A Spatial-Temporal Representation of Land Subsidence in the Northwest Phoenix Valley, Arizona

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Dynamic Phenomena:

There are currently 26 identified active land subsidence features in the state of Arizona covering over 2,000 square miles.[1] By means of spatial query, 15 of the 26 land subsidence features are partially or completely within a few of Arizona's Urbanized Areas (Avondale, Phoenix - - Mesa, and Tucson have known land subsidence features).[2] This is important because the impact from land subsidence has serious potential consequences:

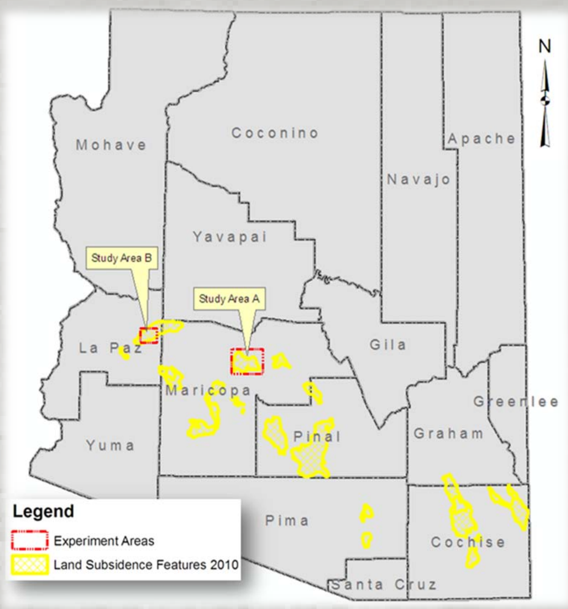

FIGURE 1 MAP OF KNOWN SUBSIDENCE FEATURES AND RESEARCH STUDY AREAS

"The results of land subsidence are increased susceptibility to flooding, structural damages (buildings, roads and highways, railroads, flood control structures, well casings, gas and water pipes, transmission lines, electric and gas substations, and sewer lines), flow reversal in drains, sewers, canals, irrigation systems, and aquifers and ground fractures (desiccation cracks, giant desiccation cracks and earth fissures".[3]

Research Questions:

A frontier in GIScience is converting objective data of dynamic and complex real world phenomena into spatial-temporal building blocks for generating new knowledge. My study includes the analysis of objective data for a complex and dynamic phenomena called land subsidence. The analysis of land subsidence and its temporal state are considered within two known subsidence features within Arizona. Questions my research will attempt to resolve include:

1. **Can the temporal state of land subsidence be derived from InSAR data processing?**
2. **What are the query limitations of GIS both spatially and temporally for the derived results?**
3. **Can this information then be effectively represented with GIS to in the hope to simplified subjective analysis to advance our understanding of land subsidence?**

Data Processing:

Each study area received digitized land subsidence polygons, cross-sections, and sample location points separated by 1 mile. The temporal durations between InSAR processing ranged between 165 days to over 12,000 days.

Source Date Range	Number of Days	Study Area	Temporal Coverage
2004-03-08 to 2010-02-15	2,171	A	Long
2008-02-11 to 2010-02-15	736	A	Medium
2009-03-02 to 2010-02-15	378	A	Short
1957-1997	12,000	A	Extremely Long
2004-02-05 to 2010-02-18	2,206	B	Long
2008-02-14 to 2010-02-18	736	B	Medium
2009-01-29 to 2010-02-18	386	B	Short
2010-03-08 to 08-20-2010	165	B	Extremely Short

TABLE 2 TEMPORAL RANGES FOR DATA USED IN RESEARCH

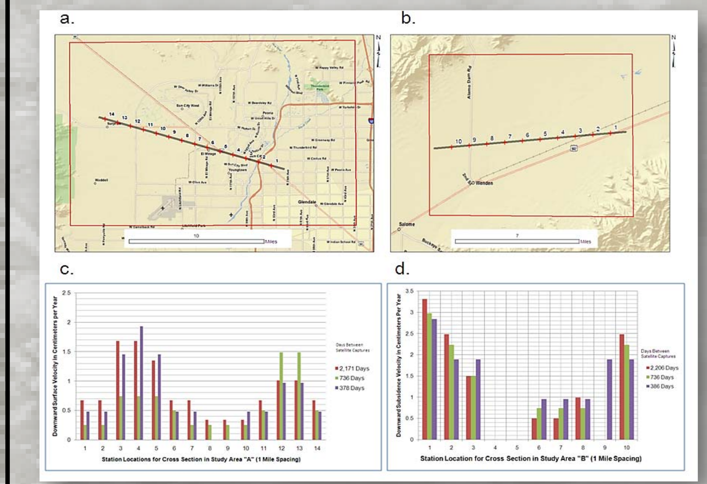

FIGURE 5 CROSS SECTIONS FOR STUDY AREAS AND VELOCITY OF LAND SUBSIDENCE

Both study areas had three temporally interdependent sets of land subsidence velocity data representing their respective land subsidence features. Temporally, the various time samples should match if land subsidence velocity is in a steady state for any given location along the tested cross-sections.

InSAR Processing:

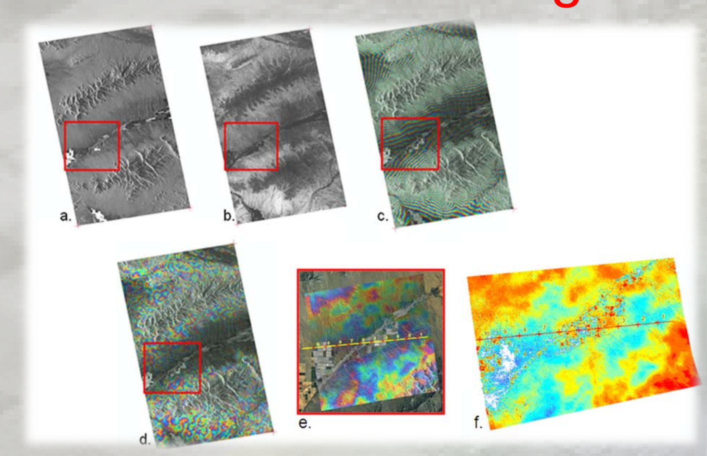

FIGURE 6 FOR CROSS STUDY AREA B THE FOLLOWING WERE DERIVED FROM INSAR PROCESSING: (A). SINGLE LOOK COMPLEX SCENE (2010-08-20), (B.) COHERENCE IMAGE (2010-08-20 AND 2010-01-23) (C.) COLOR INTERFEROGRAM (D.) DIFFERENTIAL-INTERFEROGRAM (E.) DIFFERENTIAL-INTERFEROGRAM WITH CROSS-SECTION "B" OVERLAY (F.) VERTICAL DISPLACEMENT MAP WITH CROSS-SECTION "B" OVERLAY

GIS Representation:

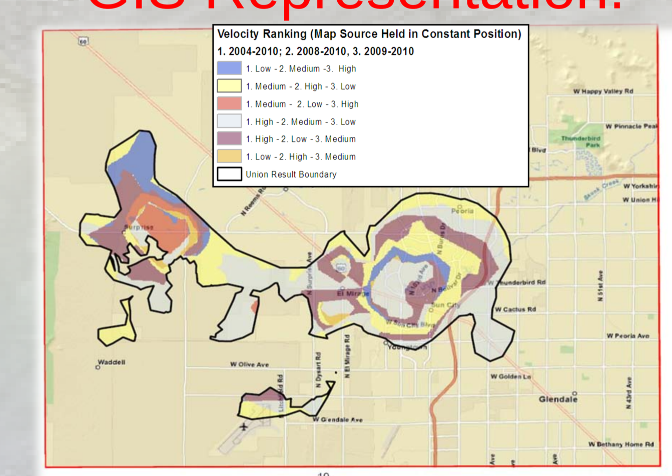

FIGURE 7 FOR STUDY AREA A SHOWING RANK ORDER CHANGES IN VELOCITY POLYGONS.

Space and Time GIS:

Space-time GIS is not an easy task as both are continuous and too rich in detail to fully capture without generalizations. Donna Peuquet has offered the "Space-time Triad" as part of a theoretical framework that three queries GIS should be solvable when dealing with spatial-temporal data in an advanced system:

1. **When + Where → What**
2. **When + What → Where**
3. **Where + What → When**

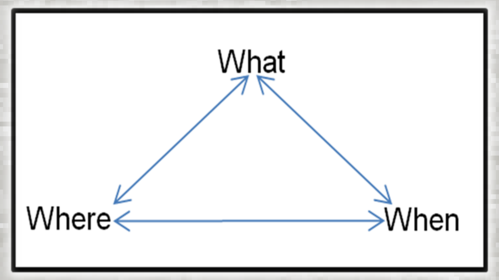

FIGURE 2 WHAT, WHEN, WHERE (PEUQUET, 2002)[4]

Also important, pattern recognition is paramount for the analysis of spatial-temporal knowledge creation. The following patterns will be applied for investigating land subsidence velocity:

Spatial: REGULAR, CLUSTERED, CHAOTIC, RANDOM

Temporal: STEADY STATE, OCILLATING, CHAOTIC, RANDOM

Results:

The behavior of land subsidence was determined to be spatially clustered. The multiple time spans showed how trending in velocity at some locations changed abruptly and were not consistent for each location. These micro-changes in land subsidence velocity if missed could be problematic for at risk critical infrastructure as the results were **temporally chaotic**.

Space-time TRIAD[4] questions were mixed as software limitations provide query capabilities to answer **When + Where → What.**

The representation of land subsidence, although not new to GIS has now been reviewed over multiple interdependent timeframes with a focus on its velocity. **Figures 7 and 8 effectively represent simplified subjective analysis to advance our understanding of land subsidence.**

Velocity Graph:

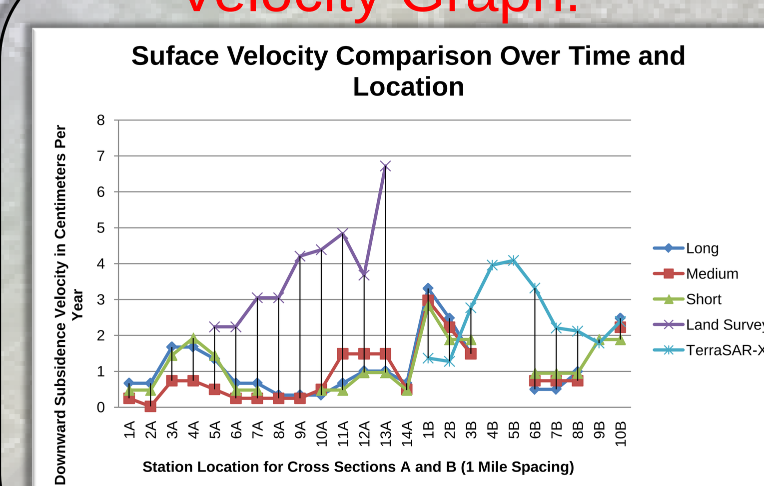

FIGURE 8 THE GRAPH ABOVE SHOWS LAND SUBSIDENCE VELOCITY FOR ALL SAMPLE POINTS FOR CROSS-SECTIONS A AND B. EACH LINE COLOR REPRESENTS DIFFERENT SAMPLE TIME DURATIONS.

Methods:

The listed source documents were required for each study area. An additional requirement was that InSAR was used to compute land subsidence.[7] For consistency, both sites were to be processed the same. A controlled variation was added to each Study Area with an additional data source. Study Area "A" included field survey land subsidence information from 1957-1991. Study Area "B" incorporated the processing of Level0 (raw amplitude and phase data) from TerraSAR-X for the creation of InSAR. At the core, a total of six maps from ADWR showing land subsidence were used as a secondary source.

Primary and secondary observational data were processed in this experiment. Cross-section were used to generate one mile stationing. This was to done to enable a profile of information to be generated. Digitized polygons were provided attribution based on their source document. Velocity was calculated in centimeters to maintain conformity with source documents.

$$(V) = \frac{\Delta x}{\Delta t}$$

Study Area A	Study Area B
Land Subsidence in Western Metropolitan Phoenix Based on ADWR EnviSat Time-Series InSAR Data Time Period of Analysis: 5.9 Years 03/08/2004 To 02/15/2010	Land Subsidence in the McMullen Valley, Maricopa and La Paz Counties Based on ADWR EnviSat Time-Series InSAR Data Time Period of Analysis: 6.0 Years 02/05/2004 To 02/18/2010
Land Subsidence in Western Metropolitan Phoenix Based on ADWR EnviSat Time-Series InSAR Data Time Period of Analysis: 2.0 Years 02/11/2008 To 02/15/2010	Land Subsidence in the McMullen Valley, Maricopa and La Paz Counties Based on ADWR EnviSat Time-Series InSAR Data Time Period of Analysis: 2.0 Years 02/14/2004 To 02/18/2010
Land Subsidence in Western Metropolitan Phoenix Based on ADWR EnviSat Time-Series InSAR Data Time Period of Analysis: 0.9 Years 03/02/2004 To 02/15/2010	Land Subsidence in the McMullen Valley, Maricopa and La Paz Counties Based on ADWR EnviSat Time-Series InSAR Data Time Period of Analysis: 1.0 Years 01/29/2009 To 02/18/2010
OFR Report 94-532 Figure 2. Land subsidence in part of the western Salt River Valley, 1957-1991.[7]	TerraSAR-X Amplitude and Phase - Single Look Complex Scenes. 2010-01-23, 2010-03-08, 2010-08-20.

TABLE 1 SOURCE DOCUMENTS

Study Areas:

Study Area "A" is located to the Northwest of Phoenix and includes Sun City, Sun City West, Surprise, portions of Peoria, Glendale and Luke Air Force Base. The location for this study was selected as it encompasses the "Western Metropolitan Phoenix Land Subsidence feature".

Study Area "B" is located within the McMullen Valley groundwater basin and is roughly 60 miles to the northwest of Study Area A. The main community within the study area is Wendon, Arizona.

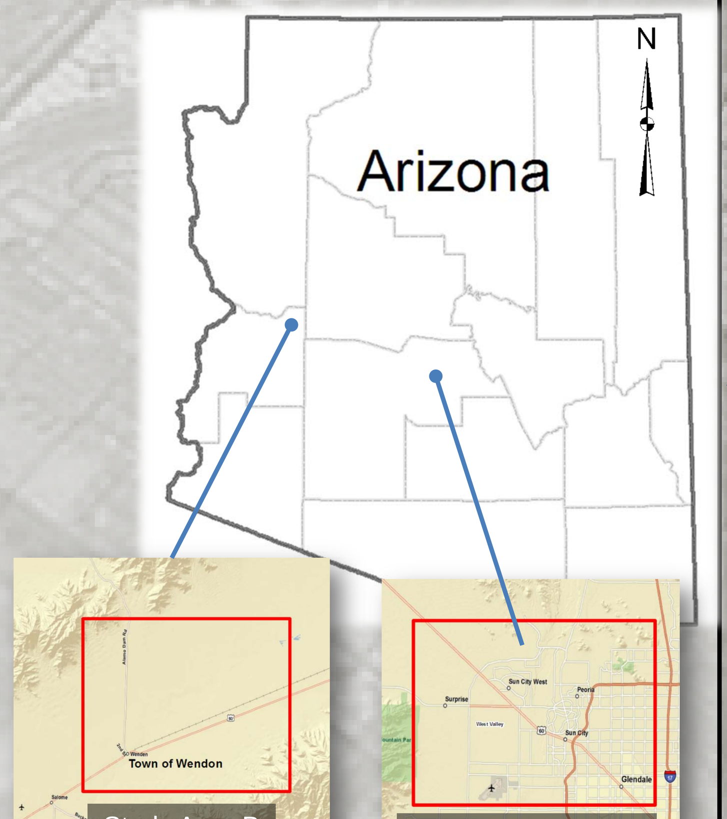

FIGURE 4 RESEARCH STUDY AREAS

Interferometric Synthetic Aperture Radar:

"Topographic mapping with InSAR relies on acquiring data from two different look angles and assumes that the scene imaged did not move between data acquisitions. If the look angles of multiple data acquisitions are identical, equivalent to having a zero baseline, there is no sensitivity to topography, and the interferogram can be used to extract information regarding scene dynamics" [5]

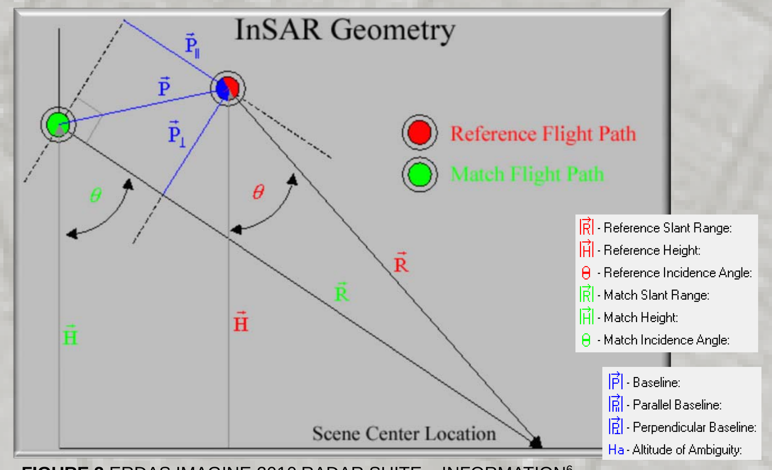

FIGURE 3 ERDAS IMAGINE 2010 RADAR SUITE – INFORMATION[6]

The electromagnetic wavelengths used in this research was 3 cm. Scene coverage was close to identical. The figure shown to the left depicts the geometric organization of the satellite, orbital position, and ground solution. The difference resulting from the two image captures minus terrain effects provides a highly accurate surface change solution.

References:

[1, 2,7] Arizona Deparment of Water Resources, http://www.azwater.gov/azdwr/GIS/ (last accessed December 5, 2010: 6:42 pm)
[3] Budhu, Muniram, Adiyaman, Ibrahim Bahadir. 2009. Mechanics of land subsidence due to groundwater pumping *International Journal for Numerical and Analytical Methods in Geomechanics* 34:1459-1478.
[4] Peuquet, Donna J. 2002. *Representations of Space and Time*. The Guilford Press.
[5] Madsen, S., Zebker, H. 1998. Imaging Radar Interferometry. Principles & Applications of Imaging Radar: manual of Remote Sensing Third Edition, Vol. 2. ed. Henderson, Floyd, Lewis, Anthony. John Wiley and Sons.
[6] ERDAS 2010, 2009. *Radar Interferometry User Guide*. Norcross, GA. ERDAS, Inc.
[7] Schumann, Herbert H. Land Subsidence and Earth-Fissure hazards Near Luke Air Force Base, Arizona. 1995. *U.S. Geological Survey Subsidence Interest Group Conference, Edwards Air Force Base, Antelope valley, California, November 18-19, 1992: Abstracts and Summary*. ed. Prince, Keith R., Galloway, Devin L., Leake, Stanley A., pp. 18-21.

Background: ESRI Imagery ArcGlobe Oblique View of Northwest Phoenix, Arizona