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Effect of wind on seismic exploration random noise on land: Modeling and analyzing

Guanghui Li [a], Yue Li [a,*], Baojun Yang [b]

[a] Department of Information, College of Communication and Engineering, Jilin University, Changchun 130012, China
[b] College of GeoExploration Science and Technology, Jilin University, Changchun 130012, China

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ABSTRACT

Random noise is a key factor which impacts the Signal Noise Ratio (SNR) of seismic records, and its interference without regularity makes seismic data process difficult. It is a first requirement for noise attenuation to know how random noise generated. Since the main effect of wind on seismic noise, we model wind-induced noise by wind induced vibration theory, aeroacoustics and wave equation, and analyze the influencing factors which cause the differences of noise in the desert in Tarim basin, the loess tableland in northern Shaanxi, the mountain land in Yunnan and the forest belt in north in China in this paper. There are wind speed, surface roughness, terrain, and vegetation. The greater the wind speed, the rougher the surface, the higher and the steeper the mountain, the more the vegetations and the thinner the branches and leaves of vegetations, the greater the amplitude and the frequency of wind-induced noise is. The simulated results explain the differences of wind induced noise in different areas. It lays a foundation for random noise attenuation both in data acquisition and data processing.

1. Introduction

In seismic data processing, random noise which mainly wakens the Signal Noise Ratio (SNR) of seismic records is difficult to attenuate because of its irregularities. People continue to improve the original methods and propose new methods of the SNR enhancement. However, learning how random noise generated is an urgent issue. Many studies have been conducted to understand noise properties by field trials, for example, the correlation between random noise and wind speed or buried depth is obtained by field measurement (Young et al., 1996; Barajas-Olade and Ramadan, 2011), but few have been devoted to theoretical simulation.

Seismic random noise is classified into natural noise and cultural noise according to the types of noise sources (Ward and Crawford, 1966; Bonnefoy-Claudet et al., 2006a,b). In seismic exploration on land, natural noise is generated by wind (wind friction over rough terrain; trees and other vegetation or tall buildings swinging or vibrating in wind; leaves, branches, or stalks of plants rustling when wind blowing, etc.) or by rushing waters (water waves striking the coast) when collecting stations near seas or rivers; cultural noise is man-made noise (people's cultural life, individual and public commuter traffic and trains, industrial machineries etc.). In this paper, field data is collected from the desert in Tarim basin, the loess tableland in northern Shaanxi, the mountain land in Yunnan and the forest belt in north in China, respectively, wind is the main factor which affects random noise. We model the source functions of wind induced noise on the basis of wind induced vibration theory and aeroacoustics, and make wave equation as the noise propagation equation. Wind induced noise is obtained as a superposed wave field by solving the inhomogeneous wave equations and superposing all the solutions. The factors which lead to the differences in different data acquisition areas are analyzed, including wind speed, surface roughness, terrain, and vegetation. The theoretical simulation mentioned in this paper will provide guidance to noise attenuation in field data acquisition and in data processing.

Wind induced noise is classified into noise generated by wind friction over rough terrain and noise driven by wind friction through trees according to the real environment of data acquisition mentioned in this paper. Then, they will be described respectively in the following sections.

2. Noise generated by wind friction over the earth's surface

Terrain is divided into flat and mountainous terrain roughly in consideration of the effect of terrain on wind speed. The desert, the loess tableland and the forest belt are flat terrain type, and the mountain land is mountainous terrain type. It is assumed that the earth is

* Corresponding author at: College of Communication Engineering, Jilin University, Changchun, Jilin 130012, China.
E-mail addresses: liguanghui0352@163.com (G. Li), liyue@jlu.edu.cn (Y. Li), yangbaojun@jlu.edu.cn (B. Yang).

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homogeneous, isotropic, elastic, half-infinite media, and the noise is generated by the deformation motion of the earth surface when wind blows over it (Sorrells and John, 1971). In wind induced vibration theory, wind speed is the sum of average wind speed and fluctuating wind speed, which is expressed as

$$v = \overline{v} + v_f \tag{1}$$

where $\overline{v}$ is average wind speed and v_f is fluctuating wind speed.

Average wind speed which changes exponentially over height above the ground is expressed as

$$\frac{\overline{v}(z)}{\overline{v}_{10}} = \left(\frac{z}{10}\right)^{\alpha} \tag{2}$$

where $\overline{v}_{10}$ is reference wind speed (average wind speed at 10 m above the ground), $\overline{v}_z$ is average wind speed at z meters above the ground, and α is roughness coefficients of the ground surface. The classification of roughness coefficients of ground surface is shown in Table 1 and corresponding drag coefficients of different surface roughness is shown in Table 2.

As we know, the Davenport fluctuating wind speed spectrum (Davenport, 1961) is expressed as

$$S(\omega) = 4K\overline{v}_{10}{}^2 \frac{x^2}{\omega(1+x^2)^{4/3}} \tag{3}$$

$$x = \frac{600\omega}{\pi\overline{v}_{10}} \tag{4}$$

where $S(\omega)$ denotes wind speed spectrum, ω angular frequency of fluctuating wind, $\overline{v}_{10}$ means wind speed at 10 meters over the ground, K drag force coefficient of the earth surface, and x turbulence integral scale coefficient, respectively.

On the basis of Shinozuka theory (Shinozaka and Jan, 1972), we can obtain the expression of fluctuating wind speed in time domain by harmony superposition method as

$$v_f(t) = \sum_{i=1}^{N} \sqrt{2S(\omega_i)\Delta\omega}\ \cos(\omega_i t + \varepsilon_i) \tag{5}$$

where v_f denotes fluctuating wind speed, N component numbers, ε_i the initial phase of corresponding component which is a random variable distributed in (0, 2π) uniformly, ω_i frequency of corresponding component, Δω frequency increment, and ω_L, ω_H the lower and upper limit of the frequency range (ω_L, ω_H) divided into N equal ones, respectively.

According to the concept of fluctuating wind pressure spectrum and Weiner–Khintchine theorem, fluctuating wind pressure spectrum is written as (Kareem, 1982)

$$S_f(\omega) = \rho^2\overline{v}_z S(\omega) \tag{6}$$

where $S_w(\omega)$ is fluctuating wind pressure spectrum, ρ the air destiny, $\overline{v}_z$ wind speed at z meters.

Table 1
Roughness coefficients of ground surface.

Ground roughness	Roughness coefficients
A: offshore sea surface, sea island, coast, lakeshore and desert	0.12
B: field, country, jungle, hill and town and suburb with sparse houses	0.16
C: urban with dense buildings	0.22
D: urban with dense and high buildings	0.30

Table 2
Drag coefficients of different surface roughness.

Ground roughness level	A	B	C	D
K	0.0013	0.0022	0.0046	0.0129

By the same method as Eq. (5), we can obtain fluctuating wind pressure in time domain as

$$P_f(t) = \sum_{i=1}^{N} \sqrt{2S_f(\omega_i)\Delta\omega}\ \cos(\omega_i t + \eta_i) \tag{7}$$

where P_f denotes fluctuating wind pressure, η_i is the initial phase of corresponding component which is a random variable distributed in (0, 2π) uniformly, the rest of parameters are defined as above.

Eq. (1) shows that wind speed is the sum of average wind speed and fluctuating wind speed, similarly, wind pressure is also the sum of average wind pressure and fluctuating wind pressure, which is written as

$$P = \overline{P} + P_f \tag{8}$$

where P is wind pressure, $\overline{P}$ is average wind pressure, which is expressed as $\overline{P} = \overline{v_z}^2/1600$ when the air destiny $\rho = 1.25\ \text{kg/m}^3$ (uniform value), and P_f is fluctuating wind pressure.

The force of wind on the earth surface can be written as

$$f(t) = \overline{v(z)}^2/1600 + \sum_{i=1}^{N} \sqrt{2S_f(\omega_i)\Delta\omega}\ \cos(\omega_i t + \eta_i) \tag{9}$$

all the parameters are defined as above.

Eq. (9) is the source function of noise induced by wind friction over rough terrain. The noise caused by deformation of the earth's surface when wind blowing over it propagates by wave equation. Based on the theory of elastodynamics, when elastic waves propagate in the homogeneous, isotropic, and elastic media, it satisfies the equation

$$\nabla^2\phi\left(\vec{r},t\right) - \frac{1}{c^2}\frac{\partial^2\phi\left(\vec{r},t\right)}{\partial t^2} = M\left(\vec{r},t\right) \tag{10}$$

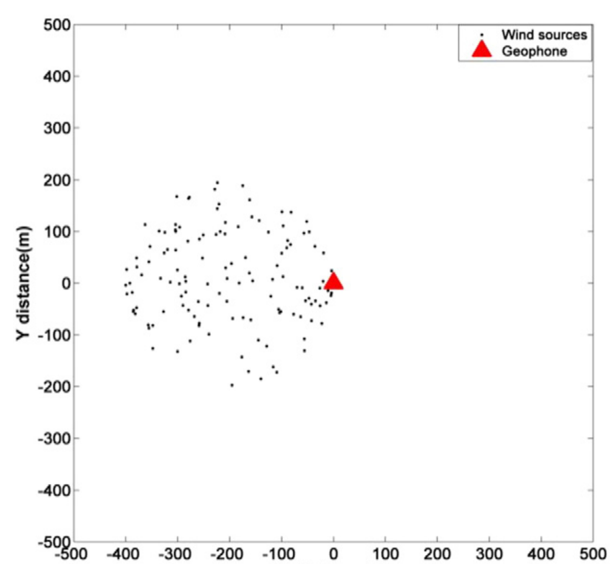

Fig. 1. Spatial distribution of noise sources (black dots) caused by the force of wind on the ground surface.