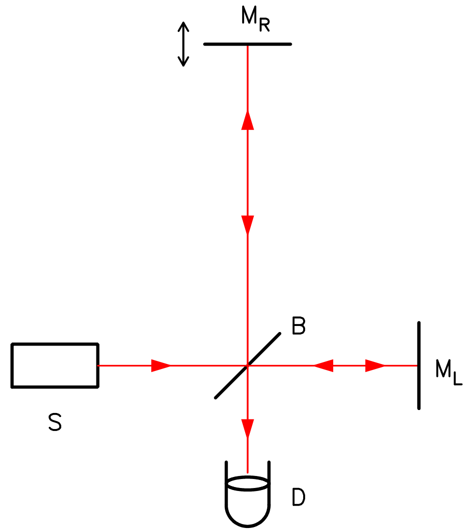
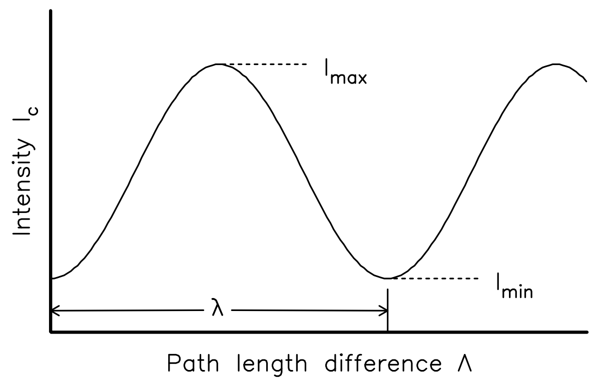
Laser Strainmeters

Basic Concept

- Measure changes in distance optically, using an interferometer.
- Became possible with the development of the laser, which produced narrowband light, and made interferometry possible over long distances.
- Needs to have
  1. A light source that is narrowband and stable in frequency (over the time period of interest).
  2. A stable light path.
  3. A way of attaching the interferometer ends to the ground.

Interferometry





A **Michelson interferometer** has two arms, one fixed (to M_L) and one variable (to M_R).

The light from S is split at the beamsplitter B; the beams recombine at B to give an output to the detector D.

The bottom frame is the intensity at *D* as M_R moves.

If M_R moves by $\lambda/8$, the path length changes by $\lambda/4$: from light or dark to zero. This is 7.25×10^{-8} m: $\varepsilon = 1.53 \times 10^{-10}$ for *L* 500 m.

We can get higher resolution by measuring the intensity, but this is more complicated.

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

Optical Paths

What we measure is the change in **optical path length**, which is 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

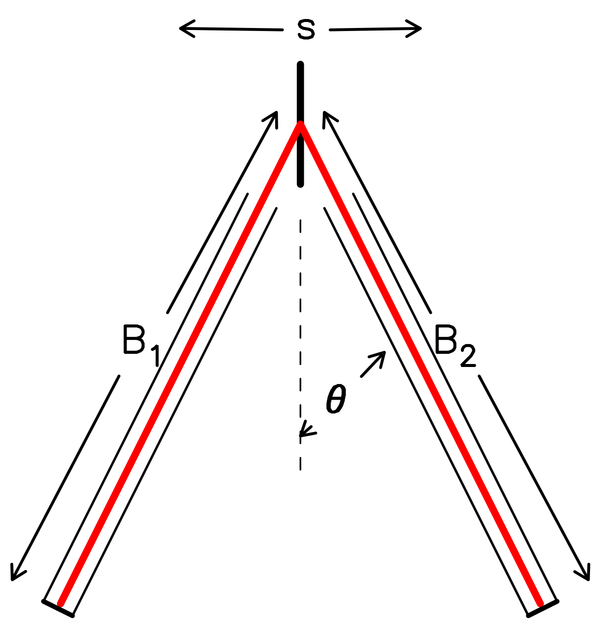
Basically, this is glass—really transparent glass.

- 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}.
- Cost is much lower; does not need to be exactly along a straight line.

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 Fibers

Fibers are "loose" inside a metal jacket.

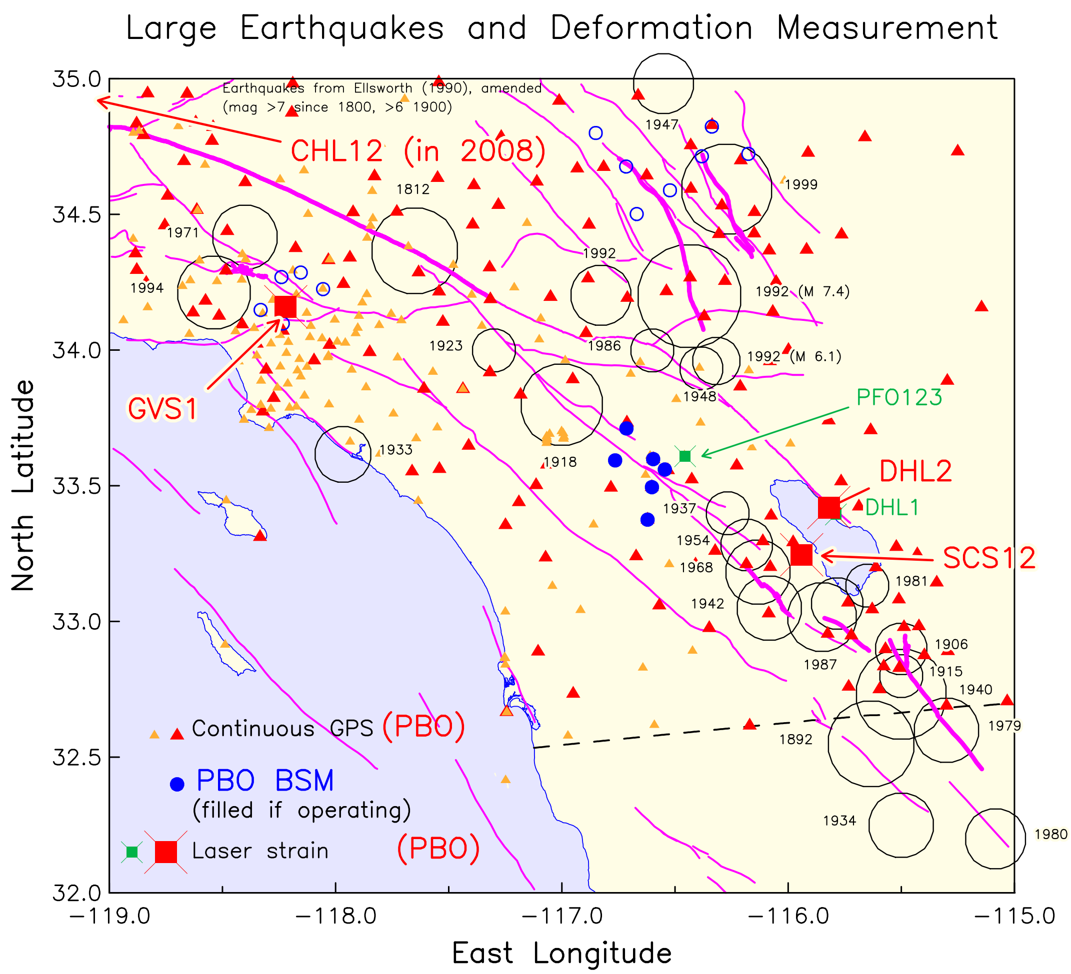
- Points to be anchored are "glued" in place, and the fiber tensioned between them.

SAFOD Fiber Strainmeter

- 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.

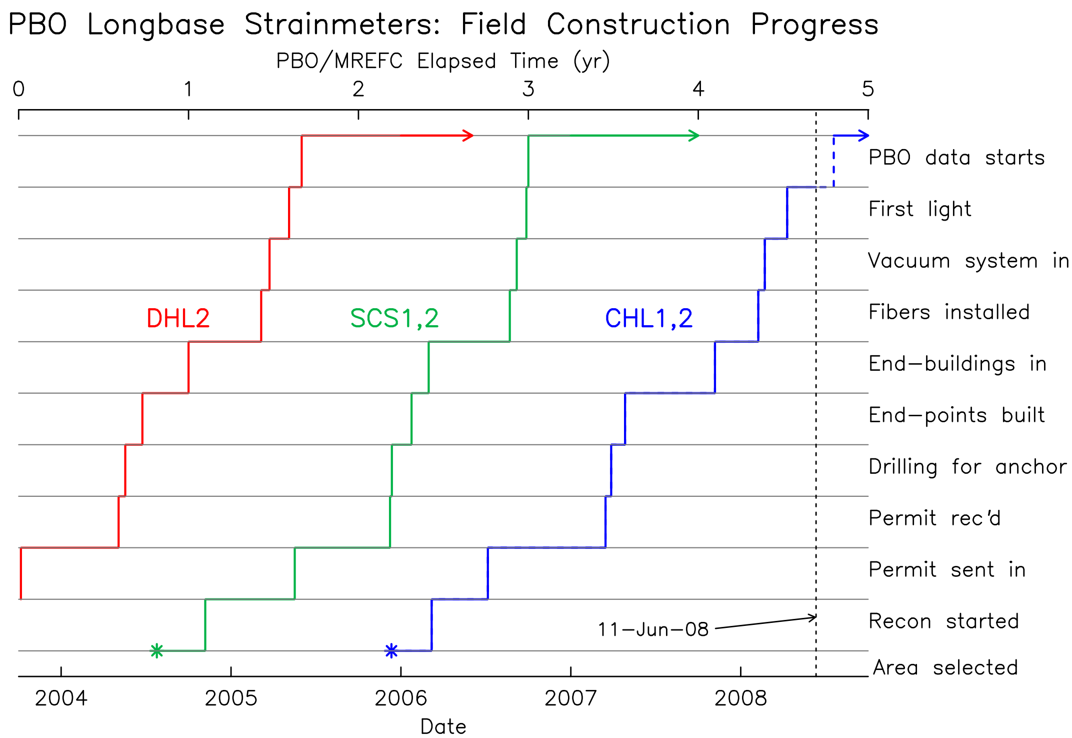
Long-Base Laser Strainmeters

Five built before PBO (one now operated by PBO). One (Yucca Mountain) closed). Five built for PBO; two of these are in progress



First site (Durmid Hill) chosen before start of PBO; others selected later.

- Salton City, to have more data from the Salton Trough.
- Cholame, to have data from the region of tremors south of Parkfield.



Durmid Hill

- 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 mud-stones), planed off by Lake Cahuilla.
- Short-term loading signals from trains and seiching,
- Both components show long-term strain rates consistent with geodesy.
- Last several months (and especially since April) have seen rapid aseismic events, suspected to be fault creep: depth unclear.

Salton City

- 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.

Cholame

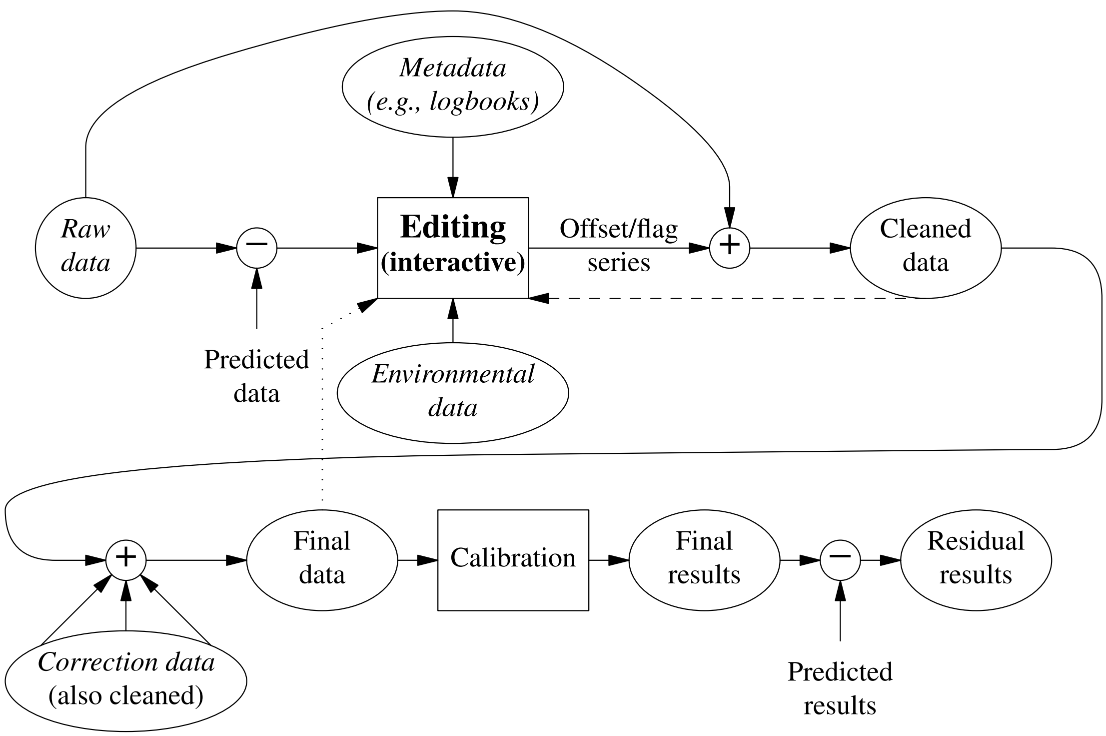
- Two components, 438 m NS and 379 m EW, close to each other (not quite perpendicular).

Glendale-Verdugo

- Built 2000 as part of SCIGN: 559 m long, next to freeway.
- PBO data starts 2005.
- Affected by rainfall (anchoring problem), but data otherwise good.

Laser Strainmeter Data Processing

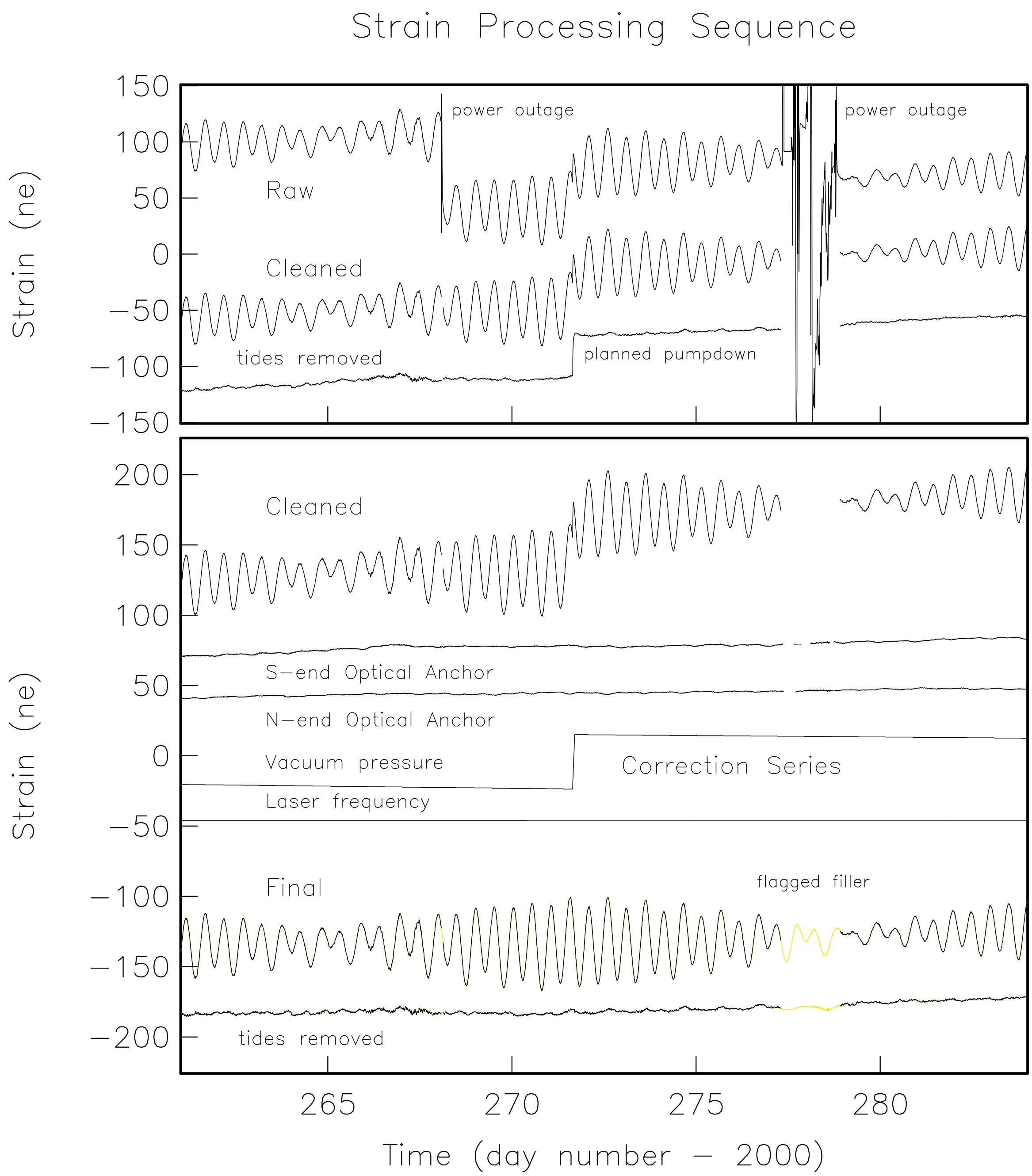
The aim is to produce data that are ready for scientific use, with all problems addressed—for a system that in some ways is still a "lab" device.



Data channels to be considered are:

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).

Along with records from visits to the field.



Laser Strainmeter Data Access

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.

Use of Level 2 data is highly advisable.