Sea Wave Origin of Microbaroms and Microseisms

WILLIAM L. DONN

Lamont-Doherty Geological Observatory, Columbia University
Palisades, New York 10964
City College of New York, New York, New York 10031

BHOOPAL NAINI

Lamont-Doherty Geological Observatory, Columbia University
Palisades, New York 10964

Microbaroms and microseisms have nearly identical frequencies and a common direction of approach, viz., from the same ocean storms. This finding is indicative of a common generating source for both microbaroms and microseisms. The only mechanism that appears capable of transmitting energy into both the atmosphere and the sea bottom is associated with the surface waves in a storm area.

Microbaroms are atmospheric low-frequency acoustic (infrasonic) waves. These are nearly sinusoidal sound waves that fall far below the lower limits of audible frequency, having periods close to 5 sec. Their pressure amplitude usually varies from 1 to 5 μb but may reach 10 μb. Microbaroms are associated with marine storms, from which they radiate with propagation speeds appropriate to the speed of sound. Details of microbarom propagation and source regions have been given by *Donn and Posmentier* [1967] and *Donn and Rind* [1971].

Microseisms, on the other hand, are the continuous background components of a seismic record. The common storm microseisms (4–8 sec in period) that usually dominate the seismogram also emanate from marine storm systems. The ground particle motion of the microseisms is dominantly that of Rayleigh waves, i.e., retrograde and elliptic.

A comparison of simultaneously recorded storm-generated microseisms and microbaroms is given in Figure 1. Each is recorded here on standard seismograph drums, and several minutes of each line is shown. As the noise level is very low, the characteristic sinusoidal and beat-like pattern of both types of signals is quite evident. The strong semidiurnal amplitude variation of microbaroms, not shown by the microseisms, is a propagation effect that will be referred to below.

Copyright © 1973 by the American Geophysical Union.

It has been shown by *Oliver and Ewing* [1957] that the microseism spectra frequently show a double peak, the first in the vicinity of the common storm microseisms (4–10 sec in period) and the second in the region of 20 sec in period. The microseisms in the latter group have been correlated with ocean waves of a similar period generated in intense cyclonic marine storms. The microseisms in the former group, by far the dominant type, appear to be twice the frequency (or one-half the period) of related ocean waves. It is with these common strong storm microseisms of one-half ocean wave period that microbaroms are correlated in this paper.

Donn and Posmentier [1967] showed a striking similarity between the visual and spectral characteristics of microbaroms and microseisms recorded simultaneously and apparently generated within the same marine storm area. The results of this single case suggested a common origin for both microseisms and microbaroms.

OCEAN WAVE ORIGIN OF MICROSEISMS AND MICROBAROMS

Of the many theories of microseisms proposed over the years, only the ocean wave theory of *Longuet-Higgins* [1950] with exten-

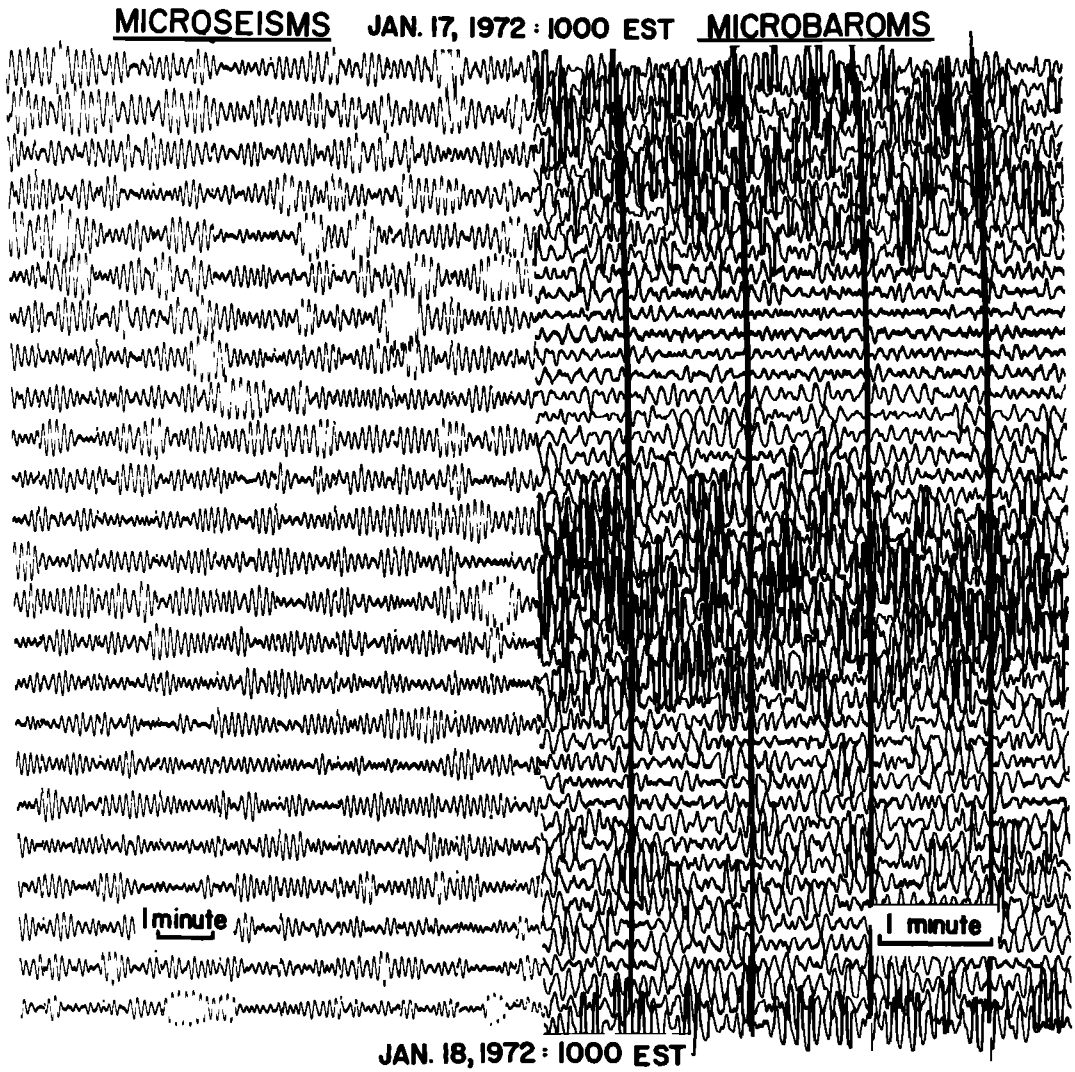

Fig. 1. Vertical portions of 24-hour drum records of microseisms and microbaroms; the microbaroms show strong semidiurnal amplitude variations, whereas microseisms are essentially unchanged in amplitude. Time scale of the seismogram, whose drum rotation rate is 24/day, is one-half the scale of the microbarogram having 48 rotations per day.

sions by *Hasselmann* [1963] appears to have quantitative validity, although other suggestions of ocean wave origin have been made [e.g., *Daniels*, 1952, 1953]. A requirement in the generation of microseisms by ocean waves is that components of the wave pressure spectrum be transmitted effectively to the sea bottom with horizontal phase velocities equivalent to those of free seismic waves. Longuet-Higgins met this requirement by employing an earlier treatment by *Miche* [1944], which demonstrates a nonlinear pressure term that will reach the bottom without the severe attenuation of the first-order gravity wave effect and that would have high phase velocities. Longuet-Higgins demonstrated that the presence of this high-velocity second-order pressure effect would result from the standing waves developed by interference of gravity waves of exactly equal and opposite wave numbers. In his more general statistical treatment, *Hasselmann* [1963] showed that the interaction of waves of slightly different wave numbers would produce compressional waves of high horizontal phase velocities that could couple to seismic waves.

Posmentier [1967] applied the basic Longuet-Higgins approach to the generation of acoustic disturbances in the atmosphere. He showed that the pressure variations above a water wave interference pattern would also oscillate with a period $T/2$ as in the model of microseism generation by interfering ocean waves. Posmentier's analysis indicated that the interfering wave coupling mechanism would generate atmospheric infrasound if the ocean surface contained patches of standing waves, requiring only that the directional sea wave spectrum have significant energy in approximately opposite wave numbers.

In several separate analyses of microseisms and ocean waves the senior author concluded that the requirements of exactly opposite wave numbers could not be met in the real ocean in the cases considered and sought a different mechanism of microseism generation [e.g., *Donn*, 1952, 1953]. The theoretical extensions of Hasselmann and Posmentier described above suggested that the problem of microseism generation might be examined experimentally by an investigation of simultaneously occurring microseisms and microbaroms. To this end a detailed study was made of the simultaneous spectra and approach vectors of microbaroms and microseisms.

Data Acquisition and Analysis

Infrasound in the passband 1–10 sec is recorded at Palisades (Lamont-Doherty Geological Observatory) by a tripartite array of capacitor microphones as described earlier by *Donn and Posmentier* [1967]. Microseism data were taken from the Lamont vertical component seismograph ($T_0 = 15$ sec). All acquisition is by both visual drum recording and analog magnetic tape. Taped signals were processed for amplitude spectra of microbaroms and microseisms as well as cross correlation of microbaroms in the Saicor analog computer. The amplitude spectrum of a time series $a(t)$ is given by the relation

$$A(f) = \frac{1}{2T} \int_{-T}^{+T} a(t) e^{i2\pi ft}\, dt$$

The cross-correlation function $R_{x,y}(\tau)$ computed for time lags between pairs of the tripartite microbarom array is given by

$$R_{x,y}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T}^{+T} x(t) y(t+\tau)\, dt$$

where τ is the time lag between a pair of transducers and T is the duration of the time series. Directions and speeds are then quickly calculated from the time lags computed by the correlation.

Microseism approach directions are constructed after the method of *Lee* [1935] by comparing phases among the horizontal and vertical component seismograms.

Data

A large number of individual cases of prominent microseisms and microbaroms at times of low noise level were studied in detail as described previously. The cases illustrated here are typical of the entire series of hundreds of cases.

In Figure 2*a* simultaneous amplitude spectra of microseisms and microbaroms are compared for seven different times during the 2-day interval of March 26–27, 1968. All amplitudes are in arbitrary units on a linear scale. Spectral peaks for both signals are strong at 5 sec. For

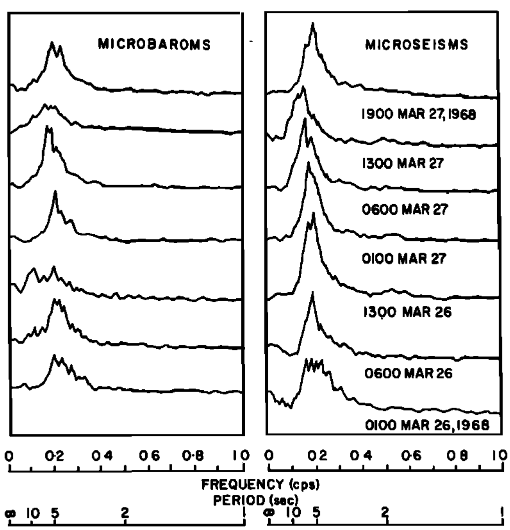

Fig. 2*a*. Simultaneous amplitude spectra of microseisms and microbaroms at seven distinct intervals during March 26–27, 1968. Each spectrum was taken over a continuous interval of 20 min duration. All times are GMT.

both signals a small increase in period is evident in the spectra of 0600 and 1300 of March 27. Contours of ocean wave height in the adjacent Atlantic Ocean at 1200–0000 GMT, March 27, are shown in Figure 2b together with arrows indicating the computed source azimuths of both signals. A strong extratropical cyclone generated the area of high waves that reached 10 meters northeast of Labrador and south of Greenland. The source azimuths are coincident within experimental error, and both point unambiguously to the region of high waves.

The confidence attached to the spectra in Figures 2–5 is very high (as can be inferred from the nature of the signals in Figure 1). In analog measurement the normalized statistical

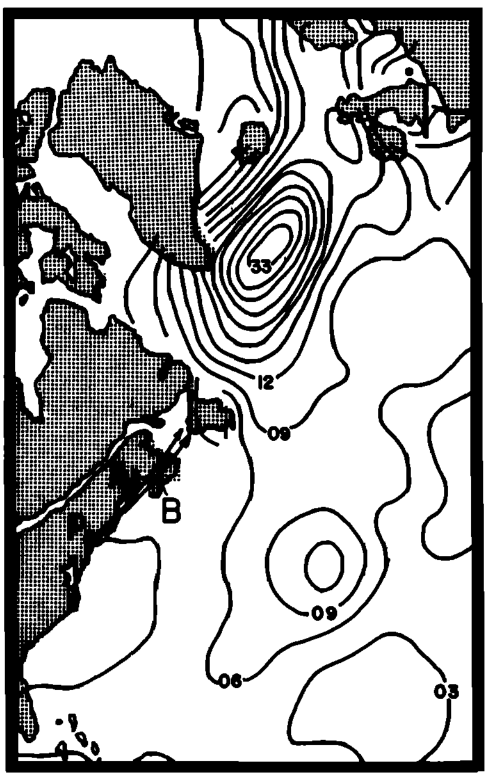

Fig. 2b. Chart of wave heights for the North Atlantic Ocean at 1200 GMT, March 27, 1968. Wave height contours are at 0.9-meter intervals. The P is Palisades, New York (Lamont-Doherty Geological Observatory). Computed directions of source for microseisms and microbaroms are shown by arrows A and B, respectively. The chart is produced by the U.S. Navy Fleet Numerical Weather Facility.

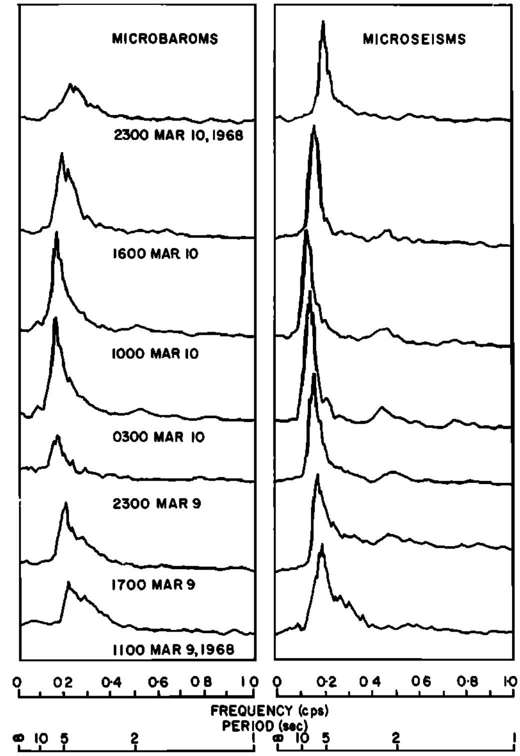

Fig. 3. Comparison of simultaneous microseism and microbarom amplitude spectra for March 9 and 10, 1968.

error of a spectrum measurement ϵ is given by *Bendat and Piersol* [1966] as

$$\epsilon \simeq 1/(B_\epsilon T)^{1/2}$$

where B_ϵ is the bandwidth of the analyzer narrow bandwidth filter in hertz and T is the equivalent true averaging time in seconds. For $B_\epsilon = 0.1$ Hz and $T = 1500$ sec (the sped-up record length over which integration was carried out), ϵ is 0.08, or the amplitudes of the spectral points have a statistical error of 8%.

Figures 3, 4, and 5 give spectra of microseisms and microbaroms for three other cases. Again, the period of spectral peaks is essentially identical. Also significant is the small but noticeable increase of period for both signals for the central spectra.

Comparisons of spectra and azimuths are given for a number of time series of both microbaroms and microseisms in Figure 6. Spectra are essentially identical in absolute values and in trends.

With the exception of January 5–6, 1967, microbarom and microseism azimuths indicate a common source and differ by angles within the experimental error. This error is about $\pm 5°$ for microbarom vectors. The accuracy of computed microseism azimuths depends primarily on the degree of phase matching between the horizontal components of the seismograph system and on the percentage of Rayleigh waves and Love waves in the sample measured and thus depends on the actual waves selected for analysis. For pure Rayleigh waves of microseism period generated by an earthquake, *Donn* [1954] showed the experimental error to be 10°. For microseisms from storms in the same region as those considered here, the mean error was smaller but the standard deviation was much greater (20°). The case of January 5–6, 1967, is complicated by the presence of a very broad source, making directions less reliable.

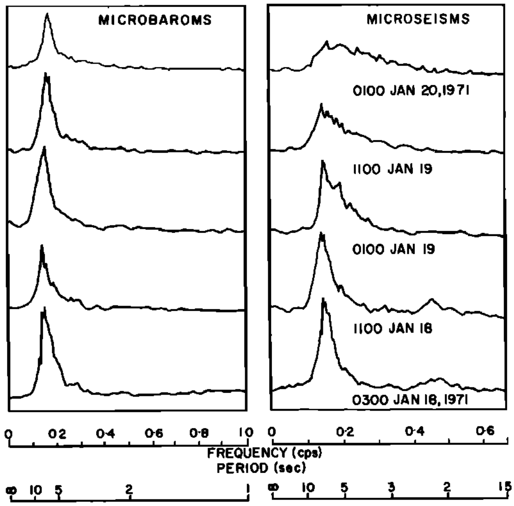

Fig. 5. Comparison of simultaneous amplitude spectra of microseisms and microbaroms for January 18–20, 1971.

DISCUSSION

The similarity in visual and spectral parameters of both microbaroms and microseisms leads to the possibility of the air waves' being coupled to the ground waves rather than their having a common source. This idea is somewhat reinforced by the knowledge that infrasound has been radiated from earthquake waves [e.g., *Bolt*, 1964; *Cook*, 1962; *Donn and Posmentier*, 1967]. On investigation it seems clear that both signals propagate independently on the basis of the following information:

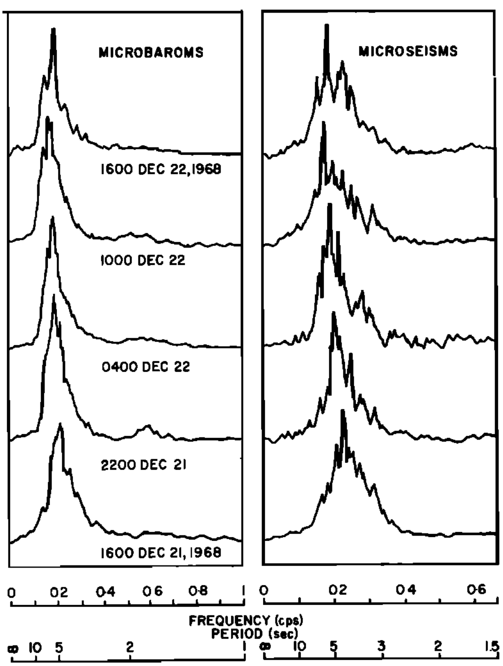

Fig. 4. Comparison of simultaneous amplitude spectra of microseisms and microbaroms for December 21–22, 1968.

1. The horizontal trace (phase) velocities of microbaroms measured across our arrays and those of others have essentially normal acoustic values for the atmosphere. The measured speeds of microseisms, on the other hand, are more than an order of magnitude higher [*Donn and Blaik*, 1953], and thus the possibility of resonant coupling of microseism energy to microbaroms by phase velocity matching is obviated.

2. The possibility of generation of microseisms by any ground loading effect of microbaroms is negated by the disparate velocities as well as the relatively large amplitudes of microseisms.

3. The reverse, or generation of microbaroms by sonic radiation from the vertical ground motion of microseisms, is also negated by the velocity difference plus the relatively large microbarom pressure change compared with calculated effects based on the formula

$$p = \rho c v$$

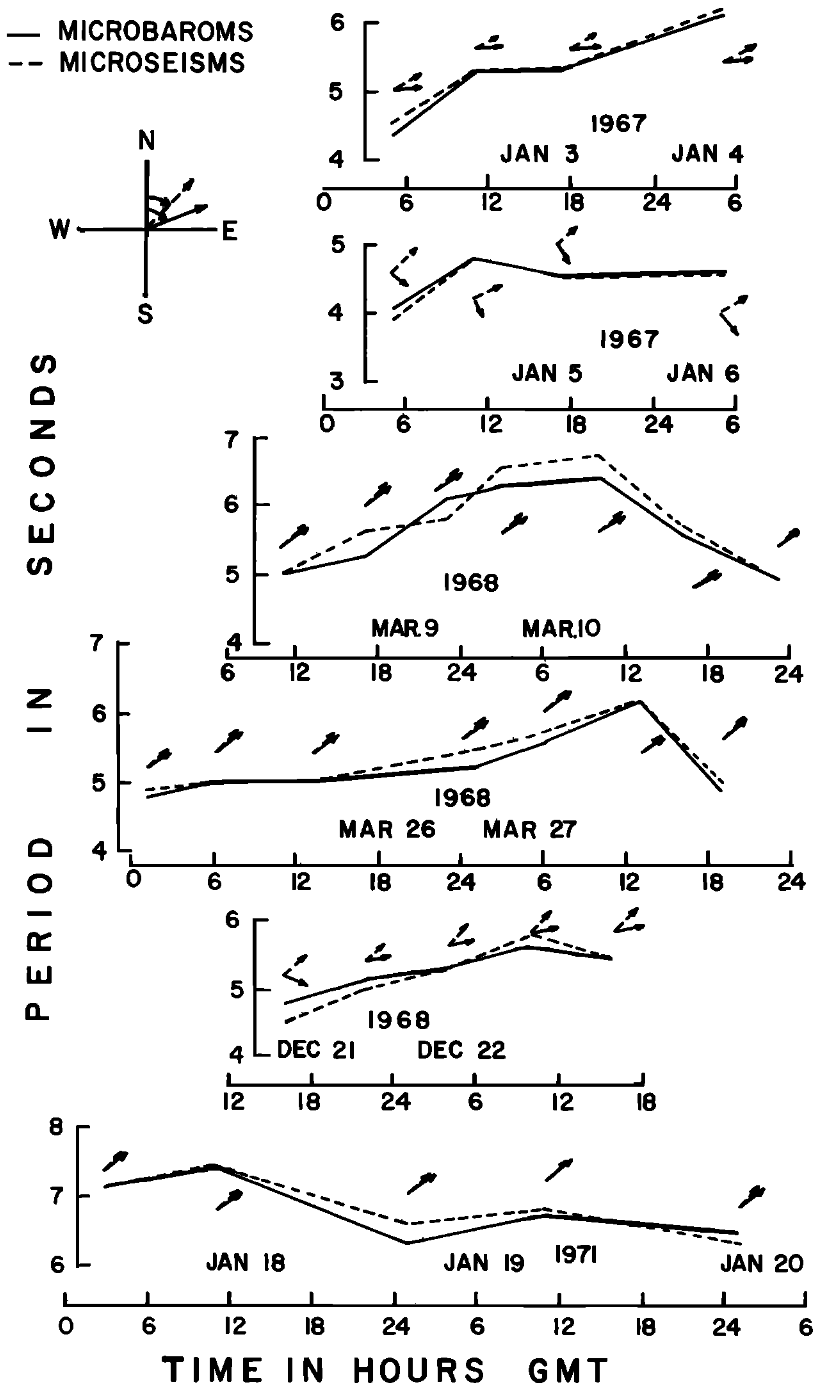

Fig. 6. Time series of simultaneous spectra of microseisms and microbaroms for a number of cases, together with arrows indicating source directions at the time of each computation.

where p is the air pressure change in microbars or dynes per square centimeter, ρ is its density, c is the acoustic speed in air, and v is the vertical velocity of the ground wave. Observed microbaroms are from 1 to 10 microbars in pressure amplitude or at least 2 orders of magnitude higher than the value calculated from this formula.

4. Finally, microbaroms show strong semidiurnal amplitude variations as shown in Figure 1. Simultaneous microseisms, on the other hand, do not show such variations but remain strong as a function of storm size and intensity. *Donn and Rind* [1971, 1972] have shown that the microbarom amplitude variations of the type in Figure 1 are propagation effects caused by the rotating pattern of atmospheric tidal winds at an elevation around 100 km.

CONCLUSIONS

Analysis and interpretation of simultaneous microseisms and microbaroms show that the two propagate independently through the ground and atmosphere, respectively, and are not coupled by any resonant or nonresonant mechanism. Also, the data of simultaneous spectra and source azimuths of microseisms and microbaroms lead to the inescapable conclusion that the generating mechanism is a source common to both phenomena. Ocean waves, in the form of interference patterns, seem to provide the only source mechanism that can meet the constraints of similarity of spectra and direction for wave phenomena transmitted to both the atmosphere and the sea bottom. The experimental data on wave period, although they are less firm, do support theoretical requirements that the period ratio of waves to microseisms and microbaroms be in the ratio 2:1.

Acknowledgments. This research was supported by National Science Foundation grants GA 33710X and GA 17454 and Army Research Office-Durham grant DA-AROD-31-124-71-G90. Necessary weather and wave charts and records were furnished by the National Weather Service and the U.S. Navy Fleet Numerical Weather Facility. Lamont-Doherty Geological Observatory of Columbia University contribution 1981. City University Institute of Oceanography contribution 19.

REFERENCES

Bendat, J., and A. Piersol, *Measurement and Analysis of Random Data,* p. 260, John Wiley, New York, 1966.

Bolt, B., Seismic air waves from the great Alaskan earthquake, *Nature, 202,* 1095–1096, 1964.

Cook, R. K., Strange sounds in the atmosphere, 2, *Sound, 1,* 25–33, 1962.

Daniels, F. B., Acoustical energy generated by ocean waves, *J. Acoust. Soc. Amer., 24,* 83, 1952.

Daniels, F. B., Generation of infrasound by ocean waves, *J. Acoust. Soc. Amer., 34,* 352–353, 1953.

Donn, W., Cyclonic microseism generated in the western North Atlantic Ocean, *J. Meteorol., 9,* 61–71, 1952.

Donn, W., A comparison of microseisms and ocean waves recorded in southern New England, *Eos Trans. AGU, 34,* 471–476, 1953.

Donn, W. L., Direction studies using microseism ground-particle motion, *Eos Trans. AGU, 35,* 821–832, 1954.

Donn, W., and M. Blaik, A study and evaluation of the tripartite seismic method of locating hurricanes, *Bull. Seismol. Soc. Amer., 43,* 311–329, 1953.

Donn, W., and E. Posmentier, Ground coupled air waves from the great Alaskan earthquake, *J. Geophys. Res., 69,* 5357–5361, 1964.

Donn, W., and E. Posmentier, Infrasonic waves from the marine storm of April 7, 1966, *J. Geophys. Res., 72,* 2053–2061, 1967.

Donn, W., and D. Rind, Natural infrasound as an atmospheric probe, *Geophys. J. Roy. Astron. Soc., 26,* 111–133, 1971.

Donn, W., and D. Rind, Microbaroms and the temperature and wind of the upper atmosphere, *J. Atmos. Sci., 29,* 156–172, 1972.

Hasselmann, K., A statistical analysis of the generation of microseisms, *Rev. Geophys. Space Phys., 1,* 177–210, 1963.

Lee, A. W., The three components of microseismic disturbance at Kew Observatory: Discussion of the records for 1932, *Geophys. Mem. 36,* pp. 1–10, Meteorological Office, London, 1935.

Longuet-Higgins, M. S., A theory of the origin of microseisms, *Phil. Trans. Roy. Soc. London, 24,* 1–35, 1950.

Miche, M., Mouvements ondulatoires de la mer en profondeur constant ou décroissante, *Ann. Ponts Chaussees, 114,* 25–87, 131–164, 270–292, 396–406, 1944.

Oliver, J., and M. Ewing, Microseisms in the 11-to-18-second period range, *Bull. Seismol. Soc. Amer., 47,* 111–127, 1957.

Posmentier, E., A theory of microbaroms, *Geophys. J. Roy. Astron. Soc., 13,* 487–501, 1967.

(Received July 28, 1972;
revised March 12, 1973.)