Piñon Flat Observatory: Continuous Monitoring of Crustal Deformation

Report for 2005

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1. Introduction

The Southern California Earthquake Center provides partial support of Piñon Flat Observatory (PFO), as part of its data collection activities. PFO provides high-precision strain data which is used both for studies of the seismic cycle in Southern California, and for comparison with other types of measurements of crustal deformation: notably data from the SCIGN GPS array.

SCEC funds help to keep the observatory operating to continue to measure crustal deformation: at this point the data from the longbase and other instruments at PFO, provide the longest ultra-broad-band records of crustal motion (from minutes to years) available from any plate boundary. The cost of running the observatory includes salaries for technical personnel, travel costs for them to visit the site, supplies, and of course the power bill. In addition, SCEC funds provide some support of senior personnel (Wyatt) to oversee the activity, deal with more complicated problems, and improve on data access.

2. Science Results

In the absence of a significant geophysical event, it is in the nature of this kind of data collection that there may not be something new to report in the data every year; however, even without events, the accumulation of data can reveal new information. This year we can give examples of both new events, and new information from longstanding data collection.

2.1. Triggered Aseismic Slip Near PFO

We report strong evidence for deep aseismic slip following a very recent earthquake near PFO (12 June 2005, 15:41:46.27, or 2005:163.654). This magnitude 5.2 shock was in the San Jacinto fault zone; though it occurred within the Anza slip gap, it was in a region of abundant small and moderate earthquakes that bound a 15-km section of fault that is relatively aseismic (a seismicity gap). Waveform studies show (from directivity) that the mainshock rupture was probably on a fault plane conjugate to the main fault trace, at a depth of 16 km (P. Shearer, pers. commun.).

This earthquake has been followed by a normally decaying aftershock sequence from a volume commensurate with the likely rupture zone. However, it also triggered an increase of seismicity along the fault zone NW of the epicenter, in the seismicity gap: **Figure 1** shows a map view and cross-section, with the aftershocks and triggered events in purple, background seismicity in gray, and the mainshock epicenter as a black star. The spatial extent of triggered seismicity suggested possible triggered slip over a larger part of the fault zone; and we have in fact observed changes in strain at PFO that strongly support such slip having occurred. The bottom panel of **Figure 1** shows the time series from all three long-base strainmeters at PFO; note that the coseismic offset was not recorded because strong ground shaking deflected the strainmeter laser beams. Two strain records (from the NS and EW instruments) show a clear

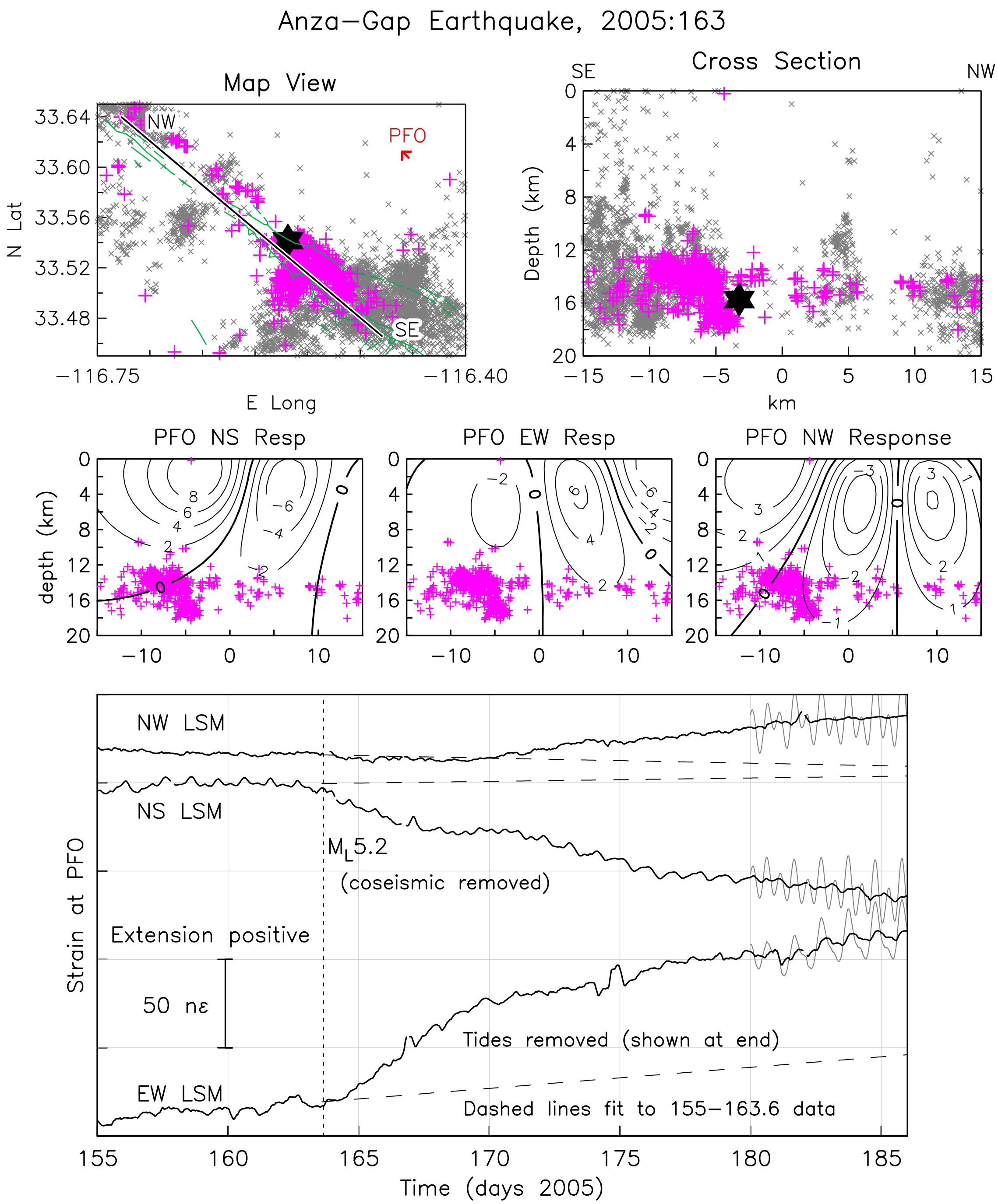

Figure 5

strain change over the seven days after the earthquake. The NW-SE strainmeter shows no response until about a week after the earthquake.

The middle panel of **Figure 1** shows, along with the triggered seismicity, contours of the amount of strain that would be produced on each instrument for right-lateral strike-slip of 0.1 m over a 1×1 km patch on the fault plane. The response seen—roughly equal and opposite on the NS and EW, and near zero on the NW—is consistent with slip at about 5 km (horizontal coordinate of the cross-section), which is in the region of the triggered earthquakes; the later positive strain on the NWSE would be produced by slip further to the NW. The moment release inferred depends on the depth, which is not well constrained, but if the slip is colocated with the aftershock seismicity, the aseismic moment release is equivalent to a magnitude (M_w) 5.0 event, close to the mainshock moment. (This would induce <1 mm motion at the nearest GPS points, quite undetectable.) We are pursuing a more formal inversion of this data set; for now we offer it as an example of the unique capabilities of the long-base strainmeters, and one of the very few examples of aseismic slip at seismogenic depths on a strike-slip fault.

As a result of these observations the PBO has given a higher priority for borehole strainmeter installations in the Anza area.

2.2. Permeability Changes from Seismic Waves

Since the early 1980's, we have monitored water-level changes in four wells at PFO, which were originally drilled for borehole strainmeters in 1981. All of these show tidal changes as the fractured-granite system responds to tidal changes in strain. A recent re-examination of these data, in collaboration with Prof. Emily Brodsky and Jean Elkhoury of UCLA, shows changes in these tides (in some wells) coincident with earthquakes that have produced strong shaking at the site: both permanent changes (until the next shock) and transient changes that decay over the weeks following the earthquake. These presumably reflect changes in the local hydraulic regime, and can serve as a useful model for understanding how cracks in the crust can be affected by, and heal after, large dynamic strains—a topic of clear interest for understanding possible dynamic triggering of earthquakes.

Tidal fit to baro−corrected PFO Water Heights

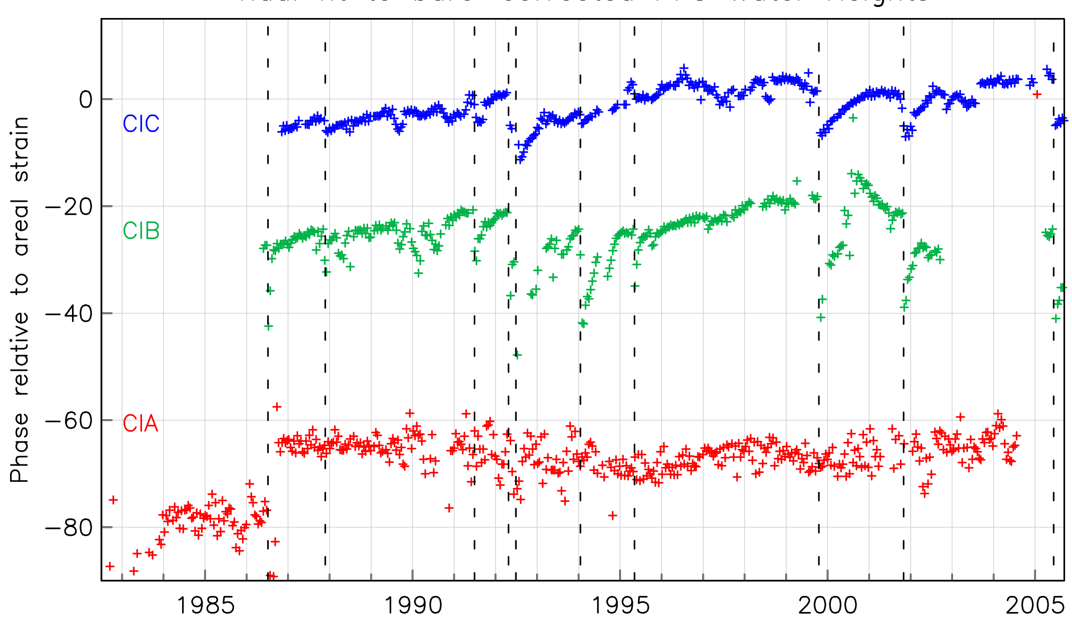

Figure 2

Figure 2 shows the results of an analysis of the time-varying semidiurnal tidal phase for three of these wells, which are located at the apices of a 300-m triangle. The tides are largest in well CIC, smallest in CIA. The phases are shown relative to the phase of the areal strain tide as measured with the laser strainmeters at the observatory (one of the very few places where the amplitude and phase of this tide is known from measurement). Table 1 gives parameters for the earthquakes indicated by dashed lines. It is clear that the closer and larger earthquakes cause significant transients at two of the wells. What is interesting, for CIB, is that transients are also visible from events (such as Northridge and Sierra Madre) for which the actual shaking at PFO was relatively slight.

A SCEC proposal from Prof. Brodsky discusses some of the possible mechanisms for this. But the most important point about these observations, in the context of this report, is that they could never have been obtained without the kind of sustained operation we have been able to maintain at PFO: only many years of monitoring these wells could provide enough examples to allow a pattern of response to earthquake shaking to emerge. Sustaining this sort of long-term monitoring is not easy; and SCEC's support has been important in allowing us to do so.

Year	Day	Magnitude	Distance	Name
1986	189	5.6	46	N. Palm Springs
1987	328	6.6	87	Superstition Hills
1991	179	5.8	160	Sierra Madre
1992	114	6.1	41	Joshua Tree
1992	180	7.3	66	Landers/Big Bear
1994	17	6.6	204	Northridge
1995	127	4.8	36	Joshua Tree
1999	289	7.1	111	Hector Mine
2001	304	5.1	13	Anza
2005	163	5.2	14	Anza

3. Observatory Operations

In the past year we have also made significant progress on several specific items related to observatory operation. Of course, there is also maintenance of many items; over the course of the year, we average 1–2 trips per month both to introduce new equipment and to fix problems. Typically the latter involves work on the facility and the laser strainmeters (lasers and vacuum systems). Much of the work reflects the age of some of the equipment at PFO; we have been using specially-requested NSF I&F funds, and capital funds from the Green Foundation (Dallas) and from the SIO Director's Office to purchase some badly needed new equipment, such as air conditioners and replacement power supplies.

3.1. Data Access

To get data from the PFO instruments to the wider community, we need (1) reliable data links from the site to our lab; (2) a system to collect the data and send it over these links; and (3) the procedures and personnel to make the data available to the community in an easily-usable form. The first of these has been available for some time, through the NSF-funded HP/WREN (*hpwren.ucsd.edu*) and RoadNet (*roadnet.ucsd.edu*) projects. We have 45 Mb/s TCP/IP capability at the repeater on Toro Peak, overlooking PFO, with a radio link to the PFO trailer providing 8 MBits/s to the local network.

Using part of the funds that Scripps provides as a match to SCEC support, we assembled an Internet-compatible data recorder for PFO: a copy, extended to handle 128 channels, of our current standard onsite datalogger, which also provides automated and off-site control of strainmeter beam-steering and vacuum pumpdowns. The extension to 128 channels revealed some serious problems with the system not evident in our earlier 32-channel systems; after fixing the code and extensive checks, this datalogger was installed at PFO in the spring of 2005, and we have been using it as the primary data source since day 140 of this year. This datalogger provides raw data in near real time through RoadNet, but our standard processing relies instead on a daily download. We have developed systems for making the raw data files available on the Web (*pfostrain.ucsd.edu*); this now includes the main series of 5-minute-sample data from the strainmeters at PFO, Glendale, and Durmid Hill.

A bigger challenge is providing the data in a ‘‘cleaned-up’’ form that is more suitable for most users; a challenge, since some of the data editing can only be done by experienced personnel. We are working on this problem with support from the PBO, and will apply whatever developments we make to the PFO data.

3.2. Seismic Test Facility

With funds from NSF Ocean Sciences and other sources (not SCEC) a group at IGPP (including ourselves) has constructed a new seismic test facility. This is a substantial structure, consisting of four 15.6 m^2 vaults with footings 5 m below grade, and includes several test boreholes. Two of the vaults have seismic piers (granite piers especially installed) and two are designed for simultaneous testing of many instruments. One vault will soon house the IDA/IRIS/TerraScope VBB system; another already houses a ring-laser gyro system with seismic sensitivity installed by a group from the Technical University of Munich, Germany. This makes PFO the only place in the world with the ability to measure seismic displacements, rotations, and strains.