Seismological Research Letters

Rose Parade seismology: signatures of floats and bands on optical fiber

--Manuscript Draft--

Manuscript Number:	
Full Title:	Rose Parade seismology: signatures of floats and bands on optical fiber
Article Type:	Article - Regular Section
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Manuscript Region of Origin:	UNITED STATES
Abstract:	
Suggested Reviewers:	
Opposed Reviewers:	

Initial submission

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February 24, 2020

Dear Editor Allison Bent,

I am submitting a manuscript entitled "*Rose Parade seismology: signatures of floats and bands on optical fiber*" to be considered as an *Earthquake Lite* contribution for *Seismological Research Letters*. As we discussed previously over email, our Pasadena Distributed Acoustic Sensing (DAS) network recorded the 2020 Rose Parade which consists of a sequence of floats and marching bands. Their seismic signatures are remarkable rich and broadband. We think this fun piece is a great demonstration of DAS and quite appropriate for the Earthquake Lite section. We appreciate your consideration of this contribution.

P.S. During submission, I can not find the option of "Earthquake Lite" as a paper type. So I had to choose "regular section". Please feel free to revise as needed.

Sincerely yours,

Zhongwen Zhan

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Rose Parade seismology: signatures of floats and bands on optical fiber

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The Rose Parade is an annual parade in Pasadena, California to celebrate the New Year's Day since 1890 ("About Rose Parade", 2020). It features flower-decorated floats, marching bands, equestrian units, and is followed by the Rose Bowl Game, an annual American college football game. The Rose Parade is attended by over 700,000 spectators along the streets of Pasadena and viewed by over 65 million via broadcast ("Tournament of Roses 2019 Statistics & Data", 2020). Following the same route as in the past decades, the 2020 Rose Parade started northward on Orange Grove Boulevard, traveled mostly along Colorado Boulevard to the east, and then turned north on Sierra Madre Boulevard (red line in Figure 1b). This route partially overlaps with the city's underground fiber-optic cables (dashed blue line in Figure 1b), which we have converted into a dense seismic array using distributed acoustic sensing (DAS) technology.

In November 2019, the City of Pasadena granted California Institute of Technology (Caltech) access to two strands of dark fiber, forming two overlapping loops around the city. At the Caltech ends of the fibers, two DAS instruments (one ODH-3 from OptaSense, the other HDAS designed by University of Alcala and Aragon Photonics) are connected and shine laser pulses into the fiber clockwise and counter-clockwise, respectively. The same instruments then record the "echo" of Rayleigh scattering from intrinsic fiber defects and measure the integrated strain over every few meters along the fiber (Hartog, 2017; Zhan, 2019). In other words, every few meters of the fiber cables are converted into a virtual seismic sensor. The Pasadena DAS array has over 5000 virtual sensors, ~700 of which are along the 2.5 km of fiber cable underneath the

Rose Parade route (thick blue line in Figure 1b). As shown in Figure 1c, the Pasadena DAS array detected the entire sequence of vibration generated by the 2020 Rose Parade over these 2.5 kilometers.

The 2020 Rose Parade started at 8:00 am (PST) on January 1st, 2020 and lasted approximately 4 hours. At about 8:50 am, the parade arrived at the junction of Wilson Ave and Colorado Boulevard, the western end of our 2.5-km seismic observing section. At the forefront was a police motorcycle squad that drove back and forth a few times to clear the parade route and warm up the audience. These motorcycles produced distinctive zig-zag patterns on the DAS space-time plots (Figure 1 and enlarged in Figure 2) in a broad frequency band from below 0.1 Hz to the 62.5 Hz, the Nyquist frequency of our data (Figure 3).

About 10 minutes later, the floats and bands arrived sequentially, at an average speed of about 2.5 miles per hour. The heavy floats (typically weighting 16,000 to 18,000 kg) produced distinct long-period signals (0.05Hz – 0.5Hz; Figure 1), due to flexure of the road under the quasi-static load (Jousset *et al.*, 2018). Two or more peaks are often present in the floats signals, presumably due to loading by the front and rear wheels, as the axle separation is larger than the channel spacing (Filograno *et al.*, 2011). The high-frequency (>10 Hz) energy from the floats is depleted compared to the regular moving vehicles, probably because of the low speed of the floats (~1.2 m/s).

The marching bands also produced observable but substantially weaker long-period flexure of the road, potentially due to the much lower and broadly distributed weight of the members. However, the bands excited strong vibration in the 0.5-10 Hz frequency band (Figure 1), which we then identified as a series of harmonic frequencies on the spectrograms (Figure 3). We do not have an in-situ measurement of the stepping frequency of the bands, but the fundamental tone of ~1.86 Hz is remarkably close to the pacing rate of the average walking page of men and women (Ji and Pachi, 2005). Therefore, we interpret the evenly spaced harmonics as due to the evenly spaced pulses in the time domain (Díaz et al., 2017), associated with the regular stepping of the marching bands.

At the east end of our 2.5-km observing section, the parade turns from Colorado Boulevard to Sierra Madre Boulevard, and large floats often have trouble making the sharp turn. This year at about 10:35 am, the float "Mrs. Meyer's Clean Day" got stuck at the junction for over 6 minutes.

This caused a wave of traffic congestion propagating to the west along Colorado Boulevard as the floats and bands stopped one after another (Figure 1). There were numerous other smaller waves of traffic congestions throughout the parade. At the end of the parade, a large group of supporting vehicles (e.g., fire engines, tow trucks, street cleaning trucks) together excited the strongest vibrations of the parade (Figure 1c).

Each year, the Pasadena Tournament of Roses Association, producer of the parade, announces awards to a subset of the floats (e.g., the most beautiful entry, the most extraordinary float) ("Pasadena Tournament of Rose Announces 2020 Float Awards Presented by FTD", 2020), based on the opinions from three judges. With the new seismic records presented here, it is straightforward to pick two more awards, the "heaviest" float and the "loudest" band, based quantitatively on the amplitudes of ground shaking they produce. The "heaviest" float this year is from Amazon Studios, featuring a real bus and a rocket on a truck (Figure S2). The "loudest" band this year goes to the "Human Jukebox" performed by the Southern University and A&M College, though the Pasadena City College Honor band came as a close second (Figure S3).

The Pasadena DAS array has only been operational since November 2019 without many significant regional or local earthquakes to calibrate the performance of the array. The 2020 Rose Parade provided a rare calibration opportunity with well-controlled unidirectional traffic, heavy slow-moving vehicles, and broadband sources right on top of a section of the array. Both of our DAS arrays, using the two fiber strands respectively, performed as well as expected. The high-quality DAS records associated to the passing vehicles can be used for traffic monitoring or shallow subsurface structures imaging (Jousset *et al.*, 2018; Huot *et al.*, 2019). In addition, the DAS records of cultural events could also serve as a unique public outreach opportunity. For example, the 2020 Rose Parade has an estimated ~65 million viewers worldwide ("Tournament of Roses 2019 Statistics & Data", 2020). The current study may provide a chance for the public to learn more about seismology and seismic networks in general.

DATA AND RESOURCES

Raw DAS records used in this study are available upon request to the corresponding author.

ACKNOWLEDGEMENTS

We thank the City of Pasadena for contributing their optical fibers for our research. We thank the OptaSense, University of Alcala, and Aragon Photonics for providing the DAS instruments, and we also thank Lisa LaFlame for installing the ODH-3. We would also like to thank Paul Lewis, Jeff Shaner, Monaly Josephy, Mary Howard, Greg Custer, and Mike Sumich for providing the floats' GPS track records to help confirm our seismic interpretations. The authors also thank Yingdi Luo for providing photos of Rose Parade. This work was supported in part by the NSF CAREER award 1848166, the Caltech-JPL President's and Director's Research and Development Fund (PDRDF). Miguel González Herráe and Hugo Fidalgo Martins acknowledge financial support from the Spanish MINECO (RTI2018-097957-B-C31) and European Commission (grant ns. 722509 and 875302).

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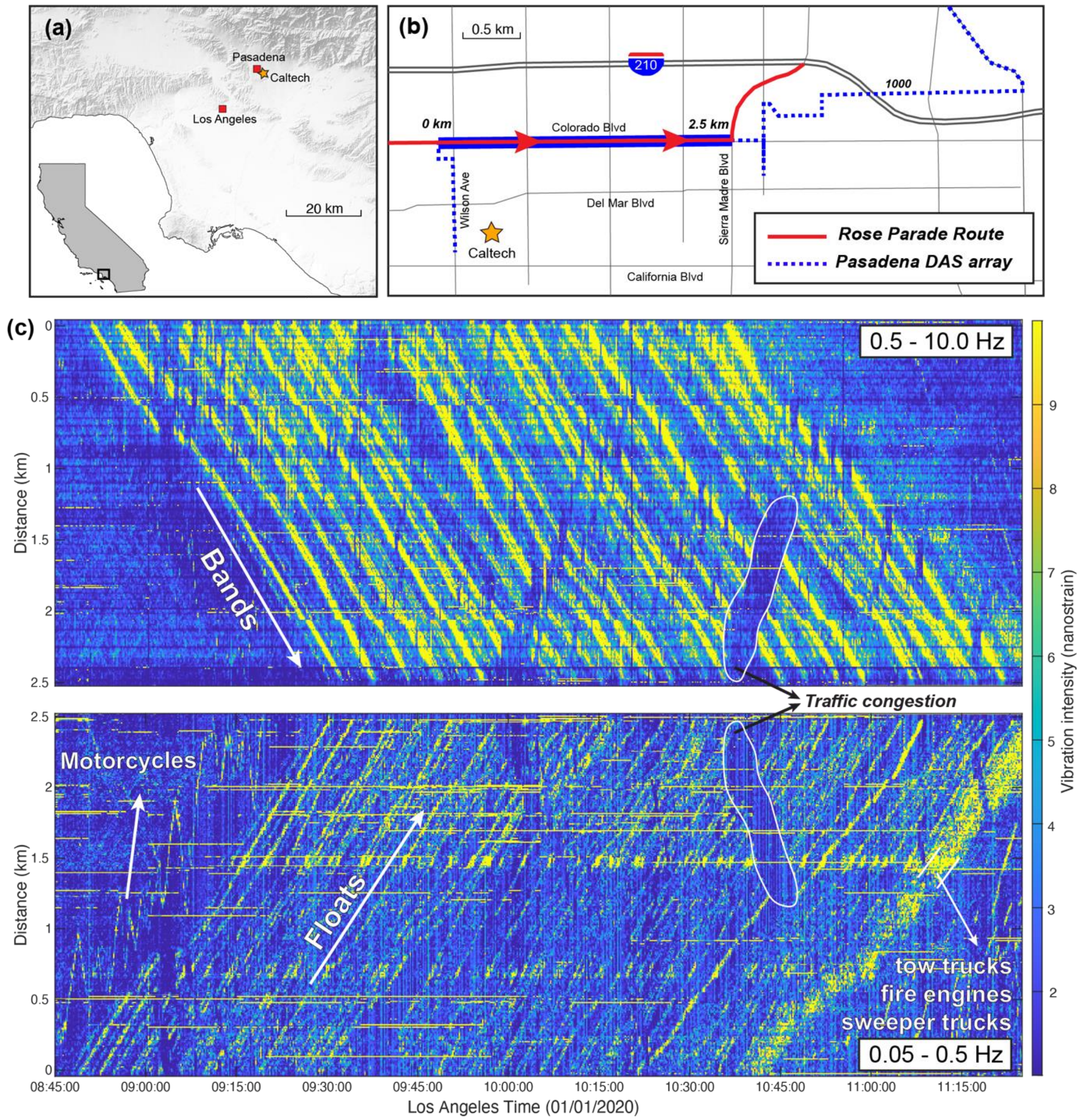

Figure 1. Seismic records show the intensity of shaking on the Pasadena distributed acoustic sensing (DAS) array. (a-b) Maps show the locations of the Rose Parade route and the Pasadena DAS array, which consists of ~5000 single-component strainmeters with a spatial sampling interval of 8 m. (c) The envelope of seismic signals filtered at different frequency bands. The seismic signals at 0.05-0.5 Hz are from the floats, while the 0.5-10.0 Hz signals are from the marching bands. The gaps on the yellow stripes are caused by traffic congestion. The upper figure has been flipped to highlight that the floats and bands appeared sequentially. The seismic data shown in this figure was acquired by the OptaSense ODH-3 system; similar seismic signals have also been clearly observed on the HDAS system (Figure S1).

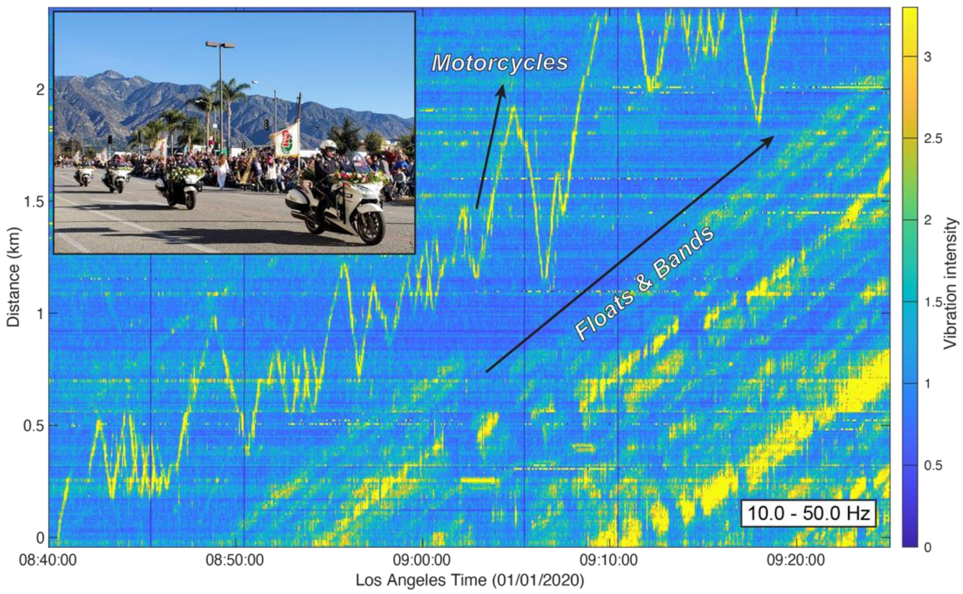

Figure 2. The seismic records (10.0 – 50.0 Hz) show the vibrations caused by motorcycles driving back and forth.

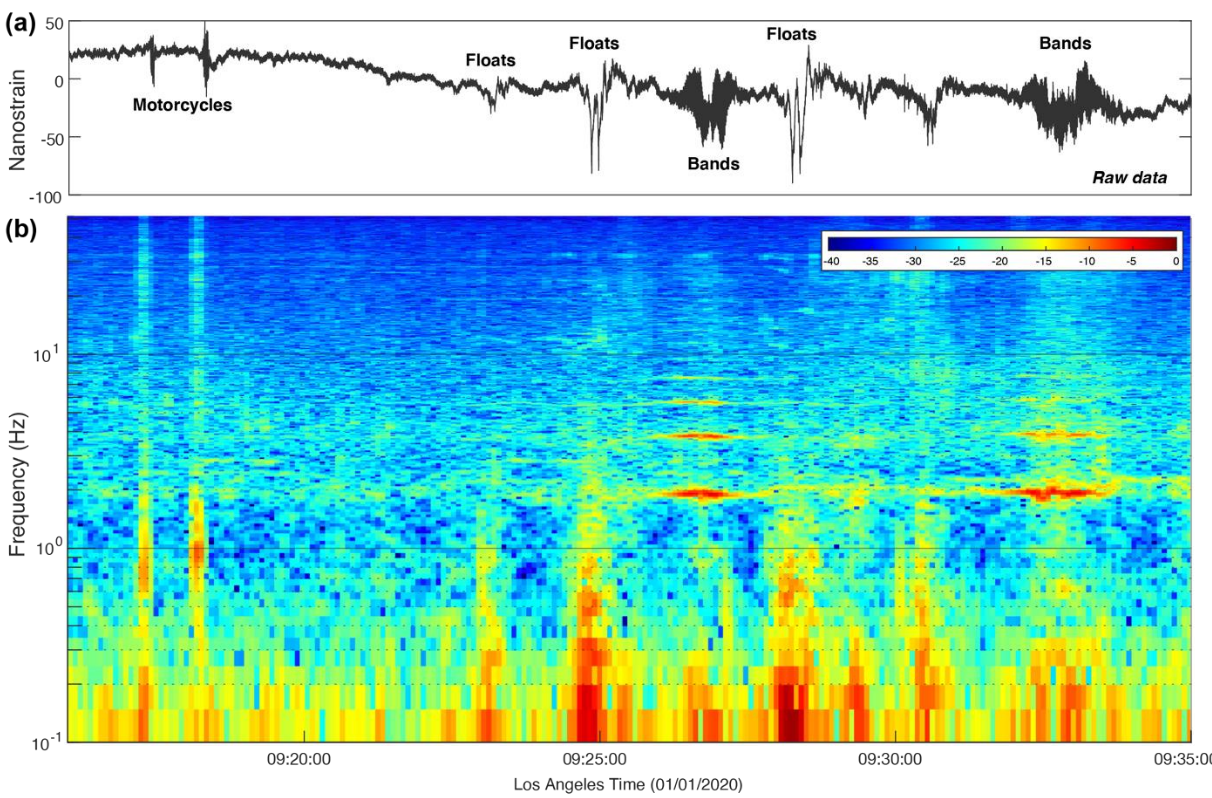

Figure 3. Time-frequency analysis. (a) Raw data. (b) Spectrogram. The spectrogram is computed following the approach given in Kilb et al (2012). Several types of signals have been identified, including the motorcycles, parade floats, and marching bands.

Supplementary material for

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This supporting material provides additional figures on data analysis. Contents of the supplementary material are shown as below.

List of Supplemental Figure Captions

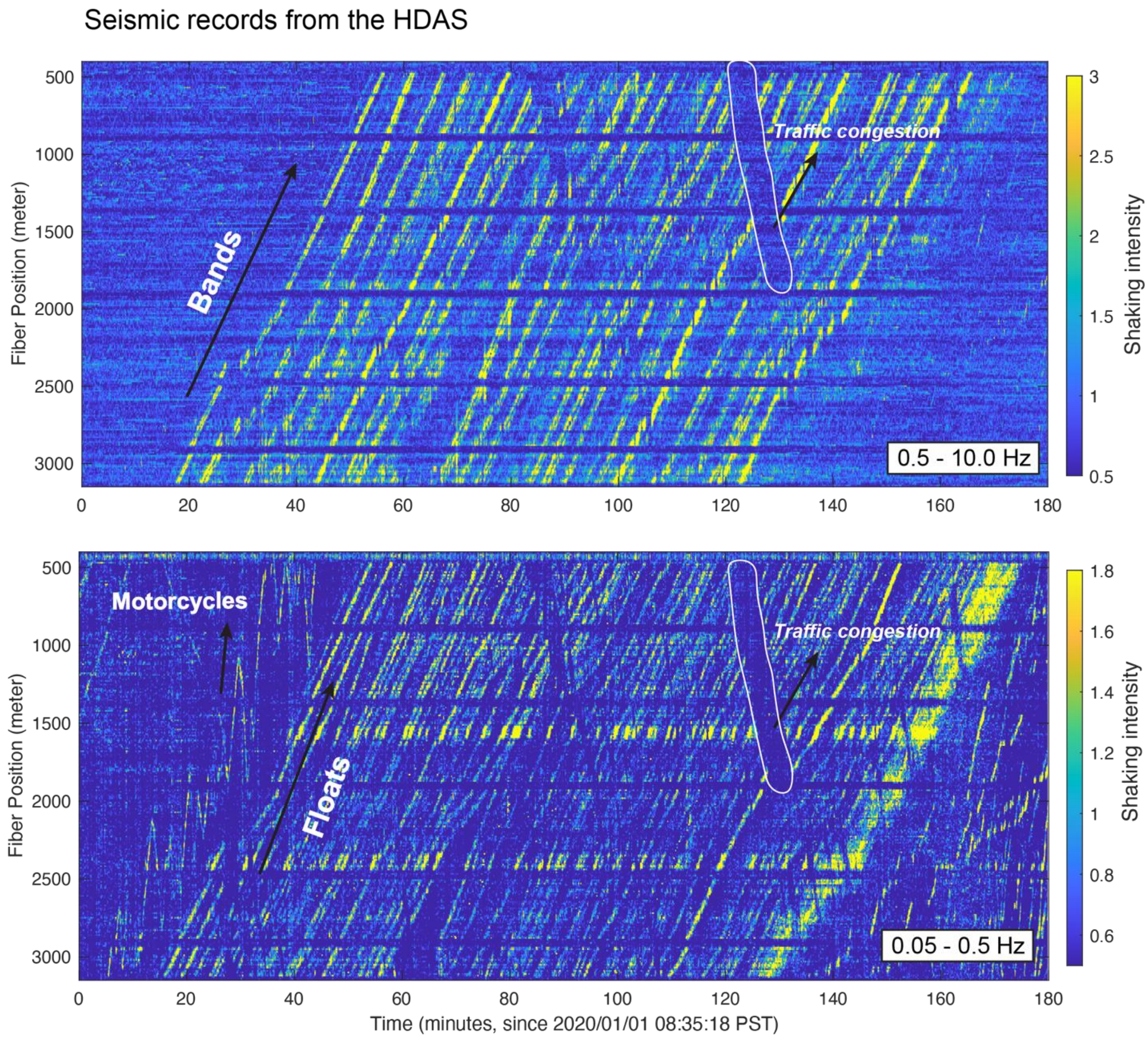

Figure S1. About 2.5-hour-long seismic record acquired by the HDAS system along the Pasadena DAS array. The Rose Parade-generated seismic signals can also be clearly observed on the HDAS system.

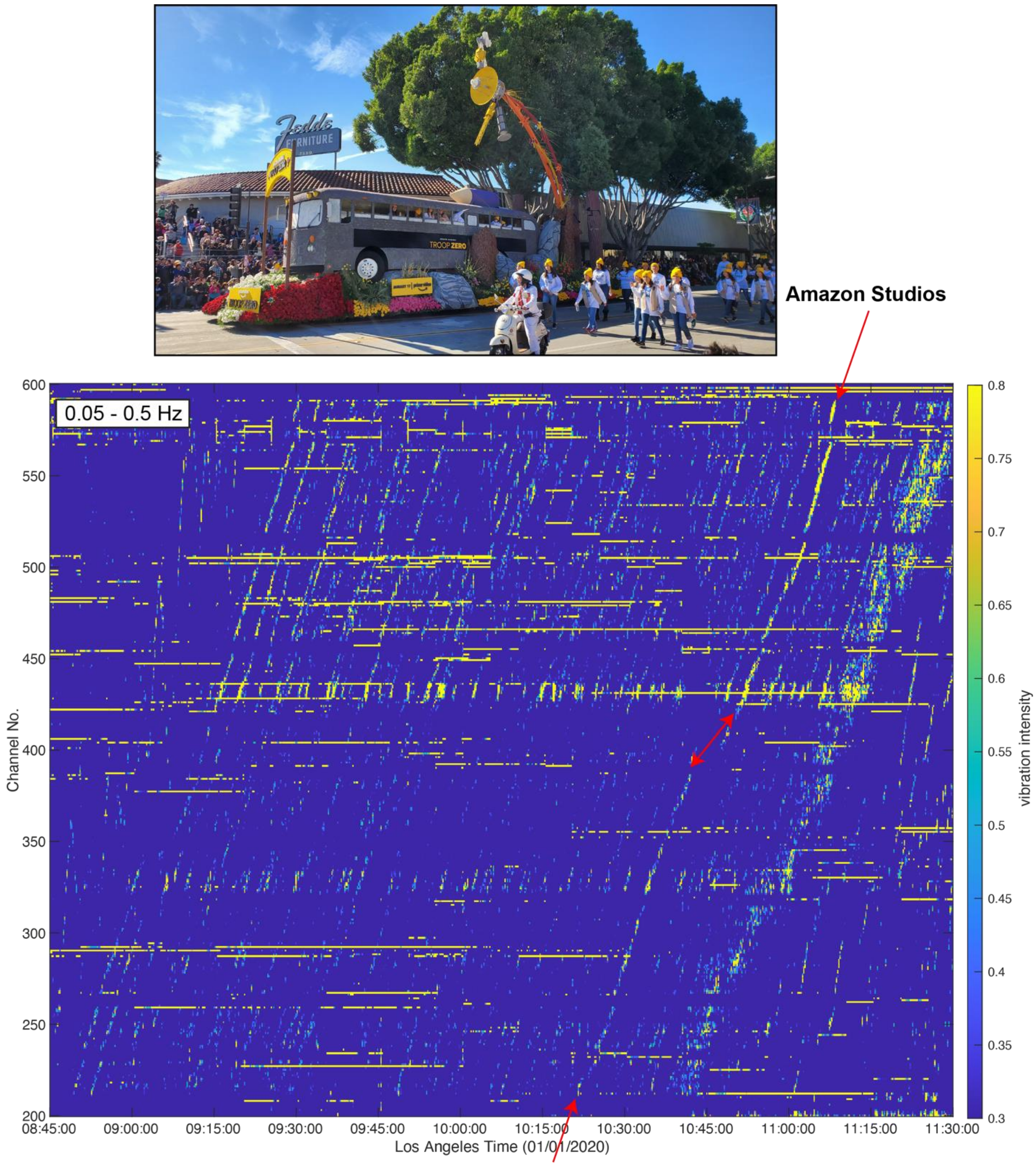

Figure S2. Record section showing the envelope of seismic signals calculated at frequency of 0.05 – 0.5 Hz. The color bar has been rescaled to show the seismically “heaviest” float. The “heaviest” float is the Amazon Studios float (upper figure), which featured a real bus, a rocket, and the Voyager spacecraft on a massive truck.

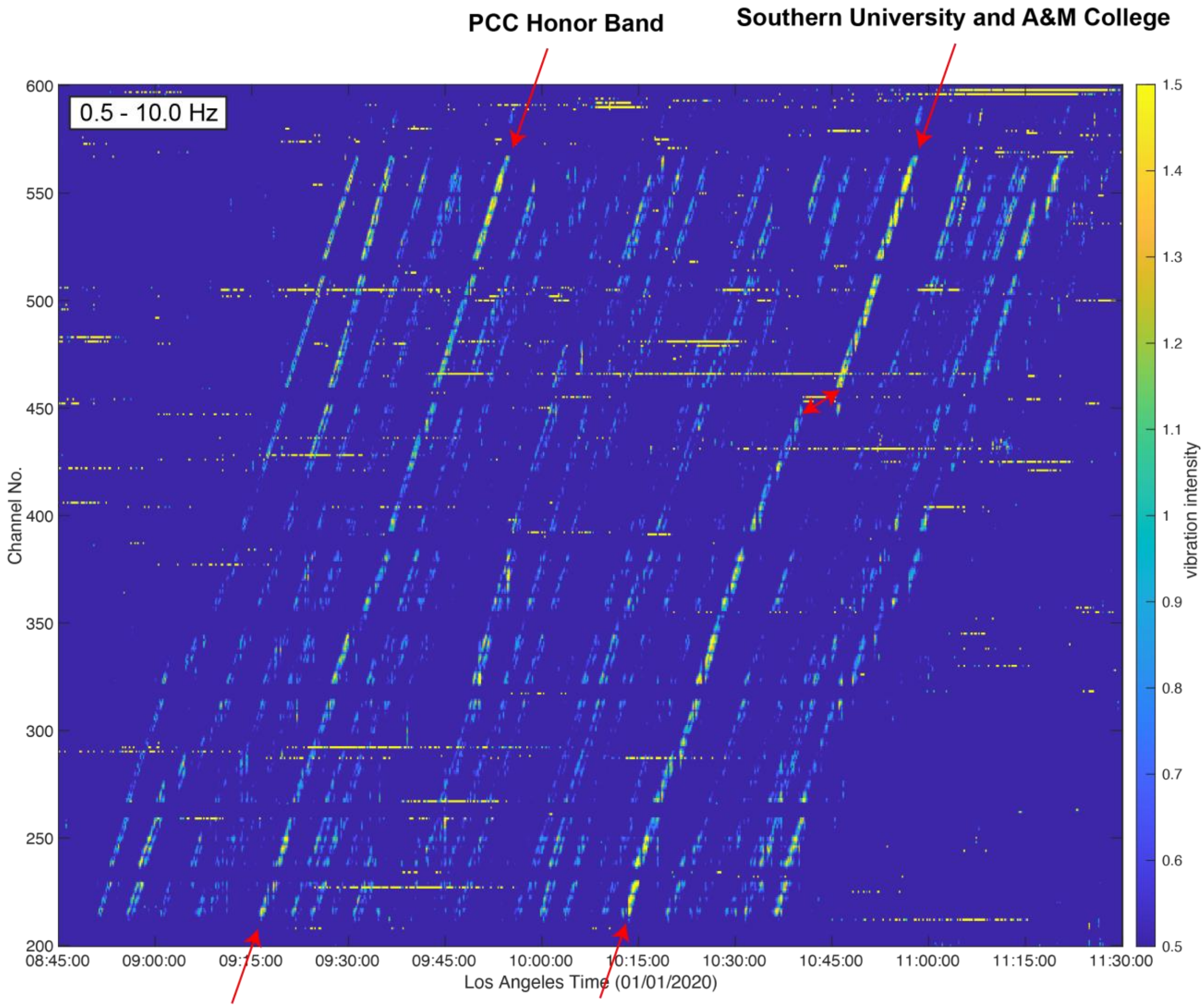

Figure S3. Record section showing the envelope of seismic signals calculated at frequency of 0.5 – 10.0 Hz. The color bar has been rescaled to show the seismically “loudest” band.