2014 SCEC Proposal

Improving the Community Geodetic Model with GPS and InSAR

PRINCIPAL INVESTIGATORS: David Sandwell[1]
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Amount of requested funding: $20,790 SIO, $1,700 CICESE

Proposal Categories:
A. Data Gathering and Products
B. Integration and Theory

SCEC Science Objectives:
1d. Development of a Community Geodetic Model (GCM) for California
2d. Development of a Community Stress Model (CSM) for Southern California.
1e. Combined modeling/inversion studies to interpret GPS and InSAR geodetic results.

Start date: Feb. 1, 2014
End date: Jan. 31, 2015

Summary of Previous Research Results

1. We have completed the development of a high spatial resolution (500m) time-independent velocity model for the San Andreas Fault system [*Tong et al., 2013*]. The final InSAR line of sight (LOS) data match the point GPS observations with a mean absolute deviation of 1.5 mm/yr. The LOS velocities and standard deviations are freely available and have been used by several interested research groups (e.g., McCaffery, Zeng, and Johnson) in the development of their high-resolution block models. We systematically evaluated the fault creep rates along major faults of the San Andreas Fault and compared them with creepmeters and alignment array data compiled in the Uniform California Earthquake Rupture Forecast, Version 2 (UCERF2). These new creep rate estimates are being used in the UCERF3 model.

2. We continue to work with CICESE scientists to acquire spatially dense GPS velocities across the Imperial and Cerro Prieto Faults in the Mexicali Valley to better constrain the velocity field of the southernmost SAF (Figure 1). We resurveyed two dense GPS arrays that were originally deployed in January of 2010 and February of 2011 using SCEC funding. The DD line was resurveyed in January of 2012. The CC line was resurveyed in January of 2013. All of these data are being archived at SCEC with the assistance of Duncan Agnew.

3. We will participate in the upcoming SCEC workshops related to the development of the Community Geodetic Model as well as the Community Stress Model. We will develop and compare deformation and stress models that incorporate available CGM, in particular the high resolution component CGM data from this research, to better understand regional and local tectonic loading processes and fault structures.

(Note that we did not apply for SCEC funding in 2013 because we had sufficient SCEC funds remaining to support another set of GPS surveys in the winter of 2013-14.)

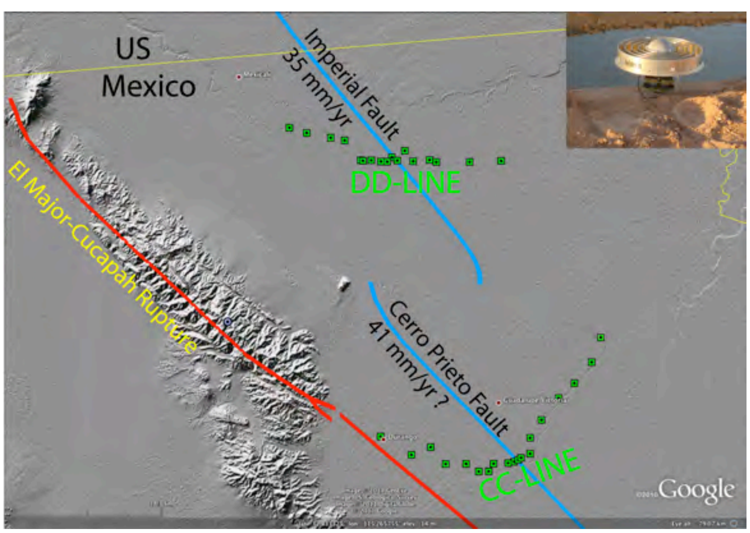

Figure 1. Location map of the region around the Imperial and Cerro Prieto Faults in Baja, Mexico. Over the past 4 years we have deployed and surveyed two new lines of GPS monuments across the Imperial Fault (DD-LINE) and Cerro Prieto Fault (CC-LINE). The monument spacing is optimized to measure the moment accumulation rate (i.e. slip rate and locking depth) of each fault. Each of these lines has been surveyed twice with 2 years time separation between each campaign. Two CGPS sites were recently installed by UNAVCO south of YUMA and in the Cucapah mountains. These two sites will serve as the 1 Hz reference stations for our proposed re-surveys of the CC and DD lines. Data from these surveys will be archived at SCEC and UNAVCO. Prior to the 2010 El Major-Cucapah earthquake, interseismic motions were constrained by 6 sites at SALD, MAYO, LPUR, CP13, CPEI, IPEO, and YUMA (not shown) [*Bennett et al.*, 1996]. Since that study more campaign sites have been added but MAYO and CPEI were vandalized.

Proposed Research

One of the priorities of SCEC4 is to investigate *stress transfer from plate motion to crustal faults*. Surface crustal velocities are one of the key boundary conditions needed for developing 3-D stress rate models. The quality and quantity of GPS and InSAR data are increasing rapidly and many groups are developing detailed crustal velocity models. We have identified two areas of weakness in these models - the southernmost SAF system in the Mexicali Valley [ref] and the small-scale deformation near faults having shallow interseismic slip [ref]. Our proposed tasks are:

(1) *Collaborate with other SCEC and PBO scientists to develop a time-dependent Community Geodetic Model (CGM) at variable spatial resolution. Work with SCEC community on optimal integration of InSAR and GPS.*

We are developing an approach to combine vector GPS and LOS InSAR data to construct a surface deformation field and its uncertainty using a remove/filter/stack/restore technique [*Wei et al.,* 2010; *Tong et al.,* 2013]. This approach considers signal, tropospheric noise, GPS site spacing, and instrument noise characteristics of each system. The main assumption of this approach is that the GPS-based model, which is removed and restored to each interferogram, is accurate at length-scales greater than 20 km. An example of this approach is shown in Figure 2 where it is clear that the LOS stack provides shorter wavelength information not captured by the GPS-based model.

While GPS/InSAR integration has been performed in many previous studies [*Petlzer et al.*, 2001; *Fialko,* 2006; *Walters et al.,* 2011] part of the improvement in this approach is to use L-band (23 cm wavelength) SAR data from ALOS-1 (Figure 2) which retains coherence better than C-band (5.8 cm wavelength) in vegetated areas [*Rosen et al.*, 1996; *Wei and Sandwell*, 2010]. This enhanced coherence of L-band over C-band improves phase unwrapping accuracy and overall facilitates the analysis of large stacks of interferograms for the recovery of near-fault interseismic deformation.

The main limitations of the ALOS-1 data is that only one look direction is available from the ascending passes and the number of repeated images is only sufficient to reduce the phase noise to ~2-6 mm/yr. In early 2014, two new InSAR satellites will be launched by the European Space Agency (Sentinel-1, C-band, 12-day repeat cycle) and the Japanese Space Agency (ALOS-2, L-band, 14-day repeat cycle). Both the ALOS-2 and Sentinel-1 spacecraft are optimized for InSAR studies because they have shorter repeat intervals than their predecessors and better-controlled orbits for shorter interferometric baselines. WInSAR scientists are working with both space agencies to acquire data over the San Andreas Fault System (SAFS). Moreover, Sandwell is a member of the ALOS-2 calibration and validation team and has a JAXA approved experiment to process acquisitions over the Pinon Flat radar corner reflectors within three months after the launch of the satellite. This will include several acquisitions along descending orbits, which will offer the needed second look direction in vegetated areas. Under this SCEC proposal we will begin the InSAR time series analysis and integration of these two new data streams with the CGPS data.

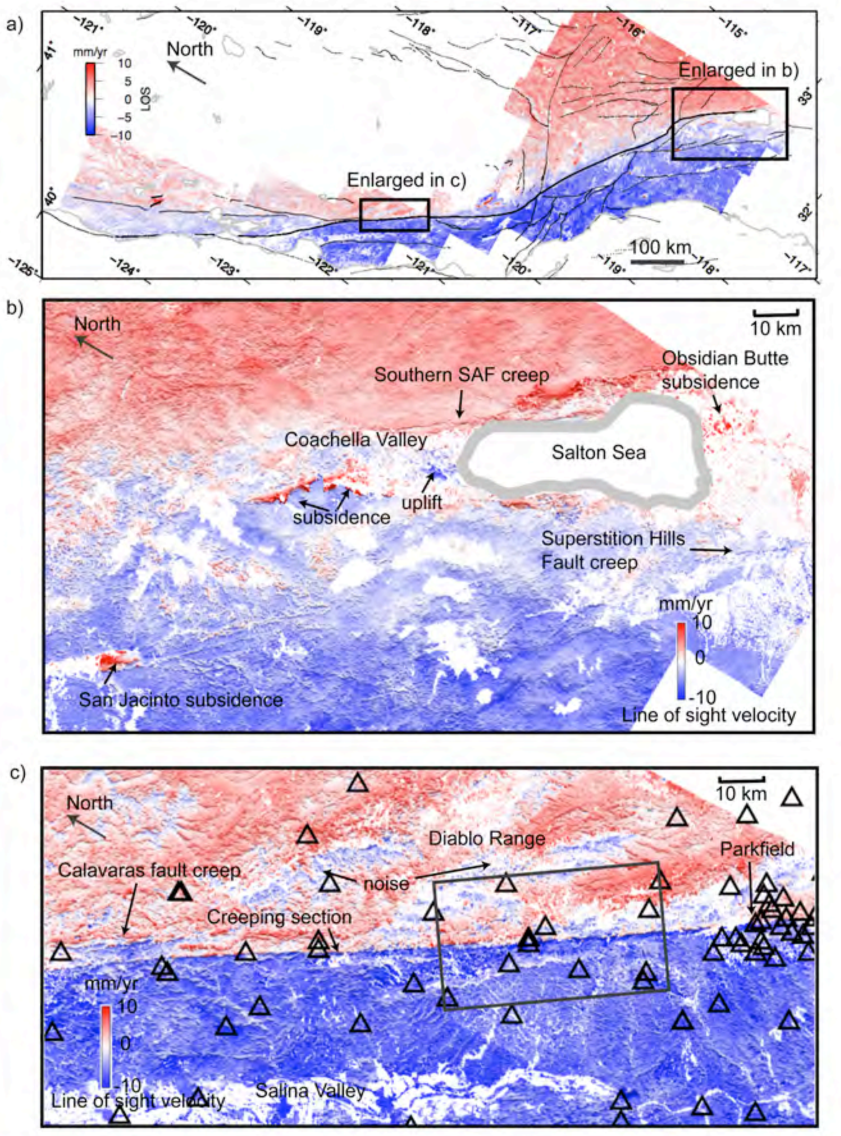

Figure 2. (a) Interseismic deformation of the SAFS derived from integrating the GPS observations with ALOS radar interferograms (2006-2010) using a remove/filter/stack/restore approach [*Wei et al.,* 2010; *Tong et al.,* 2013]. The positive value (red color) shows the ground moving away from the satellite (81° azimuth, 37° from vertical). The shading highlights the gradient in the velocity field. The areas with low coherence and large standard deviation (> 6 mm/yr.) are masked. This version is based on the analysis of 800 ALOS L-band SAR images. (b) Southern part of the SAFS shows the broad transition in velocity across the San Andreas and San Jacinto Faults that is well resolved in previous studies [e.g., *Fialko,* 2006, *Lundgren et al.,* 2009] as well as shallow creep across the San Andreas near the Salton Sea [*Lyons and Sandwell*, 2003]. Many regions of subsidence due to groundwater extraction are apparent (e.g., Indio, CA, *Sneed and Brandt* [2007]). (c) Central part of the SAFS shows the sharp velocity gradient across the Creeping Section. GPS sites are shown as triangles. A kmz file along with the LOS data and their uncertainties are available at ftp://topex.ucsd.edu/pub/SAF_model/insar

(2) Work with CICESE scientists to acquire spatially dense GPS velocities across the Imperial and Cerro Prieto Faults

The Imperial and Cerro Prieto Faults have the highest slip rates of any faults of the SAFS. The Imperial Fault north of the US Mexico Border has a slip rate of 35±3 mm/yr [*Genrich et al.,* 1997; *Lyons et al*., 2003; *Crowell et al*., 2013]. This high slip rate presumably extends south of the border (Figure 1) where the Imperial Fault passes through the eastern side of the metropolitan area of Mexicali (pop. 930,000). Further to the south, the Imperial Fault terminates and steps over to the Cerro Prieto Fault at the Cerro Prieto geothermal area, which is the largest geothermal plant in the world. Published slip rates for the Cerro Prieto fault range from 40±1.4 mm/yr [*Meade and Hager*, 2005a] to 42±1 mm/yr [*Bennett et al.,* 1996; *Dixon et al.*, 2002]. While the small error bounds suggest the moment accumulation rates on these faults are well characterized, the rate estimates are based on only 6 widely spaced GPS velocity measurements and a very simplified block model structure. The location of the El Major-Cucapah rupture to the west of both of these faults suggests that strain accumulation is widespread in the region and perhaps that the tectonics is more complicated than a single Cerro Prieto fault accommodating most of the North America/Pacific plate motion. More important, the locking depth, and therefore the seismic moment accumulation rate, is poorly constrained for the southern section of the Imperial Fault and virtually unknown along the Cerro Prieto Fault because of the sparse GPS coverage. The proximity of these faults to the metro area, combined with the water-saturated soils of the Mexicali Valley, which are prone to liquefaction, suggest these faults are the most hazardous faults of the San Andreas system.

Over the past four years we (SIO and CICESE) have installed GPS arrays across the Imperial and Cerro Prieto Faults to better characterize their moment accumulation rates and thus their seismic potential. The 19 monuments of the DD-line (Figure 1) were deployed in March of 2010 just prior to the El Major-Cucapah event on April 4 and they were first surveyed twice in May 2010. The 17 monuments of the CC-line were deployed in February of 2011 and first surveyed twice in March of 2011. The total aperture and spacing of the monuments is optimal for estimating locking depth (~8 km)[ref]. All of the monuments consist of stainless steel couplers cemented into preexisting concrete structures (mostly aqueducts). The antennas are screwed directly into the couplers for accurate and rapid deployment and the monuments follow roads for easy access. The relatively large number of monuments will help to identify those that have poor performance because of soil instability or groundwater variations.

We propose to re-survey these two arrays using the rapid-static approach with two 60-90 minute occupations at each monument. As in the past three years, all surveys will be performed in collaboration with scientists and students from CICESE (e.g. Javier and Alejandro Gonzales). We will use the instantaneous positioning technique [*Bock et al*., 2000] and the recently installed CGPS sites in the Cucapah Mountains and in Yuma to provide the high-rate reference sites needed to minimize tropospheric effects. The two occupations, spaced by ~6 hours, help to average the multipath effects. Based on our experience with these types of surveys following the El Major-Cucapah event, we expect 5-10 mm horizontal accuracies and 10-20 mm vertical accuracies. Since we expect a total variation of 30 mm/yr across each aperture, the 4-year span from the DD-line should show a significant interseismic signal and the 3-year span of the CC-line will show a marginal signal. It should be noted that both signals will be contaminated by the postseismic deformation following the El Major-Cucapah earthquake. Nevertheless, we feel it is important to begin monitoring these two arrays so that 5-10 years from now we will have a good estimate of the moment accumulation rates of these major faults.

(3) Participate in SCEC workshops related to the development of the Community Geodetic Model as well as the Community Stress Model.

Our research group (Sandwell, Tong, Gonzalez, Smith-Konter, and Zeng) have been active participants in SCEC-sponsored workshops. Under this proposal we (mostly Tong) hope to participate in the InSAR time series comparisons planned for the Community Geodetic Model. Zeng plans to collaborate with the GPS investigators to continue to compile campaign and continuous GPS datasets for the Western US with a focus on Southern California. In addition, if invited, we will participate in the activities of the Community Stress Model. We will develop and compare deformation and stress models that incorporate available CGM, in particular the high resolution component CGM data from this research, to better understand regional and local tectonic loading processes and fault structures.

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Improving the Community Geodetic Model with GPS and InSAR

Budget Period: February 1, 2014 - January 31, 2015

SALARY RECHARGES:	**Mo. Salary**	**%**	**# mos.**	**TOTAL**
David Sandwell, Professor				n/c
Xiapeng Tong, Postdoctoral Scholar	4,834	100	2	9,668
DOMESTIC TRAVEL:		**#trips**	**# people**	
SCEC Annual Meeting - Sept. 2014	150	1	2	300
FOREIGN TRAVEL:				
Fieldwork in Mexicali, Mexico	150	3	4	1,800
Three 3-day trips for 4 people				
OTHER PROJECT RELATED EXPENSES				
IGPP Network Charge	248		2	496
Communications - including NGN	90		2	180
Fieldwork supplies including car batteries solar panels				969
TOTAL DIRECT COSTS				13,413
INDIRECT COSTS:	**Base**	**Rate**		
MTDC	13,413	55.0%		7,377
TOTAL				20,790

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Improving the Community Geodetic Model with GPS and InSAR

Budget Period: February 1, 2014 - January 31, 2015

PERSONNEL:	**Mo. Salary**	**%**	**# mos.**	**TOTAL**
Javier Gonzalez				n/c
Alejandro Gonzalez, Graduate Student Researcher				n/c
FOREIGN TRAVEL:		**#trips**	**# people**	
SCEC Annual Meeting - Sept. 2012	250	1	2	500
DOMESTIC TRAVEL:				
Fieldwork in Mexicali, Mexico	200	3	2	1,200
Three 3-day trips for 2 people				
TOTAL				1,700

Current and Pending Support
Investigator: David Sandwell

CURRENT

Title: Study of Postseismic Deformation Due to the 2010 M7.2 El Mayor (Mexico) Earthquake (Y. Fialko, PI)
Source of Support: NSF EAR 1053627
Total Award Amount: $418789
Total Award Period: 05/01/11-04/30/14
Location of Project: SIO
Person-Months on Project: 0

Title: Cryosat Altimetry, Arctic Gravity Enhancements, Investigation of Ice Freeboard Measurements, and InSAR Code Development
Source of Support: ConocoPhillips
Total Award Amount: $120,000
Total Award Period: 03/01/11-02/28/14
Person-Months on Project: 0

Title: A Factor of 2-4 Improvement in Marine Gravity and Predicted Bathymetry from Cryosat, Jason-1, and Envisat Radar Altimetry: Arctic and Coastal Regions
Source of Support: ONR N00014-12-1-0111
Total Award Amount: $157,071
Total Award Period: 10/01/11-09/30/14
Location of Project: SIO
Person-Months on Project: 0

Title: A Factor of 2 Improvement in Global Marine Gravity from Cryosat, Jason-1, and Envisat
Source of Support: NSF OCE 1128801
Total Award Amount: $229,188
Total Award Period: 02/15/12-01/31/16
Location of Project: SIO
Person-Months on Project: 0

Title: Collaborative Research: Strain Rate and Moment Accumulation Rate Along the San Andreas Fault from InSAR and GPS
Source of Support: NSF EAR 1147435
Total Award Amount: $220,015
Total Award Period: 06/15/12-5/31/15
Location of Project: SIO
Person-Months on Project: 0

Title: Improving the Community Geodetic Model with GPS and InSAR
Source of Support: USC/SCEC 20123827SCEC
Total Award Amount: $23,500
Total Award Period: 02/01/12-01/31/14
Location of Project: SIO
Person-Months on Project: 0

Title: Improving Coastal Marine Gravity
Source of Support: NGA HM0177-13-1-0008
Total Award Amount: $447,487
Total Award Period: 02/11/13-02/10/16
Location of Project: SIO/PSU
Person-Months on Project: 0

PENDING

Title: Collaborative Research: Improving the Generic Mapping Tools for Seismology, Geodesy Geodynamics and Geology
Source of Support: NSF – Geoinformatics
Total Award Amount: $101,081
Total Award Period: 01/01/14-12/31/16
Location of Project: SIO
Person-Months on Project: 0

Title: Monitoring Oil Field Deformation with L-Band InSAR and Continued Improvements in Global Marine Gravity
Source of Support: ConocoPhillips
Total Award Amount: $120,000
Total Award Period: 03/01/14-02/28/17
Location of Project: SIO
Person-Months on Project: 0

Title: Improving the Community Geodetic Model with GPS and InSAR
Source of Support: SCEC (THIS PROPOSAL)
Total Award Amount: $20,790
Total Award Period: 02/01/14-01/31/15
Location of Project: SIO
Person-Months on Project: 0