INSAR is a cost-effective technique for imaging subsurface fluid flow and estimating flow properties, such as permeability. Interferometric Synthetic Aperture Radar InSAR can sample surface deformation with a spatial resolution of meters through tens of meters and with an accuracy of the order of a centimeter to as much as a few millimeters. InSAR observations might be used to image fluid-induced deformation over regions tens to as many as hundreds of square kilometers in extent. Fundamental understanding of fluid flow within the earth would otherwise be hampered by limited data coverage, and reduced temporal sampling. If the scale of investigation is small, of the order of a few meters, the results might not scale up into the kilometer range, in which faults and fracture zones control flow. Finally, in applications, one typically requires knowledge of factors influencing subsurface flow in a timely fashion to optimize or mitigate the activities. Observations associated with a CO_2 injection at the Krechba field, Algeria, with aquifers compaction in Las Vegas, and with other oil fields demonstrate the effectiveness of such a methodology, and show that Sentinel 1, with its 12 days revisit cycle and its Interferometric Wide Swath Mode, is well tailored to satisfy the needs of the subsurface applications.

Applications of DInSAR to ground water flow studies

Many groundwater basins in the arid and semi-arid western US have experienced aquifer-system compaction, or subsidence, in response to heavy pumping (Bell et al. 2008). The application of interferometric synthetic aperture radar (InSAR) studies to hydro geological problems has advanced rapidly during the last decade, and it is now routinely applied to a wide range of groundwater resource issues, including groundwater flow modeling, estimation of aquifer-system hydraulic properties, and facilitating improved management of groundwater resources. The application of Permanent Scatterer InSAR (PSInSAR) now provides an additional methodology that allows for greater resolution and accuracy in the detection of ground movement produced by aquifer system withdrawals and recharge. Results are presented of a PSInSAR prototype study in Las Vegas Valley that focuses on the pattern and timing of aquifer-system response to pumping and artificial recharge showing ground deformation maps that allow for a greater resolution in displacement time series than previously available through the use of conventional InSAR. Velocity and acceleration/deceleration analyses enable a close examination of patterns of subsidence and uplift responding to rising water levels during the study period.

This study used the PSInSAR methodology together with detailed water-level change data to examine the temporal and spatial pattern of seasonal and long-term aquifer-system response to pumping and artificial recharge in Las Vegas Valley, providing insights into important aspects of the system response that can form the basis for similar studies in other heavily pumped groundwater basins. This study demonstrates that this is a robust, high-resolution, widely applicable methodology that improves upon conventional InSAR methodologies. It could be further improved by increasing the sampling frequency and by combining data from different SAR viewing geometries and multiple satellites, thereby allowing greater resolution of annual fluctuations of the seasonal signals and detection of horizontal aquifer displacements. This evolving methodology will provide an important new tool in future groundwater research and management that can be utilized in other heavily pumped groundwater basins. In addition, the Permanent Scatterer methodology may have broader applications to hydrologic research beyond groundwater resources, such as in the natural recharge in urban areas and in the system analyses of other ground fluid reservoirs.

Applications of DInSAR to CO_2 sequestration monitoring

More examples can be found in the oil and gas industry, where InSAR data can characterize reservoir processes such as fracture growth and volumetric changes based upon the surface deformations they generate, whether from primary or enhanced oil recovery techniques, or from CO_2 sequestration. As an example, the In Salah Gas Project is well known as one of huge CCS (Carbon dioxide Capture and Storage) projects in the world, as well as Sleipner, Norway and Weyburn, Canada. The CO_2 is separated from natural gas and is injected into underground at three wells. The field is located in the rocky desert, suitable for the InSAR processing. Natural gas produced in the project contains 3-9% of carbon dioxide which is captured by a regenerative amine system and then is injected into the Carboniferous reservoir at a depth of 1,900m, from three injection wells KB-501, KB-502, and KB-503. The CO_2 injection wells are in the same formation as the producers, horizontal wells that are located on the flanks of the anticline, at depths of roughly two kilometers. The well KB-501, which we consider in this study, lies roughly 8 km to the east-northeast of the production wells, about 100 m lower in elevation. Mud losses during the drilling of numerous wells indicate flow into pre-existing fractures, dipping at approximately 81°, striking N43°W. The direction is sub parallel to the regional stress direction. The stress directions in the gas fields are remarkably consistent, striking 315°, a sign that the horizontal stress field is highly anisotropic. Breaks in the topography of the structure map of the top of the reservoir layer, as determined by seismic imaging, indicate possible faults on the flanks of the anticline, trending north-northwest.

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Monitoring at In Salah Gas Project is considered to be crucial for developing a detailed understanding of behaviors of injected CO_2 with reducing uncertainties in predictions of long term storage performance. Monitoring methods can be separated into seismic and non-seismic techniques; seismic techniques include micro seismic and 4D seismic surveys and non seismic techniques may comprise of borehole gravity, resistivity changes, and controlled source electromagnetics (CSEM). A large number of observations are required for all of these geophysical methods and generally the data acquisition may be performed at great expense. Although InSAR technique cannot sense injected CO_2 directly, the coverage of such broad area as 100km x 100km by one satellite SAR scene and repeated observations, for instance every 35 days in case of ENVISAT ASAR, make InSAR as a cost-effective method for monitoring. Adding to these advantages, because the history of surface deformation can be one of supplemental data to refine the model of underground distribution of injected CO_2, the InSAR results are expected to contribute to numerical modeling when combined with results of traditional geophysical surveys.

Surface deformation pattern related with CO_2 injection at In Salah Gas Project, Algeria, was successfully analyzed by DInSAR using 30 ENVISAT ASAR data spanning from Jul. 2003 to May 2008 . The studies were carried out using the Permanent Scatterers methodology. As part of a CO_2 sequestration research-and-development program, Berkeley Laboratory and Tele-Rilevamento Europa explored the use of Interferometric Synthetic Aperture Radar data for monitoring CO_2 injections. One goal of this work was to identify flow paths at depth and geologic features controlling flow. The injection of CO_2 into the water column induces multiphase flow because the reservoir is initially water filled. At reservoir pressure, the CO_2 behaves as a supercritical fluid, with a viscosity and density somewhat different from water. The well-head injection pressure was variable; on average a pressure of 15 MPa was maintained after the start of pumping, with peaks approaching 18 MPa early in the injection and about seven months into the injection. At these pressures, supercritical CO_2 should have a density greater than 0.85 grams/cm3. In the region of interest, the reservoir does not vary significantly in depth, and the density differences do not impact the flow. Furthermore, the advective flow almost certainly dominates the geochemical changes at depth for the two to three years of injection that we considered.

The range-change data then were inverted for volume change within the reservoir, using the approach described in (Vasco et al. 2005, Fokker et al. 2006, Vasco et al. 2008 – 2). In essence, a linear system is solved for the volume changes in the reservoir. From the sequence of pressure changes, we estimate the phase or travel time of the disturbance resulting from the onset of CO_2 injection. Because the flow rate was non uniform, there were several peaks in the time series of the pressure derivative. We focused on the time associated with the first peak of pressure derivative in each grid block. A more sophisticated approach, which we might attempt in a future study, involves deconvolving the flow-rate function from the time series of each grid block to produce the response to a step function in flow rate. The arrival-time values form the basic data set for the inversion for flow properties. The estimates were constructed for a 40-by-40 grid of cells defining the reservoir model. However, it is possible to estimate arrival times only for those grid blocks to which the pressure change had propagated during the observation interval.