Science AAAS

www.sciencemag.org/cgi/content/full/321/5895/1478/DC1

Supporting Online Material for

Postseismic Relaxation Along the San Andreas Fault at Parkfield from Continuous Seismological Observations

F. Brenguier,* M. Campillo, C. Hadziioannou, N. M. Shapiro, R. M. Nadeau, E. Larose

*To whom correspondence should be addressed. E-mail: fbrengui@ipgp.jussieu.fr

Published 12 September 2008, *Science* **321**, 1478 (2008)
DOI: 10.1126/science.1160943

This PDF file includes:

Supporting Online Material

Noise correlation Processing

We first select the seismic data by 24-hour intervals and clip the amplitudes above 10 times the average rms amplitude as a first step to avoid time localized strong energetic signal principally due to earthquakes. We then apply spectral withnening between 0.08 and 2.0 Hz and one-bit normalization in the time domain in order to converge toward a stationary data set. We finally correlate these 24-hour interval time series for every possible receiver pair (*1, 2*). Most of the contribution by earthquakes and tremors is removed by this processing, as their energy is mostly contained in a higher frequency band than the one considered here. The current cross-correlation functions are stacked into 30-day stacks while moving the stack window by a day at a time. The reference cross-correlation functions are stacked over the all time period. In order to retrieve high signal to noise ratio reference stacked cross-correlation functions, we only select correlation functions for which the average energy of the reconstructed direct waves is 1.5 times higher than the average energy of the *noise* part of the correlation functions. By this procedure, we reject 74 % of the cross-correlation functions. The detail of the relative velocity change measurements is described in (*3*).

Stability of noise correlation

We analyze the stability of the correlations with the date d over the 2002-2007 period range. For each set of $N = 30$ consecutive days (time window centered around the date d) and each couple of stations, we process the N correlations (one for each day) and then evaluate the remnant level of fluctuations:

$$\sigma(d,\tau) = \sqrt{\frac{\langle C^2(\tau)\rangle - \langle C(\tau)\rangle^2}{N-1}} \qquad (1)$$

where $\langle . \rangle$ represents an average over N sub-records. We estimate a Signal to Noise ratio (SNR) for the correlation functions by comparing the amplitude of the average correlations (30 days moving window averaging) to this level of fluctuation (Fig. S1). The strong increase in SNR in 2003 corresponds to an increase of + 20 db of the seismic station preamplification gain. Correlations are found to be quite stable over the entire period of interest, and fluctuations show a relative amplitude that arbitrarily varies between 10 % and 20 %. This means that at least 93 % of the energy of the correlations is stable for a 30 day moving window average, which can be interpreted in terms of spatial and temporal noise structure stability. It is worth noting that the fluctuation level is not correlated with the measured evolution of velocity changes.

Clock corrections

We extended the procedure described in (*4*) to detect clock jumps without reference to a propagation model. After measuring the delays between every pair of stations, an inverse procedure is used to retrieve the individual station corrections. We found several jumps that are as large as 30 ms. They are not simultaneous with the main changes of velocity associated to the occurrence of the San Simeon and Parkfield earthquakes. We finally correct these clock jumps by shifting the correlation functions and performing a new doublet analysis.

Detections of nonvolcanic tremor (NVT)

Detections of nonvolcanic tremor (NVT) in the Cholame-Parkfield region of California are carried out using twenty sample-per-second (sps) continuous data channels from 8 stations of the borehole High Resolution Seismic Network (HRSN) near Parkfield California. Continuous data amplitudes are first normalized to account for instrument gain differences and then 3 to 8 Hz band-pass filtered. Two sps root mean squared (RMS) envelope seismograms of these data are then generated using a 201 sample boxcar window. Diurnal variations in background noise levels corresponding to cultural activity can often exceed 300 % in the HRSN data. To compensate for this, daily background noise level corrections are applied to each of the RMS seismograms. Noise level corrections for each channel are determined empirically using a 28 day median average correction for each 0.5 second sample of the day, and the corrections are recalculated seasonally to help account for minor seasonal variations that take place. Following the noise level corrections, RMS seismograms are normalized to the 10 percentile amplitude level for the day being processed. The median amplitudes among the 8 envelope seismograms for each 0.5 second sample are then used to form a time series of amplitude transients (i.e., summary envelope) for the Parkfield-Cholame area. Detections for potential NVTs are then made when summary envelope amplitudes remain 300 % above the 10 % background level continuously for 3 minutes or longer. The pre-envelope 3 to 8 Hz filtered data were then visually inspected to discriminate between NVT signal and amplitude transient artifacts. The visual inspection requires temporal coherence of secondary amplitude fluctuations among several stations. It also identifies and excludes coherent non-NVT activity such as earthquake swarms, unusual cultural noise signals (e.g., the SAFOD deep drilling project at Parkfield), and occasional multi-station artifacts that can occur during network operations.

Of the 1705 potential detections made for the 2002-2007 period (inclusive), approximately 7.8 % were excluded during the visual inspection, yielding 1577 NVT detections for the region. Also excluded from the analysis are data for the hours of the day following the 22 December 2003, M6.5 San Simeon and 28 September 2004, M6.0 Parkfield California mainshocks and for the entire two days following these events. Data for these periods was dominated by amplitude transients from 1000 s of frequently overlapping aftershock signals making accurate NVT detections difficult. The total duration of the 1577 NVT detections for the 2002-2007 period was 8962 minutes, with the median and interquartile range of detection duration per event being 4.68 and 3.17 minutes respectively.

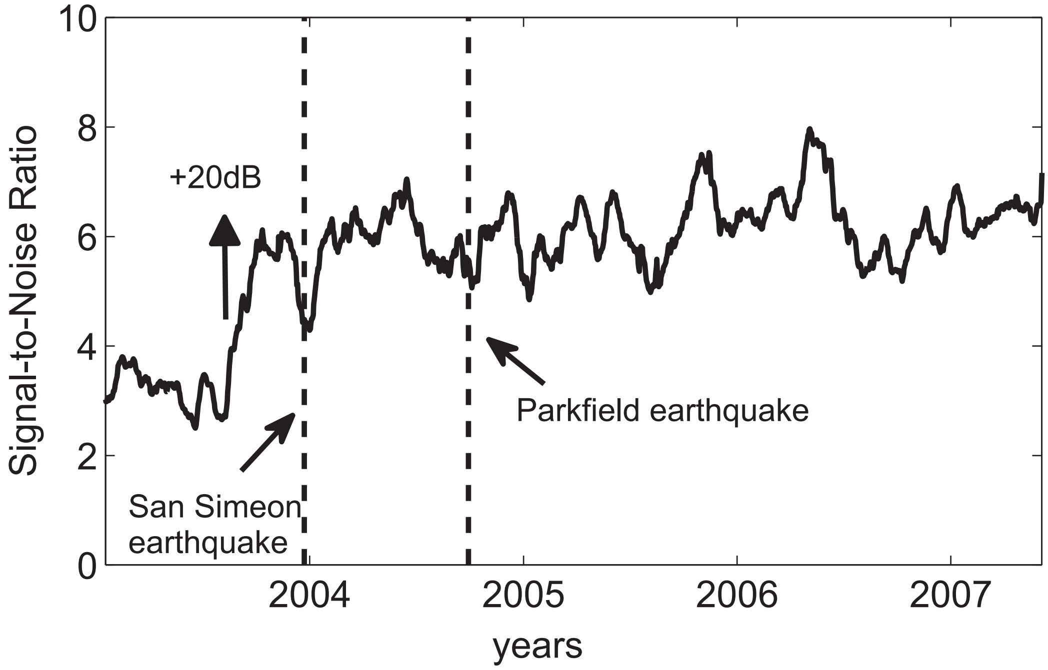
10
8
6
4
2
0
Signal-to-Noise Ratio
+20dB
San Simeon
earthquake
Parkfield earthquake
2004
2005
2006
2007
years

Fig. S1. Correlation function Signal to Noise Ratio (SNR) averaged over SNR's calculated for all receiver pairs used in the analysis of seismic velocity changes. The arrow indicating + 20 db corresponds to the seismic station preamplification gain.

References and Notes

1. G. Bensen, *et al.*, *Geophys. J. Int.* **169**, 1239 (2007).

2. F. Brenguier, N. M. Shapiro, M. Campillo, A. Nercessian, V. Ferrazzini, *Geophys. Res. Lett.* **34**, L02305 (2007).

3. F. Brenguier, *et al.*, *Nature Geoscience* **1**, 126 (2008).

4. L. Stehly, M. Campillo, N. Shapiro, *Geophys. J. Int.* **171**, 223 (2007).