Letters to the Editor

Acoustical Energy Generated by the Ocean Waves

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An estimate of the order of magnitude of the acoustical energy generated by ocean waves indicates that this energy is large enough to cause an appreciable heating effect at ionospheric levels, where most of it is absorbed. Using data obtained from surface measurements of the pressure amplitude, it is found that relative density changes of the order of 1 percent occur at ionospheric levels, and the suggestion is made that the "twinkling" of cosmic sources of radio waves is a result of this phenomenon.

SPECULATION regarding the low frequency acoustical energy which is generated by the "loudspeaker" action of ocean waves can lead to some interesting conclusions. An exact calculation or measurement of this energy is very difficult, if not impossible, but a rough estimate of its magnitude may be obtained by considering the ocean to be an infinite plane made up of pistons 40 meters square, oscillating with a period of five seconds in random phase. (This random phase assumption is probably approximately valid for waves in a storm area; as the waves travel from the storm center they tend to approach the regular succession of crests and troughs characteristic of free-wave theory and would radiate very little energy.) Assuming the amplitude of oscillation of the pistons to be 50 centimeters, application of the well-known formula for radiation from a point source[1] gives 100 ergs/cm^2/sec for the average energy radiated by the plane.

If the atmosphere were isothermal, the energy would travel upward without attenuation until it reached levels where the molecular mean free path approaches the magnitude of the wavelength, whereupon rapid attenuation would take place, the acoustical energy degenerating into thermal energy. The absorption coefficient for an isothermal atmosphere at 0°C has been calculated by Schrödinger.[2] Detailed computations based upon his results lead to the conclusion that most of the acoustical energy would be absorbed in a layer extending from 130 km to 155 km above the earth's surface, where the mean atmospheric density is of the order of 5×10^{-11} g/cm^3. Furthermore, the vertical energy flow of 100 ergs/cm^2/sec calculated above would raise the temperature of a 25-km deep layer which has this mean density about 300° per hour. If all of this energy were not lost by radiation, a vertical temperature gradient would be established, and a duct would be formed which would trap the acoustical energy, permitting it to travel great distances horizontally.

A rise in temperature is known to exist in the upper atmosphere, beginning at about 80 or 90 km and continuing up to levels well above 120 km; a completely satisfactory theory as to its cause does not exist. Another temperature increase, which begins at about 30 km and reaches a maximum at 60 km is attributed to absorption of the sun's ultraviolet energy by ozone. The ducts formed by these inversions are responsible for long-distance propation of sound, and, if the temperature distribution of the NACA standard atmosphere is assumed, about 40 percent of the energy from a low frequency sound source on the surface of the earth would be trapped in the lower duct, the remainder being propagated in the duct bounded by the earth and the inversion which begins near 90 km. (Of course these conclusions are true only in the absence of wind.)

Atmospheric compressional waves having periods similar to those of ocean waves were first observed in California by Benioff and Gutenberg,[3] who called the oscillations microbaroms because of their close resemblance to microseisms and suggested large ocean waves in storms as their possible cause. Observations of microbaroms have been made over a period of several years by the Signal Corps at Fort Monmouth, New Jersey. The pressure amplitudes were found to vary from values so small that they were masked by atmospheric turbulence, up to 6 dynes/cm^2 when a small tropical hurricane was a few hundred miles off shore. The maximum value corresponds to an energy flow of about 1 erg/cm^2/sec, which is the order of magnitude which we would expect at a point 800 km from the center of a storm area having a radius of 200 km and radiating only 4 ergs/cm^2/sec, if all of the energy were trapped between the surface and a horizontal plane at an elevation of 100 km. This suggests that the assumed amplitude of random motion (50 cm) is too large, or that the sources are not as closely spaced, or that most of the acoustical energy is converted into heat.

A typical microbarom record is shown in Fig. 1. It is obvious that the pressure fluctuations occur at a single frequency, but with changing amplitude, similar to a modulated radiofrequency carrier. The general agreement between the observed and calculated energy levels and the correlation with the presence of ocean storms tend to confirm the theory that the ocean waves cause the microbaroms by their "loudspeaker" action.

The fact that microbaroms and microseisms both have periods in the neighborhood of 5 seconds indicates a common origin. Darbyshire[4] has found that microseisms can be identified with ocean waves having twice their period, which would seem to call for ocean wave periods of the order of 10 seconds. However, as

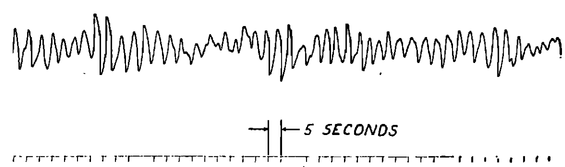

FIG. 1. A typical microbarom recording. Timing marks indicate 5-second intervals.

Darbyshire used bottom wave periods for his study, and as it is known that the bottom wave periods are approximately twice those of the surface waves, the apparent discrepancy disappears.

The observed values of pressure fluctuation amount to only a few parts per million of the atmospheric pressure at the surface of the earth and at first sight would appear to be of little significance. However, Schrödinger[2] has shown that, as such a wave travels into the upper atmosphere, the particle amplitude, relative pressure change, and relative density change vary inversely with the square root of the atmospheric density. A detailed study of the ray paths indicates that most of the rays refracted by the second inversion are refracted at levels near 120 km; the corresponding amplitude increase would be about 1800. This means that relative density changes of the order of 1 percent exist between adjacent peaks and troughs of the sound wave in the ionosphere when the microbarom pressure amplitudes are only 3 dynes/cm^2 at the earth's surface (a value which is often observed during ocean storms). At some distance from a storm, these regions of excess density would, of course, move with compressional wave velocities away from the storm center, but, when trains of microbaroms from a number of storms are crossing, something similar to a standing wave system may occur, with quasi-stationary regions of excess density. A possible result of this phenomenon is that the accompanying local fluctuations in ion density may be the cause of the "twinkling" of cosmic sources of radio waves.

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[1] H. F. Olson, *Elements of Acoustical Engineering* (D. Van Nostrand Company, Inc., New York, 1940), p. 19.
[2] E. Schrödinger, Physik. Z. 18, 445 (1917).
[3] B. Gutenberg and H. Benioff, Trans. Am. Geophys. Union **22**, 424 (1941).
[4] J. Darbyshire, Proc. Roy. Soc. (London) **A202**, 439 (1950).