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# AN OPEN DATABASE ON PROPAGATION OF LOW FREQUENCY IMPULSE NOISE IN THE ATMOSPHERE

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ABSTRACT
This paper describes four sound propagation experiments which were undertaken in Norway from 1994 to 1996. Trials were carried out at Finnskogen; a long range site, and at Haslemoen; a short range site. Summer and winter conditions were investigated at both sites. Two similar experiments were carried out at each site with and without snow cover. At Finnskogen, an experimental array of 24 by 24 km was set up, in a terrain with smooth hills, primarily covered by forest. At Haslemoen, propagation was investigated out to 1.5 km above a uniform forest and a uniform, flat open field of pasture land. One, 8 and 64 kg cylindrical charges of C-4 explosives were used as sound sources. Measurements of acoustics, seismic ground response, complex ground impedance and meteorology were carried out simultaneously. This paper gives an overview of the experiments and presents examples of data. Literature for further details is referred. An easily accessible database with all data will soon be available. The database will be a valuable tool for development, validation, and refinement of sound propagation models. The structure of this database is outlined.

## 1. INTRODUCTION

Sounds produced by military training activities can cause annoyance and have detrimental effects on civilian personnel and on wildlife or domestic animal populations. The effect of these activities can be mitigated by selecting training locations and times where propagation of the produced noise is minimised, but even then a reliable understanding and ability to predict the noise propagation is needed. Much data has been obtained for propagation above surfaces such as grass, concrete and water.[1] However, although there are a number of acoustic models in routine use for this purpose, none of the current models include the effects of typical winter ground conditions (including snow cover) and/or forest vegetation, and the temporal variation of these conditions that are especially important in northern regions. The goal of this project, referred to as the *Norwegian Trials* is to obtain experimental data of low frequency impulse noise propagation and to develop models capable of providing accurate predictions under realistic environmental conditions. Also important is a good understanding of the variation with height of meteorological conditions, since the weather greatly affects the propagation of sound waves.

The Norwegian Defence Construction Service initiated and largely sponsored this series of trials, which were carried out in co-operation with agencies from Norway, Germany, UK, and the USA.

## 2. THE EXPERIMENTS

The trials were carried out in Hedmark county, NE of Oslo, close to the Swedish border at approximately 60 °N, 12 °E. The short range trials were conducted close to the Haslemoen army camp SE of Elverum, while the long range trials were conducted at Finnskogen, E-SE of Elverum. One, 8 and 64 kg unconfined cylindrical charges of C4 explosives were used as sound sources. The TNT weight-equivalent of these charges is about a factor of 1.32 times the mass of C-4. The central frequencies of the signals were approximately 20 to 30 Hz, with most of the energy contained below 100 Hz. More than 500 shots were detonated and more than 10,000 separate recordings were made. A more detailed description of the procedure followed during the trials is given by Kerry.[2]

### Description of the short range site and trials

The largest effort in this experimental series was to perform the long range trials. To prepare for these, a smaller scale experimental series was carried out at Haslemoen, in a uniform forest of pine trees, and above a flat and uniform open field. The main intention of these experiment was to verify equipment capabilities and to establish procedures for the long range trials. Another objective was to obtain a set of reference data over flat and uniform terrain during both summer and winter conditions. However, the data has also inspired an independent analysis, presented in a number of papers prepared by the participating agencies.[2-6] A plan view of the experimental lay-out is shown in Fig. 1. For the summer trial, in June 1994, the plan was to detonate 1 and 8 kg C-4 charges, along a north to south line at a bearing of 341°, between the north and south forest acoustical towers, indicated as *Nf* and *Sf* in Fig. 1. However, due to fire hazards, the line had to be moved adjacent to a gravel road just east of the forest. The 30 m acoustical towers were remained in the forest. Thus, propagation of the wave into the forest was studied. During the winter trial, in February 1995, charges were detonated along parallel lines in the forest and over an open field, also as shown in Fig. 1. One shot series was completed within 30 minutes.

### Description of the long range trials

In the Finnskogen area the ground is undulating, with a series of 100 m high ridges running NW to SE, rising gradually from the river Glåma to the Swedish border. Intervening valleys are silt-filled, with areas of marshland and lakes. A cross shaped array was set up as shown in Fig. 2. The north axis was directed toward true north. Shot points are indicated as x.xx, where the two decimals indicates the distance from the central point in km. The vegetation is mostly coniferous forests, but some deciduous forests are present in the northern parts. One set of experiments was carried out in September 1994, and to study the effect of a snow cover the experiments were repeated in February 1996. Normally, detonations followed a common

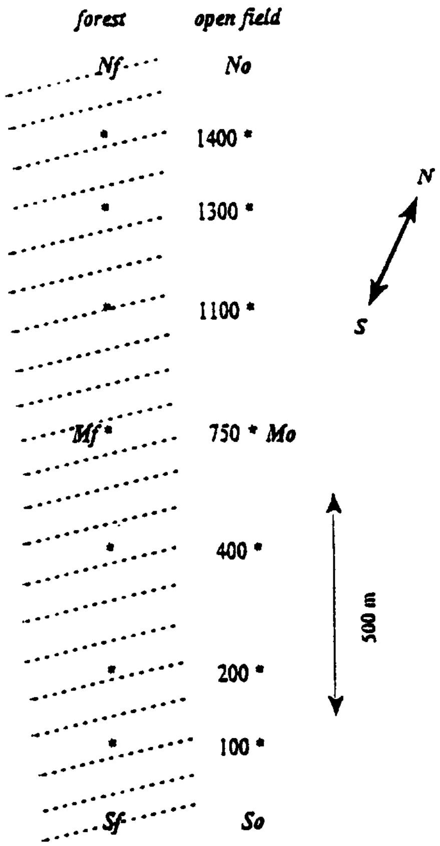


Figure 1. Plan view of short range trial.

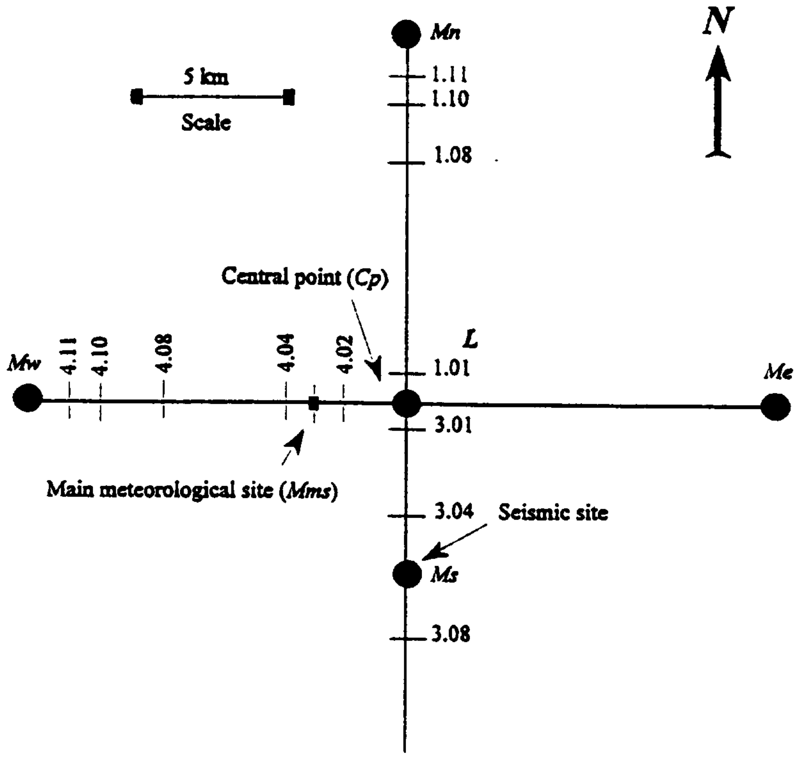


Figure 2. Plan view of long range trial.

sequence, along the north-south axis from positions 1.11 to 3.04 or along the west-east axis from positions 4.11 to 4.01, with three minutes intervals between each shot. This sequence was repeated at least three times ineach direction. To study the effect of different pressure wavelengths, 1, 8 and 64 kg charges of C-4 were detonated first at location 1.08 and then at location 3.08. During the winter trials, identical weight charges were also detonated at location 4.02 in a rapid sequence, to study the effect of weather variability.

Acoustical measurements

Acoustical measurements on either or both trial sites were carried out by: University of Salford (UoS), UK, US Army Corps of Engineers Construction Engineering Research Laboratory (CERL), US Army Cold Regions Research and Engineering Laboratory, (CRREL), Institut für Lärmschutz (IfL), Germany, Norwegian Geotechnical Institute (NGI), Norwegian Defence Construction Service (NDCS) and Applied Research Associates (ARA), USA.[3]

On the short range trials, masts, up to 30 m in height, for microphones were erected at *Nf*, *Sf*, *No* and *So* as indicated on Fig. 1. Equipment was manned by personnel from UoS, ARA, NGI and NDCS. Typically, B&K sealed microphones were used, followed by 2639 preamplifiers, and signals were recorded on multi-channel DAT recorders, with 20 kHz bandwidths. Data sampling frequency varied due to the digitisation rates used by the individual recording agencies, however it was usually 12.8 kHz. Table 1 shows the locations of the microphones at the different stations. (Note: Index *f* and *o* represent forest and open field, respectively.)

On the long range trials, masts for microphones were erected at *Mn* (CERL), *Me* (IfL), *Ms* (NGI), *Mw* (IfL) and *Cp* (UoS, ARA & NDCS). The instrumentation used was similar to the short range trials, except a higher quantity. Table 1 also shows the locations of the microphones at the different stations for these trials. (Note: Indexes *n, s, e, w* represent north, south, east and west respectively and *Cp* represents the centre point.)

Table 1. Microphone Heights at Measurement Locations.

| | TRIALS | | | |
|---|---|---|---|---|
| | Short | | Long | |
| | Summer | Winter | Summer | Winter |
| Height (m) | | | | |
| 0 | *Nf* | *Nf, Sf ,No, So* | *Mn, Ms, Mw, Cp* | *Ms, Mw, Cp* |
| 1 | | *Sf, So* | *Mn, Me, Ms, Mw* | *Mn, Me, Ms, Mw* |
| 2 | *Nf, Sf* | *Nf, Sf, No* | *Mn, Me, Ms, Mw, Cp* | *Mn, Me, Ms, Mw, Cp* |
| 4 | *Nf, Sf* | *Nf, Sf, No, So* | *Mn, Me, Ms, Mw, Cp* | *Mn, Ms, Mw, Cp* |
| 8 | *Nf* | *No, So* | *Mn, Me, Ms, Mw, Cp* | *Mn, Ms, Mw, Cp* |
| 16 | *Nf, Sf* | *Nf, Sf* | *Mn, Mw, Cp* | *Mn, Ms, Mw, Cp* |
| 24 | *Nf* | | *Cp* | |
| 30 | *Nf, Sf* | *Nf, Sf* | *Mn, Cp* | *Mn, Ms, Mw, Cp* |

Seismic measurements

The majority of the seismic measurements were conducted by NGI, however additional measurements were made by CRREL.

On the short range trials, seismic measurements were carried out close to the *Sf* and *So* positions. For measurements of horizontal and vertical particle velocities, accelerometers were placed on the surface and at different depths in the soil. During the winter trial, accelerometers were also placed in the snow and at the snow surface. Microphones and geophones were as well placed on the ground and snow surfaces, and in the snow. This data was recorded on a digital system with a frequency of 4000 Hz. Since the ground motion waves are fairly long and the sharp wave discontinuities are smoothed out by the earth, this sampling rate should be adequate for the required resolution. However, the data was "back-up" recorded on an analogue tape system which will contain higher frequency components, if required. During the long range trials, similar seismic measurements were carried out, but with more extensive instrumentation, at position *Ms*.

Figure 3 shows a typical recorded pressure and ground velocity time history from the short range winter range trials. Conditions were *superseismic*, which means that the air pressure wave travels faster than the ground waves.[6] Ground motions appear after the air pressure wave arrives. Conditions at the long range site were typically *transeismic*, which means that the media's sound speed is between the ground's shear wave and compressional wave speeds. Understanding the air-ground interaction for different ground types is essential when predicting annoyance at these low frequencies, partly because ground transmitted waves might cause building vibrations.

In addition, profiles of ground density and compressional and shear wave speeds for the different sites, were obtained using a Spectral Analysis of Surface Waves (SASW) method.[7, 8] These measured parameters serve as input in many sound propagation models.

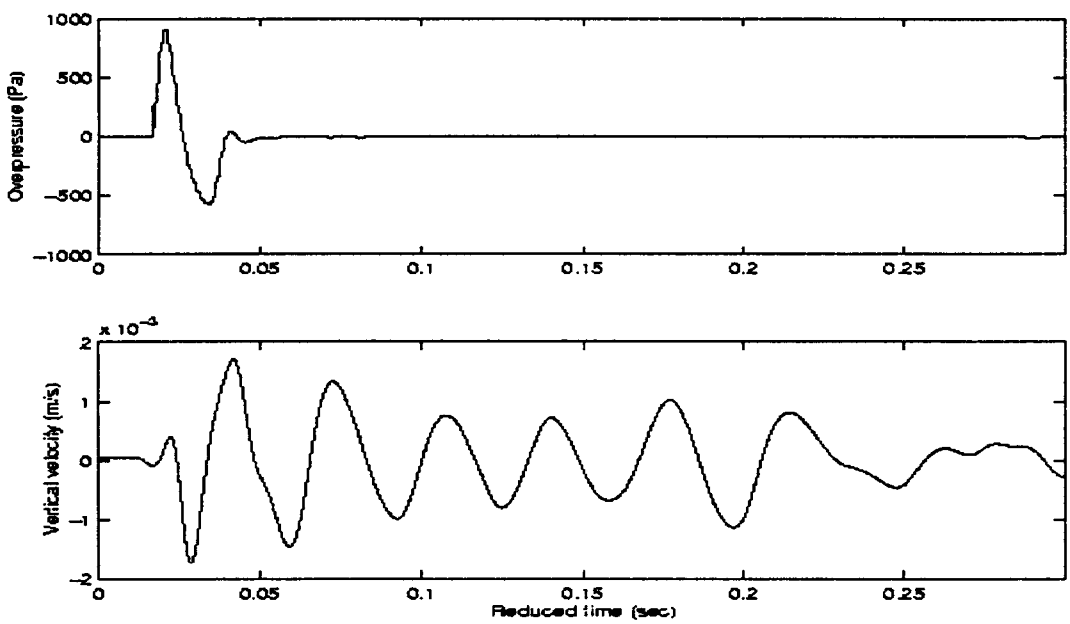


Figure 4. Typical recorded overpressure and vertical particle velocity at the snow surface, 100 m from a 1 kg charge detonation. Haslemoen winter trial, February 1995. Data provided by UoS and NGI.

Surface classification

A quantitative classification of the surface, at both test sites was performed by the Sintef DELAB,[5] Norway, CRREL, and NGI.

Complex impedance of the ground and snow surfaces as a function of frequency, was measured at different locations at the two sites by Sintef DELAB. Both *in situ* measurements and indirect impedance tube measurements were carried out, applying different methods, for the sake of comparison. Some pioneering work on measurements of ground impedance for infrasound frequencies has been carried out in this investigation. Figure 3 shows two plots of the acoustical impedance of the natural surface and a snow covered surface. CRREL measured the different essential snow parameters, such as depth, permeability (flow resistivity) and porosity. In addition, NGI performed a general classification of the natural surface of the ground, including snow on the ground and on the trees, as well as using ground penetrating radar to determine profiles of snow depth and density.

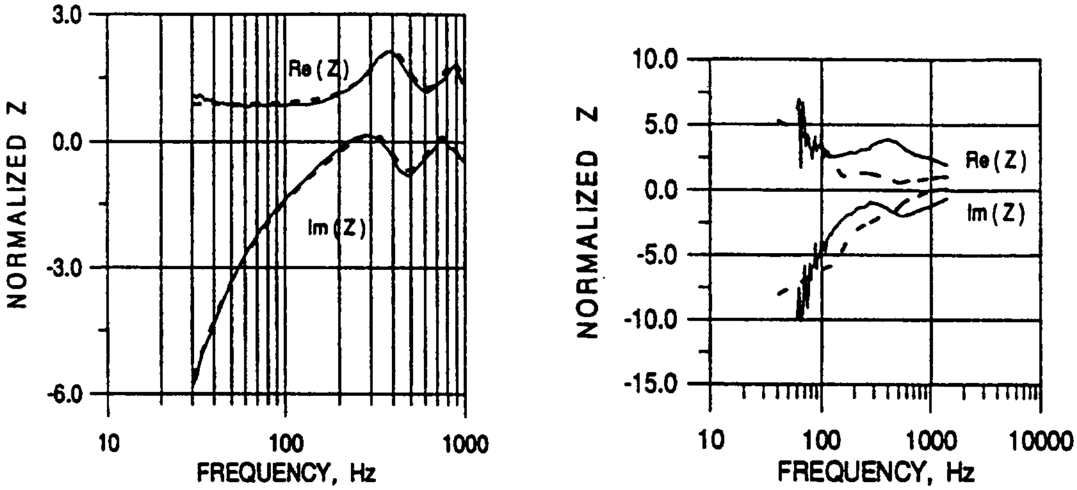


Figure 4. Plots of measured acoustical impedance, *Z*, of snow surface (left) and dry forest floor (right), measured with different methods. *Z* is normalised to the specific air impedance. Data provided by Sintef DELAB.[5]

Forest classification

A classification of the vegetation at both of the sites is currently in preparation by Sintef DELAB and NDCS.

Meteorological measurements

A variety of extensive meteorological measurements were made the University of Bergen (UoB), Norway, CREL, and the NDCS. Mainly, three basic types of instruments were used: Aanderaa Automatic Weather Stations (AWS), a tethered balloon (the Tethersonde from Appl. Tech. Inc.), and radiosondes. The AWS were placed on masts and wooden towers (Table 2 shows the measuring heights). Wind speed and air temperature were measured at each height, while wind direction was measured at the greatest height at each station. Sampling intervals were every 10 minutes. The Tethersonde measured wind speed, wind direction, air temperature and height above ground. Sampling interval was 11 seconds. The balloon could be launched at any desired speed, but a hysteresis effect and drifting had to be taken into account. The balloon was launched at position *M* at the short range site. At the long range site, it was launched at points *Mms*, *Cp* (summer only) and *Mn* (winter only). In addition to the above, turbulent fluctuations of wind and air temperature were measured with an ultrasonic anemometer and thermometer at a few heights at each site.

Radiosonde data are available above 1000 m. These are probably relevant for a study of propagation at the longest ranges.

TABLE 2 Locations and heights of Automatic Weather Stations at the two sites

| Haslemoen | | Finnskogen | |
|---|---|---|---|
| position | heights (m) | position | heights (m) |
| *Nf* | 2, 10 & 30 | *Mn* (1.12) | 2, 5, 10 & 30 |
| *C* | 2, 10, 14, 18 & 25 | *Mw* (4.12) | 2, 5, 10 & 30 |
| *Sf* | 2, 10, 15, 19 & 25 | *Cp* (0.0) | 2, 5, 10 & 30 |
| *M* | 2, 5 & 10 | L | 2, 5 & 10 |
| | | *Mms* (4.03) | 2, 5, 10, 15 & 24 |

(Note: Positions refer to Figures 1 and 2. *L* was used only during the summer trial.)

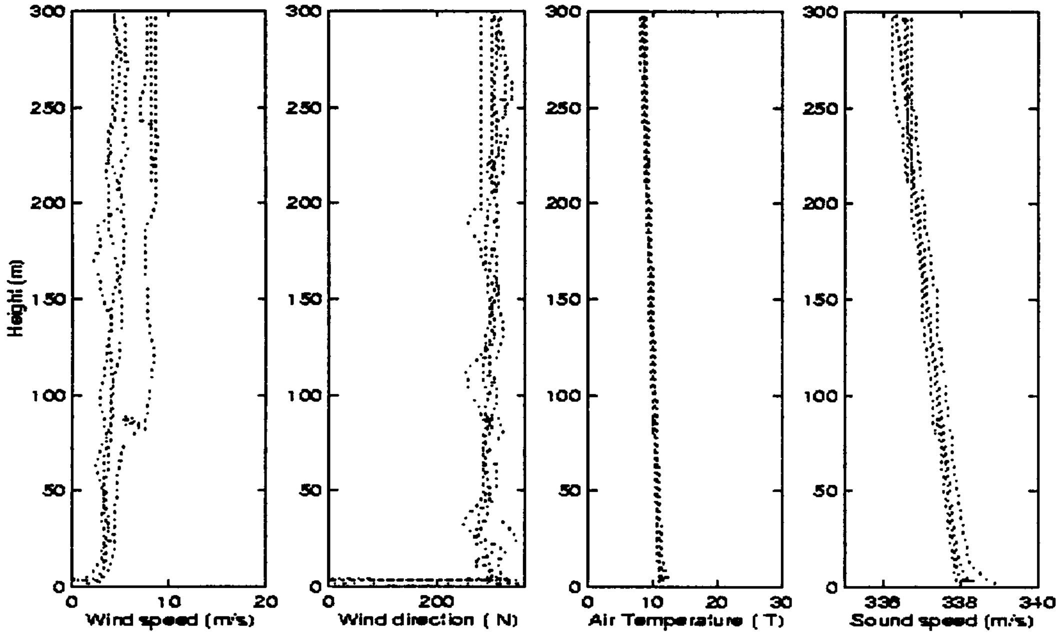


Figure 4. Meteorological profiles measured by the Tethersonde at Haslemoen, 15 June 1996 from 1808 to 1922, local time (UTC + 1hour). The profile at right is the resulting directed sound velocity profile towards true north.

## 3. THE DATABASE

The completion of these tests resulted in over 10,000 separate data sets for the acoustical time histories only. When individual data points, such as the impedance measurement and forest characterisation and the meteorological recordings are added the total amount of information rises quickly. A major problem was that several different agencies recorded data and this was done on their equipment. Therefore, there were as many different data formats as there were agencies. All data were assembled and converted into a common format so any of the data could be easily used by any one person. However, having the data alone is not sufficient.

Additional information is needed to inform the user how the data was obtained, how it is related to other data, specifics on the individual measurement, how the data was processed, etc. In order to meet these extensive requirements by non-involved personnel, the data is being installed in a database.

The database will be relational and based on Microsoft's Access program. Tools will be built into the database which will allow users to view the data and perform a limited amount of processing. By the user asking a question to the database interrelated data may be easily retrieved. A knowledge of relational databases will help the user in navigating through this vast amount of information.

## 4. CONCLUDING REMARKS

The purpose of this paper was to present an overview of a sequence of four long range sound propagation experiments that was undertaken in Norway from 1994 to 1996. Data are currently being analysed by the participating agencies, but will be made available for anyone who desire to develop and verify sound propagation models, or just study the phenomenology involved. All data from these experiments will be easily accessible in an open database. More information about the data will soon be able to be found on a world wide WEB site that is currently under construction.

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