# RELATIONSHIPS BETWEEN SINKHOLE-RELATED FEATURES AND INSAR-DETECTED SUBSIDENCE POINTS IN WEST CENTRAL FLORIDA


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## Abstract


West-Central Florida, the "sinkhole alley," is known for its high rate of sinkhole activity. Sinkholes in this area are usually formed from the erosion of overlying soil and sediment into open fissures of dissolved limestone bedrock. They are one of the leading natural disasters in the area and therefore precursory detection is crucial to alleviate risks of property damage. Using the Interferometric Synthetic Aperture Radar (InSAR) method we can detect surface subsidence. InSAR is an airborne remote sensing technique that uses multiple Synthetic Aperture Radar (SAR) images to create elevation changes over time. Using the Persistent Scatterer Interferometry (PSI) method, processed InSAR datasets can be used to create time series datasets of localized subsidence. We complete a statistical analysis to determine if individual INSAR time series points show evidence of rapid raveling events which could be indicated by a slope break within the time series. We examine whether slope breaks are correlated with the timing of both groundwater withdrawal and intense rainfall events. A weighted spatial density analysis will be completed to examine the relationships between the timing of slope breaks from the statistical analysis, and nearby geomorphological features of sinkhole related activity or vulnerability. Clusters of INSAR points are expected to be in close proximity to sinkhole features.


## Introduction

West-central Florida is considered the "sinkhole alley" due to its high rate of sinkhole activity. Sinkholes in this region are usually formed from the erosion of overlying soil and sediment into open fissures of dissolved limestone bedrock (Tihansky, 1999). Since sinkholes are one of the leading natural disasters in this area precursory detection is crucial to alleviate risks of property damage. Detection of surface subsidence is possible using the Interferometric Synthetic Aperture Radar (InSAR) method. Synthetic Aperture Radar (SAR) is a radar technique used to create high resolution images of the Earth's surface, InSAR uses the difference in phase of multiple SAR images to create elevation models (Burgmann et. al, 2000). InSAR allows for a spatial analysis of sinkhole related features on a regional scale, it has been widely used to assess sinkhole deformations in the dead sea (Nof et al., 2019; Atzori et al, 2015; Yechieli et al., 2016). Imaging in sinkholes in Florida is difficult because of sparse vegetation that lower the coherence of SAR images and smaller diameter of sinkholes compared to the Dead Sea (Oliver-Cabrera et. al., 2019). Therefore, to properly implement the use of time series datasets as sinkhole related subsidence points collected in west Florida, we need to connect points to surface features related to surface and hydrological features related to karst terranes.

Previous research approaches were focused on creating hazard and risk maps and models for sinkholes using already collapsed sinkhole locations (Frumkin et al., 2011; Tharp, 1999). Some studies delineated sinkhole occurrences as they related spatially to drywell complaints, differences in groundwater head and other surface hydrological features (Aurit et al., 2013; Whitman, 1999). In this research we analyze the spatial distribution of possible sinkhole locations from InSAR derived time-series datasets showing subsidence in West-Florida. To complete this analysis we first use aerial photos to see how past surface water features in the 1940's relate to current InSAR detected subsiding areas. Digital Elevation Map (DEM) of the study area is used is used to compare overall subsidence to elevation differences.

### InSAR data Acquisition and Analysis

InSAR data acquisition was completed by the TerraSAR-X satellite with X-band sensor. The repeat pass interferometry and spotlight acquisition mode were used to collect high resolution data between the years 2015-2018 for three site locations in West Florida Figure (1). For this study we focus on one of the three sites. The Stanford Method (StaMPS) software was used to implement the Persistent Scatter Interferometry (PSI) method to produce displacement information for three site locations in west-central Florida (Oliver Cabrera et. al., 2019). PSInSAR datasets were analyzed by colleagues at the Florida International University.

Cluster analysis?

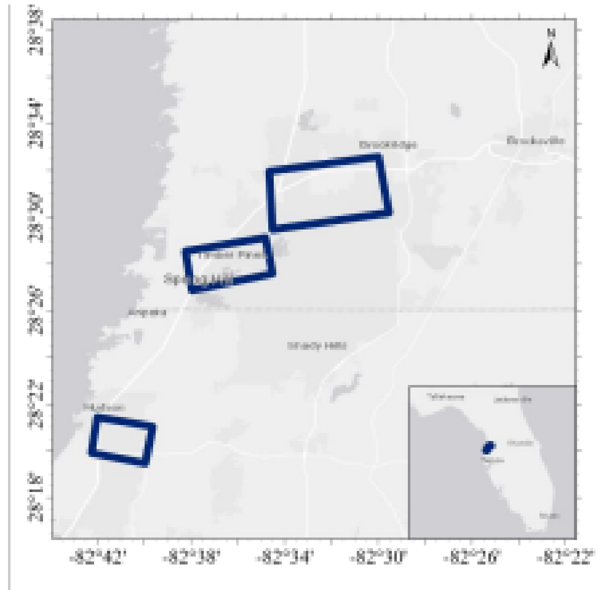



***Figure 1: InSAR study area in West-Central Florida. This study focuses on the site 2 (middle).***

## Methodology

To analyze the relationship of InSAR derived subsidence points and surrounding surface water and topography, we first complete a statistical analysis to identify points within each time series that indicate sudden movement. These sudden movements (slope breaks) are assumed related to sinkhole formations. We then complete specific spatial techniques in GIS: kriging and NEAR analysis to understand how time series datasets with defined slope breaks related spatially to other surface features.

### Slope Break Analysis

Slope break analysis was carried out using Matlab where a single model with the slope and intercept of two lines was fitted to each time series. This two-line model was allowed to sample throughout the selected time series to calculate line statistics for potential slope break times between set thresholds Figure (2). The slope uncertainty values of both lines added throughout the time series were saved. The timing of a possible kink was determined by finding the model fit where both lines before and after the designated kink had the lowest combination of slope uncertainty values. A p test was then computed to determine if the points were statistically better represented by a two-line fit than a single line regression. Sites were then divided into two categories a two-line fit (with a slope break) or a one line fit (single slope). For this study we will be using the two-line fitted time series points as possible forming sinkholes.

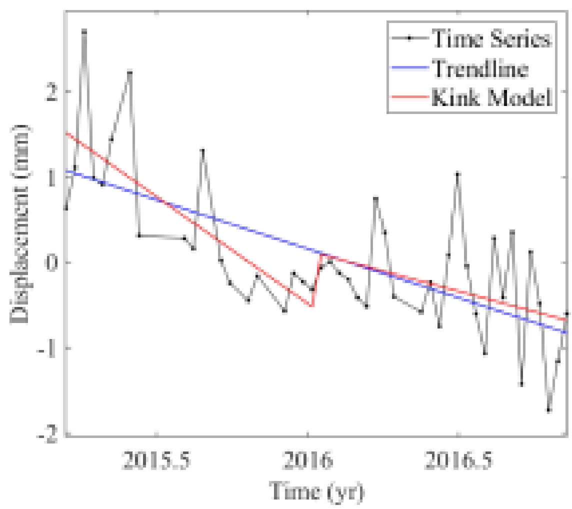



***Figure 2: Example of a time series dataset with slope break/kink location. This kink model was selected because the slopes before and after the kink had the lowest combination of slope uncertainties. The slope break for this dataset is in early 2016.***

### *GIS methods*

***Digitizing Aerial Photos, Near Analysis, Kriging*** Aerial photos from the University of Florida (UF) library database were georeferenced in ArcGIS Pro. Areas that were clear surface water features were digitized for analysis. These water features had low pixel values similar to pixel values of the remaining water features in the image (figure 3). Using the *Generate Near Table* feature the distances between each timer-series point and their nearest surface water polygon features were calculated. This was implemented using polygon features from both the USDA surface water hydrography layer and the digitized surface water features from the 1944 aerial photographs. A subsidence prediction surface was created using the Kriging Tool (Figure 6).

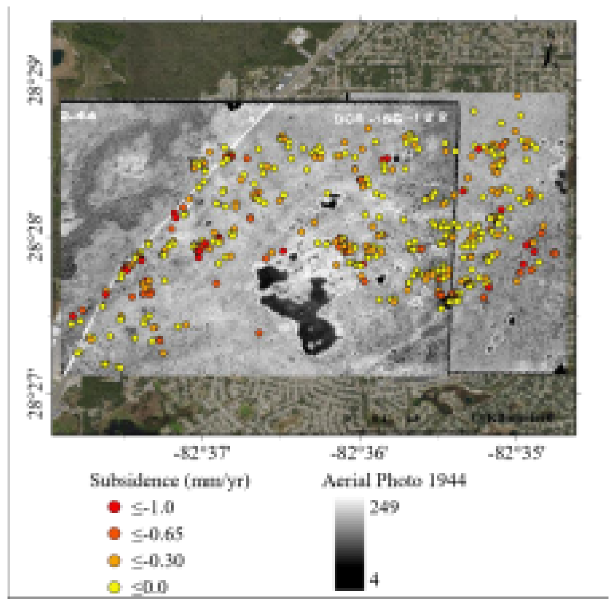



***Figure 3: Image of site location in west central Florida overlain by a georeferenced aerial image from 1944. PSInSAR subsidence points are also present on image. Surface Water Features can be identified by low (black) pixel values.***

## Results

NEAR analysis values show that slower slopes are closest to water features in both the 1944 identified features and the USDA surface water features Figure(3). This may be heavily related to the number of slower slopes.

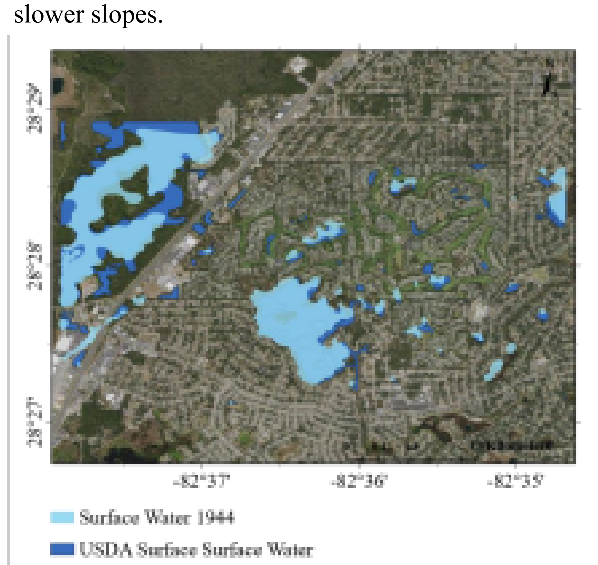
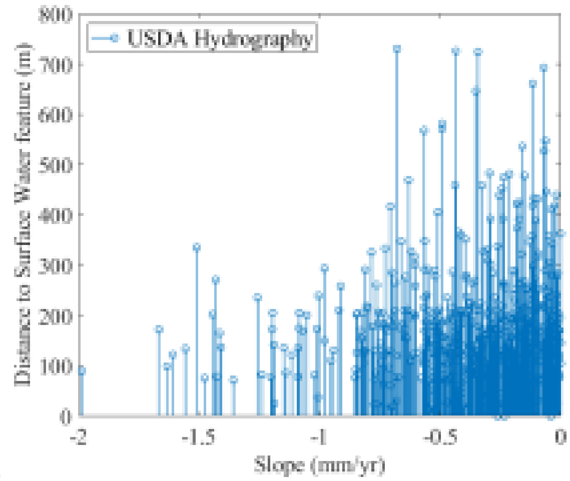


*Figure 4: Map of digitized surface water features and surface water features from the USDA.*





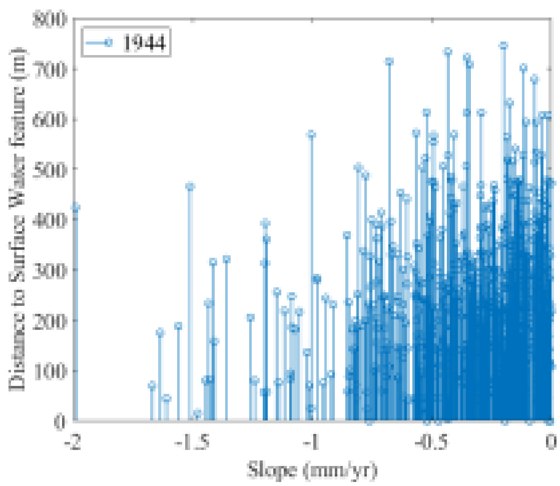



***Figure 5: Stem plot showing the correlation between slope of each time series and their distances to the closest water feature from the USDA layer (top) and the 1944 digitized water features (bottom).***

A qualitative analysis of the Krigged surface of subsidence velocities shows clear correlations between rate of subsidence and low elevation in DEM layer.

## Contributions?

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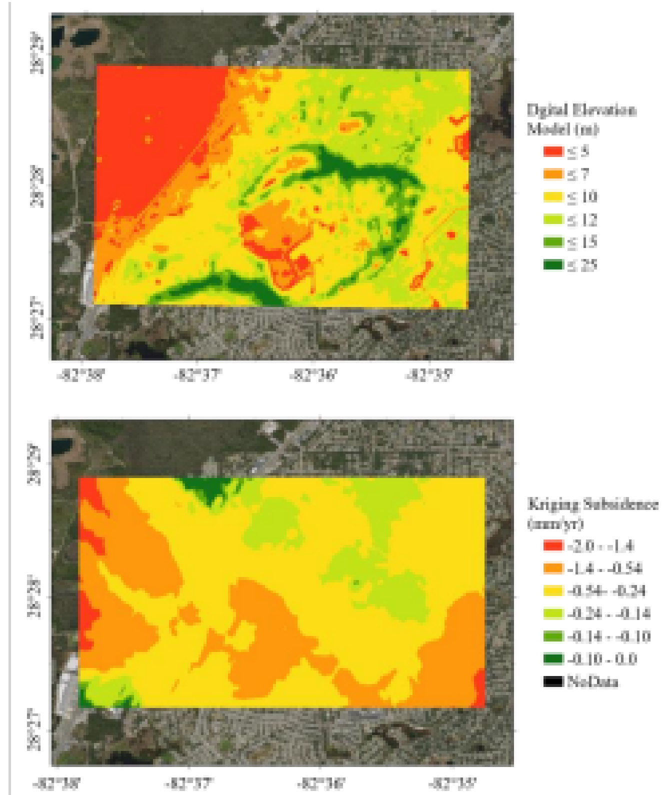


***Figure 6: Maps of the 3 meter DEM layer of site from USDA (top) and the interpolated subsidence surface created using the Kriging tool (bottom).***

## Acknowledgements/Author


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