LAND SUBSIDENCE INDUCED BY GROUNDWATER PUMPING, MONITORED BY C-BAND D-INSAR AND FIELD DATA IN THE TOLUCA VALLEY, MEXICO

Calderhead AI, Martel R, Alasset P-J, Rivera A, Garfias J

Excessive groundwater pumping within geologic structures composed of compressible clays leads to land subsidence potentially causing significant damage to buildings and infrastructure. Differential Synthetic Aperture Radar Interferomerty (D-InSAR) is a powerful technique used for detecting surface deformation on the sub-centimeter scale (Franceschetti and Lanari, 1999). The method has been used by Galloway et al., 1998; Amelung et al., 1999; and Hoffmann, 2001 for detecting and monitoring subsidence from groundwater extraction. The objective of this work is to present a multi-disciplinary approach combining and contrasting C-band D-InSAR results and field data monitoring of land subsidence due to groundwater pumping in the Toluca Valley, Mexico. A semi-arid to temperate climate, a high concentration of 'natural' backscattering from objects such as buildings and other cement and metallic structures, along with the slow deformation of land due to groundwater pumping in a compressible aquifer are very suitable conditions for applying the D-InSAR technique.

The region of interest was always focused on the Toluca Valley and particular emphasis was put on the industrial corridor. Image data was available from December 1995 until May 2008. A total of 30 SAR images from the C-band ERS-1, ERS-2, ENVISAT-ASAR and RADARSAT-1 sensors were used. The software used to process the radar data was EV-InSAR 4.0 ® by MacDonald, Dettwiler and Associates Ltd. (MDA). Forty four D-InSAR pairs were obtained with only 31 of those results with usable interferograms and subsidence maps.

Field work involved obtaining historical and current groundwater levels. These levels were used as a guideline for determining when the subsidence began and to what degree the groundwater level decline has affected the subsidence rates. Additionally, two magnetic reed switch probe extensometer systems were installed in the Industrial Corridor. The objective of installing the extensometers was to obtain accurate field measurements at point locations. Additionally, due to the fact that the extensometers are equipped with an array of magnetic sensors it is possible to quantify the compaction between layers. Due to the compressible clay content and the excessive groundwater pumping in the basin, subsidence is observed in the Toluca Valley. According groundwater level and geologic data, subsidence probably first started occurring in 1962 when a water budget deficit first appeared.

For all D-InSAR image pairs, high baseline values, atmospheric effects, temporal decorrelation, and vegetative cover were the limiting factors in obtaining a maximum number of usable interferograms. In the case of RADARSAT-1, baselines below 800 m were useful however baselines with values below 600 m had more reliable results. The urbanized part of the valley had the best results where 'natural' reflectors, such as buildings were abundant. In these areas, usable results were obtained from pairs with up to 3 years difference, however best results were obtained when the time difference was less than 1 year. Vegetative cover was a major factor in obtaining usable results; best results were obtained in the drier season (November to the end of April) when vegetative growth is least. When comparing ENVISAT ASAR and RADARSAT-1 results, it was found that when using shorter baselines and time differences between images, the RADARSAT-1 InSAR results detected very similar subsidence locations and magnitude to ENVISAT-ASAR. For the Toluca Valley, the ENVISAT ASAR mission had shorter baseline differences than RADARSAT-1; and thus more useful pairs. Differences in the results can also be attributed to atmospheric effects.

Errors in the measured subsidence from the field data could exist since the extensometers do not reach bedrock. However, comparing the InSAR results with the extensometers, we notice that there is a direct correlation. ENVISAT ASAR and RADARDAT compaction results follow the extensometer measurements very closely. Although clay is found at deeper depths (>300m), the results imply that the compaction is occurring in the upper 110 m portion of the valley. These results further validate the InSAR technique and the usefulness of the extensometer.

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