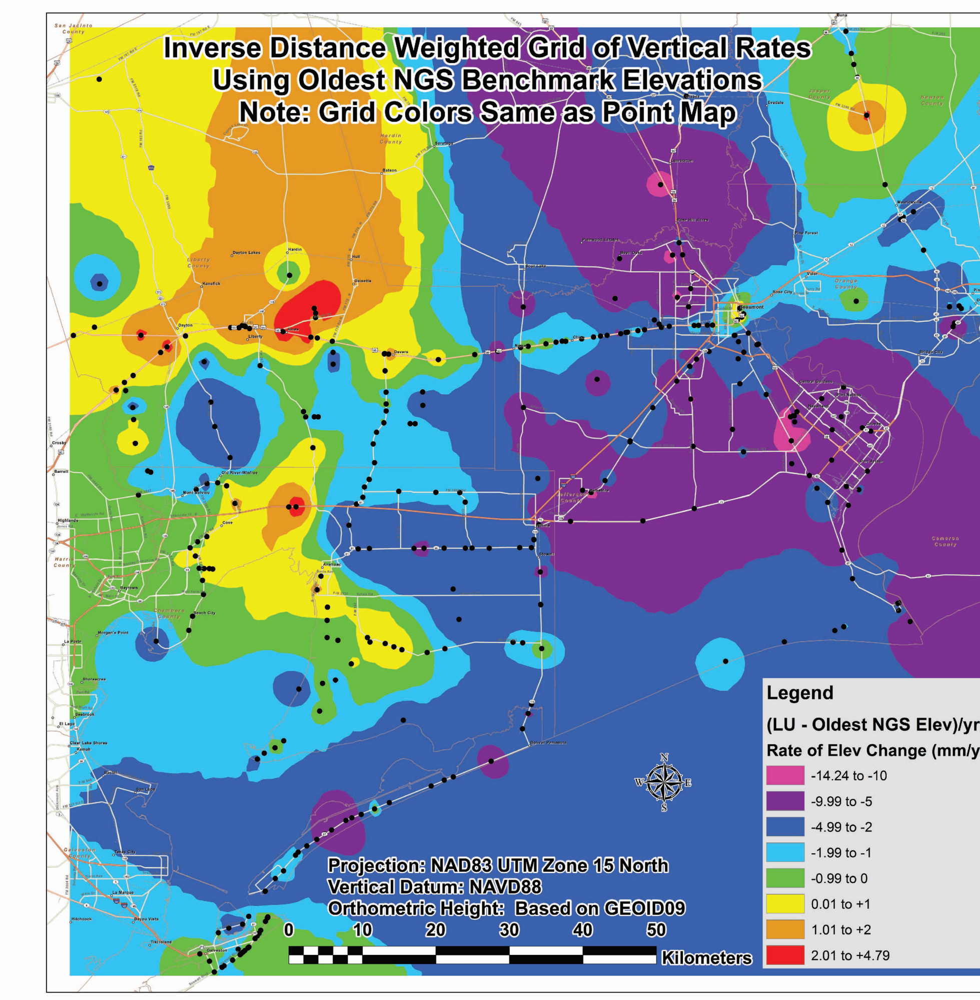


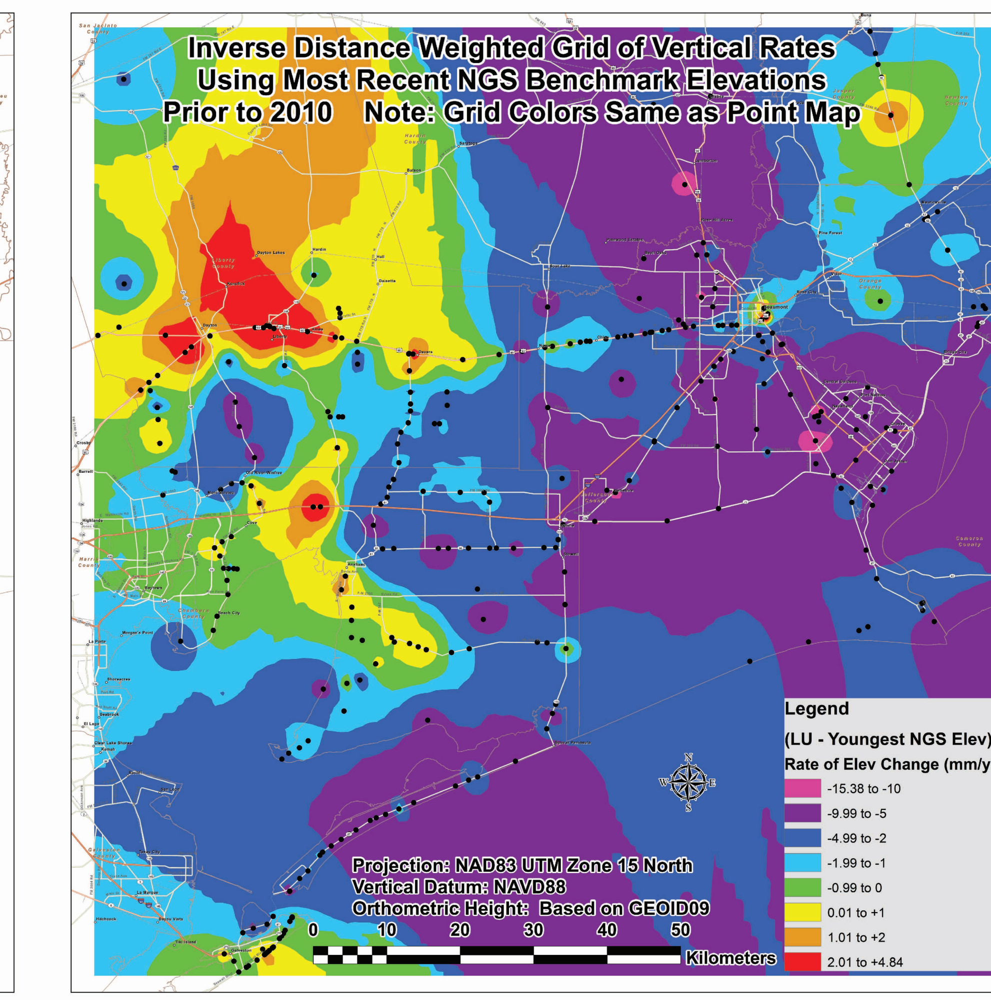












RESULTS:

1) A total of 336 benchmarks were remeasured and used in this study to determine current elevation and horizontal positions, and to calculate the rates of vertical change. These measurements were made with a survey-grade Trimble R8 GNSS antenna and receiver operating in RTK mode with Western Data Systems network of base stations used for differential corrections. Static measurements made over several days on 49 RTK benchmarks compared mostly well with the RTK data.

2) NGS datasheets were used to determine the original elevations. The problem with these datasheets is that the dates at which the elevation measurements were made is never clearly given. Dates of monumentation and subsequent occupations are given, along with who occupied the benchmark, but these dates are not indicated next to the Current or Superseded Survey Control. Because of this, two subsidence/uplift maps were generated, one using the oldest date and measurement and the other using the youngest date and measurement if a separate measurement existed, otherwise the youngest date was used for the only measurement. Another potential source of error is bad previous measurements, or poor ties along some survey transects. This may have caused the relatively linear low subsidence rates along Highway 90 from Beaumont west to Dayton. One positive result of both maps is that the subsidence and uplift rates look very similar in a broad scale.

3) CORS GPS height data downloaded for 19 stations were used to determine vertical rates that were compared to those determined from nearby benchmarks in this study. The average difference in rates is only 0.63 mm/yr with a standard deviation of 2.72 mm/yr. Maximum difference were between 6.63 and -7.34 mm/yr. This supports the conclusion that the RTK data is yeilding relatively accurate rates. Rates from the other 65 posted locations, determined from published subsidence data, do not agree with the RTK data as well. On average, the RTK data show 11.70 mm/yr less subsidence than the nearby published rates, possibly due to the concentration of published data in localized areas of relatively rapid subsidence (oil, gas, water, sulphur withdrawal), or differences in measurement techniques/datums.

4) In general, there are areas in southeast Texas that are subsiding at much faster rates than others. The counties of Chambers, Galveston, Liberty, and Jefferson have areas where subsidence rates are significant, ranging up to -15.54 mm/yr, but mostly averaging between -2 and -10 mm/yr. Surprisingly however, some areas of Liberty, Chambers, and Jasper Counties, as well as the downtown Beaumont area are experiencing uplift up to +5.50 mm/yr. The higher subsidence rates are particularly highest in the metropolitan areas of Port Arthur and surrounding communities, Bridge City, Lumberton, north and south Beaumont, areas northeast of Winnie, northeast of Mount Belvieu, and parts of the Bolivar Peninsula. Several problems could result from this higher rate of subsidence, including cracked foundations and roads, increased flooding risk, and particularly increased storm surge risk to the Bolivar Peninsula, Port Arthur-Beaumont area and surrounding communities.

5) Although flooding from rain events and storm surge (e.g. Imelda, Harvey, Ike) is not restricted to areas of increased subsidence, not resurveying benchmarks in these areas often enough, or incorporating the rates into building or maintenance of structures such as levees, can underestimate the flood hazards in these areas.

6) This study suggests that using a combination of most recent RTK elevation measurements and previous measurements reported on NGS datasheets can be used to initially determine subsidence/uplift rates in areas where no previous studies exist, but subsequent reoccupations should be performed for more accuracy.

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SOURCES OF PREVIOUS SUBSIDENCE DATA

Published Data: Bawden et al., 2012; Gabrysch and Neighbors, 2005; Kasmarek, 2013; Kolker et al., 2011; Looff, 2001; Morton et al., 2001; Mullican, 1988; Ratzlaff, 1982; Shinkle and Dokka, 2004; Swanson and Thurlow, 1973; White and Morton, 1977; White and Tremblay, 1995; Winslow and Wood, 1959.
Downloaded CORS GPS Data: Nevada Geodetic Laboratory GPS Network Map, http://geodesy.unr.edu/NGLStationPages/gpsnetmap/GPSNetMap.html, 2018-2019.