Form 1 Proposal No.
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＜Cover Sheet＞
Researcher Profile

Principal Investigator, PI:

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Christopher Crosby	UNAVCO	crosby@unavco.org
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Biographical Information, Experience, Papers in Related Fields of Principal Applicant:

David T. Sandwell is Professor of Geophysics in the Institute for Geophysics and Planetary Physics, Scripps Institution of Oceanography, University of California, San Diego. Much of his current research is focused on the use of GPS and radar interferometry data to measure crustal deformations associated with earthquake processes. He was a PI on the ALOS-1 mission and attended most of the PI meetings and symposiums. A more complete CV and publication list can be found at http://topex.ucsd.edu/sandwell.

The following publications used PALSAR data from ALOS-1:

Brooks, A. B., J. Foster, D. Sandwell, C. Wolfe, P. Okubo, M. Poland, and D. Myer, Magmatically Triggered Slow-Slip at Kilauea Volcano, Hawaii, Nature, 321, 2008. http://topex.ucsd.edu/sandwell/publications/120.pdf

Fialko, Y, A. Gonzalez, J. J. Gonzalez, S. Barbot, S. Leprince, D. T. Sandwell, D. C. Agnew, Static Rupture Model of the 2010 M7.2 El Mayor-Cucapah Earthquake from ALOS, ENVISAT, SPOT and GPS Data, Abstract T53B-2125 presented at 2010 Fall Meeting, AGU, San Francisco, CA, 13-17 Dec, 2010.

Myer, D., D. Sandwell, B. Brooks, J. Foster, and M. Shimada, Inflation along Kilauea's southwest rift zone in 2006, Journal of Volcanology and Geothermal Research, 177, p. 418-424, 2008. http://topex.ucsd.edu/sandwell/publications/118.pdf

Sandwell, D. T., D. Myer, R. Mellors, M. Shimada, B. Brooks, and J. Foster, Accuracy and resolution of ALOS interferometry: Vector deformation maps of the Father's Day Intrusion at Kilauea, IEEE Trans. Geosciences and Remote Sensing, 46, 3524-3534, 2008. http://topex.ucsd.edu/sandwell/publications/117.pdf

Sandwell, D., R. Mellors, X. Tong, M. Wei, and P. Wessel, GMTSAR: An InSAR Processing System Based on Generic Mapping Tools. UC San Diego: Scripps Institution of Oceanography. Retrieved from: http://escholarship.org/uc/item/8zq2c02m, 2011. http://topex.ucsd.edu/GMTSAR

Tong, X., D. T. Sandwell, and Y. Fialko, Coseismic Slip Model of the 2008 Wenchuan Earthquake Derived From Joint Inversion of InSAR, GPS and Field Data, J. Geophys. Res., 115, B04314, doi:10.1029/2009JB006625, 2010. http://topex.ucsd.edu/sandwell/publications/126.pdf

Tong, X, D. T. Sandwell and B. Smith-Konter, High-resolution interseismic velocity data along the San Andreas Fault from GPS and InSAR, *J. Geophys. Res., in press*, 2012. http://topex.ucsd.edu/sandwell/publications/141.pdf

Tong, X., D. Sandwell, K. Luttrell, B. Brooks, M. Bevis, M. Shimada, J. Foster, R. Smalley Jr., H. Parra, J. C. Báez Soto, M. Blanco, E. Kendrick, J. Genrich, and D. J. Caccamise II, The 2010 Maule, Chile earthquake: Downdip rupture limit revealed by space geodesy, Geophys. Res. Lett., 37, L24311, doi:10.1029/2010GL045805, 2010. http://topex.ucsd.edu/sandwell/publications/133.pdf

Wei, M., and D. T. Sandwell, Decorrelation of ALOS and ERS interferometry over vegetated areas in California, IEEE Geosciences and Remote Sensing, 10.1109/TGRS.2010.2043442, 2010. http://topex.ucsd.edu/sandwell/publications/129.pdf

Wei, M., and D. Sandwell, The M7.2 El Major-Cucapah Earthquake in Baja California: Extensive Liquefaction Identified in ALOS InSAR Data, Alaska Satellite Facility News & Notes, v. 6:4, Fall 2010. http://www.asf.alaska.edu/news_notes/6-4/m72-el-major-cucapa-earthquake-baja-california

Wei, M., D. Sandwell, Y. Fialko, and R. Bilham Slip on faults in the Imperial Valley triggered by the 4 April 2010 Mw 7.2 El Mayor-Cucapah earthquake revealed by InSAR Geophys. Res. Lett., doi:10.1029/2010GL045235, in press, 2011. http://topex.ucsd.edu/sandwell/publications/134_GRL_triggered_EQ.pdf

Wei, M., D. T. Sandwell, and B. Smith-Konter, Optimal Combination of InSAR and GPS for Measuring Interseismic Crustal Deformation, J. Adv. in Space Res. doi:10.1016/j.asr.2010.03.013, 2010. http://topex.ucsd.edu/sandwell/publications/131.pdf

Signature of principal applicant: David T. Sandwell ___ Date: October 29, 2012

Form 2 Information of Proposal Contents

1. Research Category (check one)* [√]

Calibration and Validation: [X] Sensor calibration [ ] Validation of geophysical parameters

Utilization and Scientific Researches: [ ] Disaster and earthquake [ ] Land-use and land-cover research

[ ] Vegetation, forestry and wetland [ ] Agriculture [ ] Geography [ ] Geology

[ ] Hydrology [ ] Snow and ice [ ] Polar research [ ] Oceanography and coastal zone

[ ] Resources related research [ ] Climate and whether [ ] Polarimetry and interferometry

[ ] Education [ ] Others

* Our priority for the proposal selection will not be judged from your selected category.

2. Main Sensor (check one or more)

[X] PALSAR-2 [ ] None

3. Supplemental Sensor (check one or more)

[X] PALSAR [ ] AVNIR-2 [ ] PRISM [ ] JERS-1/SAR [ ] JERS-1/OPS [ ] None

4. Research Title:

GEOMETRIC AND INTERFEROMETRIC CALVAL OF ALOS-2 PALSAR ALONG THE SAN ANDREAS FAULT SYSTEM

5. Abstract of Proposal: (within 600words)

Is California prepared for the next big earthquake? Estimates of earthquake potential along major faults, such as the San Andreas Fault system (SAFs), are used for developing scenario earthquakes, for setting regional building codes, and for setting earthquake insurance rates. While the timing of a major earthquake cannot be accurately predicted, the moment magnitude can be accurately estimated from geodetic measurements of present-day crustal deformation. The current array of 700 continuously operating GPS stations in western North America does not completely resolve the crustal deformation gradients (strain) along the major faults because the average station spacing is too large. We propose to refine the crustal deformation measurements by using repeated interferograms from ALOS-1/2 PALSAR. ALOS-1 PALSAR was the first InSAR satellite capable of measuring interseismic deformation along the entire SAFs because it operates at L-band where temporal decorrelation is less of a problem. This improved correlation increases phase unwrapping accuracy and overall facilitates the analysis of large stacks of interferograms for the recovery of near-fault interseismic deformation. However ALOS-1 only collected SAR data on ascending tracks so only one component of high spatial resolution interseismic deformation could be recovered. Moreover the long 46-day repeat cycle of ALOS-1 combined with its drifting baseline resulted in only 10-15 usable interferograms in each area. ALOS-2 with its shorter temporal baseline of 14 days, multiple look directions, and better orbit control will offer a revolutionary new data set for obtaining both high spatial resolution and good temporal sampling of the entire San Andreas Fault system.

Our proposed investigation will involve the following tasks related to ALOS-2:

- Contribute to the validation of the geometric accuracy of ALOS-2 PALSAR data using radar corner reflectors at Pinon Flat, CA.
- Modify GMTSAR software to work with ALOS-1 and ALOS-2 ScanSAR data at L1.1
- Assess the accuracy of ALOS-2 FBD and ScanSAR interferograms using the array of 750 continuously operating GPS receivers in California.
- Perform an integration of ALOS-2 InSAR with CGPS data to resolve small-scale crustal deformation along the San Andreas Fault system.

6. Research Schedule

YEAR	MONTHS	ACTIVITY	PERSON
2012	NOV	Attend CALVAL meeting.	Sandwell
2013	MAR - DEC	Begin ALOS-1 investigation. Modify GMTSAR to process PALSAR-1 L1.1	Mellors, Sandwell, Wessel
2013	SEP	Attend PI Symposium	Sandwell
2013	OCT	Check and repair radar corner reflectors at Pinon Flat, CA	Sandwell, Fialko, Tong
2013	OCT-DEC	Enjoy launch of ALOS-2	All
2014	FEB-JUN	Begin processing ALOS strip-mode and ScanSAR data and evaluation of geometric accuracy.	Sandwell, Mellors
2014	-	Attend PI Symposium	Sandwell, Fialko, . . .
2014	JUL-DEC	Construct interferograms from ALOS-2 and evaluate phase accuracy of ScanSAR.	Tong, Wei, Fialko, Sandwell
2015	JAN - DEC	Begin analysis of deformation along SAF. Combine InSAR with GPS from UNAVCO. Distribute pre-processor code for ALOS-2	All
2015	-	Attend PI Symposium	Sandwell, Fialko, . . .
2015	Fall	Prepare interim report	Sandwell, . . .
2016	JAN - DEC	Continue analysis of deformation along SAF. Combine InSAR with GPS from UNAVCO. Develop 100m strain rate models for SAFs.	All
2016	MAR	Attend PI Symposium	Sandwell, Fialko, . . .
. . .	. . .	. . .	. . .
20xx	-	Prepare final report for investigation.	All

7. Request form for JAXA archived data (Form 2a)

Satellite/ sensor	Region of interest (Path-Row/lat-lon)	Season	Process level	No. of scenes
ALOS-1 PALSAR	Pinon Flat, CA latitude 33.6˚, longitude -116.6˚	All	L1.1	73

* Detailed data ordering and provision procedure will be informed by JAXA.

8. Data order form for ALOS-2/PALSAR-2 (Form 2b)

Satellite/ sensor	Region of interest (Path-Row/lat-lon)	Season	Process level	No. of scenes
ALOS-2 PALSAR-2 Swath (70 km)	San Andreas Fault system Latitude 33˚ to 40˚ Longitude -124˚ to -116˚ (see figure 2 of proposal)	FBD Swath coverage twice per year separated by 6 months, ascending and descending. Any season is OK. This will require 6 14-day cycles out of the possible 26 cycles/yr.	L1.1	288/yr.
ALOS-2 PALSAR-2 ScanSAR (350 km)	San Andreas Fault system Latitude 33˚ to 40˚ Longitude -124˚ to -116˚ (see figure 2 of proposal)	ScanSAR coverage (350 km) 20 cycles/yr. ascending and descending.	L1.1	320/yr.
ALOS-2 PALSAR-2				
ALOS-2 PALSAR-2				
ALOS-2 PALSAR-2				
ALOS-2 PALSAR-2				

* Detailed data ordering and provision procedure will be informed by JAXA.

Form 3 Proposal No.
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Kazuo Tachi
Director
Program Management and Integration Department
Space Applications Mission Directorate
Japan Aerospace Exploration Agency (JAXA)
2-1-1 Sengen, Tsukuba-shi, Ibaraki 305-8505, JAPAN

Application Form For Research Agreement For the Advanced Land Observing Satellite-2 between the Japan Aerospace Exploration Agency and the Research Organization (for the fourth RA)

Dear Mr. Tachi:

We have read and agree to comply with all the terms and conditions of the "Research Agreement for the Advanced Land Observing Satellite-2 between the Japan Aerospace Exploration Agency and the Research Organization (for the fourth RA)" and apply for conclusion of the Agreement.

Principal Investigator:

Name: David T. Sandwell

Title: Professor of Geophysics

Department: Scripps Institution of Oceanography

Organization: University of California San Diego

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Country: USA E-mail: dsandwell@ucsd.edu

Telephone: +1 858 534 7109 Facsimile: +1 858 534 5332

PI Number: ________________(Leave blank for JAXA use)

Research Title:

GEOMETRIC AND INTERFEROMETRIC CALVAL OF ALOS-2 PALSAR ALONG THE SAN ANDREAS FAULT SYSTEM

RO Contact Point for Contract Matters (Please fill in if there is a contact point other than PI):

Name: same as PI above

Department: ________________

Organization: ________________

Address: ________________

Country: ________________ E-mail: ________________

Telephone: ________________ Facsimile: ________________

Co-Investigators: Attachment

*Signature of Authorized Personnel at RO
Name and Title of Authorized Personnel
Name of Research Organization

*Signature of the person el duly authorized to conclude the reseach agreement on behalf of the RO

PI No. ______________________
(Leave blank for JAXA use)

List of Co-Investigators

Co-Investigators

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Matt Wei	Woods Hole Oceanographic Institution	mwei@whoi.edu
Bridget Smith-Konter	University of Texas at El Paso	brkonter@utep.edu
Christopher Crosby	UNAVCO	crosby@unavco.org
Paul Wessel	University of Hawaii	pwessel@hawaii.edu

GEOMETRIC AND INTERFEROMETRIC CALVAL OF ALOS-2 PALSAR ALONG THE SAN ANDREAS FAULT SYSTEM

OBJECTIVES

The ultimate objective of our research is to improve our understanding of stress accumulation rate along the San Andreas Fault system using InSAR and GPS deformation measurements. This will involve the following tasks related to ALOS-2:

- Contribute to the validation of the geometric accuracy of ALOS-2 PALSAR data using radar corner reflectors at Pinon Flat, CA.
- Modify GMTSAR software to work with ALOS-1 and ALOS-2 ScanSAR data at L1.1
- Assess the accuracy of ALOS-2 FBD and ScanSAR interferograms using the array of 750 continuously operating GPS receivers in California.
- Perform an integration of ALOS-2 InSAR with CGPS data to resolve small-scale crustal deformation along the San Andreas Fault system.

SIGNIFICANCE IN RESEARCH FIELD

The San Andreas Fault system (SAFs) is a transform fault connecting the seafloor spreading ridges in the Gulf of California to the seafloor spreading on the Juan de Fuca Ridge off the Coast of Oregon (Figure 1). The metropolitan areas of San Francisco and Los Angeles lie along this transform fault and thus are at risk of a destructive Earthquake. Major earthquakes have occurred in 1906 in San Francisco and 1857 north of Los Angeles but a long section of the southern San Andreas Fault has remained locked for over 300 years so there is a concern that this will be the site of the next major rupture [1]. The main objective of our research is to use space geodetic tools to measure the present-day strain accumulation rate and to convert this measurement to stress accumulation rate using a physical model. When combined with historical and paleoseismic information, the stress provides critical information for earthquake hazard assessment.

Deformation along this plate boundary is being monitored by 750 continuously operating GPS (CGPS) receivers. While the accuracy of the CGPS data is excellent, the typical 10 - 20 km spacing of the CGPS sites is not adequate for resolving the small-scale deformation along the faults that is needed for estimating stress accumulation rate. C-band interferometry from ERS-1/2 and Envisat was used to demonstrate that the combination of the highly accurate CGPS measurements with the high spatial resolution of the InSAR was able to resolve the crustal strain over the lightly vegetated regions of Southern California. However, the C-band interferograms suffer from temporal decorrelation over most of the SAFs.

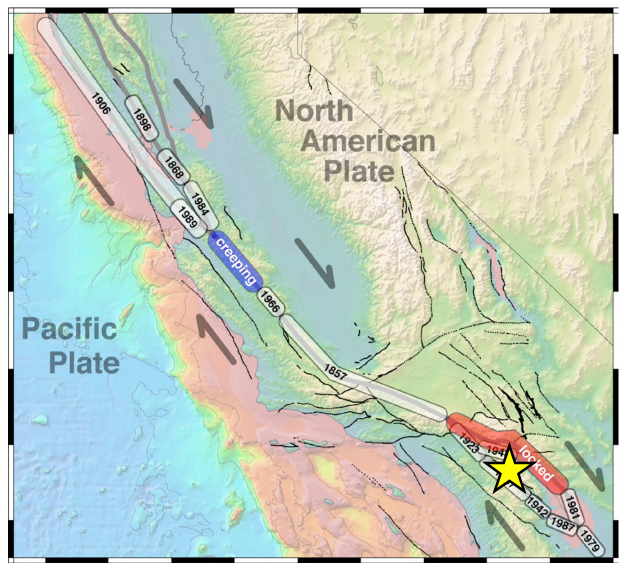

Figure 1 *The major sections of the San Andreas Fault system labeled with the years of the last major rupture of each segment. The southernmost locked section of the San Andreas Fault (red) has not experienced a major earthquake in at least 300 years. The next event along this section should release more than 7 m of accumulated slip; typically large California earthquakes have a maximum slip of 6 m. Pinon Flat Observatory (yellow star) hosts a wide array of geodetic and seismic instrumentation, including three large radar corner reflectors.*

ALOS-1 PALSAR was the first InSAR satellite capable of measuring interseismic deformation along the entire SAFs because it operates at L-band where temporal decorrelation is less of a problem. This improved correlation increases phase unwrapping accuracy and overall facilitates the analysis of large stacks of interferograms for the recovery of near-fault interseismic deformation. An example *Tong et al.,* [2] integrated 1222 SAR scenes, from ALOS-1 ascending data spanning from the middle of 2006 to the end of 2010, totaling more than 1100 interferograms (Figure 2). The final InSAR line-of-sight (LOS) data match the point GPS observations with a mean absolute deviation of 1.3 mm/yr. This InSAR LOS dataset can constrain rapid velocity gradients near the faults, which are critical for understanding the along-strike variations in stress accumulation rate and associated earthquake hazard.

This analysis of ALOS-1 data showed that at least 10, long timespan interferograms are needed to reduce the atmospheric noise to below the 2-mm/yr level needed for resolving near-fault crustal deformation. Because ALOS-1 only collected SAR data on ascending tracks, only one component of high spatial resolution interseismic deformation could be recovered. Moreover the long 46-day repeat cycle of ALOS-1 combined with its drifting baseline resulted in only 10-15 usable interferograms in each area. ALOS-2 with its shorter temporal baseline of 14 days, multiple look directions, and better orbit control will offer a revolutionary new data set for obtaining both high spatial resolution and good temporal sampling of the entire San Andreas Fault system.

We have recently obtained funding from the US National Science Foundation to analyze CGPS and InSAR data from ALOS-1 and ALOS-2 to:

- Resolve secular plate boundary deformation using GPS and InSAR measurements.
- Use integrated GPS-4D model-InSAR technique to better constrain fault slip rates and determine the depth of the locked/creeping transition on active faults of the SAFs.
- Generate high-resolution estimates of strain rate and seismic moment rate along major faults of the SAFs.
- Explore methods for isolating non-tectonic deformation contributions common in both InSAR and GPS data.

This investigation includes funding to develop tools and methods for processing ALOS-2 data as well as some funding for travel to ALOS-2 PI meetings in Japan.

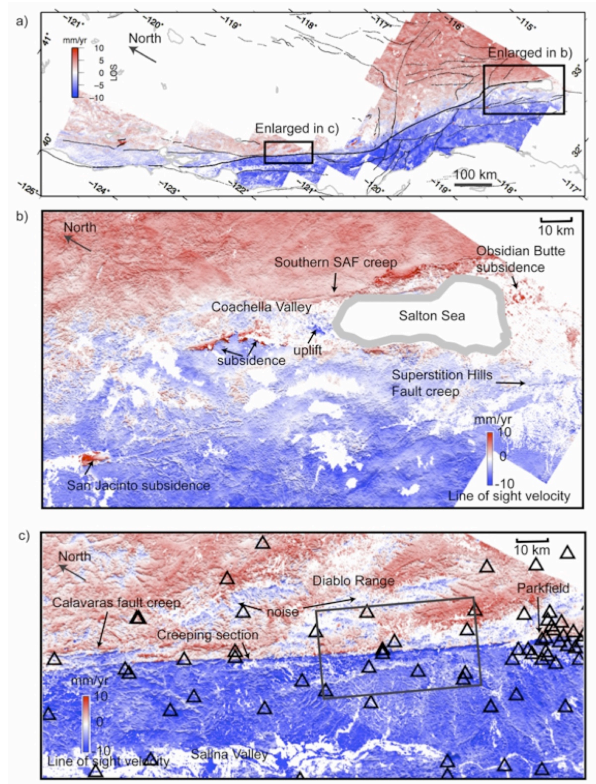

Figure 2 *(a) Interseismic deformation of the SAFs derived from integrating the GPS observations with ALOS-1 radar interferograms (2006-2010) using a remove/filter/stack/restore approach. 1222 SAR images were processed for this investigation. The positive value (red color) shows the ground moving away from the satellite at 10 mm/yr (81˚ azimuth, 37° from vertical). The areas with low coherence and large standard deviation (> 6 mm/yr) are masked. (b) Southern part of the SAFs shows the broad transition in velocity across the San Andreas and San Jacinto faults that are well resolved in previous studies [1] as well as shallow creep across the San Andreas near the Salton Sea. Many regions of subsidence due to groundwater extraction are apparent (e.g., Indio, CA). (c) Central part of the SAFs shows the sharp velocity gradient across the Creeping Section. GPS sites are shown as triangles. A full resolution version of this LOS velocity map and its relationship to faults and cultural features can be downloaded as a KML-file for Google Earth from the following site. We encourage all reviewers of this proposal to explore the remarkable detail of this data set.* ftp://topex.ucsd.edu/pub/SAF_models/insar/ALOS_ASC_masked.kmz

COLLABORATION WITH JAXA SCIENTISTS

Our group has been collaborating with JAXA scientists for 12 years in order to improve the scientific utilization of ALOS-1 data. There were two main components of our ALOS-1 research.

First in consultation with JAXA engineers, we developed algorithms and software to exploit the new modes of operation of ALOS-1. We were perhaps the first group, outside of Japan, to: (1) create an interferogram with FBS to FBS L1.0 data [3]; (2) create mixed-mode FBD to FBS interferograms [4]; (3) interpolate the state vectors to verify better than 10 cm orbital accuracy [4]; (4) show the phase noise (in mm) for PALSAR is only 1.6 times worse than the phase noise at C-band even though the wavelength is 4 times longer [4]; (5) demonstrate the expected improved temporal correlation properties of L-band with respect to C-band [5]; and (6) develop the ability to create ScanSAR to ScanSAR interferograms as well as ScanSAR to FBD-mode interferograms (Figure 3) [6]. We also discovered, as did our Japanese colleagues, that ionospheric waves with 20-40 km wavelength cause phase distortions as large as 20 cm that add significant noise to interferograms [6]. We were unable to correct these phase distortions using GPS-derived ionospheric models because they have insufficient spatial resolution to capture even the 40-km length scales. **Since our algorithms, software, and funding (NSF) are independent of JAXA, our group provides an independent check of the strengths and weaknesses of ALOS PALSAR.**

The second main aspect of our ALOS-1 investigation was to use these new InSAR data to image crustal deformation associated with: volcanic inflation at Kilauea, Hawaii [4,7,8]; the major deformation and decorrelation from the M7.9 Wenchuan, China earthquake [6]; the widespread deformation from the M8.8 Maule, Chile earthquake [9] (Figure 3); and most recently, the deformation and liquefaction from the M7.2 El Major-Cucapah earthquake just south of the US-Mexico border in the Mexicali valley [10,11,12].

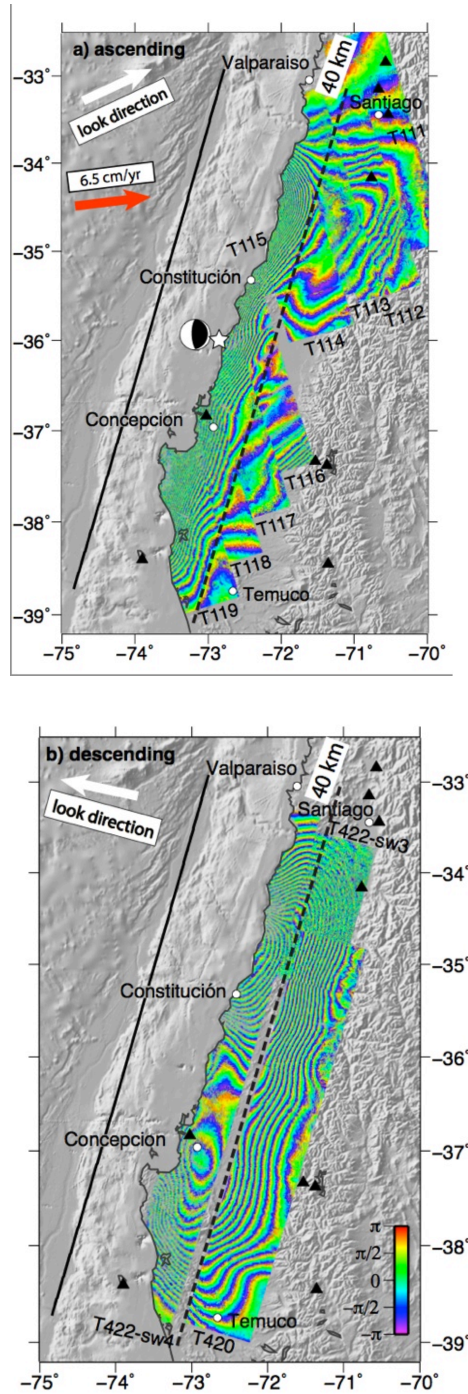

Figure 3 *ALOS interferometry for the 2010 Maule Chile processed with GMTSAR [9]. (a) Nine tracks of ascending interferograms (FBS-FBS mode) and (b) two tracks of descending interferograms (two subswaths of ScanSAR-ScanSAR mode and ScanSAR-FBS mode, and one track of FBS-FBS mode). The black triangles show the locations of the 13 GPS sites used in the inversion. These LOS data were hosted on the UNAVCO supersite (http://supersites.earthobservations.org/chile.php) and have been used in two other publications.*

METHODOLOGY, ALGORITHM TO BE USED, and TRUTH DATA

We propose to continue our collaboration with JAXA scientists to improve the scientific utilization of ALOS-2 SAR data as well as to use these data for our own scientific investigations. Our investigation can be divided into two main areas of Calibration/Validation (years 1 and 2) and Scientific Research (years 2 +).

CALVAL: Radar Corner Reflectors

We maintain three radar corner reflectors at Pinon Flat Observatory, located between the San Andreas and San Jacinto Faults, to support the radiometric, geometric, and interferometric assessment of SAR data (Figure 4). These are permanent installations designed to remain in place for the lifetime of the ALOS-1/2 missions and beyond. The precise locations of the reflectors and their radiometric design are available to any investigator (Table 1). Each year we visit the site and make repairs as necessary.

Using these three corner reflectors, we tested the geo-location accuracy of ALOS-1 PALSAR. This exercise validates three aspects of the ALOS data and processing: the accuracy of the raw L1.0 radar data, the accuracy of the ephemeris provided with the L1.0 product, and the accuracy of our SAR processor used to convert the raw data to SLC. JAXA performed a similar analysis using their processing. We found the difference between the image-based coordinate and the orbital-based coordinate to be relatively small in both range (-1.2 +/- 0.6 pixel) and azimuth (0.6 +/- 1.1 pixel). The mean difference in range could be due to the path delay through the ionosphere. Based on this analysis, we conclude that ground control is not needed for ALOS-1 and orbital-based image alignment should be accurate to better than about 15 m in range and 10 m in azimuth.

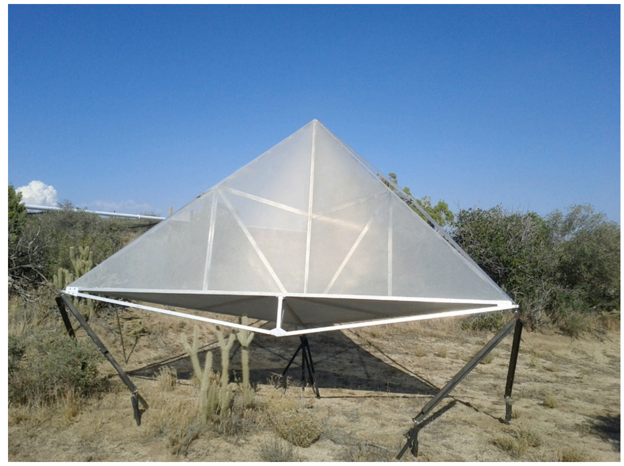

Figure 4 *One of the 2.4 m radar corner reflectors at Pinon Flat Obs. installed in 1998 (photograph taken September 12, 2012). This arid region, at an elevation of 1200 m, is relatively flat with a surface of decomposed granite sparsely covered by bush and grass. Three radar corner reflectors are oriented to reflect energy from ascending (A1) and descending (D1 and D2) ALOS passes.*

Table 1. Coordinates of Radar Reflectors

	lat	lon	height	azimuth
A1	33.612246	-116.456768	1258.990	257.5˚
D1	33.612253	-116.457893	1257.544	102.5˚
D2	33.607373	-116.451836	1254.537	102.5˚

Latitude and longitude in decimal degrees and elevation in meters relative to the WGS-84 co-ordinate system and ellipsoid. The survey point is the apex (lowest corner) of each reflector.

We proposed to perform a similar geometric calibration analysis for ALOS-2. One of the main differences between ALOS-1 and ALOS-2 products is that the L1.0 will not be available for ALOS-2 so all processing will begin at the higher SLC level. Prior to the launch of ALOS-2 we will re-do the corner reflector analysis of the 73 ALOS-1 scenes beginning at the SLC level. This will involve some minor software development that will also be used for the geometric calibration analysis of ALOS-2 data. After the launch of ALOS-2 we will begin a systematic analysis of the geometric accuracy of at least two modes – FBD (70 km swath), and ScanSAR (350 km swath). For this analysis we will request 52 acquisitions per year for SAR data collected over the Pinon area. For our needs we would be happy with the data collected for the basic observation scenario because we need to retain InSAR compatibility for all the acquisitions.

CALVAL: InSAR software

During our ALOS-1 investigation we formalized our InSAR processing software into a system called GMTSAR [13]. GMTSAR is an open source (GNU General Public License) InSAR processing system designed for users familiar with Generic Mapping Tools (GMT). GMTSAR was largely designed around the capabilities of ALOS-1. One of the key contributions of this software related to ALOS-1 PALSAR is a suite of pre-processing tools that will ingest L1.0 PALSAR data in either the AUIG or ERSDAC format and create data files that are compatible with either GMTSAR or ROI_PAC. All of this software, as well as installation instructions and sample data sets are available at http://topex.ucsd.edu/gmtsar. An example interferometric analysis is shown in Figure 2. Under our proposed ALOS-2 investigation we will continue and refine this software development. In particular we will develop software to perform interferometry on the L1.1 data. This will involve the development of code to interpolate a repeat SLC image to form an interferometric match with the reference image.

Our proposed software development for ALOS-2 will include the following:

- Write a pre-processor to convert the native L1.1 SLC data and associated orbital information to a generic format that can be processed with GMTSAR.
- Continue to refine our ScanSAR software to perform ScanSAR to ScanSAR interferometry as well as ScanSAR to FBD interferometry. We will focus our efforts on the most common data modes used for the ALOS-2 basic observation strategy.
- All of this software will be open and available for use as a pre-processor for GMTSAR or as a preprocessor for other InSAR packages such as ROI_PAC.

Scientific Research: High resolution crustal Deformation of the San Andreas Fault System (SAFs)

The main focus of our proposed investigation during years 2 until the end of the ALOS-2 mission will be to construct high spatial resolution (200 m) vector surface deformation measurements by combining the high accuracy, GPS point measurements, provided by the Plate Boundary Observatory, with the high spatial resolution InSAR measurements from ALOS-1 and ALOS-2. We will use these integrated data to invert for locking depth and slip rate along all the major faults of the SAFs to estimate 3-D crustal strain accumulation rate and moment accumulation rate.

Our approach will utilize a 4-D dislocation modeling code to generate a starting model of the SAFs interseismic velocity field. Incorporation of the most up-to-date geodetic and geologic measurements is a major priority of this proposed research; we will use the most recent unified GPS velocity field compiled by T. Herring and will adopt geologic slip rate estimates provided to the UCERF3 modeling community by R. Weldon and T. Dawson. We proposed to increase the spatial resolution of the 4-D dislocation model (currently operating at 1 km) to 200 m to better resolve the sharp deformation gradients at creeping faults.

Using the new high-resolution (200 m) deformation model we will estimate strain and moment accumulation rate along all the major strands of the SAFs. Along the Creeping Section, this analysis will help to distinguish between the two hypotheses proposed by *Titus et al.,* [14] to explain the 14 mm/yr slip rate deficit near the fault with respect to the far-fault slip rate. They proposed that either the Creeping Section is partially locked at intermediate depth or there is accommodation by slip on parallel faults 35 km away from the SAF. Both hypotheses have significant implications for earthquake hazard.

As seen in many previous InSAR studies and as well as our pilot study, non-tectonic deformation can sometimes dominate the geodetic velocity signal with both seasonal and secular contamination. We propose to visually examine all the InSAR LOS maps in relation to regional land use and locations of wells to identify geodetic data (both GPS and InSAR) that should be down weighted or not used in model inversions. This will be facilitated through the use of Google Earth where all the relevant data can be easily investigated and flagged. Our current ALOS analysis provides an example of the utility of this approach and we have already made preliminary notations on the LOS maps at ftp://topex.ucsd.edu/pub/SAF_models/insar/ALOS_ASC_masked.kmz.

ANTICIPATED RESULTS

CALVAL: Radar Corner Reflectors

We anticipate three types of results.

1) The known stable reflection points at Pinon Flat, CA (Figure 4) will provide geometric validation targets for ALOS-2 using a variety of modes – spotlight, strip, and ScanSAR.
2) The reflectors were installed prior to the launch of ALOS-1 and are permanently installed, they will provide stable reflection points for cross calibration of ALOS-2 with ALOS-1 as well as ERS-2, Envisat, and TerraSAR-X.
3) Processing of the data from these reflectors sites will be used to calibrate our GMTSAR processing software [13].

CALVAL: InSAR software

We anticipate two major results related to our InSAR processing:

1) We will modify and share the codes to pre-process the ALOS-2 data starting at the L1.1 level. This will be tested first using ALOS-1 data and then using ALOS-2 data after the satellite launch. Currently we distribute a pre-processor for ALOS-1 and we plan to construct and distribute a preprocessor for ALOS-2.
2) The more frequent and controlled acquisitions from ALOS-2 ScanSAR will be used to construct large stacks of interferograms. We propose to use GMTSAR for the basic processing and image alignment and will freely distribute the codes with no copyright restrictions.

Scientific Research: High resolution crustal Deformation of the San Andreas Fault System (SAFs)

The main motivation for our research with ALOS-2 is to improve our understanding of stress accumulation rate along the San Andreas Fault system using InSAR and GPS deformation measurements. The improved spatial and temporal resolution of ALOS-2 combined with multiple look directions will resolve the small-scale deformation associated with strain concentrations near faults. These improved measurement when combined with historical and paleoseismic information, will improve earthquake hazard assessment.

PRODUCT UTILIZATION PLAN

Prior to the launch of ALOS-2

73 scenes – ALOS-1 from AUIG archive. During the first year of the investigation we request 73 scenes of data from the AUIG archive for CALVAL of L1.1 over the Pinon Flat corner reflectors (latitude 33.6, longitude -116.5). We have already processed all these data beginning at L1.0. However since ALOS-2 data will only be available at the SLC level (L1.1) we will modify our software and reprocess the interferograms to validate the software changes.

During the first year after launch

288 scenes of FBD
320 scenes of ScanSAR
Our proposal covers the entire San Andreas Fault system shown in Figure 2a. For ALOS-1 this area is covered by 72 frames along 14 tracks. For our ALOS-2 investigation we request data for the same area along both ascending and descending corresponding to 144 frames. One possible operation scenario is to acquire complete strip-mode coverage twice each year (winter and summer, or spring and fall). This amounts to 288 scenes of standard 70-km FBD frames and will take 6 of the 26 possible repeat cycles. During the other 20 cycles we request ScanSAR (350 km swath) coverage. We estimate 320 scenes since each ScanSAR frame covers the area of about 9 FBD frames.

Years 2 + after launch

288 scenes of FBD/yr.
320 scenes of ScanSAR/yr.
We hope to repeat the SAR coverage scenario from year one during the following years so request the same amount of data each year.

WORK PLAN

Work will be performed by graduate students at Scripps Institution of Oceanography (e.g. Xiaopeng Tong) with supervision from David Sandwell, Yuri Fialko, and Rob Mellors. Matt Wei and Paul Wessel will assist in the software development. Bridget Smith-Konter will be involved in the model development for the InSAR/GPS integration. Chris Crosby at

UNAVCO will provide the GPS time series and provide computer support for data archiving. Sandwell plans to attend at least one CALVAL or PI meeting per year in Japan. Results will be published in major scientific journals and presented at international meetings.

DATA PROCESSING AND ANALYSIS EQUIPMENT

Data will be processed using computer facilities at SIO, Lawrence Livermore National Laboratory (LLNL), and UNAVCO. LLNL hosts several supercomputers that will be used for the time series analysis.

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