Imaging the subsurface structures of the southern San Andreas fault using ambient noise and anthropogenic sources

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Introduction

We use ambient noise and anthropogenic sources to image the subsurface structures of the southern San Andreas Fault (SSAF) in the Coachella Valley. The data are recorded by a 4-km long dense nodal array across the SSAF. We detect and categorize frequent anthropogenic activities at nighttime. We then evaluate whether the noise wavefields are diffuse and extract surface wave signal from Cross Correlation (CC). We further propose that that wavefields generated from train and 'coda' of car are well diffused and can be employed for seismic imaging.

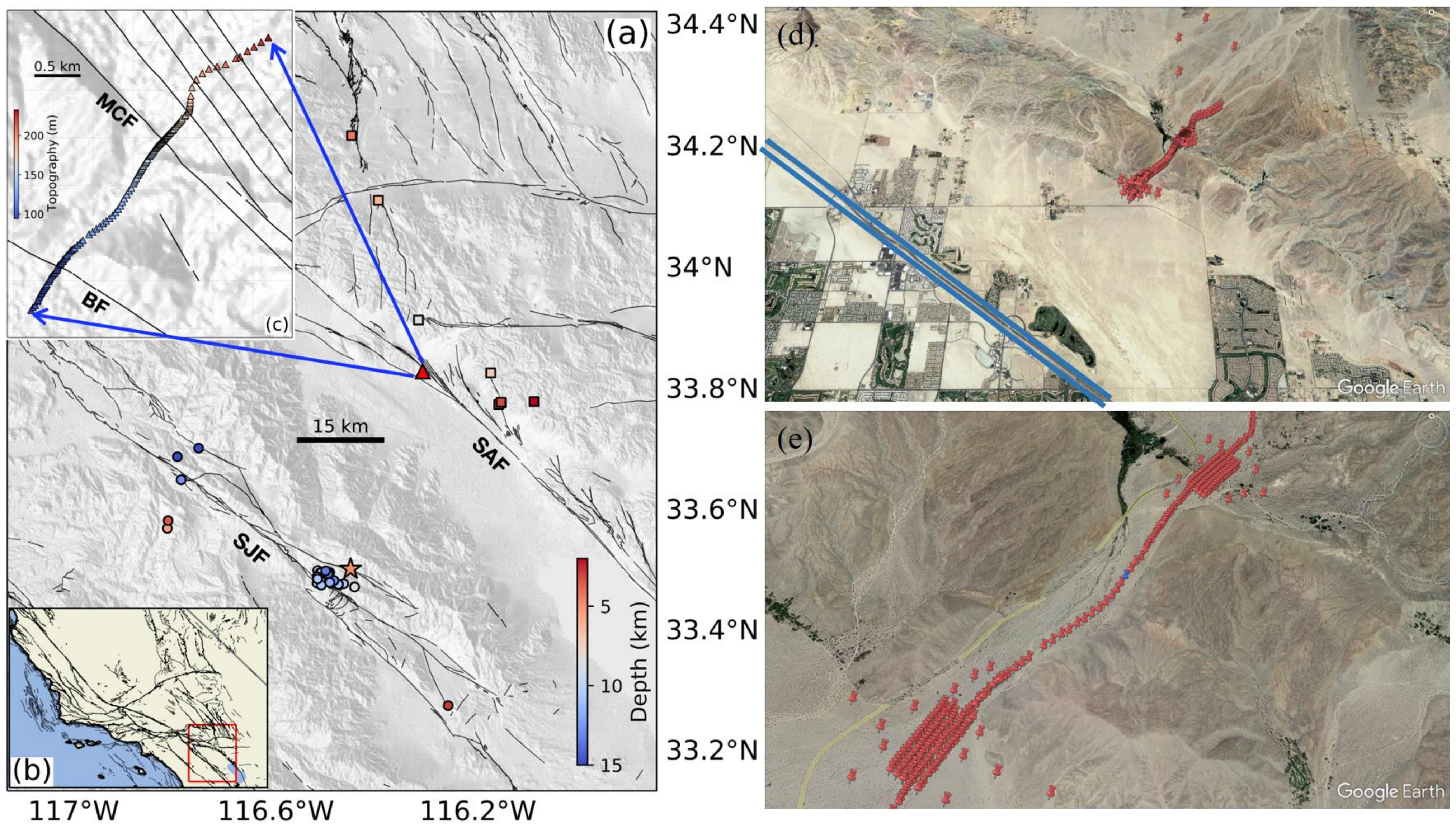


Fig. 1 Map of the study area and array geometry. Left panel: geological setting of SSAF area. Right panel: a zoomed-out view of array position and surrounding facilities (double line indicate location of I-10 highway and train rail) and a zoomed in view of local road. Blue pin indicate the station we use to detect train and car events.

Methodology

Seismic wavefield can be expressed as a superposition of normal modes, $\psi(\mathbf{r},t)=\sum_n a_n u^{(n)}(\mathbf{r})e^{-i\omega_n t}$

For a fully diffuse wavefield, the statistics of the modal amplitudes require

$$\mathrm{E}[a_n]=0,$$
$$\mathrm{E}[a_n a_m]=0,$$
$$\mathrm{E}[a_n a_m^*]=F(\omega_n)\delta_{mn}.$$

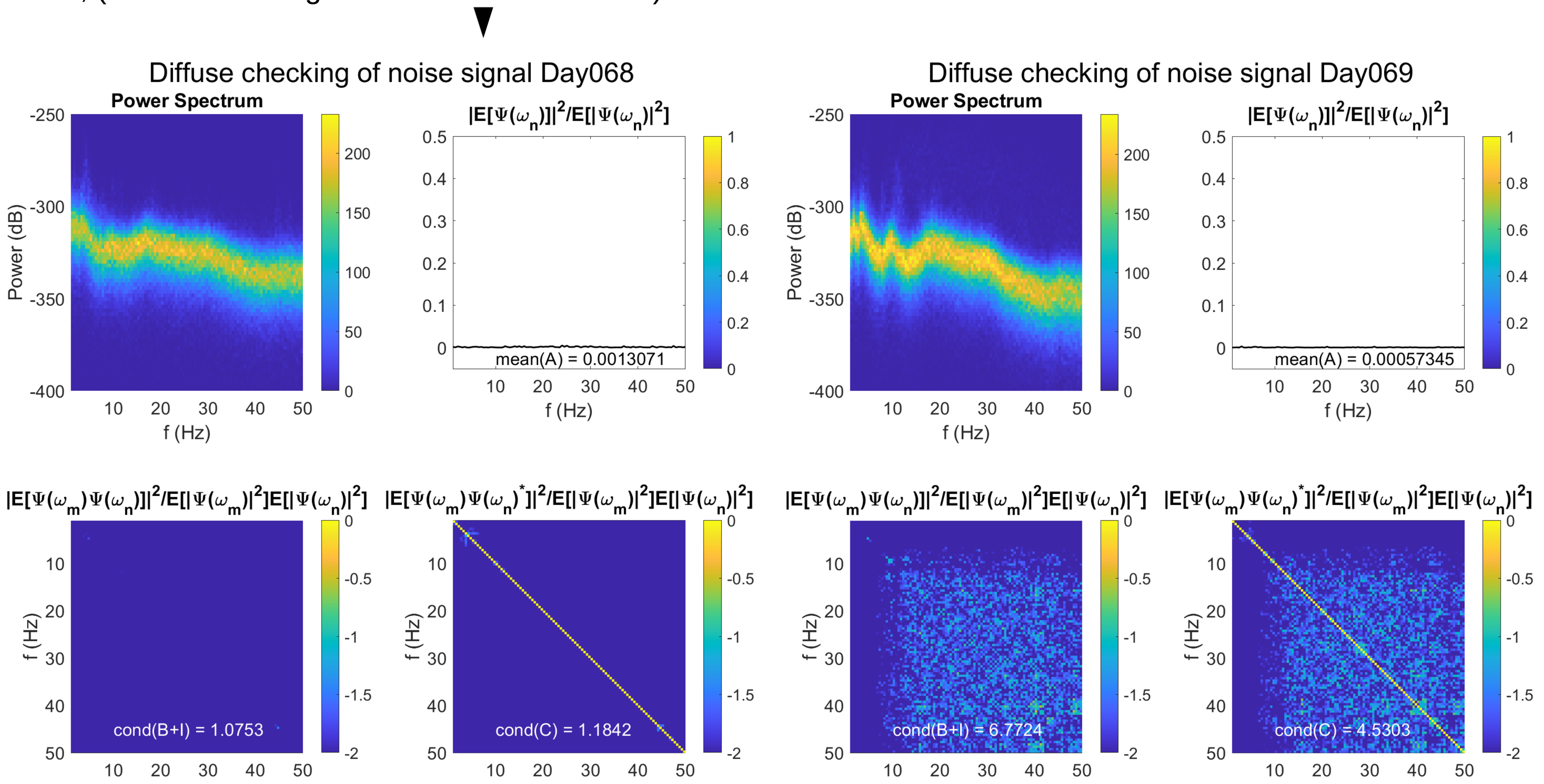
These necessary conditions can be expressed as 3 unitless criteria:

$$A(\mathbf{r},\omega_n)=\frac{|\mathrm{E}[\psi_F(\mathbf{r},\omega_n)]|^2}{\mathrm{E}[|\psi_F(\mathbf{r},\omega_n)|^2]}=0$$

$$B(\mathbf{r},\omega_m,\omega_n)=\frac{|\mathrm{E}[\psi_F(\mathbf{r},\omega_m)\psi_F(\mathbf{r},\omega_n)]|^2}{\mathrm{E}[|\psi_F(\mathbf{r},\omega_m)|^2]\mathrm{E}[|\psi_F(\mathbf{r},\omega_n)|^2]}=0$$

$$C(\mathbf{r},\omega_m,\omega_n)=\frac{|\mathrm{E}[\psi_F(\mathbf{r},\omega_m)\psi_F^*(\mathbf{r},\omega_n)]|^2}{\mathrm{E}[|\psi_F(\mathbf{r},\omega_m)|^2]\mathrm{E}[|\psi_F(\mathbf{r},\omega_m)|^2]}=\delta_{mn}$$

Fig. 2 Two examples of noise diffuse estimation. Three criteria are calculated from 2 days' 'quiet' nose, (car and train signals have been removed)



References

- Meng, Haoran, Yehuda Ben-Zion, and Christopher W. Johnson. "Detection of random noise and anatomy of continuous seismic waveforms in dense array data near Anza California." Geophysical Journal International 219.3 (2019): 1463-1473.
- Liu, Xin, and Yehuda Ben-Zion. "Estimating correlations of neighbouring frequencies in ambient seismic noise." Geophysical Journal International 206.2 (2016): 1065-1075.

Results

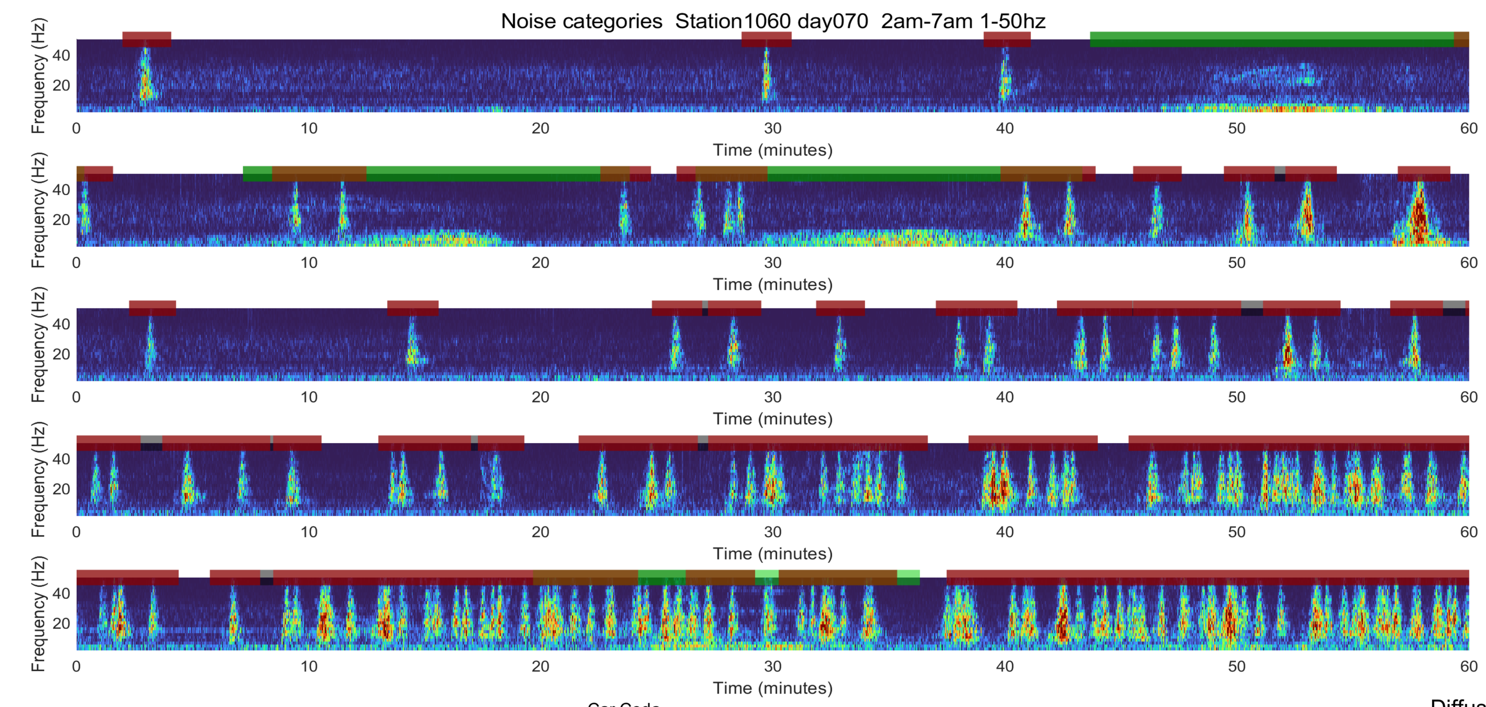


Fig. 3 Noise categorization of nighttime of Station 1060, shown as spectrograms. Red floating bars indicate detected car events; Green floating bars indicate train events. Other time period are good 'quiet' noise.

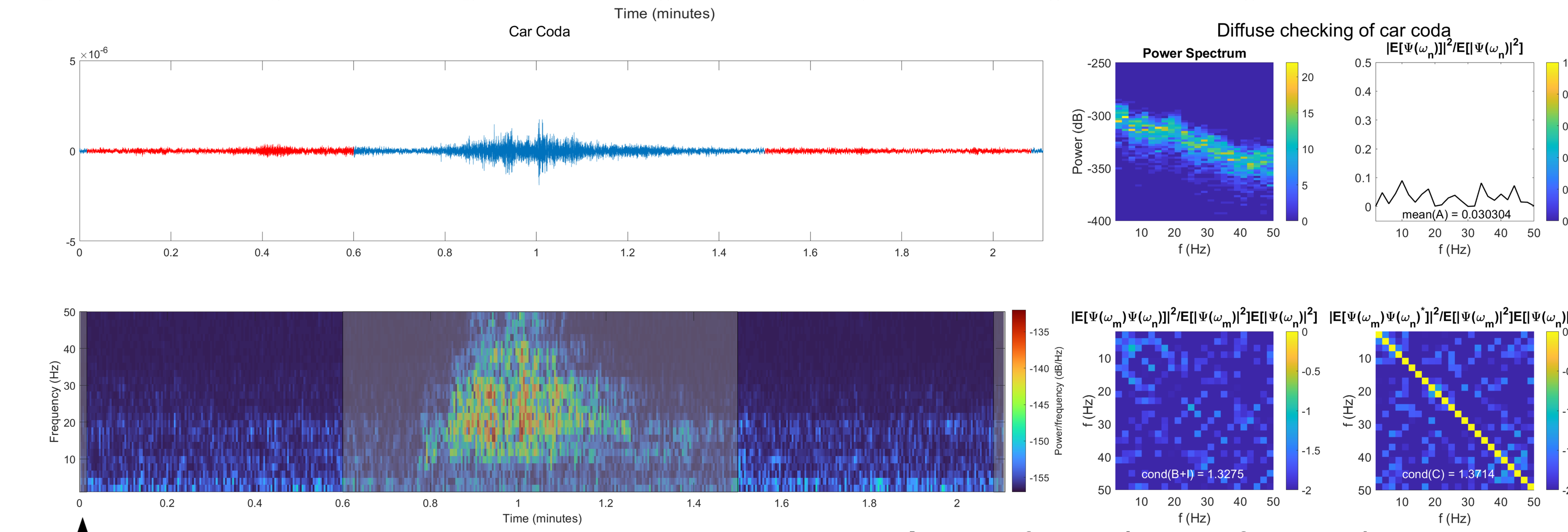
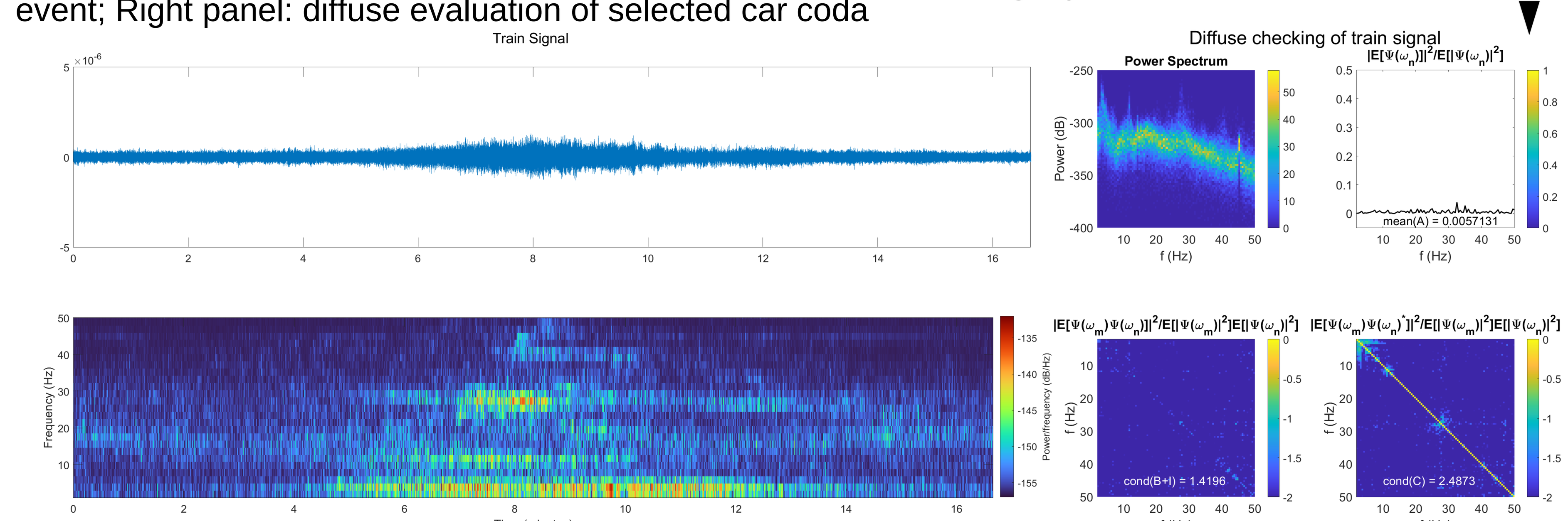


Fig. 4 Left panel: Waveform and spectrogram of a car event; Right panel: diffuse evaluation of selected car coda

Fig. 5 Left panel: Waveform and spectrogram of a train event; Right panel: diffuse evaluation of train signal



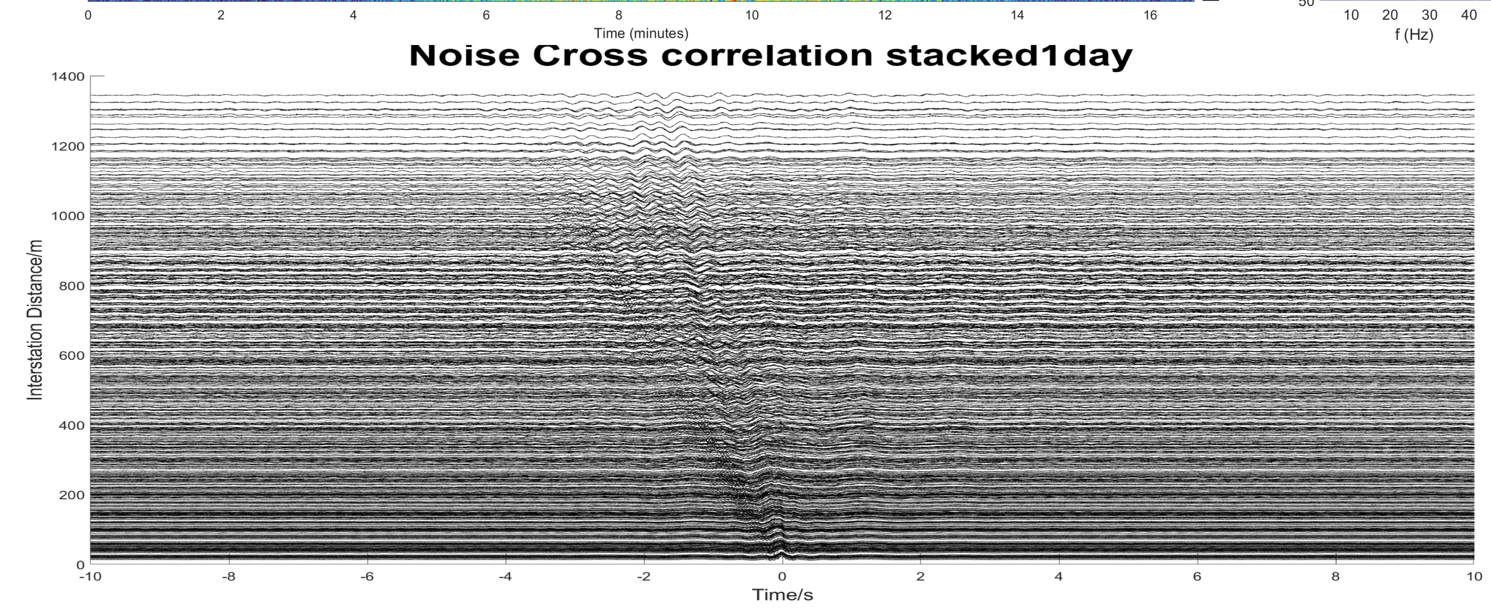


Fig. 6 CC of 'quiet' noise of day 68. The continuous waveform is truncated into non-overlapping segments of 30 s. Normalization is applied before stacking.

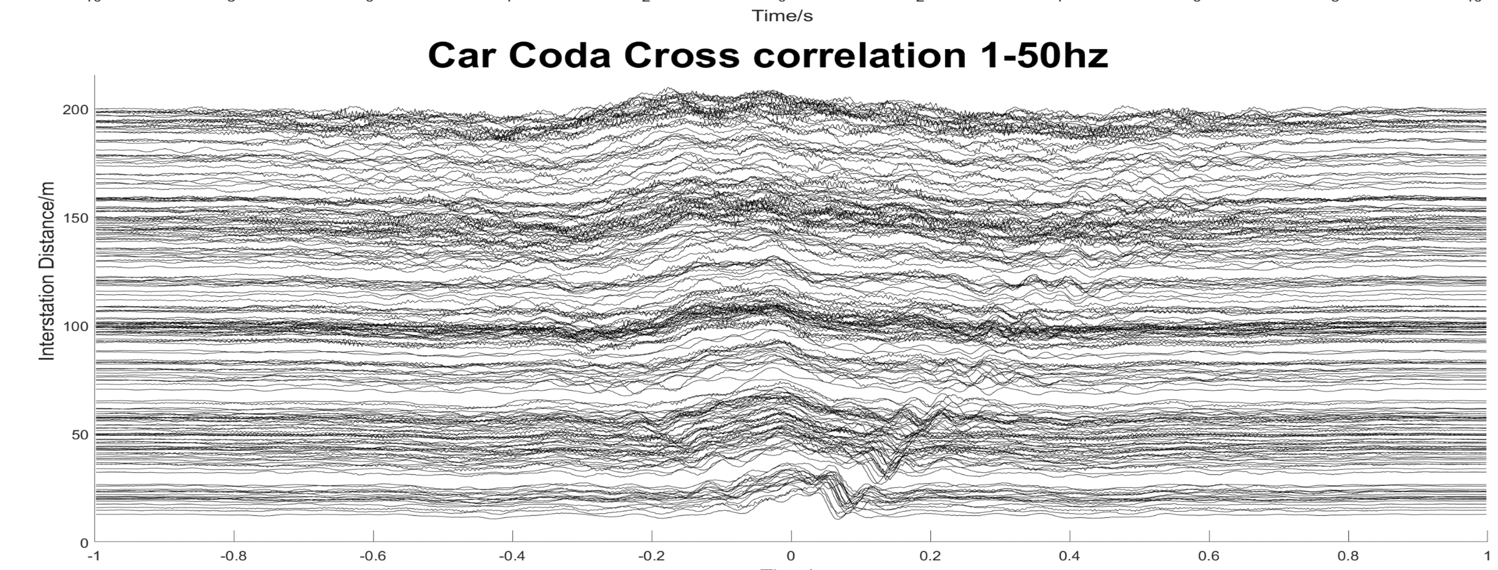


Fig. 7 CC of car coda. The coda is selected to avoid direct car energy (Fig. 4, red waveform and unshaded spectrogram) The waveform is truncated into non-overlapping segments of 2 s. Normalization is applied before stacking.

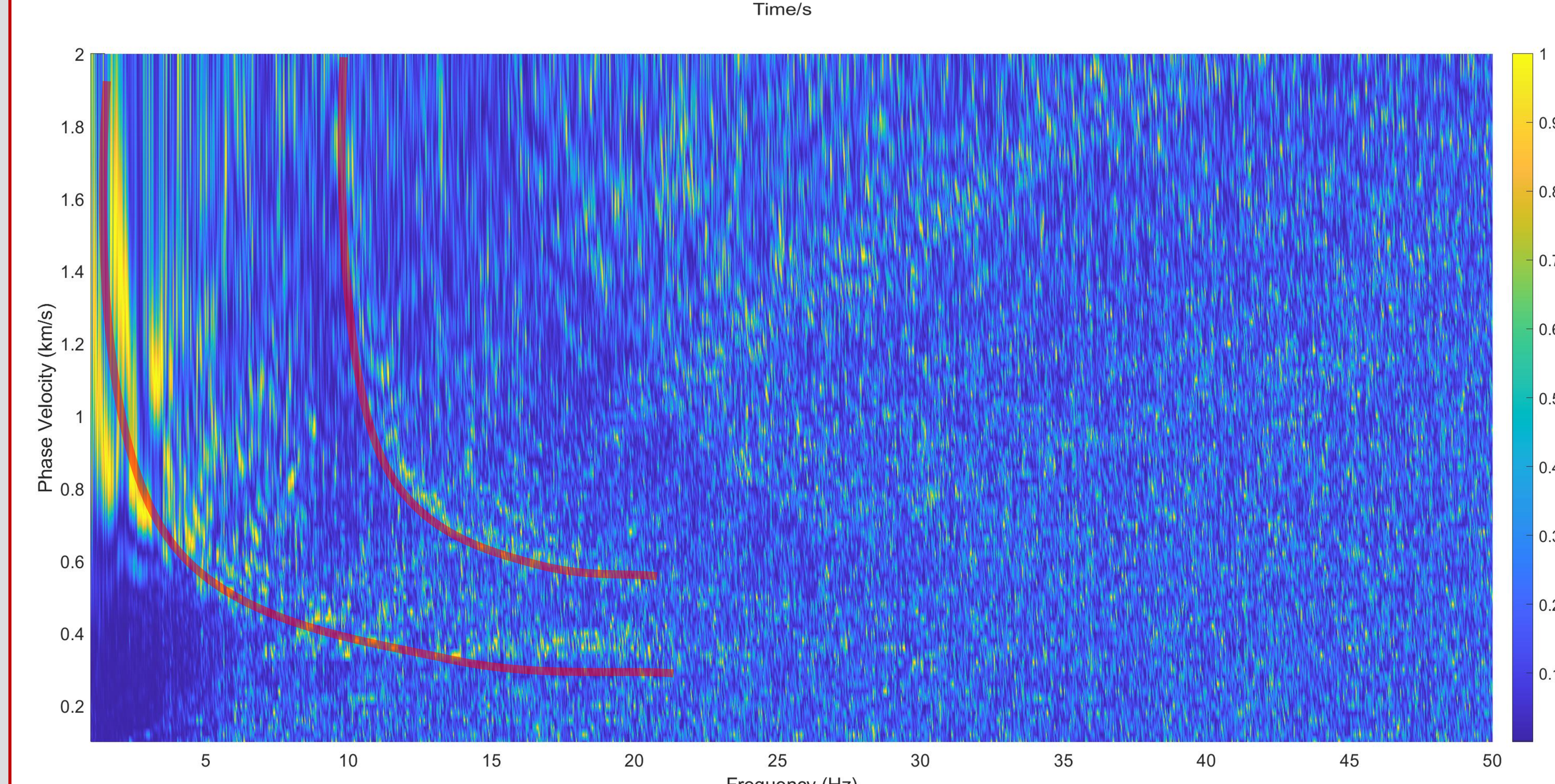


Fig. 8 Multi-Channel Analysis of Surface Waves (MASW) to get an average phase velocity dispersion. The dispersion is extracted from CC of 'quiet' noise of day 68. 2 red curves indicate plausible phase velocity dispersion of fundamental and higher mode surface wave