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CASE STUDY: FINNSKOGEN TRIALS, 14 SEPTEMBER 1994

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ABSTRACT

Airblast pressure measurements of sixteen 8-kg C-4 explosive charges, fired on 14 September 1944, at Finnskogen, Norway, have been analyzed for their propagation dependence on measure weather conditions. Pressure signatures were obtained from gages at five station locations on a cruciform array, from shot locations at various points along the north-south axis. Shot-to-gage distances ranged from 1 km to 17 km Weather measurements were assembled from a 30 m micrometeorological tower, Tethersondings to 1 km height, and radiosondings to higher altitudes. This trials phase was to investigate airblast propagations over hilly terrain, with 300 m variations, during summer ground conditions.

Sixteen explosions of 8-kg C-4 were fired along a north-south line near Finnskogen, Norway, on 14 September 1994, with airblast measurements at three locations along the line, as shown by the terrain cross-section in Figure 1. Shot series of five shots at about 3-minute intervals were fired beginning at 0910 UTC and 1000 UTC times, with a six shot series at 1040 UTC. Firing sequences began at the north end and progressed south.

Weather conditions were measured on a 30-m mast at the Center Station and by Tethersonde ascensions to roughly 1 km above the surface, with radiosonde balloon observations to higher altitudes. Temperatures and winds at altitudes were used to calculate directed sound velocity (DSV) versus height curves for each of the three series, as shown in Figure 2. Below 1400-m MSL, light, generally northerly winds caused a moderate *inversion* in DDS to duct southbound airblast, and a DDS *gradient* to refract northbound sounds upward, away from ground. Winds changed relatively little throughout this firing period. Note, for subsequent reference, that near-calm conditions at 1400-m MSL, give a DSL only 2 ms $^{-1}$ lower than the surface value. A small increase in near-surface northerly wind component and/or a decrease at 1400-m MSL could create a complex, dog-leg refractive structure that could enhance or even focus airblast at long ranges, typically about ten times the ducting layer depth.

Wind-ducted, *southbound* waveforms that were recorded at Center and South Stations, for the various shots are shown in Figure 3. Pressure measurements were made at several heights above ground, but no clear and coherent height dependence has been established from these or other similar test events. Therefore, only 30-m mast-top measurements are shown at Center and North Stations, and 8-m (shorter installed mast) at South Station. In a first-order attempt to normalize these figures, pressures (Pa) were multiplied by gage distances (km), so that for loss-less *acoustic* propagations, graphed amplitudes would be constant for all shots and gages. If a Standard Explosion shock decay rate were used for normalizing, it would have shown about 7% lower pressures at 2 km, 25% at 7 km, and 32% at 16 km range, and not particularly significant to this qualitative review.

At Center Station, there was moderate excess attenuation with distance, whereas inversion ducting might well have shown some propagation enhancement. The wave train was lengthened and collected more oscillatory cycles as it traveled. The second peak, which follows the first negative phase, appeared to travel about 1.5 ms^{-1} slower than the arrival time, but because records were not all made with an absolute time base, only relative speeds can be estimated for the time coordinate. Actually, from acoustic ray tracing calculations, earliest arrivals should come from the upper levels of an inversion with slower propagations following closer to the ground. Terrain appears, however, to have attenuated first arrivals more than subsequent oscillations, contrary to effects expected from the cross-section in Figure

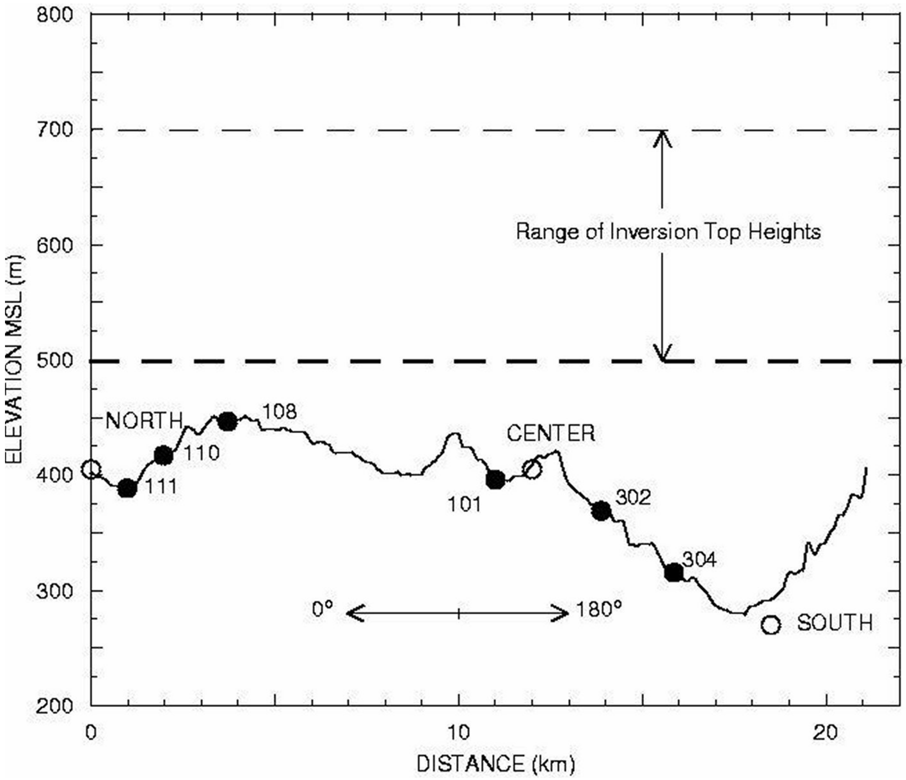

Figure 1: Terrain elevation cross-section north-south axis, with six shot points and three gage stations.

1. Another interesting feature is that ray calculations show that delay should be about one-third of the 4-5 ms^{-1} inversion strength, in agreement with curves in Figure 2.

At South Station, at relatively low elevation, pressures were much weaker than at Center. This could be expected from terrain blocking of more distant measurements. Excess attenuation of 2-4 km propagations, however, must be attributed to details of wind flow over the terrain down-slope, because there is no interfering terrain shown by Figure 1.

Northbound propagations, in generally upwind gradient conditions, are shown in Figure 4. Very weak waves were recorded at the Center Station, clearly blocked by the uphill terrain. North Station records at 1-2 km (N-1, N-2), were attenuated in gradient propagation as compared to C-1, but not so much when compared S-2. By N-11, however, gradient attenuation was clearly strong by reference to C-11, becoming comparable to S-7 to S-17. Then by N-16 wave amplitude jumped up becoming comparable with C-11. This apparently demonstrated a ray convergence from focusing that was suggested by Figure 2 near 1400-m MSL from an undetected wind variation.

In conclusion, airblast measurements on this date can generally be explained qualitatively by consideration of weather observations and terrain. There were a couple questions left open for exploration, using other trial days, to determine whether apparent anomalies were repeatable or random statistical variations.

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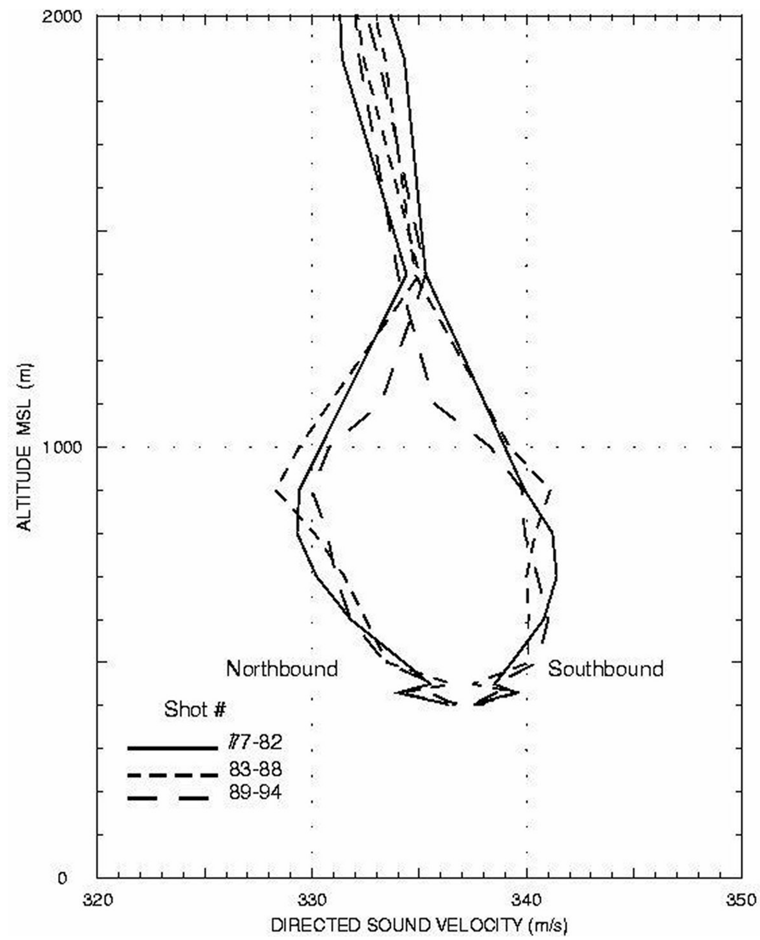

Figure 2: Sound velocities to N, C, S gages.

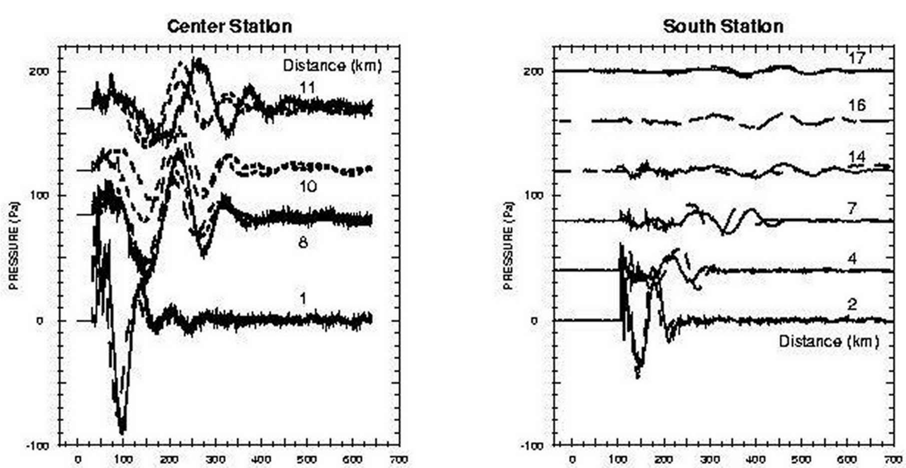

Figure 3: Pressure X Distance, southbound Shot#077-094 8-kg C-4.

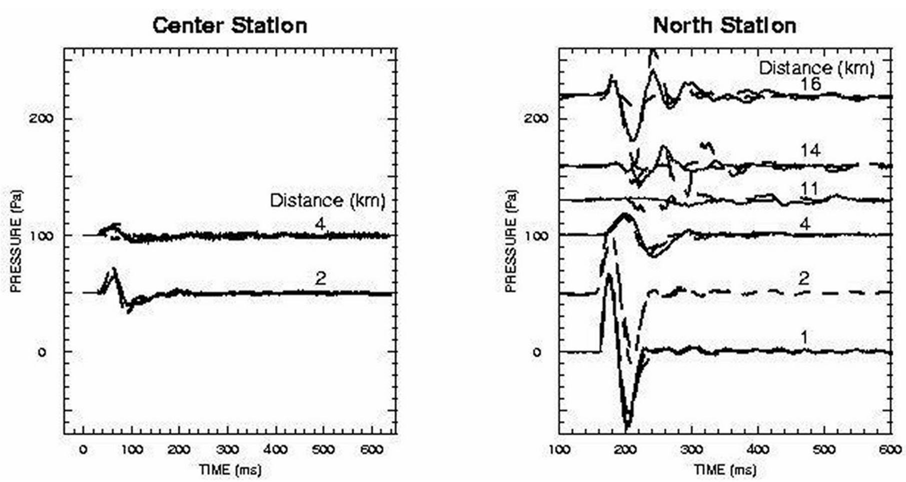

Figure 4: Pressure X Distance, northbound Shot#077-094 8-kg C-4.