Field experiment on ground-to-ground sound propagation from a directional source

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ABSTRACT

When predicting sound propagation in long distance, meteorological effects resulting from wind and temperature should be taken into consideration. Regarding this problem, many studies have been carried out by field measurements, numerical analyses and physical experiments. To predict and assess traffic noise by vehicles, trains and aircrafts, the sound sources are roughly modeled as omnidirectional. In reality, however, the sources have their inherent directivities according to their shapes, and the directivity can affects noise propagation characteristics as well as the meteorological effects. In this study, a field experiment on ground-to-ground long distance sound propagation using an omnidirectional loudspeaker and two types of directional loudspeakers were conducted at a flat field which approximately satisfied hemi-free field condition. To examine the relationship between the directivity effects and the meteorological effects, sound propagation characteristics by an omnidirectional loudspeaker and those by directional loudspeakers were compared. In addition, sound propagation by the omnidirectional point source was analyzed using Crank-Nicholson Parabolic Equation analyses and the experimental results were validated. Consequently, it was confirmed that sound propagation from the directional sources showed the same trend for excess attenuation characteristics as that from the omnidirectional source by considering its directional characteristics.

Keywords: Meteorological effects, Directional source, long distance sound propagation, excess attenuation

I-INCE Classification of Subjects Number(s): 24.6

1. INTRODUCTION

The influence of meteorological effects resulting from wind and temperature is remarkable to long distance sound propagation. Regarding this problem, many studies have been carried out by field measurements, numerical analyses and physical experiments(1-4). To predict and assess traffic noise by vehicles, trains and aircrafts, the sound sources are roughly modeled as omnidirectional. In reality, however, the sources have their inherent directivities according to their shapes, and the directivity can affects noise propagation characteristics as well as the meteorological effects. Therefore it is necessary to grasp the influence of the sound source directivity to long distance sound propagation. In this study, we conducted the field experiment on ground-to-ground long distance sound propagation, in which an omnidirectional loudspeaker and two types of directional loudspeakers were used in the flat field which satisfied hemi-free field condition, and effects of meteorological condition and the source directivity were experimentally investigated. In addition, verification of an experimental result and parametric study on the meteorological effects were performed using a

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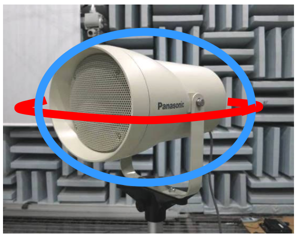
numerical analysis by the Crank-Nicholson Parabolic Equation (CN-PE) method (5).

2. Directional sound sources

Figure 1 (a) and 1 (b) show directional loudspeakers used in this experiment. In advance of the outdoor field experiment, their directional characteristics were measured in an anechoic room.

(a) Directional loudspeaker 1



(b) Directional loudspeaker 2

Figure 1 – Directional sound source

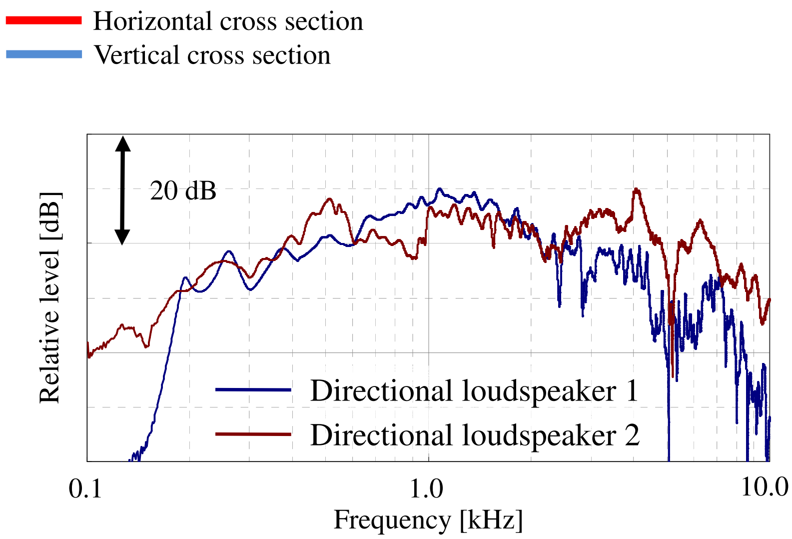


Figure 2 – Frequency characteristics of directional loudspeakers

Figure 2 shows frequency characteristics of sound pressure level measured at a point 2 m away from in front of the respective loudspeakers. Frequency components ranging from 250 Hz to 2 kHz could be reproduced from the loudspeakers. Figure 3 shows directivity characteristics of sound pressure level of the two directional loudspeakers. It is shown that the directional loudspeaker 1 has sharper directivity characteristics than the directional loudspeaker 2. Since the directional loudspeaker to is not rotational symmetry, directivity characteristics in to plains perpendicular to each other were measured(see Fig.3 b and Fig.3 c), Comparing these results, the horizontal directivity is a bit sharper than the vertical one.

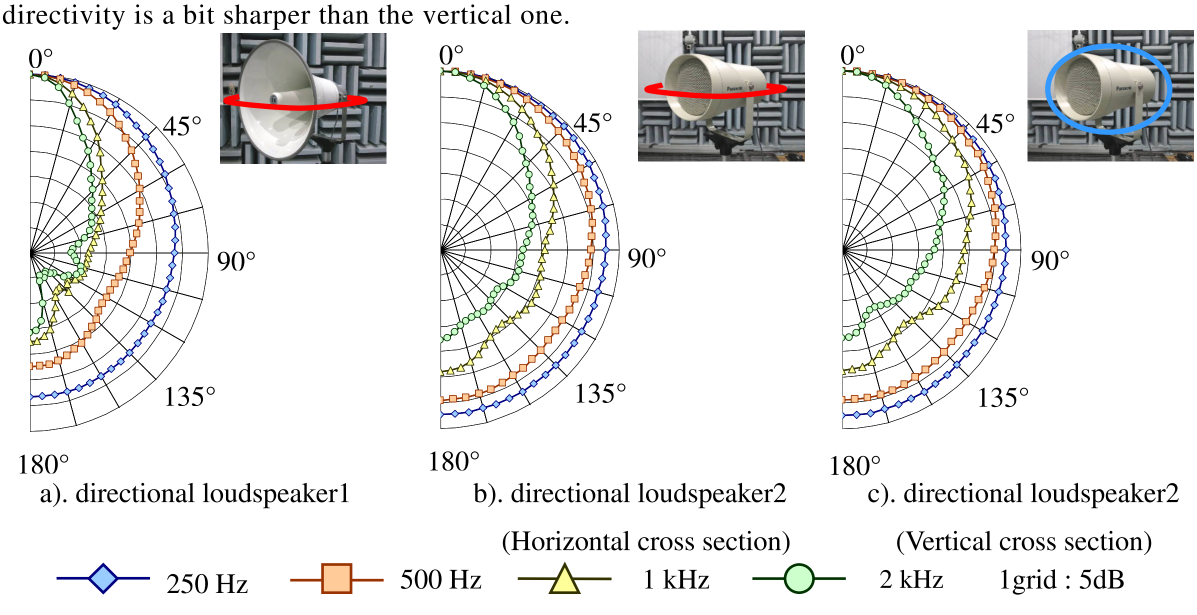


Figure 3 – Directivity characteristics of the two directional loudspeakers

3. Field experiment

3.1 Outline

Field experiment on outdoor sound propagation was carried out in early-mid July 2013 at a measurement field having a runway with a length of 1 km and a width of 60 m located at Taiki aerospace research field. Figure 4 shows the layout of the measurement field. The runway extends in the east and west direction. The sound sources were set at the center position of the runway, and 11 receiving points were arranged on the centerline of the runway with equally a 100 m intervals. In order to grasp meteorological condition, two-dimensional ultrasonic anemometers were set at 3 points of west-300 m point, east-300 m point and center point as shown Fig.4. Figure 5 shows setting configurations of sound sources, microphones and anemometers. The microphones and anemometers were set at their heights of 1.2 m as shown in Fig. 5.

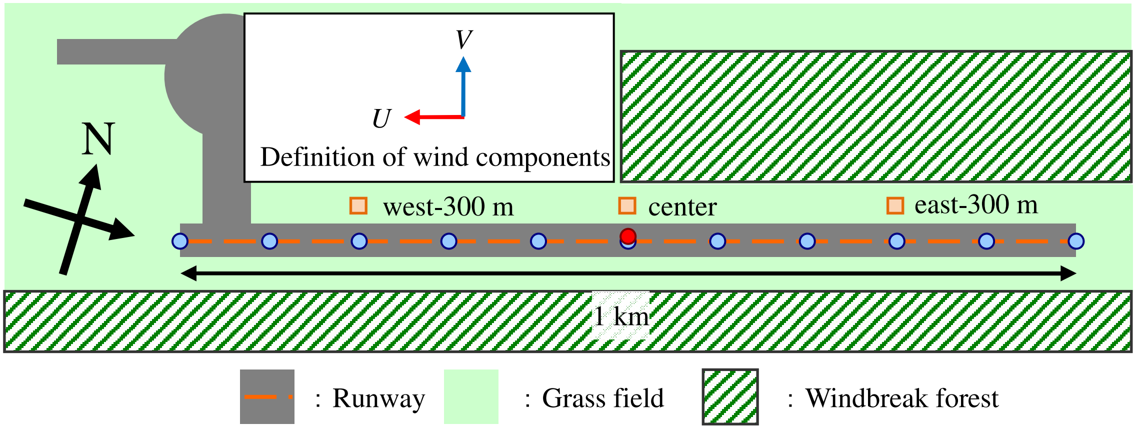


Figure 4 – Layout of the measurement field

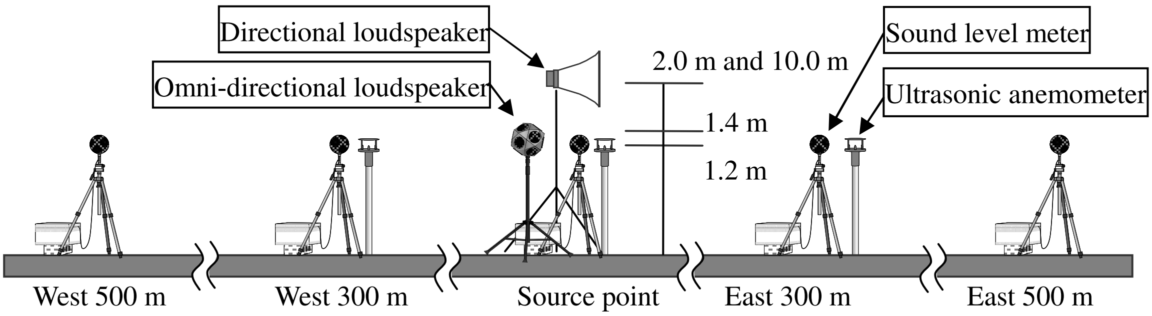


Figure 5 – Setting configurations of equipments

Figure 6 – Sound receiving point

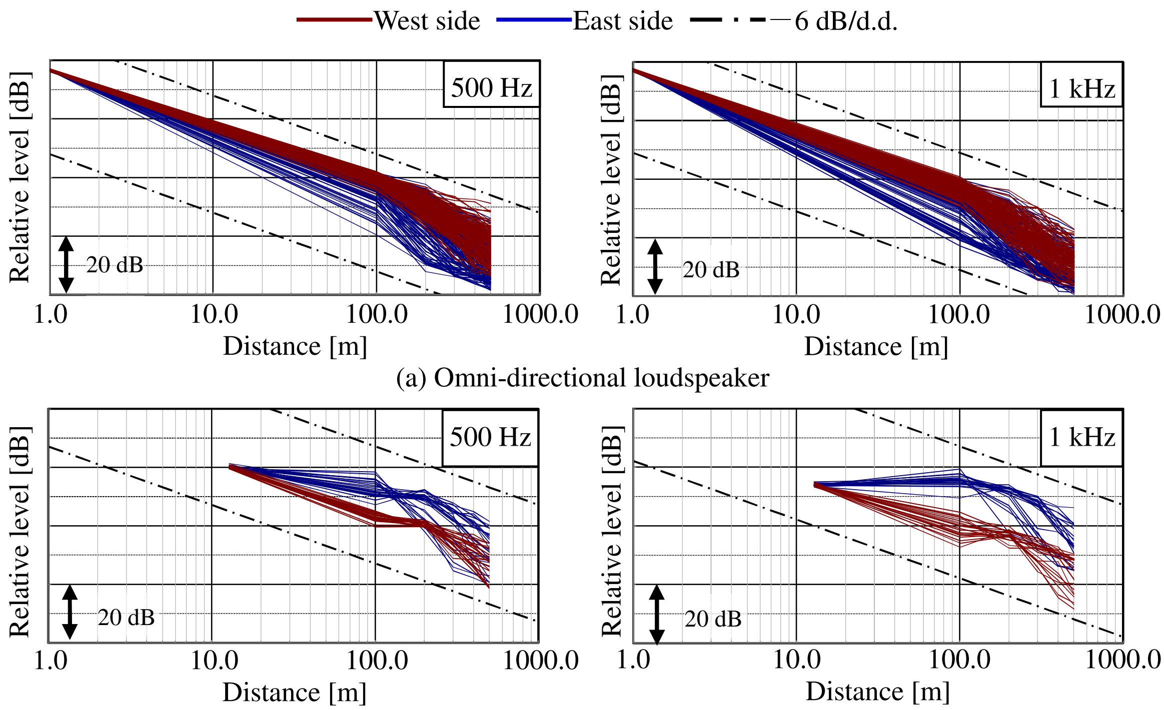
Figure 7 – Experiment scenery for source point

In this experiment, three loudspeakers (an omnidirectional loudspeaker and two directional loudspeakers) were used. The omnidirectional loudspeaker was set at a point of the height of 1.4 m and two directional loudspeakers were set at two points of their heights of 2 m and 10 m using an extensible pole, as shown in Figs. 6 and 7. The directional loudspeakers were pointed to the east and west along the runway. As the source signal, swept-sine signals were used in order to measure impulse responses from the source points to the receiving points. In order to secure sufficient signal-to-noise (S/N) ratio, time duration of the swept-sine signal was set to 60 sec as sufficiently long duration to obtain enough sound energy. The frequency components included in the source signals ranged 5 octave bands from 125 Hz to 2 kHz for the omnidirectional loudspeaker and 4 octave bands from 250 Hz to 2 kHz for the directional loudspeakers.

4. Experimental results

4.1 Characteristics of distance attenuation

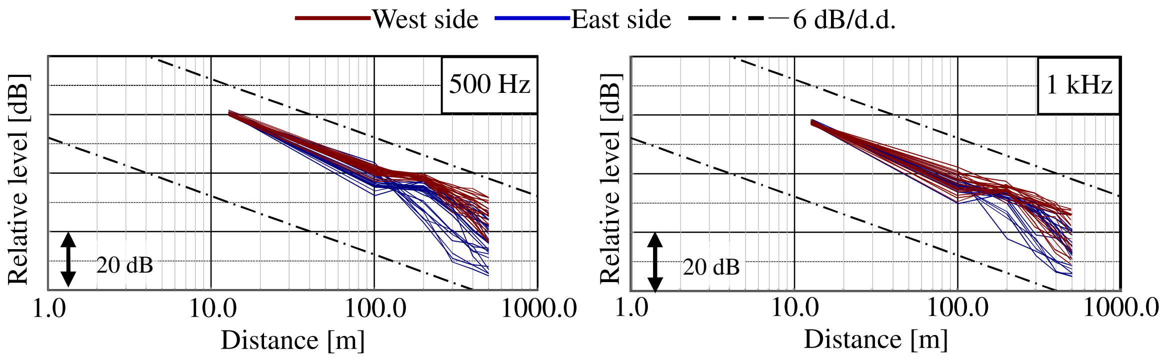
Figures 8 (a) and 8 (b) show characteristics of distance attenuation of sound pressure level when the omnidirectional loudspeaker was set at the height of 1.4 m(Fig. 8 (a)) and the directional loudspeaker 1 was set at the height of 10 m (Fig. 8 (b)). 163 data for the omnidirectional loudspeaker and 54 data for the directional loudspeaker 1 measured for 10 days were overdrawn. In the case of the directional loudspeaker 1, the direction of the loudspeaker was set in the east. In these figures, all of the measurement data is overwritten regardless of the wind conditions. From all figures shown here, it is clear that the variation of the sound pressure level became larger as the distance became larger. When the distance was 500 m, the variation extended to 20 dB. For the omnidirectional loudspeaker, the distance attenuation in the western side tended slightly gentler than that in the eastern side. This is because wind direction on the measurement period tended to be easterly and as the result the measurement points tended to be at the downwind side. Regarding the directional loudspeaker 1, the sound pressure level at the east side was obviously larger than that at the west side because the loudspeaker pointed to the east. In order to eliminate the effect of the directivity characteristics, the direction angle of the loudspeaker at the respective measurement points were calculated and the effects of the directivity characteristics were corrected from the measurement data based on the directivity characteristics shown in Fig. 3 (a), 3 (b) and 3 (c). The calculation results are shown in Fig. 9. The tendency of the variation of the sound pressure level became similar as those for the omnidirectional loudspeaker.



(a) Omni-directional loudspeaker

(b) Directional loudspeaker 1 (height 10 m and east direction)

Figure 8 – Distance attenuation of sound pressure level



Directional loudspeaker 1 (height 10 m and east direction)

Figure 9 – Corrected distance attenuation regarding the source directivity

4.2 Excess attenuation

Excess attenuation over a standard condition, in which no wind or no strong temperature profile is assumed, was calculated for sound propagation from the three loudspeakers. As a reference sound pressure level, only distance attenuation on a rigid surface was taken into consideration. Under a geometrical condition shown in Fig. 10, sound pressure level at a receiving point P is calculated as a summation of contributions for direct path and reflecting path in energy base as,

$$L_{\mathrm{Dist}} = 10\log_{10}\left(10^{\frac{L_{\mathrm{Direct}}}{10}} + 10^{\frac{L_{\mathrm{Reflect}}}{10}}\right), \tag{1}$$

where, L_{Direct} and L_{Reflect} are sound pressure levels for direct and reflect paths, respectively, and they are calculated as follows.

$$L_{\mathbf{Direct}} = L_0 - 10\log_{10}\left(\frac{R_{\mathbf{d}}}{R_0}\right)^2 + \Delta L_{\mathbf{dir}}(\theta_{\mathbf{d}}), \tag{2}$$

$$L_{\mathbf{Reflect}} = L_0 - 10\log_{10}\left(\frac{R_{\mathbf{r}}}{R_0}\right)^2 + \Delta L_{\mathbf{dir}}(\theta_{\mathbf{r}}), \tag{3}$$

where, L_0 denotes the sound pressure level at a reference point R_0 m distant from the sound source, $\Delta L_{\mathrm{dir}}(\theta_{\mathrm{d}})$ and $\Delta L_{\mathrm{dir}}(\theta_{\mathrm{r}})$ denote the corrected values of the correction [dB] due to the source directivity at the angle θ_{d} and θ_{r}, respectively. For the omnidirectional loudspeaker, $\Delta L_{\mathrm{dir}}(\theta_{\mathrm{d}})$ and $\Delta L_{\mathrm{dir}}(\theta_{\mathrm{r}})$ are 0 dB for all angles, and for the directional loudspeakers 1 and 2, measured results of the directivities of the loudspeakers described in the chapter 2 were used as the values of $\Delta L_{\mathrm{dir}}(\theta_{\mathrm{d}})$ and $\Delta L_{\mathrm{dir}}(\theta_{\mathrm{r}})$. The excess attenuations were of obtained as differences between measures values and the reference sound pressure levels.

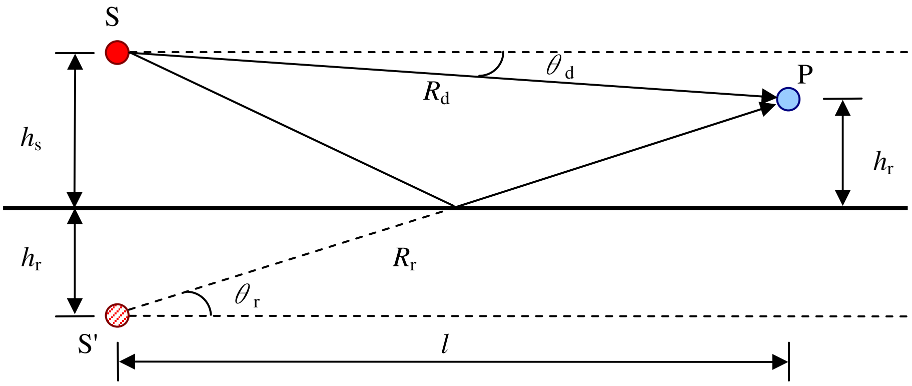


Figure 10 – Geometrical configuration of the source, receive and a flat, rigid surface

Excess attenuation levels for all measurement data were calculated as the procedure mentioned above and the results were arranged in relationship with the vector component of the wind speed at 1.2 m high, U. U is positive in the downwind direction and negative in the upwind direction. The calculation results are shown in Figs. 11, 12 and 13. The figures show that the excess attenuation is related to the vector wind speed, distance from the source, frequency of sound and height of the source. The excess attenuation becomes larger as the absolute value of the vector wind speed becomes larger in negative, as the distance from the source and receiving point becomes larger, and as the frequency is higher.

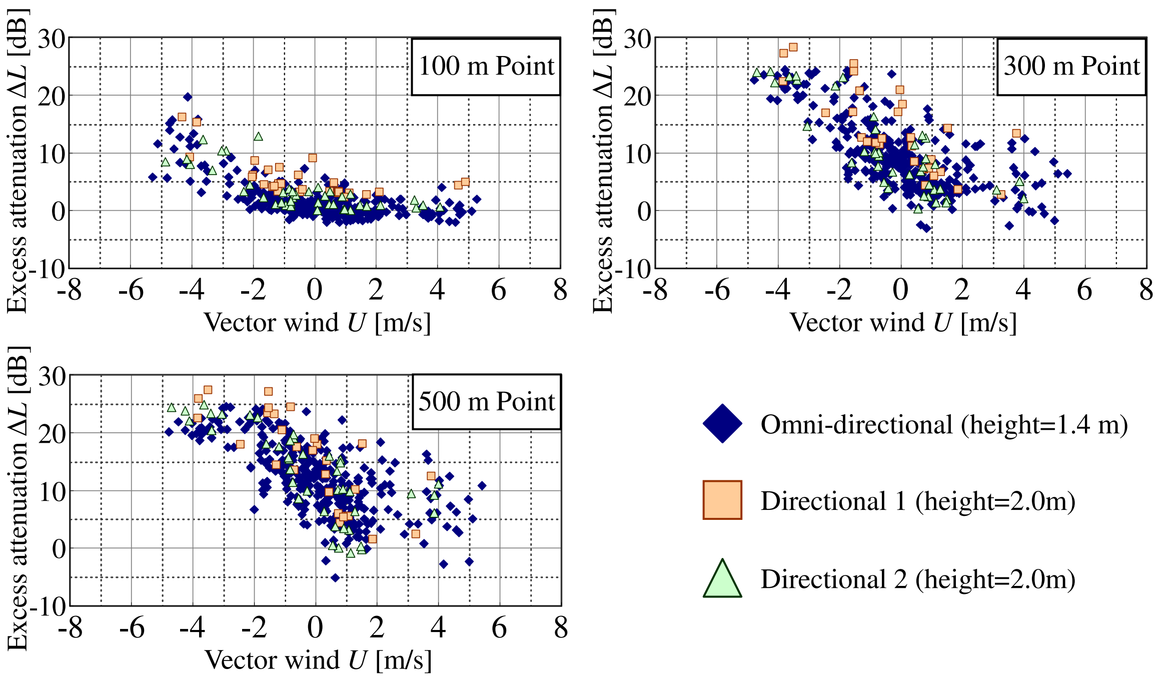


Figure 11 – Excess attenuation 500 Hz (directional speaker height=2.0m)

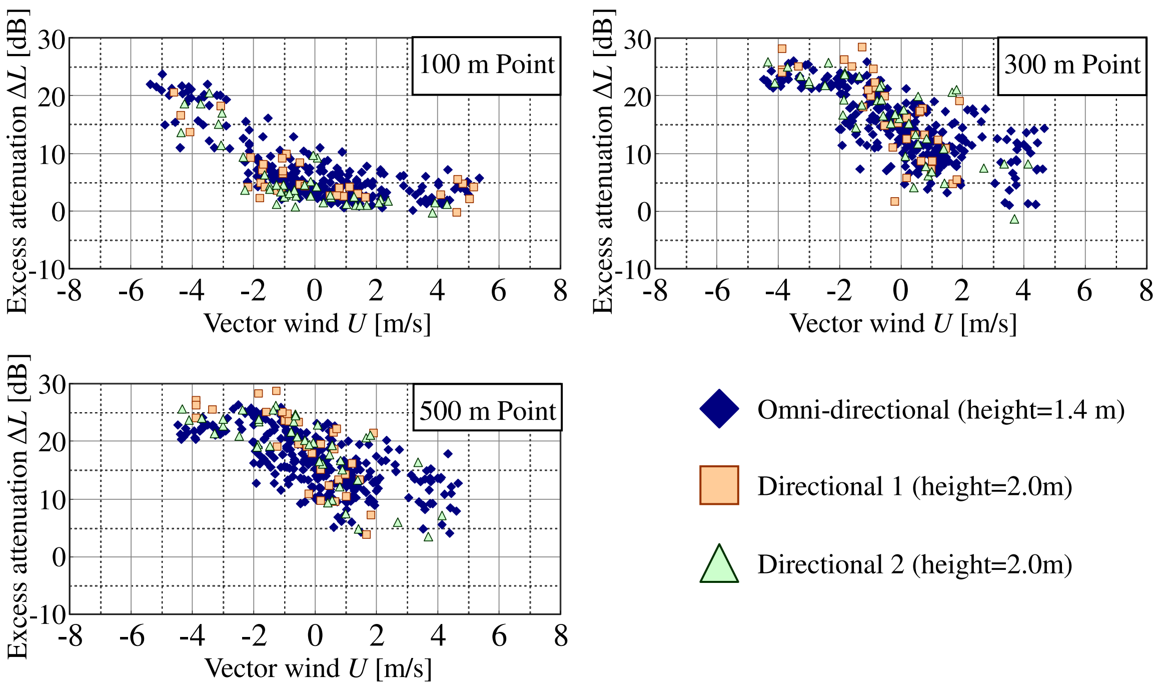


Figure 12 – Excess attenuation 1 kHz (directional speaker height=2.0m)

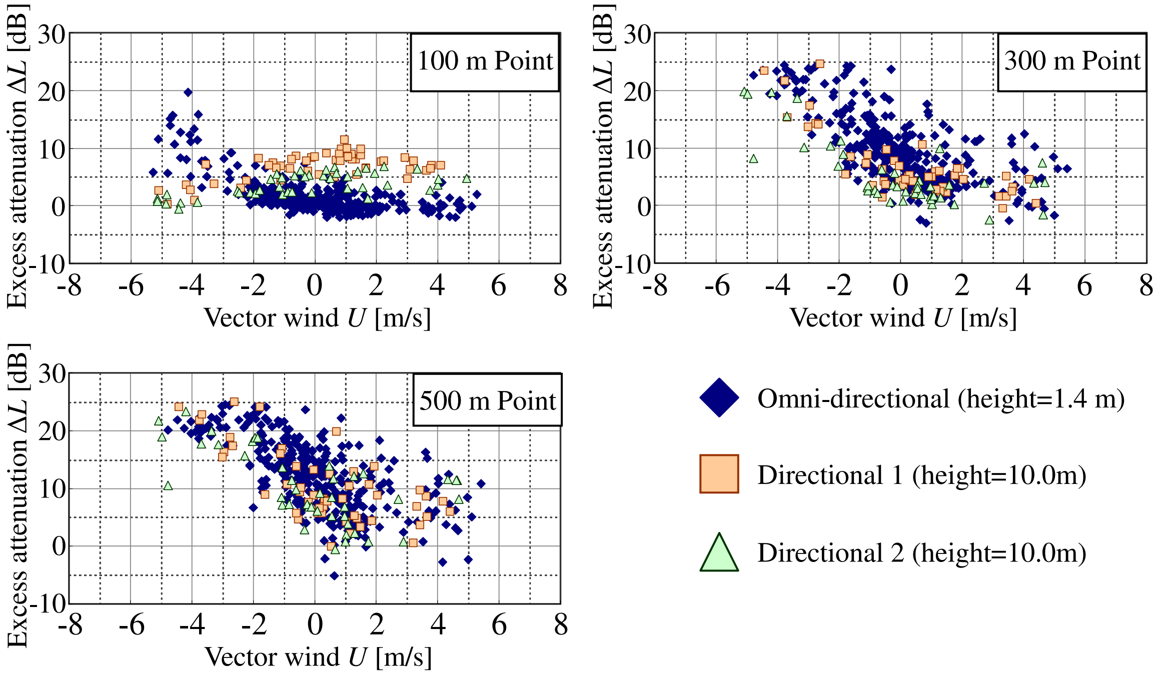


Figure 13 – Excess attenuation 500 Hz (directional loudspeaker height=10.0m)

5. Comparison between measurement and PE analysis

Crank-Nicholson Parabolic Equation (CN-PE) analyses were conducted for the same geometrical configuration of the source and receivers as the experiment for the omnidirectional loudspeaker, of which height is 1.4 m. The calculation results were compared with the experimental results. In the calculation, meteorological conditions of wind speed U and temperature T were set as,

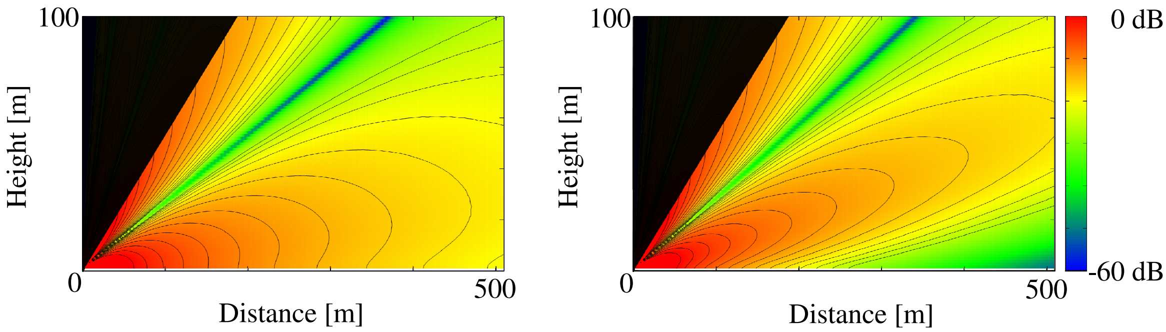
$$U(z) = a \cdot \log\left(1 + \frac{z}{z_0}\right), \tag{4}$$

$$T(z) = T_0 + bz, \tag{5}$$

where, z is the height [m], z_0 is the roughness length [m], T_0 is the temperature in Celsius degree [°C] on the ground and b is a rise rate of the temperature. The parameters z_0, T_0 and b were set to 0.0003 m, 17 °C and 0.03, respectively. Then, sound speed at the height z, $c(z)$, is expressed as follows.

$$c(z) = 331.5 \cdot \left(1 + \frac{T(z)}{273}\right)^{1/2} + U(z), \tag{6}$$

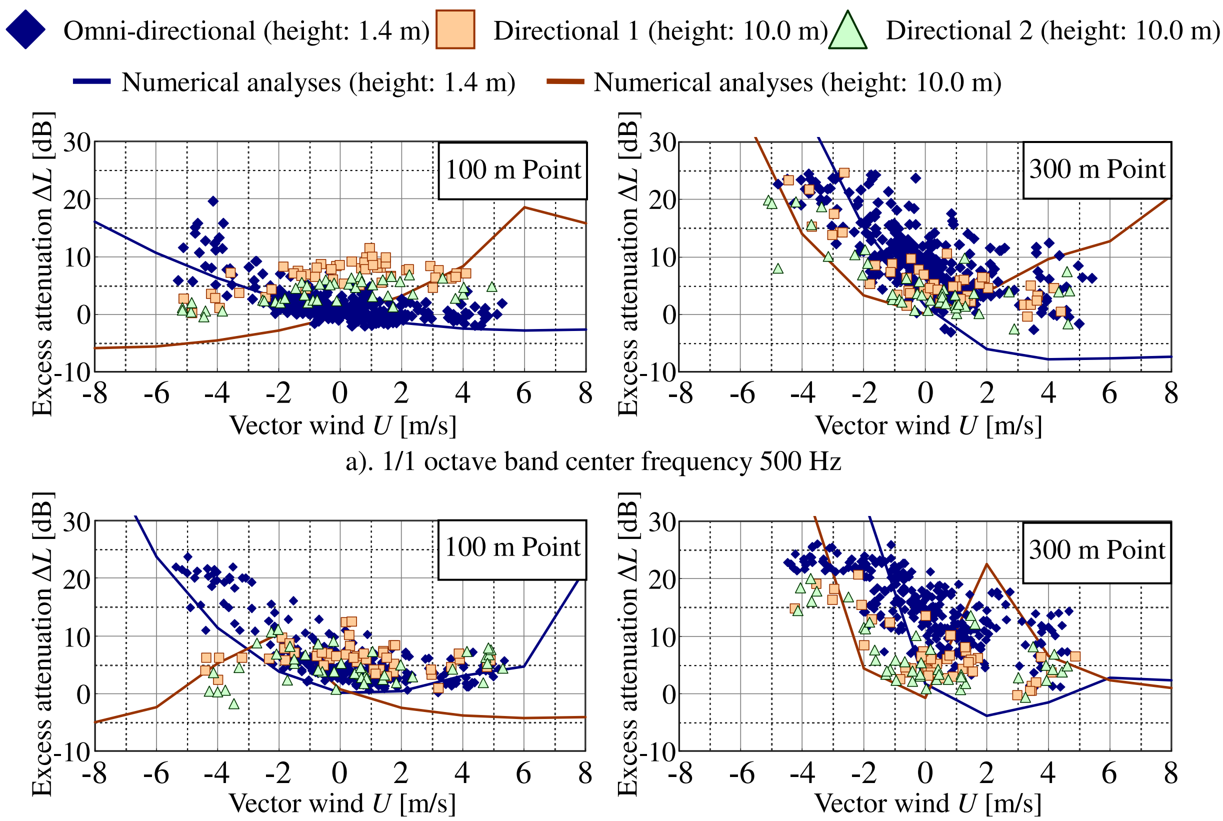
Under the above conditions, sound pressure distribution for single frequencies of 250 Hz, 500 Hz and 1 kHz was calculated. Figure 14 shows an example of calculation result for 250 Hz, which shows an influence of wind speed on the sound pressure distribution.



(a) U at 1.2 m is 0 m/s (b) U at 1.2 m is −4 m/s

Figure 14 – Calculation result of CN-PE analysis at 250 Hz

The excess attenuation for an omnidirectional source was calculated as a level difference between a case where the vertical distribution of wind speed, temperature and sound speed was set parametrically and a case where the vertical distribution of the sound speed was uniform. Figure 15 shows calculated excess attenuation overdrawn on the measurement results. Here, it should be noted that the measurement results were analyzed as 1/1 octave band values, whereas the calculation results were for single frequency. Calculation for single frequency may emphasize an influence of sound interference as sharp peaks or dips in the graph. Comparing the calculation and measurement for the omnidirectional source, similar tendency is seen in the results for 100 m point, whereas the difference between them is considerable in the results for 300 m. In the figure, calculated excess attenuation for an omnidirectional source located at 10 m high is shown as references. The calculated excess attenuation characteristics in relation to vector wind speed are similar with the measured ones for the directional loudspeakers 1 and 2.



a). 1/1 octave band center frequency 500 Hz

b). 1/1 octave band center frequency 1 kHz

Figure 15 – Comparison of the excess attenuation between the field experiment and numerical analyses

6. CONCLUSIONS

In this study, long distance sound propagation from several types of sound sources, an omnidirectional loudspeaker and directional ones, were investigated experimentally to examine the relationship between the directivity effects and the meteorological effects. In addition, sound propagation by the omnidirectional point source was analyzed using the Crank-Nicholson Parabolic Equation analysis and the measurement results were validated. Consequently, it was confirmed that sound propagation from the directional sources showed the same trend for excess attenuation characteristics as that from an omnidirectional source.

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