

ALOS Data for Land Subsidence Monitoring in Arizona

By Brian Conway, Arizona Department of Water Resources

The Arizona Department of Water Resources (ADWR) has been collecting and processing Synthetic Aperture Radar (SAR) data using interferometry (InSAR) since 2005. The InSAR products produced are used by ADWR for statewide land-deformation monitoring for the purpose of improved water-resource management and more specifically, to determine the spatial extent, magnitude, and time-series history of land-deformation features within south-central and southern Arizona. ADWR has collected, processed, and analyzed C-band SAR data from the European Space Agency's European Remote Sensing Satellite 1 (ERS-1) and ERS-2, Envisat satellites, and the Canadian Space Agency's RADARSAT-1 satellite. Recently, ADWR has started to utilize L-band SAR data from the Japanese Advanced Land Observing Satellite (ALOS) provided by the Alaska Satellite Facility (ASF).

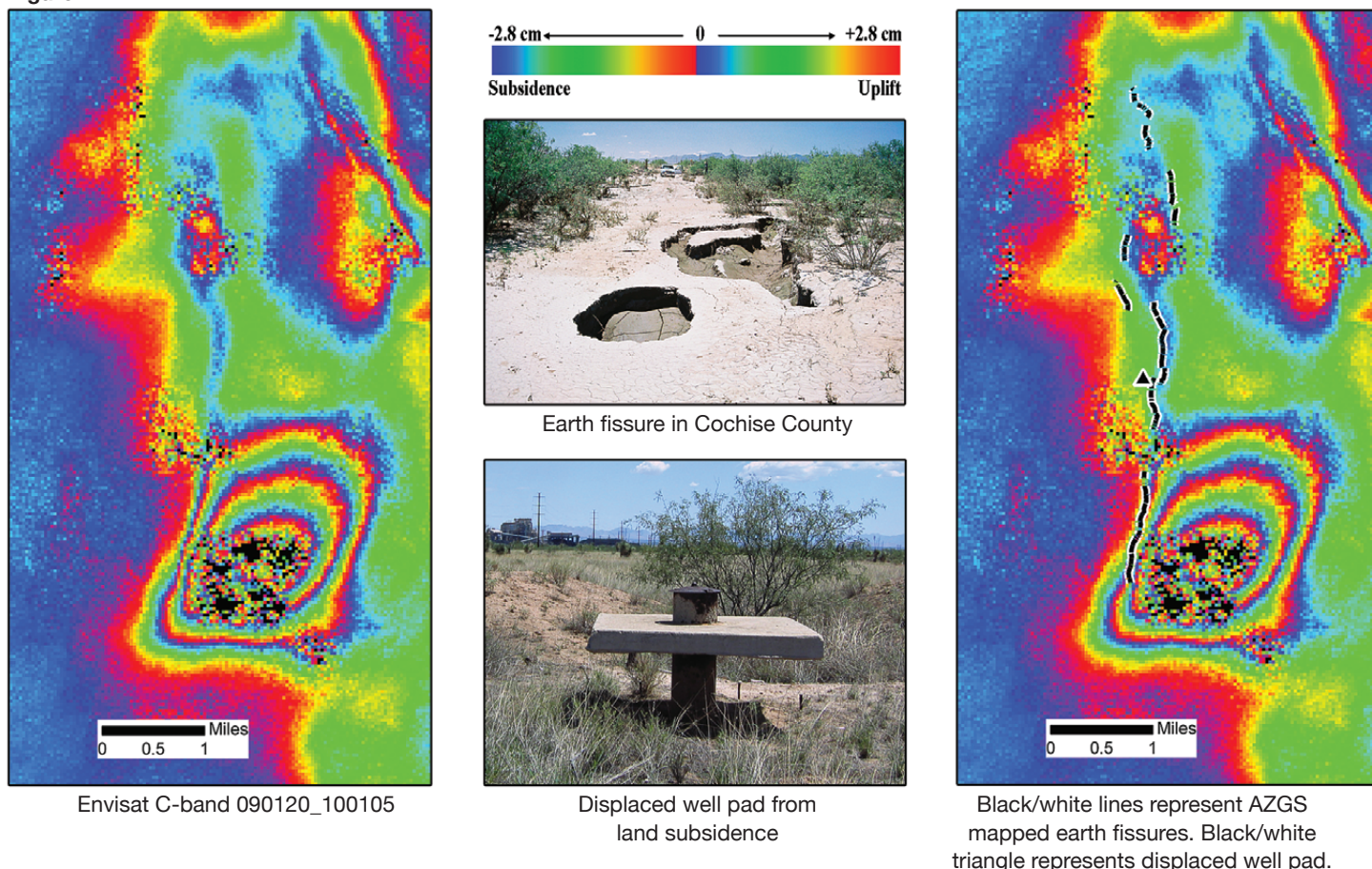
Land subsidence has been occurring across Arizona since at least the 1940s when it was first documented. A few areas in

Maricopa and Pinal Counties have subsided more than 20 feet since 1940. Land subsidence has damaged roads, sewer lines, flood-retention structures, and many other types of infrastructure throughout Arizona.

Cochise County, located in southeastern Arizona, is home to some of the largest agricultural areas within the State. InSAR products have proven to be an invaluable tool in this region, allowing hydrologists to not only identify the location of land-subsidence features, but to also monitor recurring land subsidence and uplift cycles that are caused by seasonal pumping demands related to crop water needs. The largest annual deformation rate detected (11 centimeters) by ADWR using InSAR products in Arizona is located in Cochise County and was identified using Envisat C-band SAR data between January 20, 2009, and January 05, 2010 (Figure 1). Numerous active earth fissures have been mapped by the

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Figure 1



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Arizona Geological Survey (AZGS) and occur along areas of differential land subsidence that are easily detected with InSAR.

L-band SAR data acquired from ASF have allowed ADWR to complement recent Envisat C-band SAR data and improve coherence within some of the agricultural areas (Figure 2). The interferogram that was formed using L-band data from December 06, 2006, and December 14, 2009, illustrates the extent and magnitude of land subsidence caused by this seasonal, high-demand groundwater use. ADWR depth-to-water data show that groundwater levels have declined as much as 150 feet since 1950 within these active land-subsidence features. The L-band SAR data identifies the highest magnitude of land subsidence over the 3-year period to be 40 centimeters.

Additional L-band data for Cochise County will provide critical information to help us better understand how land

subsidence is changing floodplains, altering aquifer hydraulic properties and survey elevations, and contributing to earth-fissure development. Future ADWR InSAR products will not only be used by ADWR, but by engineers, geologists, surveyors, floodplain managers, and other scientists for their own monitoring, modeling, and infrastructure projects.

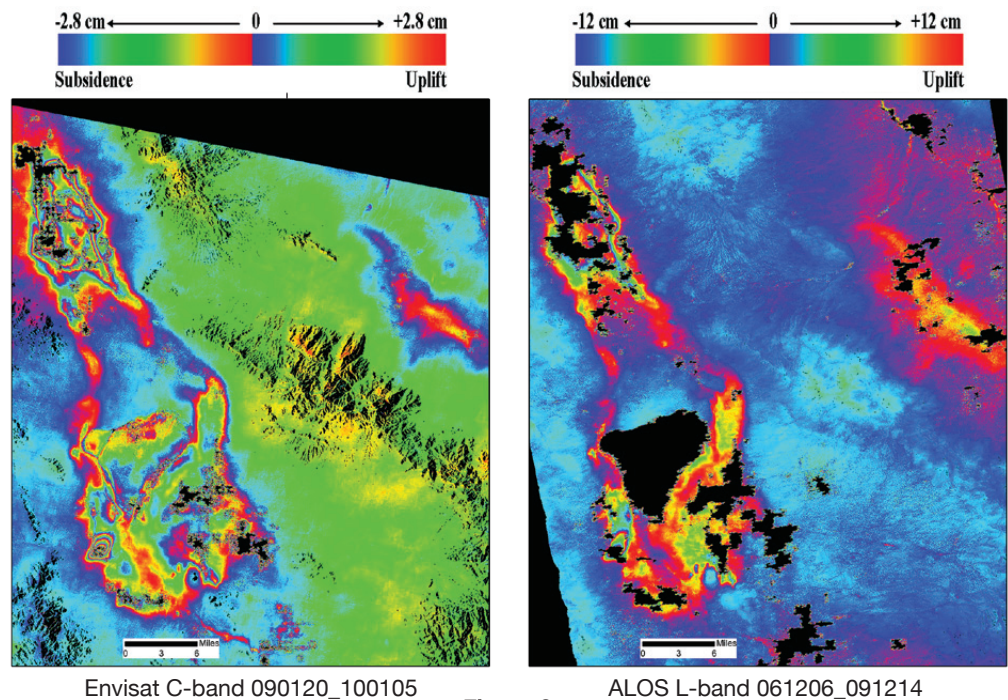


Figure 2

The M7.2 El Major-Cucapa Earthquake in Baja California: Extensive Liquefaction Identified in ALOS InSAR Data

by Meng Wei and David Sandwell, Scripps Institution of Oceanography

A magnitude 7.2 earthquake struck Northern Baja California, Mexico, at 3:40 p.m. Pacific Time on April 4, 2010. The epicenter was located in Mexico about 63-km southeast of Calexico, California (Figure 1). This earthquake temblor was widely felt through southern California and some reports came in from more distant locations such as Santa Barbara, California, and Las Vegas, Nevada. This earthquake was the largest earthquake in the region in the last 18 years, after the M7.3 Landers earthquake in 1992.

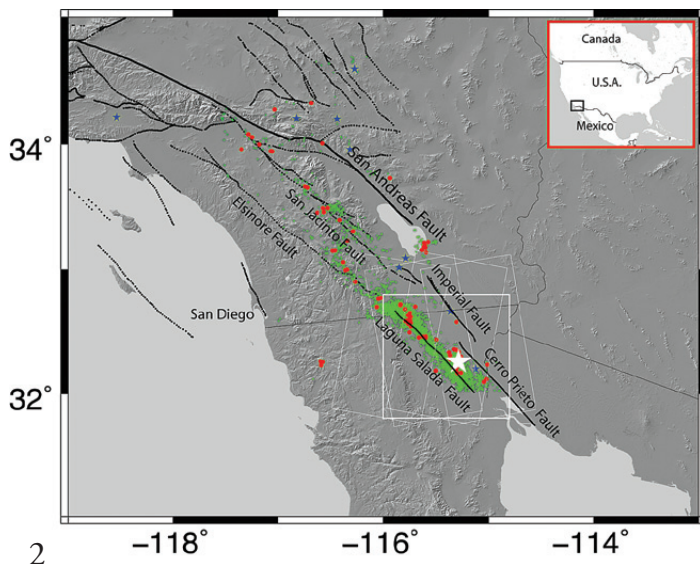


Figure 1: Map of Southern California and Northern Baja California, Mexico. The inset map shows the geographical relationship between the study region (box) and the border between the U.S.A. and Mexico. In the main figure, bold black lines and black-dotted lines represent major faults in the area. Thin-black lines are national and state borders. Blue stars are earthquakes of magnitude 6 or above since 1969. White star is the epicenter of the April 4th Baja California earthquake in 2010. Red dots are earthquakes one day before or after the major event, April 3 and April 5, 2010. Green dots are earthquakes (magnitude >1) within one month after the mainshock event, April 5–May 5, 2010. Earthquake data is from the Southern California Earthquake Center. The white-square box covers the extent of Figure 2. The four tilting rectangular boxes are the areas of ALOS track T211, T212, T532, and T533.

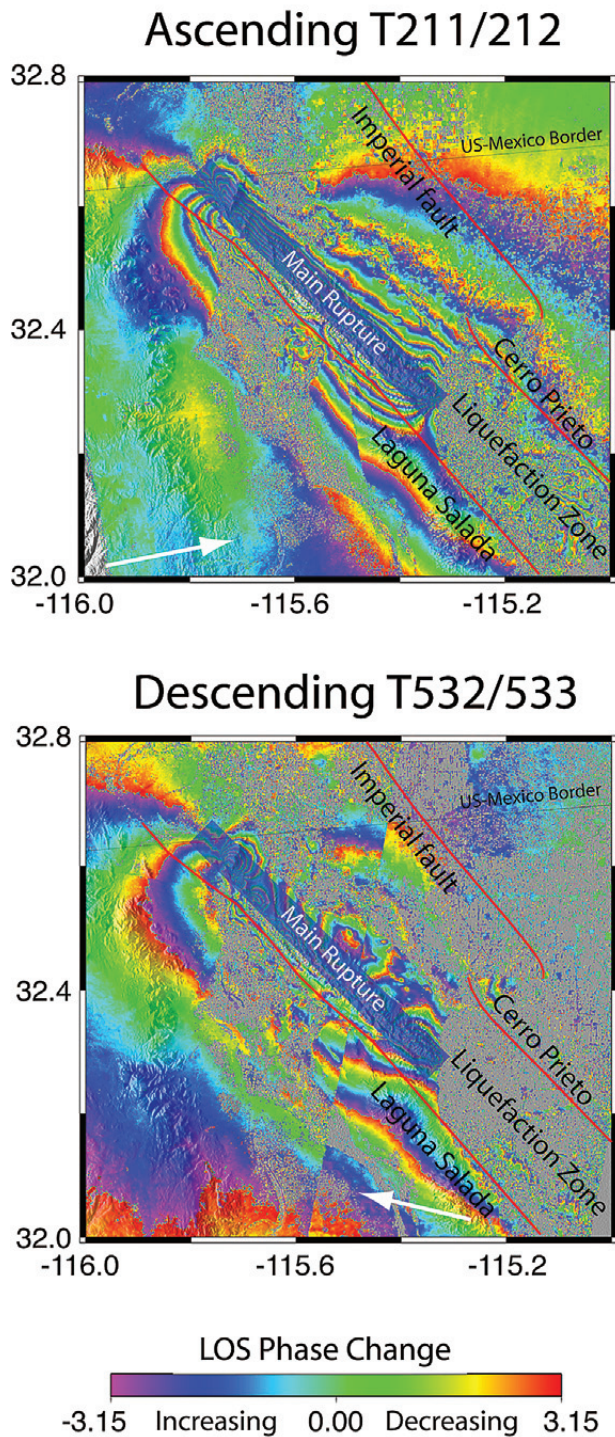


Figure 2: ALOS interferograms show the co-seismic deformation of the M7.2 April 4th Baja California earthquake. The left figure is from ascending tracks T211 and T212. The right figure is from descending tracks T532 and T533. Color change from blue to red represents a decrease in range. The interpretation is that the fault is right lateral and with a vertical component of east-side down. The rupture did not occur on any of the three main faults of the region: Imperial, Cerro Prieto, or Laguna Salada (red lines). Fault scarps of the main rupture are evident in the Cucapa mountains (blue-shaded area). The interferograms are decorrelated in the liquefaction zone, which is bounded by the Cerro Prieto and Laguna Salada Faults.

The 120-km long bilateral rupture lasted for more than 45 seconds causing extensive damage to buildings in Calexico [United States (U.S.)] and Mexicali (Mexico). According to a CNN report, the Assistant Director of Civil Protection in Tijuana said at least two people died and more than 100 were injured in Mexicali. The entire city of Mexicali, a large metropolitan area and the capital of Mexico's Baja California state, lost power as a result of this earthquake. The most significant damage occurred in the agricultural areas of the Colorado River Delta southeast of the main rupture, where irrigation systems had to be shut down. Approximately 35,000 people were displaced from their damaged homes and are now living in tent cities. The extent of damage to the agricultural areas due to liquefaction is far worse than initially reported.

The mainshock rupture, as revealed by aftershocks and radar interferometry, occurred on largely unmapped faults in the Cucapa Mountains and beneath the Colorado River Delta (Figure 2). Two of the highest slip-rate faults of the San Andreas system, the Imperial and Cerro Prieto Faults (35-40 mm/yr), are within this general area. Figure 2 shows the Advanced Land Observing Satellite (ALOS) Interferometric SAR (InSAR) data collected on April 17 along tracks 211 and 533, on May 4 along track 212, and on May 16 along track 532 in 2010. Two main features emerge: 1) The main rupture in the Sierra El Cucapa consists of at least two concentrations of right-lateral and east-side down normal faulting. Interferograms are decorrelated in the steep mountain areas where the combination of strong ground acceleration and steep slope produced major surface slides; 2) The southwest extension of the rupture goes beneath the agricultural area of the Colorado River Delta where the aqueduct system was destroyed. More importantly, the ALOS interferogram reveals the full extent of the 18-km by 60-km liquefaction zone. It is bounded on the east by the Cerro Prieto fault and on the west by the Laguna Salada fault. Field observations show that the roads have undulations with vertical amplitudes of 20-50 cm and most of the concrete-lined aqueducts are fractured. Interferograms are decorrelated over much of the area, although azimuth offsets help to delineate the zone of deep slip.

In the first few weeks after the earthquake, the scientific community gathered seismic and geodetic data sufficient to map the rupture plane as well as to assess areas of highest ground acceleration. Repeat-pass radar InSAR data was a critical component of this effort providing cm-precision co-seismic deformation maps over a 100-km by 400-km region. Field geologists use these maps as a reconnaissance tool for mapping the rupture. The U.S. Government Research Consortium datapool at the Alaska Satellite Facility (ASF) was a critical resource needed for rapid response to this earthquake, since it contained most of the pre-earthquake ALOS SAR images. ASF also worked in collaboration with the Japan Aerospace Exploration Agency (JAXA) to optimally schedule post-earthquake acquisitions. The critical data were acquired on April 17, May 4, and May 16, 2010, along the ascending and descending tracks shown in Figure 2. The interferograms show that the fault slipped both vertically, east-side down, and horizontally, right lateral. More importantly, these maps also reveal details of the

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surface rupture and the extent of the liquefaction zone. A preliminary co-seismic model based on InSAR can be found at Professor Yuri Fialko's website at <http://igpp.ucsd.edu/~fialko/baja.html>.

While timely data access (24 hr) was available for the two April 17 ALOS acquisitions, access to later acquisitions, including the May 4 and May 16 acquisitions, were typically delayed by 2 weeks. It is important to reduce this delay time, as rapid response to large earthquakes like this one is crucial for advancing scientific knowledge about the earthquake and to help mitigate seismic hazards within the community affected by the earthquake. Compared to the 2-weeks delay of attaining the ALOS data for this region, the data from the European Environmental Satellite (Envisat) are accessible to the U.S. scientific community within approximately one week. The delay of the ALOS data for the 2010 Baja California earthquake emphasizes the importance of a need for a U.S. InSAR satellite such as Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI), planned to be launched in 2017.



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