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Advanced InSAR Techniques for Measuring Surface Deformation in Geothermal Fields

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Satellite interferometric synthetic aperture radar (InSAR) techniques have been successfully used for two decades now to detect and measure surface deformation due to water withdrawal, earthquakes, mining, oil and gas production, and CO_2 sequestration. Detection of sub-centimeter deformation with millimeter precision has been repeatedly demonstrated, including examples from several geothermal fields. Recent advances show significant advantages over conventional InSAR, such as capability to detect time series of surface movements amidst vegetated areas, to capture nonlinear changes, and to remove more effectively atmospheric artifacts. These newer techniques make use of so-called "permanent" scatterers (PS), where deformation time series are extracted for numerous points in the study areas. The PS points play the role of benchmarks, typically corresponding to man-made structures (buildings, bridges, dams, water pipelines, antennae) and stable natural reflectors (e.g. large boulders). The technique used by TRE is thus known as PSInSAR™. It was first developed and patented at POLIMI (Politecnico di Milano) and was further improved at Tele-Rilevamento Europa (TRE) in Italy (Ferretti et al., 2000). Its most recent improvement, SqueeSAR™, is sensitive to previously undetected weaker signals and is thus capable of extracting information from even more PS points.

These techniques have been used in the Salton Sea geothermal field in the Imperial Valley of southern California and the San Emidio geothermal field in Nevada. In both cases SAR data were available from descending and ascending orbits, i.e., when the satellites moved north-south and south-north, respectively. Thus it was possible to combine the results from these different geometries and convert the deformation observed in the line-of-sight (LOS) direction to the satellites into two components – a vertical component and a horizontal component in the west-east direction. The two orbit geometries are such that the horizontal component in the south-north direction cannot be constrained. Still, it is a great advantage to be able to decompose the results in at least two components, because the information from the LOS deformation is limited only to determining if surface movement has occurred towards the satellite or away from it.

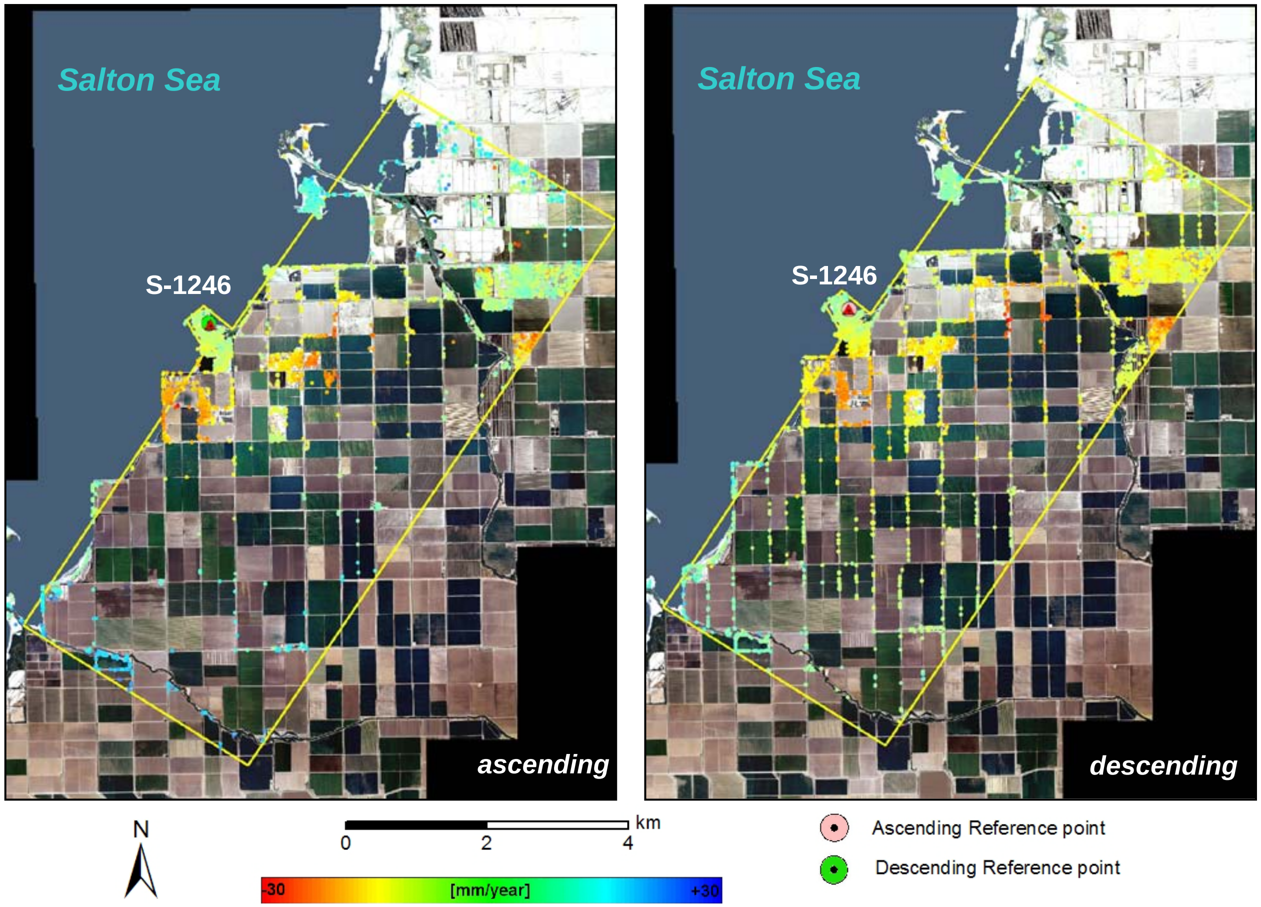

Figure 1. PS deformation rate maps at the Salton Sea geothermal field. Left – PS from ascending orbits. Right – PS from descending orbits. Color scale shows deformation rates in mm/yr along LOS. Positive and negative values denote movement towards and away from satellite, respectively. Red triangle shows location of reference benchmark S-1246. Rates are referenced to two PS points in the vicinity of S-1246, marked with pink and green circles for the ascending and descending orbits, respectively. Maps are superimposed on orthophotos from USGS (http://seamless.usgs.gov). From Eneva et al. (2009).

The study of the Salton Sea geothermal field in southern California was part of a research project carried out by Imageair, Inc. with the California Energy Commission. SAR data for this study area, 21 descending and 18 ascending scenes, were previously collected by the Canadian satellite Radarsat-1, and were made available by the Alaska Satellite Facility (ASF). These data covered a nearly two-year period, May 2006 – March 2008. The Salton Sea geothermal field is located in an area densely covered by agricultural fields, where conventional InSAR does not produce results, but PSInSAR™ led to the identification of two distinct subsidence bowls. Figure 1 shows the color coded LOS deformation rates (mm/year) at the individual PS points, mostly aligned along roads and canals. The deformation rates were extracted as the slopes of the individual time series of deformation observed at each PS location. CalEnergy, the operator of the field, has provided ground-based, leveling data at 79 benchmarks, which turned out to be in a very good agreement with the PSInSAR™ observations at nearby PS points (Eneva et al., 2009). From the deformation rates at the PS points, two subsidence bowls could be interpolated (Eneva and Adams, 2010), on which Figure 2 zooms in, showing vertical and east-west horizontal components of deformation of up to 30 mm/year. The "drag" of subsidence would be associated with corresponding horizontal movements in the opposite directions, which would cancel each other somewhere inside the subsidence bowls. The right panel of Fig. 2 confirms this expectation. The smaller subsidence bowl is distinctly split almost in the middle by eastward horizontal movements in its western portion and westward movements in its eastern portion. The larger subsidence area also displays a combination of eastward and westward horizontal movements, although their configuration is tilted compared with the smaller bowl.

The Salton Sea geothermal field is located in a tectonically active area, the Salton Trough, characterized by overall subsidence and prolific seismicity. It was estimated that regional extensional tectonics may be responsible only for a small portion of the maximum subsidence in the

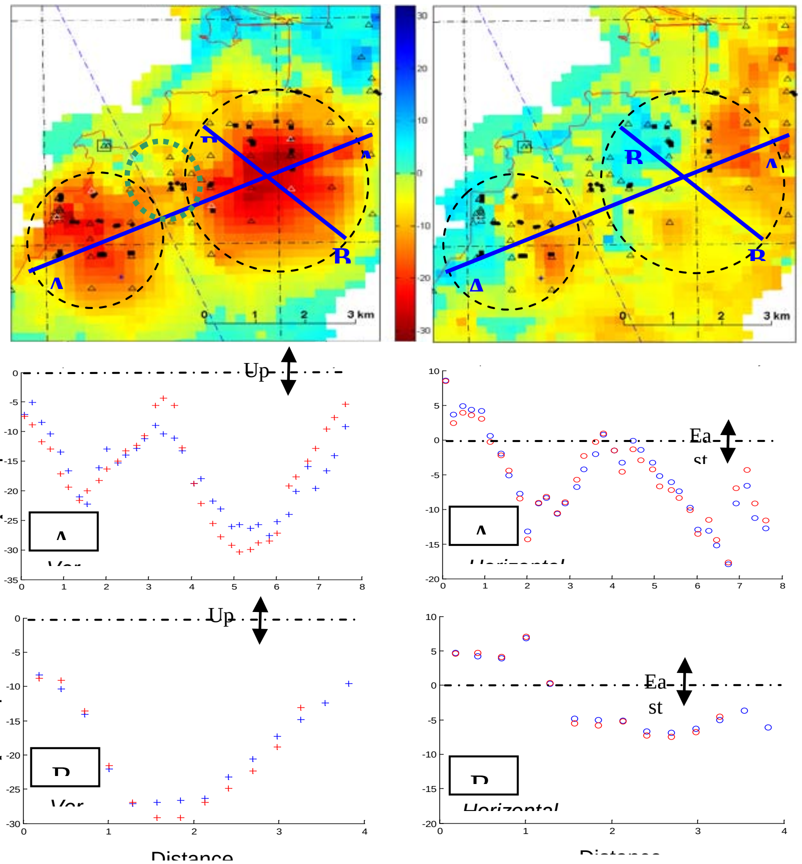

Figure 2. Examples of deformation profiles at the Salton Sea geothermal field. Left – vertical rates. Right – horizontal west-east rates. Maps on top – in the plot on the left yellow to red colors indicate subsidence and blue colors mark uplift; in the plot on the right yellow to red colors indicate westward horizontal movement and blue colors show eastward movements.

SqueeSAR™ approach is significantly superior since it produced series at tens of thousands of PS and DS locations throughout the coverage made it possible, among other things, to depict the loca- illustrated in Figure 3.

geothermal field (Eneva and Adams, 2010). However, it is not straightforward to attribute the surface deformation to geothermal production and injection versus local extensional tectonics, characterized by a complicated network of faults and rotational blocks. CalEnergy asserts that this field represents only a small portion of a vast geothermal resource, and thus no significant changes in pressure and fluid levels have taken place after many years of operation. This puts the emphasis on local tectonics as the reason for the observed subsidence.

The study of the San Emidio geothermal field in Nevada is part of a DOE project with US Geothermal. The SAR data used are from European satellites, including 38 descending ERS scenes covering the period May 1992 January 2001, and 53 descending and 43 ascending Envisat scenes collected in the period October 2003 – June 2010. These data were provided by the European Space Agency (ESA). The method used in this case was SqueeSAR™, which provided a very high number of PS points, as well as so-called distributed scatterers (DS). The latter are small areas producing weaker signals than the PS points, but

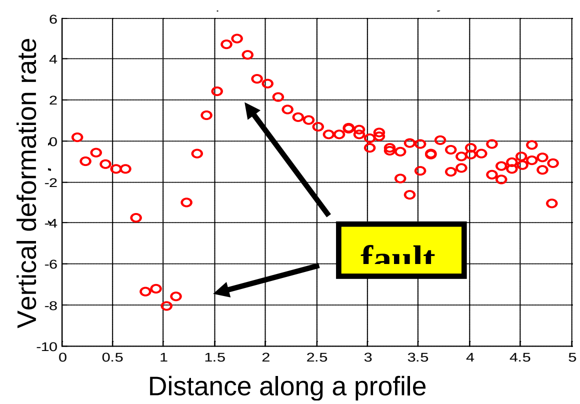

Figure 3. Vertical deformation rate along a profile crossing a fault in the San Emidio geothermal

still significant enough to be informative and useful. This field is in a relatively dry area and conventional InSAR would have also produced results, but the deformation time field. This dense tion of faults, as

Given the unprecedented power of these advanced InSAR techniques, it may be possible in the future to identify the locations of blind faults and other features, possibly useful in geothermal exploration. This may help, in conjunction with other methods, to pinpoint the locations of drilling targets. Also, similar to observations in CO_2 sequestration fields (Vasco et al., 2010), it may be possible to identify the paths of fluid flow through fracture networks, such as those of interest to the development of enhanced geothermal systems (EGS).

References:

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