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Infrasonic Signals from an Accidental Chemical Explosion

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BACKGROUND

A series of large accidental explosions occurred at a chemical plant in Henderson, Nevada on May 4, 1988. The explosions were produced by the ignition of stores of ammonium perchlorate produced for solid rocket fuel at the Pacific Engineering and Production Co. This material, prior to the incident, had been believed to be non explosive. The blasts destroyed the plant and caused one death. There was a series of explosions over a period of time with two major explosions which we will identify as A at 18:53:34 (all times herein will be given in C.U.T.) and B at 18:57:35. J. W. Reed (1992) provides further details of the explosions in his report on near-field blast damage. Signals from events A and B as well as smaller events were detected by the infrasound arrays operated by the Los Alamos National Laboratory at St. George, Utah (distance 159 km) and at Los Alamos, N.M. (distance 774 km).

EQUIPMENT

The two infrasonic arrays are operated in a continuous mode and thus were able to monitor these explosions. Both arrays utilize 100C microphones produced by the Chapparal Physics Co. There were five microphones at St. George and four at Los Alamos. The microphones are connected to noise reducers consisting of a series of porous hoses radiating from the microphones. The overall size of the arrays is about 200 m. In typical operation the sampling rates are 20 samples per second and the frequency band analyzed is 0.5 to 3 Hz. A standard beam-forming procedure is employed in the analysis.

THE DETECTIONS

Figure 1 shows a portion of the analysis output for St. George. Each dot represents the results for a 20 second window of the azimuth; the trace velocity, and the average correlation coefficient between the sensor pairs; the multiple signals are obvious in the change in character from the random pattern of the dots to lines. Events A and B both produced two signal at each array due to differing propagation paths.

Table I provides the details of the signals and shows, in order, the signal name, the peak arrival time T, peak-to-peak amplitude A, peak frequency F, the trace velocity V_t, the azimuth Θ, and the average propagation velocity V. The azimuths show reasonable accord with

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the expected great-circle azimuths of 230.5° for St. George and 274.0° for Los Alamos. The differences are close to our usual variance of about 3°.

INTERPRETATION

The occurrence of double signals for each event at both arrays indicates that two propagation channels were present for signal transmission to each site. However the differing velocities between the two sites strongly suggests that the physical mechanisms were different for the two arrays.

The St. George site is located only about 0.6 of a typical ozonospheric bounce distance from the source and so the signals there are unlikely to be ozonospheric returns according to our present understanding. Other possible mechanisms for the high velocity St. George signals are tropospheric returns or Lamb wave propagation. From the trace velocities we deduce an inclination angle to the surface of the arriving rays of about 9° . This, in turn, implies a maximum propagation height of about 12 km. A preliminary examination of the atmospheric profiles up to about 10 km in the source area does not appear to support the notion of tropospheric propagation. In Figure 2 we show a portion of the signal B1. The abrupt onset of the signal is suggestive of a Lamb wave. The signal A1 shows a very similar character. On the other hand, there is some question of the ability of Lamb waves to be effective at such short ranges. ReVelle and Whitaker (1996) provide further discussion of Lamb wave characteristics. The secondary signals at St. George with V = 0.275 km/s appear to have V too low for normal ionospheric returns. At the same time the trace velocities are too low for normal ozonospheric returns and, again, ionospheric or ozonospheric returns normally would not be expected at this short range from the source. Consequently at present we cannot explain the nature of A2 and B2. The peak frequencies show reasonable consistency between A1 and B1 and again between A2 and B2.

At Los Alamos the principal signals from A and B have V = 0.297 km/s which is normal for ozonospheric propagation. Los Alamos is about 3.1 ozonospheric bounces from the source. The trace velocities give an inclination angle of about 17° which suggests a maximum propagation height of about 36 km. This is low but plausible for ozonospheric propagation. The smaller signals with V = 0.280 km/s are also probably ozonospheric since their trace velocities support this. It should be noted that in our experience there are frequently two or more signals near the ozonospheric return velocity from large sources. The peak frequencies are considerably larger than those at St. George except for B2.

It is clear that a full interpretation of the signals at St. George will require further analysis including possible modeling efforts using available wind data.

SIGNAL CONGRUENCE

One of the interesting features of the signals at St. George is the close congruence of some of the signals over a period of time. Figure 3 gives a comparison of the signals A2 and B2 for a period of over one minute near their peaks. There is a striking agreement of the two signals for features of about 2 second period and longer with some agreement even for shorter periods. These two signal regions are separated by four minutes. Presumably this gives an indication of atmospheric constancy for infrasound propagation over this interval of time and at this distance; an interpretation might be possible in terms of atmospheric turbulent element "lifetime". The fact that A and B are distinctly different sources in terms of configuration, size and perhaps detonation characteristics and yet produce such signal similarity is an indication that at a range as small as that to St. George the local source character is effectively reduced to a "point source" for propagation purposes.

EXPLOSION YIELDS

We attempt to make an estimate of the explosive yield for sources A and B using the relation

$$A^* = 4.69 \times 10^4 \times (R/W^{1/2})^{-1.35} \qquad (1)$$

where A* is an amplitude in microbars corrected for the effects of stratospheric winds as previously described by Mutschlecner and Whitaker (1990), R is the range in kilometers, and W is the explosive yield expressed in kilotons of nuclear free air burst. The expression 1 is an improved version, using two additional events, of that given by Whitaker et al (1990) derived empirically from the observation of experimental chemical high explosive sources. Since this relation was derived for ozonospheric signals, we employ the signals A1 and B1 at Los Alamos. Available stratospheric observations of the zonal and meridional components of the winds were used to estimate the correction from A to A* but these corrections are quite small since May 4 is close to the transition time of the stratospheric zonal winds. We obtain for sources A and B respectively 1.4 and 3.7 kilotons nuclear equivalent free air burst yields or about 0.7 and 1.8 kilotons of surface burst. Reed (1992) has estimated the explosive size by his analysis method which employs close-in blast damage reports, in this case from Henderson and Las Vegas, Nevada. He finds a source size of 227 Mg of HE on the surface which is approximately equivalent to a 1 kiloton nuclear air burst. Thus our estimate is larger than Reed's by nearly a factor of four. At the present time the cause of this disagreement is not understood although it may be related to the fact that the blast damage is probably caused by low elevation propagation whereas the ozonospheric signals are produced by the launch of much higher elevation rays.

CONCLUSIONS

The Henderson explosions present an interesting and challenging set of infrasound observations. The case may be unique in providing two very large sources separated in time by only four minutes. To fully understand the propagation details will require further analysis and probably a modeling effort. The understanding of the St. George signals in the context of Lamb waves would be valuable for a better understanding of this mode of propagation.

The improved understanding of long range infrasonic propagation is now especially important in the context of the Comprehensive Test Ban Treaty (CTBT). A porton of the plan for CTBT monitoring includes a global distribution of sixty infrasound arrays to provide for the monitoring of signals in as uniform a way as possible. It is expected that under this global network many signals and interpretation questions of the type described here will be encountered. Investigations of propagation over the ranges of hundreds to thousands of kilometers will be highly desired.

ACKNOWLEDGMENTS

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TABLE I: SIGNALS FROM THE HENDERSON EXPLOSION

St. George, Utah

Sig ID	T	A	F	V_t	Θ	V
A1	01:33	92	0.643	347	236	332
A2	03:13	43	0.536	347	236	275
B1	05:33	108	0.621	347	236	333
B2	07:14	72	0.566	347	236	275

Los Alamos, New Mexico

Sig ID	T	A	F	V_t	Θ	V
A1	36:58	6.8	0.820	354	278	297
A2	39:40	4.7	0.810	354	278	280
B1	40:57	12.9	0.830	354	278	297
B2	43.34	3.0	0.689	354	278	280

Column Notes
T = minutes : seconds after 19 hours C.U.T.
A = p-p amplitude in μbar
F = peak frequency in Hz
V_t = trace velocity in m/s
Θ = azimuth in degrees from N through E
V = average signal velocity in m/s

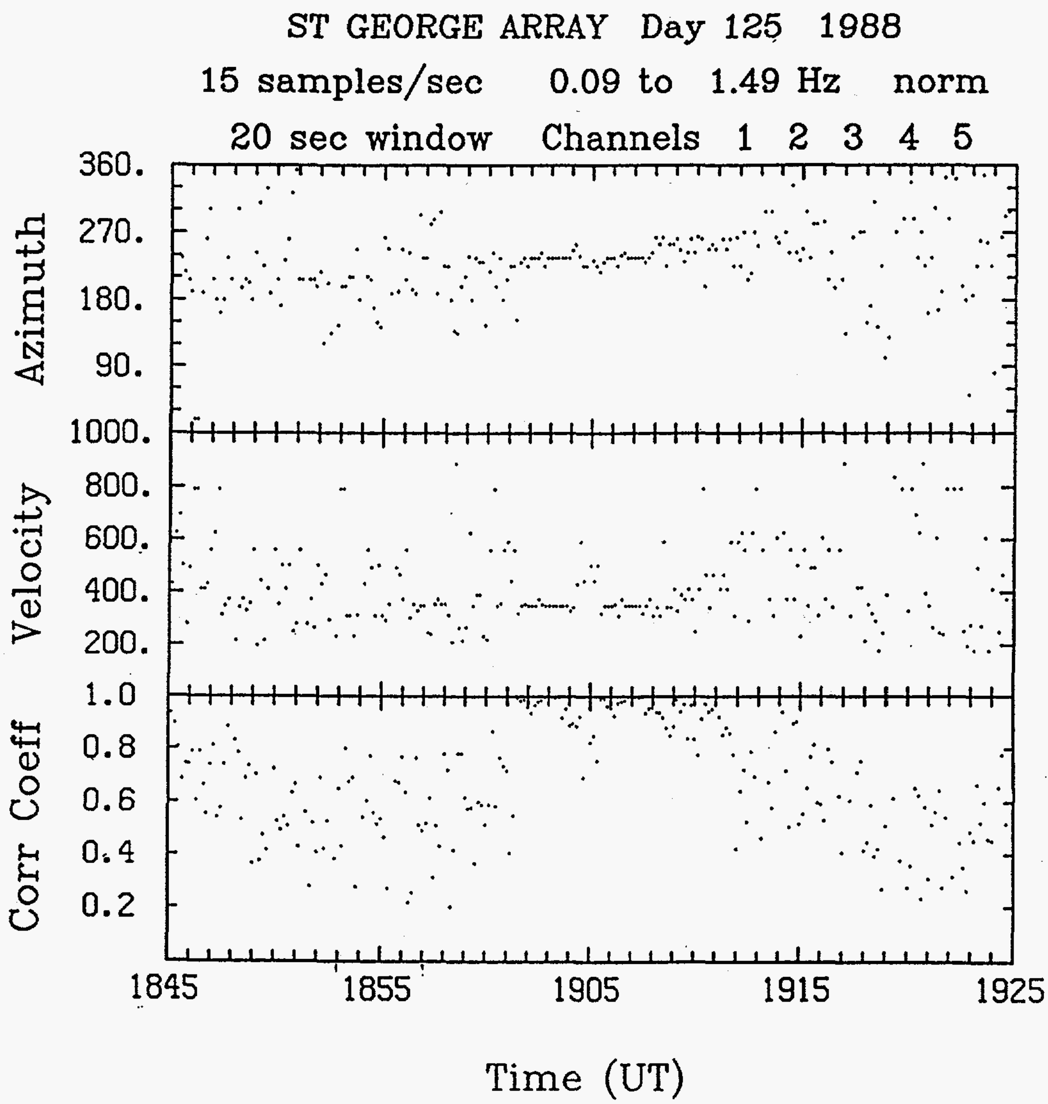

FIGURE 1. Survey plot showing the analysis of St. George data for the Henderson event. The panels from top to bottom show the azimuth from the array in degrees, the trace velocity in meters / second, and the average correlation coefficient.

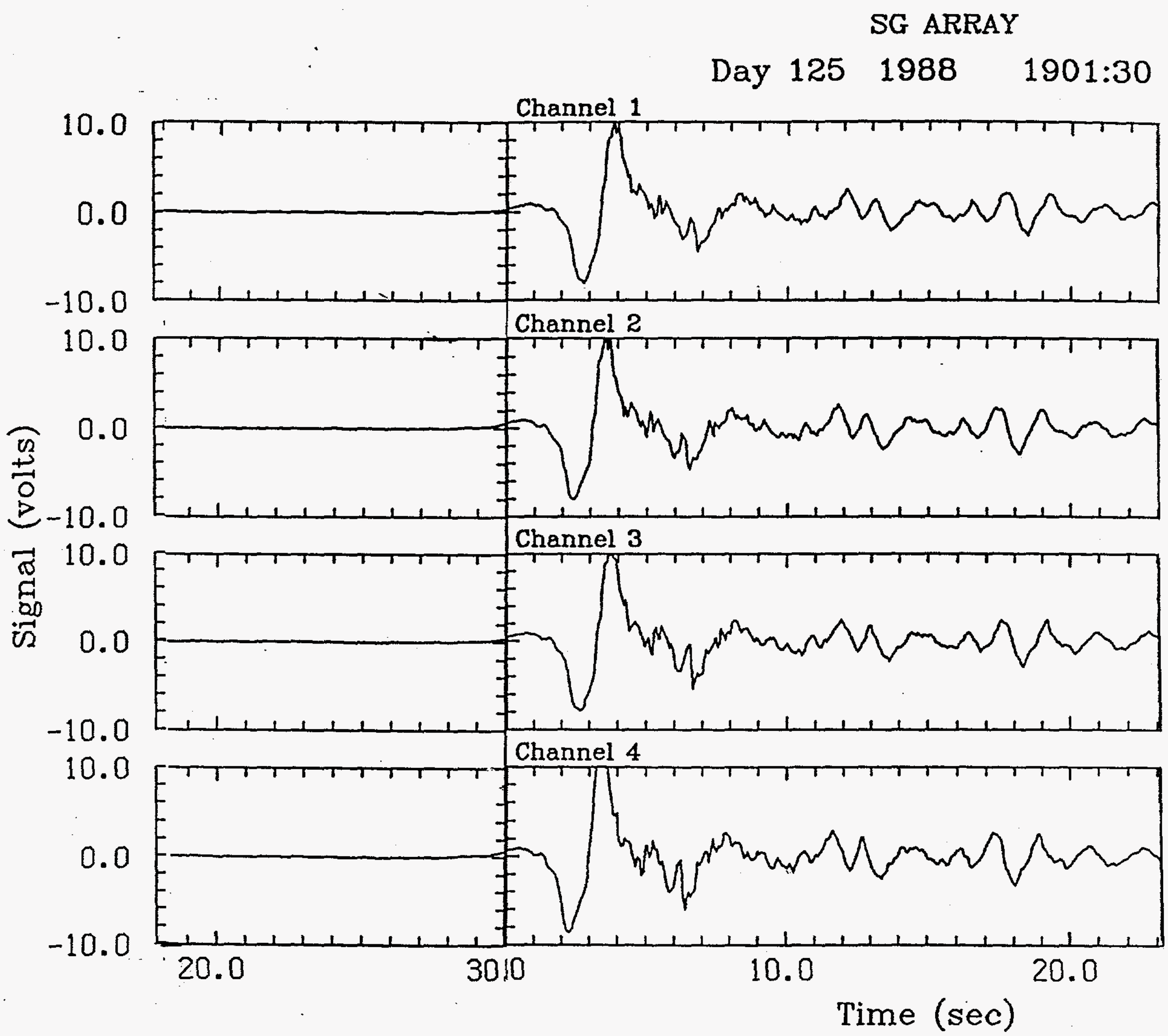

FIGURE 2. A portion of the signal B1 seen at St George showing the abrupt onset of the signal. Signal level is given in microphone volts (about 0.2 volts / μbar).

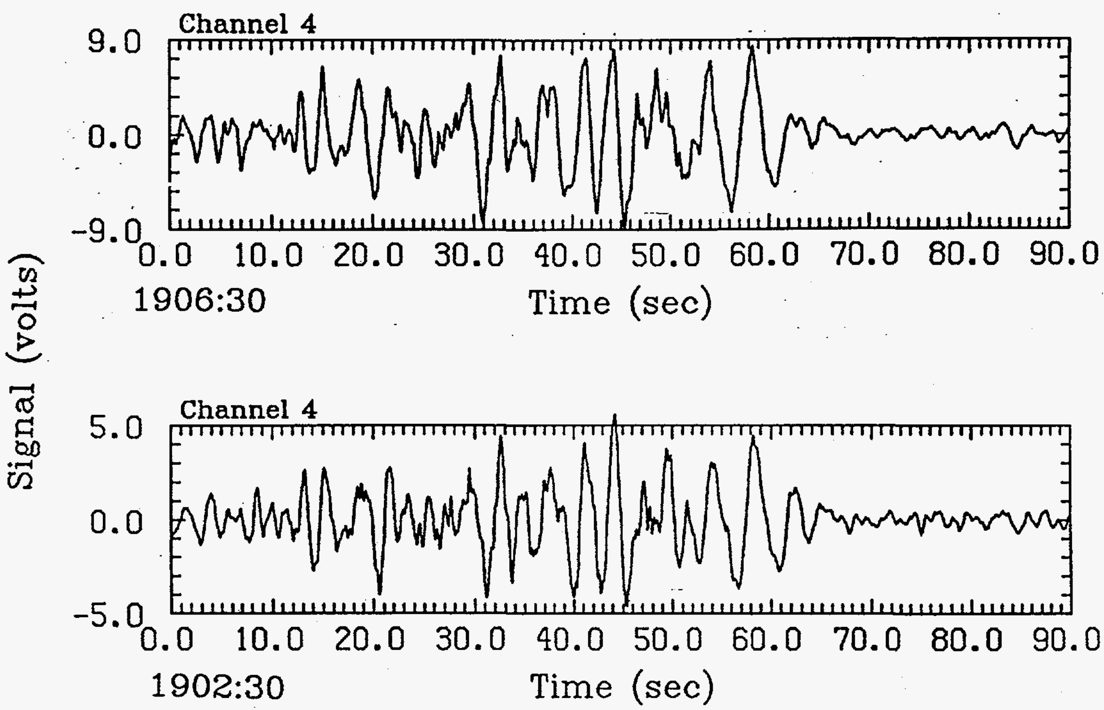

FIGURE 3. A comparison of a portion of the signals B2 (top) and A2 (bottom) at St. George showing the close similarity of the signals.