WESTERN NORTH AMERICA CRUSTAL DYNAMICS RESEARCH: WINSAR CONSORTIUM

PI 114

Eric Fielding[1] *and the WInSAR Consortium*[2]

[1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA.
[2] Western US InSAR Consortium, hosted at UNAVCO, Boulder, Colorado, USA.

1. INTRODUCTION

This final report is for the project PI-114 *Western North America Crustal Dynamics Research: WInSAR Consortium* that was originally proposed by David Sandwell, who was the WInSAR (Western US InSAR Consortium) Executive Committee Chair at the time of submission. The original investigation PI-114 had 45 co-investigators, the institutional representatives who represented the membership of WInSAR at the time the ALOS proposal was written. WInSAR presently has 93 institutional representatives and a total of 230 individual members (see http://winsar.unavco.org for more details). This report is written by the current WInSAR Excecutive Committee chair on behalf of the membership.

One of the main tasks of this WInSAR investigation was to provide JAXA with a priority list of data acquisitions to serve the needs of this large group of US investigators. The 50 scene per year allocation for the WInSAR group was, of course, insufficient to achieve the research objectives so WInSAR members helped to organize, and justify funding for, the US Government Research Consortium (USGRC) sponsored by NASA, NSF and USGS that has purchased a large pool of PALSAR data (currently ~200,000 scenes) housed at the ASF DAAC. There will be a second final report for PI-114 submitted to JAXA representing the results of David Sandwell and his colleagues at the University of California, San Diego. The final report presented here will summarize briefly the research findings and publications of the WInSAR membership.

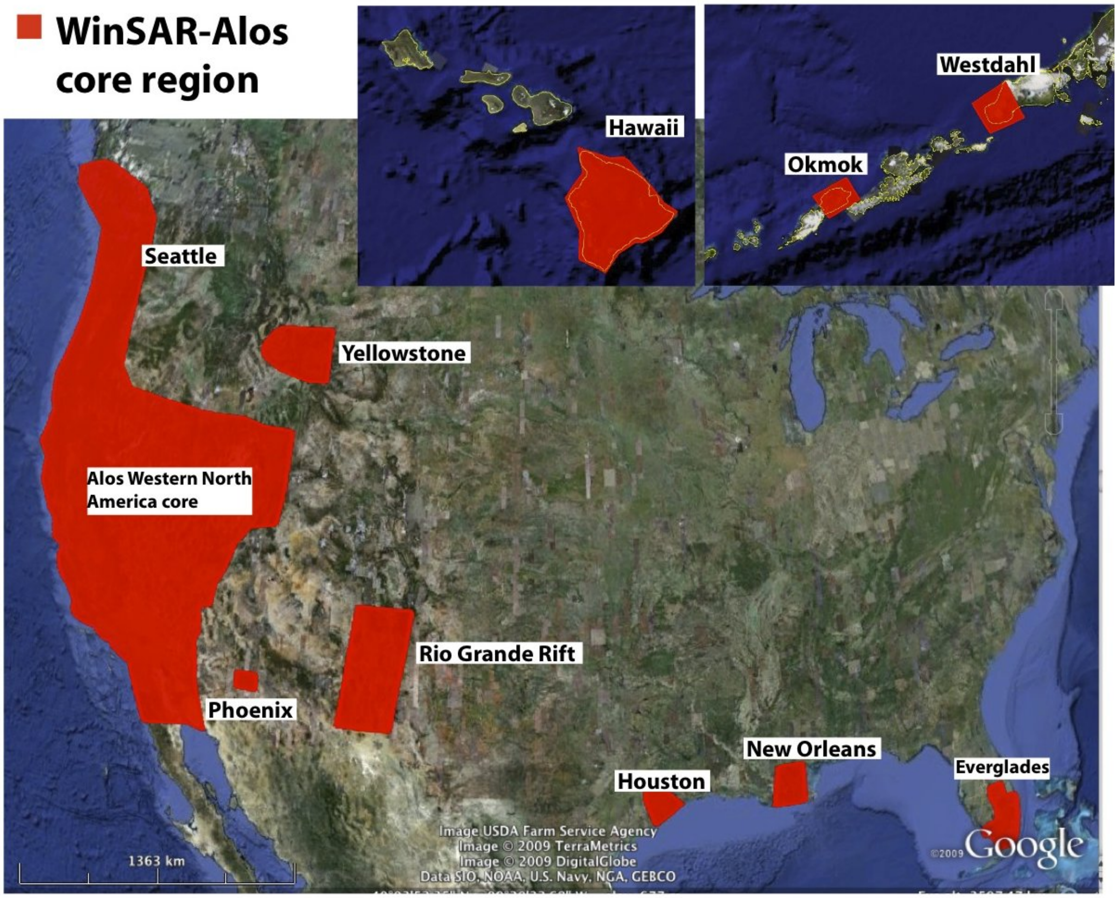

Fig. 1: WInSAR core area and additional North American sites of study outlined in red were used to request PALSAR data from the US Government Research Consortium.

2. SUMMARY OF PROPOSED RESEARCH

The western part of North America is the focus of intensive scientific research into a variety of plate boundary processes including earthquakes, volcanism, mountain building, and micro-plate tectonics. We proposed to use ALOS PALSAR data, with its unique L-band capabilities, for the following:

- Monitor strain accumulation and release along the North American/Pacific Plate Boundary with an emphasis on the San Andreas Fault Zone.
- Monitor the deformation of volcanic systems in the western US.
- Monitor crustal deformations at selected sites in the Basin and Range province and along the Baja California peninsula.

Under the auspices of the US Government Research Consortium, WInSAR members have also expanded their research using the ALOS PALSAR data into other areas of the Americas and the rest of the world. Additional research topics of research include ground subsidence due to groundwater withdrawal, subsidence due to sediment compaction and other processes in the Mississipi River Delta, and water flow in the Everglades.

Our originally proposed tasks and objectives follow:

- Modify existing InSAR processing algorithms to accommodate PALSAR data for change detection and DEM generation.
- Work with the ALOS team to schedule PALSAR data acquisitions over western North America. This will be done in co-ordination with the Alaska Satellite Facility (ASF).
- Compare L-band PALSAR-derived interferograms with C-band interferograms from ERS/Envisat as well as GPS measurements.
- Reduce the errors in PALSAR interferograms by modeling ionospheric and atmospheric artifacts.
- Publish and present scientific results in journals, scientific meetings, and at ALOS team meetings.

3. ALOS PALSAR DATA AND PROCESSING

PALSAR data are used in this project to create interferograms of volcanic, coseismic, interseismic and postseismic surface deformation in western North America and other regions of active tectonics and volcanism, along with other surface changes caused by hydrologic and sedimentary processes. In addition to the 50 scenes/year quota of data obtained through our PI project, we also benefited from a large number of PALSAR scenes obtained through the US Government Research Consortium (USGRC) data pool at the Alaska Satellite Facility. WInSAR members submitted a number of proposals through the ASF U-PASS (User-Proposal Application Submission System) to get quotas of PALSAR scenes for a number of areas that were purchased from the ALOS Americas Data Node (AADN) and put into the USGRC L1 Data Pool at the ASF DAAC. Other ALOS scenes were acquired directly at the ASF DAAC through downlinks via the NASA Tracking and Data Relay Satellite System (TDRSS) since April 2009. The USGRC was set up to provide the data through the data pool to users approved by the US government funding agencies involved. The SAR Data Center (DAAC) run by the Alaska Satellite Facility for NASA manages the USGRC data pool.

There were two big WInSAR proposals submitted by Falk Amelung, the WInSAR chair in 2009, to the USGRC to request PALSAR data for Latin America and North America as subscriptions, where both archived and all future acquistions were requested (see Fig. 1 and http://winsar.unavco.org/ALOS_UPASS.php for areas covered). The Latin America proposal was approved for 10,000 scenes and had received 5800 scenes as of February 2011. The North America proposal was approved for 10,000 scenes per year (Fig. 1) and it had received 11,096 scenes by February 2011. Earlier WInSAR proposals for the Americas included a Latin America proposal submitted in 2007 by Matt Pritchard that received 3350 scenes.

Worldwide, there were several other WInSAR proposals to the USGRC specifically for the 2008 Sichuan, China earthquake dataset, the 2010 Haiti earthquake dataset, and for other seismically active areas. These included large proposals submitted by Rowena Lohman (15,940 scenes requested) and David Sandwell (4724 scenes requested) for global regions for WInSAR data needs.

Coherence of the L-band data is excellent; however, limitations are presented by (1) relatively sparse sampling in time (usually greater than the 46-day repeat interval), (2) lack of descending orbit acquisitions as other instruments are switched on during the daytime flyovers and (3) substantial atmospheric and ionospheric artifacts. We thus complement the ALOS data with acquisitions from other spacecraft such as the ESA Envisat satellite and, for a few events, with GPS data from other sources.

All SAR data from the ALOS and Envisat satellites were processed from the raw signal data (Level 1.0 for PALSAR and Level 0 for ASAR). The GMTSAR system [1] was developed by Sandwell, Mellors, Tong, Wei and Wessel and includes a preprocessor for the ALOS PALSAR L1.0 data that has been used for most WInSAR research. The GMTSAR system also has programs for SAR image focusing, interferogram generation (stripmap and ScanSAR) and postprocessing that were used for some of the research described here (see report by Sandwell in this volume for more detail). GMTSAR software is available at http://topex.ucsd.edu/gmtsar.

Other research used PALSAR processed with the JPL/Caltech ROI_pac interferometric SAR (InSAR) package [2] (see http://roipac.org) along with the ALOS PALSAR preprocessor that is part of GMTSAR for the stripmap FB data. We also used the GMTSAR preprocessor to convert the ScanSAR WB1 data to faux stripmap data using the method described in [3] and completed the WB1-WB1 InSAR processing with ROI_pac. Pixel tracking or sub-pixel correlation calculations were performed using ROI_pac and GMTSAR. Corrections for topography rely on a version of the Shuttle Radar Topography Mission (SRTM) 3-arcsecond (90 m) spacing digital elevation model (Farr and Kobrick, 2000) that has the voids filled with other data sources, on data from the US Geological Survey (USGS) National Elevation Dataset (NED), or on special local digital elevation models acquired by LiDAR data.

4. RESULTS

Very brief summaries of research done by WInSAR members using ALOS PALSAR data are presented below.

4.1 Volcanic and earthquake events

First we present the results of studies for volcanic and earthquake events.

2007 Kilauea Volcano Rifting: The first event investigated by WInSAR members with ALOS PALSAR data was the "Father's Day" (June 17-20) 2007 volcanic rifting event on the east rift of Kilauea volcano. PALSAR interferograms and pixel tracking analysis allowed the extraction of vector deformation maps for the rifting event and other deformation at Kilauea that resulted in three publications [4][5][6]. See also the Sandwell et al. report in this volume for more details.

2007 Pisco, Peru Earthquake: The first earthquake investigated by WInSAR members with PALSAR data was the August 2007 Pisco, Peru Mw 8.0 earthquake. Ascending track PALSAR interferograms were combined with descending and ascending Envisat interferograms to study the slip distribution, rupture propagation and tsunami generation of this large subduction zone event in three publications [7][8][9].

2007 Tanzania Volcanic Rifting: A swarm of earthquakes in Tanzania marked a rifting episode on the East African Rift in July and August 2007. Analysis of ALOS PALSAR, Envisat, and Radarsat-1 InSAR revealed that the rifting involved both faulting and dike injection with several separate events during the episode [10a].

2007 Crandall Mine, Utah Collapse: The Crandall Canyon Mine, Utah, collapses in August 2007 resulted in a total of nine fatalities. Analysis of ALOS PALSAR mapped the pattern of subsidence of the surface and constrained modeling of the event. A combination of collapse and fault motion was required to fit the observations and elastic-plastic deformation at shallow depths further complicated the surface subsidence pattern [10b].

2008 Nima-Gaize, Tibet Earthquake: For the Nima-Gaize earthquake in central Tibet, interferograms with excellent coherence reveal coseismic and postseismic surface displacements due to slip on two faults, the mainshock (M_w6.4) fault plane and the fault plane of the largest aftershock (M_w5.9). The postseismic deformation field is closely correlated spatially with the coseismic field, suggesting that afterslip on the same fault planes [10][11]. See also Bürgmann et al. report in this volume for more details.

2008 Yutian, Tibet Earthquake: The March 2008 Mw 7.2 Yutian earthquake was the largest normal fault earthquake in Tibet in the last decade. We obtain a clear coseismic signal with L-band radar, which can be inverted for slip on a curved fault plane. Postseismic deformation is also under study and so far shows no viscoelastic deformation, only afterslip. See Bürgmann et al. report in this volume for more.

2008 Wenchuan, China Earthquake: A devastating Mw 7.9 earthquake occurred on 12 May 2008 beneath the Longmen Shan mountain front in the Sichuan province of China. The earthquake epicenter was located in Wenchuan County and the rupture continued into Beichuan County, where damage to the city of Beichuan was extreme. The earthquake caused great damage extending at least 300 km along the Longmen Shan and adjacent areas. The coseismic deformation field was well captured by PALSAR interferograms, which when combined with GPS measurements and with Envisat interferograms constrained detailed models of the geometry and slip distribution of the earthquake [12][3][13]. For the Wenchuan earthquake, WInSAR studies processed both ascending fine beam (8 paths, 470–477, with 8 to 13 frames on each path) and descending wideswath interferograms to completely cover the 300-km rupture. A total of more than 200 PALSAR frames were analyzed for the coseismic deformation, and more than 1000 PALSAR frames are being studied for postseismic and preseismic deformation. See the Sandwell et al. and Bürgmann et al. reports in this volume for more details on the coseismic and postseismic results.

2010 Haiti Earthquake: The large Mw 7.0 Haiti earthquake in January 2010 caused extremely large amount of damage and fatalies due to its location near Port-au-Prince. ALOS PALSAR data was the key information for locating the fault or faults that ruptured in this devastating event. Fortunately, both ascending and descending PALSAR scenes were acquired over the area before and after the event to provide interferograms that mapped the surface deformation. The surprising result of several studies using PALSAR [14][15] was that the main fault slip was on a previously unrecognized fault the Leogane Fault and not on the major plate boundary fault, the Enriquillo Fault. This means the Enriquillo Fault has more accumulated strain that is likely to cause future earthquakes.

2008 Tungurahua, Ecuador Volcanic Eruption: The February 2008 eruption of the Tungurahua volcano in Ecuador was studied with PALSAR and other data. InSAR analysis and elastic modeling show that there was inflation of a magma body beneath the volcano both before and at the same time as the surface eruption [16].

2010 Maule, Chile Earthquake: The great Mw 8.8 earthquake that started near Maule, Chile in February 2010 ruptured at least 600 km of the subduction zone. Analysis of PALSAR ascending strip map and descending ScanSAR and stripmap data captured the coseismic deformation of this very large event, using more than 200 frames of PALSAR. Early results show the down-dip limit of slip is about 150 km from the trench axis [17][18].

2010 Baja California, Mexico Earthquake: A large Mw 7.2 earthquake struck Baja California on April 4, 2010. It was given the name El Mayor-Cucapah earthquake after the areas most affected in the mountains west of the Mexicali Valley. In addition to the main ruptures, many faults to the north had triggered slip that was mapped by ALOS PALSAR, Envisat and UAVSAR interferometry [19][20]. The main fault ruptures were quite complex and extend for approximately 120 km along several faults, some of which were not previously recognized and caused extensive liquefaction in the Mexicali Valley and Colorado River Delta [20][21][22].

4.2 Other surface deformation

In addition to the events described above, WInSAR scientists have investigated a number of other types of surface deformation including interseismic deformation [23] and the variation of coherence over vegetated areas [24].

5. ACKNOWLEDGMENTS

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