A.1 Proposal Title

SAN ANDREAS FAULT NATURAL LABORATORY

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A.4 Region of Interest

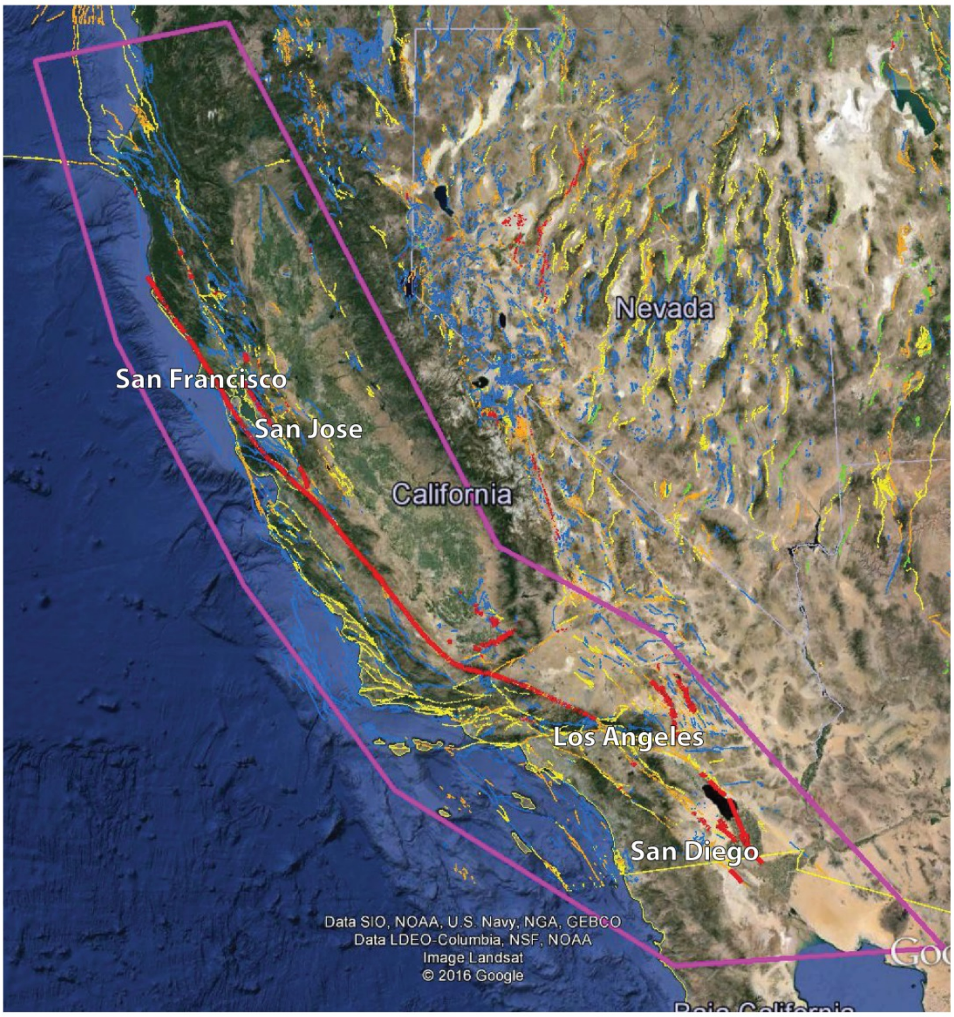

Figure 1 – The region of interest for this proposal (also included as a KMZ file) is shown with the magenta polygon together with mapped faults. Faults that have been active in the last ~150 years are shown in bold red. Faults active in the Holocene and Pleistocene are orange. Other known faults that have been active in the Quaternary are shown in green, yellow and blue.

The proposed San Andreas fault (SAF) Natural Laboratory region covers most of the state of California, as shown in Figure 1. The region of interest for this proposal is the part of the greater SAF system that includes historically active fault segments and concentrations of mapped faults (Figure 1). This area extends from a point at the northern tip of the Gulf of California in northern Baja California, Mexico through the state of California including San Diego, Los Angeles, San Jose and San Francisco to a little north of Cape Mendocino where the SAF joins the Mendocino Fracture Zone (Figure 2).

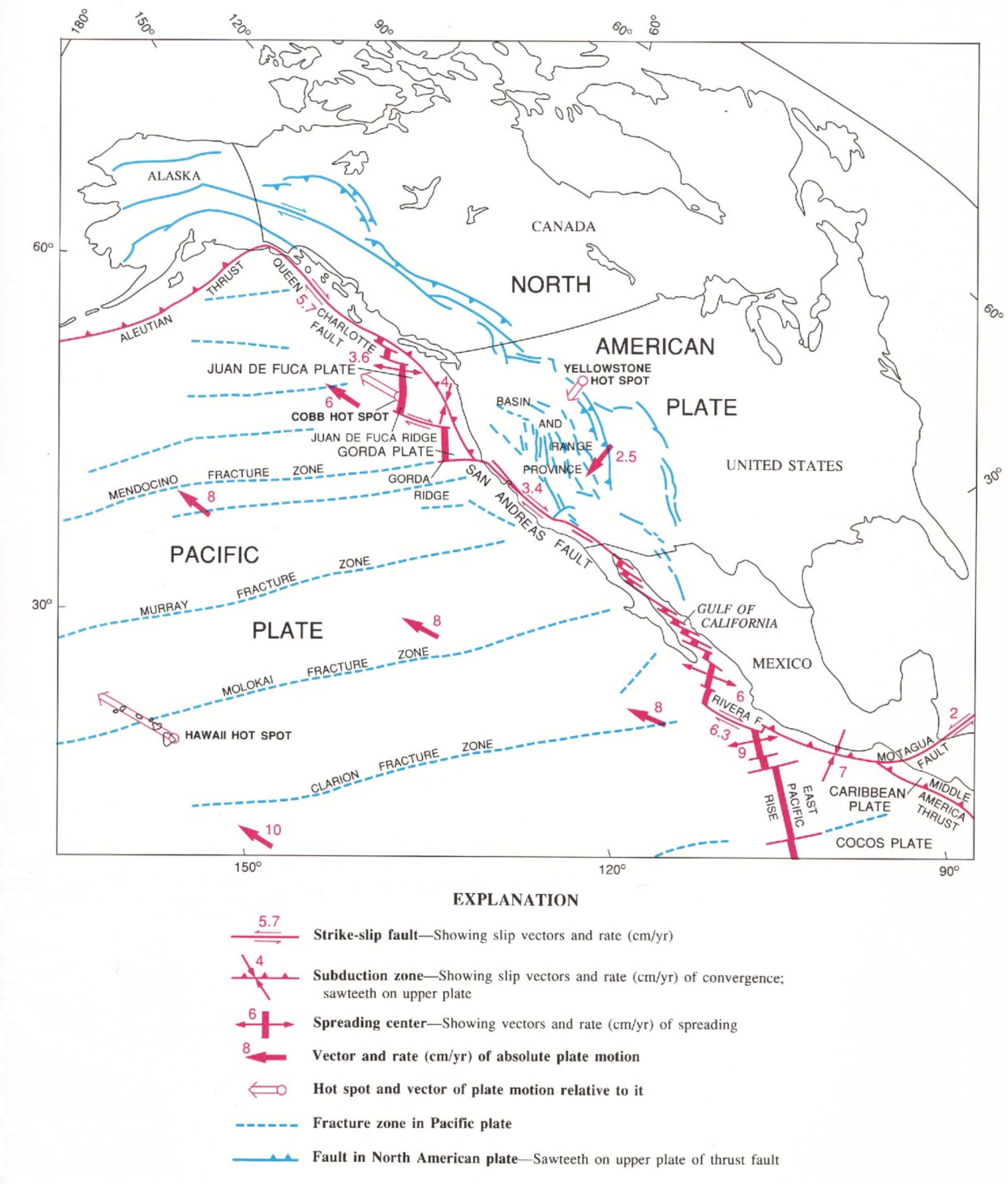

Figure 2 – Tectonic setting of the San Andreas fault (from Wallace, 1990).

A.5 Natural Laboratory motivation

This proposed Natural Laboratory fits into the GEO GSNL Initiative to stimulate a broad effort to monitor and study the San Andreas Fault System. Providing open access to SAR data from platforms that are currently difficult to access will enable more detailed (temporally and spatially) studies of interseismic and aseismic deformation processes in the fault system and a better response to seismic events. Contained within the CVs of the Core Team are many examples of studies of the SAF system that speak to both scientific interest in the studying the fault system and the qualifications of the team members.

The SAF only came to prominence after the 1906 San Francisco earthquake. Study of the effects of the earthquake, in particular maps of displacement, led to the understanding of the nature and potential of the SAF and represented a major advance in understanding strike-slip faults. The SAF system is dominated by the right-lateral slip in the SAF, but other faults in the system are left-lateral, reverse and, less commonly, normal in nature. The 1906 earthquake also led to the development of elastic rebound theory and the founding of the Seismological Society of America (also in 1906) an international society devoted to the study of earthquakes for the benefit of society. The earthquake history of California, in particular the devastating 1906 San Francisco earthquake, is well known worldwide and will be summarized, but can be found in more detail here:

http://earthquake.usgs.gov/earthquakes/states/california/history.php

The 1906 earthquake of M 7.8 occurred along the SAF, as did an earlier earthquake of similar magnitude in 1857 along the southern SAF. Between the San Francisco and Los Angeles metropolitan regions lies a section of the SAF known to creep continually, and it has relatively less earthquake hazard as a result. Transitional behavior at either end of the creeping section is known to display a full range of seismic to aseismic slip events and accompanying seismicity and strain transient events. Because the occurrence of these events is exceedingly well documented by extensive instrumental networks, the Natural Laboratory proposal would potentially be especially effective in California. The baseline level of information regarding past events and the strain accumulation and release process is very well known, as compared with many other parts of the world. The wealth of publications regarding the occurrence of various geophysical phenomena along the SAF system means that the scientific bar has been set very high. In order to make novel contributions, state-of-the-art science data are required.

In more recent years, the 1989 Loma Prieta earthquake struck adjacent to the SAF and caused the most damage along the western side of the San Francisco Bay Area, although the current concern is more related to the potential for future events along the Hayward Fault along the eastern side of San Francisco Bay. In Southern California, earthquakes struck in 1992 (Landers), 1994 (Northridge) and 1999 (Hector Mine) as well as the 2010 El Mayor – Cucapah earthquake that occurred just south of the US-Mexico border. Of these four notable events, all were above M 7 and produced extensive surface faulting except for the 1994 Northridge event, which was close to the Los Angeles urban area and was M 6.7 on a buried thrust fault. Nevertheless, Northridge caused by far the most destruction, topping $20B (US) and resulting in 57 fatalities. The Landers, Hector Mine and EM-C events occurred in desert areas away from major urban centers, and each proved to be a new and unique test-bed for making rapid progress in earthquake science (e.g. Massonnet et al., 1993; Peltzer, 1998). InSAR studies were linked to GPS deformation and mapping of surface ruptures and seismicity in a series of important papers about these earthquakes. The hazard in California remains extremely high, with tens of millions of people living in close proximity to the SAF system as it runs past both San Francisco and Los Angeles. Dense in-situ networks are used for earthquake monitoring, as well as development of an earthquake early warning capability.

The main motivation of this proposal is to provide easier access to data from SAR platforms so scientists can combine InSAR data with in-situ GPS and seismological data to conduct more detailed studies of the SAF system. The main advances that can be made with such studies are: 1) better assessment of the seismic moment accumulation rate for all the fault segments in the SAF system, 2) better study the segments of the fault that creep either continuously or in discrete creep events (e.g., Wei et al., 2009) , and 3) better respond to earthquakes.

Tong et al. (2013) used ascending ALOS-1 data to measure interseismic velocity along locked and movement on creeping sections of major strands of the SAF system. They found that using the InSAR data increased the resolution near the faults (the spacing of the continuous GPS stations was insufficient to capture near-fault deformation). The Tong et al. study represents a state-of-the-art study of the SAF using InSAR and GPS, but great improvements can be made using satellites with better temporal sampling, better baseline control and views from ascending and descending orbits. The Sentinel 1 data and ALOS-2 data will enable a dramatic improvement in the accuracy of moment accumulation rates along all segments of the SAF system. This will greatly improve the seismic hazard assessment for the different fault segments. TerraSAR-X (TSX) data already archived over four of the main creeping section of the SAF (Figure 5) will enable very high resolution studies of these fault segments and give valuable measurements that could shed new light on the mechanism responsible for slow slip events. Detailed measurements of average yearly creep rates will also enable better estimates of the earthquake potential for these creeping fault segments. Although Cosmo SkyMED (CSK) data does not have the degree of orbital control that TSX does, the temporal density of the data in areas of the fault system could also be very useful for scientists conducting time-series analysis (particularly with permanent scatterers) along the SAF.

Massonnet, D., M. Rossi, C. Carmona, F. Adragna, G. Peltzer,K. Feigl, and T. Rabaute, (1993) The displacement field of the Landers earthquake mapped by radar interferometry, Nature, 364, 138-142.

Peltzer, G., P. Rosen, F. Rogez, and K. Hudnut, (1998) Poro-elastic rebound along the Landers 1992 earthquake surface rupture, J. Geophys. Res., 103, doi: 10.1029/98JB02302.

Tong, X., D. T. Sandwell, and B. Smith-Konter (2013), High-resolution interseismic velocity data along the San Andreas Fault from GPS and InSAR, J. Geophys. Res. Solid Earth, 118, 369–389, doi:10.1029/2012JB009442.

Wallace, R. E., (1990), The San Andreas Fault System, California, U. S. Geological Survey, Prof. Paper 1515, 283 pp.

Wei, M., D. Sandwell, and Y. Fialko (2009), A silent m(w) 4.7 slip event of october 2006 on the superstition hills fault, southern California, J. Geophys. Res., 114(B07), 402, doi:10.1029/2008JB006135.

A.6 In situ data

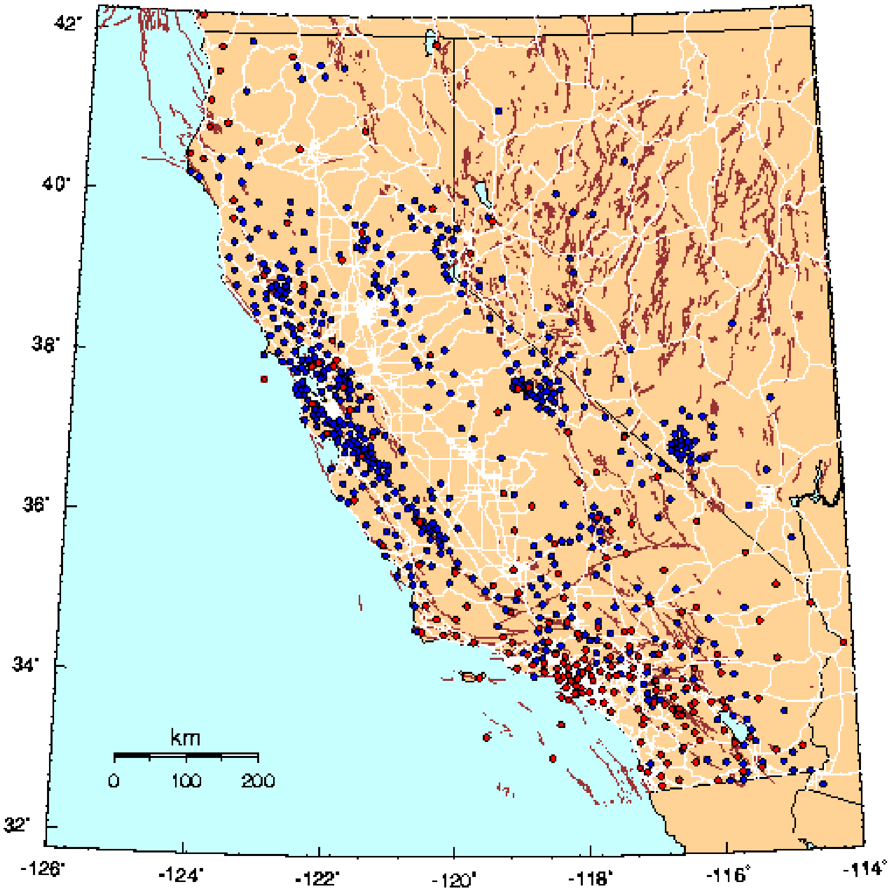

Figure 3 -The instrumental infrastructure of the project partners covering the area of the San Andreas Fault system. California Integrated Seismic Network (CISN) short-period stations (blue) and broadband stations (red). CISN members also operate ~1500 strong-motion instruments. –source: http://www.cisn.org/instr/

Open access to in-situ data for the San Andreas Fault system region is provided through the existing data centers operated by UC Berkeley and California Institute of Technology, as well as by UNAVCO and IRIS and by the USGS. All data and meta-data are provided in openly described and standardized formats. In addition to abundant seismological and geodetic data, aerial photos and electro-optical imagery, geological maps, airborne LiDAR and multispectral data, and a wide variety of other data types are also available. Open access to seismic waveform (in FDSN, SEED, format) and earthquake data from Broadband, short-period and strong motion data in California can be found centralized in the www.cisn.org website (Figure 3). The California Integrated Seismic Network (CISN) is a partnership among federal, state, and university agencies involved in California earthquake monitoring. The CISN is dedicated to serve the emergency response, engineering, and scientific communities. The seismological archives listed in the CISN site have existed for decades and are well supported. The number of stations at these archives will continue to grow and accessibility is always improving.

Open access to GPS/GNSS signals logged by receivers at survey points, processed results of the raw measurements (such as geodetic positions of survey points), or geologic velocities of those points can be found at the Plate Boundary Observatory website pbo.unavco.org (Figure 4). The PBO site is part of a continuing national observatory.

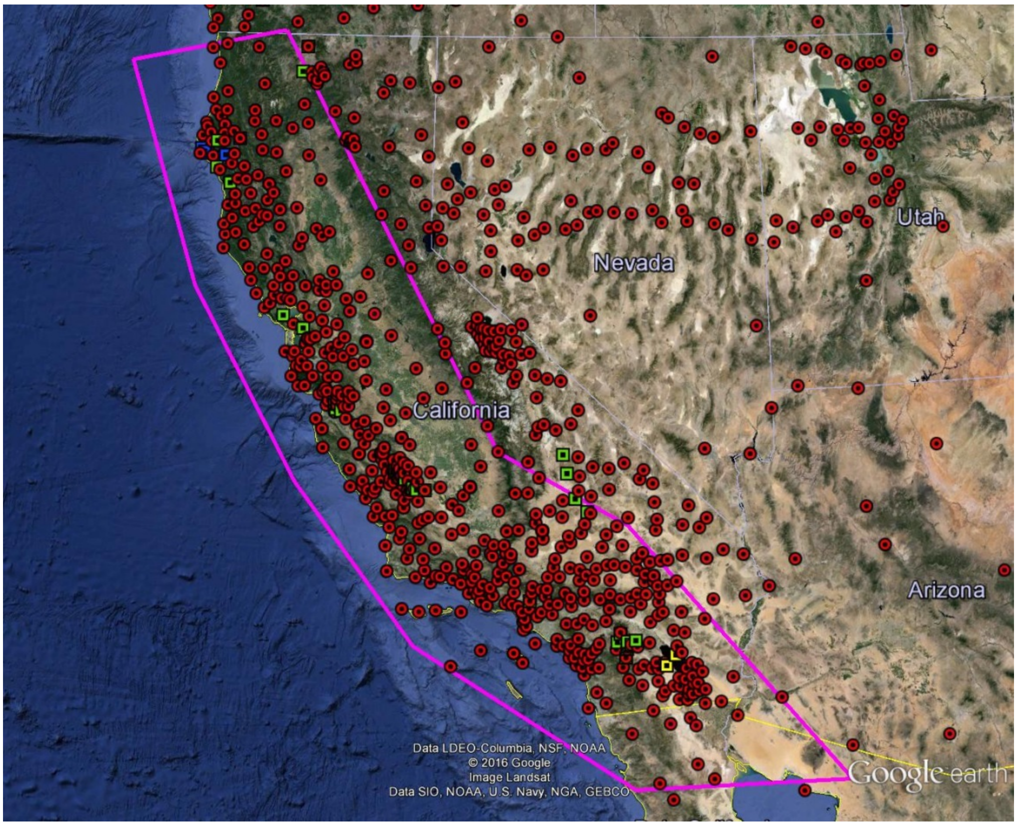

Figure 4 - Plate Boundary Observatory (PBO) network of continuous GPS stations (red circles) and area of interest (magenta polygon).-- source: http://pbo.unavco.org/

Links to other open data sources and direct links to sites within the CISN are as follows:

http://www.ncedc.org/

http://www.data.scec.org/

http://www.unavco.org/

http://www.iris.edu/hq/

http://www.scec.org/

http://earthquake.usgs.gov/

A.7 Natural Laboratory activity work plan

The San Andreas Fault Natural Laboratory proposal is intended to begin a new phase of open data sharing to facilitate improved scientific research for the future. We anticipate access to begin during the next three years with further establishment of a mutually agreed structure for obtaining and distributing imagery. Satellite data will be accessed through established platforms (e.g. DLR Supersites portal, UNAVCO SAR data access platform, the ESA Geohazard Platform, etc.), possibly exploiting a single interface for data browsing and discovery, and using web services for data download. Our goal is to achieve a state much like with the in-situ data for the San Andreas Fault region, that is, open access to all data. If that is not immediately possible, we will work with CEOS partners to take reasonable steps in the next three years of this collaboration to get this accomplished. Soon after the Natural Laboratory is established we will prepare a Data Management Plan (DMP). In this plan we will endeavor to provide open access to all research products such as deformation maps and source models in digital format for use and re-use by all concerned parties.

A.8 Available Resources

The San Andreas Fault Natural Laboratory in-situ data are an in-kind contribution amounting to over $15M (US) per year and representing a long-term investment over the past several decades of well over $300M (US). Research funds through the peer-review competitive awards process amount to over $10M (US) per year through USGS, NSF and NASA programs, some of which are coordinated through the National Earthquake Hazard Reduction Program (NEHRP; http://www.nehrp.gov/).

A.9 EO data requirements

The San Andreas Fault Natural Laboratory would require SAR data as follows; TerraSAR-X, COSMO-SkyMed, Radarsat-2, ALOS-2, as well as future missions and archival data. ALOS-1 PALSAR data over the proposed site area is already available at the Alaska Satellite Facility (https://www.asf.alaska.edu/sar-data/palsar/) by registering as a NASA Earthdata user and agreeing to a EULA. Several pre-existing arrangements exist among subsets of the user community, including WInSAR. The Natural Laboratory project would endeavor to consolidate requests and users into a more efficient structure for coordinate tasking requests, data acquisition and distribution.

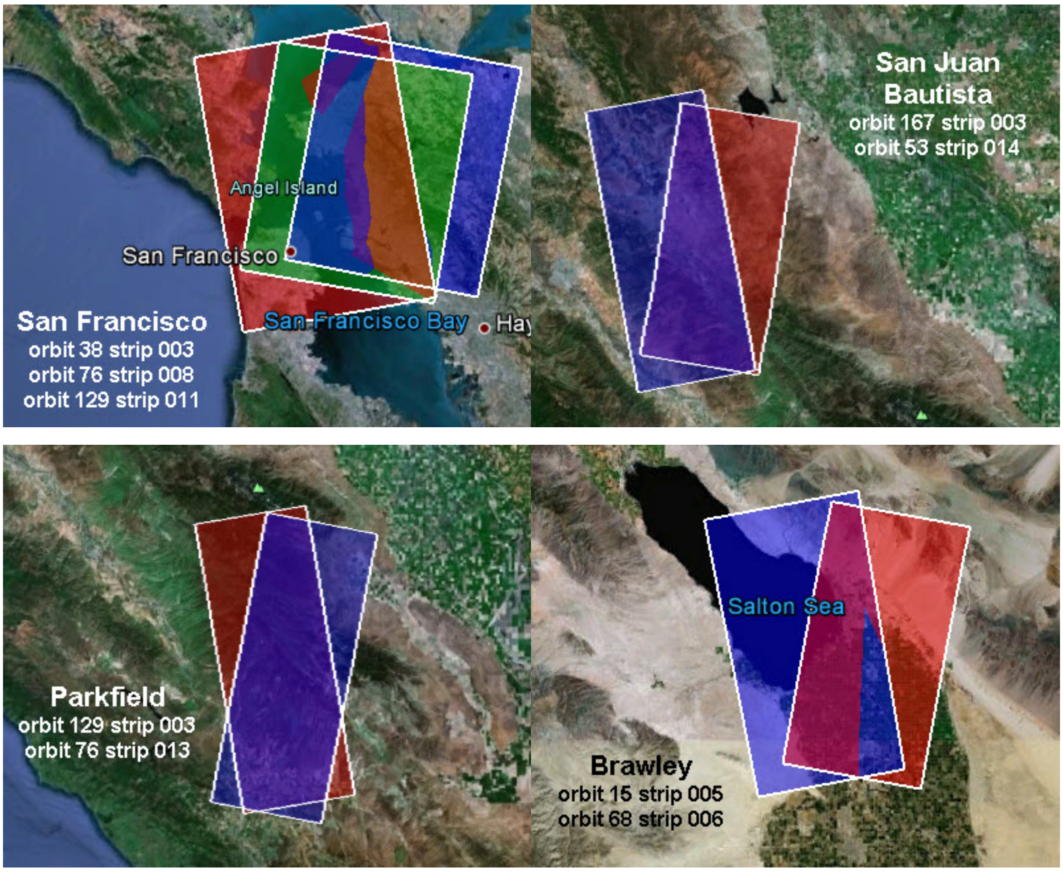

Figure 5 – Sample TerraSAR-X acquisition currently tasked by the WInSAR consortium - Source: https://winsar.unavco.org/tasking_tsx.html

The main data requirements address two seismic deformation sources: 1) interseimic and 2) earthquake. The data breakout below is for SAR data, but access to high-resolution electro-optical imagery (e.g. Worldview, SPOT-6/7, Ikonos and Pléiades) could prove very useful mapping earthquake deformation and developing high-resolution topographic models.

Interseismic data requirments:

The best way to measure interseismic strain accumulation is with temporally dense InSAR datasets. Figure 5 shows four areas where TSX data has been routinely acquired in the last 5 years. The number of archived TSX stripmap acquisitions in these four areas, plus the greater Los Angeles area, that we seek to put in the San Andreas Fault Natural Laboratory are listed in a table below, along with COSMO-SkyMED HRImage data acquisitions. The number of requested acquisitions per year continuous with these archives is also listed. The European Space Agency is actively acquiring Sentinel 1 TOPSAR data in the SAF area of interest and the Japanese Space Agency is covering the area well with ALOS-2 SCANSAR images. Since Sentinel 1 data is open access, we do not include them in the table, but since ALOS-2 data is difficult to access, we include them. We are asking for only SLC data, and in the case of ALOS-2, all of the SCANSAR data, and STRIPMAP data in areas where the Core Team is actively conducting research. Since the northern part of the SAF Natural Laboratory region is heavily vegetated, the L-Band ALOS-2 data is particularly important for the area from about San Francisco north. We are asking for SCANSAR images from about mid-February 2015 onward…after the burst alignment problem was fixed.

SAR Platform	Archived acquisitions requested	Yearly acquisitions
TSX Stripmap	920	400 (continuous with archive)
CSK Stripmap (STR_HIMAGE)	3850	400 (continuous with archive)
ALOS-2 (SCANSAR)	200	180 (continuous with archive)
ALOS-2 (STRIPMAP)	1310	400 (in select areas)

Earthquake Data requirements:

The Mw 6 Napa earthquake that struck the San Francisco Bay area on August 24, 2014 was the largest earthquake to strike the bay area since the 1989 Loma Prieta earthquake. One interesting facet of the earthquake was the shallow afterslip that continued for months after the event. Events like this that occur in the SAF system could benefit from the Natural Laboratory designation. Although the Napa earthquake and afterslip were well covered by multiple platforms, the full set of InSAR data acquired by different space agencies has still not been used to study the slip processes because of difficulty accessing the data. In the table below we show the number of archived scenes we request to add to the natural laboratory for the Napa earthquake. The German Space agency has already released a few TSX scenes that we can include. Given a future event of this magnitude, (depending of the number of archived data) this would be representative of the number of data we might request. A larger M7-8 earthquake could lead to much larger requests. The "Future Earthquake" request in the table below is for a more probable earthquake with magnitude near 6.

Platform	Archived scenes requested (SLC)	Future Earthquake (SLC)
ALOS-2 (SM and SCANSAR)	34	30
CSK stripmap (STR_HIMAGE)	40	40
RSAT-2 (variable beams)	25	30
TSX (SM)	20	40

A.10 Declaration of commitment

The proposed natural laboratory team is committed to carrying out the objectives of this proposal with the expressed goal of making all digital scientific products (including interferograms) part of a fully open data policy. The only restrictions to SAR (RAW or SLC) data are those that might be required by the respective space agencies. Ideally, we would have an open data policy for these data as well, similar to the European Space Agency's policy to Sentinel 1a data. If the proposal is successful, we will be open to collaborations with other natural laboratories, supersites and international initiatives. We will also support the posting of scientific products generated by the team for use openly by the entire scientific community and emergency planning/response entities on a website for such use.

A.11 Further comments

Non-scientific stakeholders that would respond to an earthquake or are interested in Disaster Risk Reduction (DRR) in the SAF Natural Laboratory area of interest are: 1) stakeholders that are interested in events or DRR anywhere in the AOI, and 2) stakeholders that are interested in smaller areas within the AOI. The main stakeholders for the whole AOI are the California Office of Emergency Services (CalOES, http://www.caloes.ca.gov) and the Federal Emergency Management Agency (FEMA, http://www.fema.gov). The other stakeholders are local utilitiy companies, local search and rescue teams and local building planning commissions. During earthquake emergencies results will be made available as soon as possible on a website, in a format (such as KML) that is easily ingested in portable platforms. This will enable quicker damage assessment (important for resource assignment) and detection of surface rupture and after-slip. After the Napa earthquake, interferograms of co-seismic and post-seismic slip were invaluable for mapping surface rupture and continuous after-slip hazards at the surface. Other scientific products (slip models) can be used to reassess earthquake risk resulting from stress transfer.