

Recording wind microstructure with a seismograph

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Abstract. In an effort to characterize the effects of atmospheric waves on seismic sensors at the surface of the earth, we used geophones to perform some simple experiments allowing us to "watch" the wind. By examining the wind noise on the resulting seismograms, we were able to characterize the microstructure of atmospheric wind gusts at a horizontal scale of 1 to 10 m. In a first experiment to detect the wind-induced wave field, we placed 96 geophones on the ground in a straight line aligned parallel with the wind at intervals of 0.3 m. We recorded the resulting data using a 96-channel exploration seismograph. In essence, the seismograph system served as a linear array of 96 ground-level wind sensors. On a 1- to 2-m scale, wind-gust details became apparent after the seismograph had recorded for a period of 7.5 s. When wind-gust speeds were between 4 and 7 m/s (as measured directly from the time-and-distance relationships obtained from the seismogram), the wavelength of the gusts was between 3 and 6 m. In a second experiment, we used an array consisting of three parallel lines of 32 geophones each and were able to detect the lateral components of wind motion and turbulence relative to the long axis of the array. We noted variations in both space and time in the effect of the wind gusts on the geophones. The sensing system we describe is preliminary; however, when further refined, it may be a useful way of looking at the microstructure of atmospheric motion near the ground. The data we obtained also suggest that when models are constructed and near-ground atmospheric observations are made using grid spacings of more than 1 m, the results may be subject to serious spatial-aliasing effects. The authors offer these results in the hope that they will stimulate new, cross-disciplinary scientific inquiry. Moreover, applications of the technique might include the generation of data to support improved modeling of atmospheric turbulence at meter scales, which could be of interest to those requiring information about wind shear, wind-induced soil erosion, the dispersion of pollutants and toxins, and other subjects of interest.

Introduction

Many atmospheric movements, including wind motion, occur as wave phenomena. Wave phenomena that occur on a kilometer scale sometimes appear as cloud patterns in the troposphere. However, the types of atmospheric wave phenomena discussed here occur at ground level and can be measured on a scale of 10 m or less. In an effort to characterize the effects of atmospheric waves on seismic sensors placed on the ground, we performed some simple experiments using geophones to observe the wind in time and space.

To our knowledge, atmospheric waves whose wavelengths are a only few meters in scale and occur within a few cen-

timeters of the terrestrial surface have not been treated extensively in the literature. From the perspective of atmospheric investigations, Geiger (1966) cited several studies of wind-speed point measurements from 5 cm to several meters above the ground, but none of these examined turbulence or microstructure. Zhang et al. (1992) studied the effects of an orchard canopy on wind turbulence at above-ground heights of several meters. Wilczak and Tillman (1980) examined the three-dimensional structure of convection in the atmospheric surface layer. Paw U et al. (1992) studied coherent structures in turbulence within and above agricultural plant canopies. Finnigan (1979a, b) studied the wave patterns produced by wind turbulence in waving wheat, and the results qualitatively resemble what we found on our seismograms.

The preceding citations refer primarily to wind effects as they relate to atmospheric science, but various seismological aspects of wind noise have been noted in the literature as well. Robertson (1965) measured wind noise as a function of topography, although the pass band examined was below 3 Hz. Robertson also cited an observation by Bradford et al. (1964) stating that the coupling of wind noise to the ground at such low frequencies becomes serious when surface-wind speeds exceed 15 knots. Meidav (1969) observed that short geophone arrays, i. e., those with spacings of about 1.5 m, oriented perpendicular to the seismic line, were effective "if there is any noise source in a direction perpendicular to the line, or if there is a strong cross wind."

Map View of Field Layout for Fig. 3

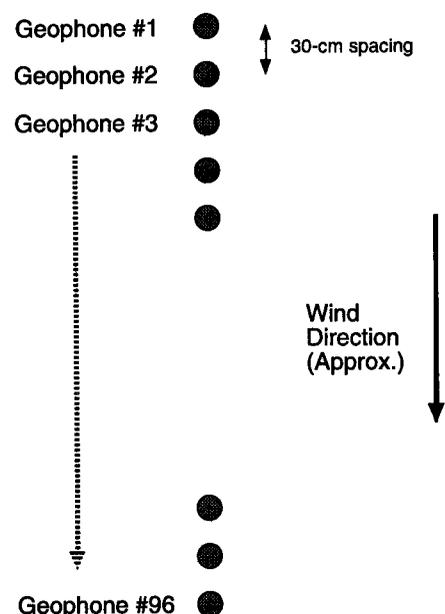


Figure 1. Field layout for the single line of geophones used to collect the data in Fig. 3.

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Research Procedures and Results

We investigated near-surface wind noise using state-of-the-art, high-resolution seismic-exploration equipment; specifically a 96-channel Bison Instruments Model 24096 seismograph with 24-bit, analog-to-digital (A/D) conversion on each channel. We performed vertical-component seismic field tests at two sites, employing two field geometries. To gather the first set of data, we placed 96 geophones 30 cm apart in a line parallel with the direction of the wind (Figure 1), set the seismograph to record for 7.5 s, and specified a sample interval of 0.5 ms on each recording channel. As an aid to interpreting the plots presented in Figures 3, 5, and 6, we have included a synthetic seismogram (Figure 2) depicting a noiseless, nondispersive, nonturbulent wind gust moving in a direction parallel to the line of geophones and having a constant wind speed of 7 m/s. The simulated data in Figure 2 are intended to help the reader recognize the extent of the wind-motion detail that can be seen in the actual data provided in Figs. 3, 5, and 6. Figure 2 assumes a linear spread of geophones similar to the one in Figure 1, but with only 48 geophones attached to the ground in a line parallel with the direction of the wind. The wind gust oscillated the air for about 3 s at each geophone location and moved progressively down the line of geophones, taking about 4 s to traverse 28 m.

During the first experiment, the wind was gusting between 4.5 and 7 m/s (10 and 15 mph) as calculated from the time-and-distance relationships obtained from the seismogram (Figure 3). We were able to see some variation in the effects of the gusts on the geophones along the line in both space and time, with wind disturbances displayed as a function of time at each of the 96 locations. For example, between 3.8 s and 6.5 s in time, at distances between 2 m and 10 m, we began to see indications of the wavelengths of the wind gusts. For reference, lines have been drawn to show wind speeds of 4.5 m/s and 6.7 m/s. For the most part, the wavelengths were between 3 m and 6 m, although some may have been smaller.

In the second experiment, we arranged the geophones on the ground in three parallel lines (Figure 4), which allowed us to examine wind components and turbulence that were lateral to the long axis of the array. Each line consisted of 32 geophones, with the lines spaced 1.2 m apart. The inter-geophone distance within each line was 0.6 m. We detected two principal gusts of wind propagating across the geophone array (Figure 5). On the east line, about 2.3 s was required for the wind gust to propagate about 20 m, which translated into a wind speed of 8.7 m/s (~19 mph). The second gust was characterized by two pulses on the west line between 4 and 5 s.

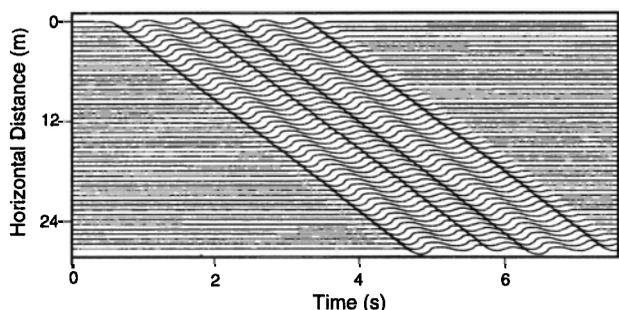


Figure 2. A simulated, noiseless, nondispersive, nonturbulent wind gust with a wind speed of 7 m/s.

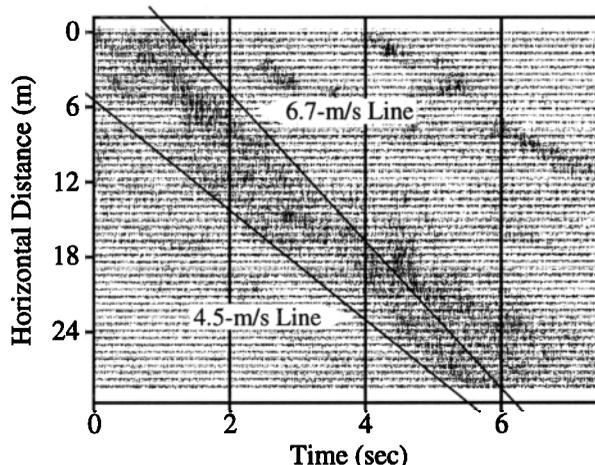


Figure 3. Wind-strip register recorded for 7.5 s using single, 100-Hz geophones spaced on 0.3-m centers. Wind disturbance is displayed as a function of time at each of 96 locations. Reference lines were added to show wind speeds of 4.5 m/s and 6.7 m/s.

The middle line showed a much-subdued pulse in this time frame. The east line showed pulses that were less distinct as well. Note that we doubled the time scale in Figure 6 because we changed the sample interval to 1 ms on each channel; we observed two principal gusts of wind whose speed was about 5.8 m/s. Again, we noted detail in the wind gusts, with the level of detail varying from one line to another.

Discussion

We were able to see variations in both space and time when observing the effect of a wind gust on geophones placed in a

Map View of Field Layout for Figs. 5-6

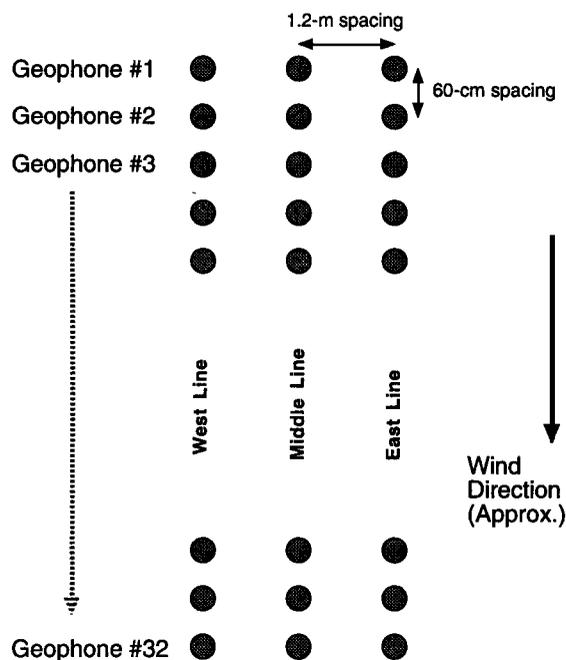


Figure 4. Field layout for the geophone data presented in Figs. 5 and 6. Three lines of 32 geophones each were planted in the ground, with 1.2 m between the lines. Intergeophone distance for each line was 0.6 m.

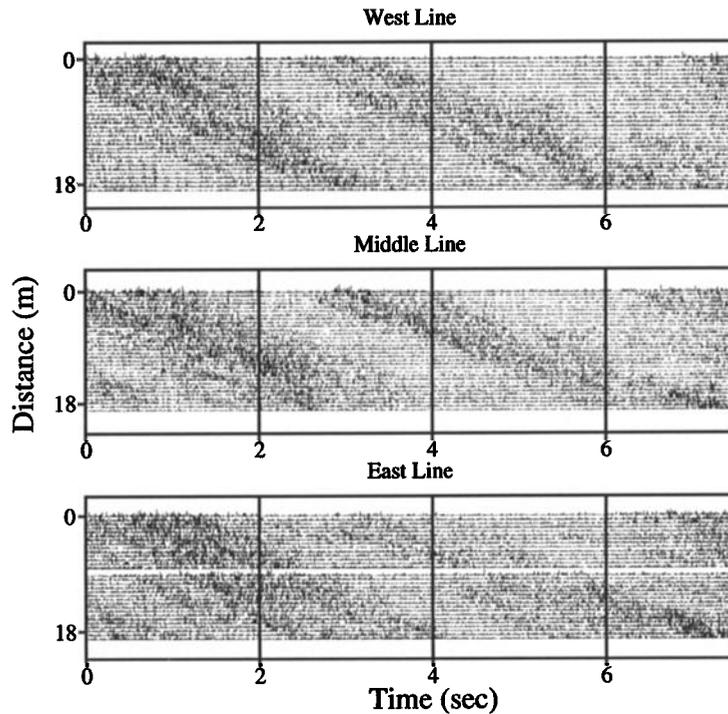


Figure 5. Two principal gusts of wind propagating across the geophone array. On the east line, about 2.3 s was required for the wind to propagate about 20 m, for a wind speed of 8.7 m/s or ~19 mph. The second gust registered two pulses on the west line at times between 4 s and 5 s. The middle line shows a much-subdued pulse in this time frame, and the pulses on the east line also are less distinct.

line on the ground. Clearly, seismic sensors are affected in complicated ways when wind gusts shake their connector cables while simultaneously disturbing nearby grass, trees, roots, and other objects. To seismologists, this information may be seen as interference that takes the form of noise. However, to those interested in near-surface atmospheric

physics, such information may constitute usable signal. A seismograph could be used to monitor and measure the wind eddies that form around objects on the ground as well as to look at the way air moves near and around topographic variations, for example.

The geophones we used in our experiments are designed to

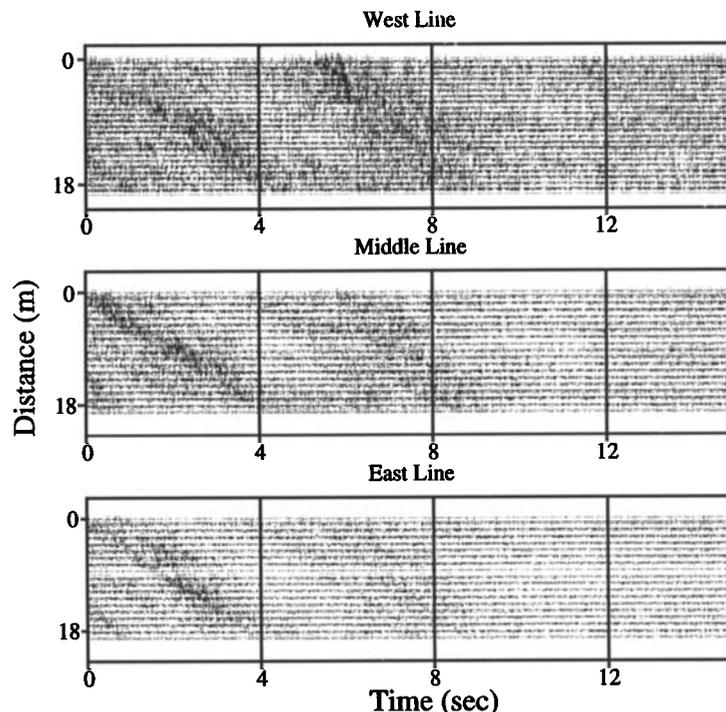


Figure 6. The time scale has been doubled in this figure because the sample interval was changed to 1 ms per channel. Two principal gusts of wind, with a wind speed of 5.8 m/s or ~13 mph, can be seen. Wind-gust details are visible, with the level of detail varying from one line to another.

detect vertical motion, but wind motion near the ground exhibits a strong horizontal component; therefore, the frequencies that are excited in the geophones may not necessarily be a linear function of the frequencies or velocities of atmospheric wind. Consequently, the data we recorded are not amenable to classical spectral analysis. Using seismic sensors designed to measure horizontal wind motion and calibrating the seismograph recordings to an array of anemometers would likely overcome these limitations. In our experiment, anemometers arranged along the geophone line would have provided useful comparison data but were not available to us.

The procedures we used allowed us to measure wind speed at ground level, but we have not determined how those measurements might translate to wind speed at heights above the ground ranging from several decimeters to several meters. In concept, geophones could be placed at heights of about 1 m without redesigning the experiment. In addition, each geophone could be fitted with a sail- or flag-like device that would amplify the signal strength of the wind.

We have not determined how the apparent wavelengths of the wind at ground level vary with changes in wind speed or other conditions. As turbulence increases with increasing wind speed, apparent wavelengths may change.

The data suggest that any atmospheric wind-turbulence observations made or models constructed using grid spacings of more than 1 m may be subject to serious spatial-aliasing effects. Recording unaliased wind microstructure with a multi-channel seismograph conceivably could provide experimental data to support improved meter-scale modeling of atmospheric turbulence. Such data might be useful to those working with aerosol and particulate dispersion, turbulence around structures, and the erosion of soils by wind. Wind-speed and turbulence data ranging from minutes to hours could be recorded by adding a larger disk drive to the recording system.

Conclusions

A multichannel seismograph equipped with geophones can be used to display atmospheric-wind microstructure at the terrestrial surface, in two dimensions, on the scale of a few meters. In principle, this information could be extended to three dimensions, within a meter or so of the ground's surface, without substantially modifying the equipment required for the experiment.

Data from individual geophones may not be conclusive when viewed out of context, much as a single pixel, when sep-

arated from an overall computer display, may not be representative of the whole. However, when we made observations in the context of information obtained from several other geophones, we were able to see detail in both wind speed and turbulence in a time-dependent, two-dimensional wind field.

To provide a basis for comparison and error analysis, future field experiments would benefit from the inclusion of precise wind-speed measurements obtained from anemometer arrays. Geophones could be made much more sensitive to the presence of wind by the attachment of small, flag-like devices to the top of each sensor. In addition, the number of recording channels and geophones easily could be increased. Ideally, this preliminary research will stimulate the formation of some worthwhile, cross-disciplinary scientific questions and foster possible collaboration with other investigators.

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