Avoiding wind noise: How helpful is geophone-burying?

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Abstracts

Wind noise can seriously degrade seismic data quality. An experiment was designed to measure the effect of wind noise on geophones. Geophones were planted in a field and background noise was measured under a variety of wind conditions. The data show a consistent correlation between recorded noise levels and wind speed. This verifies that the experimental procedure is good for measuring wind-noise alone. Different geophone planting techniques were evaluated to determine their susceptibility to wind noise. These evaluations show that it is advantageous to bury geophones since the signal to noise ratio improves by approximately 3 dB for every 10 cm of depth. Multicomponent geophones were used in the study. The analysis of experimental data also shows that vertical elements in multicomponent geophones are about 4 dB less sensitive to wind noise than horizontal elements.

Introduction

Wind noise poses a significant challenge to acquiring high-quality seismic data. In extreme cases, strong winds can shut down seismic recording due to degradation of the signal-to-noise ratio. In areas of persistent heavy wind, additional source effort may be required to overcome wind noise. In either case, strong wind can significantly increase the cost of acquiring seismic data. It is therefore worthwhile to investigate ways of mitigating the effect of wind on seismic recordings.

In this study, we aim to relate wind-noise-susceptibility to various methods of planting geophones. An experiment was designed to answer two primary questions: Can we accurately measure, and uniquely identify wind-related noise on geophones? If so, how do wind noise levels vary with different geophone planting techniques? By observing the geophone plants that are least affected by wind noise, we can find how best to evade the wind. By making quantitative measurements of wind noise, we can relate noise susceptibility to the amount of effort needed to shield geophones from the wind. This information can help us reach a balance between geophone planting effort (cost) and wind noise level. It is hoped that knowledge gained through this experiments can be used to optimize acquisition efforts and ultimately reduce the cost of acquiring seismic data in windy conditions.

The experiment

In the simplest of terms, the experiment consists of exposing geophones to wind, and measuring the geophone output signals. The ideal experimental facility would allow us to control the wind speed while operating in an outdoor, seismically silent environment. Wind tunnels allow wind speed to be controlled, but they also generate significant amounts of vibratory noise and pose a challenge for simulating outdoor ground conditions. Our experiment uses natural wind as the wind source. Rather than control the wind speed, our apparatus allows nature to vary the wind speed. By choosing the times at which we listen for wind noise, we can get a set of observations over a wide range of wind speeds.

The experiment apparatus consisted of a Geometrics Strataview R60 system: a 60 channel 24-bit seismic recorder with internal hard-disk based storage. Additional equipment included notebook computer, three digital anemometers, and a 60-channel spread of geophones (Figure 1).

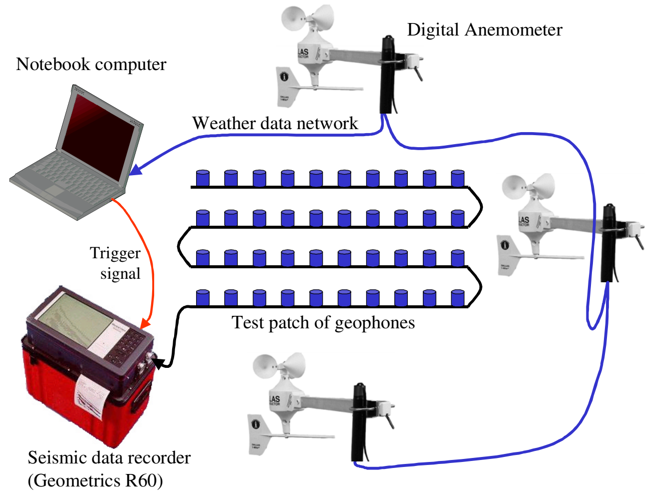

FIG. 1. Apparatus used to perform the wind-noise experiment.

A test-patch of geophones was deployed in a 20m x 16m area. Though some tests were performed on single-component marsh geophones, we shall limit our discussion to the 3-C geophones present on the spread. Oyo Geospace GS20DM geophones were spaced approximately 2m apart and the geophone lines were spaced approximately 4m apart. We wanted to keep the test-patch small, so that the wind would not vary greatly over the area of the test patch. At the same time, we wanted to include sufficient space between geophones so that wind noise generated on one geophone would not be detectable on adjacent geophones.

The 3-C geophones were deployed in holes of differing depths. Some holes were back-filled with soil, while others were left open to the air. Hole-depths varied between 5 cm and 50 cm. All the holes were dug with a shovel, and made as small as practical.

FIG. 2. Three anemometers were setup at the field site to monitor wind speed. Once configured, the anemometers were distributed around the periphery of the test area (visible in the background) and adjusted to stand 30cm above the ground.

Three anemometers were placed around the periphery of the test-patch. The anemometers measure wind speed at a height of 30 cm above ground level. It is customary to measure wind speed at a height of 10 m above ground level. By measuring wind speed near the ground, we can be certain that the measured wind speed is representative of the wind that impinges on the geophones and surrounding ground. The anemometers were supported by standard laboratory retort stands (Figure 2). To address concerns that the anemometers and the retort stands might generate their own noise, we placed them at least 3m away from any of the test geophones.

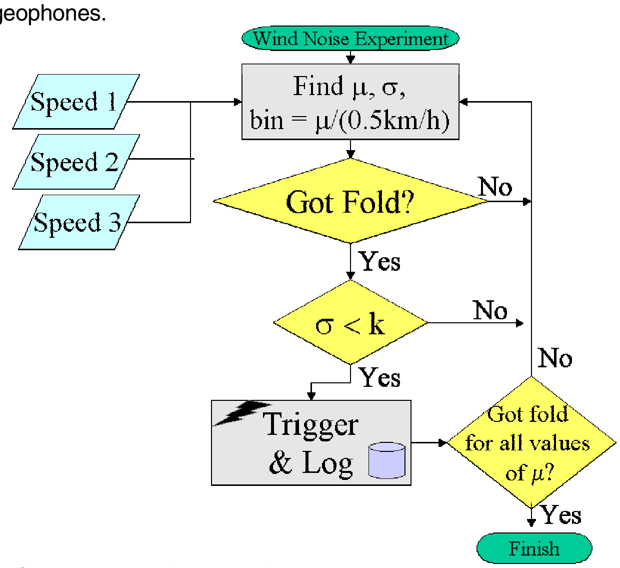

FIG. 3.Flowchart for the software that monitors the anemometers and triggers the recording geophone records. The procedure is based on the mean wind speed for all anemometers (μ) and the standard deviation between anemometer measurements (σ).

A notebook computer accessed the anemometer measurements by means of a "Dallas 1-wire" network. This network allows the computer to access the wind speed measurement of each independent anemometer. Using custom-written control software, the computer periodically queried each anemometer and analyzed the wind speed measurements. When speeds were within a desired range and were consistent between anemometers, a trigger signal was transmitted to the seismic recorder.

The seismic recorder was configured to record 512 ms long traces using a sample interval of 0.250 ms. Upon receipt of a trigger signal, the recorder would acquire and save a "shot" record to disk.

A gang of four deep-cycle automotive batteries powered all electrical equipment. These batteries allowed the experiment to run in excess of 24 hours without a hard-wired power supply. By powering the experiment with batteries we avoided background noise from generators or over-land power lines.

Procedure

A program running on the notebook computer acquired "shot" records at wind speed intervals of 0.5km/h. When 30 records were acquired at a particular wind speed range, the computer stopped acquiring records for that speed. In essence we acquire a fold of 30 with a bin width of 0.5 km/h.

The experiment was performed over a number of days. The authors paid close attention to weather forecasts and ran the experiment anytime there was a chance of winds greater than 20 km/h. Between periods of wind, the batteries were recharged, and any acquired data was downloaded from the recorder.

Results

After acquiring several days' worth of data, the data were transferred to Landmark's ProMAX seismic processing system. Trigger sequence numbers were used to associate wind speeds logged on the notebook computer, with seismic records stored on the recorder. Wind speed values were inserted into the trace headers as appropriate.

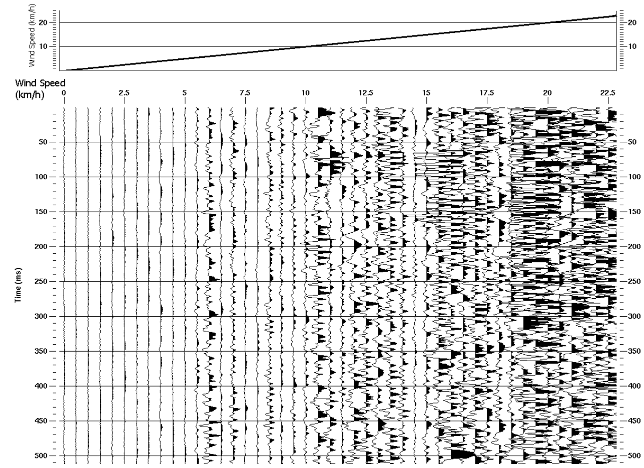

FIG. 4. Traces acquired by a single geophone element over a range of wind speeds. The equally gained traces shown an increase in background noise as the wind speed increases.

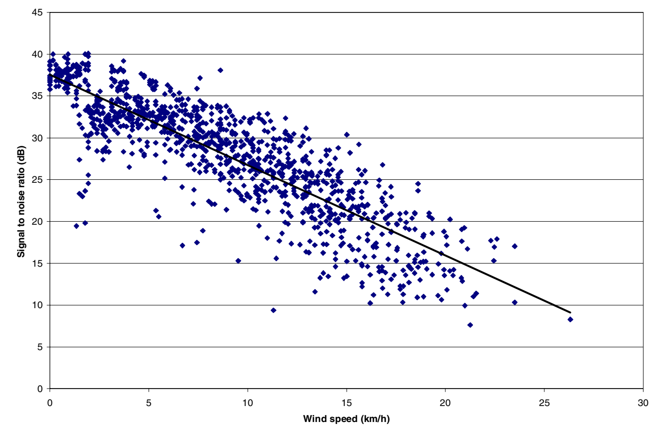

FIG. 5. Signal-to-noise ratio versus wind speed measurements obtained from a geophone buried 16.5 cm below the surface. The signal to noise ratio decreases linearly with wind speed.

One can see that the presence of noise appears to increase with wind speed. Using decibel units, and expressing the noise level as a SNR (signal-to-noise ratio), we obtain an analogous but seemingly contrary relationship: that the SNR decreases with wind speed (Figure 5). A line of best fit drawn through the data points in Figure 5 has a slope of –1.08. This means that the SNR decreases by approximately 3dB for every 3 km/h of wind.

Another way of viewing the effect of wind is to observe traces in the frequency domain. Figure 6 shows a wind speed spectrogram. Here the power spectrum is plotted for each trace using pixel darkness to indicate the power amplitude at a particular frequency. Traces are arranged from left to right in order of increasing wind speed. Since an equal number of traces are present for each wind speed (rounded to the nearest 0.5 km/h) we obtain a smooth, linear wind speed range from left to right. The figure was generated from 1020 traces acquired by a single geophone element over a period of 14 hours. There are several possible origins for the vertical stripes. Several aircraft were spotted during our experiment, vehicular traffic, and inaccurate wind-speed readings are the most likely possibilities. These stripes can be removed by stacking traces acquired with similar wind speeds..

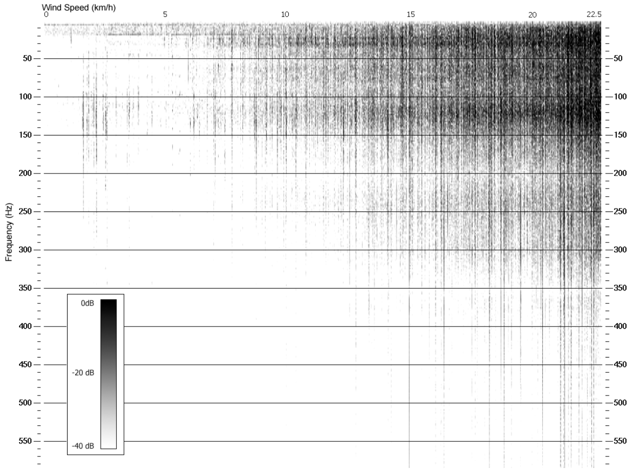

FIG. 6. Data acquired by a single receiver are displayed versus wind speed. Traces have been transformed into power amplitude values in the frequency domain. The wind speed increases from left to right and frequency increases top to bottom. Dark areas indicate the presence of noise.

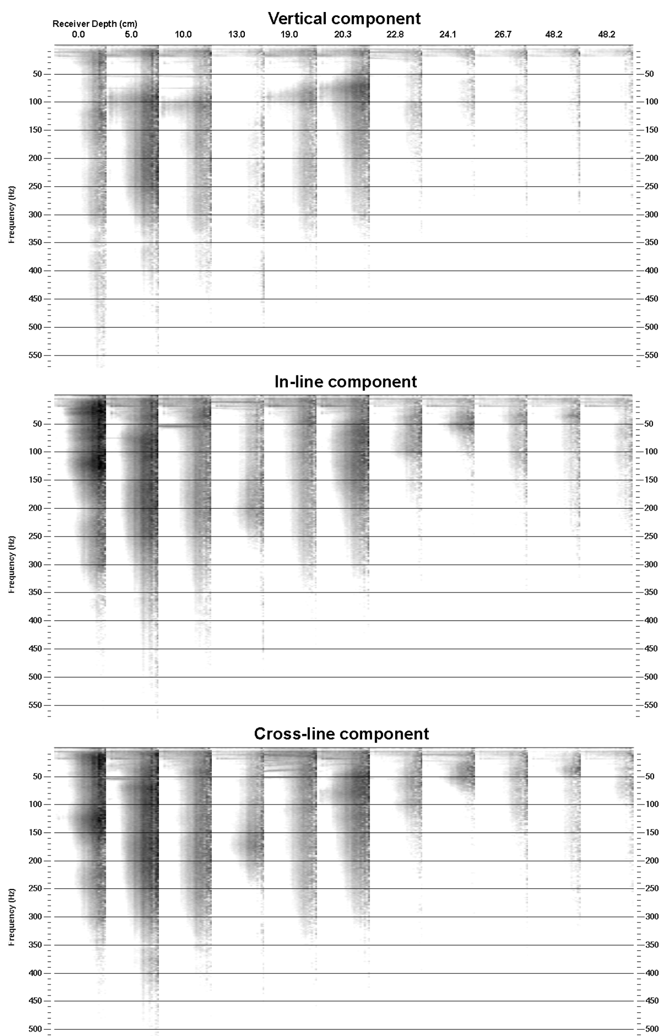

FIG. 7. A series of spectrograms for geophones at different depths. Each spectrogram is composed of power traces sorted by wind speed from 0 km/h to 22.5 km/h (left to right).

The data in Figure 6 is representative of most of the geophone elements. It is clear that noise increases with wind speed, and that there are few sources of noise other than wind. The constant sources of noise appear as horizontal lines in the spectrographs. Figure 6 shows the slight presence of noise in frequencies below 20Hz. If a number of station's spectrographs are examined (Figure 7) we see some background noise occurring around 60 and 75 Hz. We believe this noise is related to the electrical noise emitted by the recorder, computer or a distant power line. It is important to note that these narrow-band noise signals makeup an insignificant percentage of the overall noise at high wind speeds. Further analysis of the data show that we are able to isolate and measure wind noise.

Figure 7 shows a series of wind-spectrograms for geophones at different depths. Each of the three spectrogram panels correspond to the vertical, in-line, and cross-line components. Spectrograms that line-up vertically originate from the same 3-C geophone. Because all spectrograms were plotted at the same scale, it is easy to see that horizontal components contain much more wind noise than vertical elements from the same geophone. The vertical components appear to pick-up wind noise in a band centered about 150Hz, whereas the horizontal components pick-up a broader band of wind noise.

FIG. 8. Geophones were placed on the surface, and buried in holes of different depths. The figure shows holes of 18cm (top), 5 cm (right), and 0 cm (bottom).

Buried geophones

What is the effect of burying geophones? Figure 9 shows the noise reduction versus geophone depth for geophones in covered holes. We can see a linear relationship between noise reduction and geophone depth. By applying a least squares fit to the covered-hole data points, we obtain a slope of the best-fit line, and thus, an approximate noise-reduction to depth relationship: **The SNR improves by 3dB for every 10cm of buried geophone depth.** It is interesting to see that this relationship holds true for both the vertical and horizontal components. In fact, the best-fit lines run almost perfectly parallel. The two lines of best fit therefore have the same slope, but a different intercept. The difference in intercept tells us the relative wind-sensitivity difference between vertical and horizontal geophone elements. **The horizontal elements are 4dB more sensitive to wind noise than vertical elements.**

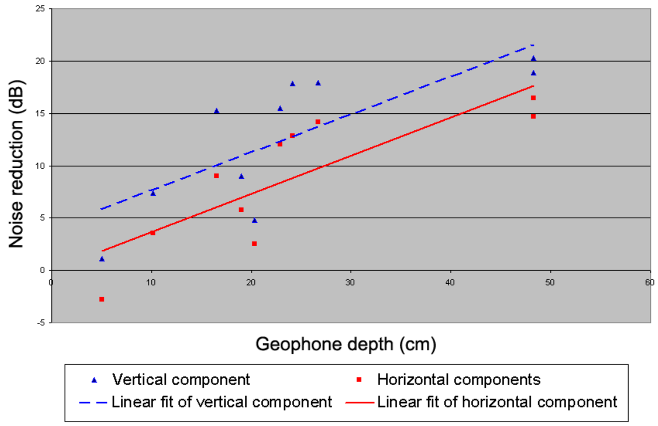

Figure 9. Noise reduction for buried geophones relative to a horizontal-component geophone planted on the surface.

Geophones in uncovered holes

Only four geophones in the test patch were placed in holes that were not backfilled and covered with soil. With so few data points for uncovered geophones, we are unable to see a definite relationship between hole depth and noise reduction. What we can say that is that in 3 out of 4 cases, geophones in uncovered holes were significantly more prone to wind noise than those covered holes of the same depth. We estimate that covering holes (and excavating geophones at the end of a shooting program) is only incrementally more labor intensive than digging the hole. Based on our limited data, we recommend burying geophones, rather than leave them in uncovered holes.

Discussion

The experiment was successful in uniquely identifying and measuring wind noise on geophones. The absence of long periods of strong wind during the three weeks of fieldwork is unfortunate. We hope to repeat these experiments in the near future, and choose a test area that is more likely to receive strong wind. The wind abating effects of different geophone plants might be easier to judge with more data points.

The experiment is subject to a number of sources of error. The anemometers indicate an average wind speed over a period of several seconds. Since the seismic recorder only records for half a second at a time, it is possible that data were acquired during brief fluctuations in wind speed. Once again, with more observations, these random fluctuations in wind speed become statistically insignificant. Another important source of error are the variations in noise sensitivity from channel to channel. For this experiment to give conclusive results, the geophone elements need to be equally sensitive, the recorder's channels need to be equally sensitive, and the geophone cabling needs to be equally susceptible (or impervious) to environmental noise. It is unlikely that this is true for our geophones and recording system. In designing the experiment we attempted to reduce these effects by duplicating as many measurements as possible and utilizing as variety of geophones / cable / recording-channel combinations. With more geophones and recording channels it may be possible to reduce these noise sensitivity variations and have more confidence in the results.

Conclusions

Multicomponent field crews are accustomed to performing in-field quality control using vertical component data. This is because the vertical component generally looks best; the radial component will normally have much lower frequency content, and the transverse component is usually devoid of noticeable events. In the face of noisy looking horizontal component data and even automated "poor SNR" warnings from acquisition computers, field crews have been known to continue shooting because the vertical component data continues looking good. This experiment has shown that horizontal components are much more prone to wind noise than vertical components. If high quality horizontal data are to be acquired, we recommend that crews monitor both vertical and horizontal shot records for excessive wind noise, and that they heed "poor SNR" warnings even if the vertical component shows little sign of wind noise.

Based on our measurements, we determined that SNR improves by 3 dB for every 10cm of buried geophone depth. We also determined that SNR improves by 3 dB for every 3 km/h decrease in wind speed. Combining these observations we can infer that to maintain a constant SNR in the face of increasing wind, one should bury geophones an extra 10 cm for every 3 km of increased wind speed. This conclusion is based on a small dataset, and additional fieldwork is required to see if this simple rule of thumb is generally applicable. We believe that we have succeeded in designing an experimental technique that is simple and effective. We look forward to seeing results of future wind related studies using the same technique.

Acknowledgements

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