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Widespread urban seismic quietening during the 2024 total solar eclipse

Benjamin Fernando * [1]

[1]Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, Maryland, USA

Author contributions: *Conceptualization*: BF. *Investigation*: BF. *Writing - Original draft*: BF. *Writing - Review & Editing*: BF.

English Solar eclipses are known to have significant geophysical impacts, in particular on meteorological, ionospheric, and magnetospheric conditions. However, relatively little attention has been paid thus far to the seismic impacts of solar eclipses, except to demonstrate that celestial alignments are uncorrelated with global-scale seismicity. In this paper, we consider seismic activity across the North American continent during the 2024 total solar eclipse. In general, a continent-wide seismic quietening is observed during the eclipse, with urban areas in the path of totality seeing almost an order-of-magnitude decrease in the velocity spectral power in some frequency bands. Outside of totality, and in non-urban areas, noise levels were less, or not at all, reduced from April 2024 background averages. Exceptions were noted in some remote areas which experienced higher-than-average traffic associated with eclipse-chasing. Our results also support past findings that the Earth-Moon-Sun syzygy does not increase tectonic seismic activity, i.e. that eclipses do not trigger earthquakes.

French Les éclipses solaires sont reconnues pour avoir des impacts géophysiques significatifs, particulièrement par rapport aux conditions météorologiques, ionosphériques et magnétosphériques. Cependant, leurs impacts sismiques ont été jusqu'ici relativement peu étudiés, excepté quant à la démonstration que les alignements célestes ne correspondent pas à une sismicité globale. Dans cet article, nous nous penchons sur l'activité sismique à travers le continent nord-américain durant l'éclipse solaire totale de 2024. En général, nous observons une atténuation sismique à l'échelle continentale durant l'éclipse, notamment en milieux urbains dans l'axe de la totalité, où la puissance spectrale de vitesse est diminuée de près d'un ordre de grandeur dans certaines bandes de fréquences. À l'extérieur de la totalité, ainsi que dans les milieux non-urbains, les niveaux de bruit sismique sont moins, ou ne sont pas du tout, diminués par rapport à la moyenne de fond pour le mois d'avril 2024. Nous avons noté quelques exceptions dans certaines régions éloignées qui ont subi un trafic de véhicules et de piétons plus élevé que la moyenne en raison de la chasse à l'éclipse. Nos résultats supportent aussi ceux d'études antérieures selon lesquelles la syzygie Terre-Lune-Soleil n'augmente pas l'activité sismique tectonique, c'est-à-dire que les éclipses ne déclenchent pas de séismes.

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*Corresponding author: bfernan9@jh.edu

Spanish

Se conoce que los eclipses solares conllevan impactos geofísicos consigo, particularmente en las condiciones meteorológicas, ionosféricas y magnetosféricas. Sin embargo, se ha dado muy poca atención a los impactos sísmicos generados por eclipses solares, excepto para demostrar la falta de correlación entre el alineamiento de los astros y la sismicidad de nuestro planeta. El presente estudio considera la actividad sísmica registrada en Norte América durante el eclipse solar del año 2024. Durante el eclipse se observó una calma sísmica alrededor del continente, con una reducción en centros urbanos de aproximadamente un orden de magnitud en la potencia espectral de velocidad de algunas bandas de frecuencias. Mientras que en áreas rurales y durante la no totalidad del eclipse, existió una reducción o eliminación de los niveles de ruido en comparación al promedio del ruido de fondo de abril 2024. Opuestamente en áreas más remotas se experimentó un aumento en el tráfico vehicular y peatonal asociado con los cazadores de eclipses. Además, estos resultados sustentan teorías pasadas en donde se comprueba que la sizigia Tierra-Luna-Sol no incrementa la actividad sísmico-tectónica, (i.e. los eclipses no desencadenan terremotos)

1 Introduction

Solar eclipses are significant social and cultural events (Goldy et al., 2022), and also have widespread biological, atmospheric, and magnetospheric-ionospheric impacts (e.g. Wheeler et al. (1935); Tsai and Liu (1999); Adushkin et al. (2007); Gerasopoulos et al. (2008); Aplin et al. (2016)).

From a seismic perspective, celestial alignments (of which solar eclipses are a special case) have long been incorrectly linked to elevated levels of seismic activity (Hughes, 1977). However, solid-body tidal stresses within the Earth are only negligibly higher when the Earth-Moon-Sun system is at exact syzygy (i.e. during a solar or lunar eclipse as compared to a normal full or new Moon). The implications of this (that any supposed correlation between large earthquakes and planetary alignments is statistically meaningless) have been robustly and repeatedly demonstrated (e.g. Khalisi (2021); Romanet (2023)).

Nonetheless, there are a number of ways in which the occurrence of a solar eclipse may have an indirect impact on seismicity. Firstly, the passage of the Moon's shadow across the Earth is known to have an impact on the dynamics of the planetary boundary layer and the surface illumination and temperature (e.g. Eaton et al. (1997); Amiridis et al. (2007)). In general, both wind speed and surface temperature are observed to decrease during totality (Harrison and Hanna, 2016). Although most seismometers are buried to isolate them from wind stresses as far as possible, they are never totally decoupled, and hence a decrease in measured seismic noise levels may occur as the wind speed drops.

Secondly, it is known that seismic noise levels are sensitive to human behaviour. For example, past work in urban geophysics has measured local seismic changes associated with music concerts and sports matches (Denton et al., 2018; Tepp et al., 2024); whilst global noise decreased dramatically during COVID-19 lockdowns in 2020 (Lecocq et al., 2020). As such, human behaviours which impact seismic noise levels (e.g. those associated with transport, Riahi and Gerstoft (2015)) are likely modified during an eclipse, potentially producing a decrease in noise levels.

Finally, 'hybrid' effects are also possible. For example, it is known that wind turbines produce substantial amounts of seismic noise which is detectable many kilometres away (Saccorotti et al., 2011; Stammler and Ceranna, 2016). In general, as the wind speed drops, turbine speed also drops and hence seismic noise levels will decrease. Conversely, the decrease in ground illumination during an eclipse greatly reduces the output of photovoltaic systems, necessitating the electrical grid to switch to alternative generation sources (which are generally seismically louder, as they involve more moving parts than photovoltaic systems). Similarly, other artificial structures such as buildings and radio masts are known to couple wind into ground vibrations (Hu et al., 2020), with the resulting ground excitation generally weakening as the wind speed drops. As such, mechanical equipment (especially that related to power generation) is affected by the eclipse and can indirectly cause a change in the seismic noise levels.

1.1 Aims

In this paper, we explore whether any changes in seismic noise levels were observed across the North American continent during the 2024 total solar eclipse. We will compare stations within the totality band to those outside of it, and urban stations to rural ones.

2 Data

2.1 The 2024 April 8 total solar eclipse

The 2024 April 8 total solar eclipse (also known as the ‘Great North American Eclipse’) was a magnitude 1.0566 occultation of the Sun by the Moon that occurred during Saros Cycle 139. The path of totality began over the open Pacific, making landfall in the Mexican state of Sinaloa at 17:07 UTC (11:07 local/UTC-6).

Tracking north-east, the totality centreline crossed the United States-Mexico border in south-west Texas. Within the US, totality was also visible from parts of Oklahoma, Arkansas, Missouri, Illinois, Kentucky, Indiana, Ohio, Pennsylvania, New York, Vermont, New Hampshire, and Maine. The totality centreline crossed the Canada-United States border a number of times in Ontario and Quebec before reaching New Brunswick; with Canadian totality also including parts of Nova Scotia, Prince Edward Island, and Newfoundland and Labrador. The path of totality ended in the North Atlantic Ocean. The eclipse paths used in this paper were calculated by NASA’s Scientific Visualisation Studio (NASA SVS et al., 2023).

A number of major population centres lay within the path of totality, including Mazatlán, Montréal, Dallas, San Antonio, Austin, Little Rock, Indianapolis, Cleveland, Buffalo, and Rochester. However, not all of these cities host urban seismometers from which data was accessible.

2.2 Seismic data

Our analysis makes use of broadband and high-frequency seismic data from the Canadian, Arkansas, Kentucky, Lamont-Doherty (New York), New England, New Madrid (Missouri/Tennessee/Arkansas), Ohio, Oklahoma, Pennsylvania State, and Texas seismic networks. No station on the Mexican National Seismic Network experienced near- or complete- totality, though numerous stations in Texas are located close to the border, and hence are also sensitive to seismic activity in Mexico.

Instrument responses were removed and data were high-pass filtered above 20 s to remove deconvolution artefacts. In our analysis, we consider the vertical component of ground velocity. Data for each station were downloaded for a five hour window, from 15:50 UTC to 20:50 UTC, for each day in April 2024 (i.e. for a maximum of 150 hours of data per station, assuming uninterrupted data for each day was available). This time interval was chosen to correspond to the entire passage of the Moon's shadow over the continent on April 8, and this date range was chosen to provide a baseline for comparison. Although the eclipse occurred on a Monday, we do not exclude weekends from our analysis, as at many stations no distinction in noise levels between weekdays and weekends was apparent. Days with non-continuous data in this 5 hour window were discarded, and stations where data for April 8 was non-continuous were also discarded in their entirety.

For each station, the five-hour interval was divided into ten-second windows with 25% overlap between windows. This procedure produces 2,400 unique windows per station per day, each containing 7.5 s of unique data and 2.5 s of data overlapping with the previous window. In each 10 second window, the median power spectral densities were calculated for April 8, and the ratio of these to the mean for all days in April within the same 10 second window was taken.

In total, 251 stations met the quality checks described above. This produces in excess of 10,000,000 unique 10 second windows for all of April across the entire network, and 602,400 individual comparisons of the noise level on April 8 to that on other days in the month.

For completeness, we note that of course a number of earthquakes occurred in April 2024. These include an M 4.4 earthquake near Stanton, Texas, on April 10, and a M_w 4.8 quake in New Jersey on April 8 (Boyd et al., 2024), the latter of which attracted substantial attention. There is no reason to link these events to the eclipse in any way, but some of them occurred between 15:50 and 20:50 UTC and hence elevate our background noise for the rest of the month. We cannot meaningfully remove all earthquakes from our dataset, but their effects are diminished because we evaluate median rather than mean or peak power spectral densities within each 10 second window. Nonetheless some, especially the Texas event, are noticeable in the animations presented in the supplement. Fortunately, this event occurred after the time of totality so does not interfere with our measurements of seismic quietening during totality itself.

3 Results

3.1 Noise levels at individual stations

We begin by considering the noise levels at a variety of individual stations, both inside and outside the path of totality and in urban, rural, and semi-rural environments. They have been chosen as a representative sample from across North America, and are shown in Fig. 1 for a five-minute window commencing at the start of totality or maximum eclipse, as appropriate. This duration is chosen as it is sufficient to encompass the entirety of totality at TX.FW04 (Dallas, TX), which is the longest of any station shown at approximately 4 minutes.

Panels 1**A)** to 1**D)** are for four stations in the path of totality. **A)** to **C)** are within the major metropolitan areas of Dallas, Cleveland, and Montréal respectively. The totality period is observed to be considerably quieter than the monthly mean across all frequencies, and the quietest in all of April across most frequencies. The greatest difference between the totality power and the mean power is at Cleveland, where an almost order-of-magnitude quietening (-8 to -9 dB at 10 Hz) is observed.

Conversely, panel 1**D)** shows data from a seismometer located within a very rural area near Duxbury, Vermont,

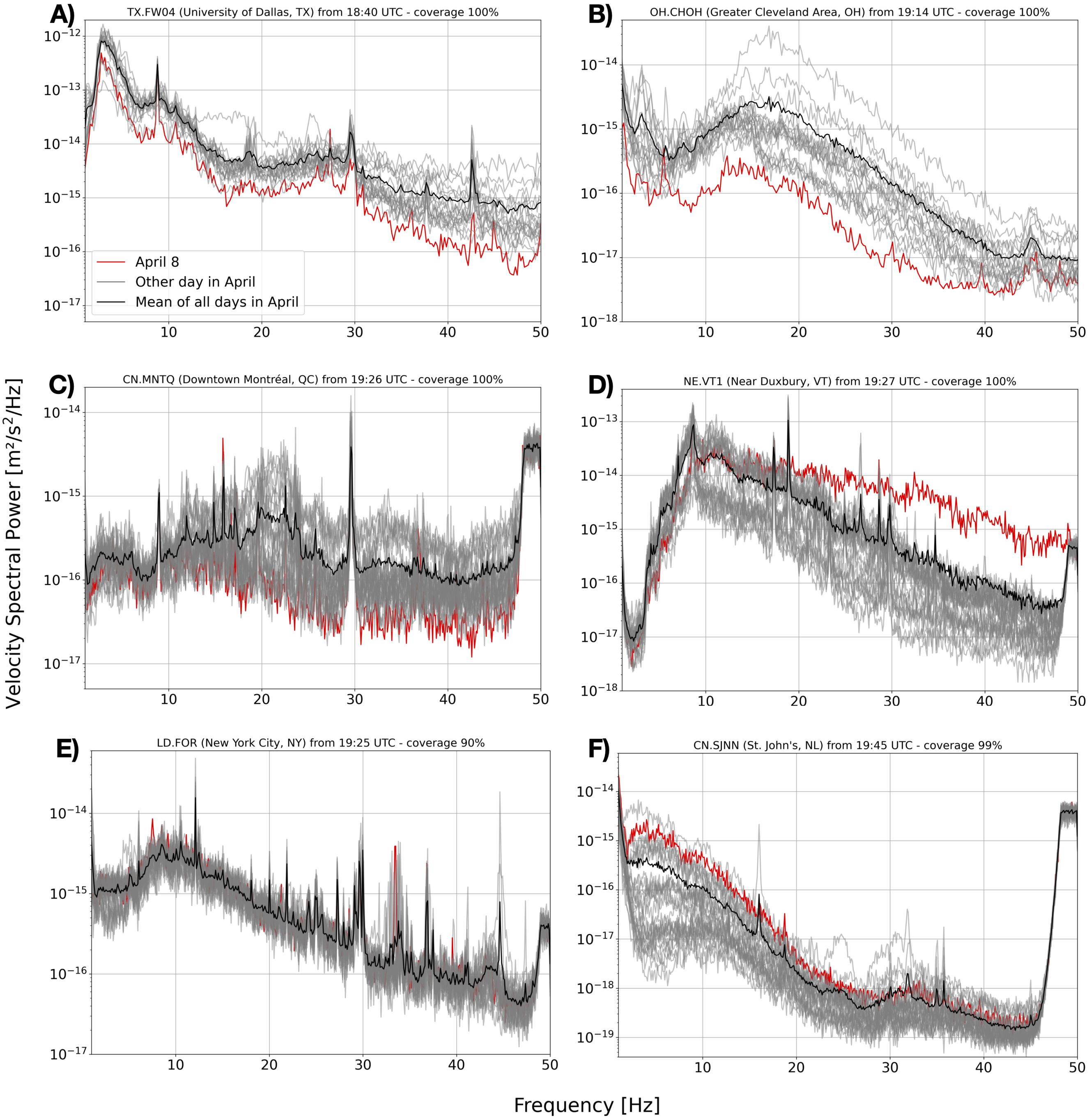

Figure 1 Median velocity spectral power for a five-minute window commencing at the start of totality (panels **A)** to **D)**, stations within totality) or maximum eclipse (panels **E** and **F)**, outside totality). Red lines are the spectral power on April 8, grey lines are other days in April, and the black lines are the mean of all days in April with data available. Data are shown between 1 and 50 Hz to highlight bands in which anthropogenic and wind noise are expected to be strongest. Note that instrument responses, environmental noise floors, and sensitivity ranges are not the same for all instruments and hence different vertical scales are used on each panel, and different roll-offs are observed.

though in proximity to interstate I-89. Above 20 Hz (where vehicular-generated seismic noise is strongest, Meng et al. (2021)), the period of totality is considerably louder than all other days in April, by around 10-12 dB. We consider that this is likely due to significantly increased vehicular traffic in the area specifically due to the eclipse, as noted by local press outlets in Vermont[1,2].

Panels 1**E)** to 1**F)** show data from two areas outside the path of totality. **E)** shows data from The Bronx, in New York City, where solar obscuration was approximately 90%. The period of maximum eclipse is indistinguishable from other days in April, indicating no significant seismic quietening. In a large metropolis such as New York City, we consider that there are a number of contributing causes to this. Firstly, many mechanical and transport systems likely continued to operate during maximum eclipse, including those running underground which are more strongly seismically coupled to the solid Earth and hence are responsible for a disproportionate amount of seismic noise. Secondly, at 90% solar obscuration, sky darkening is still challenging to perceive with the human eye. As such, human behaviours are likely much less strongly modified than within cities experiencing totality.

Panel **F)** shows data from a seismometer located within an urban-rural area outside of St. John‘s, Newfoundland. At this site, solar obscuration is near total (>99%). In the 1-30 Hz band April 8 is somewhat louder than the April mean, but not significantly so. Between 30 and 50 Hz it is effectively indistinguishable from the monthly average. The fact that April 8 is not significantly different from any other day is likely attributable to this station's semi-rural location (on the edge of a major city but not in close proximity to major transport links), and the fact that it is extremely close to the coast. As such, background noise levels are likely determined not by anthropogenic factors but rather by environmental processes which are not significantly modified on the timescales of the eclipse.

3.2 Temporal evolution of noise levels

Next, we consider the temporal evolution of noise levels during the eclipse. It is important to note that in general, anthropogenic seismic noise is variable on many timescales (diurnal and sub-diurnal). We do not perform any smoothing other than using a 25% overlap in our 10-second noise calculation windows, and hence noise 'spikes' are still present on a variety of timescales. Snapshots of an animation showing quietening 'propagating' across North America in the wake of the Moon's shadow are shown in Fig. 2. The full animation (in which the temporal evolution of the signal is clearer) is available online: https://tinyurl.com/eclipseseismic.

A more detailed plot of the temporal evolution of the noise floor for the stations shown in Fig. 1 are shown in Fig. 3. Stations outside totality show no clear temporal trend and hence we omit them here.

At the stations in Dallas and Montréal Fig. 3**A)** and **C)**, we observe a similar pattern. Prior to the onset of the eclipse, noise levels are similar to the monthly average. After first contact, we notice a slight loudening, which lasts around 30-45 minutes. This is followed by a substantial quietening down to the point of totality, during which noise levels are signficantly depressed. Noise levels remain below average following totality for around 15-30 minutes, before increasing to higher than monthly average levels. We consider that this likely corresponds to an influx of visitors and traffic, and hence higher noise, early on in the eclipse; followed by reduction in anthropogenic activities

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[1] https://www.burlingtonfreepress.com/story/news/2024/10/28/vermont-total-solar-eclipse-spending-millions-tourism-foliage-leaf-peeping/75840608007/

[2] https://www.manchesterjournal.com/business/aprils-eclipse-boosted-vermonts-economy-but-it-was-no-match-for-foliage-season/article_9043c756-953c-11ef-9446-dba2eddc1205.html

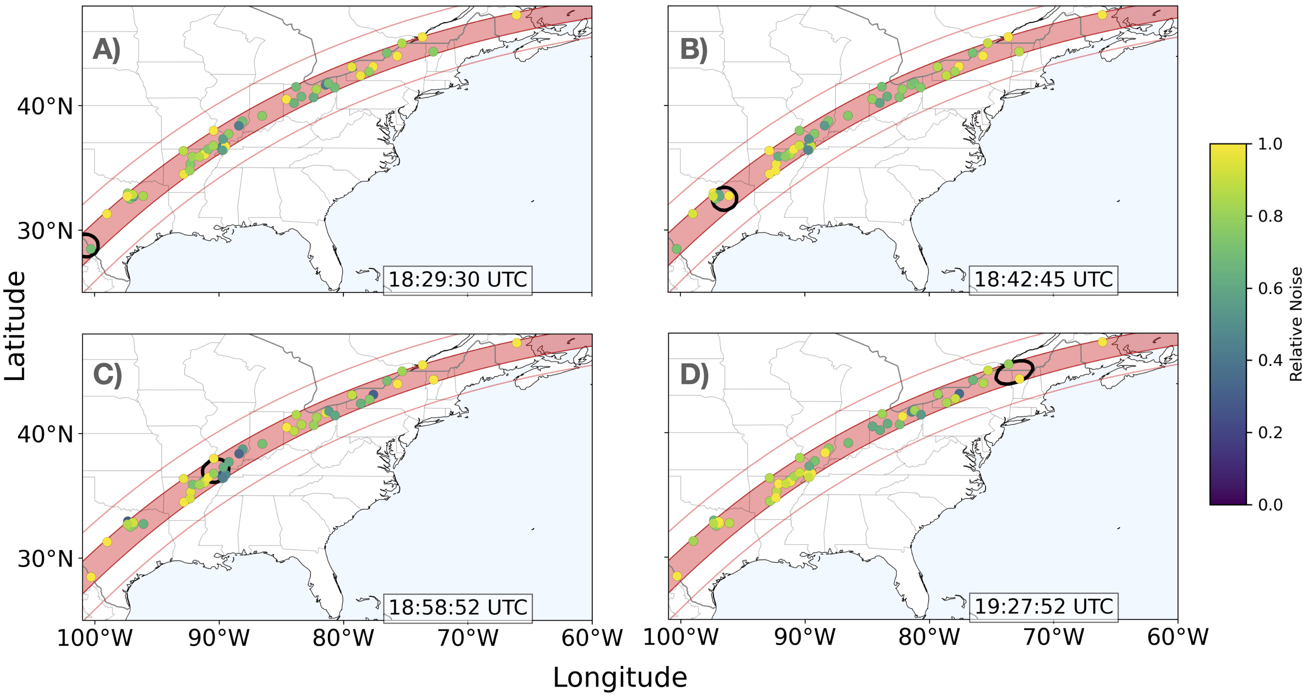

Figure 2 Noise levels as recorded across the United States and Canada. Only stations within the path of totality itself (red band, red lines are 95% obscuration limits) are shown, and the black polygon indicates the position of the Moon's shadow projected onto the Earth's surface. **A)** shows the network at the point at which the Moon's shadow crosses the Mexico-United States border, and the first station moves into totality, whilst **B)** shows the network with the Moon's shadow directly over Dallas (including station TX.FW04, which is shown in Fig. 1). **C)** shows quietening over the central part of the New Madrid Seismic Network. **D)** shows the Moon's shadow shortly before it departs the Earth, over the St Lawrence Seaway. Slight quietening at CN.MNTQ in Montréal is noted, whilst NE.VT1 in Vermont is louder than average, as previously discussed. The full animation is available online: https://tinyurl.com/eclipseseismic. Note that the colourscale in these plots saturates at a value of 1.0 (i.e. bright yellow hues indicate noise at or above the mean for April).

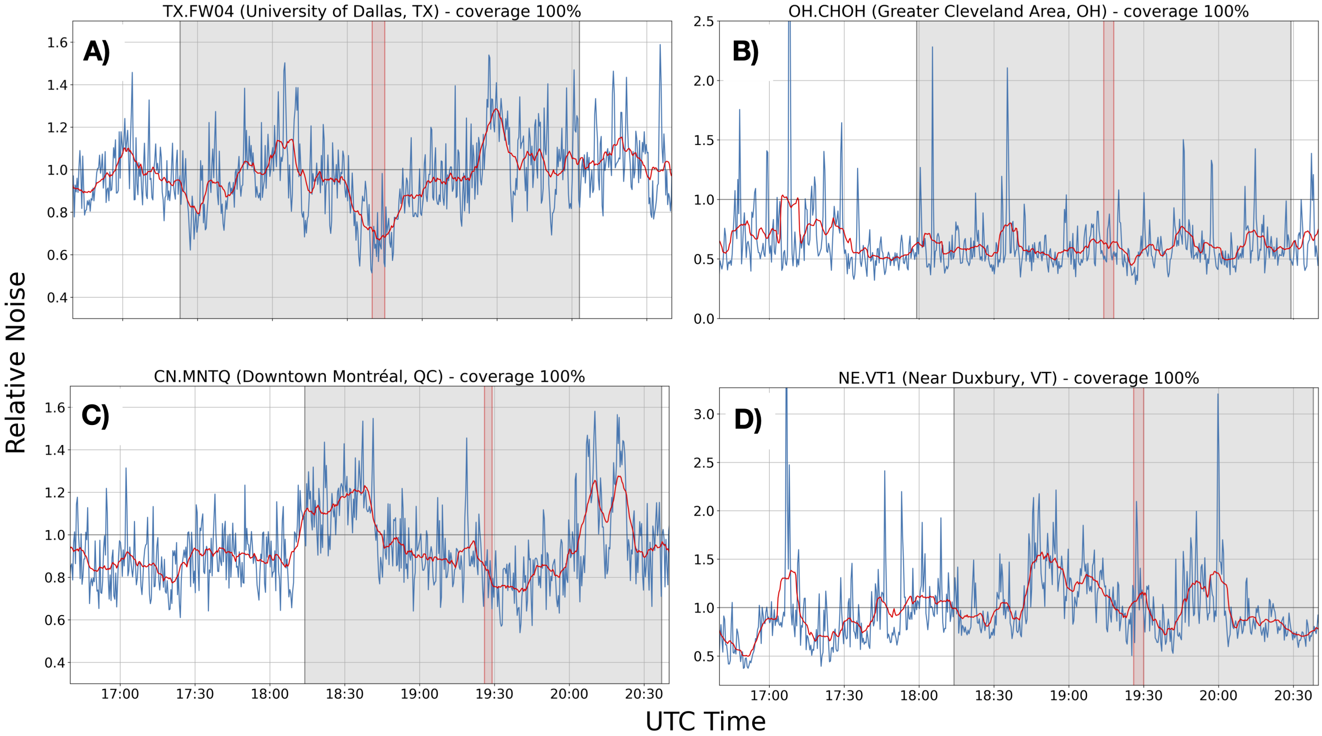

Figure 3 The evolution of the noise floor for the four stations shown in Fig. 1: **A)** in Dallas, Texas, **B)** in Greater Cleveland, Ohio, **C)** in Montréal, Quebec, and **D)** near Duxbury, Vermont. The grey shaded area corresponds to the time window of partial eclipse, between first and fourth contact (i.e. when the Moon is covering some portion of the Sun). The red shaded area corresponds to totality. The red line is the 10-minute rolling-averaged noise. Note that different vertical scales are used on each panel.

around totality. Following totality, increased traffic from departing observers likely results in higher-than-average noise levels for the remainder of the partial eclipse.

At the station near Duxbury (Fig 3**D)**, noise levels prior to eclipse onset are higher than average. A loudening following first contact is clear, similar to at Montréal and Dallas. A slight drop in noise levels toward totality is evident, though at the time of total obscuration we actually notice a peak. The post-totality loudening is also observed. Exactly why this station is different is not clear, but a number of possible eclipse-related reasons are possible, for example last-minute traffic associated with trying to find a better viewing position or a break in the clouds.

At Cleveland (Fig 3**B)**, no clear rise and fall in noise levels is evident, though the variability of the noise is clearly reduced during totality. Given that the whole period considered is significantly below the monthly average, we consider that this may be due to people modifying their behaviours for the entire day of the eclipse, rather than just around totality.

4 Conclusions

We analysed seismic data from over 250 seismometers located across North America during the April 8, 2024 solar eclipse. Seismic quietening was observed in cities within the path of totality continent-wide, with up to an order-of-magnitude reduction in velocity power spectral density levels as compared to the rest of the month's background.

Conversely, more rural stations saw little to no change in noise levels, indicating that decreased anthropogenic activity (e.g. reduced transportation and machinery operation) rather than modified surface temperature or planetary boundary layer dynamics were responsible for quietening in urban areas. Some exceptions were noted in remote locations, in particular in those areas where media reported increased tourist and vehicular activity from eclipse-chasers; in these locations substantial seismic loudening was observed.

We also acknowledge the effects that weather likely had on direct anthropogenic noise generation during totality. We suspect that in urban regions where conditions were inclement and the eclipse was clouded-out, the departure from normal noise levels was less significant than in regions where conditions were optimal and behaviours were more strongly modified. However, due to the patchiness of mid-to-high altitude cloud over North America on April 8, it is challenging to quantify this. It is also possible that the weather impacts were more significant outside of the totality band than within it; as audiences within totality were likely more committed to attempting to view the eclipse, and more likely to have modified their behaviours (and hence their noise-producing activities) in anticipation.

The observed continent-wide seismic quietening in urban areas and unchanged seismic background noise in most rural areas also allows indicates that no increase in tectonic seismicity occurred around the sub-lunar/sub-solar point on the Earth's surface due to the eclipse. Leaving aside that the response of the solid Earth to the gravitational attraction of the Sun and the Moon (the solid body tides) is complex, non-uniform across the Earth's surface, and non-instantaneous, our results do demonstrate that no 'triggering' of earthquakes occurred as a result of these three bodies being exactly aligned. This is entirely commensurate with numerous past studies which find no statistically meaningful correlation between global earthquakes and celestial alignments; but with the problem approached from the opposite direction wherein we examined seismic activity during an exact Earth-Moon-Sun syzygy (the alignment which has the maximum impact on the stress variation within the solid Earth). This constitutes an additional piece of evidence that celestial alignments have no impact global-scale impact on earthquake occurrence.

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Data and code availability

Eclipse shapefiles were sourced from the NASA Scientific Visualisation Studio (https://svs.gsfc.nasa.gov/5073) and processed using Shapely (Gillies et al., 2007).

Seismic data were sourced from the Canadian (Natural Resources Canada, 1975), Arkansas (no DOI), Kentucky (Kentucky Geological Survey/Univ. of Kentucky, 1982), Lamont-Doherty (New York, Lamont Doherty Earth Observatory (LDEO), Columbia University (1970)), New England (Albuquerque Seismological Laboratory (ASL)/USGS, 1994), New Madrid (no DOI), Ohio (Ohio Geological Survey, 1999), Oklahoma (Oklahoma Geological Survey, 1978), Pennsylvania State (Penn State University, 2004), and Texas (Bureau of Economic Geology, The University of Texas at Austin, 2016) seismic networks. Data were accessed through IRIS https://www.iris.edu/hq/ and processed using ObsPy (Beyreuther et al., 2010) and NumPy/SciPy signal processing routines (Virtanen et al., 2020; Harris et al., 2020). Maps were made using Cartopy (Met Office, 2010 - 2015) and Matplotlib (Hunter, 2007).

Competing interests

The authors declare no competing interests.

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