The seismic signature of rain

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SUMMARY

Rain has long been a problem for land seismic surveys. I measured the seismic signature of rainfall using both water dripped from height using a pipette, and natural rain in Winchester, England, over a three month period. My results showed that rain noise is concentrated at frequencies above 80 Hz with a detectable range of less than 1 m. Drops of water landing directly on a geophone result in events with amplitudes nearly 30 times larger than those landing next to the geophone. Items placed on the surface of the ground, such as cables, absorb the energy of the impact and reduce the level of the resulting seismic noise. Burying geophones results in attenuation of rain noise by between 7.7 and 8.6 dB/0.1 m. But, given the effort required to bury geophones, it is likely that data processing algorithms, or the placement of vibration absorbent matting, are likely to be the preferred strategies for dealing with noise.

Key words: Rain, land seismic, noise.

INTRODUCTION

Participants in land seismic surveys soon discover the importance of weather to the success of their survey and, their own personal comfort; a fact acknowledged in one of the first articles published in Geophysics (Ransone 1938). Of particular concern is rain because after significant rainfall the ground can become saturated making logistics far more difficult and changing the nature of the surface affecting 4D and microseismic surveys. The impact of the droplets on the ground produces seismic noise, reducing data quality even after the data is stacked (Brittan et al. 2008, Normark 2011). Despite its potentially serious impact, I am not aware of any studies directly measuring the seismic signature of rain (rather than its effects).

Each raindrop hitting the ground will act as a small seismic source. Rainfall varies, both in the number of drops falling and their size. The amount of energy imparted into the ground by the impact of a drop will be largely governed by the drop's size and speed. Larger drops should result in larger seismic events due to their increased mass; but, in addition, larger raindrops also fall faster (Laws 1941); thus the resulting seismic signature, would increase beyond the level expected just from their mass. The size of a raindrop is directly proportional to the intensity of the rain (Laws and Parsons 1943), thus the seismic noise resulting from rain should increase considerably depending on the rainfall rate due to larger drops and higher velocities.

Generally speaking the weight of an impact source is proportional to its low frequency output (Keiswetter and Steeples 1995). A spherical 2 mm diameter drop with a mass of approximately 4.2 mg, falling at a typical terminal velocity of 10 m/s (Beard 1976) will impart just 0.2 mJ of energy. Although small, during heavy rain the density of drops can be as high as 495 /s/m^2 (Lull 1959) resulting in significant seismic noise.

METHOD

The test site was located in an open, grassed, area adjacent to a graveyard in Winchester, England (51° 3'39.42"N, 1°18'3.31"W). The thin top soil is clay-rich and overlays a layer containing large fragments of flint. Beneath this the soil becomes richer in clay with a solid layer of chalk at around 0.3 m. Data was recorded on multiple days between October 2015 and January 2016. My initial tests, aimed at determining the likely spatial extent at which raindrops are likely to cause noise, were conducted using a straight line of 12 geophones with 0.1 m spacing. Water was then dropped onto the ground from a height of 2.5 m using a pipette. Measurements of natural rainfall were made using a grid of 12, 0.2 m spaced 10 Hz geophones. To determine the effects of burial depth on rain noise the geophones were later buried at depths of 0.1, 0.2, and 0.3 m (Figure 1).

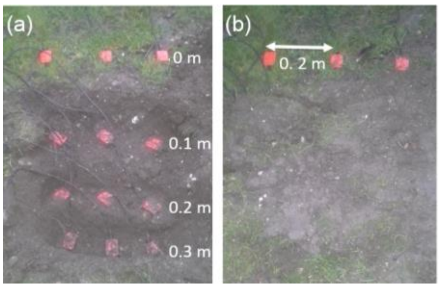

Figure 1: Geophone configuration used to test the effects of geophone burial on rain noise before (a) and after (b) burial and compaction.

PROCESSING

The only processing applied to the data was to count the number and magnitude of the small seismic events resulting from raindrop impact to gain an indication of rainfall rate and drop size.

RESULTS

Figure 2a shows a record acquired when water was dripped next to the center of the geophone line. The impact of the drop of water is clearly evident, as is its moveout. The absolute value of the maximum amplitude normalized by the maximum amplitude of the central geophone, the rms of the normalized traces in the time window above (containing no drops) and the resulting S/N, are shown in Figure 2b and c respectively. Although the amplitude is significantly higher than the noise level near the impact position it drops relatively rapidly. This can be seen more clearly on Figure 3, which shows the amplitude decay vs. offset. Beyond an offset of between 0.8 and 1 m the impact of the drop is no longer visible.

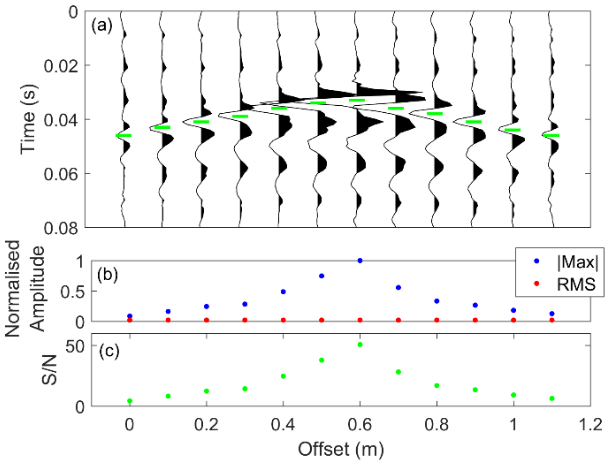

Figure 2. Example record when water was dropped near the center (offset = 0.6 m) of a line of 0.1 m spaced geophones. The green lines on the wiggle plot show the times picks whose normalized amplitudes and S/N are shown below.

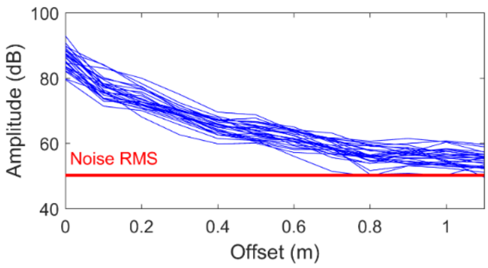

Figure 3. The decay in amplitude of water drops impacting the line adjacent to the first geophone (offset = 0). The red line indicates the rms of the noise (measured when water was not being dropped).

Figure 4 shows the traces recorded by two geophones, when water was dropped next to the geophone, onto the geophone, and onto a cable running next to the geophone. When water was dropped next to the green geophone the amplitude averaged 2.1 times that measured at the red geophone. When the water was dripped directly onto the green geophone the ratio increases to 29.8. Interestingly the magnitude measured at the red geophone is reduced by more than 50%, indicating that much of the energy of the drop has been absorbed during its collision with the geophone, increasing noise on the impact geophone but reducing it for the remainder. Water dropped onto the cable next to the green geophone (that runs to the red geophone), resulted in a ~40% reduction in amplitude at the green geophone. Interesting the magnitude of the events measured by the red geophone also decrease in magnitude, indicating that the cable absorbs energy from the drop but the energy is not transmitted down the cable to the red geophone.

After these initial tests were completed the geophones were laid as a grid on the surface (Figure 4d) for the recording of natural rainfall. Figure 5c and Figure 5d shows typical records obtained when it was and wasn't raining respectively. Figure 5a and Figure 5b summarize 6 hours of data recorded on the morning of 30 October 2015. On this day it rained steadily for the first 2 hours or so, and then for a brief period after 3.5 hours. Figure 5a shows the power spectral density calculated for each 16 s record. Comparing this with the total number of drops recorded (Figure 5b) we can see that the periods of rainfall coincide with increases in the spectral density between around 80 and 450 Hz. Histograms of the trace amplitudes (Figure 6a and Figure 6b) for the records shown in Figure 5c and Figure 5d respectively emphasize the extreme amplitudes resulting from the impact of the rain, when it is not raining (Figure 6b) the amplitude distribution is approximately normal, as we would expect for ambient noise (less than 0.04% of amplitude values ≥ 0.05 mV). When it is raining the proportion of amplitude values ≥ 0.05 mV increases by a factor of 56 to more than 2%. The power spectral density functions (Figure 6c) and their relative difference (Figure 6d) demonstrate that the majority of rain noise is restricted to frequencies above 80 Hz.

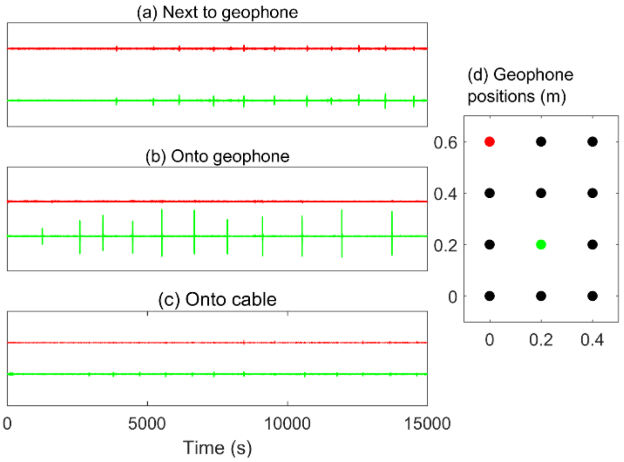

Figure 4. Example traces measured using two geophones when water is being dripped (a) next to the green geophone, (b) onto the green geophone and (c) onto the cable running to the red geophone but located next to the green geophone. The positions of the two geophones, with colors corresponding to the other plots, within the test array are shown in (d).

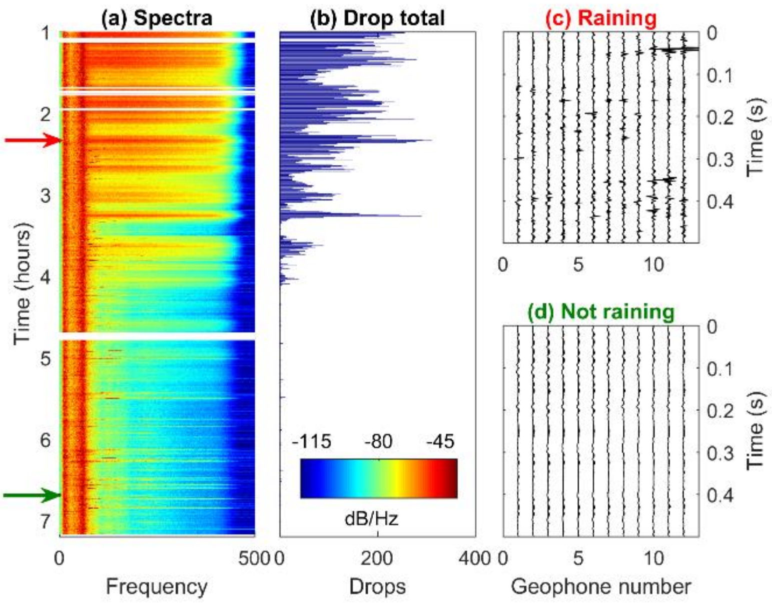

Figure 5. (a) Frequency time plot and (b) number of drops recorded, for 6 hours of data recorded on 30 October 2015. (c) and (d) show individual records where it was and wasn't raining respectively as shown by the red and green arrows on (a).

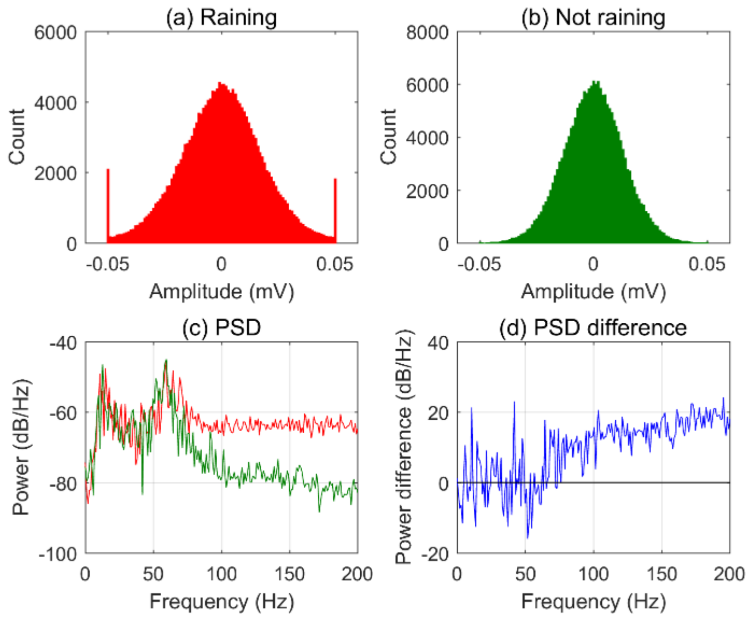

Figure 6. Trace amplitude histograms for two records when it was (a) raining and (b) not raining. (c) shows the average trace power spectral density (PSD) with the colors corresponding to those shown in (a) and (b). (d) shows the difference between the two traces PSDs.

Figure 7 shows the relationship between the average event magnitude caused by a raindrop and the rainfall rate (expressed as drops/record where each record was 16 s long). There is a clear positive trend: as the rainfall rate increases the event magnitude, indicative of larger raindrops, also increases.

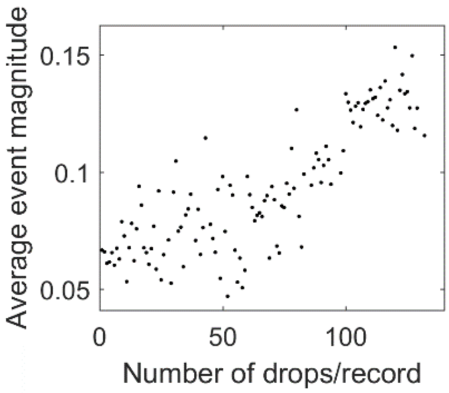

Figure 7. The relationship between average seismic event magnitude and number of drops in a 16 s long record.

Figure 8 shows frequency time plots for geophones buried at four different depths (a) through (d) as shown in Figure 1, along with the total number of drops measured by the surface geophones adjusted to give an approximate rainfall rate (e). A reduction in high frequency (>100 Hz) energy with depth is immediately obvious as is a reduction in the level of ambient noise from other sources (<100 Hz).

Figure 9 shows power spectra of three records when it was (a) and was not (b and c) raining, as indicated by the green arrows on Figure 8. For every 0.10 m of depth the rain noise (frequencies above 100 Hz) was reduced by ~5 dB (Figure 9d). Below this frequency, where other sources of ambient noise dominate, the reduction diminished with no significant difference seen at ~10 Hz. Data acquired when it wasn’t raining shows that the noise level at 4:30 am (Figure 9c, t = 29.5) was between 5 and 10 dB lower than the noise level at 4:52 pm, irrespective of the burial depth.

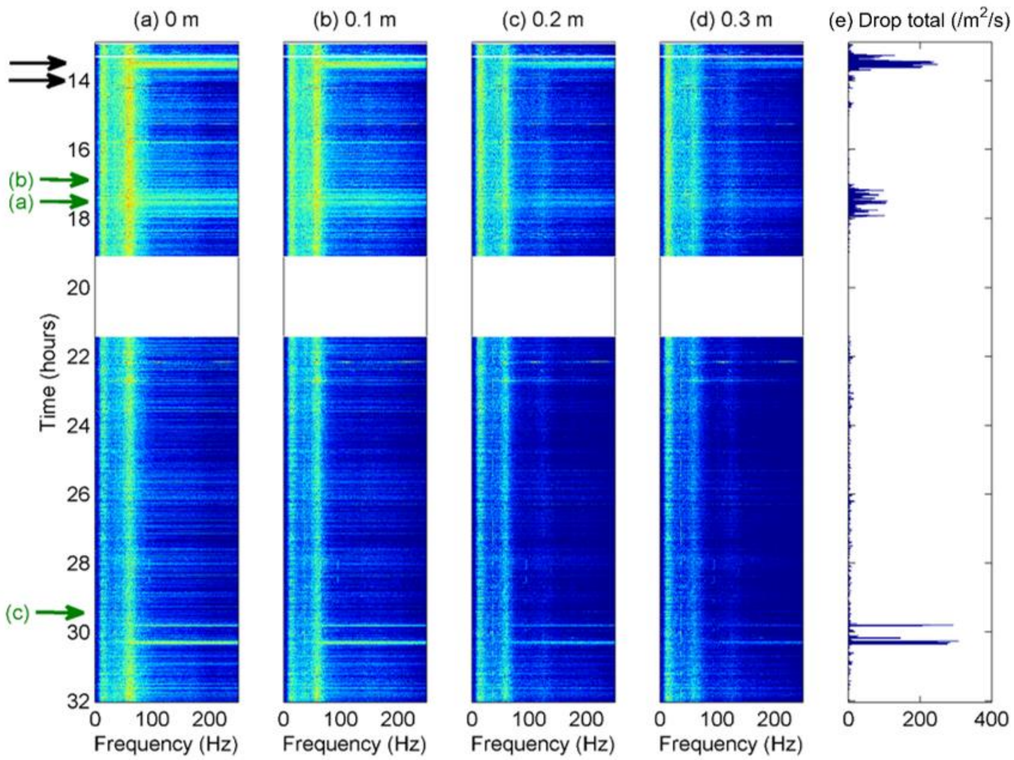

Figure 8. Frequency time plots for geophones at four different depths as indicated in the titles. The black arrows the data shown in Figure 10.

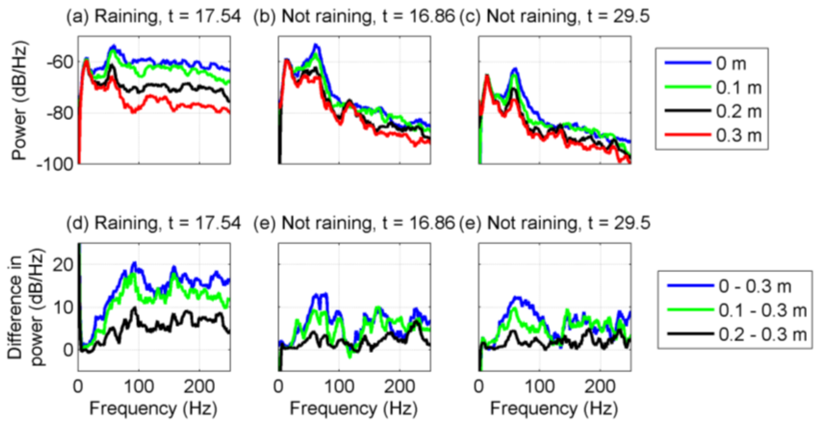

Figure 9. Comparisons of the mean power spectra of geophones buried at four different depths for three different times.

Figure 10 shows the power spectra for four different geophone depths when it was (t = 13.5 hours) and wasn't raining (t = 14.06 hours), as indicated by the black arrows on Figure 8. As the burial depth increases the frequency at which rain noise becomes appreciable (i.e. when the difference shown in Figure 10e to h is appreciably greater) also increases, at 0.1 m this occurs at ~60 Hz but at 0.3 m it is ~125 Hz.

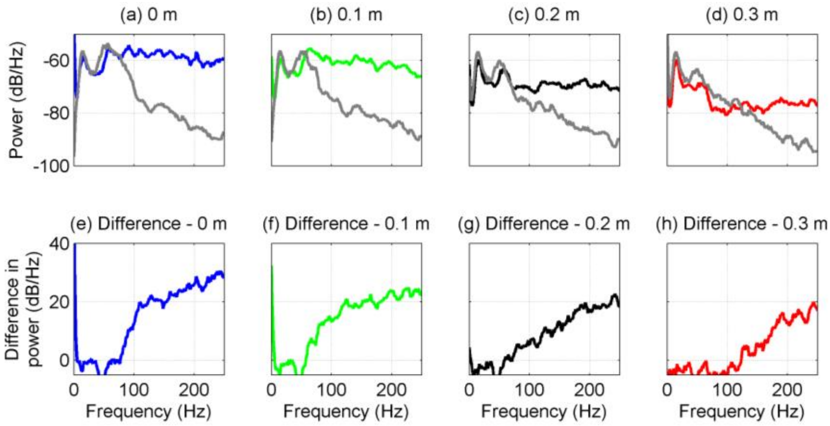

Figure 10. Average power spectra for geophones at four different depths. The grey line indicates the result when it wasn't raining (t = 14.06 hours) and the colored line when it was (t = 13.5 hours).

Figure 11 shows data acquired over two days in January 2016. The PSD difference plots show the average difference in the PSD between 100 and 200 Hz for each 10 cm of burial. The greatest improvement, averaging around 12 dB, is obtained by burying the geophones at 0.1 m. Increasing the depth by a further 0.1 m makes little difference (averaging 3 dB) but increasing the depth to 0.3 m resulted in an additional 10 dB reduction.

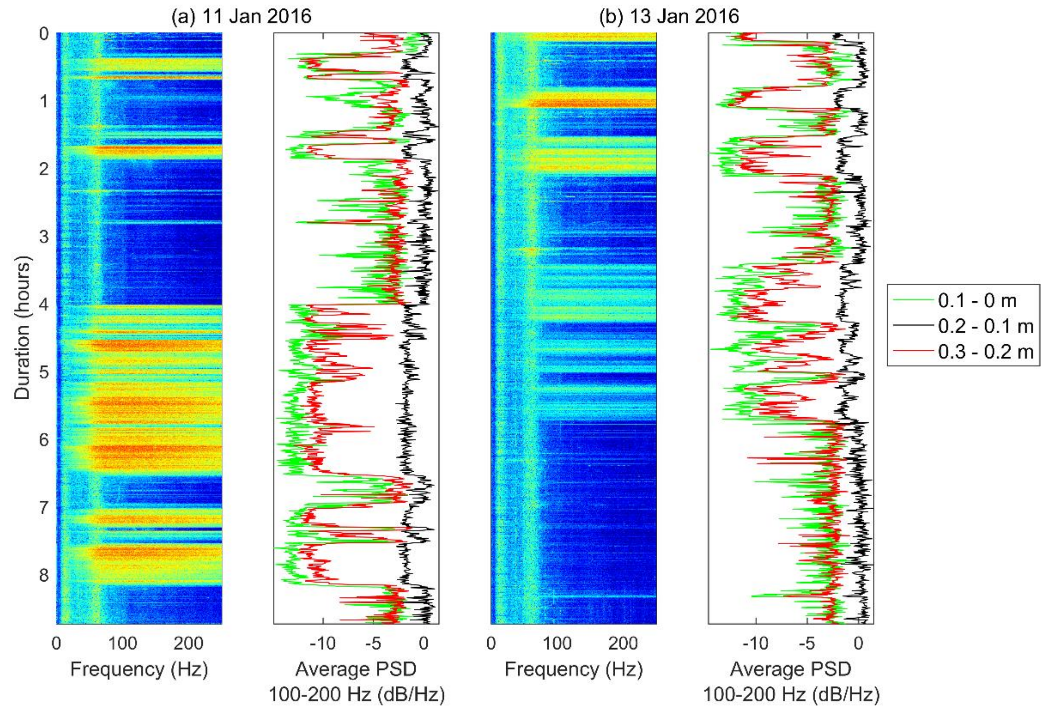

Figure 11. (a) Average frequency time plot for the three surface geophones, (b) the average power between 100 and 200 Hz for the geophones at different depths, and (c) the difference between the power spectra.

Figure 12 is a scatter plot showing the relationship between the level of noise attenuation achieved by burying the geophones at 0.3 m calculated between 100 and 200 Hz and the average noise level (again calculated between 100 and 200 Hz) at the surface, a proxy for rainfall level. The maximum attenuation ranges from 23 to 28 dB for the heaviest rain equivalent to 7.7 to 8.6 dB/0.1 m. As the rain decreases then the level of attenuation is reduced.

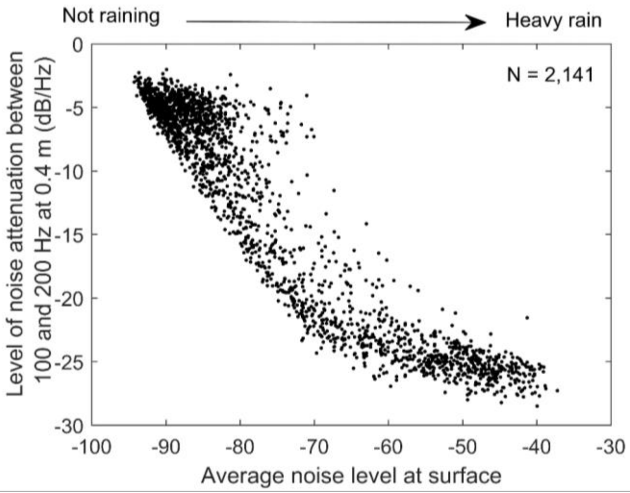

Figure 12. Scatter plot showing the relationship between the level of noise attenuation achieved (an average of the reduction in the PSD between 100 and 200 Hz) and the average noise level at the surface (a proxy for the level of rain).

DISCUSSION AND CONCLUSIONS

My results confirm the observations of other authors (Brittan, Pidsley, Cavalin, Ryder and Turner 2008, Normark 2011) that rain can be a significant source of noise. The spatial extent of the noise caused by an impacting drop is of the order of 0.8 m, so it is unlikely that the impact of individual raindrops will be recorded on more than one trace.

The noise resulting from water falling directly onto the geophone casing is around 30 times that when the drop of water falls next to it. Given the size of a geophone casing we would expect such an impact every 2.2 s during light rain and 1.3 s for heavy rain. The impact energy is reduced if the drop lands on another object (e.g. the cables) which suggests that acoustic dampeners, as suggested by Monk (2008), have promise for reducing rain noise.

In agreement with the results of Olhovich (1964) and consistent with marine studies (Scrimger et al. 1989), most of the rain noise occurs at frequencies above 80 Hz. This implies that its removal may be as simple as the application of a band-pass filter. More advanced, de-spiking techniques are also likely to be successful given the highly localized, high frequency, nature of rain noise. In agreement with previous rainfall studies (Barclay and Buckingham 2013, Ma et al. 2005, Nystuen et al. 1993) I found that the heavier the rain, the larger the raindrops (and the resulting seismic noise) resulting in the relationship between rainfall rate and seismic noise being non-linear (Figure 7).

Burying geophones is effective at reducing rain noise, a decrease of between 7.7 and 8.6 for every 0.10 m of depth being obtained. Even at 0.30 m, however, rain noise was not completely attenuated. The reader is cautioned, however, that attenuation did not increase linearly with depth, likely a result of the soil profile. For this reason a similar set of measurements are recommended before a decision is made to bury geophones to avoid rain noise on a full survey. Although burial is effective, processing the data, or covering the geophones with absorbent material, are likely to be the preferred approaches due to the effort involved in burying large numbers of sensors.

Rain during a seismic survey can result in the generation of levels of seismic noise considerably higher than the signals we hope to record. These results, however, offer encouragement that rain need not prevent the acquisition of seismic data. Although not tested here, numerous data processing algorithms offer the ability to remove the short duration, high frequency, spatially-limited, noise resulting from rainfall. If not successful, then deployment strategies such as burial and the placement of vibration absorbent matting should also be effective.

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