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OZONOSPHERE OBSERVATIONS FROM PROPAGATION OF
ATOMIC BLAST WAVES

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ABSTRACT

Observations of refracted sound waves from atomic tests at the Nevada and Pacific Proving Grounds are evaluated to show temperature and winds in the ozonosphere. A simplified method of making these interpretations is presented to reduce the computation work load normally associated with atmospheric sound studies.

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Abnormal propagation of sounds from high-explosive blasts has been investigated by Gutenberg,^{1/} Cox,^{2/} Crary,^{3/} Johnson and Hale,^{4/} Kennedy,^{5/} and others to determine, from refracted sound patterns, atmospheric conditions at levels above the reach of normal weather observing equipment. The velocity of sound propagation is the speed of sound, a function of temperature, plus a wind component. Since both quantities vary with altitude, sound rays are bent by atmospheric refraction. Snell's law for refraction, in its most convenient form, is expressed by Eq 1 (Fig. 1), where V is the sound velocity, θ is the inclination of the ray to the horizontal, and V_p is a constant - the so-called characteristic velocity of the ray. This characteristic velocity represents the ambient sound velocity when the ray has become horizontal and $\cos \theta = 1$; it is the horizontal projection of the wave-front velocity vector. Thus two observing stations at known distances from a shot point and the same elevation will record differences in arrival time for refracted sound signals. The apparent velocity determined by dividing the distance between stations by the difference in arrival time is the characteristic velocity.

A third observing point is used by most investigators to determine the azimuth of the arriving signal. Most results show this angle between an arriving signal and the shot point bearing to be quite small. Errors in applying the small azimuth shifts to give wind patterns are usually too large to allow confidence in the results.

Sandia Corporation operates microbarographs to record signals from atomic tests at the Nevada and Pacific Proving Grounds to aid in predicting and preventing damaging blast wave propagation into inhabited areas.^{6/} By simply adding another sensing unit at regular recorder stations, incidence angles and characteristic velocities of arriving sound signals have been determined. Small effects of azimuth shifts have been neglected.

Equations 2 and 3 (Fig. 2), derived by Johnson and Hale,^{4/} give travel distance and time for a ray of given characteristic velocity in passing twice through a layer of constant sound velocity gradient. Angle θ is related to V and V_p by Snell's law (Eq 1). Summations of distance and of time through the layers of the known atmosphere are subtracted from the known distance to the microbarograph from the shot point and from the total transit

time for the signal to give the distance and the time of travel in the unknown atmosphere.

A single-gradient structure for the unknown atmosphere would have V_2 equal V_p , and h_2 unknown. In general the two equations are not satisfied by the time and distance remainder quantities.

On the other hand, assumption of a two-gradient unknown atmosphere (Fig. 3) allows determination of a family of structures since there are two equations (Eqs 4 and 5) in three unknowns (V_2 , h_2 , and h_3). Crary^{3/} has shown the loci of (V_2, h_2) points in the family to be very nearly along a straight line. A typical family of solutions is shown in Fig. 4.

Kennedy^{1/} has postulated a hyperbolic cosine structure satisfying a time, distance, and characteristic velocity condition set, but his heights for ray crests are usually found to be within the range of results from the two-gradient family.

The relatively small impulses received from high-explosives shots usually allow only one analysis for characteristic velocity and atmospheric structure from an observation. However, on atomic bomb tests a great number of impulses refracted by the unknown atmosphere are often received. The characteristic velocities for these impulses do not necessarily increase with later arrivals, as should be true for higher trajectories. Even when succeeding signals have higher characteristic velocities, their separation time is usually not sufficient to allow a reasonable two-gradient solution for the region above the first two-gradient family, as shown in Fig. 5.

^aHere the minimum sound velocity-height shear is 40 fps/1000 ft. Conditions have been observed requiring zero or even negative sound velocities to satisfy two-gradient solutions.^{2/}

Developing a process for fitting an atmosphere to best satisfy the many conditions presented by several signals appears to be a formidable task. Some further approximations are thus necessary to make a consistent analysis of signal groups observed.

Dual microbarograph installations were operated at various times during the Nevada atomic tests in the spring of 1953; locations are shown in Fig. 6. Distances and bearings to the stations at St. George and Cedar City, Utah,

Bishop, California, and Goldfield and Las Vegas, Nevada, are shown.

The strongest anomalous signal observed on each record has been analyzed to obtain a two-gradient family of structures for the unknown atmosphere. An 'average' structure, defined as one giving the height of the ray crest midway between the extremes for each family, was assumed for each observation. These sound velocity points are plotted versus height in Fig. 7. It was noted from this plot that each station had a preferred region for signal returns. This observation led eventually to the plot (Fig. 8) of crest height, h , divided by station distance, D , versus mean transit velocity (distance, D , over transit time, t) divided by characteristic velocity, V_p . The root-mean-square straight line through the data points is represented by Eq 6; a surprisingly simple relation, independent of the known atmospheric structure, is thus obtained for determining the height at which characteristic velocity equals sound velocity. Recomputation of these sound velocities versus height using Eq 6 changes their values in Fig. 7, as indicated by the vertical bars. No bar indicates that shifts were too small to be noted on the scale used. Considering the uncertainties of the two-gradient method, these error displacements seem trivial indeed.

All the signal impulses observed were analyzed in this way to give point values for sound velocity versus height. Points for various dates and locations are shown in Figs. 9 and 10. An average resolution into mean speed of sound and mean wind direction and speed for this test series is shown in Fig. 11. Shown for comparison is the sound speed-vs-height curve obtained from the Rocket Panel⁷ atmospheric temperature-vs-height structure.

Microbarograph results from the Pacific tests in the spring of 1954 were less successful in many respects. As shown in Fig. 12, stations were operated at Kwajalein, Eniwetok, and Ponape for the Bikini tests. The distances were so great as to allow only approximate determination of the number of reflected cycles for each impulse. Considerable subjectivity was involved in establishing the sound velocity-vs-height points. Results for the Pacific tests are presented in Fig. 13. There were not enough reliable data to allow separation of mean winds and temperatures.

For these large-scale tests in the Pacific two additional types of signal were very noticeable, as shown in Fig. 14. Rounded, long-period

gravity waves moved horizontally at speeds of 950 to 1100 fps, about 100 fps slower than the speed of sound. The sharp, shock-like impulse having an early arrival time and very high incidence angle was noted on several records. This shock is apparently the result of supersonic propagation through the high atmosphere, where the ambient pressure term in Eq 7 becomes very small.

No accuracy estimate for any of these results is possible. A number of minor bugs in the observation system tend to restrict confidence in the numerical results. However, these difficulties are being corrected, and future tests will be instrumented to facilitate data-reduction techniques so that considerably more accurate and reliable soundings may be obtained.

The linearized determination of velocity-height points proved quite accurate when checked over a wide range of hypothetical atmospheric structures.

Fig. 1

Eq 1 $V/\cos \theta = V_p$ Snell's Law

Figure 2

Eq 1 $V_p = V / \cos \theta$ Snell's Law

Eq 2 $s = 2(h_2 - h_1) \cot \left(\frac{\theta_1 + \theta_2}{2} \right)$

Eq 3 $t = 2(\text{gd}^{-1}\theta_1 - \text{gd}^{-1}\theta_2) (h_2 - h_1) / (V_2 - V_1)$

Symbols

V = Sound velocity	s = Horizontal distance
V_p = Characteristic velocity	t = Travel time
θ = Inclination of ray to horizontal	h = Height
$\text{gd}^{-1}\theta$ = Anti-Gudermannian of the angle θ

Figure 3

$$\text{Eq 4 } s = 2 \left[(h_2 - h_1) \cot \left(\frac{\theta_1 + \theta_2}{2} \right) + (h_3 - h_2) \cot \left(\frac{\theta_2}{2} \right) \right]$$

$$\text{Eq 5 } t = 2 \left[(gd^{-1}\theta_1 - gd^{-1}\theta_2)(h_2 - h_1) / (v_2 - v_1) + (h_3 - h_2) gd^{-1}\theta_2 / (v_p - v_2) \right]$$

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Fig. 6 Nevada Proving Ground Region

Fig. 7 - Sound velocity vs height

Fig. 8 - $\bar{v}/v_p$ en h/D

Fig. 9

51

Fig. 11 - UPSHOT-KNOTHOLE Composite Ozonosphere Conditions

60
40
20
1400

Altitude (km)

Fig. 12 Pacific Proving Ground

Fig. 13 - Sound velocity-height, Pacific Proving Ground, Spring 1954

Signal types
 March 1, 1954
 Eniwetok microbarographs
 Spacing: 54,656 ft
 Surface sound velocity, $V_0 = 1144 \text{ fps}$

From Rankine-Hugoniot relations:

$$\text{Eq 7: } \sigma = c \left(1 + 0.857 \frac{p}{P} \right)^{1/2}$$

where: σ = shock speed
 c = speed of sound
 p = perturbation pressure
 P = ambient pressure

Fig. 14

References

1. Gutenberg, B., "Sound Propagation in the Atmosphere", Compendium of Meteorology, Amer. Met. Soc., Boston, 366-375 (1951)
2. Cox, E. F., et al, "Upper Atmosphere Temperatures From the Helgoland Big Bang", J. Met., 6:300-311 (1949)
3. Crary, A. P., "Stratosphere Winds and Temperatures from Acoustical Propagation Studies", J. Met., 7:233-242 (1950)
4. Johnson, C. T., and Hale, F. E., "Abnormal Sound Propagation Over the Southwestern United States", J. Acoust. Soc. Amer., 25:642-650 (1953)
5. Kennedy, W. B., and Brogan, L., Determination of Atmospheric Winds and Temperature in the 30-60 Km Region by Acoustic Means, Final Report on Contract No. AF19(122)-252, Denver Research Institute, U. of Denver, 30 June 1954
6. Cox, E. F., et al, "Meteorology Directs Where Blast Will Strike", Bull. Met., 35:95-103 (1954)
7. The Rocket Panel, "Pressures, Densities, and Temperatures in the Upper Atmosphere", Phys. Rev., 88:1027-1032 (1952)

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