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METEOROLOGICAL MEASUREMENTS DURING NORWEGIAN TRIALS

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ABSTRACT

During "Norwegian Trials" extensive meteorological measurements have been carried out. Wind velocity and air temperature were measured at different levels and locations, both within Haslemoen, the short range trials site, and at Finnskogen, the long range trials site. Experiments were carried out during summer and winter conditions at both locations. In the forest, meteorological parameters were sampled both below and above tree tops, and turbulent fluctuations of wind and temperature were measured by a sonic instrument. In addition, a tethered balloon was used to measure variations of wind and air temperature in the lowest 1000 metres of atmosphere.

Data from the forest show patterns which are well known from forest meteorology. In fair weather conditions, vertical temperature gradients have opposite signs above and below tree tops. Wind speed has a minimum at the level where the forest is most dense. These phenomena are interesting when studying medium range sound propagation in forested terrain.

Meteorological parameters have a major influence on sound propagation in the atmosphere. It is demonstrated that weather causes a great variation of sound levels along ground.

Measurements by tethered balloon resulted in a manifold set of sound velocity versus height profiles. Pure upwind and downwind situations were encountered, together with classical morning inversion breakups. However, in many cases, profiles were extremely complicated, with large gradients caused by both wind and temperature. This shows that one should not uncritically use simple profile parameterizations, such as logarithmical, in propagation models.

1. INTRODUCTION

A group from Geophysical Institute at University of Bergen was responsible for meteorological measurements during these trials. Seldom have such extensive meteorological measurements been carried out during atmospheric sound propagation experiments and, hopefully, these trials will give new insight to a research field which is in strong progress. Data from these measurements will be incorporated and available in an open database with all data from the trials which will be established in the future.

At Haslemoen and Finnskogen propagation ranges of up to 1400 and 24000 metres, respectively, were studied. At these ranges, it is possible only to measure time average values of relevant atmospheric variables which are absolute air temperature and wind speed and direction. Fluctuations of these variables can not be measured over the entire propagation path in a reliable and adequate way. At Haslemoen, the ground was flat and homogenous along the propagation path, so that horizontal homogeneity of wind and temperature can be assumed. At Finnskogen, this was not the case, and how this should be treated in future theoretical studies is still an unsolved problem.

For modelling purposes the most relevant atmospheric parameter is directed sound velocity, V. For absolute air temperature T and horizontal wind speed U it is defined by,

$$V(z) = c_0\sqrt{(1 + T(z)/273.15)} - U(z)\cos[\alpha(z) - \beta], \qquad (1)$$

with c_0 the adiabatic sound speed at T = 273.15 K, α the wind direction (from which the wind blows), and β the source to receiver bearing.

2. INSTRUMENTATION

In the lowest 30 metres of the atmosphere, measurements were carried out with Aanderaa Automatic Weather Stations (AWS). Thermometers and wind sensors have accuracies of ± 0.1 K and ± 0.2 m/s, respectively. Table 1 shows sampling levels

Haslemoen		**Finnskogen**	
Station/location	Levels (m)	Station/location	Levels (m)
Mast north	2, 10 & 30	"1.12"	2, 5, 10 & 30
Central Tower	2, 10, 14, 18 & 25	"4.12"	2, 5, 10 & 30
South Tower	2, 10, 15, 19 & 25	"0"	2, 5, 10 & 30
Mast Open Field	2, 5 & 10	"1.1"	2, 5 & 10
		"4.03"	2, 5, 10, 15 & 24

Table 1: Locations of AWS at the two sites

at each station for the two experiment sites [1].

Thus, the profiles close to the ground were sampled with a high resolution. At forest stations, one sensor level was always chosen to be close to the tree-tops. Wind direction was measured at the highest level at each station. Sampling intervals were 10 min.

A sonic instrument from Appl. Tech. Inc. (SWS) was used to measure fluctuations of air temperature and wind components in and above the forest, at the central tower at Haslemoen and at the sand pit at Finnskogen. The accuracy of this instrument is ± 0.05 m/s for wind speed and ± 0.05 K for temperature fluctuations. A qualitative picture of turbulence level development can be obtained from these measurements, but one should keep in mind that these measurements are from one single point in space only. The SWS sampling frequency is 10 Hz.

In addition, a Tethersonde balloon was used to measure wind and temperature in the lowest 1000 metres of atmosphere. Every balloon flight cycle took less than 1 hour, and in most cases about 30 minutes. Height resolution is better than 10 metres. These balloons should not climb too quickly, since that could reduce data accuracy. Radiosondes were applied during the Finnskogen trials, but these data are not presented here. Radiosonde data from Gardermoen airport are available for all trials.

A complete description of meteorological instrumentation during all four experiments, can be obtained from the authors [2].

3. GENERAL WEATHER CONDITIONS DURING THE TRIALS

In the Haslemoen summer test in June 1994, fair weather with light winds was experienced most of the time. However, strong low level jets (100-200 m AGL) were observed in some cases. These appear graphically as "discontinuities" in wind and also temperature profiles. Such transient phenomena are impossible to forecast, and will have great influence on sound propagation in the downwind case, where they will cause enhancement and even focusing of sound. In the winter trial at Haslemoen in February 1995, fair weather and light winds prevailed while studying propagation above forest, and morning temperature inversions were present. While studying propagation above an open field, clouds and precipitation were present, and mean winds increased up to 8-9 m/s. For two of the shot series, winds were so strong that the Tethersonde could not be launched. The situation became less stationary and more turbulent, and thus average values are less representative and reliable. Low level "discontinuities" of wind and temperature were present this time as well. They were not of a transient nature, but persisted for hours.

Finnskogen summer trials in September 1994, and winter trials in February 1996 lasted two weeks. Periods of both cloudy weather with a neutrally stratified atmosphere and clear skies with big diurnal variations in atmospheric stratification were encountered this time. Wind speed was low most of the time. The fair weather periods were characterized by cold nights and mornings with strong inversions in the lowest 300-500 metres, destruction from below in daytime, and very light winds. The strongest inversions normally appear just after sunrise. Figure 1 reveals a classical example of morning inversion breakup, as recorded by Tethersonde at 21 September 1994. Both ascent and descent data are presented. The figure clearly demonstrates how the ground is heated by solar radiation and how the statically unstable air close to ground penetrates deeper and deeper into the inversion and is destroying it from below. Air close to ground increases its temperature with a rate of approximately 2 K/hour in this period. At 12.30 the atmospheric boundary layer stability is very close to neutral (constant potential temperature). During this process, while winds are almost negligible, propagation conditions are well defined. Some of the acoustical data obtained will be useful for correlating sound levels with different inversion strengths.

4. EXAMPLES OF DATA OBTAINED

In this section, examples of meteorological data obtained during the trials are presented. AWS data from the forest revealed that the canopy layer was so dense that the tree tops worked as an active surface. This means that, in clear sky situations, most of the solar radiation is absorbed by the forest close to the tree-tops and does not penetrate down to the ground. When tree tops and the surrounding air are heated, stratification in the forest becomes stable, since the ground keeps its temperature, and downward directed turbulent heat flux is prevented. At night, the tree tops are cooled by longwave radiation, and stratification becomes unstable. At the same time, an inversion forms in the atmospheric boundary layer above the tree tops. Figure 2 shows how vertical temperature gradients above and below the tree tops are of opposite sign or different strength in many cases, even during the Haslemoen winter

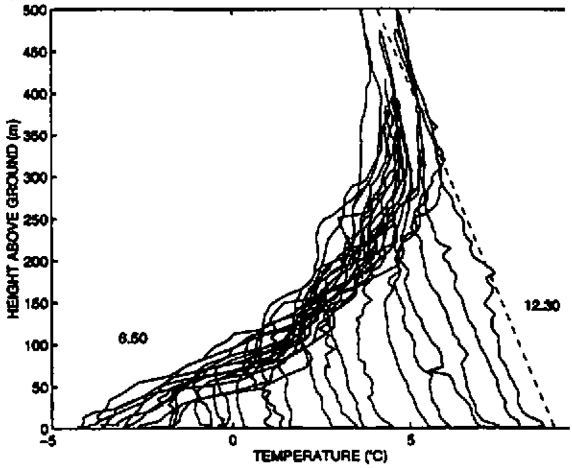

Figure 1: Morning temperature inversion breakup at Finnskogen, 21 September 1994.

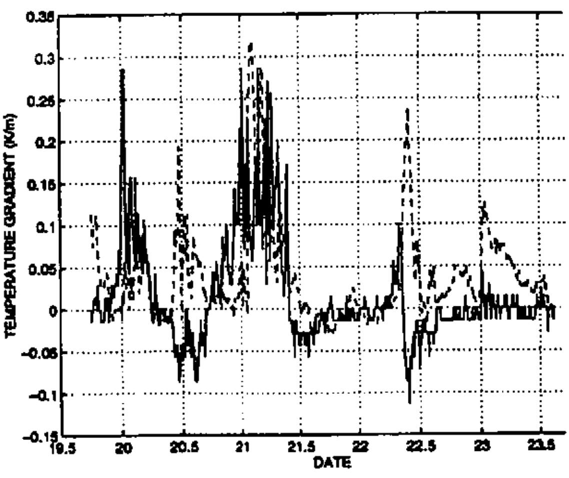

Figure 2: Vertical temperature gradients above and below the tree tops at the central tower at Haslemoen from 19 February 5.20 p.m to 23 February 2.40 p.m.
Solid line: $(\Delta T/\Delta z)_{2-18m}$, dashed line: $(\Delta T/\Delta z)_{18-35m}$.

trials, when solar radiation was moderate. The large fluctuations observed are mostly caused by variation in air temperature close to the tree tops at 18 m AGL. These have relatively low heat capacity and wind gusts will cause rapid cooling. Temperature at 25 m. and especially at 2 m. varies more slowly.

As mentioned above, SWS data can give a qualitative picture of the degree of atmospheric turbulence. Production of turbulent kinetic energy per unit mass, *TKE*, is defined by,

$$TKE = 1/2[\overline{u'^2} + \overline{v'^2} + \overline{w'^2}], \qquad (2)$$

i. e. *TKE* is proportional to the sum of variances of the three wind components. An average is taken over 10 minutes. Figure 3 shows values of *TKE* as measured by the SWS at the central tower, just above the tree tops during the Haslemoen winter trials in February 1995. It clearly appears how *TKE* increases dramatically in the last two days when mean wind speed increased by a factor of 2-3, as described in Section 3.

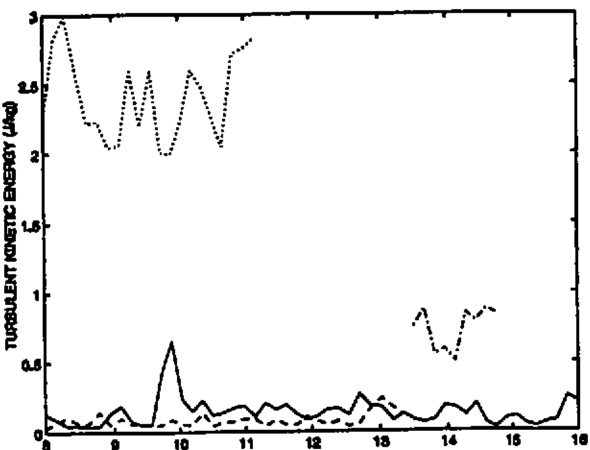

Figure 3: Values of TKE observed close to the tree tops at central tower during Haslemoen winter trials, 1994. Solid line: 20 February, dashed: 21 February, dash-dot: 22 February, dotted: 23 February.

Since each shot series, even at Haslemoen, lasted for about 30-60 minutes, averaging in time and space of Tethersonde and AWS data had to be carried out for later theoretical treatment. This work has been carried out by JWR Inc., New Mexico [3]. When average profiles are available, one should still not forget about the raw data. Discrepancies in future theoretical studies might be explained by "discontinuities" in the profiles which were partly smoothed out by averaging. These average profiles are presented here as sound velocity, *V*, defined in Eq. 1. Examples of sound velocity profiles for propagation toward north tower and south tower, respectively, during the Haslemoen winter trials are presented in Figure 4, for ten shot series. These profiles are associated with many types of weather conditions as described in Section 3, and a manifold of sound velocity profiles is revealed. This figure clearly documents that smooth, logarithmical profiles which appear from applying similarity theory, will not describe the propagation conditions well here.

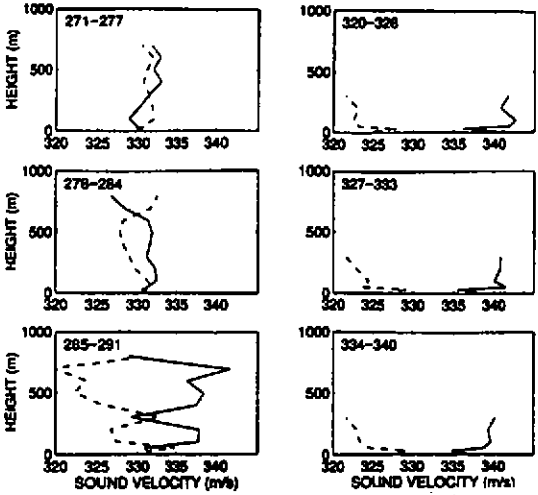

Figure 4: Profiles of V for ten shot series during Haslemoen winter trials, 1994. Solid lines: V toward north tower, dashed lines: V toward south tower. Numbers indicate the shot series.

As can be expected, transmission losses observed during this trial have large standard deviations. For the Haslemoen winter trial, an example is shown in Figure 5 for four frequencies and all measuring ranges. This figure contains data from all shot series carried out during the trial, above both forest and open field. Source height is 2 m. and receiver height is 4 m AGL. When data from the two sites are separated, the picture is similar (not shown here). It is interesting to note that, for the two lowest frequencies, standard deviation does not increase with distance. This observation indicates that these are less affected by meteorology at these ranges. Acoustical data presented here were sampled by Dept. of Applied Acoustics, University of Salford, UK.

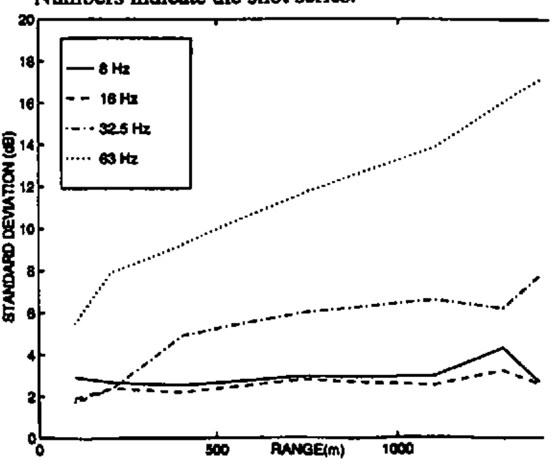

Figure 5: Standard deviation of transmission losses as a function of range for all shot series during Haslemoen winter trials, 1994.

End Notes and References

[1] A complete description of experiment layout is given by University of Salford at Internoise'96.

[2] Described in four technical reports by T. de Lange and L. R. Hole.

[3] Jack W. Reed. JWR Inc. Albuquerque, NM, fax: 1-505-2654731.