Listening to Manchester: Using citizen science Raspberry Shake seismometers to quantify road traffic

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Abstract

Road traffic is a major contributor to greenhouse gases in our cities. This study has been designed to test whether low-cost citizen science seismometers (Raspberry Shakes) can be used to quantify temporal and spatial variations in road traffic. I used a network of seismometers installed around Greater Manchester to record signals in the frequency range 1-50 Hz. Data were processed using the open source ObsPy package. Results show that daily variations in seismic noise in this frequency range correlate directly with vehicle counts from open access traffic cameras installed nearby. In addition, a simple peak-counting method can be applied to the seismometer recordings to measure individual passing vehicles, which correlate directly with in-person traffic counts. Two seismometers were installed close to a School Streets pilot project to test if traffic volumes increased just outside the road closure section. Results to data show no increase in seismic vibrations attributable to road traffic, over 6 road closure days. The combination of low unit cost and transparent (i.e., open) data from these seismometers makes them a useful tool to simultaneously quantify anthropogenic noise – including road traffic – and share the results with the wider public.

Non-technical summary

Road traffic in urban areas contributes significantly to the amount of carbon dioxide and particulates in the atmosphere. It is important therefore to accurately measure and quantify road traffic and how it varies over space and time – for example, in response to policy changes. Camera-based systems for counting vehicles can be expensive and can generate concerns in the public over anonymity. In this study, I used low-cost seismometers – more commonly used to record earthquakes and volcanic eruptions – to quantify variations in road traffic around Greater Manchester. By comparing the data from the newly installed seismometers with data from existing digital traffic cameras, I show that the seismometers can accurately count vehicles across a range of locations from city centre to more rural communities. All of the data and code used in this study is publicly available – a key requirement for including the wider community in discussion and debate around the changes needed to tackle the climate emergency.

1. Introduction

1.1 Background & Rationale

The urban environment generates seismological vibrations, which can be considered as either signal or noise. Depending on the location of a specific city, the spectral content of these vibrations is of interest to civil engineers, city planners and those responsible for quantifying earthquake or volcano hazards (refs). In general, the dominant source of these vibrations in urban areas is anthropogenic – chiefly from transport and industrial activity. It is increasingly important to characterise and quantify the amplitude and spectral signature of these non-natural sources, in part to better understand their effects on, and relationship to, generally lower frequency signals from natural sources.

We are now in a climate emergency, with the concentration of greenhouse gases (GHG) in the atmosphere rising and driving global warming (IPCC, 2021). The key component in GHG is carbon dioxide (CO_2) which is generated by the burning of fossil fuels. In the Greater Manchester (GM) area, the largest single contributor to atmospheric CO_2 is transport (38%; Department for Business, Energy and Industrial Strategy, 2021). It is important to note that the traffic volume data used in these published reports are heavily dependent on estimates and extrapolations, with very few direct measurements. The Listen to Manchester project has been designed to address this issue by using low cost citizen science seismometers to quantify traffic patterns across the GM area (see Figure 1). Greater Manchester is a large urban and suburban area in NW England (UK), with a population estimated at 2.8M (census of 2021; Office for National Statistics, 2023). The area is served by a range of transport networks including trains, buses, and trams, and has a high road traffic density. One key reason for locating this project in the GM area is the simultaneous availability of public data from traffic cameras and other sensors in the manchester-i network managed by the Manchester Urban Observatory. These open data allow for direct comparisons and calibrations of data measured on the seismometer and their dissemination to the wider public.

The bedrock of the Greater Manchester area comprises Upper Palaeozoic and Mesozoic sedimentary rocks, including faulted and folded Carboniferous Coal Measures unconformably overlain by faulted Permo-Triassic sandstones and conglomerates of the Cheshire Basin. These rocks are overlain by Quaternary alluvium and river gravels in the Mersey and Irwell valleys (Plant et al., 1999). Natural seismic activity is not unknown, with a well-studied swarm of over 100 earthquakes in late 2002 beneath the city centre, up to magnitude M_L 3.9. Hypocenters of these events were located to pre-existing faults 2-3 km beneath the city, and 6 focal mechanisms show strike-slip fault movements (Walker et al., 2003).

Station	**Location (latitude, longitude)**	**Model (RS prefix = Raspberry Shake)**	**Comments on site**
Stations used in this study			
R0174	53.4324, -2.2836	RS1D	House
R36CB	53.3604, -2.1889	RS1D	Secondary school
R6C8A	53.4685, -2.2249	RS1D	University
R9098	53.4865, -2.4533	RS3D	Secondary school
RA4D0	53.4324, -2.2684	RS1D	House
S53C6	53.4775, -2.1798	RS3D	College
Other stations in Listen to Manchester network			
R1770	53.4324, -2.2684	RS1D	Primary school
R3FEA	53.4414, -2.2689	RS1D	Primary school

R34A7	53.4414, -2.2086	RS3D	Secondary school
RAEED	53.4595, -2.2247	RS1D	University
R4DD7	53.4414, -2.2084	RS3D	Botanical garden
R0DB4	53.5315, -2.1072	RS3D	College
R9E71	53.5135, -2.2729	RS1D	House
RD9D6	53.2613, -2.1542	RS3D	Secondary school
R6055	53.4144, -4.3231	RS1D	Visitor centre
R6AAD	52.8649, -4.5525	RS3D	Secondary school
R9EF0	52.9279, -4.5141	RS1D	Community hall
RC8D6	52.8198, -4.5025	RS1D	Community hall
RE28A	53.2252, -4.1534	RS3D	University
Nearest BGS broadband station			
LBWR	53.402, -1.725	CMG-3T	(no data)

Table 1. List of seismometers installed for the Listen to Manchester project, and details of the nearest reference British Geological Survey (BGS) broadband seismometer (LBWR) at Ladybower reservoir in the Peak District.

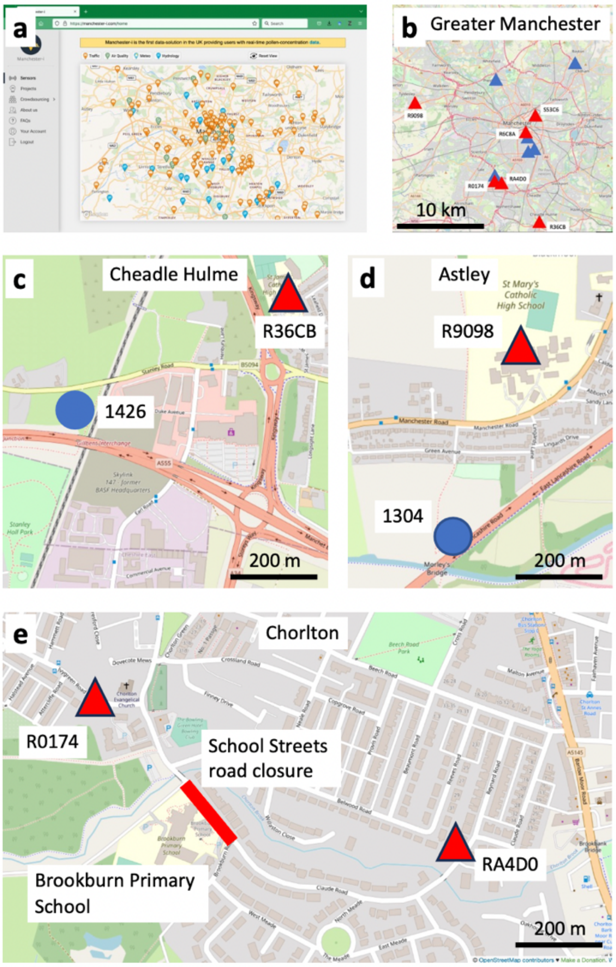

Figure 1. Maps of Greater Manchester (GM) showing locations of devices. **a**) Screenshot of manchester-i repository from the Manchester Urban Observatory, showing the distribution of traffic cameras and other environmental sensors across the GM area. **b**) Map of GM showing the Raspberry Shakes installed to date (May 2023) in the Listen to Manchester project. Stations used in this study shown by red triangles and other stations as blue triangles. **c**) Map of Cheadle Hulme (south Manchester) showing proximity of Drakewell traffic camera 1426 to seismometer station R36CB. **d**) Map of Astley (west Manchester) showing proximity of Drakewell traffic camera 1304 to seismometer R9098. **e**) Map of Chorlton (south Manchester) showing locations of seismometers installed to monitor local traffic around a school as part of the School Streets pilot.

1.2 Previous work

Previous work has quantified seismological data in urban environments using broadband seismometers including: trains, aircraft and cars around Long Beach (California, USA; Riahi & Gerstoft, 2015); crowds at rugby matches and the trains used to transport people there in

Auckland (New Zealand; Boese et al., 2015); subway (underground) trains, football matches and music concerts in Barcelona (Spain; Diaz et al., YYYY); transport in London (UK; Green et al., 2017); and crowd responses to football matches when Leicester City won the Premier League in 2015/2016 (Leicester, UK; Denton et al., 2018). A pronounced global decrease in urban anthropogenic 'noise' was recorded – in part on Raspberry Shake seismometers – during the COVID-19 epidemic (Lecocq et al., 2019). Data from a network of Raspberry Shake seismometers installed around an active geothermal drilling project in rural Cornwall has recently shown that these devices can provide useful preliminary assessment of ground motion from induced seismicity (Holmgren & Werner, 2021).

1.3 Specific scope of this paper

In this paper, I used a network of Raspberry Shake seismometers to measure and quantify road traffic over a wide urban and suburban area around Greater Manchester. Seismological vibrations are compared directly to digital traffic count data from the previously installed traffic camera network. I compare the spectral response of locally installed seismometers to time-series data from the nearest traffic cameras, and determine the optimum frequencies to characterise the local traffic volume. The key questions addressed are:

- What part of the spectral response at each seismometer is due to road traffic? And
- If we can define and isolate that response, can we use the seismometer signals to directly measure traffic volumes in the absence of specialised road traffic cameras?

Data are also presented for the example of a local road closure programme around a primary school in South Manchester, part of the School Streets road closure pilot scheme at Brookburn Primary School, Chorlton to encourage active travel.

2. Methods

A total of nineteen Raspberry Shake 1- and 3- component seismometers (models RS1D and RS3D respectively) have been deployed to date in buildings across Greater Manchester, including four in North Wales, for the Listen to Manchester project (see Figure 1). Sites include schools, universities, community halls and private domestic houses. Wherever possible, the devices were installed on concrete floors in the lowest level of the buildings, and situated away from heating or air conditioning units and areas of heavy pedestrian traffic. All devices are set to sample at 100 samples per second. Only vertical components are used in this study, as several of the deployed devices were 1D (i.e., a single vertical geophone) only. The six specific devices used in this paper are shown in red in Figure 1.

Pre-processing of the seismometer data included removing the instrument response from each station, and the application of a high pass filter set at 1 Hz. Power Spectral Density (PSD) was calculated with a Fourier transform method through the open source ObsPy PPSD object class, using half-hour segments and smoothed over one octave bands and one-eighth octave intervals (the same technique used in Green et al., 2017). PSD values are plotted and reported in decibel (dB) units with respect to acceleration power (i.e., $(m^2/s^4)/Hz$). All times are plotted and reported as either UTC or British Summer Time (BST = UTC + 1 hour), depending on the time of year.

Examples of the frequency response of two stations used in this study are shown in Figure 2. For both RS1D and RS3D devices, the flat part of the response lies between about 0.5 and 40 Hz. Plots of median PSD versus frequency shown in Figure 3 using the method of McNamara & Buland (2004) show that some of the stations experience high noise levels, confirming the previous analyses of Raspberry Shake hardware by Anthony et al. (2019) and Holmgren & Werner (2021). These elevated levels in the range 1-40 Hz are likely due to a combination of sub-optimal deployment locations and local anthropogenic noise.

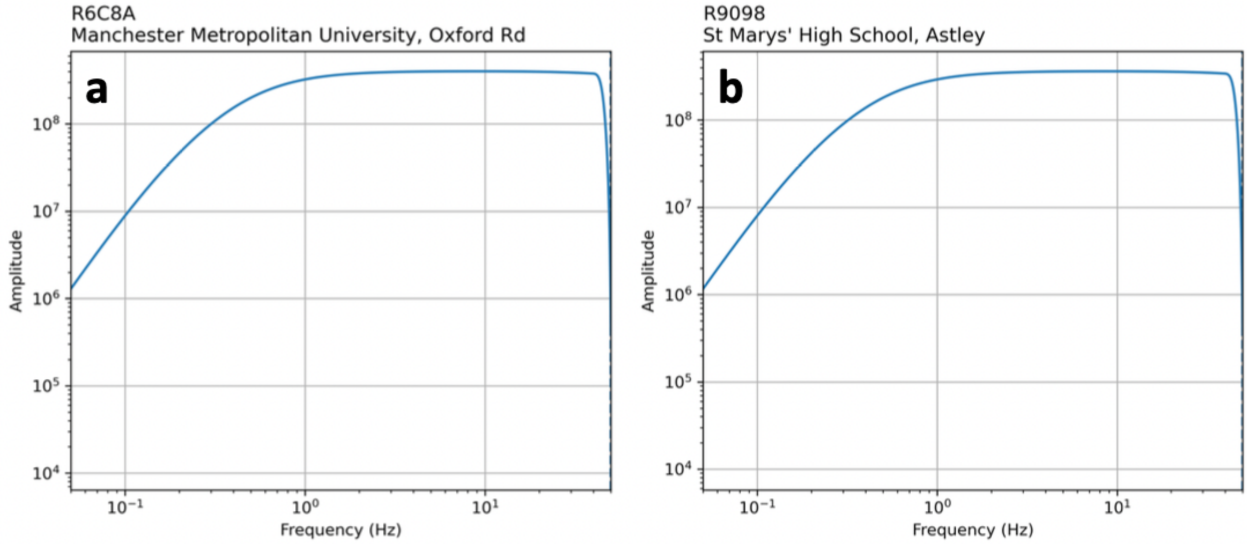

Figure 2. Frequency response of two Raspberry Shake stations used in this study. **a**) R6C8A is a 1D unit installed on Oxford Road in the city centre, with a vertical geophone only. **b**) R9098 is a 3D unit installed at Astley (semi-rural) with 2 horizontal and 1 vertical geophones.

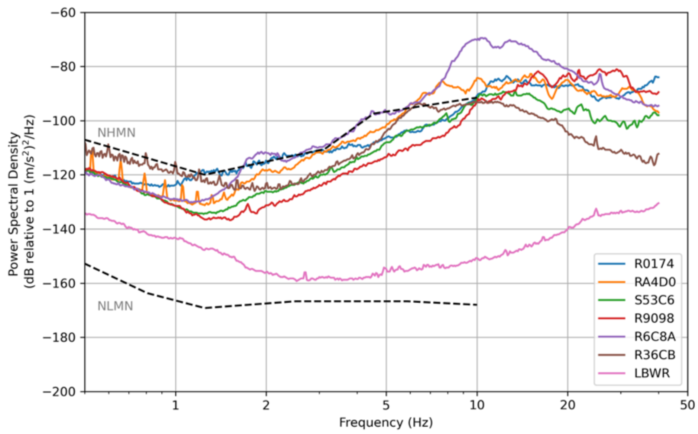

Figure 3. Plot showing vertical-component noise power spectral density (PSD) for stations used in this study over a single typical 24 hour period, and compared to that from the nearest British Geological Survey broadband station (LBWR) at Ladybower Reservoir in the Peak District, approximately 45 km ESE from Manchester city centre.

3. Results

3.1 Spatial and diurnal variations in vibrations across Greater Manchester

Vertical-component noise power varies significantly across Greater Manchester and over different timescales (weeks, days, hours; see Figures 4 and 5). Noise is much higher (+20 dB), on average, in city centre or urban locations compared to those sites in the outlying suburbs and semi-rural areas on the edge of the conurbation (compare Figures 4a & b with Figures 4c & d, respectively). The frequency band of the highest acceleration powers vary from site to site. In the city centre (station R6C8A, Oxford Road), this frequency is quite well defined between 10 and 15 Hz, whereas in a semi-rural location (R9098, Astley), it ranges from 10-30 Hz. At all sites, clear diurnal variations are visible in the spectrograms (Figure 4), with reductions of about 20 dB from the middle of the day to night time. The overall spread of frequencies is much larger during weekdays too, with ranges from 2–50 Hz for weekdays compared to 5-30 Hz for weekends and holidays.

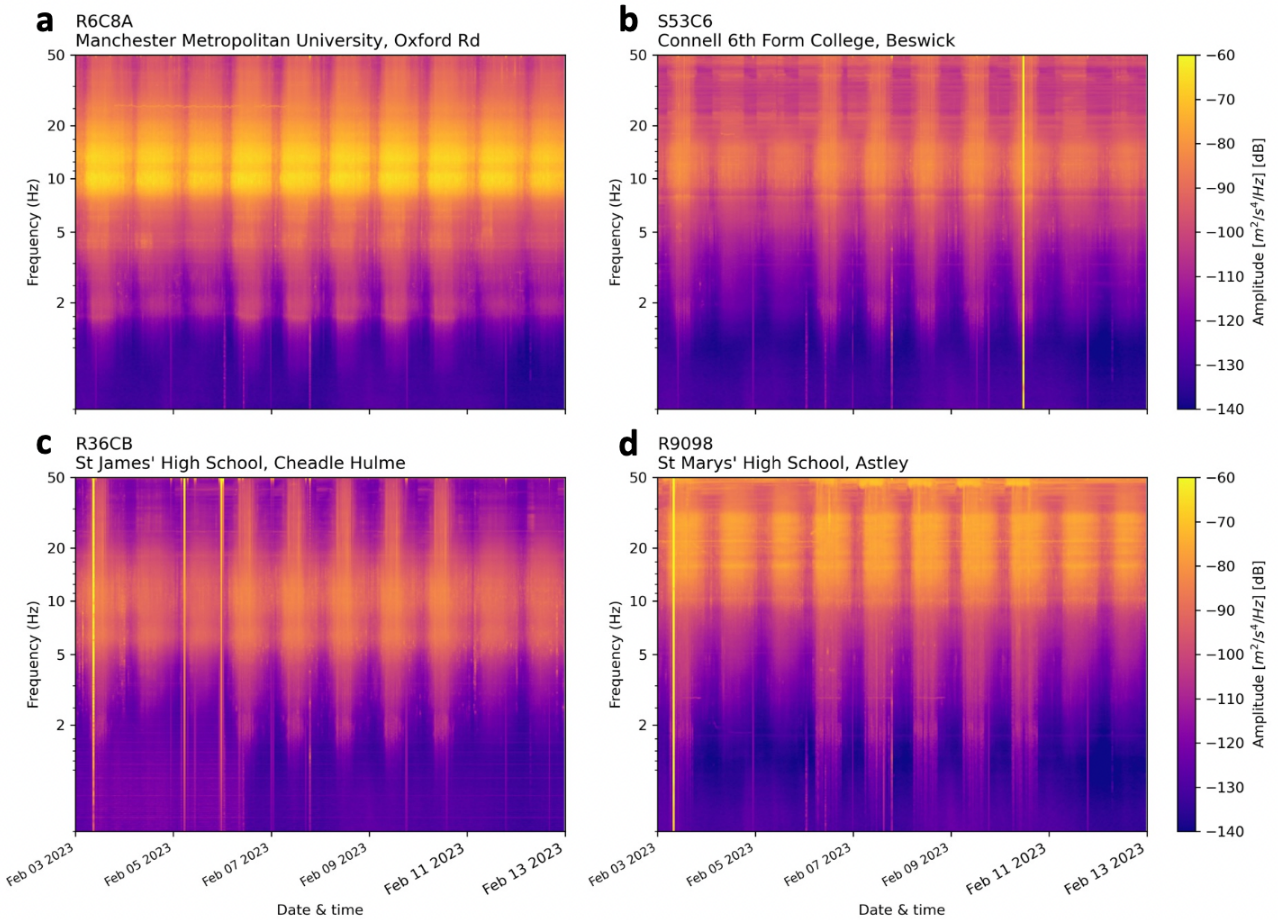

Figure 4. Spectrograms showing vertical-component noise PSD for the same 10-day period, including 2 weekends, for 4 different locations around Greater Manchester. **a**) R6C8A at Manchester Metropolitan University on Oxford Road (city centre); **b**) S53C6 at Connell Co-op Academy in Beswick (urban); **c**) R36CB at St James' Catholic High School in Cheadle Hulme (suburban); and **d**) R9098 at St Marys' Catholic High School in Astley (semi-rural).

Figure 5 shows the amplitude of noise power for selected frequencies at the same four stations shown in the spectrograms in Figure 4. The shape of the diurnal variations in noise is now more apparent. Most sites show at least 10 dB variation in peak noise between day and night, except for the city centre station R6C8A. The difference between peak noise on weekdays versus weekends, at a given frequency, is of the order of 5-10 Hz. Interestingly, different sites show different shapes i.e., gradients, of noise variation in time across each day. Some sites show a rapid morning rise in noise, followed by slower drop to night-time levels (e.g., R6C8A and R9098), whereas others show more symmetric rises and falls in the noise levels during the day (e.g., R36CB and S53C6). The shapes of temporal variation in noise at a given frequency also vary from weekdays to weekends, with weekend days generally being more symmetric over 24 hours compared to weekdays.

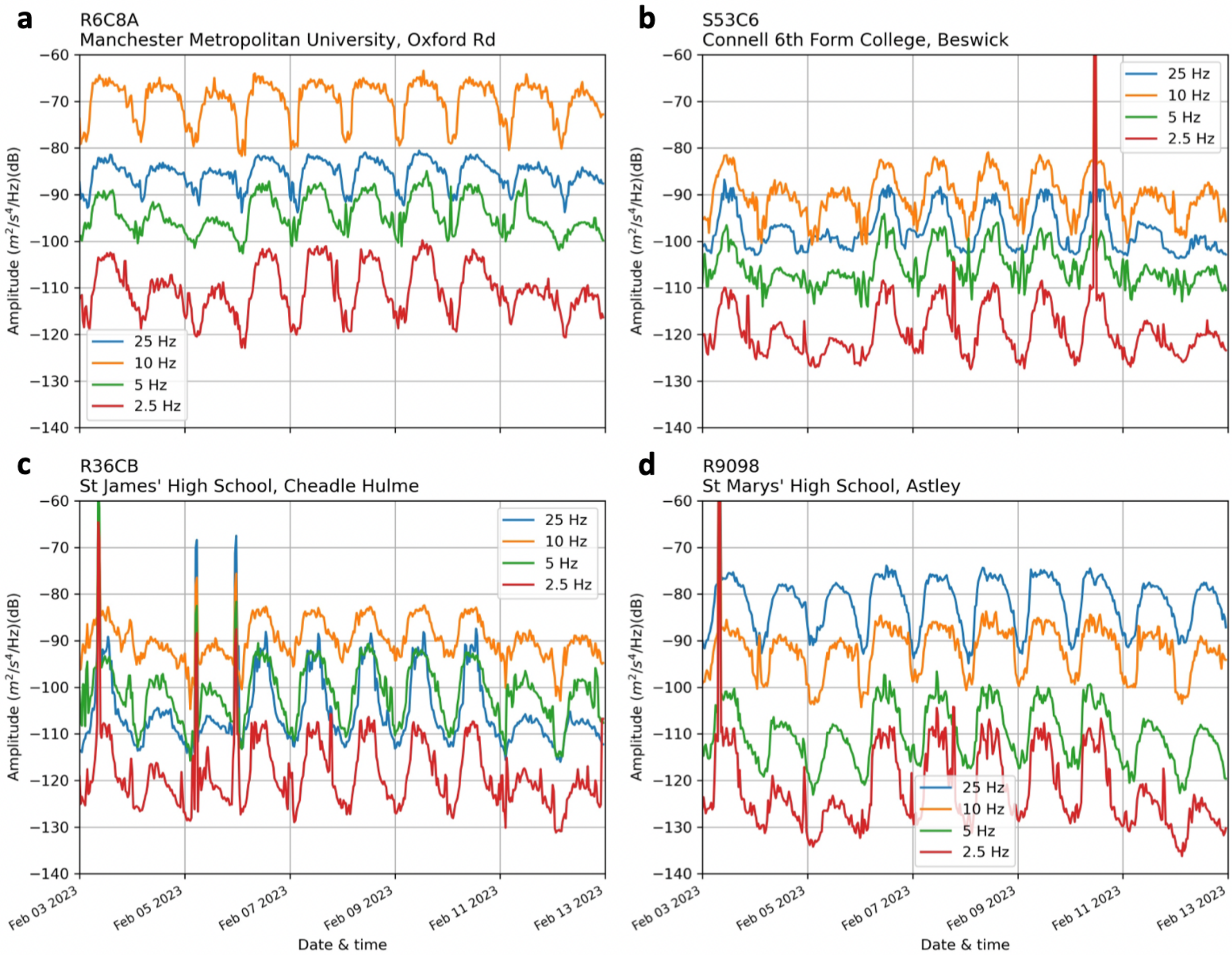

Figure 5. Plots of PSD at selected frequencies representing horizontal slices through the spectrograms shown for the 10-day periods shown in Figure 4, for the same stations.

3.2 Comparison to empirical traffic counts

a) Transport for Greater Manchester (TfGM) Drakewell traffic cameras

Traffic count data has been extracted from the manchester-i Urban Observatory, and then compared to the same time intervals as the seismometer recordings (Figure 6). Data from the Transport for Greater Manchester (TfGM) Drakewell cameras is categorised into different vehicle types, including cars, vans, buses & coaches and heavy lorries. For this study, I grouped the cars and vans together as ‘light vehicles’ and the rest as ‘heavy vehicles’. Figure 6 shows the temporal variation in traffic counts at two sites close to stations R9098 at Astley and R36CB at Cheadle Hulme for the same 10-day time interval as the seismic noise shown in Figures 4 and 5. The daily rise and fall in traffic volume is apparent at both sites, although there are significant differences. For camera 1426 at Cheadle Hulme (close to seismic station R36CB), the difference in shape and size of weekends and weekdays is obvious, with broadly symmetric rises and falls of traffic volume on each weekend day to a lower peak level, but a distinct double peak pattern on weekdays to higher levels, with a steeper morning rise and more gradual evening drop-off. For camera 1304 at Astley (close to seismic station R9098), the weekend peak counts are like those for weekdays, although again the diurnal patterns are distinct, with double peak patterns on weekdays. At both sites, the heavy vehicle traffic shows a steep morning rise and gradual fall through the afternoon on each weekday.

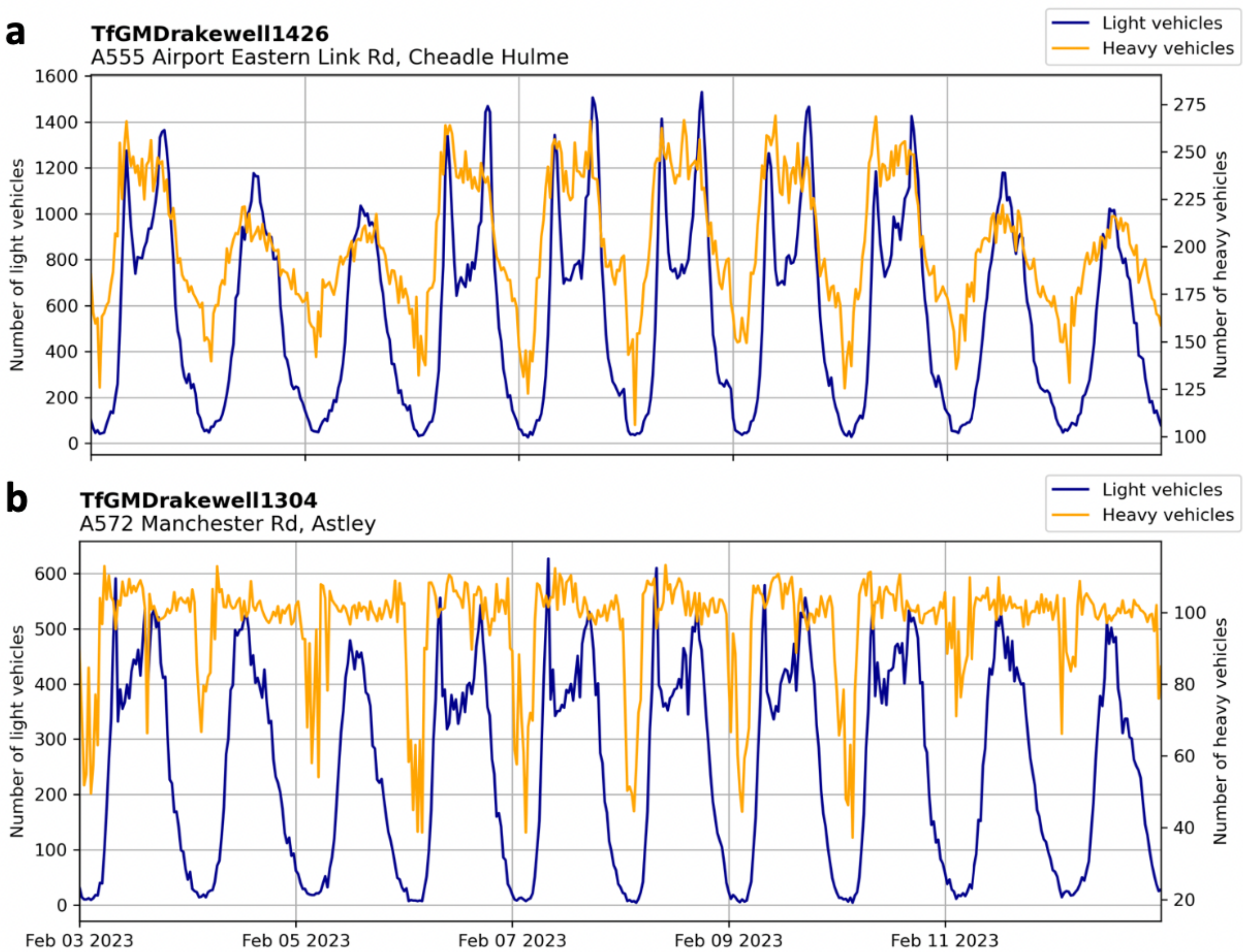

Figure 6. Plots of traffic count time series from two Transport for Greater Manchester (TfGM) Drakewell cameras located close to stations R36CB and R9098. Counts are shown for 30 minute bins across the same 10 day period

as the seismometer data in Figures 4 and 5. **a**) Drakewell camera 1426 close to seismometer R36CB in Cheadle Hulme. **b**) Drakewell camera 1304 close to seismometer R9098 in Astley. See maps in Figure 1c-d for precise locations.

The similarity of the diurnal patterns observed in both the seismic noise and traffic count data – including the changes in temporal gradients and the differences between weekdays and weekdays – strongly suggests that traffic is the source for much of the seismic noise measured at the nearest station. To investigate this apparent correspondence in more detail, Figure 7 shows plots of noise amplitude at two selected frequencies (2.5 Hz and 25 Hz) for two stations. Following Green et al., 2017 these data are plotted for five consecutive weekdays but wrapped around a 24 hour window, with the box and whisker format shows the statistical distribution in noise for each half-hour interval. There are clear differences between the two sites, with station R9098 at Astley showing much higher noise at 25 Hz than R36CB at Cheadle Hulme (for the same 5 day interval). In addition the shape of the daily variation is different with a simple plateau at -75 dB for R9098 between 8 am and 5 pm, but a steadily rising curve to a peak of -90 dB at around 2 pm in Cheadle Hulme. These patterns are repeated for the lower frequency of 2.5 Hz at both sites. Similar plots for two consecutive weekends (giving 4 days total) at each site are shown in Figure N. By comparison to the weekday intervals, the noise levels at weekends in these suburban locations are clearly lower by about 5 – 15 dB for the same time of day. The distinctive plateau in the Astley data for weekdays is absent at the weekends, replaced by a gently rising and falling curve. The gap between the noise measured at 2.5 and 25 Hz for Astley is consistently 35-40 dB for weekdays and weekends, whereas at Cheadle Hulme the gap is 10-15 dB.

The traffic count data from the closest Drakewell cameras to these two stations are plotted in the same format in Figures 7c-d and 8c-d. The data are broken down into Heavy, Light and Total vehicles and show the statistical distribution per half-hour time slot for the same intervals of weekdays (Figure 7) and weekends (Figure 8). For Astley (camera 1304 and station R9098), the single plateau in the seismic noise is closely mirrored by the pattern for Heavy vehicles (buses, coaches, and lorries), but not for Light vehicles (cars, vans) which shows a double peak pattern corresponding to the morning and afternoon rush-hours. Similarly for Cheadle Hulme (camera 1426 and station R36CB), the distinct double peak in the Light vehicle counts over 24 hours is not seen in the seismic noise for the same weekday period. For weekends, the traffic counts are slightly lower per half-hour interval, but the shape of the temporal variation over 24 hours is similar to that for weekdays for Heavy vehicles, but not for Light vehicles – the double peak (two rush-hour) pattern is now absent at weekends. From these data, I infer that the dominant contribution to the measured seismic noise between 2.5 and 25 Hz at both sites – on weekdays and weekends – probably comes from Heavy vehicles, with only a minor degree of modulation by the Light vehicle traffic.

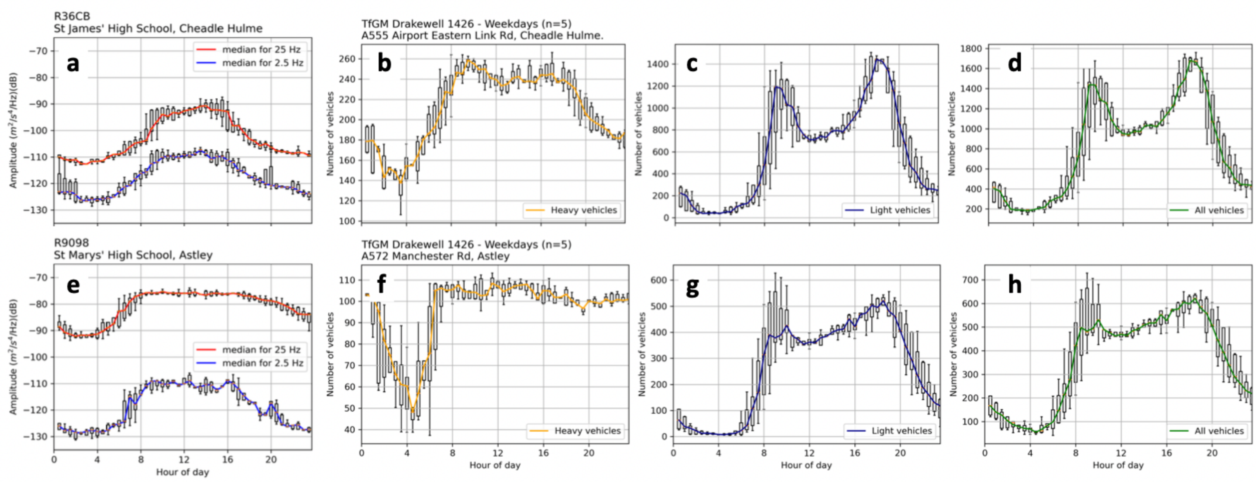

Figure 7. Plots of PSDs for selected frequencies for 5 consecutive weekdays at stations R36CB (Cheadle Hulme) and R9098 (Astley). The data are plotted in 'box and whisker' format to show the statistical distribution in 30 minute bins across 24 hours in a day. The solid coloured lines show the median and the boxes span the 1st and 3rd quartiles.

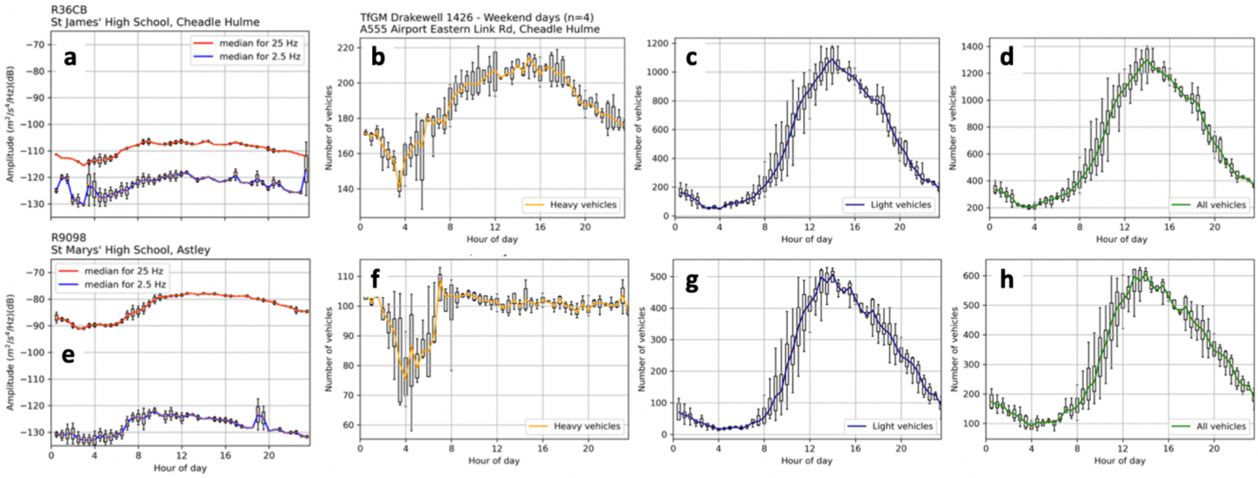

Figure 8. Plots of PSDs for selected frequencies for 2 consecutive weekends at stations R36CB (Cheadle Hulme) and R9098 (Astley). The data are plotted in 'box and whisker' format to show the statistical distribution in 30 minute bins across 24 hours in a day. The solid coloured lines show the median and the boxes span the 1st and 3rd quartiles.

b) In-person traffic counts

To further calibrate the potential for Raspberry Shake seismometers to quantify local traffic volumes, we ran comparisons between in-person traffic counts over 30-60 minute intervals outside two houses where seismometers were located in the Chorlton area of south Manchester. In-person traffic count data were collected by local volunteers at the roadside and binned at 5-minute intervals (Figure N). An example of the seismic noise is plotted in spectrogram format for frequencies between 1 and 50 Hz (Figure N). Short duration (up to a few seconds) high amplitude events are clear between about 5 to 35 Hz. A bandpass filter was applied to the raw seismometer data and the instrument response removed, before squaring the resulting velocity (Figure N). Applying a simple arbitrary threshold above the background to this plot shows a near perfect correspondence in peaks of velocity measured by the seismometer and the in-person counts (101 recorded peaks versus 98 observed vehicles, respectively). In total, we ran four separate in-person counts (during morning and afternoon rush-hours) at each of the two Chorlton stations for a total of eight calibrations, with similar results for all.

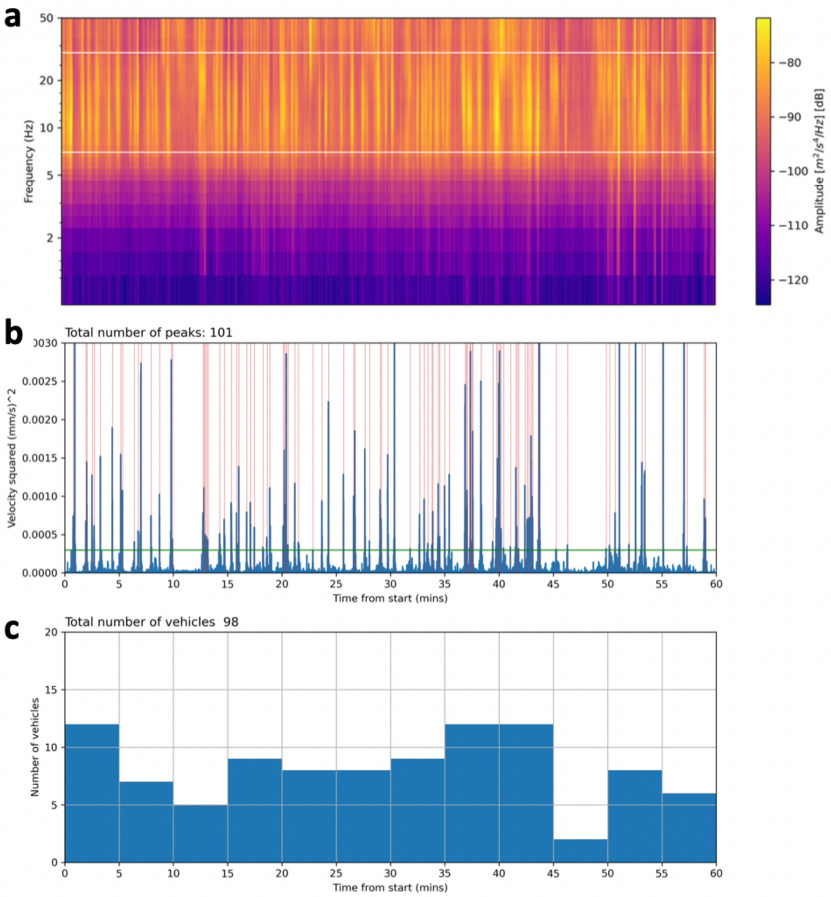

Figure 9. Plots showing the calibration of a seismometer response to in-person traffic counts in Chorlton, south Manchester. The data shown are from station RA4D0 located in a house on Claude Road. **a**) Spectrogram of vertical-component noise PSD for a time window of 60 minutes in the morning of DD/MM/23. The raw data have been high-pass filtered at 1 Hz. Note the regular high-amplitude events concentrated in the frequency range 7-35 Hz. **b**). Vertical-component velocity^2 for the same time interval as a) and filtered between 7-35 Hz. The number of peaks above an arbitrary threshold of 0.0003 mm2/s2 is 101. **c**) Bar chart of in-person vehicle counts binned into 5 minute intervals for the same time interval as a) and b) conducted directly outside the house containing seismometer RA4D0. The total number of road vehicles (excluding bicycles) is 98.

3.3 Variations of seismic noise and traffic around School Streets road closures

School Streets is a community-led initiative backed by local authorities in certain areas of the UK (Chivers et al., 2019; …). The road outside or close to a school is temporarily closed to traffic at morning drop-off and afternoon pick-up times. The aims are to reduce air pollution and traffic danger, and encourage active travel (walking, cycling) to and from school. In Chorlton, Brookburn Primary school has been conducting School Streets pilot projects to assess the impact on local traffic. On selected days, an approximately 150 m long section of Brookburn Road is closed to through traffic between 08:30 and 09:10 and then again between 15:10 and 15:50. During preliminary consultations with residents, concerns were expressed that traffic volumes may locally *increase* at either end of the closed road section, due to cars turning around to avoid the closure. To test this, we installed Raspberry Shake seismometers at either end of the closed section, close to junctions where traffic might be expected to increase (map in Figure 1e). In addition to the in-person traffic count calibrations, we measured a background seismic noise dataset from a full 5-day school week with no road closures to serve as a reference level for any changes, at two selected frequencies 25 and 2.5 Hz, shown as the shaded blue and red zones, respectively, in Figure 10. These envelopes are defined by the minimum and maximum for each 1 minute interval for the 5 days. The choice of two frequencies was based on the findings reported above that different stations record traffic variations across a frequency band rather than one well-defined frequency. Data for two separate road closures - one in the morning (Figure 10a) and one in the afternoon (Figure 10b) – are shown in Figure 10, for two stations and two frequencies (blue and red lines). The recorded noise levels sit well within the 5-day envelopes recorded for non-closure days, supporting the inference that road closures are not currently leading to increased traffic volumes at either end of the School Streets section. Over 6 road closure pilots so far, none have shown any increase in noise attributable to road traffic before, during or after the School Streets closure windows.

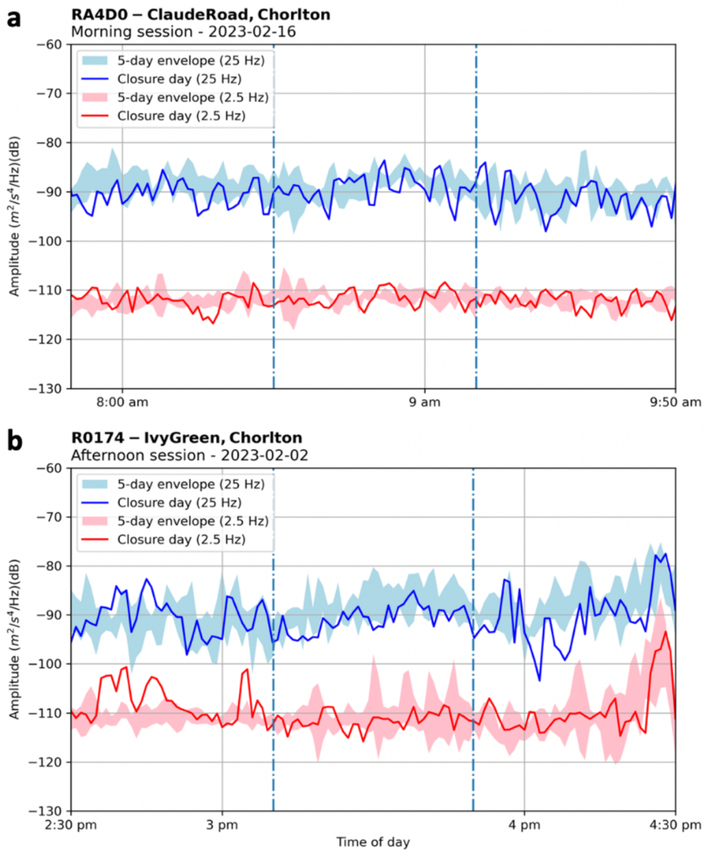

Figure 10. Plots of PSDs for selected frequencies (2.5 & 25 Hz) for School Streets closure periods in Chorlton. Shaded zones show the range (min, max) recorded over a 5-day interval during which there were no road closures to serve as a reference. **a**) Data measured at station RA4D0 on Claude Road at the eastern end of the School Streets section. **b**) Data measured at station R0174 on Ivy Green Road at the western end of the section. In both cases, the signals from the closure periods (solid lines) sit well within the background range (shaded zones), and this is consistent across two frequencies and two separate sites.

4. Discussion

As reported by Green et al. (2017) for London, it is perhaps unsurprising that there is a good correlation of seismically measured noise at certain frequencies with traffic volumes around Greater Manchester, but there are some specific features that merit further analysis. One obvious point is the geographic variation in noise levels measured by the Raspberry Shake seismometers in this study, with sites ranging from urban city centre (e.g., R6C8A at Manchester Metropolitan University, MMU) to semi-rural (R9098 at Astley). Peak amplitudes shown on the PSD spectrograms vary between sites, and the shape of diurnal variations over 24 hours is also distinct. Moreover, the diurnal patterns for weekdays are distinct from weekends and public holidays. The availability of high quality digital traffic count data from the TfGM Drakewell project through the manchester-I web portal enables the quantitative comparison of road traffic with seismic noise. Note that there is no subway or underground train network in Manchester, but there are surface trams (Metrolink) and overground rail lines. The seismometer closest to a railway line in this study is the station at Oxford Road R6C98 (MMU) at approximately 400 metres. Future analysis of train timetables in relation to the recorded data at R6C98 may explain the near constant (24/7) high amplitude noise, noting that this line is used for passenger and freight traffic.

In comparison to other cities, the measured noise is comparable in terms of power amplitudes and frequency ranges. Seismic noise from traffic in Bucharest (Romania) was measured by Groos & Ritter (2009), and spanned 1-45 Hz with a peak between 1-10 Hz. Boese et al. (2015) used borehole seismometers to measure ambient noise around rugby matches and railway lines in Auckland (New Zealand). The noise from traffic peaked at 7 Hz, in a range spanning 1-35 Hz. Riahi & Gerstoft (2015) used a dense geophone network to measure seismic noise from aircraft, trains and road traffic in Long Beach, California (USA). They could track individual heavy goods vehicles moving along highway 1-405 at night time, with a peak amplitude at between 10-20 Hz. Diurnal variations in noise recorded in London (UK) by Green et al. (2017) peaked at about 90 dB at a frequency range of 2.5 Hz (period = 0.4 s). Road traffic in Barcelona (Spain) measured by Diaz et al. (2017) peaked at X dB in a range of 8-12 Hz. These previous studies used standard broadband seismometers rather than citizen science Raspberry Shake seismometers.

In terms of other contributions to the measured noise, note that the any microseism component is probably not relevant, as the data used in this study have been high-pass filtered at 1 Hz. In addition, site specific effects from varying bedrock geology may be significant, but could only be achieved with 3-component stations to conduct HVSR analysis. The stations used in this study were a mixture of 1- and 3-component Raspberry Shakes. A first target of this future analysis would be to compare stations sited on Carboniferous Coal Measures with those on Permo-Triassic sandstones. The siting of any seismometer is a key factor in the quality of the recorded data. Some of the stations in this study were placed in sub-optimal locations – e.g., in domestic homes, not on the ground floor, and not on a smooth stable concrete base. This can result in occasional contributions to the data from non-road traffic. An example is shown in Figure 11 for station R0174 used in the Chorlton School Streets project. The event happened during one of our in-person traffic calibrations, with a volunteer counting cars outside the location of the seismometer. An intense signal of rising frequency occurs at approximately 7 minutes into the 30 minute survey, and lasts for about 7 minutes (spectrogram in Figure 11a). This signal dominates the recording and obscures the shorter duration lower energy events from passing vehicles, and therefore renders the simple peak-counting algorithm redundant in this case. Work-arounds include processing the data to remove artefacts of this form, or asking the residents of the house with the seismometer to schedule domestic appliances outside the time windows of the School Streets closures.

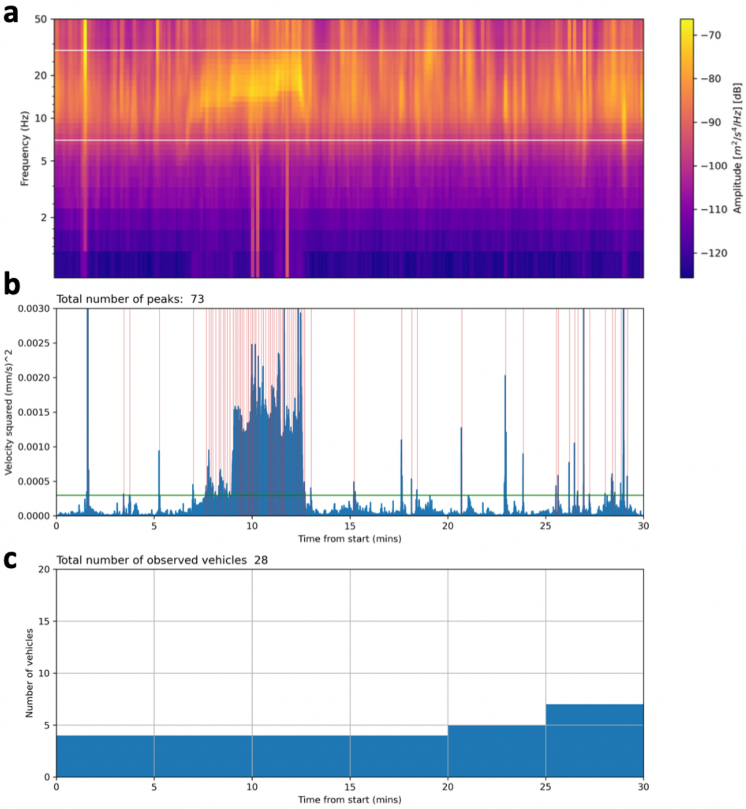

Figure 11. Plots showing the attempted calibration of a seismometer response to in-person traffic counts in Chorlton, south Manchester. The data shown are from station R0174 located in a house on Ivy Green Road. **a**) Spectrogram of vertical-component noise PSD for a time window of 30 minutes in the morning of DD/MM/23. The raw data have been high-pass filtered at 1 Hz. Note the regular high-amplitude events concentrated in the frequency range 7-35 Hz, and the rising frequency (5 to 20 Hz) event starting at about 6 minutes and lasting for about 7 minutes. This is likely to be from a domestic electrical appliance, such as a washing machine. **b**). Vertical-component velocity^2 for the same time interval as a) and filtered between 7-35 Hz. The number of peaks above an arbitrary threshold of 0.0003 mm2/s2 is 73, but dominated by events in the time window 6-13 minutes, coinciding with the rising frequency event in a). **c**) Bar chart of in-person vehicle counts binned into 5 minute intervals for the same time interval as a) and b) conducted directly outside the house containing seismometer R0174. The total number of road vehicles (excluding bicycles) is 28.

5. Summary

In this study, I used open data from a network of affordable citizen science Raspberry Shake seismometers installed across Greater Manchester to show that road traffic in different areas generates distinct and measurable signals (formerly ‘noise’) that can be correlated to changes in traffic volumes. Diurnal variations in amplitude at frequencies from 2.5 to 25 Hz correlate directly with time series of traffic counts from automatic traffic cameras, including the gradients of increase and decrease at morning and evening rush-hours, respectively. Spatial variations show much higher amplitudes in city centre locations (e.g., station R6C8A on Oxford Road) compared to suburban locations (e.g., R9098 at Astley). Over shorter time-periods (30 minutes to 1 hour), the seismometers can accurately record the passing of individual vehicles, as demonstrated by comparison of Raspberry Shake data to in-person traffic counts. Based on these findings, I have trialled the use of Raspberry Shake seismometers around a School Streets temporary road closure program in Chorlton, and found no increase in road traffic noise before, during or after the closure windows in the local area.

The data and analysis presented here shows that low-cost citizen science seismometers, like the Raspberry Shake, can be used to quantify road traffic levels in urban and suburban environments. While broadband instruments are needed to analyse the full spectrum of anthropogenic noise in these locations, lower cost devices, such as the Raspberry Shake with a limited frequency response, can still provide useful quantitative information. Moreover, their lower unit cost can enable a dense deployment of many instruments in each area. In addition, the availability of the raw seismological data through public servers (International Federation of Digital Seismograph Networks, FDSN) and the anonymity of the method – compared to perceived risks about using camera-based systems – both combine to increase transparency when communicating the results to the wider public, e.g. in School Streets road closure trials.

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Data & code availability

The raw Raspberry Shake timeseries data used in this study are available on the standard public FSDN servers – network, channel etc. The traffic camera data used in Figures M-N have been downloaded from the Manchester Urban Observatory manchester-i portal at https://manchester-i.com/ and copies of the files of traffic camera counts are stored in .csv format on GitHub at https://github.com/DaveHealy-github/listen2manchester. The Python code used to generate Figs M-N is also on GitHub at https://github.com/DaveHealy-github/listen2manchester. A snapshot of these data and code files has also been stored on Zenodo at DOI: 10.5281/zenodo.7970854 (taken 25 May 2023).

Competing interests

The author declares that he has no competing interests.

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