Detecting and Measuring Land Subsidence in Houston-Galveston, Texas using Interferometric Synthetic Aperture Radar (InSAR) and Global Positioning System Data, 2012-2014

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Introduction

Several cities in the Houston-Galveston (HG) region in Texas have subsided up to 13 feet over several decades due to natural and anthropogenic processes [Yu et al. 2014]. Consisting of 13 cities, including Houston, its largest city with 2.1 million people, HG has a population of 5.7 million people. Given the growing population and rise in urbanization, HG relies heavily on its groundwater resources to satisfy the high water demand for agricultural, domestic and industrial use. Land subsidence, a gradual sinking of the Earth's surface, is an often human-induced hazard and a major environmental problem expedited by activities such as mining, oil and gas extraction, urbanization and excessive groundwater pumping.

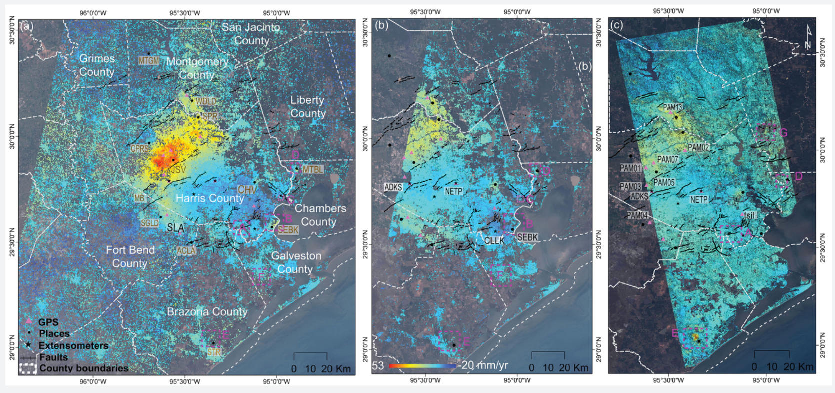


Figure a: Line of Sight Deformation maps created from the following satellite data: ERS (data period: 1995-1998) (left image), Envisat (2005-2010) (middle image) and ALOS PALSAR (2007-2011) (right image) [Qu et al. 2015]

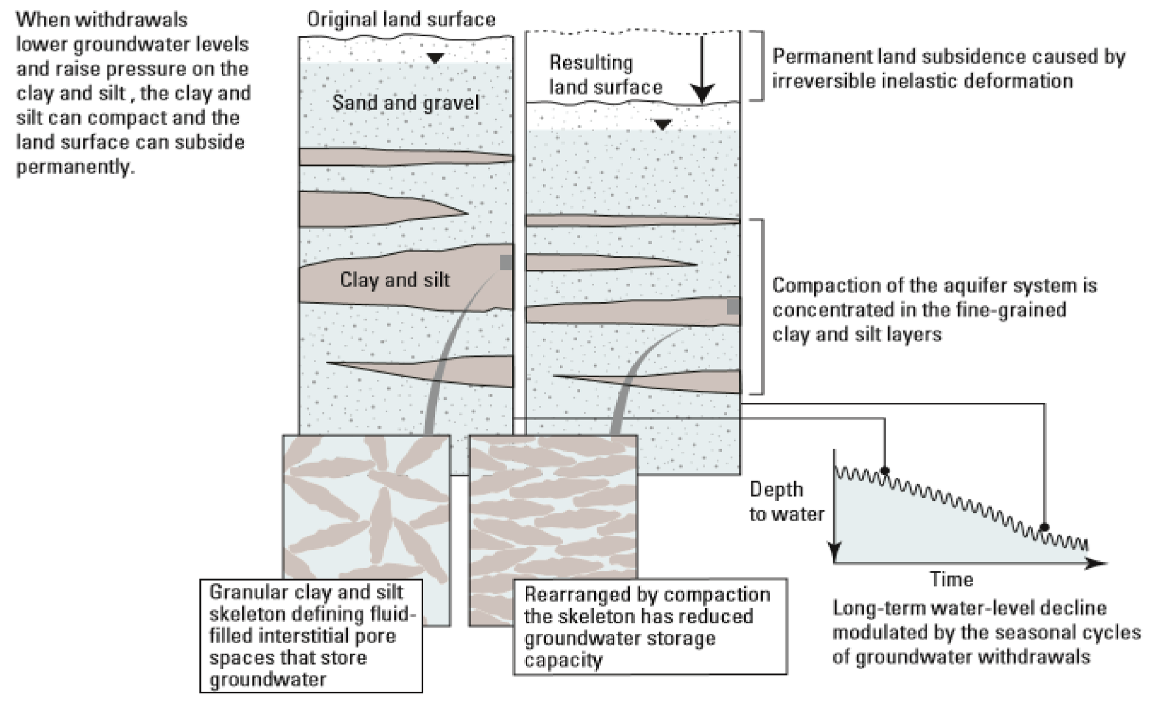


Figure b: In an aquifer, clay and silt sediments expand and compress due to naturally occuring seasonal changes in the water table. However, the inflow-outflow balance of water in an aquifer is disrupted when the rate of outflow exceeds the rate of inflow. As a result, sediments shrink and pore pressure decreases, causing the land to sink permanently [Alley et al. 1999]. [Image Source: Galloway et al. 1999, pg 9]

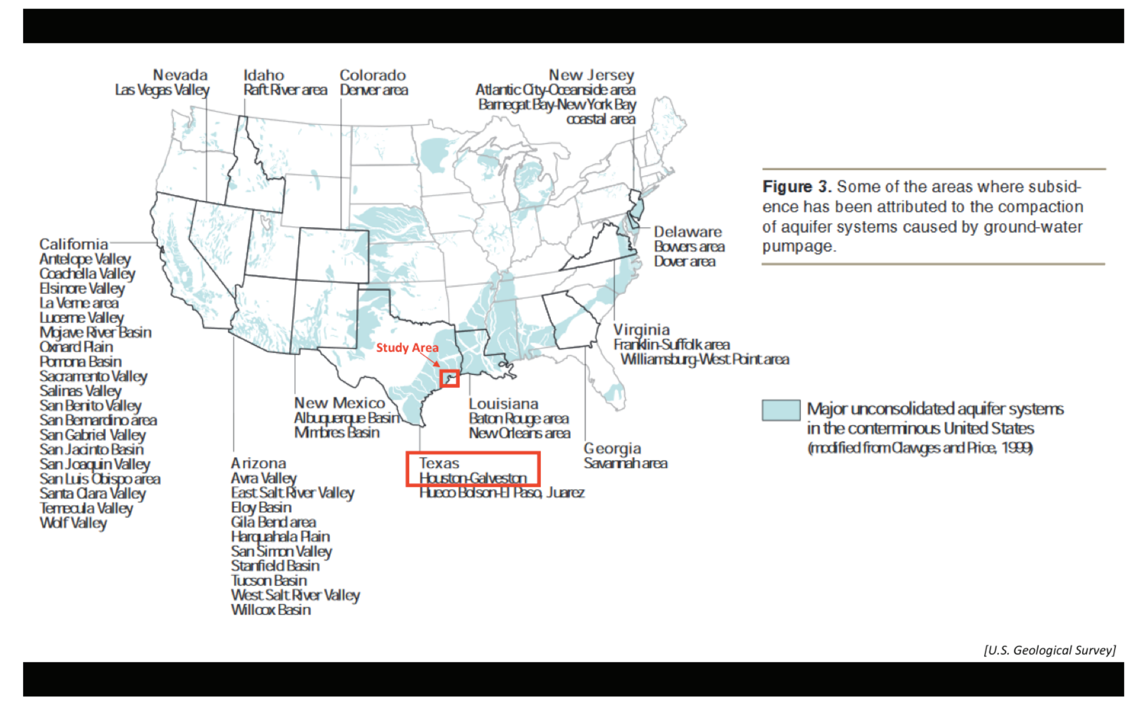


Figure c: Spatial extent of land subsidence in the United States [U.S. Geological Survey]

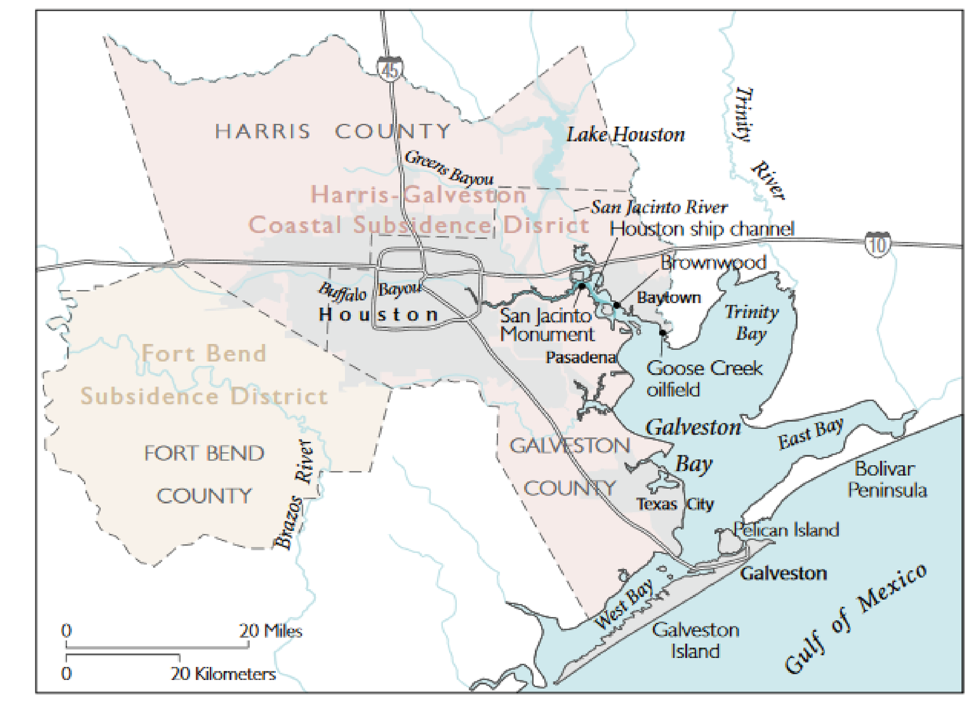


Figure d: Houston-Galveston Region [Coplin and Galloway 1999]

Fortunately, complementary geodetic methods that measure small scall movement on the Earth's surface such as Interferometric Synthetic Aperture Radar (InSAR) and Global Positioning Systems (GPS) are essential tools for monitoring and mesuring HG's subsidence [Yu et al. 2014]. In our approach, we produce and analyze time-series data from satellite and ground-based observations to determine the stability of HG's subsidence since 2012. Due to a five-year gap in new InSAR data that exits since the last study on HG by [Qu et al. 2015], we built upon [Qu et al. 2015]'s characterization of subsidence in HG by comparing subsidence patterns detected by Sentinel-1A satellite scenes in our study versus subsidene patterns detected by ERS, ALOS and Envisat satellite scenes in Qu's study. Our findings will be an important contribution to an ongoing problem in HG.

Data and Methods

A total 25 Sentinel-1A descending single look complex scenes (track 143, frames 493, 494) from July 2015 to May 2016 were acquired. The Sentinel-1A has a 12 day repeat period and acquires data on C band (4-8 GHz and wavelength of 5.6 cm). We used a 30 m Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) to extract deformation signal by substracting the topography from the images.

Furthermore, we used Generic Mapping Tools 5 SAR (GMT5SAR) [Sandwell et al. 2011] software and supplementary python scripts by [Baker 2016] to pre-process the scenes and generate a stack of 138 interferograms (Figure f) in preparation for using GIAnT (Generic InSAR Analysis Toolbox) [Agram et al. 2013; Agram et al. 2012] software to apply the short baseline subset (SBAS) approach and create a time series. Our analysis included interfograms with perpedicular baselines of <100 meters and a temporal baseline of <100 days to reduce spatial and temporal decorrelation (Figure f).

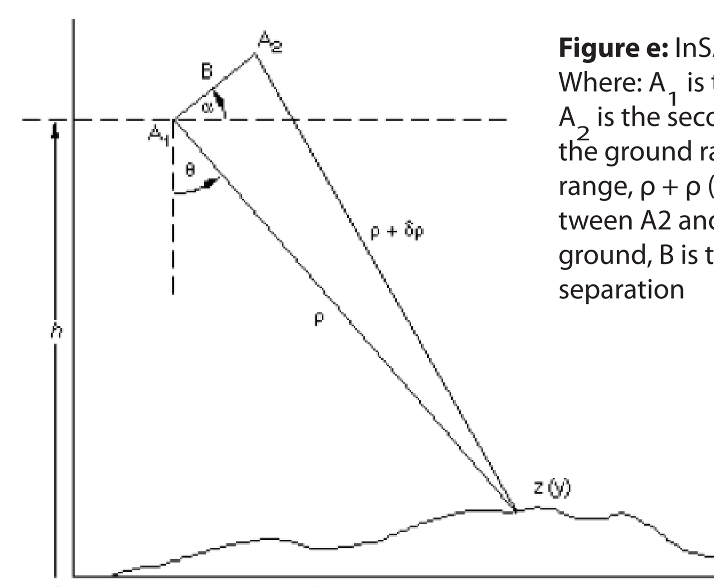


Figure e: InSAR Geometry [ESA]. Where: A_1 is the first satellite pass, A_2 is the second satellite pass, y is the ground range, ρ is the slant range, ρ + ρ (xi) is the distance between A2 and the point on the ground, B is the baseline or orbital separation

Phase is defined by:

$$\Delta\phi(x,r) \approx \frac{4\pi}{\lambda}\Delta d(x,r) + \frac{4\pi}{\lambda}\frac{B_\perp}{r\sin\theta}\Delta z(x,r) + \Delta\phi_{atmo}(x,r) + \Delta\phi_n(x,r),$$

Equation a: Phase equation [Berardino et al. 2002]

InSAR is a cutting edge technique used to measure distance and small scale movements on Earth's surface at centimeter to millimeter level accuracy. The Short Baseline Subset (SBAS) Approach is set with small temporal and spatial baseline to account for decorrelation [Berardino et al. 2002]

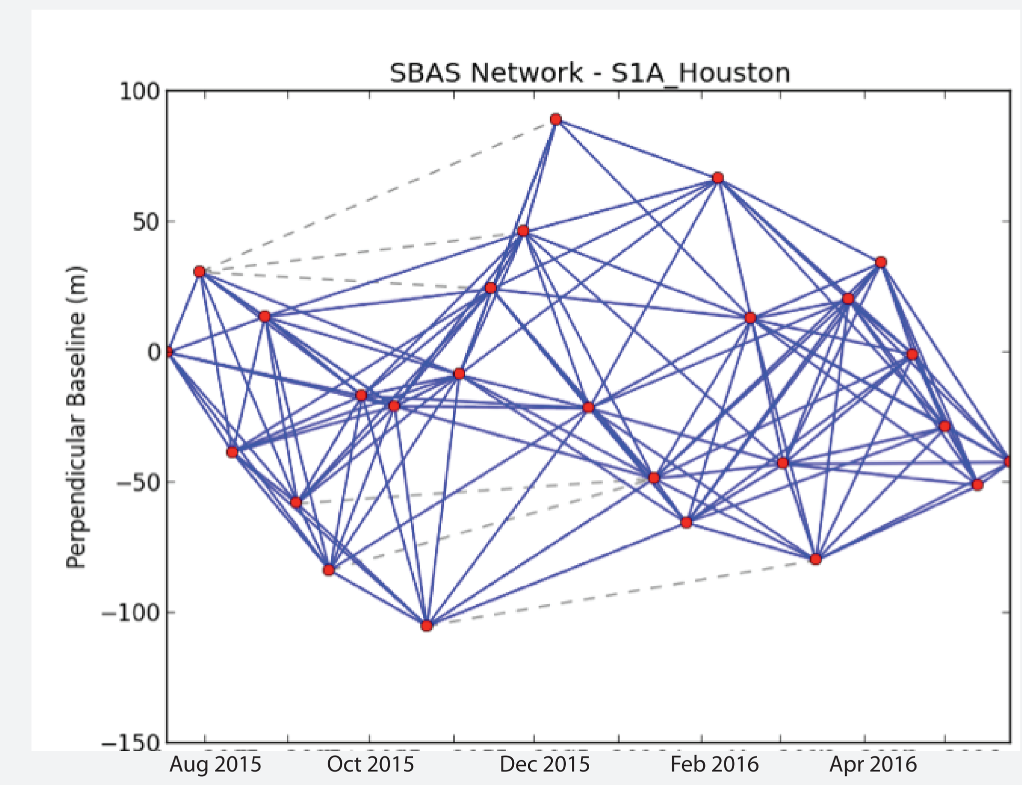


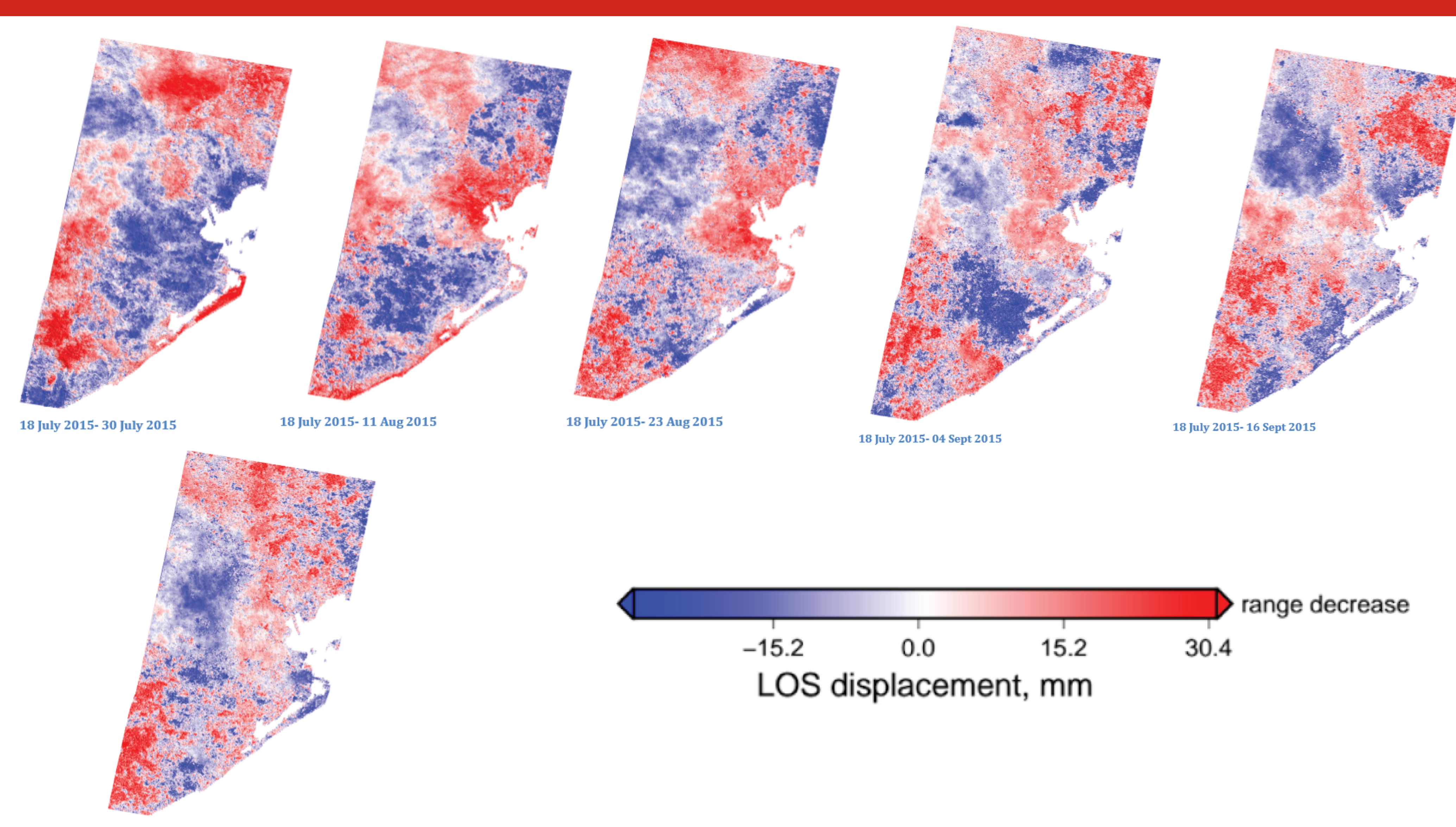
Figure f: Short Baseline Subset (SBAS) network of 138 subset SAR pairs. The blue lines represent pairs that satisfy the critial spatial and temporal baseline thresholds (<100 m and <100 days) for SBAS analysis. The dotted lines are pairs that fall outside of our baseline thresholds and are therefore left out of the analysis.

Preliminary Results

Atmospheric corrections and corrections for the digital elevation model have yet to be applied to the preliminary results.

Once these corrections have been applied, the signal-to -noise ratio will be reduced to the point of being canceled out. Therefore, the deformation signal will be more clear.

Final results of the time series data will be fully processed and presented by the American Geophysical Union Conference in December 2016.



Conclusion & Next Steps

- To update InSAR data to determine if subsidence has remained stable since 2012 (fill in the 5 year gap in data)

- Apply SBAS time-series processing to the stack and correct for atmospheric and DEM error (reduces signal-to-noise ratio across the stack; cancels out)

- Complement and validate the InSAR data with time-series data from GPS measurements

- Better management of water resources

- Creating stronger monitoring systems for land subsidence using geodetic methods

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