Long-Period Signals Observed in the Plate Boundary Observatory Borehole Strainmeters

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1. Introduction

Since 2005, UNAVCO has installed 82 borehole strainmeters as part of the Plate Boundary Observatory (PBO) project. The strainmeters were deployed across the plate boundary regions of Western United Sates and Vancouver Island, Canada (**Figure 1**). They were installed in boreholes at depths of 120–250 m, and have a strain resolution of 0.1 nanostrain (ns). Thus, the PBO borehole strainmeters are powerful for detecting subtle tectonic and nontectonic deformations.

In the strainmeter data, we observe a distinct strain variation that starts at the year of 2010 and lasts about 3–4 years. We also observe similar variation in the pore pressure sensors that are installed along with the borehole strainmeters. Below, we report our observations of the long-period signals, and explore physical models that relate the strain to the pore pressure.

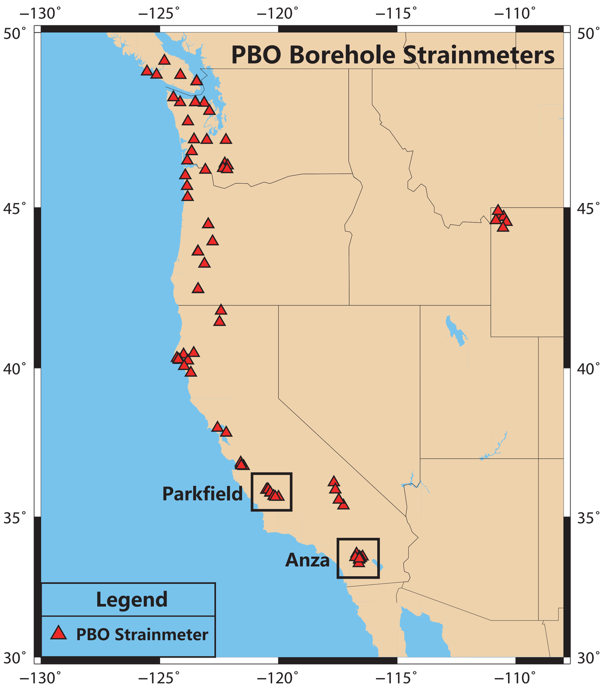


Figure 1. PBO borehole strainmeters.

2. Observation of the Long-Period Signal in Strainmeter and Pore Pressure Sensor

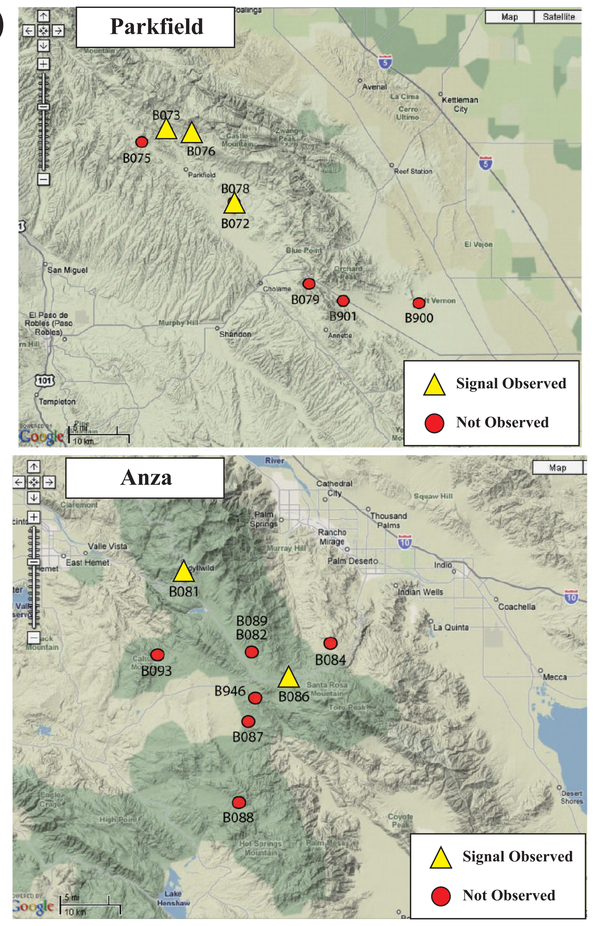


Figure 2. PBO borehole strainmeters at **(a)** Parkfield and **(b)** Anza.

In some borehole strainmeters (**Figure 2**), we observe a distinct strain variation that starts at the year of 2010 and lasts about 3–4 years (**Figure 3a**). The existence of the signal has also been corroborated by the observations in several pore pressure sensors that are installed along with the borehole strainmeters (**Figure 3b**). Besides, both the soil moisture and the equivalent water height calculated using GRACE data exhibit similar forms of water storage change at the corresponding locations during the strain variation (**Figure 4**).

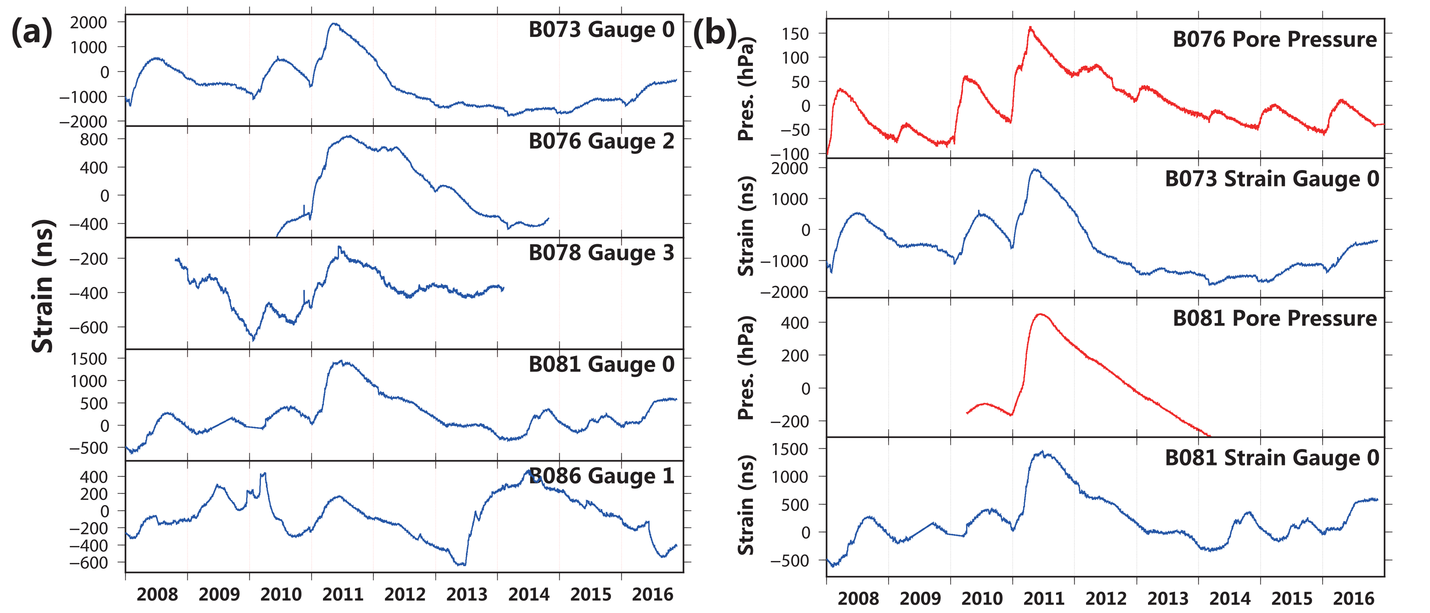


Figure 3. (a) Long-period strain signals observed in strainmeters at Parkfield and Anza (**Figure 2**). **(b)** Pore pressure signals observed in two representative strainmeters: B076 and B081.

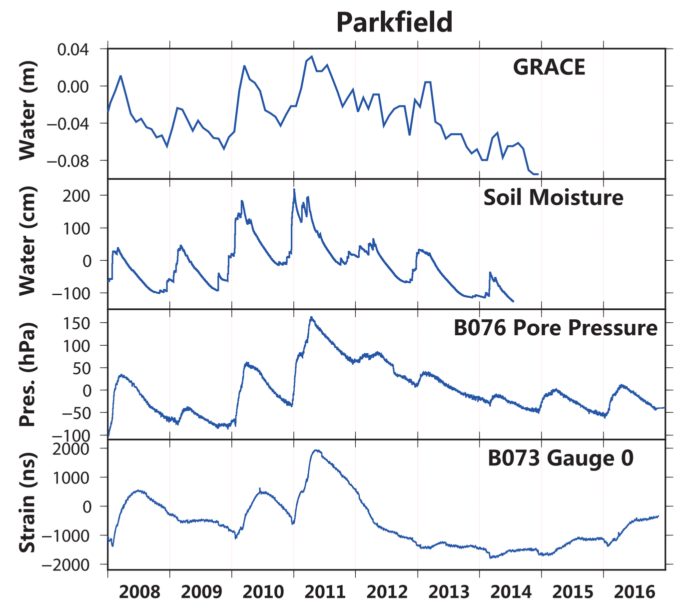


Figure 4. Comparison of variations of GRACE equivalent water height, soil moisture, pore pressure, and strain at Parkfield.

3. Strain after Calibration and Rotation to Principal Axes

B081: Study (Roeloffs, 2010) has shown that the elongations of the gauges of strainmeter B081 have small coupling coefficients to vertical strain, so the calibration matrix obtained from tidal signals can be used to calibrate the hydro-related strain signals at B081.

B073: The elongations of the gauges of strainmeter B073 are largely coupled to vertical strain, thus the tidal calibration matrix is not appropriate for calibration of the hydro-related strain signals. However, the differential strain and shear strain of the hydro-related strain can still be estimated using the tidal calibration matrix, since they are less sensitive to vertical strain.

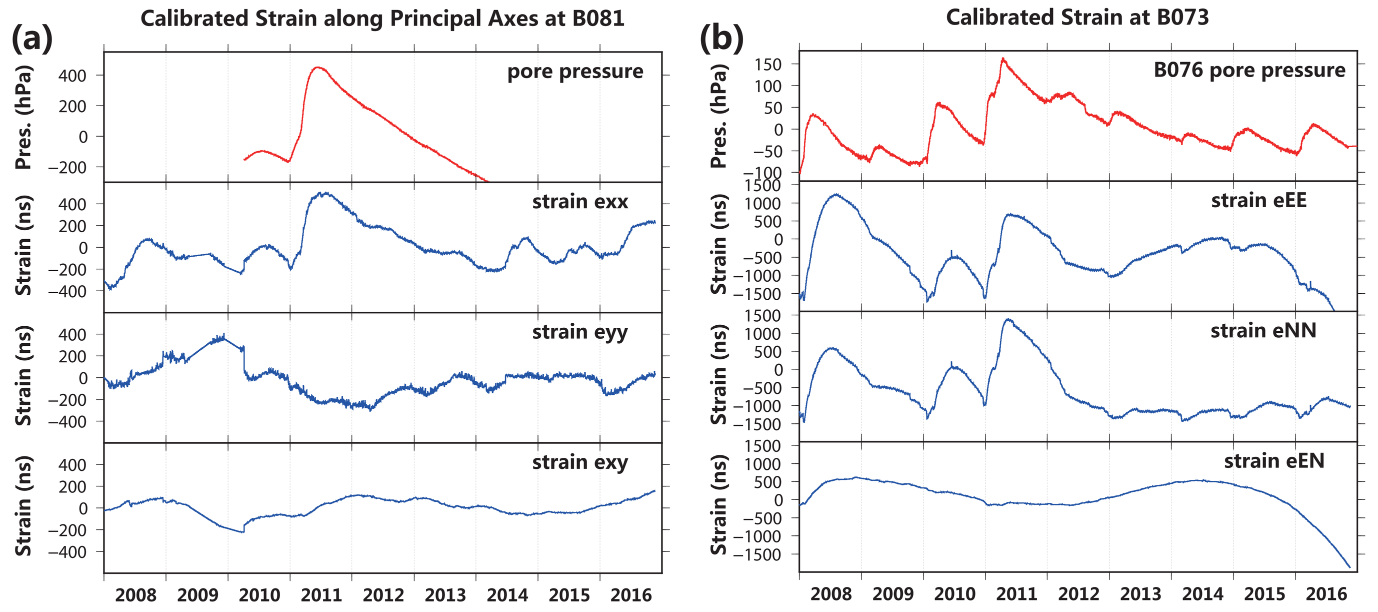
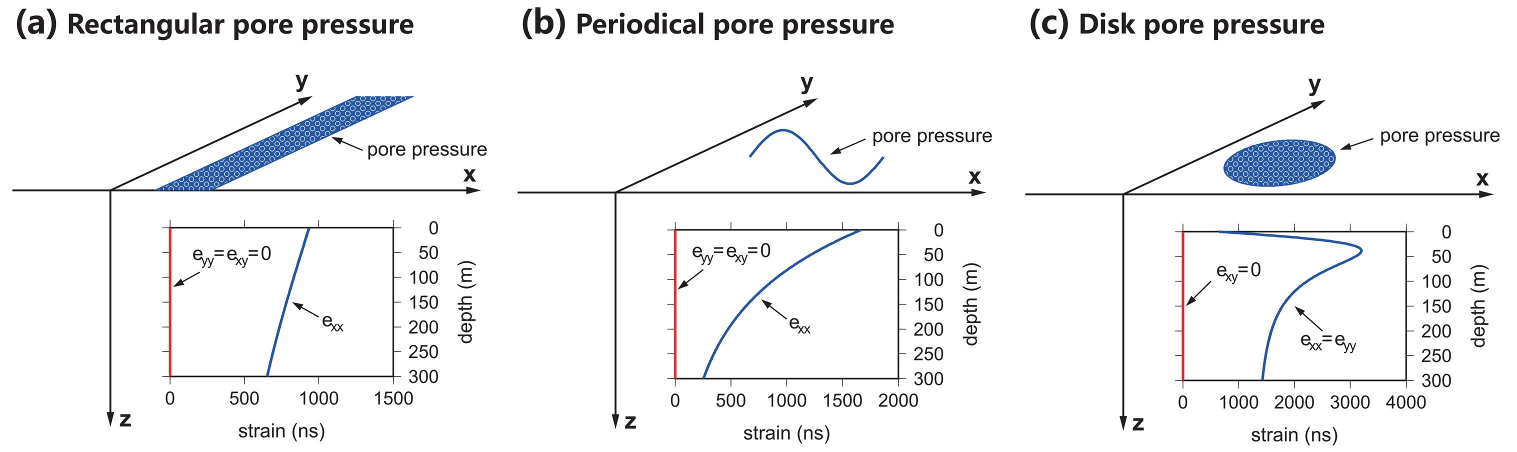


Figure 5. (a) Calibrated strain along principal axes at B081. The direction of x axis is N3°W. Note that both variations of eyy and exy are small compared to exx. **(b)** Calibrated strain at B073. Note that the shear strain exy is about an order smaller than the normal strain exx and eyy.

4. Physical Models Relating Strain Signal to Pore Pressure Variation

Figure 6. Physical models that relate the underground deformation (strain) to surface pore pressure variation. **(a)** Uniform pore pressure in rectangular region on surface, and the resulted strain (exx, eyy, and exy) at depth. **(b)** Periodical pore pressure on surface, and the resulted strain at depth. **(c)** Uniform pore pressure in a disk on surface, and the resulted strain at depth. Note that both rectangular and periodical model could produce large exx while small eyy and exy, which are observed at B081 (**Figure 5a**). The disk model produces exx and eyy with the same amplitude and small exy, which are observed at B073 (**Figure 5b**). In addition to surface distribution, the pore pressure could also distribute at depths.



5. Conclusions

1. In PBO borehole strainmeter data, we observe a distinct strain variation that starts at the year of 2010 and lasts about 3–4 years. We also observe similar signals in pore pressure, GRACE-calculated equivalent water, and soil moisture.

2. The calibrated strains exhibit large exx (~600 ns) and small eyy and exy (an order smaller than exx) along principal axes at B081, while they exhibit exx and eyy with similar amplitudes (~2000 ns), and small exy (an order smaller) at B073.

3. Rectangular, periodical, and disk pore pressure models are proposed to relate strain signal to pore pressure variation.

More Data Examples

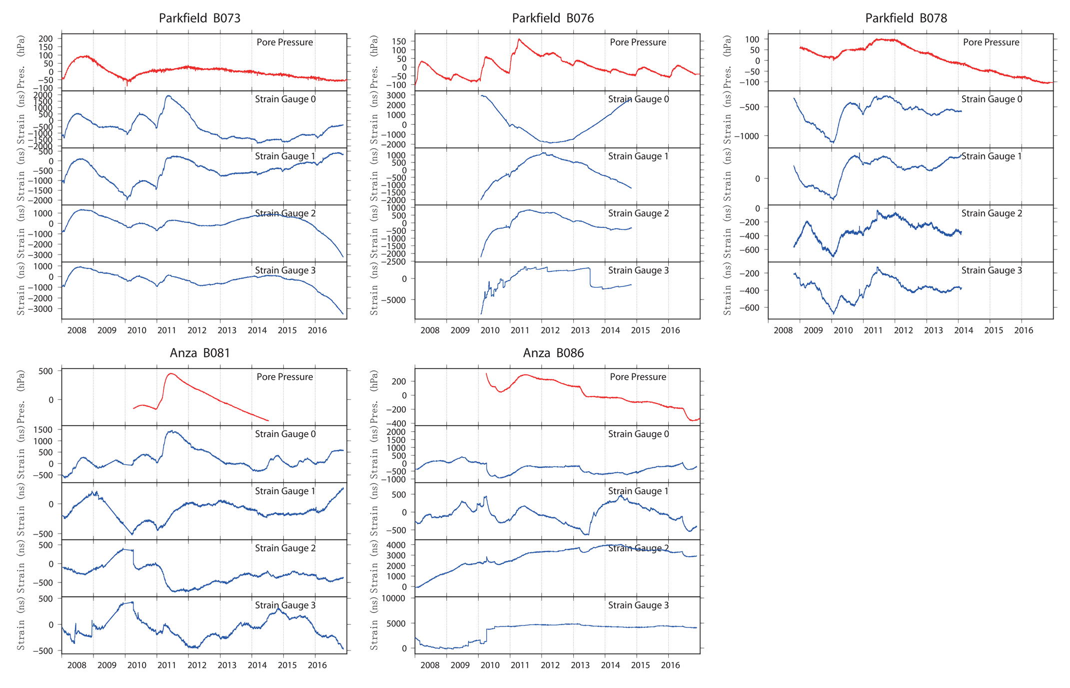


Figure A1. Observations of pore pressure (red curves) and strain (blue curves) at the strainmeters that observed the long-period signals (yellow triangles in **Figure 2**).

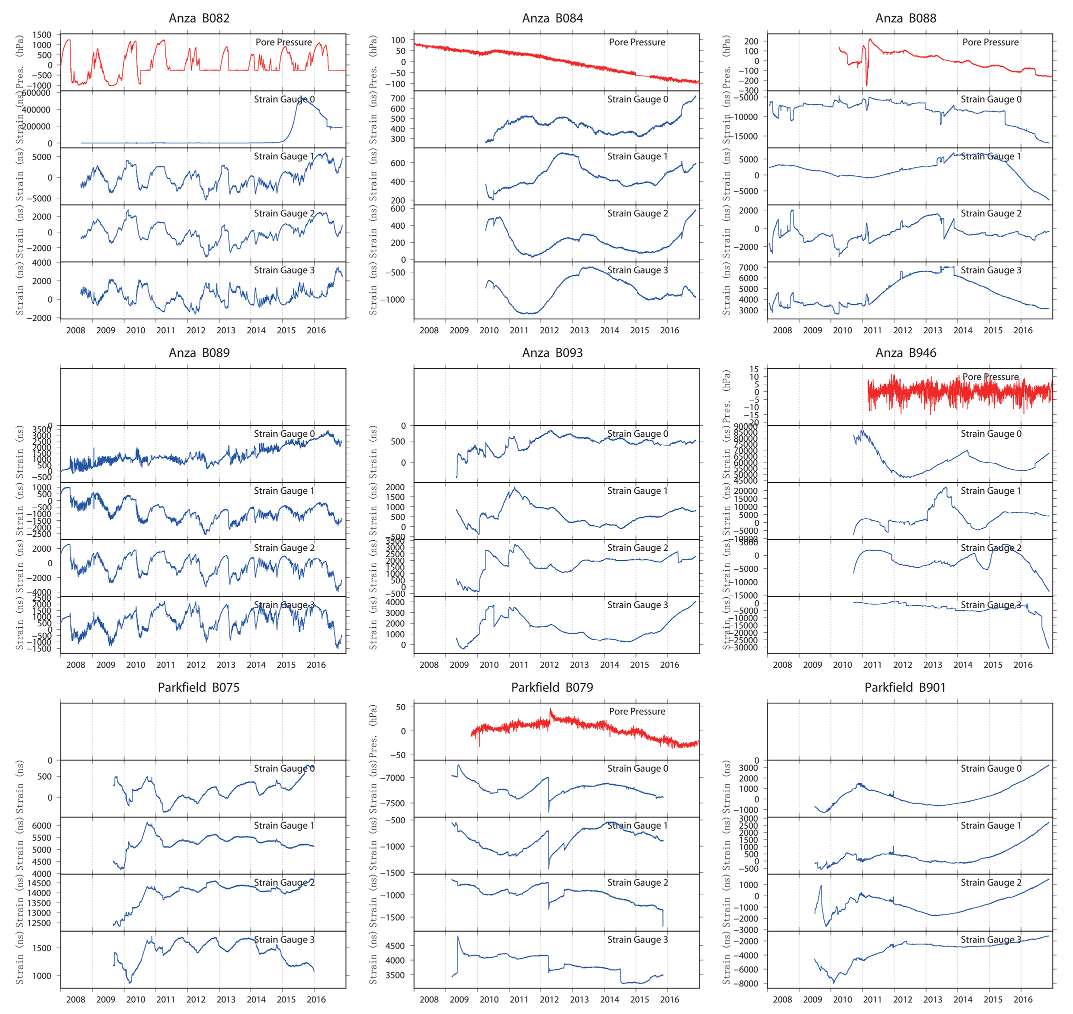


Figure A2. Observations of pore pressure (red curves) and strain (blue curves) at the strainmeters that did not observe the long-period signals, at Anza and Parkfield (red dots in **Figure 2**).

Table A1. Depths of the strainmeter gauges and pore pressure sensors of the PBO borehole strainmeters at Parkfield (**left table**) and Anza (**right table**). The instruments that observed the long-period signal are in red, otherwise in black.

Station	Strain Depth (m)	Pore P Depth (m)
B072	N/A	N/A
B073	241.4	12.8
B075	170.5	N/A
B076	198	3
B078	181.5	19.5
B079	181.5	45
B900	186	N/A
B901	181.8	N/A

Station	Strain Depth (m)	Pore P Depth (m)
B081	242.9	37.5
B082	243	22.6
B084	158.6	36.9
B086	239.9	39.5
B087	160.9	24.4
B088	159.4	15.2
B089	132.8	N/A
B093	144.8	N/A
B946	148	18.3