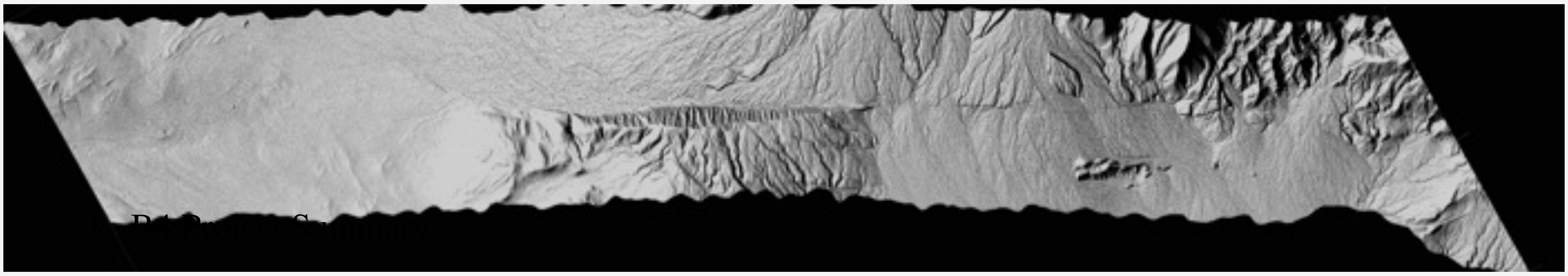

The B4 Project: Scanning the Southern San Andreas and San Jacinto Fault Zones

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Introduction

We performed a high-resolution topographic survey of the San Andreas and San Jacinto fault zones in southern California in order to obtain pre-earthquake imagery necessary to determine near-field ground deformation after a future large event (hence the name B4), and to support tectonic and paleoseismic research. We imaged the faults in unprecedented detail using Airborne Laser Swath Mapping (ALSM) and an abnormally intensive array of GPS ground control ensured accurate geo-referencing of the dataset. This paper summarizes the process of data collection and the system of archiving, and describes the dataset that is now being made openly available.

Ohio State University (OSU), the USGS, NCALM and UNAVCO collaborated on the survey, which collected the B4 data. The inspiration for B4 is to capture a pre-deformation image of the San Andreas Fault so that it might all be flown again after future large earthquakes. The scientific purpose of such spatially detailed imaging is to establish actual slip and afterslip heterogeneity so as to help resolve classic 'great debates' in earthquake source physics. We also expect to be able to characterize near-field deformation associated with the along-strike transition from continuously creeping to fully locked sections of the San Andreas fault with these data.

The enormous scale of the ALSM survey—nearly 1000 km in length and 1 km in width — made it challenging to organize. Preceding the survey, OSU and the USGS planned the flight lines and logistics of the ground data acquisition, while NCALM took the flight lines in planning the airborne logistics. The dataset is being made available by the Arizona State Univ. GEON group, the U.C. Berkeley NCALM group, the SIO Visualization Center and OSU.

Methods

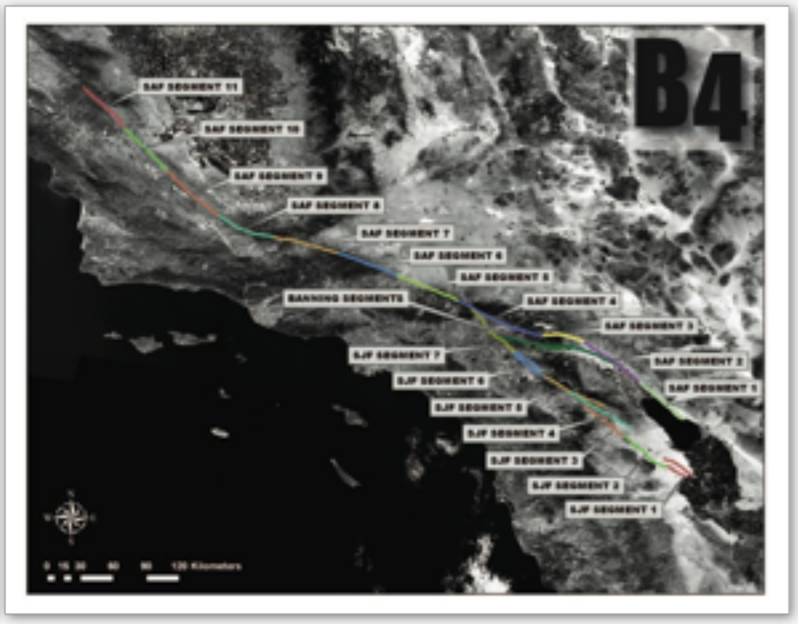
In March of 2005 OSU began laying the groundwork for the ALSM survey. The Laser data produced by an ALSM survey is independent of a reference frame without the use of GPS both in the airplane and on the ground. In a typical ALSM survey, there might be one GPS unit on the ground in addition to the one in the plane. The KARS software developed by Gerry Mader can then be used in order to constrain the flight path using phase-differential GPS. Gerry Mader processed the flight trajectories for the first version of the ALSM data, making used of a minimal subset of the B4 ground control GPS data.

The minimal ground control approach was typical for ALSM surveying within an area up to fifty kilometers radius from a single ground control point. The B4 Project investigators attempted, instead, to bring a geodetic quality to the B4 data and to achieve this, they required that there be one GPS station for every 10 kilometers of flight segment flown. This results in 3 to 6 times as many GPS units on the ground. The OSU group has recently finished reprocessing the flight trajectories using all available GPS data collected during the survey, and they are currently working on a model for weighting the influence each GPS station has on the trajectory results.

To establish ground control, OSU located old survey markers or installed new ones for the one hundred points required to fulfill this 10 km spacing over the length of the survey. Approximately 70 of the 100 markers were installed by OSU. The markers are 9 ft long by 1 inch in diameter steel rod. Each rod was driven into the ground with only inches of the rod left exposed on the surface. 75 of these points are actually within the 1 km wide swath that the plane flew over the faults, the rest were never more than 1 km away from the centerline of the flight line. In addition to these static GPS the faults, the rest were never more than 1 km away from the centerline of the flight line. In addition to these static GPS survey points the USGS temporarily boosted the data rate of nearby SCIGN (Southern California Integrated GPS Network) GPS stations to support the airborne survey. By locating each survey marker to within centimeters, and by having re-processed all of the aircraft trajectories very precisely, it is hoped and expected that the B4 Project will have produced some of the most geodetically accurate ALSM data ever collected.

All of the ground GPS data is archived at OSU. The The Static GPS table demonstrates when each GPS ground control point was occupied and what flights were in progress while the GPS data were being collected. The OSU group carried out the processing of all ground GPS data to obtain precise coordinates that could then be held fixed during re-processing of the aircraft trajectories. In most cases OSU processed the data using a network of the 4 or 5 closest SCIGN stations. In some cases, a point was not occupied long enough for a reliable solution. They were processed using the California Spatial Reference Center (CSRC) frame. These points were reoccupied after the main survey in order to provide a solution for the KARS processing.

In preparation for capturing a rupture on the fault the USGS and OSU relied on a variety of sources for a best estimate of the active fault line of the San Andreas and the San Jacinto faults. Geologists who had particular field areas provided their insight as to the active fault's location. We used a variety of fault maps for those areas where no one provided specific recommendations. Eventually we had a set of coordinates that NCALM could use for the navigation system of their plane. It was not always possible to have the plane centered perfectly over the fault, but the width of 1 km should provide spare room in most cases. In addition to preparing a flight line for NCALM we broke up the San Andreas and San Jacinto into 22 survey segments ~50 in length and 1 km in width. NCALM adjusted this to 19 survey segments ~50 km and one ~150 km² block. This division of survey segments is independent of any geological features and was only made in order to manage coordination between GPS surveyors on the ground and the aircrew. Any reference to segments of the San Andreas popularly associated with ruptures and reoccurrence intervals will be referred to as *fault segments*, thereby reserving *survey segments* for the division of the faults with the purpose of GPS surveying. We use our segment naming conventions for the organization of the hundreds of tiles of DEMs and point clouds produced from the B4 data. San Andreas Fault survey segment 1 (SAF01) begins at Bombay Beach and ends at Painted Canyon. The SAF segments continue on from there (following the mission creek strand) and finish with SAF11 which goes from highway 46 to the SAFOD site near Parkfield. The San Jacinto Fault (SJF) segment begins with SJF01 in the superstition hills around El Centro Naval Reservation. Our SJF segments finish up with SJF07 meeting up with the San Andreas fault at Cajon Pass.



figures of SAF01 and of all of the Survey Segments.

The area surveyed runs along the San Andreas 5 km from Bombay Beach on the Salton Sea all the way to Parkfield in the central part of the state. This includes the Mission Creek and the Banning fault segments of the San Andreas. The Banning fault segment has both a ~40 km flight segment and a ~150 km² block of coverage, designated Banning Segment 1 and Banning Segment 2 (BAN01 & BAN02). For the San Jacinto fault we flew from the Superstition Mountains near El Centro to Cajon Pass near Wrightwood. We included the Coyote Creek, the Clark and the Buck Ridge fault segments of the San Jacinto.

NCALM mounted Optech's latest laser, the ALTM 3100, in a twin prop Cessna 310. The ALTM is equipped to fly surveys as high as 5 km off the ground, but our desire for a dense array of laser hits dictated an average survey height of 600 meters. The Optech's laser rack unit in the aircraft includes a GPS input and has it's own inertial measurement unit (IMU). The Optech rack collects the laser data, the IMU data, and the GPS data on a hard disc in Optech's proprietary data format, a .range file. We ran the 3100 ALTM laser at 70 kHz (70,000 outgoing laser shots per second) with a mirror oscillation of 40 Hz and a scan angle of 20 degrees. Flying the laser at the low altitude of 600 meters produces a swath ~430 meters in width, with each laser hit measuring 15 cm in diameter. All of these parameters result in a laser point spread on the ground of ~0.6 m at the nadir of the swath and ~1 m at the edges of the swath. With the plane making five passes over every segment there was always lots overlap for the inner portions of 1 km wide composite swath. All point cloud and DEM coordinates are in UTM projection zone S11 for all segments except SAF Segment 10 and SAF Segment 11, which are in UTM zone S10. The reference frame is that of the California Spatial Reference Center. All the various data formats will be archived at OSU and available upon request. GEON plans to serve the raw point cloud data and DEMs, SIO Visualization center will distribute KMZ files and Fledermaus files, and NCALM at Berkeley should provide an alternative for obtaining DEMs.

A team of government employees, academic researchers and volunteers manned the GPS equipment at the numerous survey markers. UNAVCO provided 15 GPS receivers and survey grade tripods. On a given day the flight crew might attempt to fly over as much as 150 km of fault, which meant occupying more than 16 points at times. A typical day for ground crew members meant waking before sunrise to occupy a point in one flight segment for several hours and then driving hurriedly 50-100 km to set up and occupy another point for hours. There were days that reached 120°F desert heat, which affected both ground crew members and those working in the plane, as well as the GPS units and airborne system electronics. Field efforts put forth were heroic to say the least - ask our B4 field crew about the long hauls and heavy loads.

The data collected is intended for distribution to researchers. The version of the data publicly available at this time is Version 1.01. Version 1.01 of the ALSM data uses Eric Kendrick's version 26 Nov 2005 of the GPS processing. It also uses Gerry Mader's KARS results. NCALM at Berkeley will reprocess the entire data set using trajectories completed at OSU. The data have been organized in such a manner that anyone can access all the raw data needed to produce a DEM (assuming access to the REALM or other software) or one could take the half-meter DEM produced by NCALM or the point cloud format from GEON, which allows the user to tailor the data to his or her needs through selections made using their work flow.

NCALM used Terrascan and Terramatch in Microstation for calibrating, matching, and outputting the data in a point cloud format. Microstation is CAD software and the Terra package is a standard for ALSM image calibration and processing. NCALM used a Terrascan algorithm to remove low-lying brush in areas where necessary. This reclassification of data uses angles and distances to remove brush. This process does have an adverse erosional effect on the data where features are unnecessarily smoothed. For this reason both filtered and unfiltered DEMs are available.

B4 is an NSF-funded project, led by Ohio State University and the U. S. Geological Survey, that was supported in all aspects of the airborne data acquisition and laser data processing by the National Center for Airborne Laser Mapping (NCALM), in continuous GPS station high-rate acquisition by SCIGN, and in GPS ground control by UNAVCO. A group of volunteers from USGS, UCSD, UCLA, Caltech and private industry, as well as gracious landowners along the fault zones, also made the project possible. Optech contributed use of their latest scanner system, a model 3100, for the laser data acquisition along all of the faults scanned. The data set is now openly available to all researchers for non-commercial use.