EarthScope Comprehensive SAR Archive

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Proposal Submitted

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to

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EAR – EarthScope Science

1. PROPOSAL OVERVIEW

Over the last two decades, Interferometric Synthetic Aperture Radar (InSAR) has emerged as a valuable tool for detecting and monitoring changes in the Earth's surface due to seismic, volcanic, tectonic, hydrologic, etc. activities, and forecasting a variety of natural hazards. InSAR observations provide critical data to better understand and predict changes in the Earth system. The western part of North America is the focus of intensive scientific research focused on a variety of plate boundary processes including earthquakes, volcanism, mountain building, and microplate tectonics. Here we request funding to acquire SAR imagery from the European Space Agency (ESA) ERS and Envisat satellites for the following objectives, all relevant to EarthScope science:

- Monitor strain accumulation and release along the North American/Pacific Plate Boundary with an emphasis on the San Andreas Fault system.
- Monitor crustal deformation in the Basin and Range province.
- Monitor the deformation of volcanic systems in the western US.
- Monitor seismotectonic processes along the Cascadia margin and the Wasatch fault.

We request funds for imagery acquired largely after October 2008, the end of the GeoEarthScope component of the EarthScope facility construction project. We also request funds to task the Envisat satellite until October 2010 when Envisat's InSAR capability ends. The proposed new imagery combined with the available GeoEarthScope and WInSAR imagery will form a complete, unprecedented 1992-2011 SAR data set for the WInSAR core region (Fig. 1). It will lead to new scientific discoveries within the EarthScope region as well as to the development of new InSAR methods aimed at improving the accuracy of the measurement. With the new data we will for the first time be able to estimate the InSAR vertical for the EarthScope region. The next opportunity for this will not come before 2018 after 6 years of Sentinel acquisitions, Envisat's successor.

2. APPROACH

The proposed imagery will be acquired by the Western North America InSAR Consortium (WInSAR), a collection of universities and public agencies created to manage the acquisition and archiving of spaceborne SAR data for scientific use. WInSAR is based at UNAVCO in Boulder, and currently has 75 member institutions, 57 of which are U.S. institutions with full voting rights. WInSAR is governed by an Executive Committee (EC), elected by the membership for two-year terms. The current Chair and Vice Chair of WInSAR are Falk Amelung, University of Miami, and Roland Bürgmann, University of California at Berkeley, the Science Principal Investigators of this proposal.

We request funding for the acquisition, archiving and dissemination of new SAR imagery for the WInSAR core area. The actual research work will be dealt with in independent proposals by the member institutions. Some WInSAR members already have received, or will be applying for funding from NSF or NASA EarthScope Science programs. For example, the Science PI Amelung plans to submit a proposal focusing on the geodynamics of the Basin and Range province

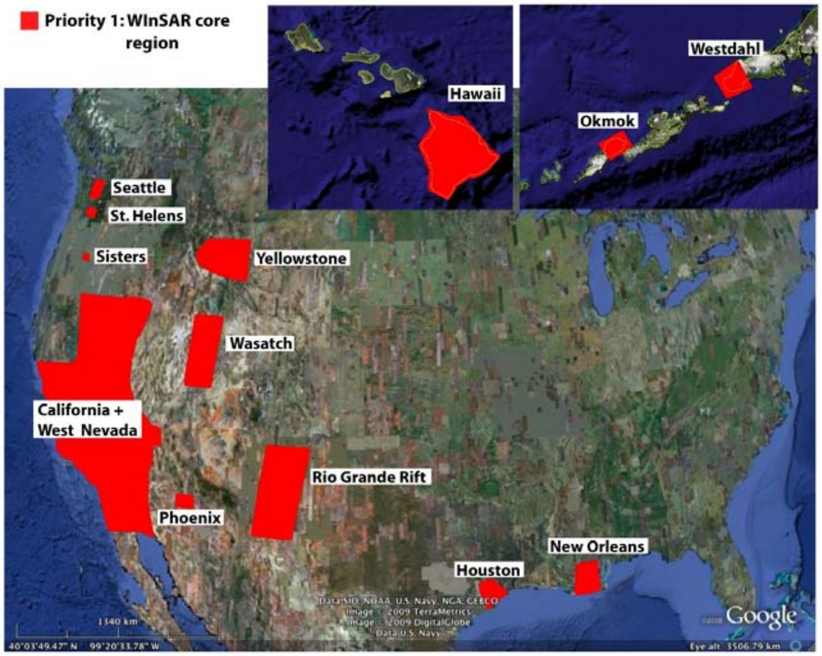

Figure 1. *WInSAR core regionas defined in WInSAR's strategic plan. WInSAR proposes to aquire the complete ERS and Envisat data sets for the marked areas for the 1992-2011 period. Using the SAR data the WInSAR membership will address first-order EarthScope science problems. The most important application is to combine the imagery for the California and Nevada area with GPS data from the PBO network to large scale InSAR-GPS integrated time series to better characterize the present-day deformation of the Pacific-North America plate boundary*

and the Science PI Bürgmann just submitted a proposal focusing on 4D faulting processes the southern San Francisco Bay area. Ten WInSAR members have already been selected by NASA for funding through the program "EarthScope: The InSAR and Geodetic Imaging Component". All these research endeavors rely on WInSAR to provide complete SAR data sets for the EarthScope area.

3. DATA REQUEST

We request funding to acquire imagery for the WInSAR core area, defined by the WInSAR members in WInSAR's strategic plan. The WInSAR core area comprises the tectonic areas in California and Nevada, the Wasatch front, the Rio Grande rift, and the volcanic areas in Yellowstone, St. Helens, Sisters, Okmok, Westdahl, and Hawaii, and the land subsidence areas in Seattle, Phoenix, Houston and New Orleans (see http://winsar.unavco.org/newsletters/WinSAR_Strategic_Plan_9-2008.pdf). The current WInSAR and GeoEarthScope collections contain 8,400 and 26,500 scenes from ESA in the core area. We request a total of $270.2 k for satellite imagery (about 13,100 scenes), plus personnel, IT costs and overhead. With these funds we will be able to acquire the remaining Envisat and ERS archive for the 1992-2011 time period for the WInSAR core area. We feel that this is an extremely good deal given the cost of the satellites and the satellite operation. In fact, the European Space Agency sees collaboration with WInSAR/UNAVCO on acquiring this imagery as the European contribution to the EarthScope project.

Details about the requested imagery are found in the budget justification. The actual data costs are $346.2k until May 2011 but $76k of this amount will be covered by the current WInSAR funding. For defining data needs, we have identified five different periods. For the first period from the start of the ERS satellite to the end of the GeoEarthScope project (June 1992-Septermber 2008) we will acquire about 9000 frames which could not be acquired during GeoEarthScope. This is largely because ESA was lacking sufficient capacities during most of the GeoEarthScope project. The second period is from the end of GeoEarthScope until the beginning of the WInSAR tasking (October 2008 to March 2009). During this time period only very little Envisat imagery was acquired because the satellite was not tasked. The third period is since the beginning of the Envisat tasking until the beginning of this project (April 2009 to December 2009). For these two periods we request the acquisition of all acquired imagery. The fourth period starts at the beginning of this proposal to the end of the Envisat interferometry mission (January 2010 to October 2010). For this period we request funding for Envisat tasking plus imagery acquisitions. The fifth period starts after the Envisat orbit is lowered to the end of this project (Nov 2010 to May 2011). For this period we only request ERS2 acquisitions because Envisat will not be usable any more for interferometry.

4. SIGNIFICANCE AND INTELLECTUAL MERIT

The InSAR vertical. InSAR measures changes in radar-line-of sight direction. The vertical component can be inferred by combining imagery acquired from descending orbits (satellite traveling South) and imagery from ascending orbits (satellite traveling North) and in some areas by integrating GPS velocity fields. For the EarthScope region it has not yet been possible to reliably estimate the vertical because of insufficient ascending imagery (most published studies use descending data only). This project will lead for the first time to the InSAR vertical by acquiring 6 year of ascending Envisat imagery. The next opportunity to measure the InSAR vertical will not be before 2018 after 6 years of Sentinel operations.

Unprecedented time-series. The advantage of Envisat compared to other satellites is that the satellite can be tasked to achieve frequent image acquisitions (the disadvantage are costs). The GeoEarthScope project utilized this tasking capability and obtained excellent image time-series (one acquisition every 35 days, the orbit repeat cycle of the satellite). This is about three to four times better than for ERS. Frequent SAR acquisitions allow measurements in vegetated areas such as Central and Northern California and lead to more precise measurements elsewhere. WInSAR resumed satellite tasking in March 2009. The objective of this proposal is to acquire all the tasked imagery, and to continue satellite tasking until October 2010 when Envisat loses its InSAR capability (the satellite will be lowered to a different orbit with a larger tube because of fuel considerations).

5. BROADER IMPACT

Infrastructure for research. The proposed imagery will significantly enhance the research infrastructure because complete data sets will be readily available for the WInSAR core region. The data archive will be updated on an automated basis by UNAVCO staff. The 2008 WInSAR strategic plan identified such a subscription-based data system (enjoyed by the GPS and seismology communities since years) as one of the top priorities improvement.

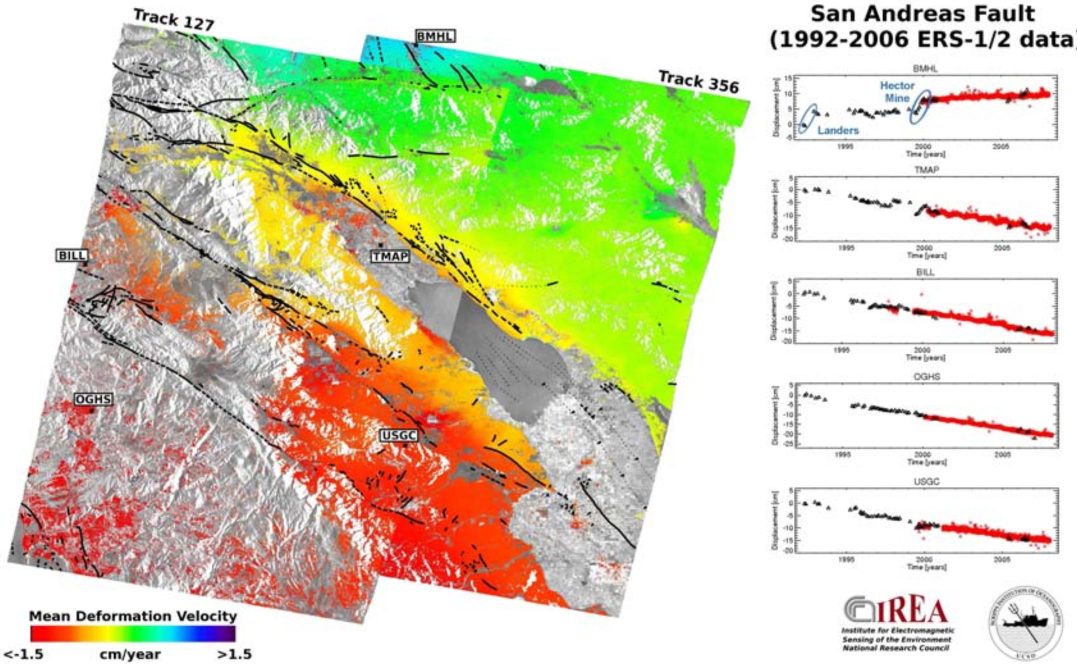

Figure 2. *A mosaic of the mean line-of-sight (LOS) velocity maps of the southern San Andreas Fault area, superimposed on a SAR amplitude image. The black wavy lines denote traces of active faults. Black squares denote the locations of five continuous GPS stations. The right panel shows a comparison of InSAR timeseries computed using the SBAS technique (black symbols) and the GPS timeseries projected onto the LOS (red symbols). Figure by Y. Fialko (SIO) and R. Lanari (IREA).*

Education. As explained below, WInSAR data are widely used for education; 14 member institutions use WInSAR data in undergraduate and graduate courses. WInSAR data resulted in 33 student theses (most of them PhD dissertations).

6. THE WINSAR FUNDING STRUCTURE

WInSAR – a consortium funded by NSF, NASA and the USGS. There is a general sentiment among the funding agencies that InSAR data should be funded on the same level by NSF, NASA and the USGS. This is the rationale behind the base funding of WInSAR with each agency contributing $50k/yr. The WInSAR E.C. feels that a temporary deviation from this balance is acceptable for four reasons. First, the proposed Envisat imagery acquisition is a science-driven unique opportunity that requires rapid action (no data are possible after 10/2010). Second, this change in the funding balance applies only for Envisat and concludes the very successful GeoEarthScope activity of the NSF (GeoEarthScope ended in 10/2008). Third, for programmatic reasons NASA has limitations in supporting the tasking and imagery purchase of foreign satellites (NASA's policy is free and open data access). Fourth, the larger picture shows that there may not be a funding imbalance. NASA covers about ~95% of the costs for ALOS imagery (through the Alaska Satellite Facility, ASF) which is also heavily used by WInSAR members.

The WInSAR EC plans to strike a new balance between the funding agencies with a WInSAR transitional proposal in 2011 until WInSAR is fully incorporated into UNAVCO in 2012. This balance will concern the Sentinel satellite(s), the Envisat successor with a planned operation time of 15-20 years, for which the imagery costs have not been determined. It is interesting to note that the level of base funding for GPS and Seismology is currently by factors of 27 and 117larger

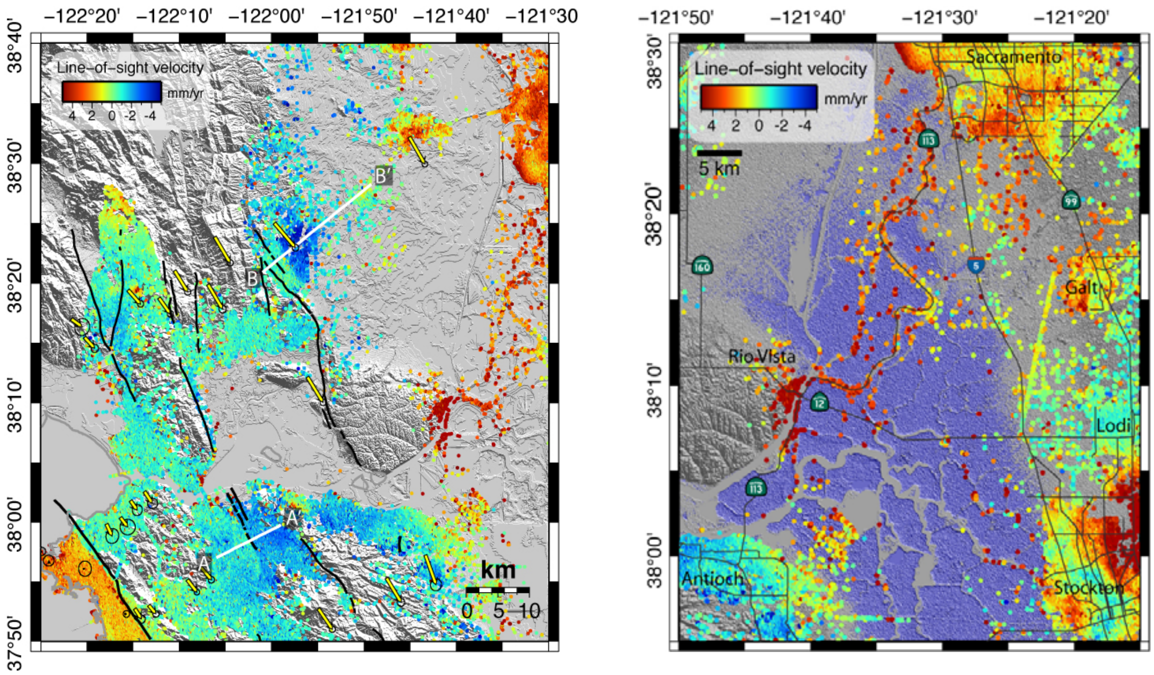

Figure 3. Left: *PS-InSAR data spanning eastern Coast Ranges and Great Valley. Note uplift feature (negative LOS velocity) near Vacaville and rapidly subsiding areas in Valley. Sharp offsets across Hayward, Concord, and Green Valley faults (black lines) are due to fault creep. Yellow arrows show horizontal GPS velocities from BAVU compilation.* ***Right:*** *PS-InSAR close-up over Sacramento Delta. Blue areas lie below sea-level, protected by levees along rivers and canals. Stable scatterers are sparse in agricultural areas. Note rapid subsidence in Delta and urban areas from water withdrawal from underlying aquifers (figure by Ingrid Johanson UC Berkeley, 2009).*

than for WInSAR (WInSAR, $150k/yr, UNAVCO facilities, $4 million/yr and IRIS, $17.5 million/yr).

7. SCIENTIFIC RATIONALE FOR CONTINUED DATA ACQUISITION FOR THE WINSAR ARCHIVE AT UNAVCO

InSAR represents an important component of EarthScope. While a new EarthScope InSAR satellite mission did not succeed as initially envisioned, InSAR represents an important component of many EarthScope science projects. Together with data form USArray, PBO and SAFOD, InSAR data compiled by GeoEarthScope and WInSAR at UNAVCO help illuminate the dynamics of Earth processes. WInSAR team members have been involved in the earliest demonstrations of spaceborne radar interferometry, the development of InSAR as a practical technique, and modeling studies that relate measured interferograms to slip and pressure changes beneath the Earth's surface. While the work described here concentrates primarily on shallow crustal processes such as earthquakes and volcanoes, consortium members investigate many other phenomena as well, including hydrology, cryospheric studies, vegetation science, and oceanography. Here we illustrate some of the ongoing research at member institutions.

7.1 THE SAN ANDREAS FAULT SYSTEM

The San Andreas Fault (SAF) in California is a major 1000-km long plate boundary fault that accommodates much of the relative motion between the Pacific and North American Plates. Most of the SAF exhibits a stick-slip behavior and is capable of producing great earthquakes

(M8+ events occurred in 1857 and 1906). The southern section of the fault has not produced a great earthquake in historic times (over more than 300 years), but geologic data indicate that it did rupture in the past. Frequent InSAR observations of the SAF are crucial for advancing our knowledge about the rate and style of secular strain build-up. Outstanding questions concern slip rates and locking depths on various fault segments and the prevalence and magnitude of surface creep. Spatially and temporally dense InSAR observations are crucial for resolving the issue of precursory deformation (or the lack of thereof), as well as the on-going debate about the mechanisms of post-seismic relaxation. Figure 2 illustrates interseismic deformation along the southernmost segment. The new results clearly reveal a relative motion between the Pacific and North American plates with nearly equal partitioning of strain between the San Andreas and the San Jacinto faults. These faults are believed to pose the largest seismic risk in southern California.

Frequent SAR acquisitions are critical to resolve subtle deformation and are necessary in some areas because of decorrelation of the radar echos. Figure 3 shows surface deformation due to active faults in Central California obtained from a permanent scatterer analysis of 80 images. Specific research questions include: (1) Locking distribution and seismic potential of the Hayward and other partly creeping faults in the San Francisco Bay region and on the creeping segment of the San Andreas. (2) Uplift rates and kinematics of active thrust faults in the eastern Coast Ranges of California. (3) Kinematics and dynamics of deep-seated landslides. (4) Transient deformation associated with slow slip events and postseismic relaxation in the SAF system.

7.2 BASIN AND RANGE

The Basin and Range Province, located between the Sierra Nevada and the Coast Ranges in the east and the Rocky Mountains and the Colorado Plateau in the west accommodates up to 25% of the relative plate motion between the North America and the Pacific Plates. Fifteen years of GPS data suggest that most of the deformation is accommodated along its margins, along the Wasatch fault in the east and in the Walker Lane in the west. A distinct zone is the Central Nevada Seismic Belt which generated several magnitude 7+ earthquakes in the past century. The outstanding science questions include: (1) Is active deformation confined to the eastern and western margins with the Central Basin and Range acting as a rigid micro-plate? (2) What is the nature of deformation of the Walker Lane? Is this region an incipient plate boundary that eventually will supersede the SAF system as the major boundary between the Pacific and North American plates? (3) Why is there an increased seismic activity in Central Nevada?

The Basin and Range province has only sparse coverage by the Plate Boundary Observatory because of its large spatial extend. InSAR has the potential of filling this observational gap. For example, a study by *Gourmelen and Amelung* [2005] discovered a broad uplift in the Central Nevada Seismic Belt at an average rate of 2-3 mm/yr. This uplift was interpreted as indicating mantle relaxation following a series of major normal earthquakes 50-80 years ago (Fig. 4). Figure 5 shows an example of recent seismic activity in the region (the 2008 M6 Wells earthquake).

7.3 EASTERN CALIFORNIA SHEAR ZONE

The Eastern California Shear Zone is located south of the western Basin and Range and also accommodates about 25% of the relative motion between the North American and Pacific plates. Deformation is accommodated along several strike-slip and normal faults such as the Owens Valley, Panamint Valley and Death Valley fault zones. The faults are slow moving (rates

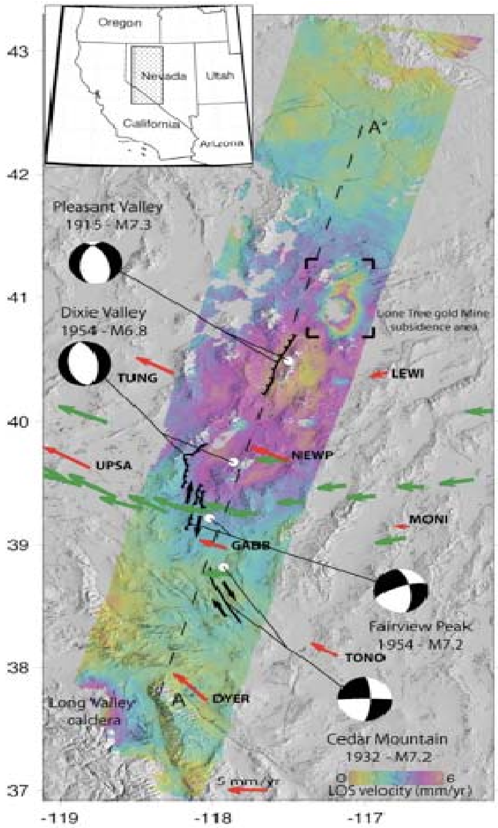

Figure 4. *InSAR ground velocity map for the central Nevada seismic belt showing post-seismic deformation following the 1917–1954 earthquakes. The epicenters (white circles), focal mechanisms, and surface ruptures are also shown. Green arrows, campaign GPS velocities; red arrows, Basin and Range Geodetic Network (BARGEN) permanent GPS velocities. This result is based on 16 SAR acquisitions. With the new Envisat data the membership will refine the Basin and Range deformation by combining InSAR time-series with CGPS, and to develop new models to explain the observations. This is also one of the top priorities of the EarthScope program. From Gourmelen and Amelung [2005].*

smaller that 5-10 mm/yr). It has been difficult to resolve these low rates with geodetic methods. Recently, Gourmelen et al. (2009) used InSAR time series to show that the Hunter Mountain fault is partly creeping and estimated its slip rate as 5 mm/yr (Fig. 6). One of the major applications of the new InSAR data will be improved characterization of contemporaneous deformation and fault slip in the Eastern California Shear Zone using time series of hundreds of images.

7.4 CASCADIA

The Cascadia subduction zone occupies nearly half of the North America plate boundary in the lower 48 states. The subduction zone strongly influences the kinematic and geodynamic behavior of the North American plate margin and is the source of some of the largest earthquakes worldwide (an M9+ earthquake occurred in 1700); yet we have only rudimentary knowledge of the contemporary velocity field, and its relationship to the seismic cycle and tectonic driving forces. While the surface conditions are not ideal for radar interferometry due to vegetation and abundant precipitation, frequent radar acquisitions can mitigate these problems, as demonstrated in

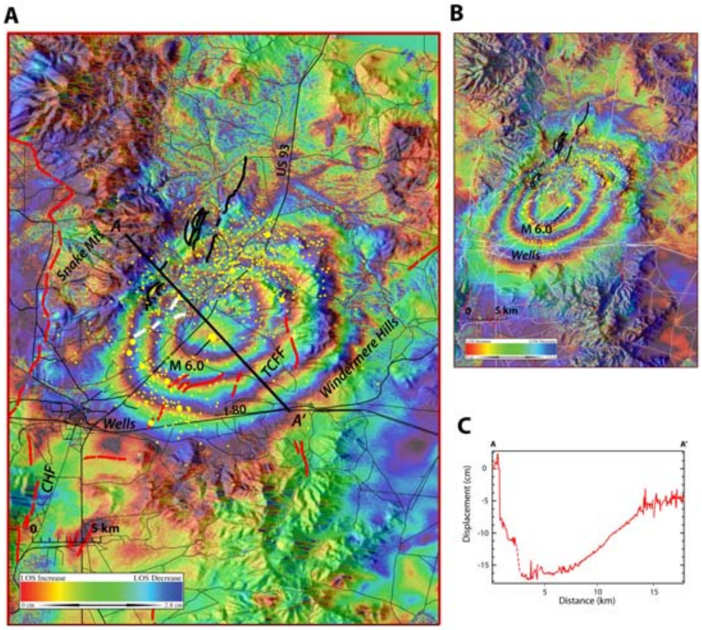

Figure 5. Wrapped interferograms showing deformation and seismicity associated with 21 Feb 2008 M 6.0 Wells earthquake: A. descending, B ascending, C LOS deformation profile. Fault slip occurred along a previously unrecognized northeast-striking normal fault along the eastern flank of the Snake Mts at Wells, Nevada (figure by John Bell, University of Nevada, Reno).

Fig. 2

Figure 7. Principal scientific objectives include: (1) establishing the character and behavior of the Cascadia megathrust and its geodynamic role in western North America, (2) determining the extent of strain partitioning in the convergent margin, and the role of continental extension, distributed transform faulting, contraction, and magmatism in accommodating deformation.

Cascade volcanoes. The 1300-km-long Cascade volcanic arc is the largest and most active volcanic system in the conterminous United States. Tracking magmatic processes and edifice instabilities requires high spatial and broad temporal strain resolution near the volcano. Understanding interactions between magmatic and tectonic processes requires broad-scale deformation monitoring. The new WInSAR data will greatly advance (in consort with PBO instruments) our knowledge of the magmatism of the Pacific Northwest, and the associated geohazards.

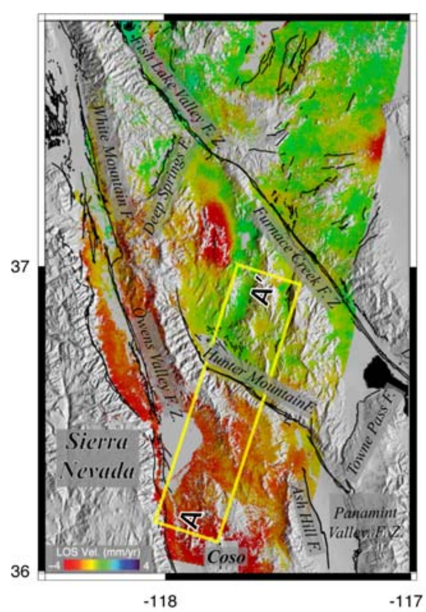

Figure 6. Velocity change across the Eastern California Shear Zone draped over topography. InSAR reveals rapid strain accumulation across the Hunter Mountain Fault. (From Gourmelen et al., 2009)

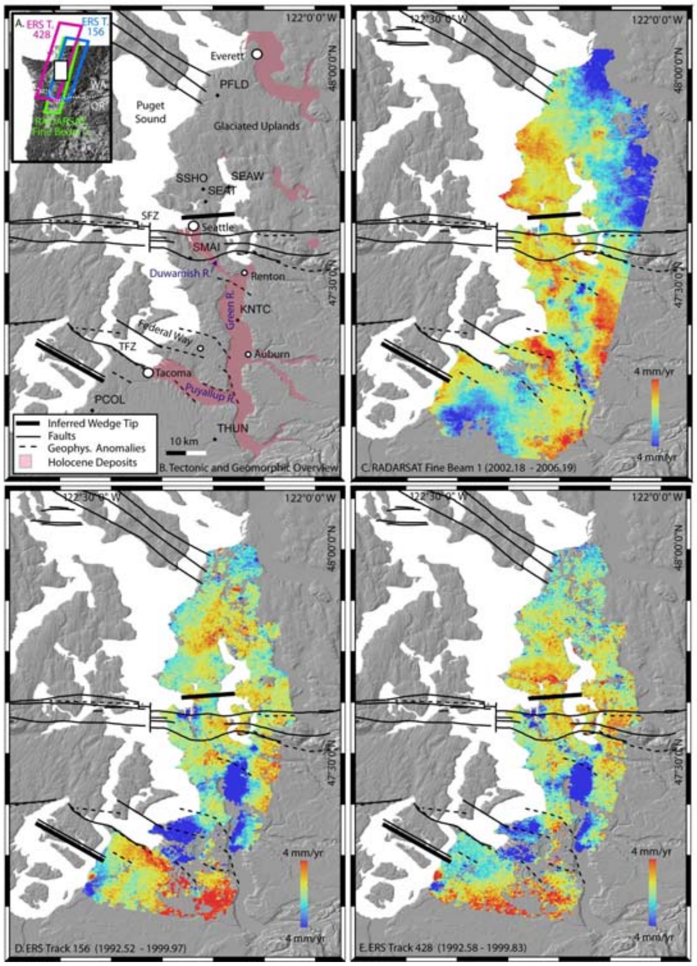

Figure 7. *Groundwater deformation in the Seattle, WA, area from 1992-2006. (a) Tectonic and geomorphic overview of the study area showing faults and areas of interest. (b-c) Patterns and magnitudes of mean radar line-of-sight (LOS) surface velocity calculated from the Canadian RADARSAT-1 (b) and European ERS-1/2 satellites (c and d). The large blue area shows net subsidence between 1992-2006 of several cm related to human activities. The areas of deformation seem to be controlled by the nature of the geologic deposits and the location of faults. There is no evidence for tectonic deformation above 2 mm/yr on the Seattle, Tacoma or other major faults. From: Finnegan et al., 2008.*

8. WINSAR DATA IN THE U.S. SCIENCE COMMUNITY

In this section we demonstrate the wide use of WInSAR data for EarthScope science. We first list a summary of the research activities at different member institutions, some of them funded by the NSF and/or NASA EarthScope science program. We then list university courses and student theses using WInSAR data. Most of these activities are relevant for EarthScope. It has to be emphasized that the member institutions completely rely on WInSAR to obtain SAR data for the EarthScope area. WInSAR has the necessary agreements with the European Space Agency. Proposals requesting funds for SAR data are commonly rejected with the comment that WInSAR should do the SAR data acquisition.

8.1 EARTHSCOPE SCIENCE CONDUCTED BY WINSAR MEMBERS

***Zhong Lu,USGS*:**USGS scientists will be conducting a Persistent Scatterer InSAR (PSInSAR) study of deformation in the Cape Mendocino area. This will tap the ERS-1/2 archive. We will also conduct a coherence test of ALOS data in the Mendocino area. In addition, USGS scientists will carry out PSInSAR studies over Parkfield area using ERS-1, ERS-2 and Envisat images.

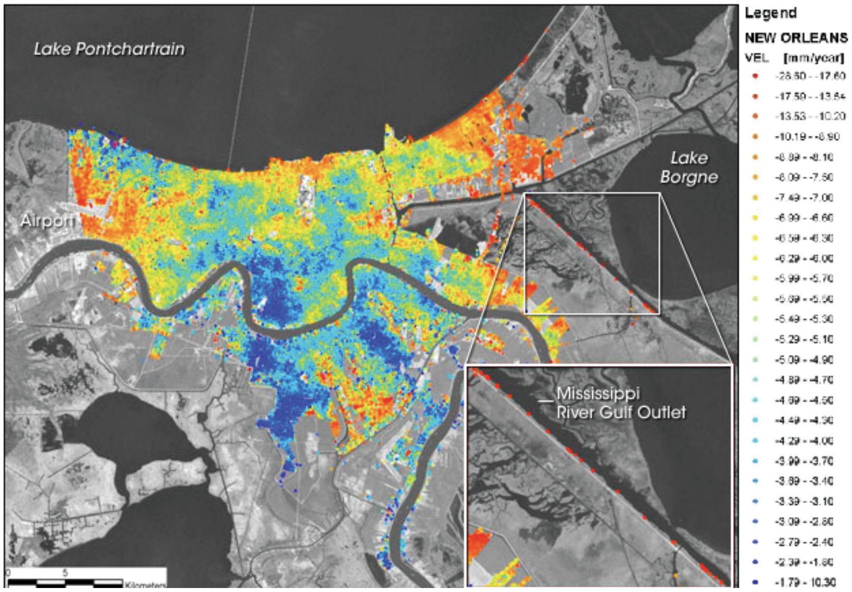

Figure 8. Land subsidence in New Orleans, Lousiana during 2002-2005 from Radarsat Permanent Scatterer interferometry (PSInSAR). Most of the city is sinking by about 7 mm/yr but scatterers at levees near the Mississipi River Gulf Outlet are subsiding at rates of 25 mm/yr. From Dixon, et al., [2006]. On of the research objectives is to develop new subsidence data for 2006- 2010.

Mark Simons, Caltech: We will pursue small amplitude tectonic deformation signals in the Basin & Range using stacks of ERS and Envisat data integrated with continuous GPS data. We are also going back and reassessing coseismic models of the Landers earthquake.

Zhenhong Li, University of Glasgow, UK: We are using WInSAR data to (1) develop and validate atmospheric correction models for reducing water vapour and ionospheric effects on SAR interferograms; (2) develop advanced InSAR time series and InSAR/GPS integration techniques to detect slow deformation signals and (3) investigate tectonic deformation of the Eastern California Shear Zone and Yucca Mountain, Nevada (collaborating with Univ. of Nevada, Reno).

Gilles Peltzer, UCLA: Fault and earthquake processes in California: Analyze InSAR deformation field near surface rupture to observe response of fault zone to co-seismic strain. Use time series data to infer temporal behavior of post-seismic deformation and develop poro-elastic models. Exploit time series data to characterize fast slip rate observed along the Blackwater fault.

Kristy F. Tiampo, University of Western Ontario: Current research into groundwater deformation and permafrost changes are underway for both the US and Canada. Ongoing studies continue using data from both the WInSAR and GeoEarthScope archives in order to refine techniques for integration of CGPS and InSAR signal, in conjunction with lidar.

Rowena Lohman, Cornell University: The large number of SAR observations available for individual areas within California allow the use of time-series techniques to detect transient strain events in Cascadia. I am applying Kalman-filter and persistent scatterer methods to data within the Salton Trough. The goal of this work is to quantify transient activity along the Imperial fault.

Matt Pritchard, Cornell: We are conducting studies in the Seattle/Vancouver area. Currently we focus on land subsidence (very relevant in Seattle because of global water level increase). We hope to eventually use long time series of ERS and Envisat data in combination with ALOS data to resolve strain accumulation related to the Cascadia subduction zone.

Mike Taylor, University of Kansas: We are using the WInSAR archive to quantify slip rates along faults that comprise the Eastern California Shear Zone (ECSZ). Characterizing the deformational style and quantifying the strain accumulation at these fault terminations will assist in quantifying bulk strain within the ECSZ of the Mojave.

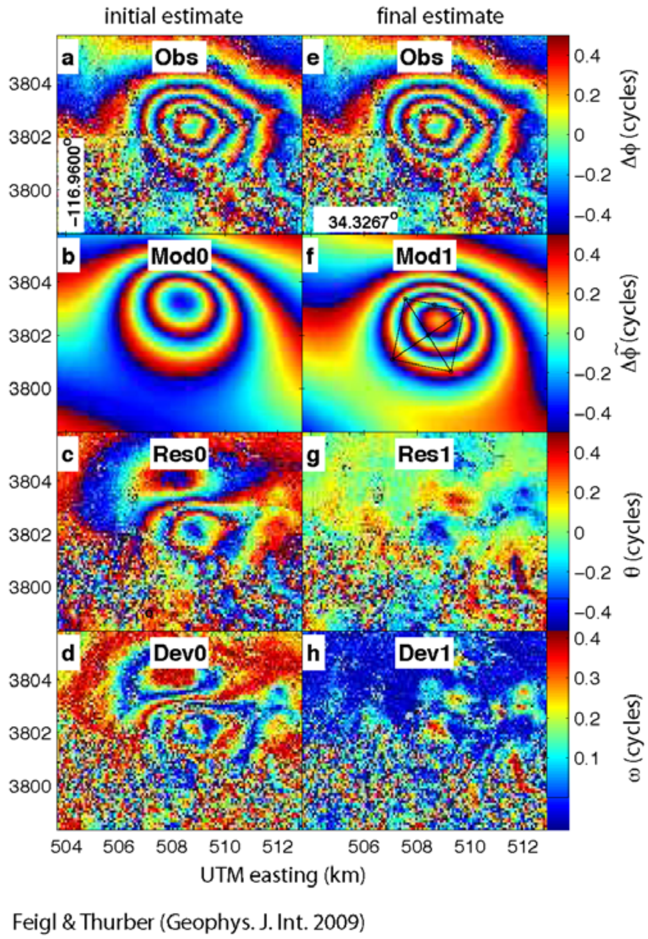

Figure 9: *Ground deformation caused by a moderate earthquake in California. The deformation was measured by interferometric analysis of synthetic aperture radar (InSAR) data, as shown in panels (a) and (e). The deformation field was also simulated by a theoretical model, as shown in panels (b) and (f). The parameters in the model were initially estimated by a trial-and-error process (b) and finally (f) by the General Inversion of Phase Technique (GIPhT) developed by Feigl and Thurber [2009]. The final estimate (right column) fits the data better than does the initial estimate (left column). The top three rows are interference patterns that show the difference in phase between a pair of images spanning the time interval from 24 April 1992 to 18 June 1993. The concentric fringes show that the magnitude 5 Fawnskin earthquake on 4 December 1992 raised the ground surface by as much as 12 cm over an area several kilometers wide.*

Andrew V. Newman, Georgia Institute of Technology: Using data collected through the WInSAR consortium we developed new models of time-dependent deformation at Long Valley Caldera (Newman et al., 2006). Over the next 3 years, we will continue to utilize SAR imagery in Long Valley Caldera, and the Valles Caldera and Socorro Magma Body in New Mexico.

David Schmidt, University of Oregon: My group is studying fault related deformation, land subsidence from groundwater recharge and extraction, as well other crustal deformation signals in the western US.

Rob Mellors, San Diego State University: Examine fault movement and properties in the Salton trough and nearby areas; map areas of groundwater withdrawal and estimate aquifer properties in same area.

John Wahr, Univ. of Colorado: We have been using WInSAR data to study land surface deformation in eastern Utah related to salt tectonics. Sedimentary strata above salt layers displace because the mobile salt moves as it gets squeezed. We are also using WInSAR data to map surface motion associated with slow landslides and rock glacier flow in the mountains of Colorado.

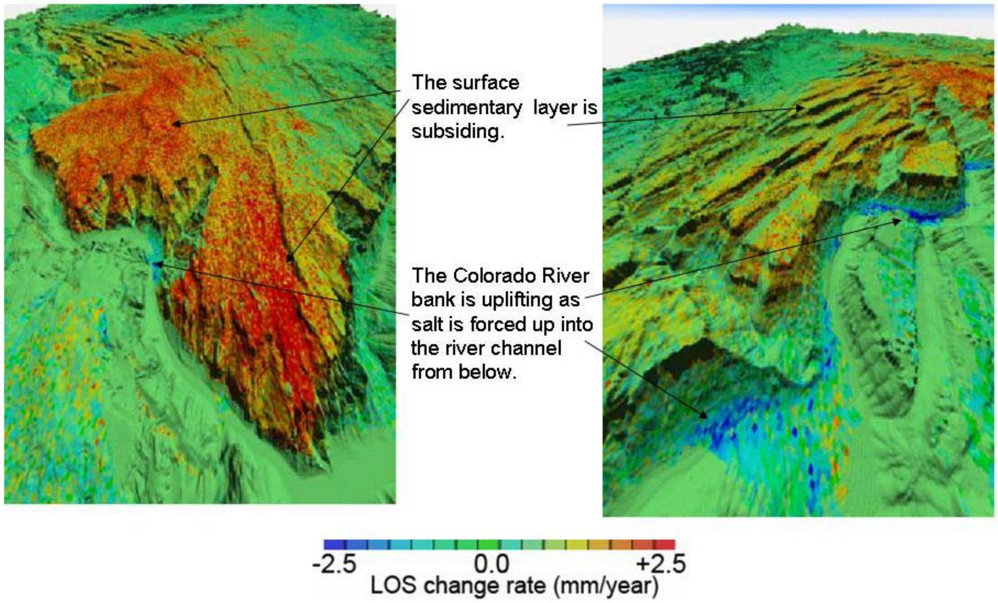

Figure 10: *Line of sight change, inferred from 11 independent ERS interferograms, for the Needles District in Canyonlands National Park, Utah. Positive LOS implies ground subsidence. The surface sedimentary layer pushes down on the underlying evaporite layer (salt), squeezing the evaporites out into the Colorado River, and subsiding. Left panel: Looking from SW of the Needles, towards the NNE. Right panel: Looking from NW of the Needles, towards the SSE. From Furuya, et al. 2007.*

Falk Amelung, University of Miami: Gravitational spreading and the volcanic systems of the Hawaiian Volcanoes, Contemporaneous deformation of the Basin and Range Province, Contemporaneous deformation of the Eastern California Shear Zone, Land subsidence is New Orleans (Fig. 8), Louisiana Everglades sheet flow.

Paul Vincent, Oregon State University: We use WInSAR data over the Pacific Northwest from Cape Mendocino to Vancouver Island along the Cascadia Margin. The applications are (1) for long-term vertical deformation measurements and (2) for short-term landslide potential and coastal erosion assessments. I also use WInSAR data inland along the Cascadia Subduction Zone to search for, and monitor seismically active crustal faults.

John Bell, University of Nevada, Reno: The InSAR Lab at the University of Nevada has been conducting a wide range of studies related to groundwater pumping and to tectonics of the western Basin and Range (mine-dewatering subsidence and baseline studies for future water exportation projects). Tectonic studies include searches for ground deformation associated with M 4-5 earthquakes, and with the 2008 M 6.0 Wells (Fig. 5) and the M 4.9 Reno earthquakes.

Ben Brooks, University of Hawaii: Continued monitoring of Big Island (Mauna Loa inflation; Kilauea ongoing eruption; Kilauea south flank slow earthquakes). Our work on the Big Island together with the GPS networks is a test-bed for persistent scatterer and atmospheric mitigation techniques. We also investigate relative sea-level changes along coastal western US.

Eric Fielding, Jet Propulsion Laboratory: We are utilizing WInSAR data to study the postseismic deformation for the Parkfield and San Simeon earthquakes, and any new earthquakes that may happen in the next years. We are using time series to study transient process associated with the San Andreas Fault system and volcanic complexes (Yellowstone, Cascades).

David Sandwell and Yuri Fialko, University of California at San Diego: Investigate (1) shallow fault creep along the San Andreas Fault system, (2) postseismic deformation mechanisms in the Eastern California Shear Zone (3) the widths of fault damage zones (4) the ionosphere effect on InSAR at Pinon Flat, CA. Develop ScanSAR interferometry techniques using ALOS data.

Howard Zebker and Paul Segall, Stanford University: We useWInSAR data to investigate crustal deformation processes in the western US (the San Andreas fault system) and the Hawaiian and Cascade volcanoes. Our approach is to use InSAR methods to characterize deformation and then to infer changes at depth through inverse modeling.

Sean Buckley, Univ. of Texas at Austin: We make use of WInSAR data for InSAR time series analysis algorithm development (e.g., PSInSAR). We are also pursuing investigations of land subsidence and aquifer modeling in several locations including the Gulf of Mexico coast. The vegetation and atmospheric effects in coastal areas require frequent acquisitions.

Steve Bowman, Utah Geological Survey: The Utah Geological Survey will be using the WInSAR archive in studies of groundwater withdrawal related ground fissures and large landslides within Utah.

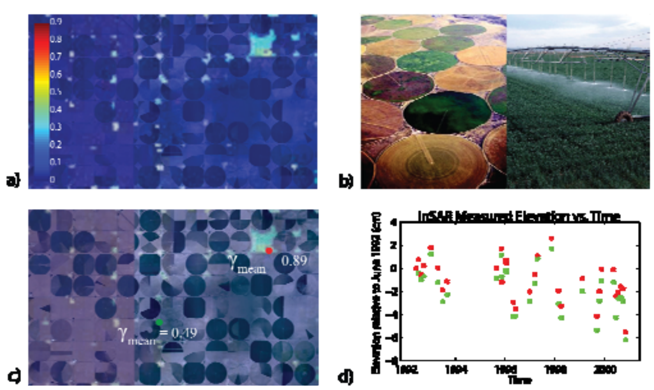

Figure 11: *a) A close-up view of the mean coherence (γmean) overlaid on a Google Earth map. b) Photos of the SLV center-pivot-irrigation fields and watering system. c) The mean coherence overlay was dimmed and we can see that the higher coherence areas show up within the interstices between the center-pivot-irrigated areas. Two pixels were selected to show an example of the elevation change time series. d) The time series of the elevation change for the two pixels in c). Figure by Jessica Reeves, Stanford.*

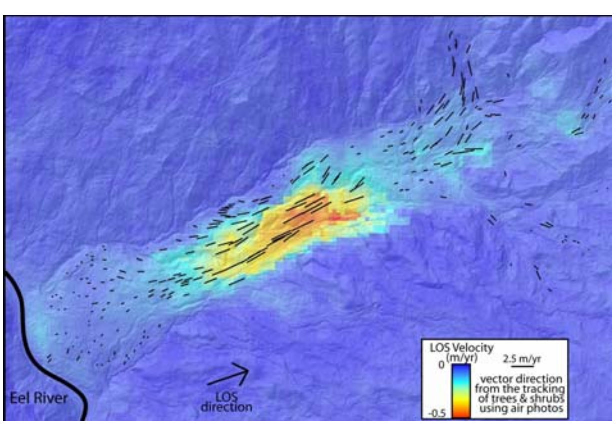

Figure 12: *Surface movement of the Boulder Creek earthflow, northern California, as revealed by InSAR (Stimely et al., 2008). Up to 0.5 m/yr of line-of-sight motion is revealed by a stack of 9 summer ALOS interferograms spanning from March 2007 to September 2007. The interferometric phase (colors) is superimposed over a shaded relief image created from high-resolution LiDAR data. Solid bars indicate the trajectory of horizontal motion as determined by the tracking of trees and shrubs in air photos dating back*

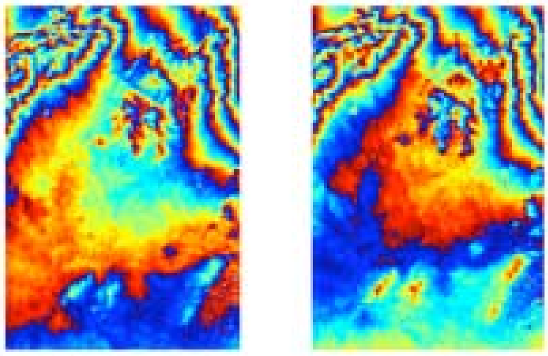

Figure 13: *Two interferograms from the same raw data (Mojave desert). The left image is 'deskewed', meaning it is referenced to zero-Doppler. The right image is 'skewed', meaning it is referenced to the Doppler centroid. Deskewing is useful for time-series applications because one would like the time series of a given pixel to be in the same coordinate system and have the same reference point, while keeping maximum bandwidth. We have added this feature to ROI_PAC in order to make our time-series application consistent, and to avoid a shift during MAI processing. From N. Bechtor, MIT.*

Muniram Budhu, University of Arizona, Tucson, Arizona: We are using WInSAR data to (1) generate InSAR to monitor land subsidence from groundwater withdrawal; (2) detect the formation and growth of earth fissures. The goal is to build a software tool to manage groundwater pumping that considers ground morphology changes.

Noel Gourmelen, Leeds University, formerly at University of Miami: Application of InSAR to the study of low deformation signals (Inter-seismic deformation, Post-seismic deformation, Glacial Isostatic Adjustment). I develop simple algorithms to measure and remove the effect of orbital uncertainties in InSAR by combining InSAR time-series with GPS time-series. Regions of interest are the Western US (Basin and Range and Eastern California Shear Zone)

Brad Hager, Tom Herring and Noa Bechor, Massachusetts Institute of Technology: During 2009 we plan to use WInSAR data to (1) develop a GPS-InSAR integration technique which includes time series analysis of InSAR data in the context of a Kalman filter. (2) refine an efficient MAI (along-track InSAR) processing algorithm (Fig. 13). We plan to apply these methods to different regions in the Western North/South America, as well as share code with the InSAR community.

Kurt Feigl, Cliff Thurber and Herb Wang, University of Wisconsin-Madison: We will continue our studies of crustal deformation in Iceland, focusing on earthquake triggering, poroelastic effects, and post-rifting deformation. We plan to monitor subsidence in western North America using the General Inversion of Phase Techique (GIPhT, Fig. 9) to model phase changes directly without unwrapping (Feigl and Thurber, 2009).

C.K. Shum, Ohio State University: **We** use WInSAR data to study: (1) the dynamics of ice mass flux across the grounding zone in E. Antartica, (2) the ocean tidal dynamics in the "thin" ice covered seas in Antarctica. We also study the improvement of accurate baseline length information by applications of precision orbit determination methodologies.

Ricky Becker, Western Michigan University: We are working on land subsidence in Amherst, NY, which is apparently due to drying in swelling clays. We plan on acquiring more data to use a persistent scatterers approach. We are also working on groundwater drawdown related subsidence in the Boston, MA area.

8.2 PUBLICATIONS BY WINSAR MEMBERS

Over the last funding period, WInSAR data resulted in almost 100 publications in leading journals (see References). These publications cover a wide spectrum of research topics from crustal dynamics to earthquake seismology to volcanology to hydrology to atmospheric sciences.

8.3 CLASSES TAUGHT USING WINSAR DATA

Integration of teaching and research is best measured by the teaching activities making use of the WInSAR archive. At least 13 member institutions are using WInSAR data for teaching. The courses offered using WInSAR data are listed in the supporting documents.

8.4 STUDENT THESES USING WINSAR DATA (SINCE 2000)

A second measure of the integration of research and teaching is the number of student theses making use of the WInSAR facility. At least 33 theses have been completed at member institutions relying on WInSAR data. We expect student data usage to increase during the next 3 years to reflect the expanding membership and archive. Some of the students have moved on to faculty positions at new WInSAR member institutions. The completed and ongoing student theses are listed in the supporting documents.

9. RESULTS FROM PRIOR NSF SUPPORT

Facility Support of the WInSAR Archive for Crustal Dynamics Research (EAR-0733437, NSF-EAR and NASA $300,000, PIs Meertens, Boler, Amelung, Burgmann; June 1, 2008 to May 31, 2011)
The WInSAR Consortium assembles SAR data acquired by the ERS and ENVISAT satellite missions in areas of active deformation in Western North America for distribution to consortium members. Current support from NSF and NASA is provided at $50K per year. The WInSAR Archive contains 8,400 scenes purchased from the European Space Agency with NSF and NASA support; these scenes are made available on-line to the 70 member organizations of WInSAR. The data acquisition over part of the funding period was highly synergetic with the GeoEarthScope initiative, which provided resources for purchasing archived data as well as scheduling of the ENVISAT satellite. This resulted in much improved temporal and spatial coverage of the WInSAR target areas. As funding for the GeoEarthScope activities expired in 2008, scheduling of new acquisitions as well as purchasing of catalog data returned to the purview of WInSAR.