Laser (Long-base) Strainmeters:

Principles, Instruments, and Data

Duncan Carr Agnew

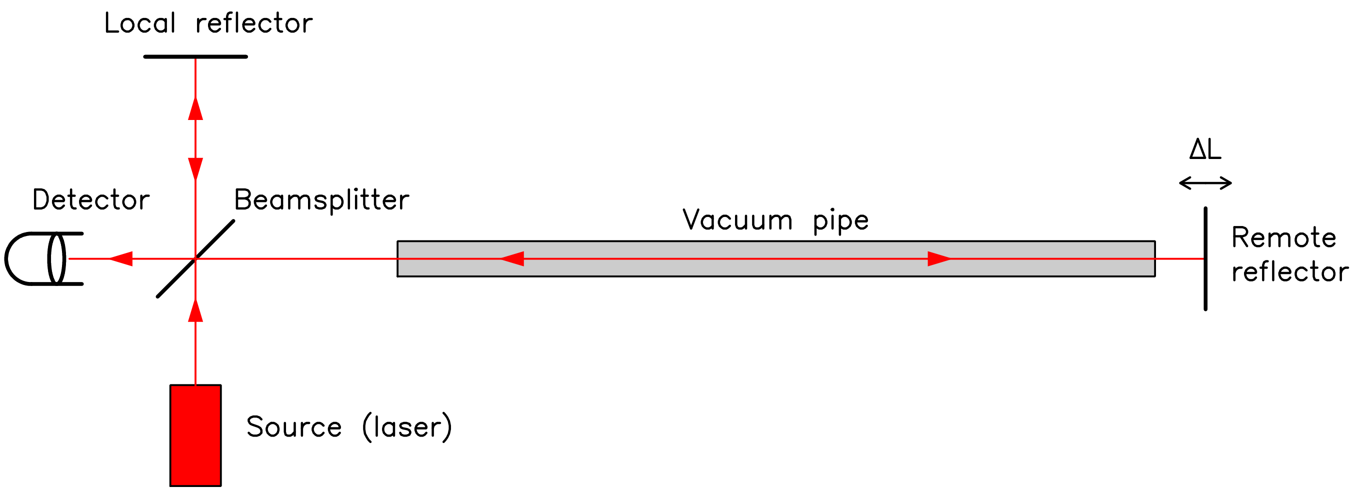
IGPP/Scripps Institution

UC San Diego

Basic Design: Overview

- Measures changes in distance optically, using an interferometer.
- Became possible with lasers: these produce narrowband light, making interferometry possible over long distances.
- Three features needed:
    - A narrowband light source that has a very stable frequency.
    - An unchanging propagation delay.
    - A stable attachment to the ground.

Basic Design Overview I: Main Interferometer

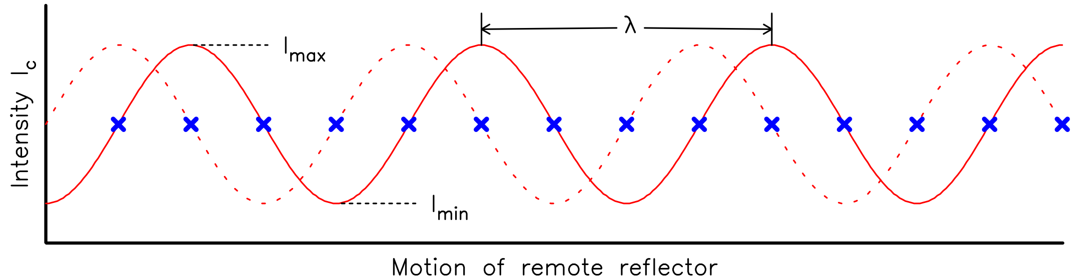


A **Michelson interferometer** has two arms, one fixed (to the local reflector) and one variable (to the remote reflector).

Light from the source is split at the beamsplitter; after making the round trip, the beams recombine there to send a signal to the detector detector D.

Basic Design Overview II: Interferometer Signal

The red lines show the intensity at the detector as the remote reflector moves; there are two because we use different polarizations to get two intensities shifted by $\lambda/4$.



The electronics counts zero-crossings, using the sign of the nonzero component to find the direction.

If the remote mirror moves by $\lambda/8$, the path length changes by $\lambda/4$, which crosses zero.

This is 7.25×10^{-8} m: $\varepsilon = 1.53 \times 10^{-10}$ for L 500 m.

All this is “just like” GPS carrier-phase, in miniature.

Optical Paths

We measure the change in **optical path length**: the actual path length times n, the index of refraction: again, just like GPS.

Air and Vacuum

Through air, the effect of pressure and temperature changes is about 10^{-6} K^{-1} and 3×10^{-4} Pa^{-1}: much too large. For a “good” (but not “high”) vacuum (1 Pa pressure) these are 10^{-5} times smaller: not a problem, but at a cost:

- Path must be straight.
- High first cost
- Long-term cost of turning dollars into nothing.

Vacuum has excellent long-term stability.

Optical Fiber

Basically, this is glass – *really* transparent glass.

Temperature coefficient of n is about 10^{-5} K^{-1}: very high.

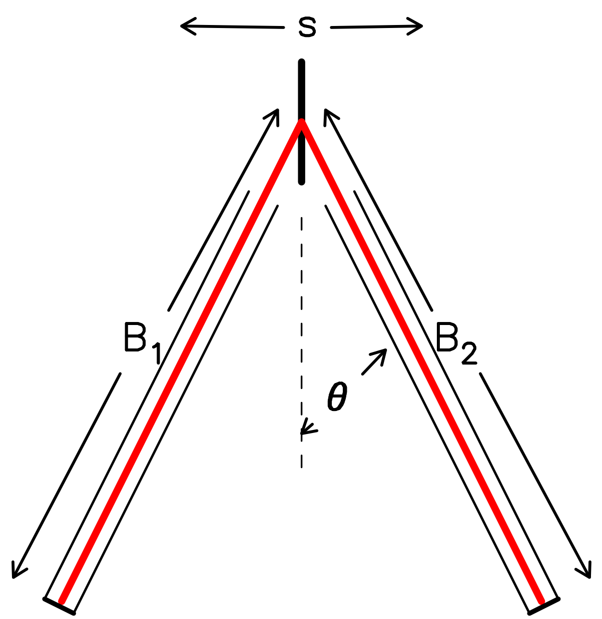
Index n does drift with time, as the fiber “ages”, at about 10^{-6} yr^{-1}.

Does not need to be exactly along a straight line, so Cost is much lower.

Anchoring

Longbase laser strainmeters use “optical anchors” to minimize noise from the near surface.

- Equal-arm interferometer at each end of the “main” system, going to 10-30 m depth.
- Best results from a pair of vacuum pipes, but fibers are adequate and much cheaper.



Anchoring with Fibers

This works because much of the false signal (from temperature) is common-mode and cancels out.

- Fibers are “loose” inside a metal jacket.
- Points to be anchored are “glued” in place, and the fiber tensioned between them.

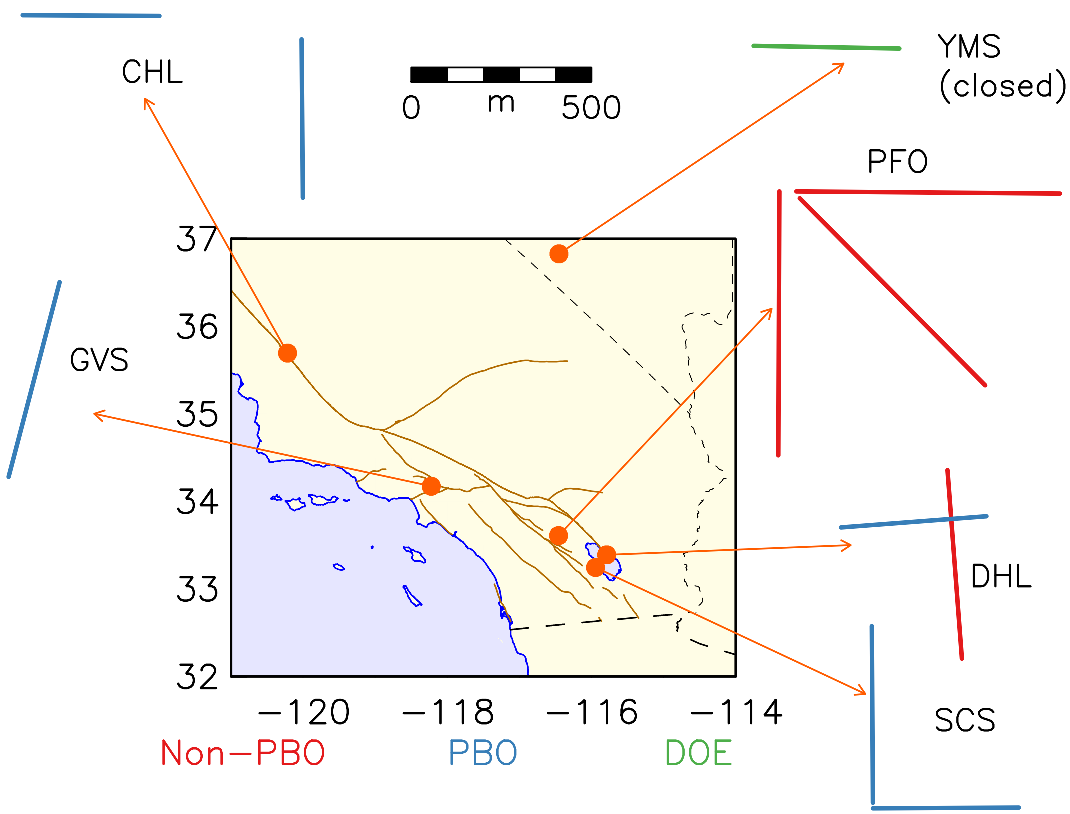
At least two fibers are monitored in each arm.

SAFOD Fiber Strainmeter

(Included because it *is* part of PBO).

- Purpose was to provide some kind of strain measurement in the SAFOD hole (originally planned to be a special GTSM)
- Fiber is installed along and outside of the casing, taped to it, and grouted in place.
- Hence, a vertical strainmeter.
- Uses Michelson interferometer arrangement, subdividing fringes for higher resolution.
- Currently has stability sufficient only for seismic data.

Long-Base Laser Strainmeters



Five built before PBO, five by PBO, one by DOE.

DHL: Durmid Hill

First site, chosen before start of PBO.

One component, 405 m, at right angles to the USGS-sponsored instrument (close to NS and EW, but 5° off to maximize sensitivity to San Andreas fault strain).

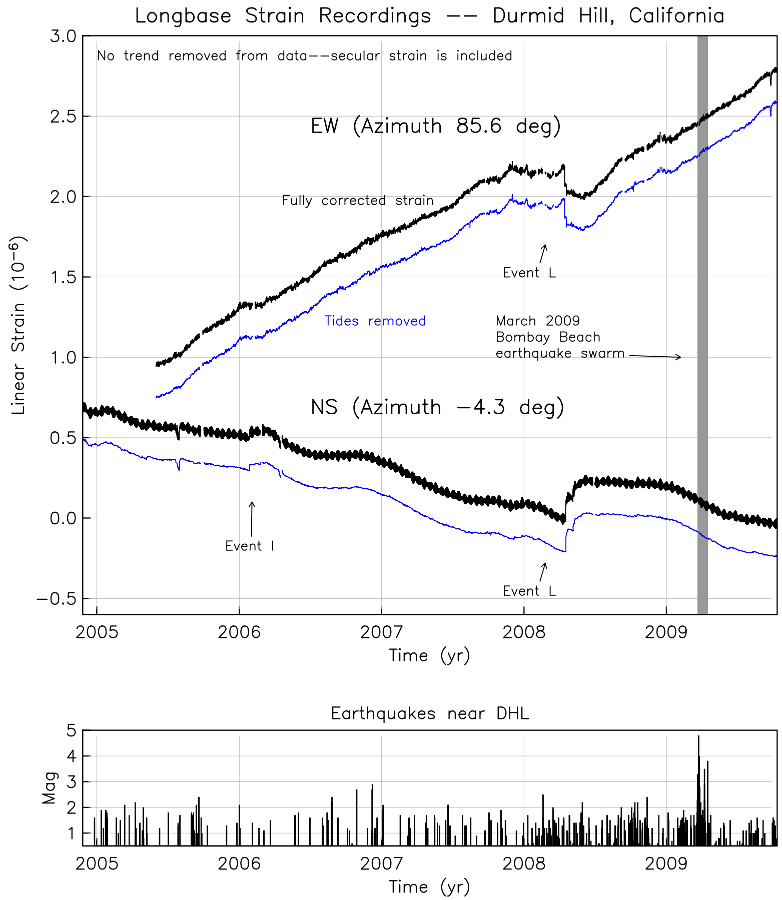
Local geology is Pleistocene sediments (clays and mudstones), planed off by Lake Cahuilla.

Short-term loading signals from trains and seiching,

Both components show long-term strain rates consistent with geodesy.

Have also seen rapid aseismic events, suspected to be fault creep.

Durmid Hill Data



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Salton City

Chosen to get more data from the Salton Trough.

Two components, NS (490 m) and EW (405 m), on Lake Cahuilla Quaternary sediments (clays and sand).

Relatively large barometric responses, in opposite senses.

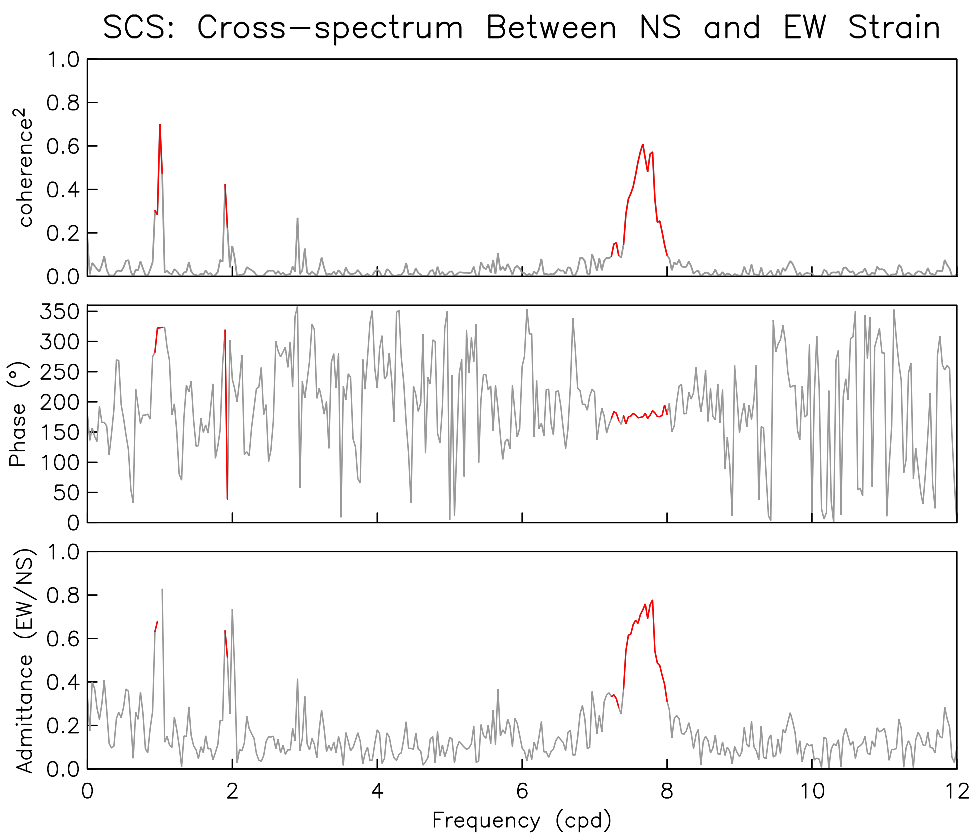
Noisier than Durmid Hill instruments, but showing reasonable long-term rates.

This is impressive, given the (poor) quality of the underlying material.

North End of SCS1

Yes, the ground really is that flat.

Salton Sea Seiche at SCS



Sloshing of water in the Salton Sea produces a small signal, but one visible in the coherence between sensors.

Cholame

Chosen to get data from the region of tremors south of Parkfield.

Two components, 438 m NS and 379 m EW, close to each other (not quite perpendicular).

Cholame: Looking North

Cholame: Looking South

Glendale-Verdugo

Built in 2000 as part of SCIGN: 559 m long, next to freeway.

PBO data starts 2005.

Affected by rainfall (a problem with one of the anchors), but data are otherwise good.

Laser Strainmeter Data Processing

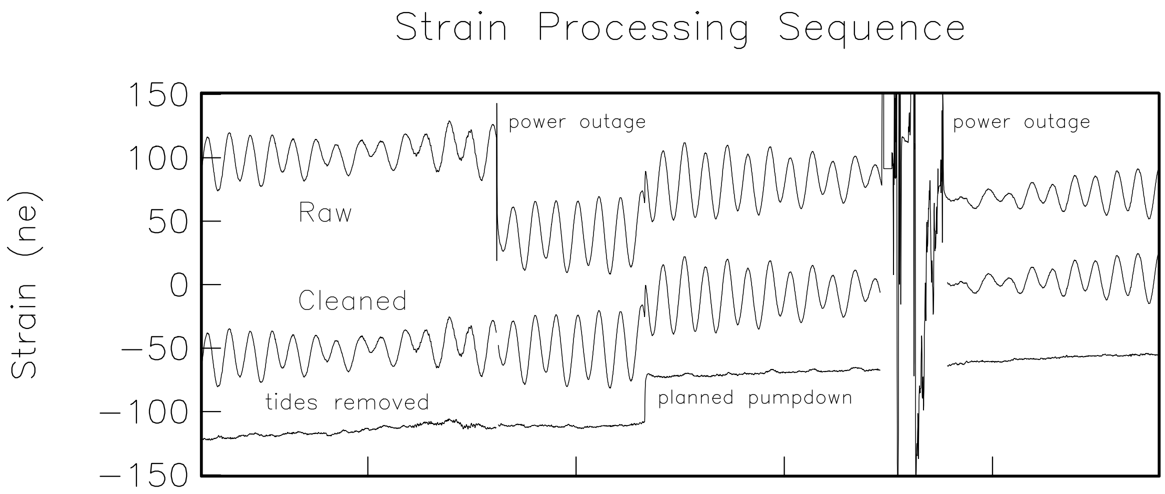
Our aim is to produce data that are ready for scientific use, with all problems addressed – for a system that in some ways is still a “lab” device.

Data channels to be considered are usually:

- 1. The main interferometer (both in 1-s and filtered form)
- 2. Both anchors (also interferometers)
- 3. The vacuum pressure (not a big contributor, depending on pumping and leaks).
- 4. The laser frequency (interpolated).
- 5. End-point temperatures (occasionally).

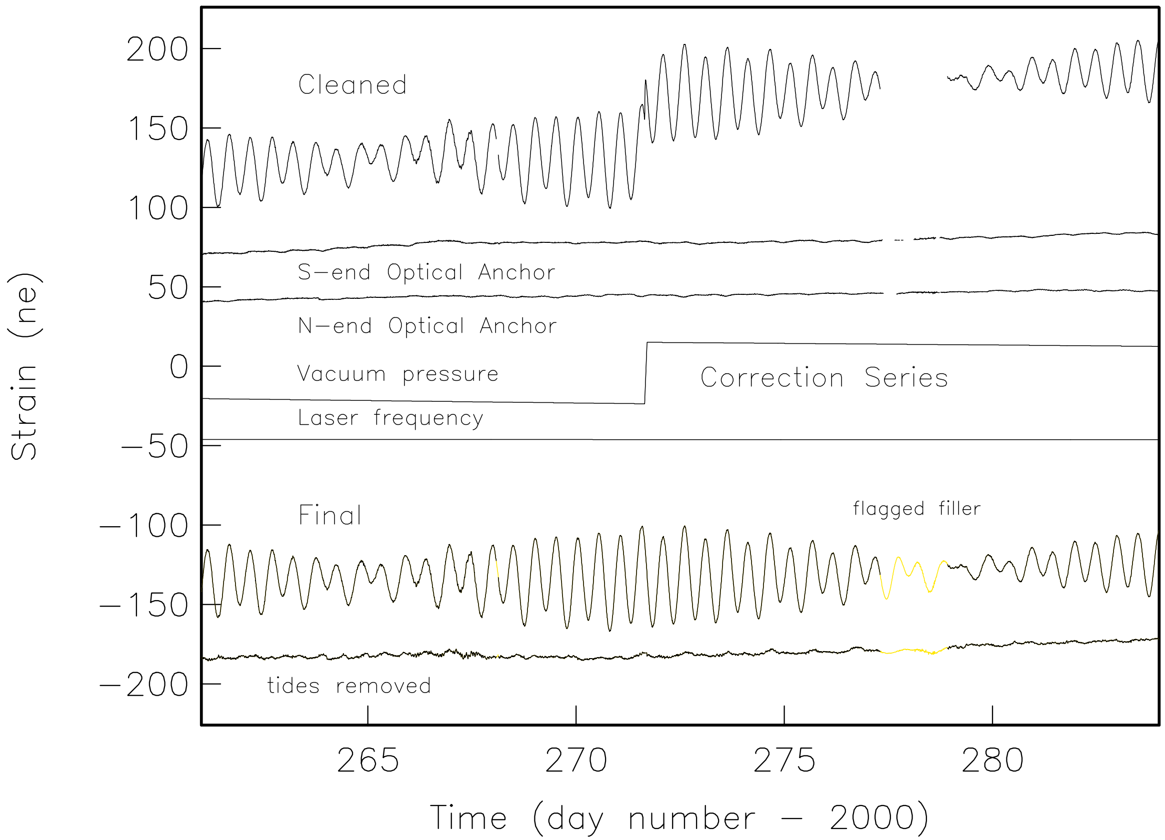
Along with records from visits to the field.

An Example of Editing



In this case, there is a (valid) offset in the main interferometer because of a (known) vacuum change; also a period when something went wrong.

Combining the Data



Access to Laser Strainmeter Data

All raw and processed data are available from PBO Strainmeter Data Center (NCEDC).

High-frequency (1-s) available as raw and SEED.

Low-frequency (5-m) data available as XML.

Unless you are looking at high frequencies, or want to get involved in the editing issues, you should use Level 2 data.

Sample of Level 2 Data

A single time point contains (in part):

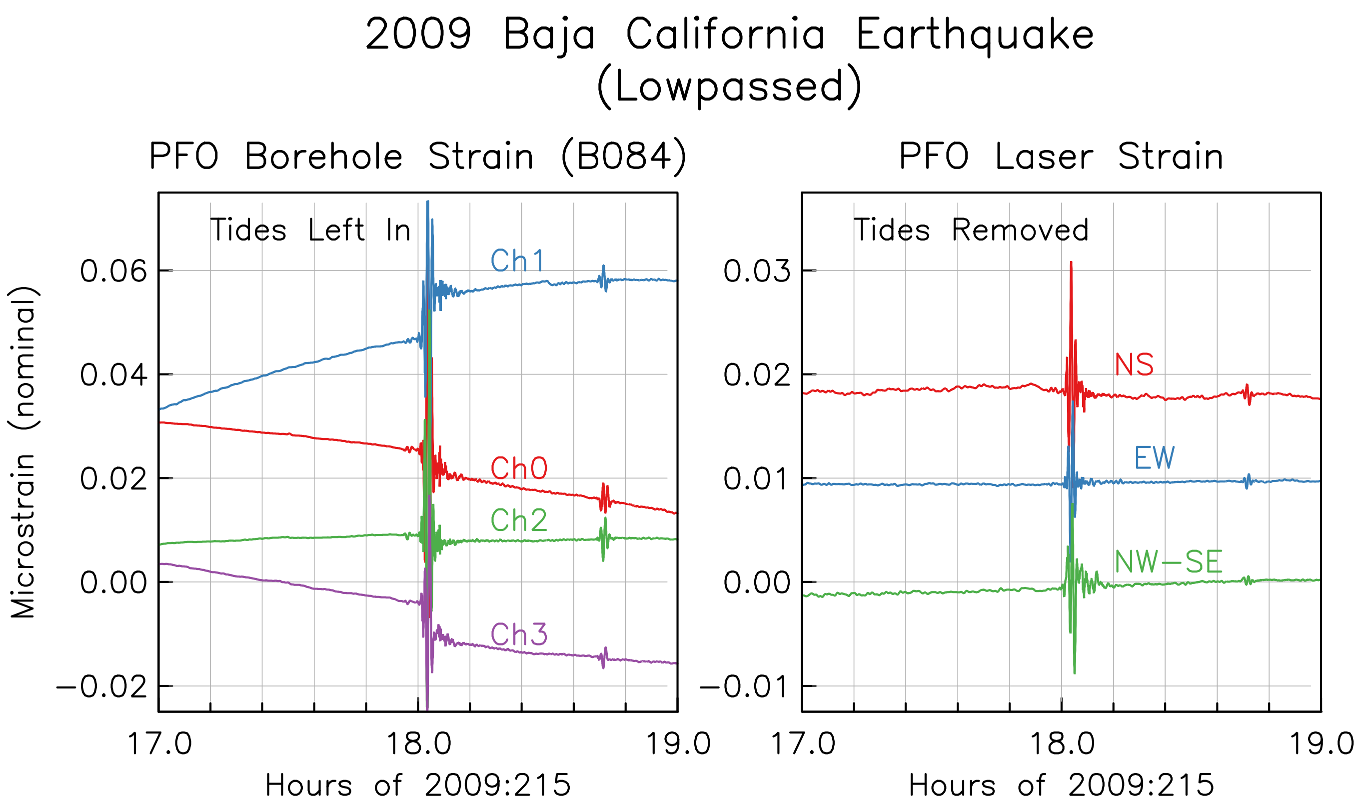
```
<obs strain ="lsm">           kind of data
<date>2010-04-04T00:00:00</date>    time of data
<s>-2594914.0</s>                   main interferometer
<s_q>g</s_q>                            and its quality
<tc>     108.6</tc>                 tidal correction
<oaic>   53481.0</oaic>             optical anchor, interferometer end
<oarc>  -27682.0</oarc>             optical anchor, remote end
<vac>       91.0</vac>              vacuum
<btpi>    -258.0</btpi>             box temp, interferometer end
<btpr>    -258.0</btpr>             box temp, remote end
<v>2010226181654</v>                creation time of file
<level>2b</level>                   level of data
```

The values in red are the key ones. The anchor data needs to be scaled to meters, then to strain, before adding it to the main interferometer data (which also needs to be scaled).

The tides are given in the same units as the main interferometer.

Application of the other data for correction is up to the user.

An Intercomparison



This earthquake was too distant for the actual coseismic strains to be visible.