Analysis of seismic signals generated by vehicle traffic with application to derivation of subsurface Q values

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Motivation

- Ground motions induced by human activities are commonly considered as background noise.
- These can cause difficulties for detecting small earthquakes and tremors.
- The vehicle-induced signals show distinguishing features in the time-frequency domain that can be modeled with soure spectra and wave propagation & attenuation.

Data

- 5 Hz ZLand nodal arrays
- Controlled experiments at SGB site using a SUV and a compact sedan.

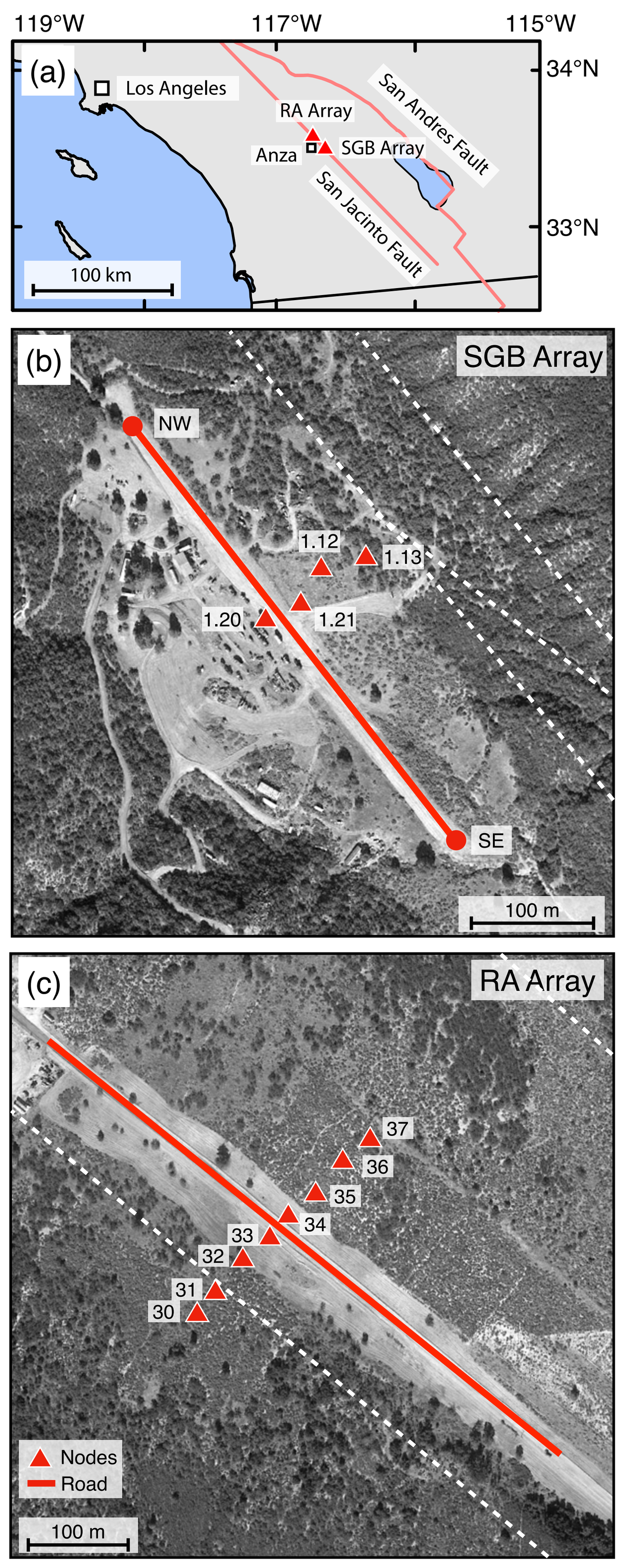


Figure 1. (**a**) A regional map showing the two seismic arrays on San Jacinto fault zone (red triangles). (**b**) and (**c**) Seismic nodes (red triangles) and dirt roads (redlines) on Google Earth image of the SGB and RA site. The white dashed lines are mapped USGS fault traces.

Modeling

- Car moves with constant speed along a straight road.
- Car can be represented by a point source.
- Primarily radiates Rayleigh waves with a source spectrum $A_0(f)$.
- Radiation pattern is nearly isotropic in all azimuth directions.
- Considering geometrical spreading and attenuation:

$$A(f,t') = \frac{A_0(f)}{\sqrt{r}} \exp\left(-\pi f \frac{r}{Q(f)c(f)}\right)$$

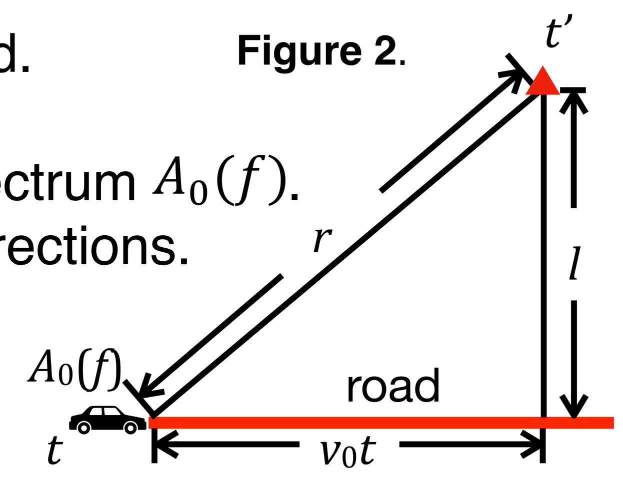
Where

$$r = \sqrt{l^2 + (v_0 t)^2}$$

$$t = (t' - t_0') - \frac{\sqrt{l^2 + [v_0(t' - t_0')]^2}}{c(f)}$$

$$t^*(f) = l/(Q(f)c(f))$$

Figure 2.



By taking the natural logarithm

$$\ln(A(f,t')) + \frac{1}{4}\ln(l^2 + (v_0 t)^2) = \left[1 \quad -\pi f \frac{\sqrt{l^2 + (v_0 t)^2}}{l}\right] \cdot \begin{bmatrix} \ln(A_0(f)) \\ t^*(f) \end{bmatrix}$$

Results

Controlled Experiment at SGB site with known moving speed.

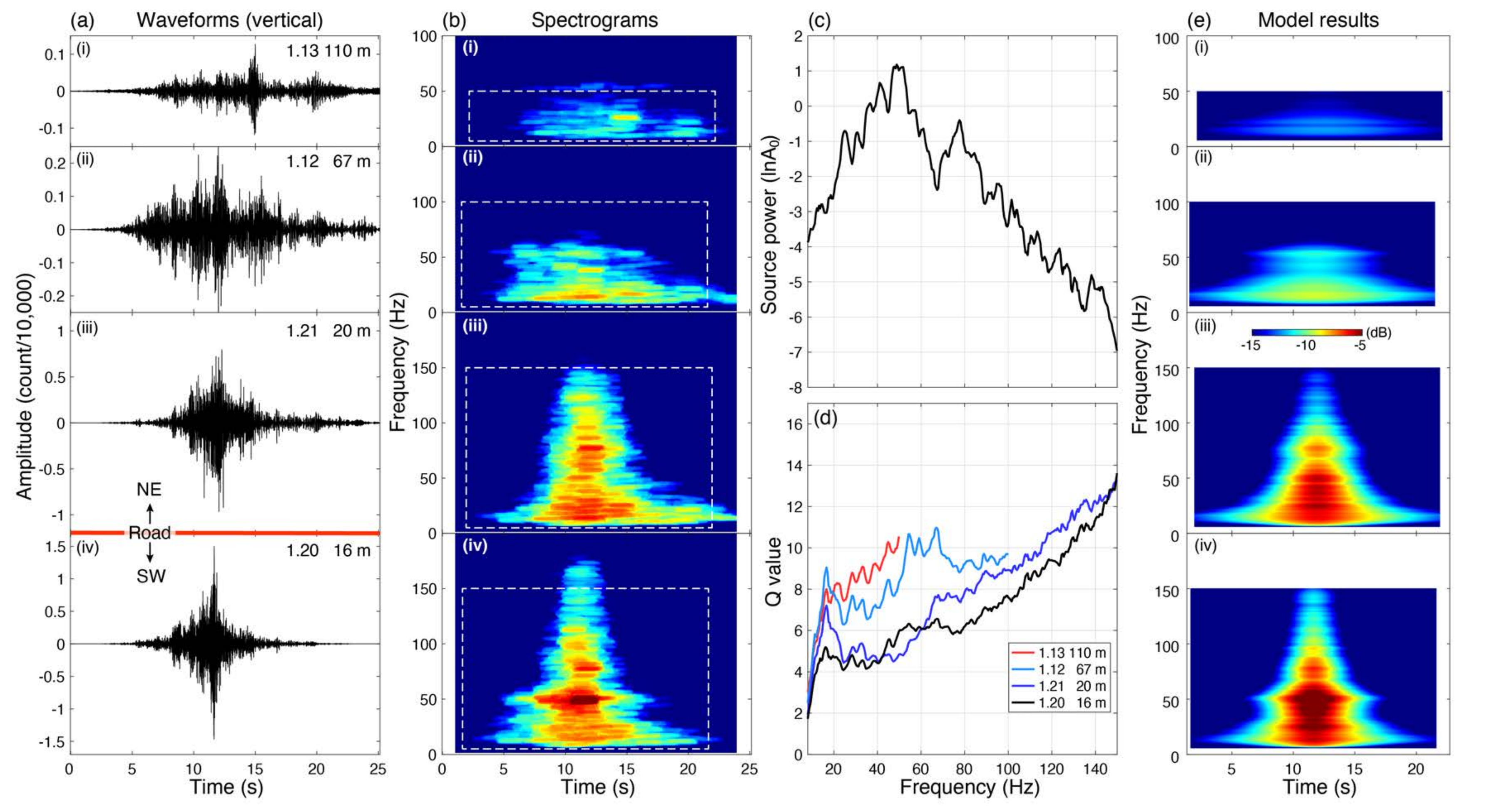


Figure 3. (**a**) Vertical waveforms recorded by 4 sensors at the SGB site during an experiment with a mid-size SUV moving at 40 km/hr. (**b**) Corresponding spectrograms. The white dashed boxes denote data incorporated in the inversion. (**c**) Resolved source spectrum of the moving car. (**d**) Derived Q values for paths between the car and sensors. (**e**) Model results using the resolved source spectrum and Q values in (c) and (d).

Car event at RA site with unknown moving speed: grid search.

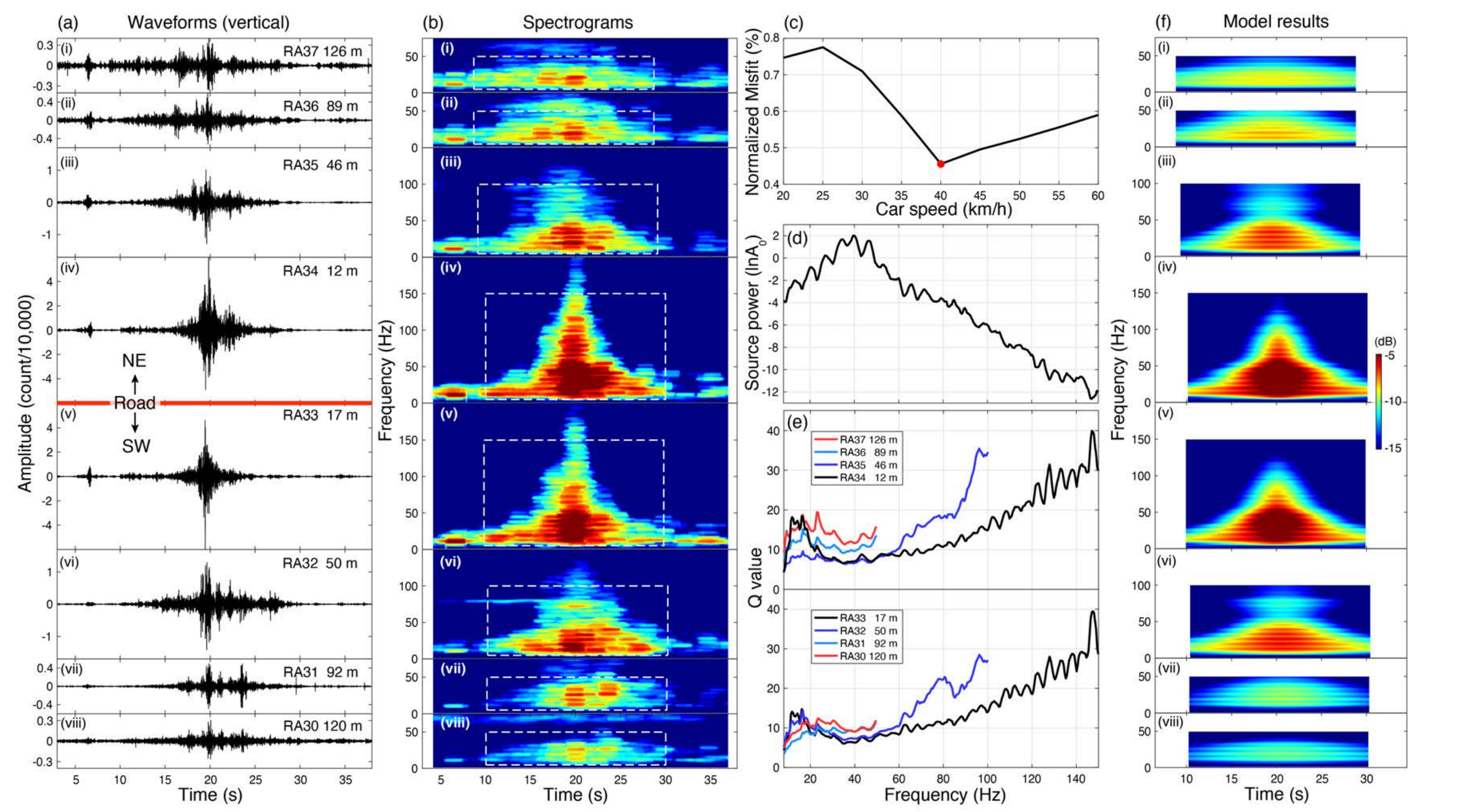


Figure 4. An event in RA site. Same as Figure 3 but the moving speed is grid searched to minimize the misfit of the observed and modeled spectrograms in (**c**).

Discussion

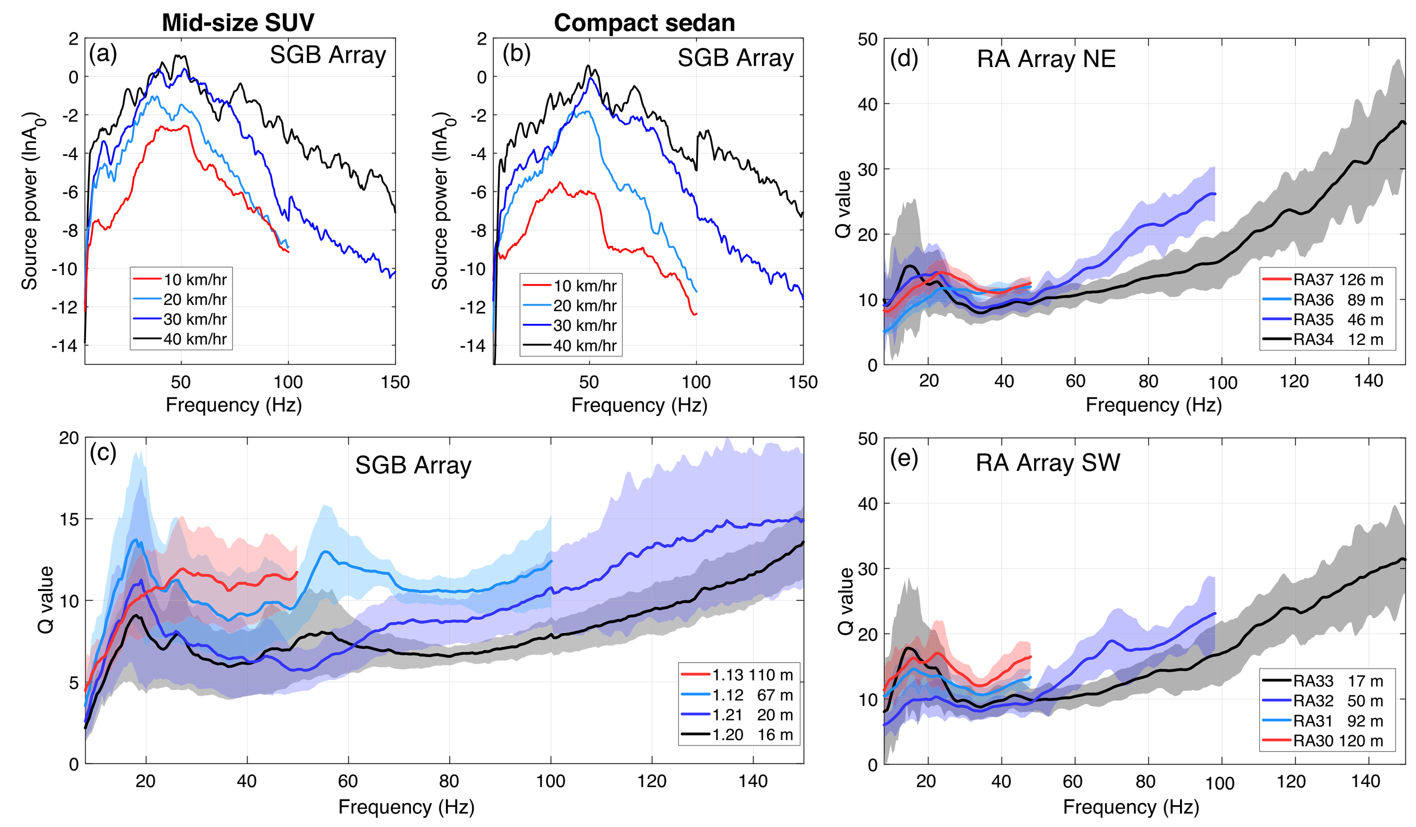


Figure 5. (**a**) and (**b**) Estimated source spectra of the two experimental vehicles moving at different velocities in SGB site. (**c**) The solid lines show the average derived Q value estimated for paths between the road and sensors. The shaded areas are one standard deviation uncertainties. (**d**) and (**e**) Resolved average Q values and corresponding uncertainties between the road and sensors at the RA array.

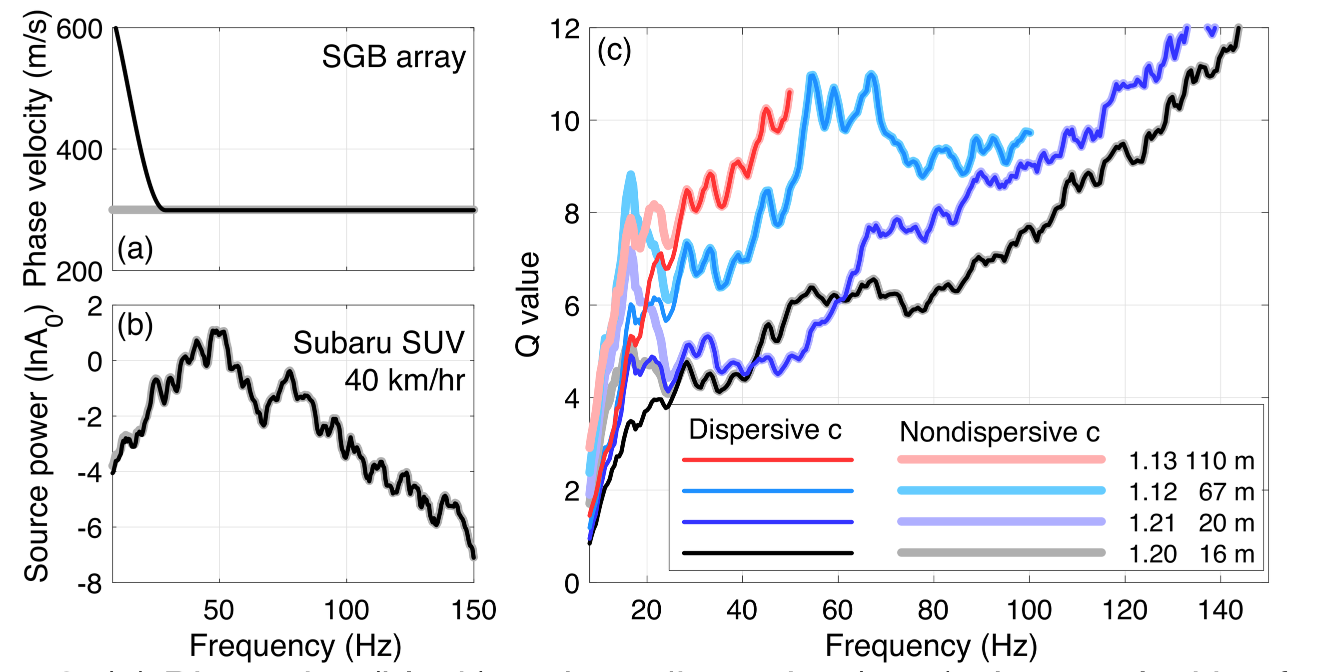


Figure 6. (**a**) Dispersive (black) and nondispersive (gray) phase velocities for the SGB site. (**b**) Resolved source spectra of experiment 1 for the two phase velocity models. (**c**) Resolved Q values considering dispersive and nondispersive phase velocities at the SGB site.

Summary

- A simple analytical solution for propagation and attenuation of surface waves is developed to quantify the spatiotemporal and frequency variations of seismic waveforms.
- The model reproduces well bell-shaped spectrograms of car signals close to roads and it allows estimating frequency-dependent Q values of the subsurface.
- The data analysis indicates Q values of 3 to 40 up to 150 Hz for road-receiver paths at the two sites.
- Possible further applications in signal classification and monitoring temporal variations of attenuation factor.

References

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