On the Apparent Duration of Low-frequency Earthquakes

Chao Song[1], Allan M. Rubin[1]

[1] Department of Geosciences, Princeton University, Princeton, New Jersey, USA, 08544

Email: chaosong@princeton.edu

AGU Fall Meeting 2021 T15D-0196

Motivation

What controls the characteristic duration of LFE templates made by stacking the cross-correlated member LFEs?

Source vs. Attenuation

Experiment 1:

- Find temporally isolated, long- and short-duration signals from the same location. Any variability in duration suggests that long-duration events owe their duration to source processes and not attenuation, if attenuation does not vary on extremely short time and space scales during episodic tremor and slip (ETS) episodes
- The relative isolation in time also makes the longer duration less likely to result from the temporal clustering of multiple typical low-frequency earthquakes (LFEs)[1]

Experiment 2:

- Given the few candidates found from 1st experiment, we next consider whether seismic waves reflected from the base of a low-velocity layer (LVL) of thickness L might set the duration
- A receiver function study[2] shows that there might be a ~2% V_s increase in the LVL beneath the tremor/LFE source areas during ETS episodes, which is recovered during the inter-ETS period
- If the above scenario is correct, there should be a change in the shape of the spectra on the time scale of ETS episodes assuming $f_c \propto 1/\tau \propto V_s$

Exp. 1: Find long-duration events

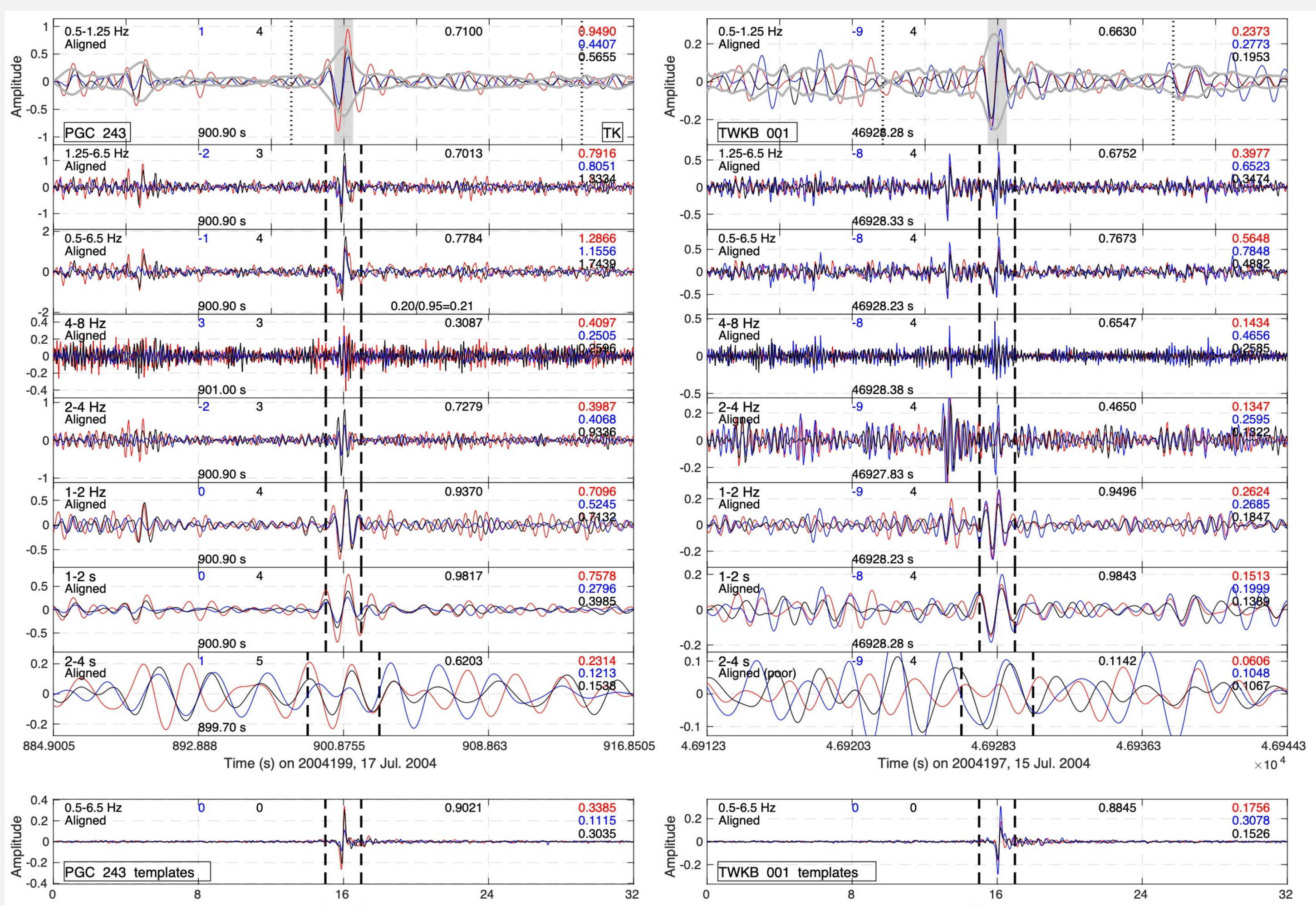


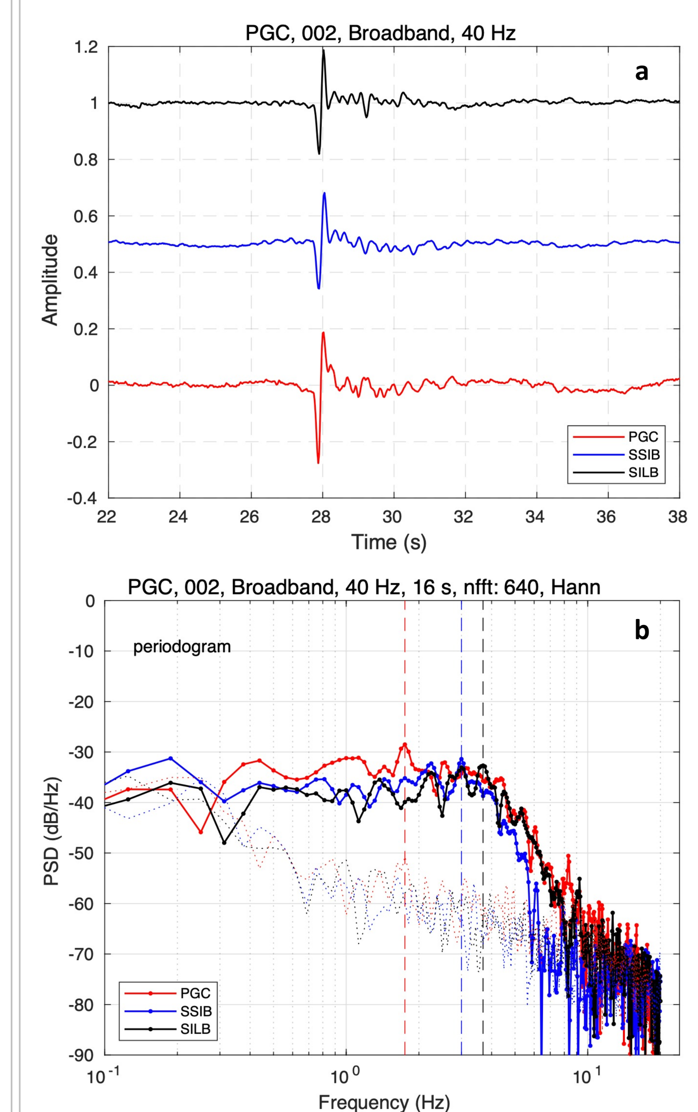
Fig. 1 Two examples of tremor signals that are isolated in time and longer in duration than the LFE templates used to obtain the shear-wave splitting correction and particle motion direction which are then used to process data to image the area around the templates better. Note that for the example on the right that has a duration of ~1 s, another signal 3 s earlier coming from roughly the same location only has a duration of ~0.4 s. However, the number of this kind of long-duration signal is small, on the order of ten throughout our catalog.

References

[1]. Song, C., & Rubin, A. M. (2021). The spatial relationship between contemporaneous tremor detections in relatively low- and high-frequency bands. *Journal of Geophysical Research: Solid Earth, 126*, e2021JB022569.

[2]. Gosselin, J. M., Audet, P., Estève, C., McLellan, M., Mosher, S. G., & Schaeffer, A. J. (2020). Seismic evidence for megathrust fault-valve behavior during episodic tremor and slip. *Science advances, 6*(4), eaay5174.

Exp. 2: Track the velocity change in time



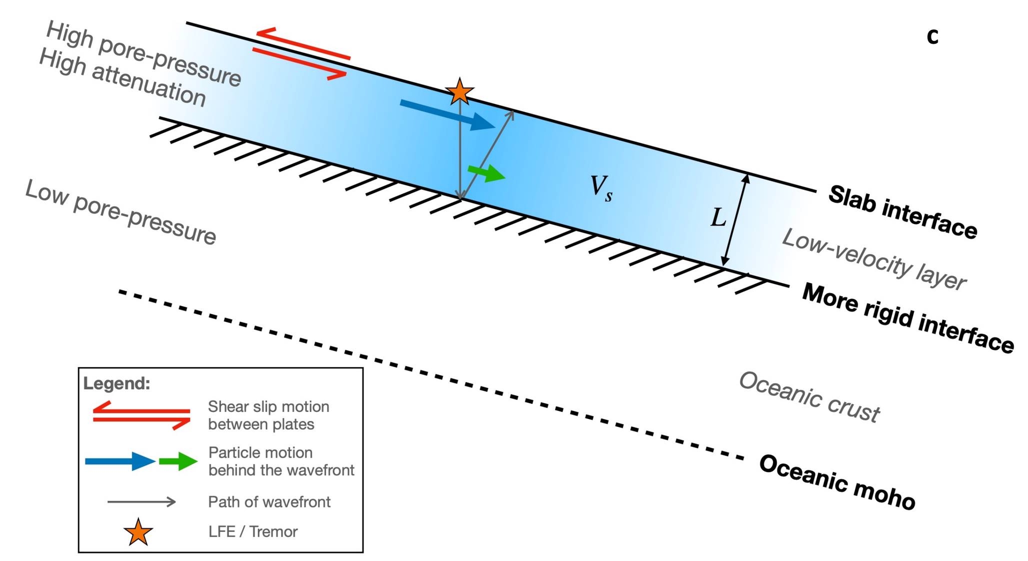
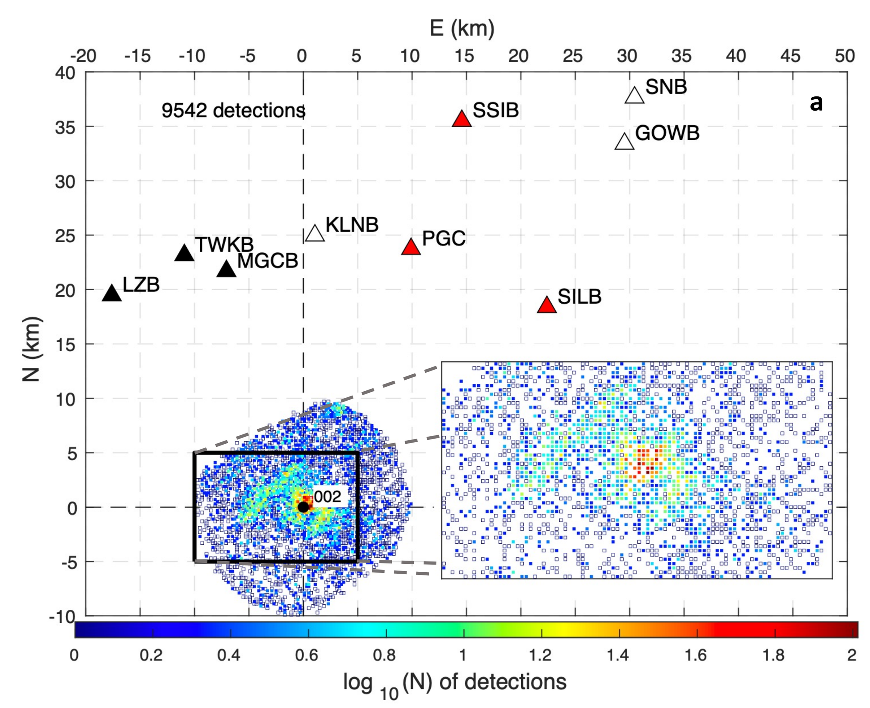


Fig. 2 (**a**) Velocity seismograms of the LFE templates for LFE family 002. There seems to be a characteristic duration of ~0.5 s. (**b**) Spectral density of the main dipole (solid) and noise (dashed) approximated by the same-length segments before and after the dipole. A characteristic corner frequency of ~4 Hz is clear. (**c**) Diagram of one mechanism that might control the characteristic source duration. The shear slip between the subducting and overlying plates generates LFE or tremor. The wave propagating in the LVL gets reflected by the more rigid base of the layer. The particle motion direction behind the reflection wave front is much smaller than the initial motion. The characteristic time required to slow down (or stop) the source (i.e., source duration τ) is $2L/V_s$. If V_s fluctuates in time, a change of duration (and tremor spectra) in time is expected.



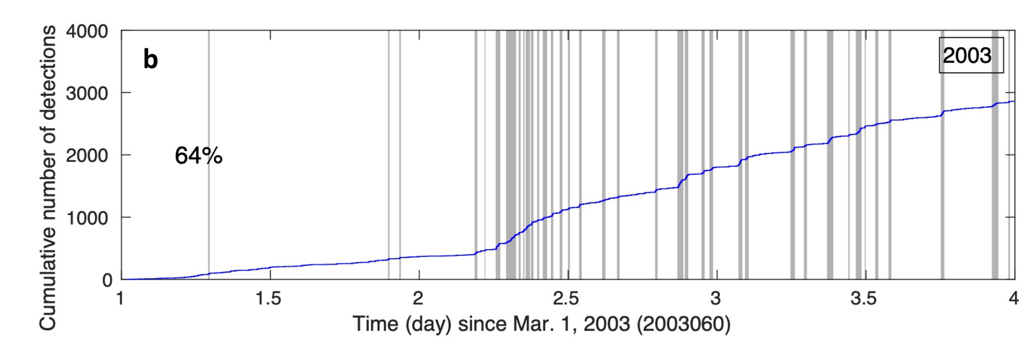


Fig. 3 (**a**) Cumulative density map of tremor detections using the PGC-SSIB-SILB detector upon data corrected by LFE templates for family 002. See the caption of Fig. 1 for the corrections. The black box around family 002 is chosen to be the area of focus. (**b**) Identified windows of temporally clustered tremor bursts. Detections in the box are grouped into bursts based upon their inter-event timings and number of events in each burst.

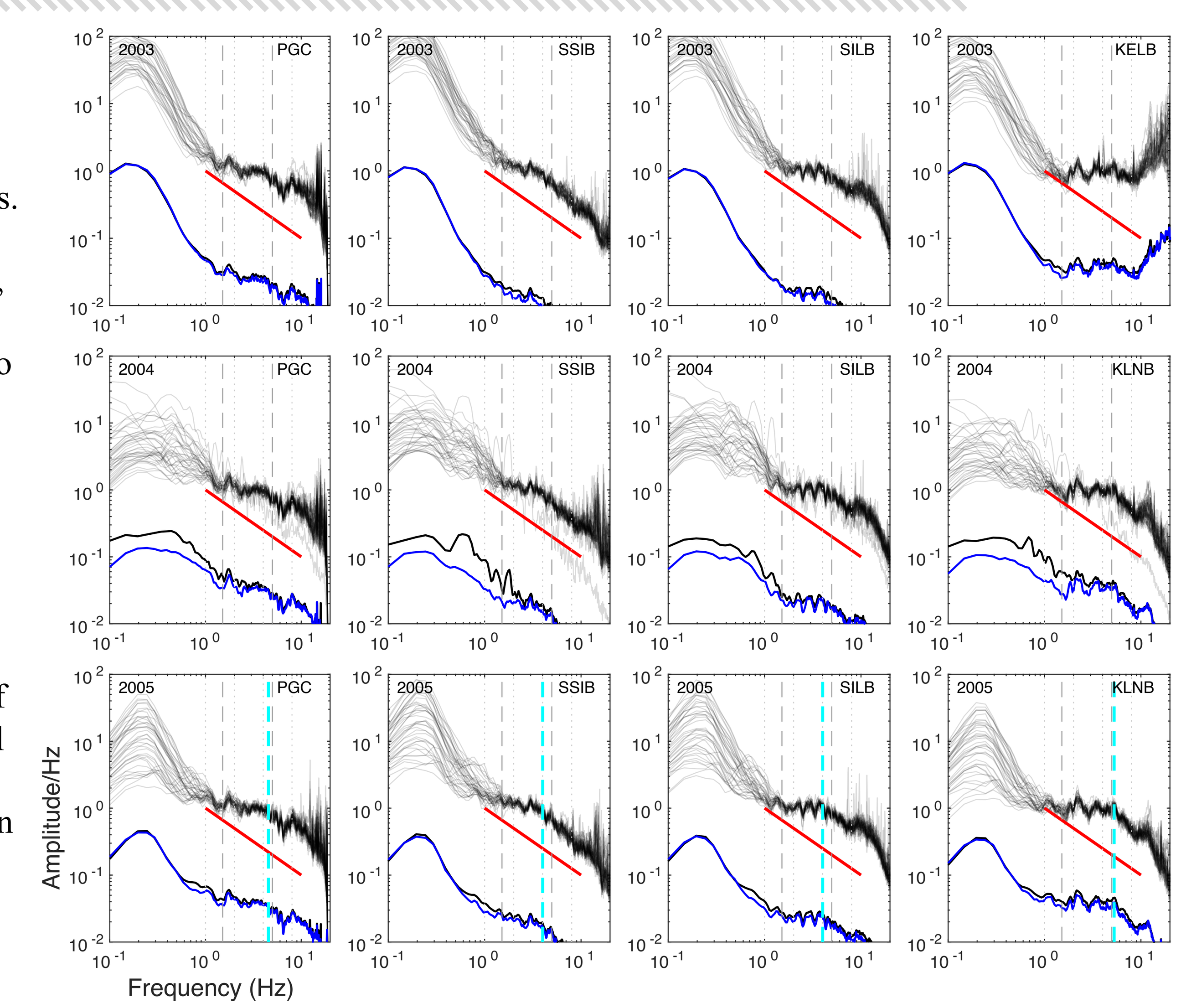


Fig. 4 Normalized amplitude spectra of the identified tremor burst windows. Each gray line denotes the moving average of the spectrum of each burst, normalized by the mean amplitude within the frequency range from 1.5 to 5 Hz (dashed gray lines). The black and blue lines are the mean and median of unnormalized gray lines, respectively. The dashed cyan line marks the picked corner frequency. The red line serves as the reference with a slope of -1. It is worthwhile to note the reproductivity of the shape of the spectra at the same station over all ETS episodes. The spectra from these burst windows are not differentiated in time in this way of representation .

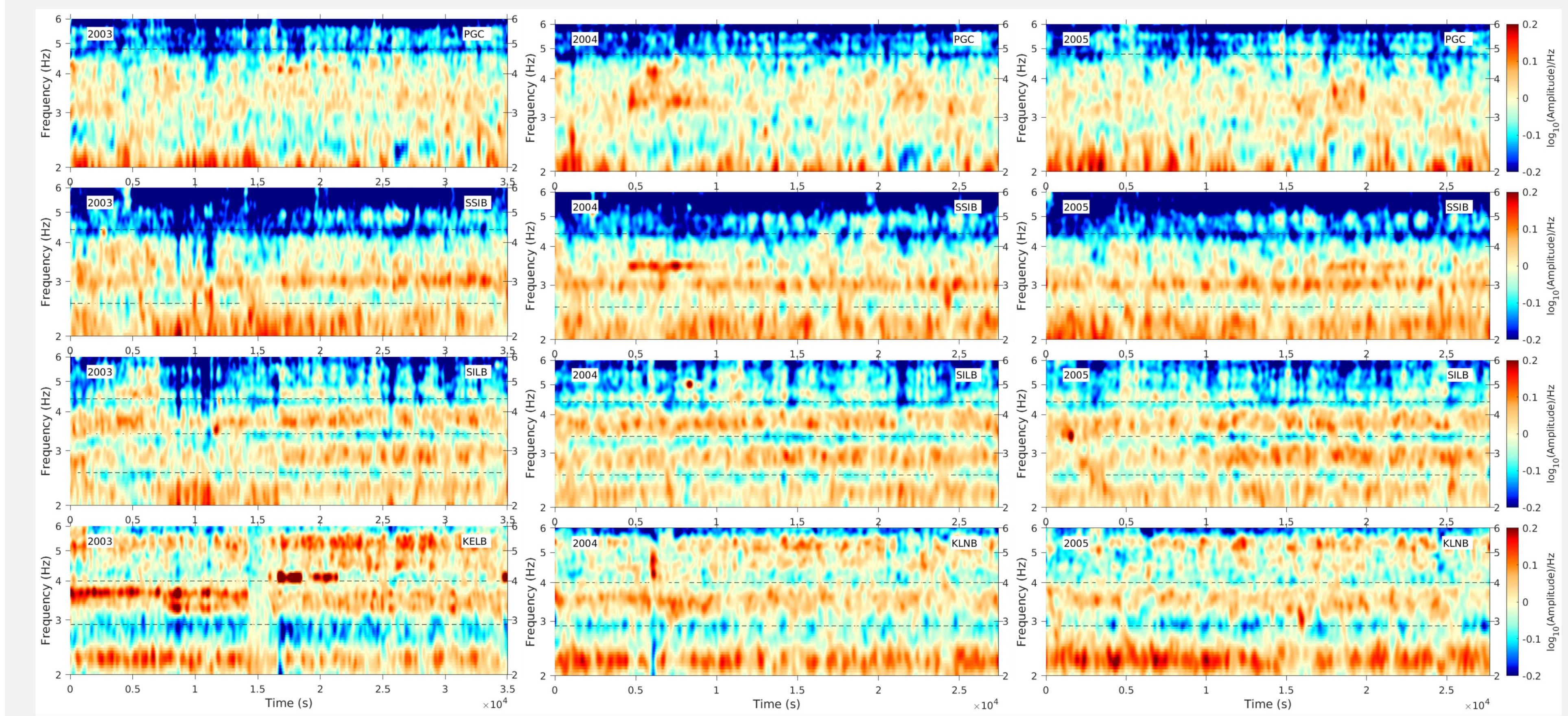


Fig. 5 Normalized spectrograms of the concatenated windows of tremor bursts for the 3 ETS episodes. Normalization is the same as that in Fig. 4. A 2-D Gaussian filter is applied to smooth the image in order to highlight the band-like features at stations SSIB, KLNB and especially at SILB. Note that the spectrogram at every station is reproducible over all episodes.

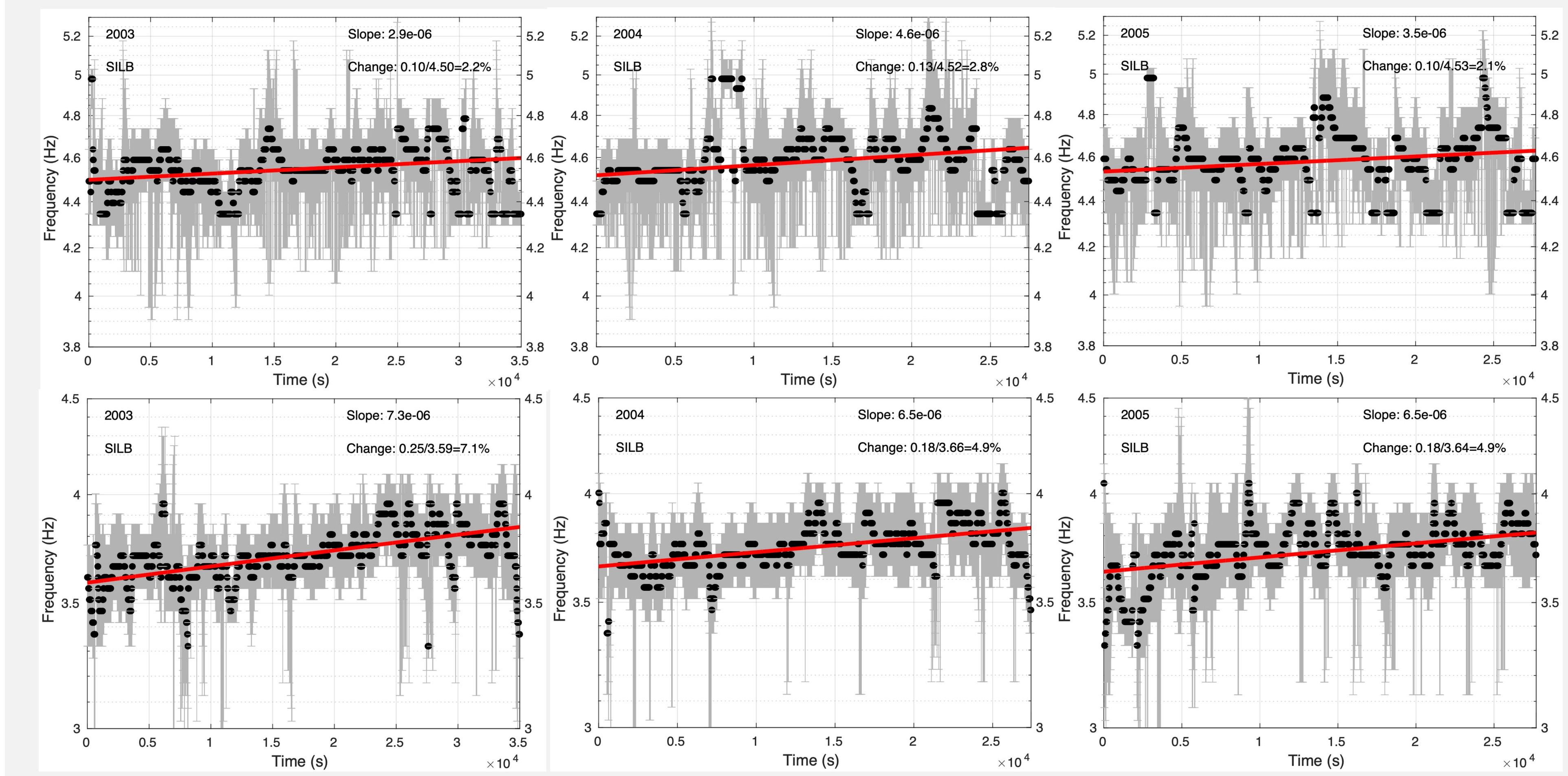


Fig. 6 The maxima of frequency and the range of 95% of the maxima for the uppermost 2 bands at station SILB. A robust linear regression using a *bi-square* weighting scheme is applied to estimate the slope and relative change in frequency. If a velocity change is real, slopes of the two bands at the same station are expected to be close. But the slope is less meaningful than a relative change, as we have few constraints on how fast a velocity change could be; one possibility is that it changes quickly once the pore pressure changes upon the stress perturbation due to the arrival of the main slow-slip front. This relative change is supposed to be reproduced as well. Assuming $f_c \propto 1/\tau \propto V_s$, a positive change corresponds to an increase of velocity (decrease of characteristic duration τ; drop of pore pressure and attenuation, etc.)

Summary

- Any variability in duration of LFE-like signals from the same location may provide insight on whether it is set by the **source process or attenuation**, but we found very few long-duration LFEs with a high signal-to-noise ratio
- That the reproducible band-like feature with a non-zero slope is only seen at station SILB, but not at other stations, does not support the hypothesis of a temporal reduction in LFE duration caused by a shear-wave velocity increase in the LVL beneath the sources
- That the band-like structure at these stations is seen only when tremor is active around LFE family 002, but not at other times at the same stations (not shown here), suggests that it is not due to near-site effects
- Unfortunately, the 2 experiments cannot determine what factors control the apparent duration of LFEs, but the model in Fig. 2c is still an appealing explanation for the near-constant duration of LFEs even without a time-dependence