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Variation in measured sound level as a function of propagation environment and distance

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The propagation environment exerts a large influence on the range of received levels of impulsive events. This talk focuses on the variation in excess attenuation over durations of less than approximately 15 minutes. Data are presented for greatly different measurement distances (25 m to 7 km) and propagation environments (sparse vegetation to forested), illustrating the effects of distance and terrain cover on sounds from a propane cannon and an artillery source. Over sparse vegetation 7 km from an artillery source, the received CSEL varied 11 dB within a 12-minute duration. In measurements up to approximately 300 m from the source, variation in received level (both peak and SEL) was less than 0.5 dB within the forest, and much more in the open. The control of the forest canopy on the micrometeorology seems to explain the effect.

1 Introduction

The received level at some location due to an impulsive event is extremely sensitive to the instantaneous meteorological conditions along the propagation path. Because the atmosphere near the ground is typically a rapidly-varying environment, variations in received level can be expected from moment to moment. These variations can be on the order of 10 dB at distances of several kilometers. Several researchers have studied this variability. See, for example, [1, 2, 3, 4]. This subset of references all contain data for sound propagation over open ground and extensive meteorological measurements.

Several researchers have studied sound propagation in forested areas. See, for example, [4, 5, 6, 7, 8]. However, all of these studies present the data as average levels with an accompanying standard deviation, and do not show any outliers. Because no mention of outliers is made, the reader cannot exactly determine the full range of possible received values. The studies do indicate greater stability of received level over time than for propagation in the open. Clearly there is something unique about this propagation environment.

This paper presents two vastly different propagation environments and distances and looks at the variations in received sound level over a 15 minute period in each. The first environment is a fairly flat area with minimal vegetation and a propagation distance of 7 km. The other environment is an open field adjacent to a forest, and the forest itself. Propagation distances in this case are up to 300 m. The structure of this paper is as follows: the long-range measurements will be described and discussed. Next the forest edge measurements are described and discussed. Finally, some possible explanations for the variations, or lack thereof, in these measurements are presented.

2 Long-Range measurements

The M109, 155 mm field howitzer is one of the noisiest weapons in the Norwegian army. As such it defines the outer boundary where noise may be a problem for neighbors. In Norway noise regulations state that maximum noise level outside of the training area is 100 dB, CSEL (C-weighted sound exposure level), for each shot. The army may produce impulsive noise of any level as often as desired within the training field, as long as the 100 dB limit is never exceeded.

To comply with the noise limit, computations are carried out to obtain noise maps of the areas surrounding the training field. Since the noise regulations give a maximum level, and not a mean level, the variation of the measured noise levels is very important. It is well known that the measured noise level will have a variation due to the non-stationary nature of the propagating medium. This variation depends on propagation distance, ground properties, terrain, wind and temperature profiles, and the stability of the atmosphere [9].

2.1 Experimental data

At Hjerkinn in Norway we measured the noise level for 25 shots from the 155 mm [10, 11]. The propelling charge was 12.2 kg of gun powder, which produced a peak chamber pressure of 300 kPa. The projectile was a DM662 cargo grenade weighing 46.95 kg. Figure 1 is a photograph of the source, and Fig. 2 shows the test site.

Figure 1: Photograph of the M109 155 mm howitzer.

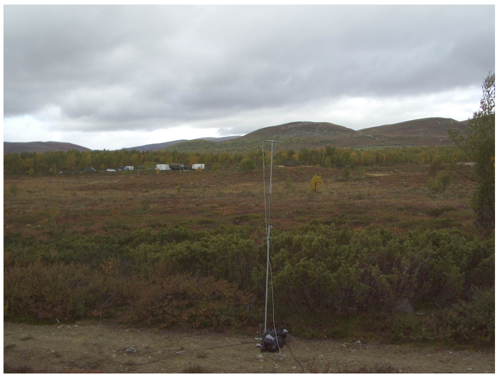

Figure 2: Photograph of the test site at Hjerkinn, Norway.

During the measurements the sound pressure was measured at 25 m, 250 m and 7 km. Measurements at 25 m and 250 m were made to establish accurate source levels close to the weapon. These are critical for meaningful predictions. The variation in received levels at 250 m was found to be less than 1 dB in overall SEL.

The measurements at 7 km accomplished two goals. The first was to evaluate the performance of the noise prediction tool "Milnoise" [12]. The second was to study the variation of received noise levels at a neighbors house during a short time where meteorological conditions were constant. The propagation path was fairly flat and sparsely vegetated, at a height of 960 m above sea level. The meteorological conditions given by NATO meteograms from a radiosonde provided moderate downward refraction with a light cross wind. Under these conditions, the variation in the measured sound level at 7 km was 12.5 dB CSEL over 8 hours. During one period of less than 30 minutes variations exceeding 11 dB were observed.

3 Forest edge measurements

Measurements to determine the acoustic effect of a forest edge were carried out. The primary goal of this study was to determine the noise mitigation potential of a forest edge. Knowledge of the acoustic influence of the forest edge region could lead to strategic placement of fire brakes or training locations to minimize noise from military training ranges. Additionally, more detailed information about this unique propagation environment could be used to enhance signal processing algorithms for acoustic detection devices.

3.1 Experimental setup

The experiment was designed to focus in on the effect of a forest edge on acoustic propagation. To meet this end, a simple-edged, even-aged plantation of *Pinus resinosa* (commonly referred to as Norway or Red pine) was chosen as the test site. Photographs of this site are included in Fig. 3 and Fig. 4, taken from the open field and looking at the forest edge and taken from the forest interior and looking towards the forest edge, respectively. A concentration of microphones was placed in and around a forest edge. Additional microphones in the open and inside the forest were also used, as the differences in propagation among these three environments was of interest (open, forest edge, interior forest). Sources were located in three positions outside of the forest and one inside the forest. A schematic of the experimental layout is included in Figure 5.

This paper focuses on one set of 30 signals generated by a liquid propane cannon (a bird scare-away device). The propane cannon source was a Reed-Joseph International Company SCARE AWAY M-4 LP Cannon (liquid propane cannon). A photograph of this device is in Fig. 6. This device produces impulsive sounds with ample low-frequency energy. This source was placed on the ground, providing an effective source height of 0.62 m. The propane cannon works by filling a bladder with propane and igniting it with a spark. The time between impulses can be set with a dial on the cannon. In this experiment, the time interval was set to 30 seconds. Therefore, 30 samples were recorded within 15 minutes. The source was located outside of the forest at the site labeled BP1 (blast point 1) in Fig 5. Signals were detected using 1/4-inch microphones Brüel & Kjær (B&K) 2639 or GRAS 26AB preamplifiers and B&K 2804 power supplies were used with B&K 4135 and GRAS 40BF 1/4-inch microphones) and recorded on two 16-channel 16-bit Yokogawa digital recording oscilloscopes, model DL750 and using type 701251 voltage input cards. Records were 5 s in duration. Each recorded signal contains 1 s pre-trigger and 4 s post-trigger. The sampling rate was set to 100000 samples/s on each channel. The microphone closest to the source in each case was used to trigger the recording. Microphones were calibrated using a B&K 4228 type pistonphone calibrator with 1/4-inch adaptors before and after each recording session. They were found to be stable.

Three meteorological towers were erected on the site, one in the open, one on the forest edge, and one inside the forest. Locations are marked in Fig. 5 as MO, ME, and MF, respectively. Each meteorological tower was 12.95 m tall. The 12-bit temperature, 8-bit temperature/relative humidity, and cup anemometers were placed at five heights: 2.6 m (8.5 ft), 5.18 m (17 ft), 7.77 m (25.5 ft), 10.36 m (34 ft), and 12.95 m (42.5 ft). The heights correspond to $0.25h$, $0.5h$, $0.75h$, h, and $1.25h$, where h is the approximate height of the trees in the forest interior. In addition to these sensors, pyranometers were installed at a height of approximately 1 m at each site to record incoming solar radiation and therefore derive cloud cover. Barometric pressure, rainfall, and soil moisture were also recorded at each site. For a full description of the experimental set-up and the test site, see [13].

Figure 3: Photograph of the forest edge test site. Taken from the open field looking at the forest.

Figure 4: Photograph of the forest edge test site. Taken from inside the forest and facing the open field.

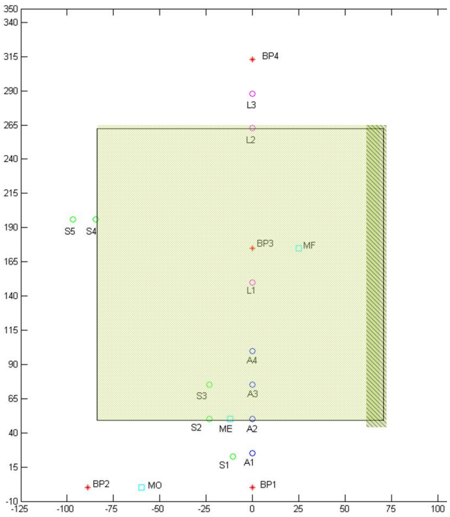

Figure 5: Layout schematic of the forest edge experiment. BP# =source location, A# =microphone array location, S# and L# are additional microphone locations, MO, ME, and MF are meteorology towers located in open, edge, and forest, respectively. The shaded box indicates the forest. Hash marks on the right indicate that the forest continued in that direction. Units are distance in meters, with the origin centered on BP1.

Figure 6: Photograph of the liquid propane cannon source

3.2 Forest edge analysis

Four different metrics are used in analyzing this data: overall unweighted sound exposure level (SEL), overall C-weighted SEL, unweighted peak level, and unweighted 1/3-octave band SEL. This variety of metrics assists in examining different features of the sound propagation. The differences between the maximum and minimum values measured at each location and for overall SEL, overall CSEL and peak level, as well as the standard deviations for each metric, are listed in Table 1. Differences in the energy-based metrics show very little variation over the entire measurement range, particularly in terms of CSEL. This indicates that the total energy is not varying significantly while the signal propagates through the forest. However, in the open field at a distance of 25 m from the source, the peak level varies by more than 9 dB. At the forest edge and into the forest, the spread in levels drops to no more than 5 dB out to a distance of 263 m (the back edge of the forest). Once the signal leaves the forest, the spread starts to increase again. Unfortunately, no measurements were made farther than 25 m beyond the back edge of the forest. The 1/3-octave band representations, shown in Fig. 7, indicate that it is fluctuations in frequencies above 300 Hz that provide variability in the received signal. Since most of the energy in a propane cannon shot is below 300 Hz, the overall SEL representations behave as expected. The peak levels are more influenced by high frequency content, and are therefore more susceptible to changes in the higher frequency bands. Figure 7 indicates that there is very little change in the lower frequencies, as evidenced by the look of a 'trunk' in the spectrum, while the higher frequencies fluctuate more in the open than in the forest. The anomalous spikes seen at locations A3, L2, and L3 are due to background noise of an unknown source.

Location	SEL		CSEL		Peak	
	Δ	std.	Δ	std.	Δ	std.
A1 (25 m)	1.6	0.4	1.7	0.4	9.3	2.5
A2 (50 m)	2.2	0.5	1.6	0.4	4.1	0.9
A3 (75 m)	2.2	0.5	1.5	0.4	4.7	0.9
A4 (100 m)	1.4	0.4	1.4	0.4	4.9	0.9
L1 (150 m)	4.0	0.9	1.3	0.4	4.5	0.9
L2 (263 m)	11.6	3.1	2.7	0.7	4.4	1.2
L3 (288 m)	5.4	1.3	1.7	0.4	5.3	1.4

Table 1: Difference in dB between maximum and minimum levels (Δ) and standard deviation (std.) measured at locations A1 - A4 and L1 - L3 (see Fig. 5) for overall unweighted SEL, CSEL, and peak level.

During the measurement period of interest, the temperature, relative humidity, barometric pressure, and solar radiation were all very stable in the open, at the forest edge, and within the forest. The wind speed increased from 0.5 m/s to 2.2 m/s over the 15 minute period in the open field. Wind direction shifted significantly at the open and edge tower sites during this time as well. However, during the entire measurement period there was negligible change in the meteorological conditions inside the forest.

4 Conclusions and possible implications

Variations in the details of the propagation medium can cause large fluctuations in received level, regardless of distance. The effect is more prominent for very long

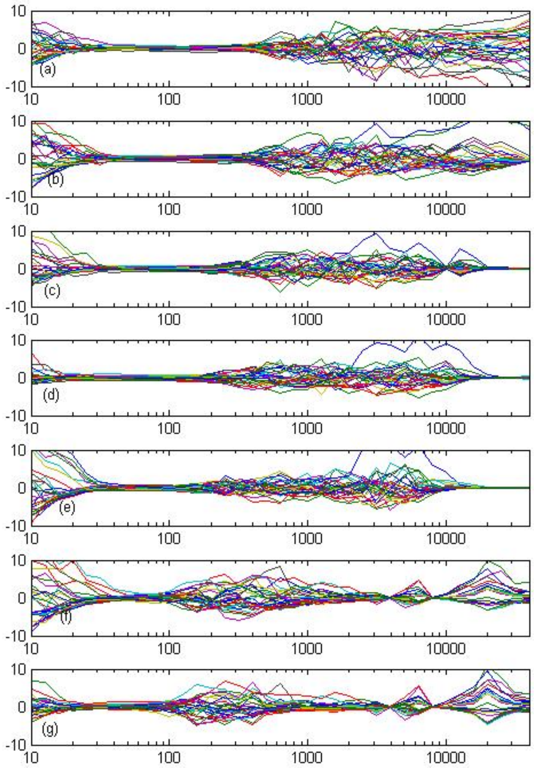

Figure 7: Individual departure (dB) from the mean 1/3-octave band spectrum vs. frequency (Hz) for each microphone position, all 30 shots displayed. The sensors are shown from the top graph downward: (a) A1, 25 m, in open, (b) A2, 50 m, at edge, (c) A3, 75 m, in forest, (d) A4, 100 m, in forest, (e) L1, 150 m, in forest, (f) L2, 263 m, at edge, (g) L3, 288 m, in open.

distances, such as the 7 km site discussed in Sec. 2. In this case, the measured variation between minimum and maximum values was greater than 10 dB. The most probable cause for these variations is turbulence. This is significant because noise regulations often cite a "not to exceed" level. Care must therefore be taken in ensuring that a sufficient number of measurements are made to truly capture the range of possible levels. However, just how many measurements constitute a "sufficient number" is still an open question.

Measurements taken within the forest reveal a very stable measurement environment. This is attributed to the extremely stable microclimate within the forest. The variability present in the open field indicates that there was some variability in the propagation medium (for example, turbulence). The implication here is that measurements taken within a forest for a source in the open will yield consistent results. Therefore, a small number of measurements is likely sufficient to determine the expected range of levels.

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