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# SUMMARY REPORT, ATMOSPHERIC PROPAGATION, OCTOBER I, 1966 TO SEPTEMBER 30, 1967

Ivan Tolstoy, et al

Columbia University
Dobbs Ferry, New York

October 1967

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TECHNICAL REPORT No. 144

# SUMMARY REPORT, ATMOSPHERIC PROPAGATION, OCTOBER 1, 1966 TO SEPTEMBER 30, 1967

by
Ivan Tolstoy
T. Herron
and
D. W. Kraft

October 2, 1967

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## ABSTRACT

This report summarizes the work performed during FY 1967. After a brief description of the system and its characteristics, a number of background studies are described. Particular attention has been given to microbarographic pressure fluctuation levels (power spectra) and cross-spectral properties such as coherence and phase lags between pairs of instruments. It is found that an important fraction of the background, in the 5- to 50-min period range, consists of slowly traveling disturbances (20-40 m $sec^{-1}$) probably associated with the jet stream. This part of the background is coherent over distances of a few km, and decorrelates rapidly for distances greater than 10 km. This report also discusses briefly immediate plans for FY 1968.

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## I. STATUS OF OUR EXPERIMENTAL FACILITY DURING 1967

The system we have had in operation for the past year is a long-period microbarographic network consisting of six to nine microbarographs within a radius of 120 km of our central recording station at Hudson Laboratories in Dobbs Ferry, New York.

These instruments, which have been described elsewhere by C. S. Clay and D. W. Kraft,[1] are constructed around a Pace gauge. The time constants of these units were adjusted so as to provide a flat response for periods of a few seconds to ten minutes. For the longer periods, the amplitude response falls off at the rate of 6 dB/octave. This achieves a certain degree of pre-whitening against a background power spectrum which rises steeply as the period $T$ increases, while still providing sufficient response to perturbations of a few $\mu$bar out to periods of the order of 90 min. All instruments were calibrated by measuring response to a pressure step function.[1] During this past year the microbarographs have been used to modulate the frequency transmitted on a telephone line to our central recording station, where the frequency is measured and the information punched on tally tapes. We thus have fully digitized tapes of pressure fluctuations from all stations, with digitization taking place at our master recording station at Hudson Laboratories.

Most of the recorded data cover the period range from about 3 min to 90 min. For $T > 90$ min our microbarograph information becomes subject to temperature effects. The short-period cutoff, on the other hand, is adjustable and has been dictated so far by sampling rate and data length

considerations. Most (but not all) of our data during 1967 were taken in 30-sec averages, i.e., the data are averaged for 30 sec and the resulting number punched on tape. Occasionally we have used other averaging times and, in particular, shorter averages enabling us to investigate periods as short as 10-20 sec.

The geometry of our microbarograph network has been changed somewhat once or twice and some stations have operated only part of the period under consideration, but, on the whole, the network or array has had the form shown in Fig. 1. As may be seen, we had three distant field stations (Catskill, Thornhurst and Lebanon, with distances from Hudson Laboratories of $100 \text{ km} < d < 200 \text{ km}$ ), two intermediate range stations (Sterling Forest and Stonybrook, $20 \text{ km} < d < 60 \text{ km}$ ) soon to be complemented by a third on Staten Island ($d \approx 50 \text{ km}$) , and four local stations: Nevis, Lamont Geological Observatory (LGO), Boyce-Thompson Institute (BTI), and Hudson Laboratories (HL). However, since until recently we have only had the capability for recording eight channels of digitized data (or two tapes), in all continuous records taken over extended periods one of the above sensors has usually been left out. (This particular deficiency of our system has now been eliminated with the installation of our new magnetic-tape recording system with digital data transmission links, capable of recording 32 channels on a single tape - see Section V.)

Concomitant with the above system we have had at our disposal an IBM 1130 system allowing us to process the tapes in various ways. We have the possibility of obtaining routinely:

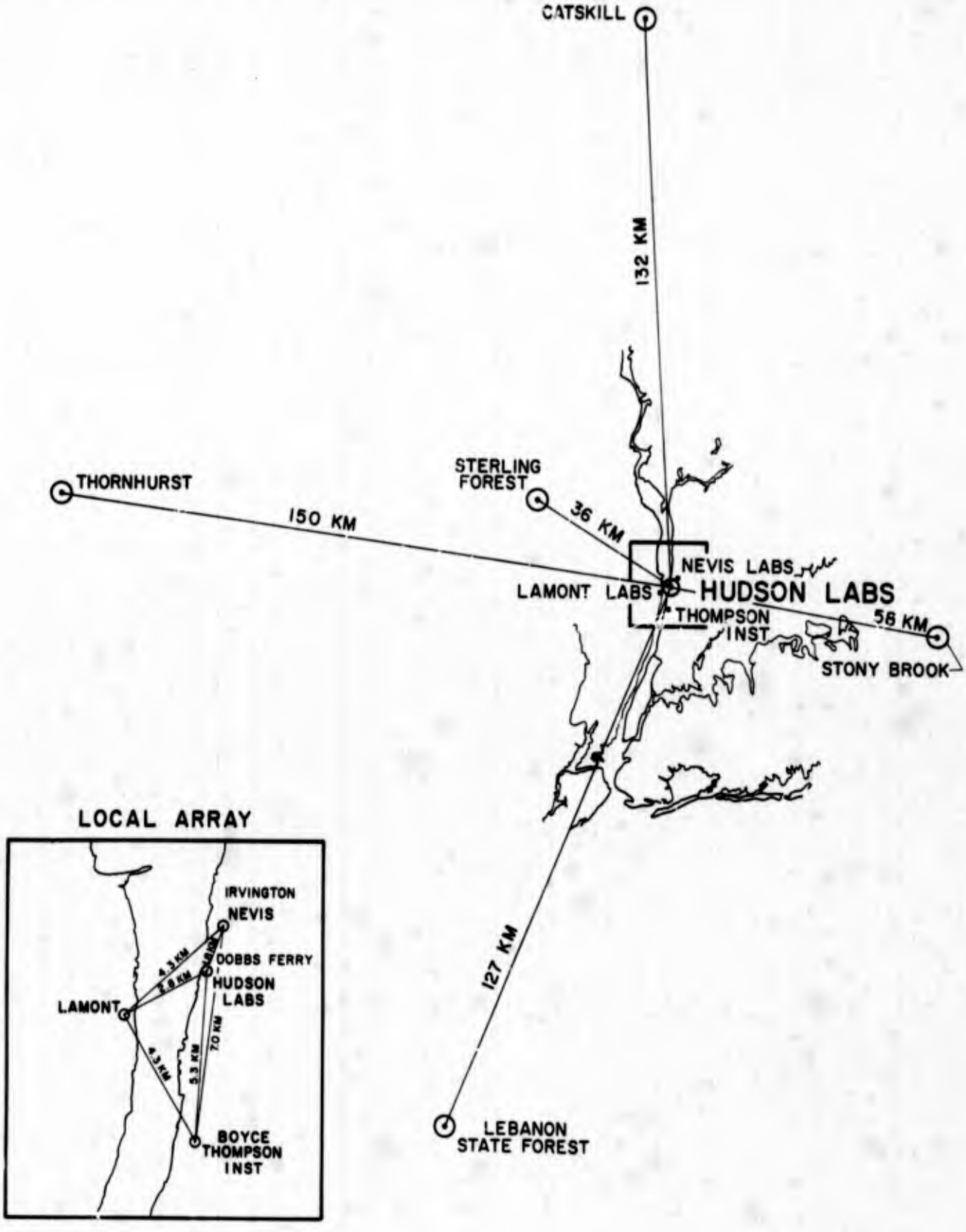


Fig. 1. Geometry of microbarograph array.

1. Power spectra.

2. Cross spectra and, specifically, coherences and phases for pairs of stations.

3. Array steering patterns of disturbances traveling across the array. In particular we can:

a) Delay, sum, and display on a Calcomp plotter.

b) Square and integrate. When applied to the results of a) this allows us to determine quantitatively the directional properties of the disturbances.

## II. SYSTEM CHARACTERISTICS

All microbarographs were tested before and after installation to determine their time constants as precisely as possible.

Tests of consistency and relative calibrations were performed on all instruments. Each instrument was first installed adjacent to the reference instrument, and its time constants were adjusted to be, as closely as possible, the same. The outputs of both instruments were digitized and recorded on the same tape. This pair of channels was then put through our cross-spectral and power spectrum routines, i.e., the coherence* and phase were calculated as a function of frequency. Two typical results are displayed in Fig. 2 and 3. It is seen that, for all practical purposes, these instruments are identical insofar as phase response is concerned, at least in the range of periods $5 \text{ min} < T < 90 \text{ min}$ .

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* Coherence is defined in the usual way as the cospectrum density squared plus the quadrature spectrum density squared divided by the first and second series power densities.

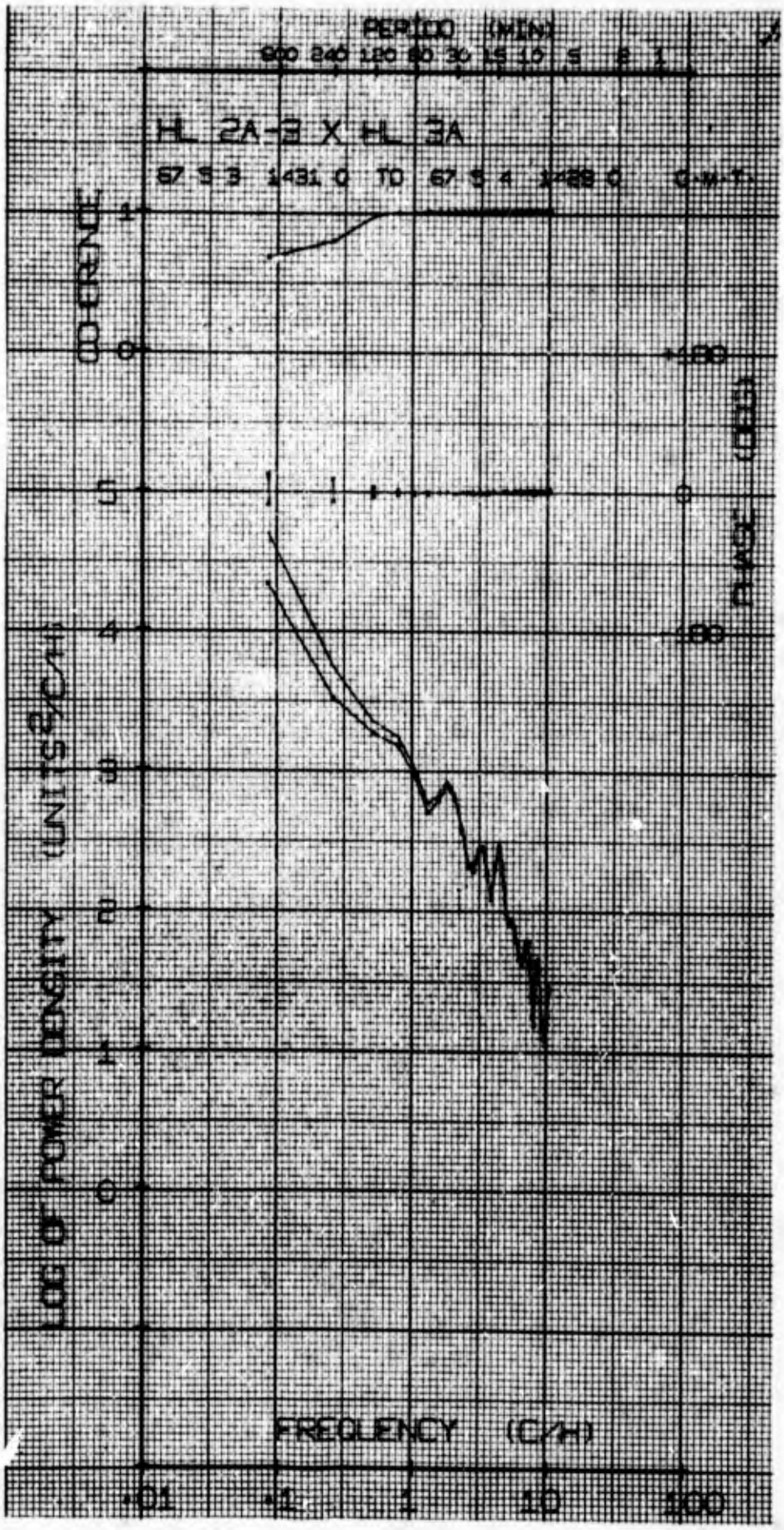


Fig. 2. Coherence (upper part of figure), phase difference (middle), and power spectra for a pair of microbarographs. Phase points are indicated with 90% confidence limits. Instruments are located side by side in a room.

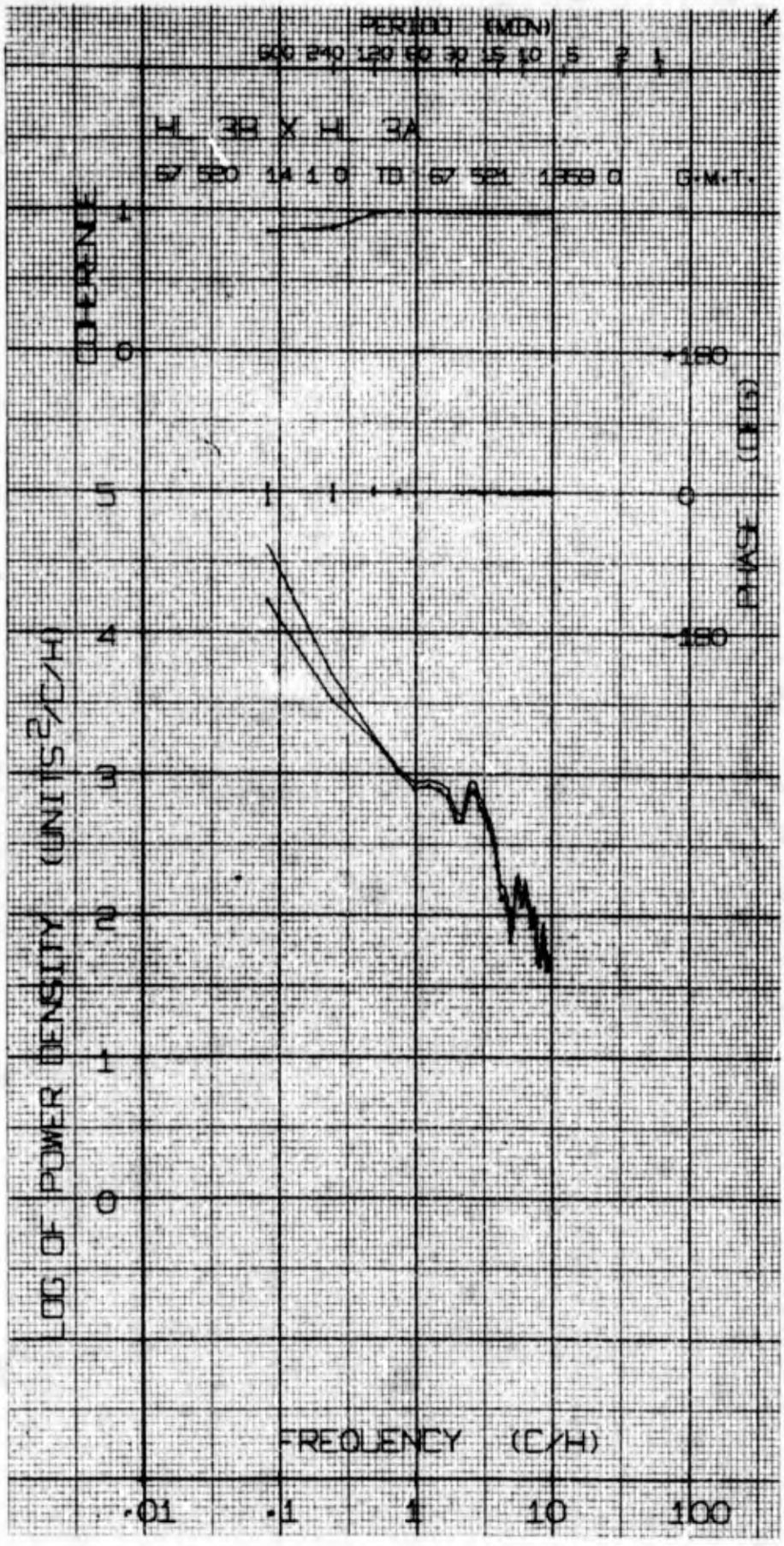


Fig. 3. Same as Fig. 2, for another typical instrument pair.

The power spectra displayed in these figures show that the amplitude response of all our instruments is essentially the same.

Additional tests were run in a similar vein to determine primarily the importance of temperature effects. Here the reference unit was kept indoors, whereas the instrument being tested was installed on the roof of the building, exposed to the sun and wind. In the absence of insulation, the instruments differed widely in their behavior. But, as soon as the outdoor instrument was insulated by means of styrofoam blocks, its behavior ceased to differ significantly from the indoor reference system – this is illustrated by Fig. 4, showing the coherence, phase, and power spectrum obtained in this manner. The appearance of coherences significantly less than one at shorter periods is probably a legitimate effect of wind-generated hydrodynamic pressures which are to some extent filtered out by the building. A coherence of approximately one seems to hold down to periods of almost 120 min, at which point it breaks and rapidly deteriorates. On another occasion (Fig. 5) the coherence curve began to break at 60 min and was down to 0.80 at the 90-min level. This was due to strong solar heating on the roof. Actually extreme conditions of this kind are not encountered in practice, since the field instruments are housed either in air-conditioned trailers or inside buildings.

Another important system characteristic is the array directionality, i.e., its capacity to inform us, under suitable conditions, about the true directions of travel of disturbances crossing our system. Clearly the properties of an array are functions of the disturbance size relative to the spacing of array elements. Specifically, if $\lambda$ is the wavelength of a

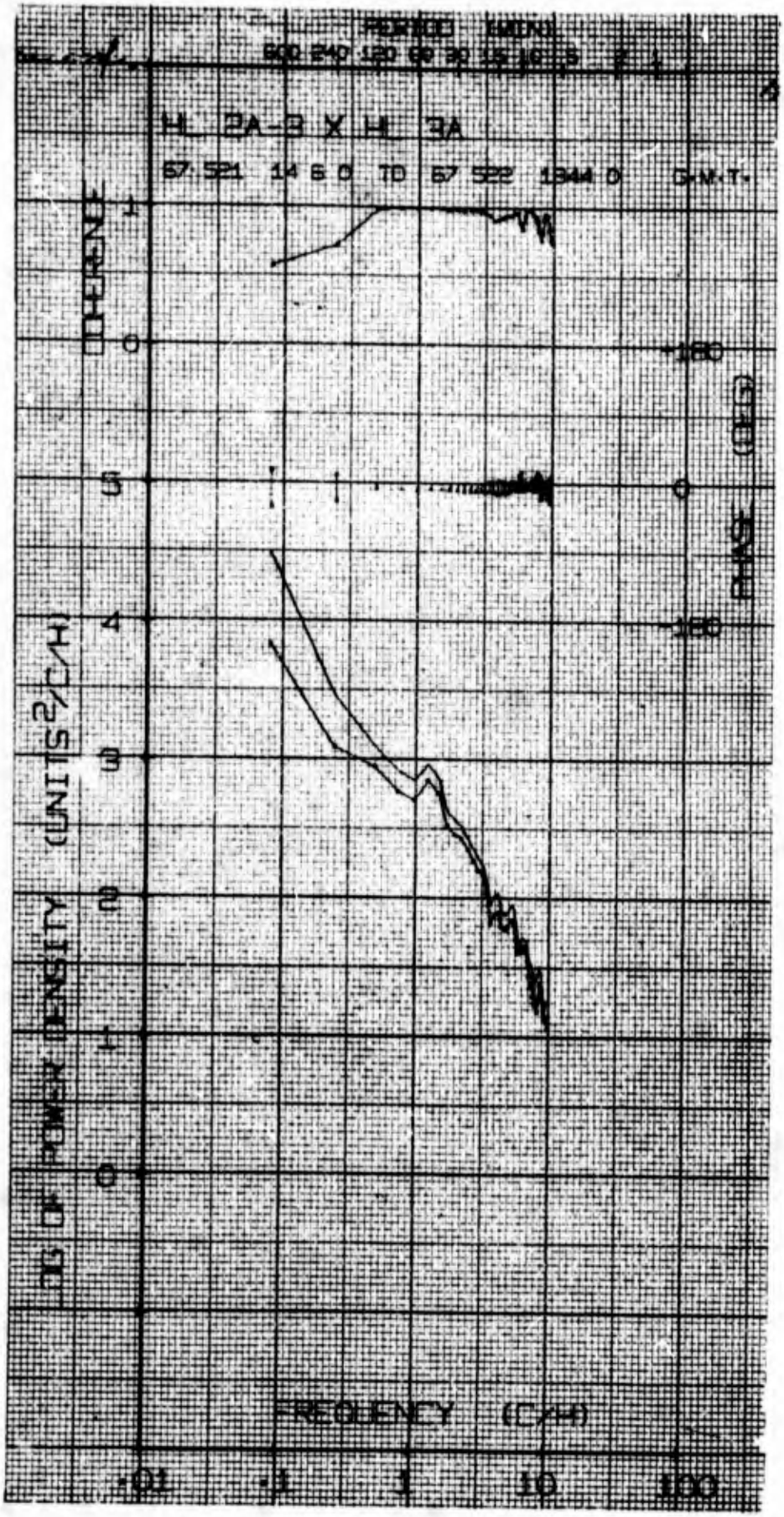


Fig. 4. Same as Fig. 2, but with one instrument in a room, and the other on the roof, exposed to elements but insulated with styrofoam blocks.

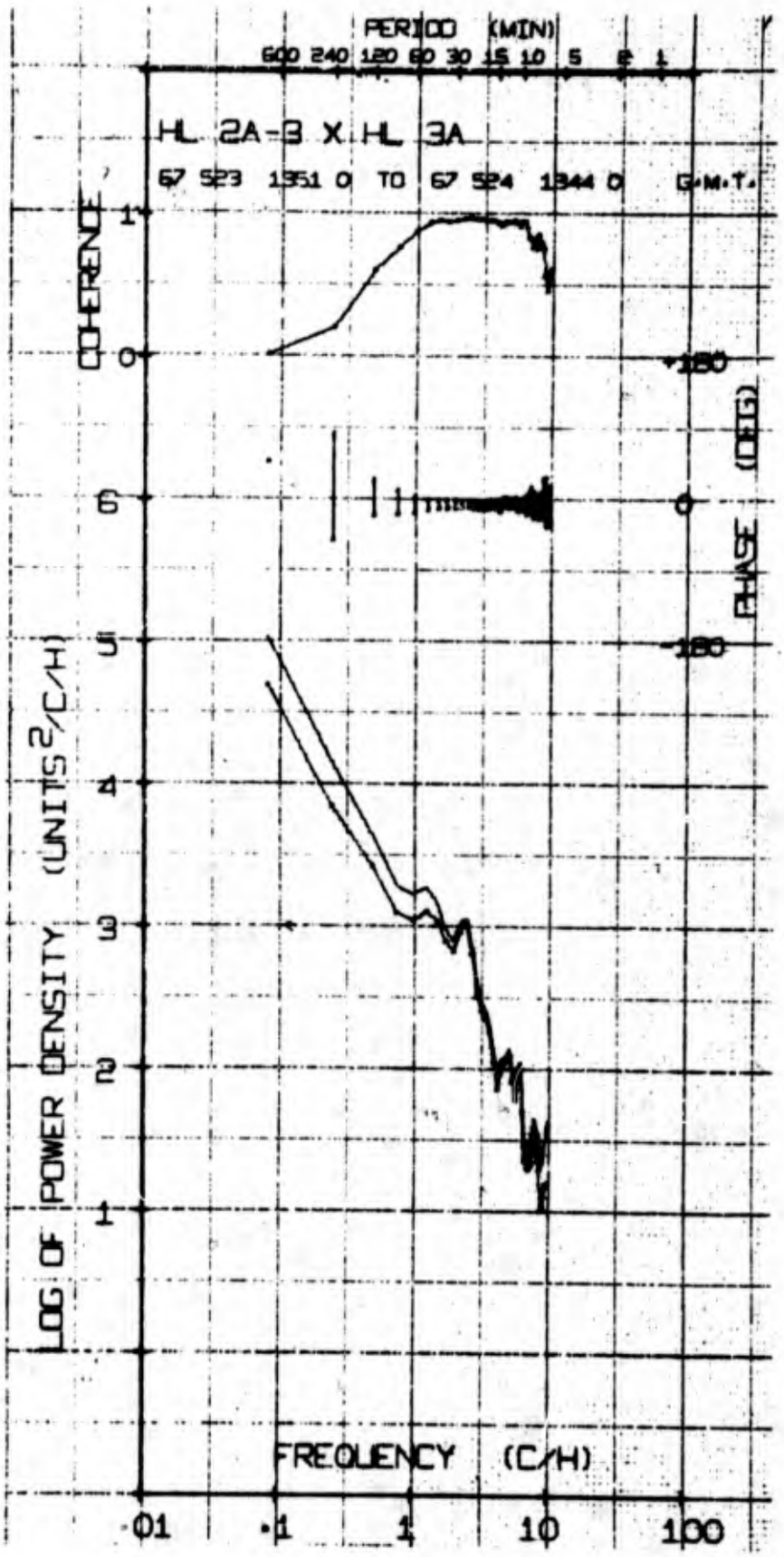


Fig. 5. Similar to Fig. 4, but taken under more extreme conditions. Of all stability tests performed on all pairs of instruments, this gave the lowest coherence and largest phase variance. Such extreme dissimilarity in environment between this pair should never be encountered in practice.

disturbance (or a spectral component thereof), and if $d$ is a measure of the spacing of the array elements, $\lambda/d$ is the critical parameter. Assuming that the relative phase uncertainties between array sensors are of the order of a few degrees, we take $\lambda/d \simeq 10$ as the upper limit for which the array can be steered wi h any degree of confidence. Thus, if we take $d$ as the average spacing between the distant stations and HL, i.e., $d \simeq 150$ km , $\lambda_{max} \sim 1.5 \times 10^6$ m $= 1.5 \times 10^3$ km is the longest wavelength for which we can obtain reliable steering information. The small local array, with $d \simeq 5$ km, , gives a $\lambda_{max}$ of the order of 50 km or so. The array characteristics were determined rather precisely by using computer-generated harmonic wave trains incident from various azimuths. For each assumed azimuth of the incident wave, we first applied our delay-and-sum routine over the chosen sample length $t_1$ to $t_2$ . We then calculate numerically

$$P = \int_{t_1}^{t_2} p^2 \, dt$$

for the resultant sum, and display $P$ on a polar plot. This gives us a picture of the quality of our results. A sharp lobe for $P$ , i.e., a narrow range of $\theta$ values for the $P$ maximum clearly implies good steering properties. The sharpness of the lobe measures the degree of uncertainty in the measurement of the true direction of travel of a plane wave disturbance. A number of typical curves are shown in Figs. 6, 7, 8, and 9.

For an ideal array and an ideal wave system we could steer down to the limit of very small $\lambda/d$ . In practice, however, two considerations

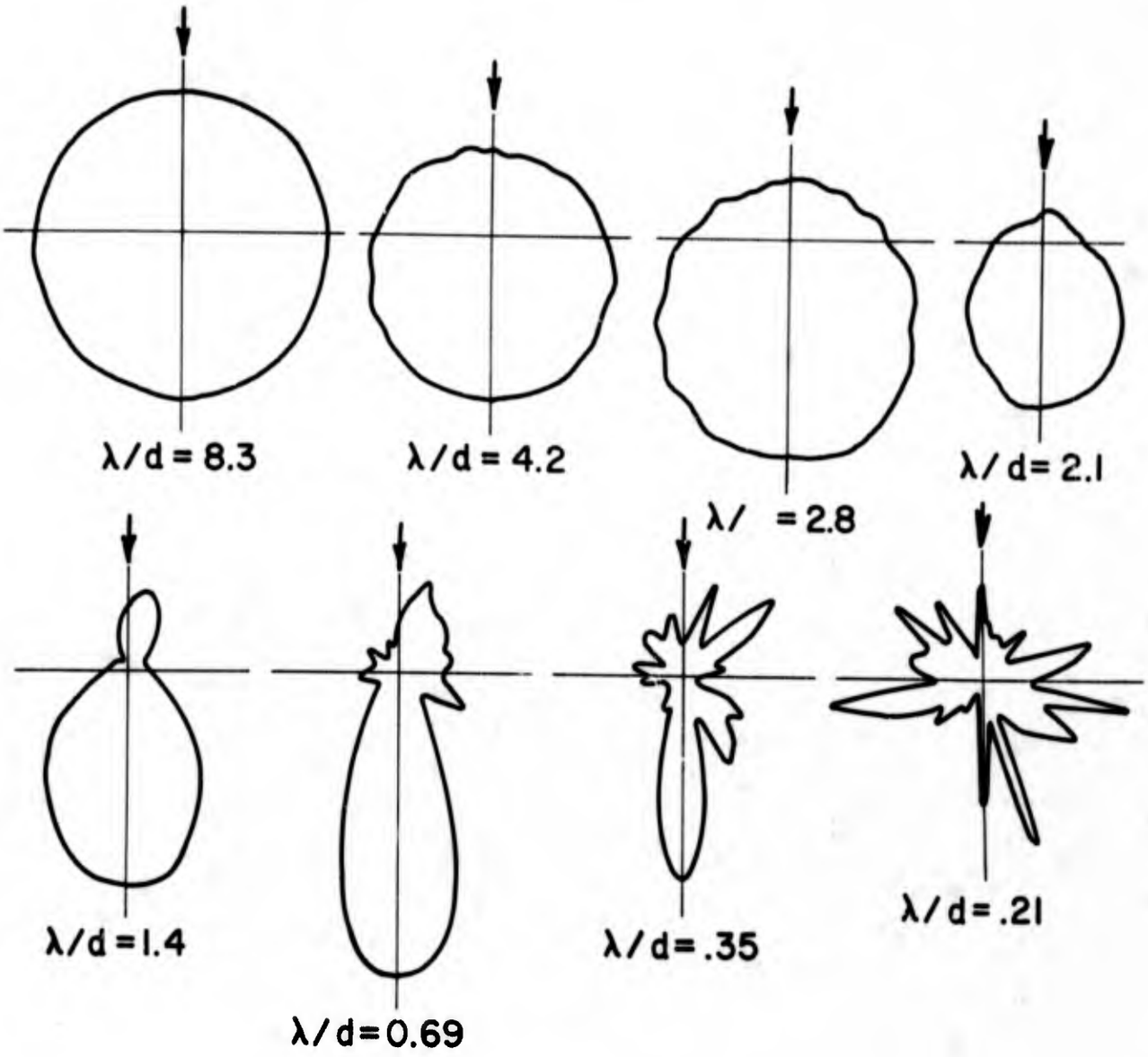


Fig. 6. Directionality of array $\left(\int_{t_1}^{t_2} p^2\, dt\right)$ for plane wave disturbance traveling southward for various $\lambda/d$ ratios, where $d = 260$ km is the maximum spacing between receivers. It is seen that near $\lambda/d \simeq 10$ directionality disappears. It is best in the range $0.5 < \lambda/d < 3.0$ .

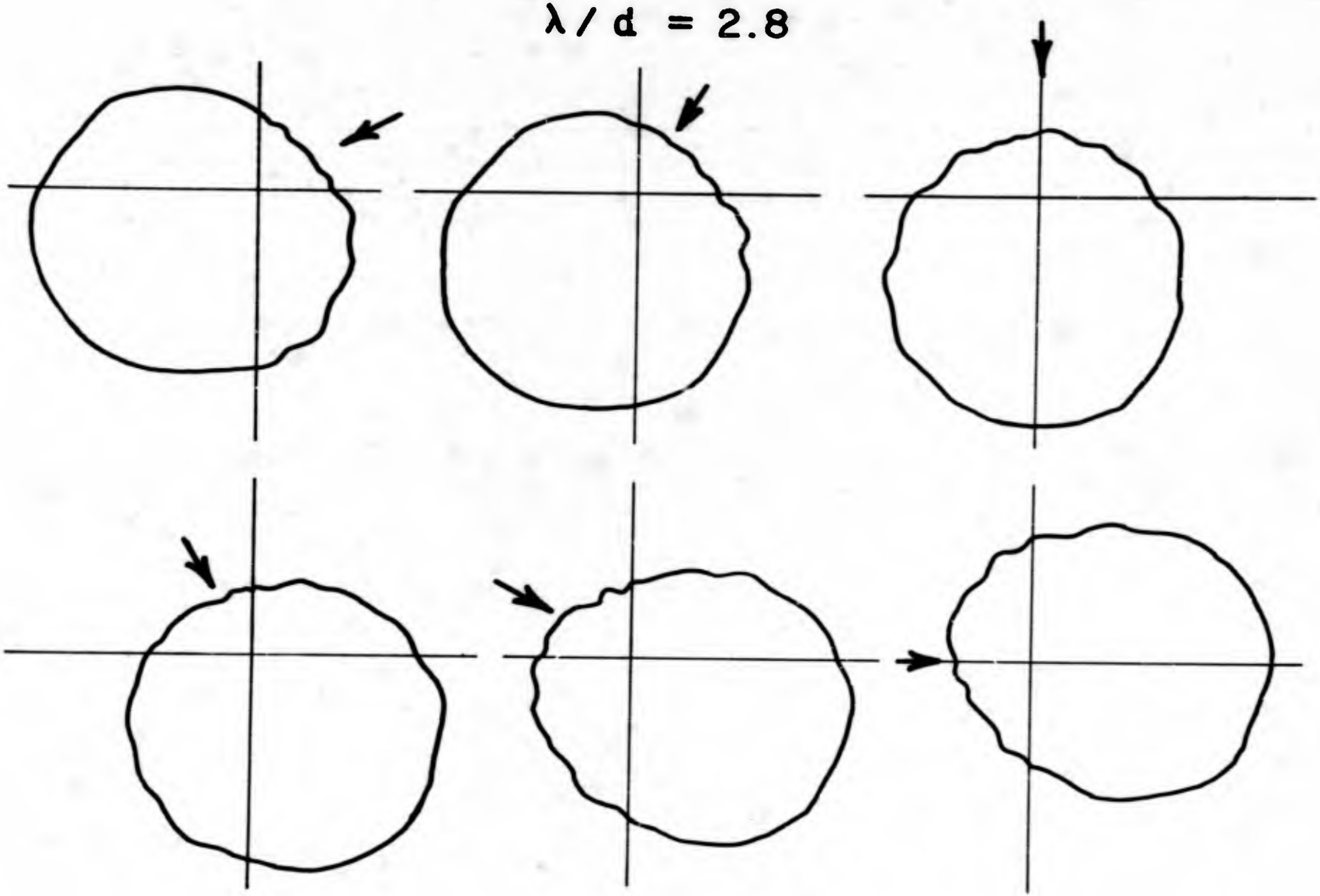


Fig. 7. Directionality for $\lambda/d = 2.8$ for various directions of arrival of a plane disturbance.

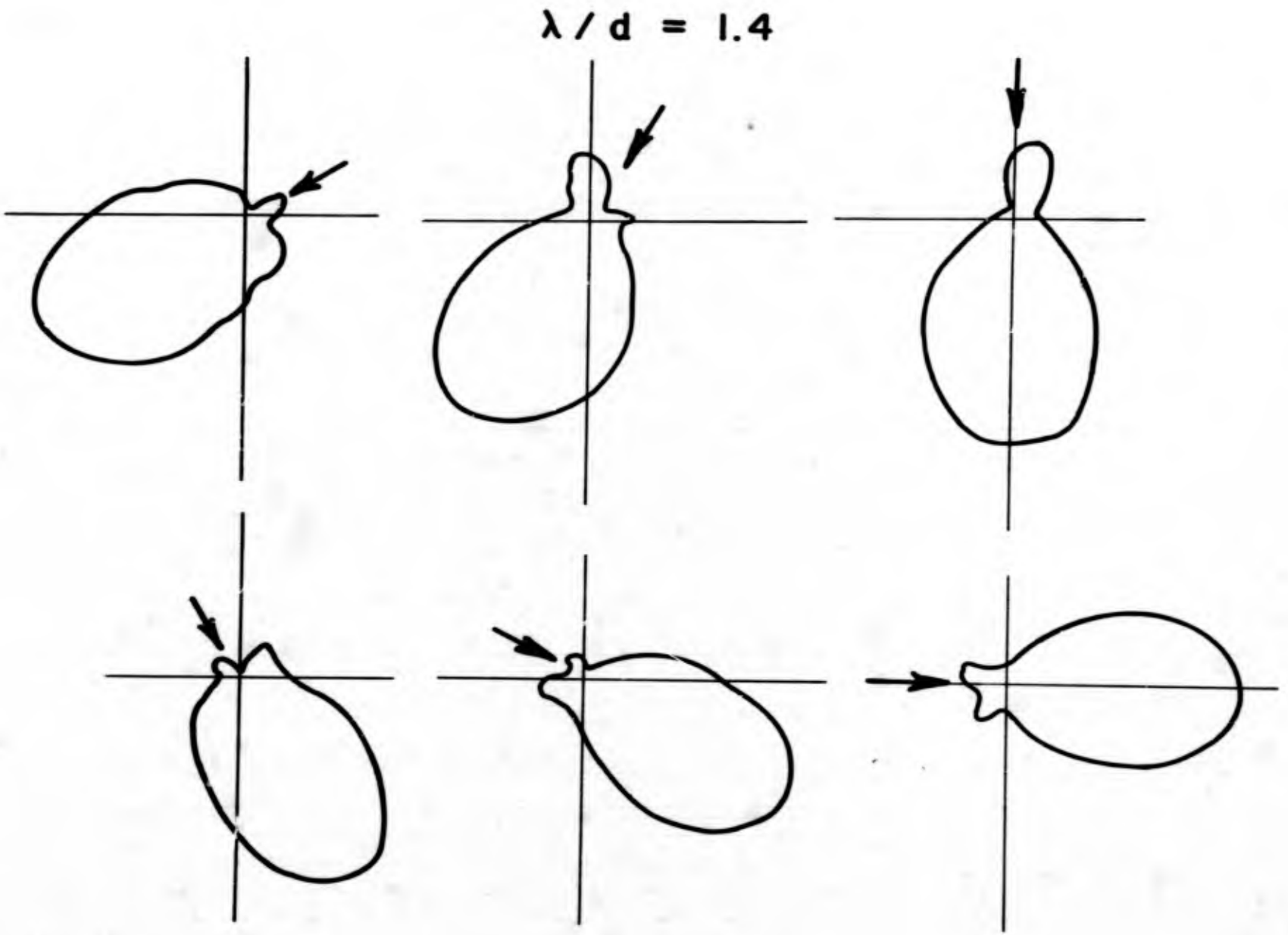


Fig. 8. Same as Fig. 7, but $\lambda/d = 1.4$ .

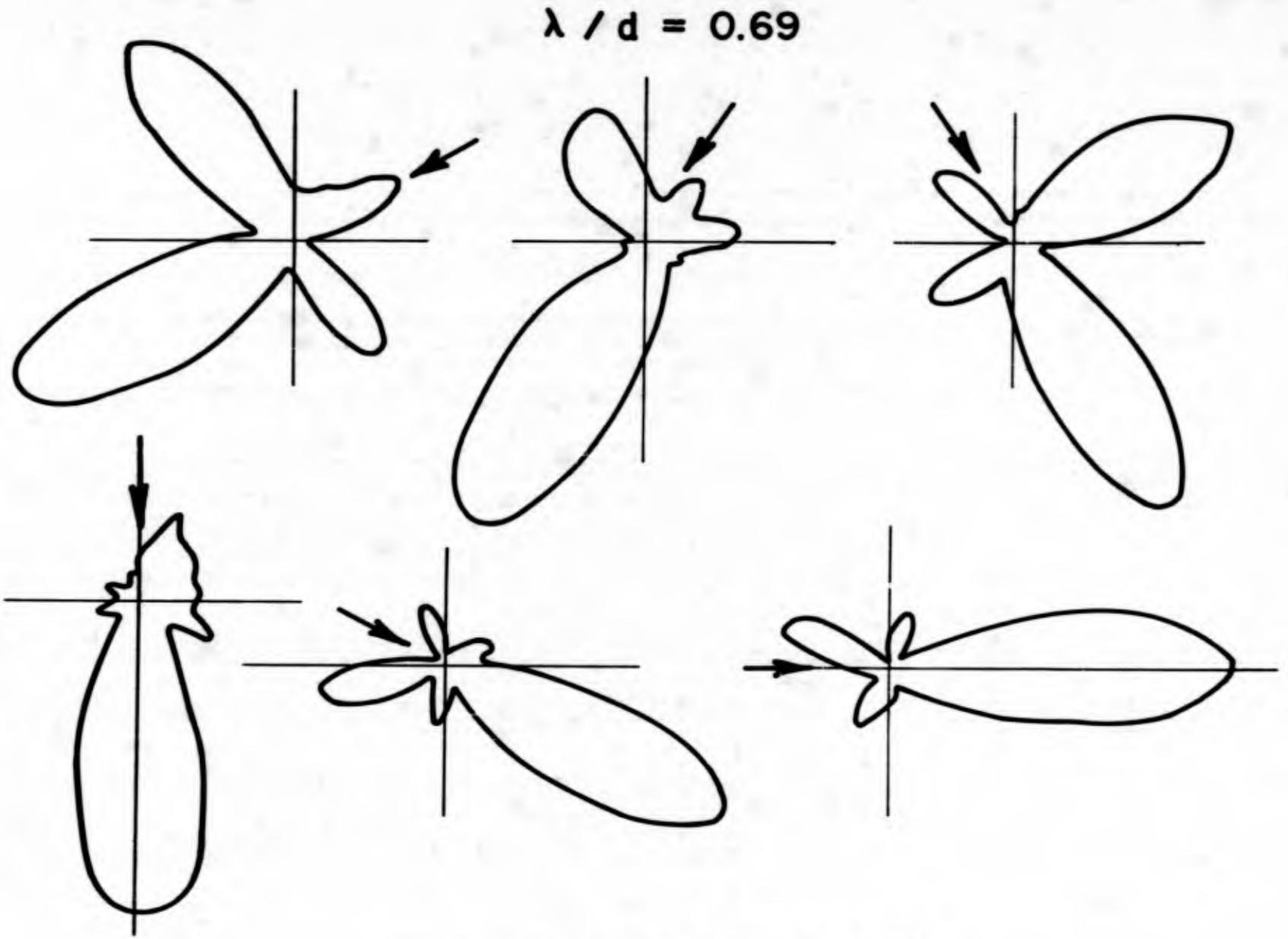


Fig. 9. Same as Fig. 7, with $\lambda/d = 0.69$ .

will limit us: the sampling rates and the decreasing coherence of the wave train. The latter feature is a property of the disturbance – and/or the background – and will be taken up in the next section describing some of our background studies. The effect of various sampling rates, on the other hand, is easy to illustrate by computer-generated wave trains, as shown in Fig. 10. This figure shows the progressively degenerating quality of the measurements as the sampling rate, i.e., the averaging time, becomes a significant fraction of a wave cycle.

## III. BACKGROUND STUDIES

With the system described in Section II a number of concurrent studies of the pressure fluctuations have been pursued systematically through the year as follows:

1. Power Spectrum Analysis: Power spectra were computed by the Blackman and Tukey method, using 24-hour record lengths. The data were pre-whitened before spectrum analysis by digitally applying a 6 dB/octave attenuation toward the long periods. A maximum lag of 10% of the record length was used in the autocorrelation, giving approximately 20 degrees of freedom to each spectral estimate. A hanning window was used to smooth the raw spectra, and the spectra were then restored to compensate for the pre-whitening. The spectra were, of course, also corrected for instrument response.

Power spectra have been obtained for almost all of the data recorded so far. If, over a period of time, all the spectra corresponding to 24-hour

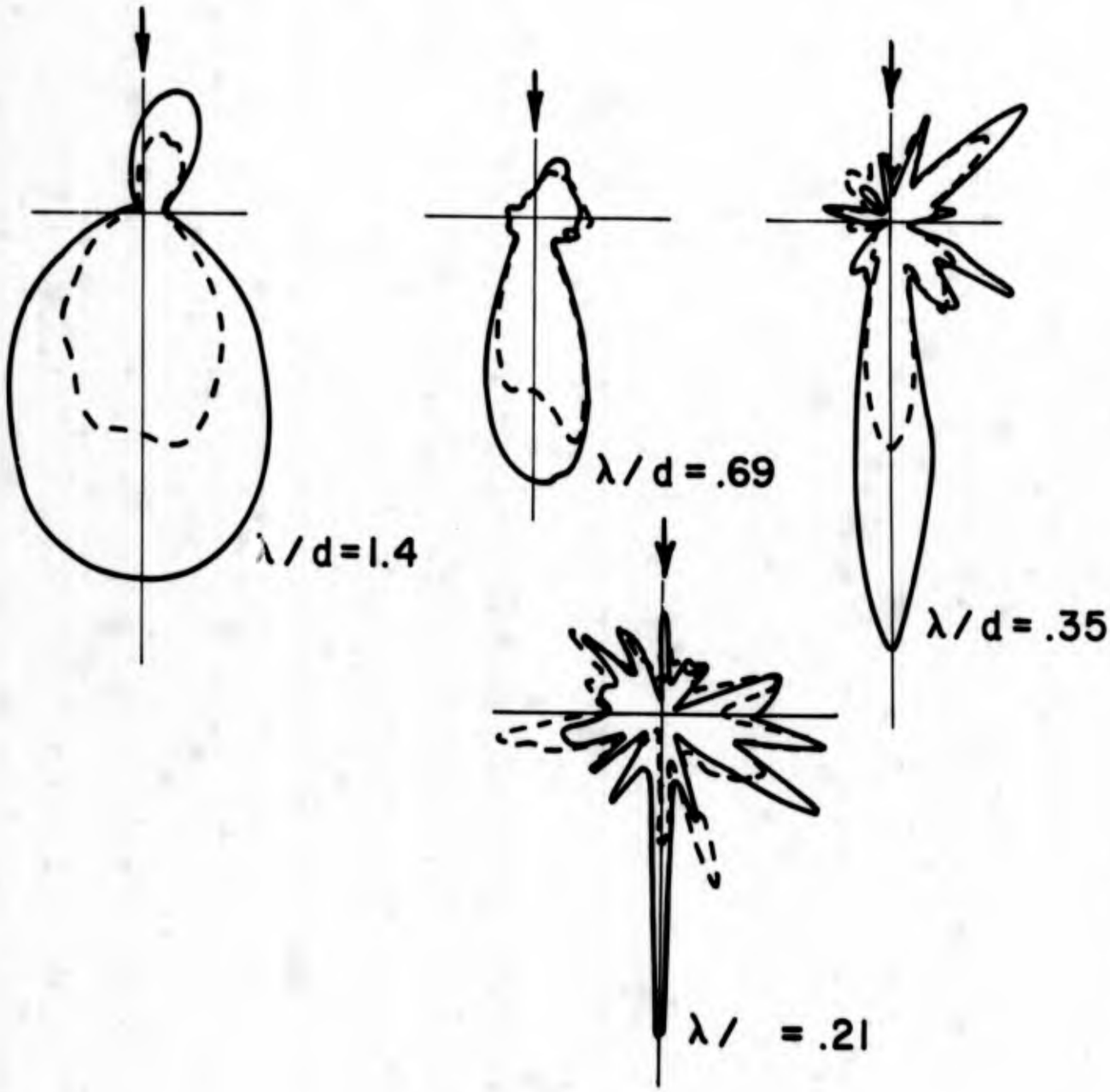


Fig. 10. Effect of sampling rate for four λ/d ratios and a southward traveling disturbance. Solid line corresponds to averaging the data for 10 sec and using this average as a data point, i.e., it corresponds to a 10-sec sampling rate. The dashed line corresponds to a 30-sec sampling rate.

samples are plotted on the same graph, one obtains plots such as those shown in Figs.11, 12, and 13. It is seen that the power spectrum levels can vary by one or two orders of magnitude within a matter of days or hours. Of considerable theoretical interest is the persistent knee in the power spectrum near periods of one hour and, also, the fact that this knee is frequently followed by spectral maxima in the 1-hour to 10-min range. Any serious effort at providing a theoretical model to explain the behavior of the background pressure fluctuations in the atmosphere will have to explain these features.

Another illustration of the variability of power levels is given by an analysis of the type shown in Fig. 14, which gives the time variation of the power spectrum levels for $T = 1$ hour and $T = 10$ min, together with a graph of daily surface wind variations. There do not seem to be, at these longer periods, any very striking correlations with ground-level wind speeds. However, further study using shorter data samples for power spectrum analysis combined with a more careful search for correlations is still required before this particular question can be put on a sound footing. Current studies are also investigating correlations with tropospheric wind conditions.

Of some interest are our monthly average power spectrum curves. Figure 15 shows monthly average power spectra for the Lebanon, Sterling Forest and HL stations: except for short periods, for which Sterling Forest is noisier, the spectra are all remarkably similar. This emphasizes the point that local conditions do not play a critical role in determining the background levels. Figure 16 compares the average curves for different

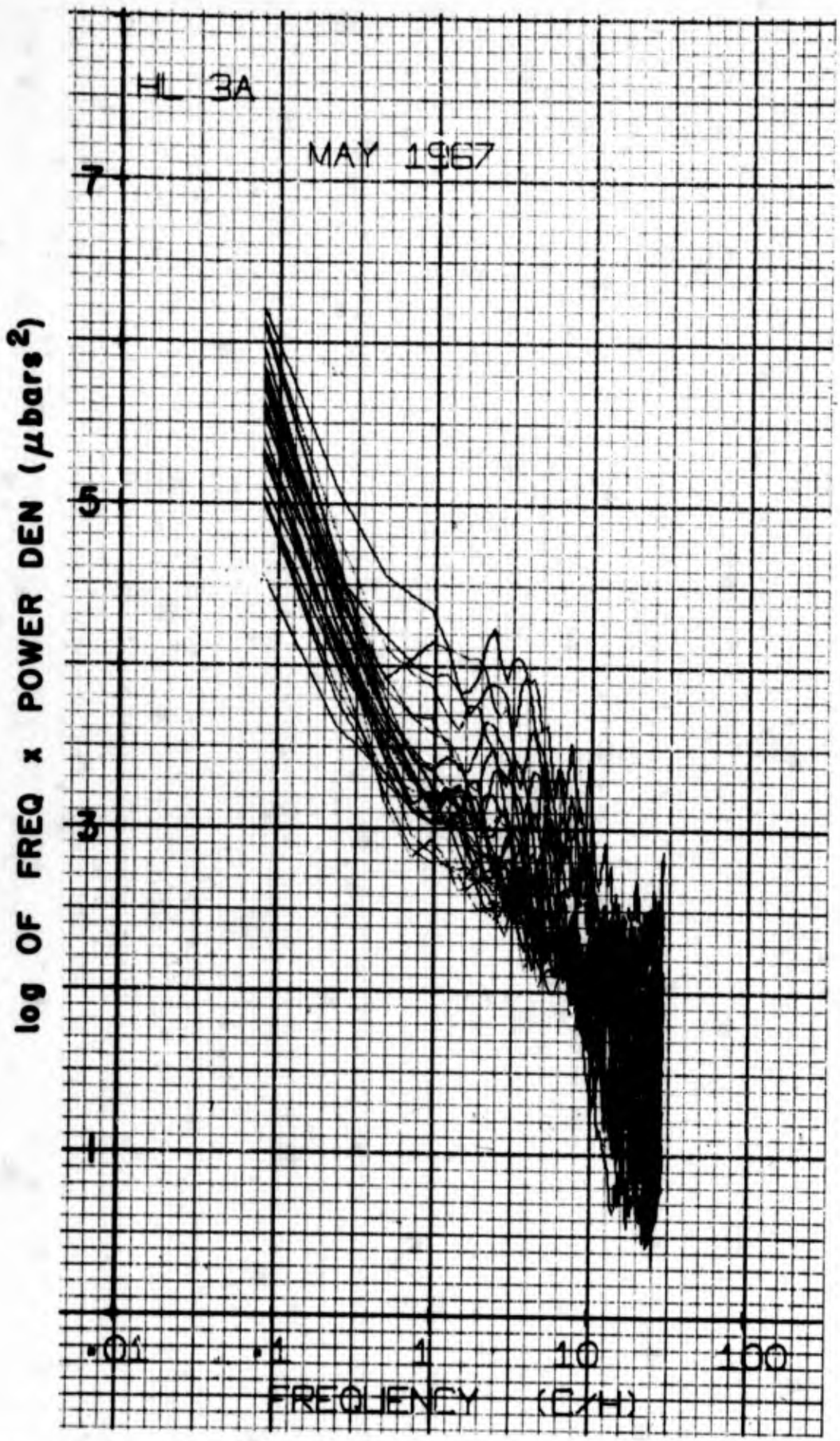


Fig. 11. Daily (24-hour samples) pressure fluctuation power spectra obtained on Hudson Laboratories microbarograph during month of May 1967. Note possible spread of about two orders of magnitude. Note also existence of pronounced knee near periods of one hour and frequently recurring maxima for $T < 1$ hour .

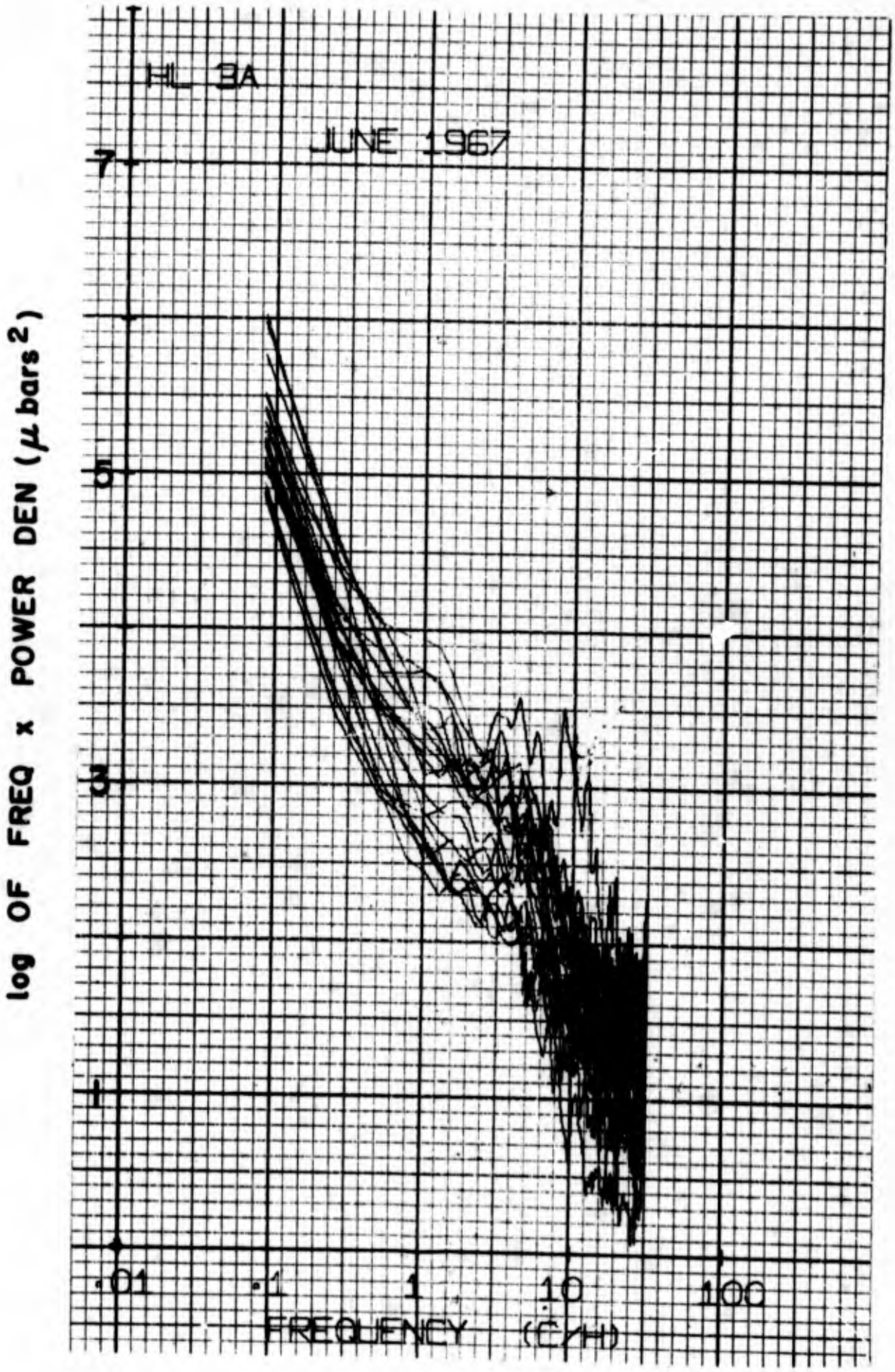


Fig. 12. Same as Fig. 11, for month of June 1967.

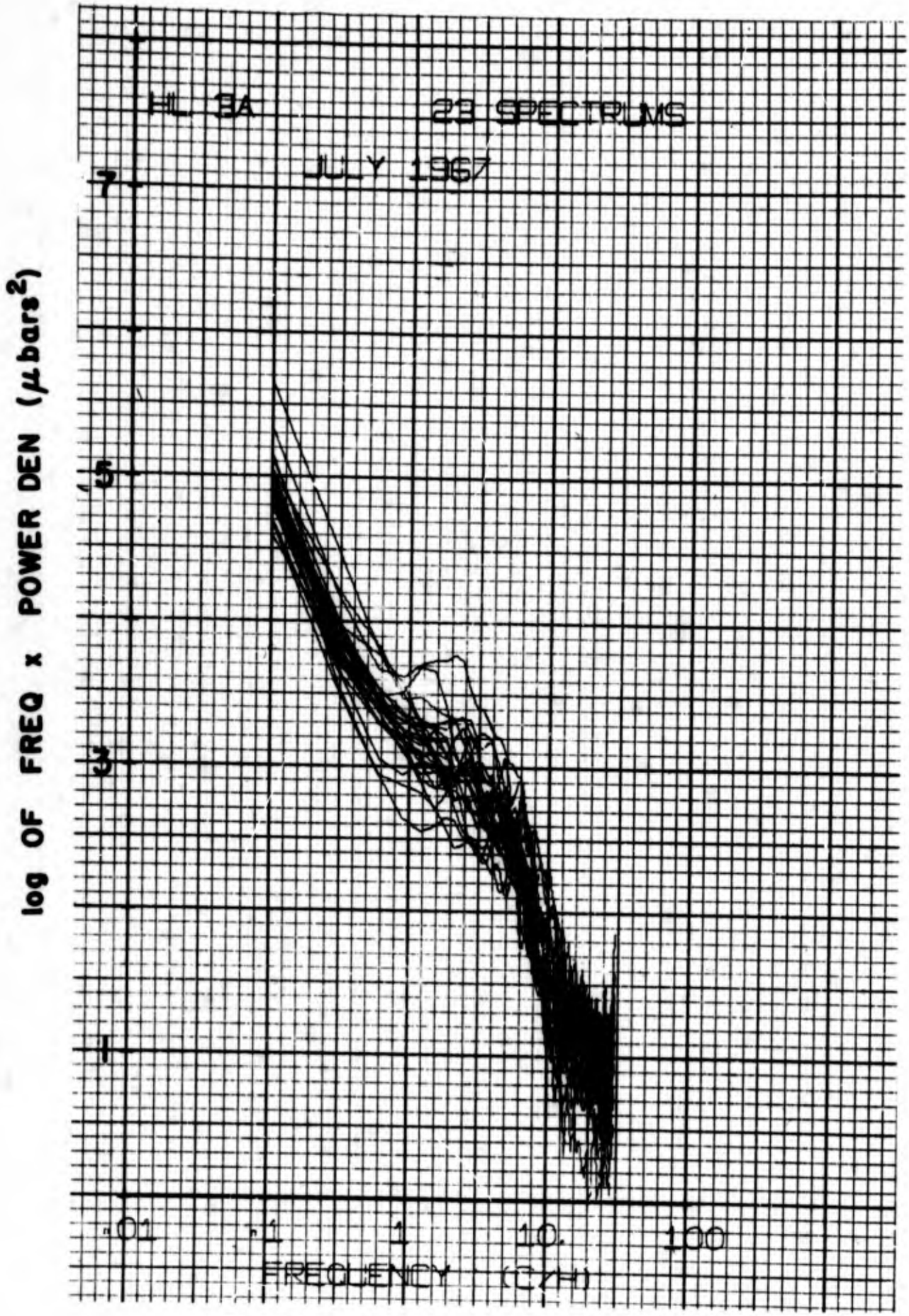


Fig. 13. Same as Fig. 11, for July 1967.

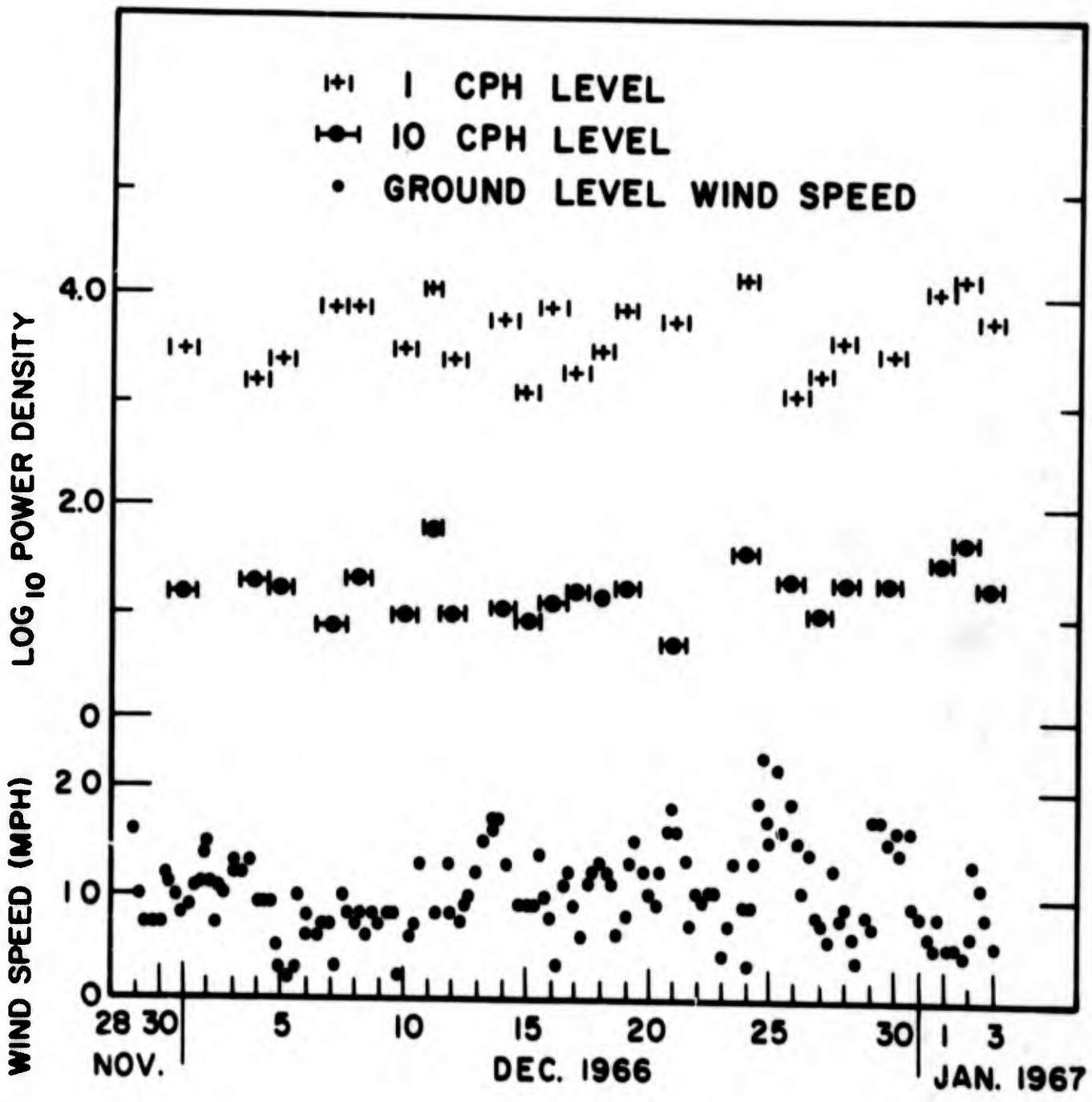


Fig. 14. Pressure fluctuation power spectra at periods of 1 hour and 6 min picked from 24-hour samples of the kind shown in Figs. 11, 12, and 13. Comparison with synoptic ground-level wind data for the New York area does not seem to show strong correlation.

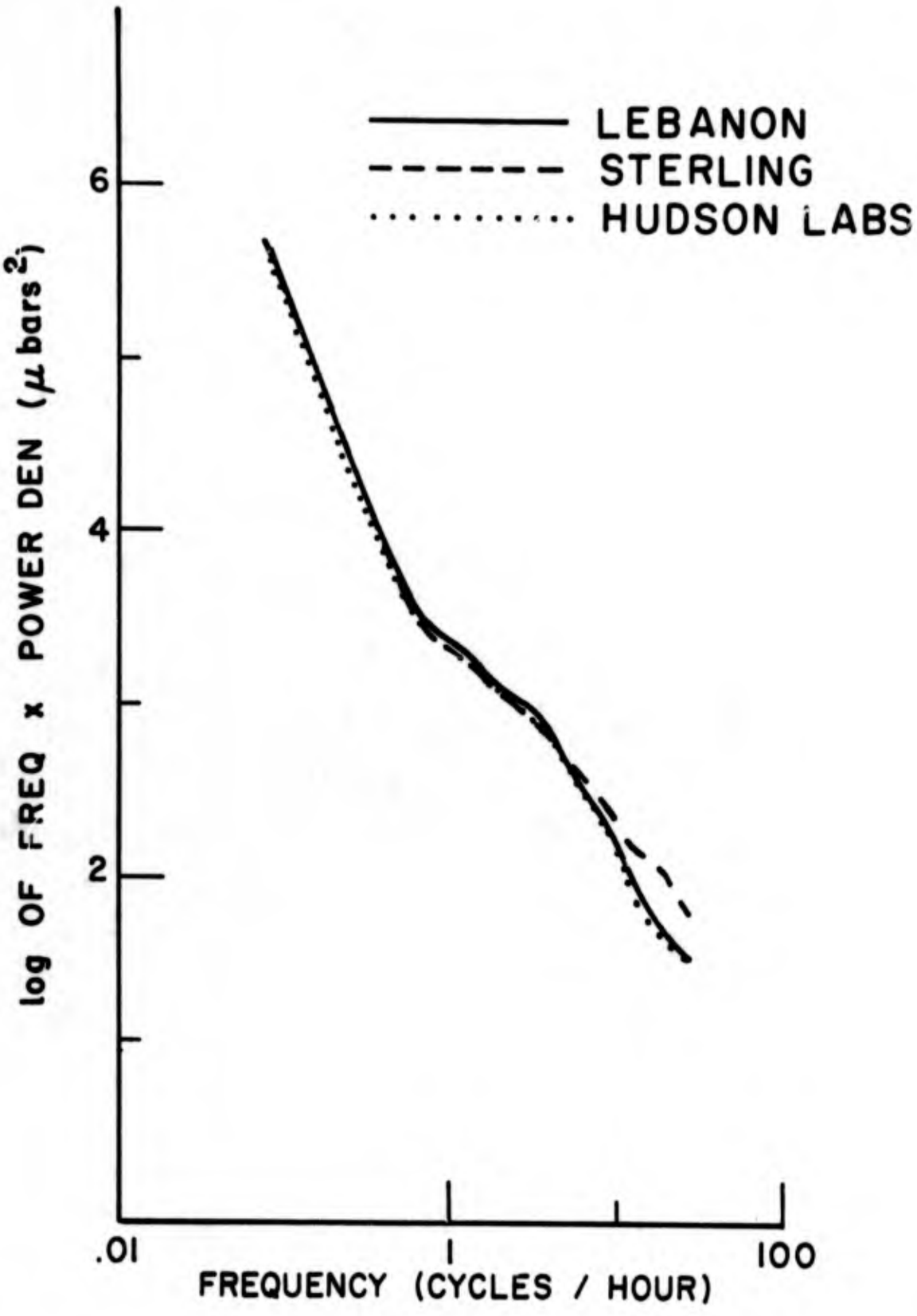


Fig. 15. Average logarithm (base 10) of power spectra versus logarithm of frequency, for May, for three stations (Lebanon, Sterling Forest, and Hudson Laboratories) shows that, for this part of the spectrum, local conditions do not appear to play a strong role. Only toward shorter periods (T < 30 min) Sterling Forest appears to depart significantly from the others. This could be a topographic effect.

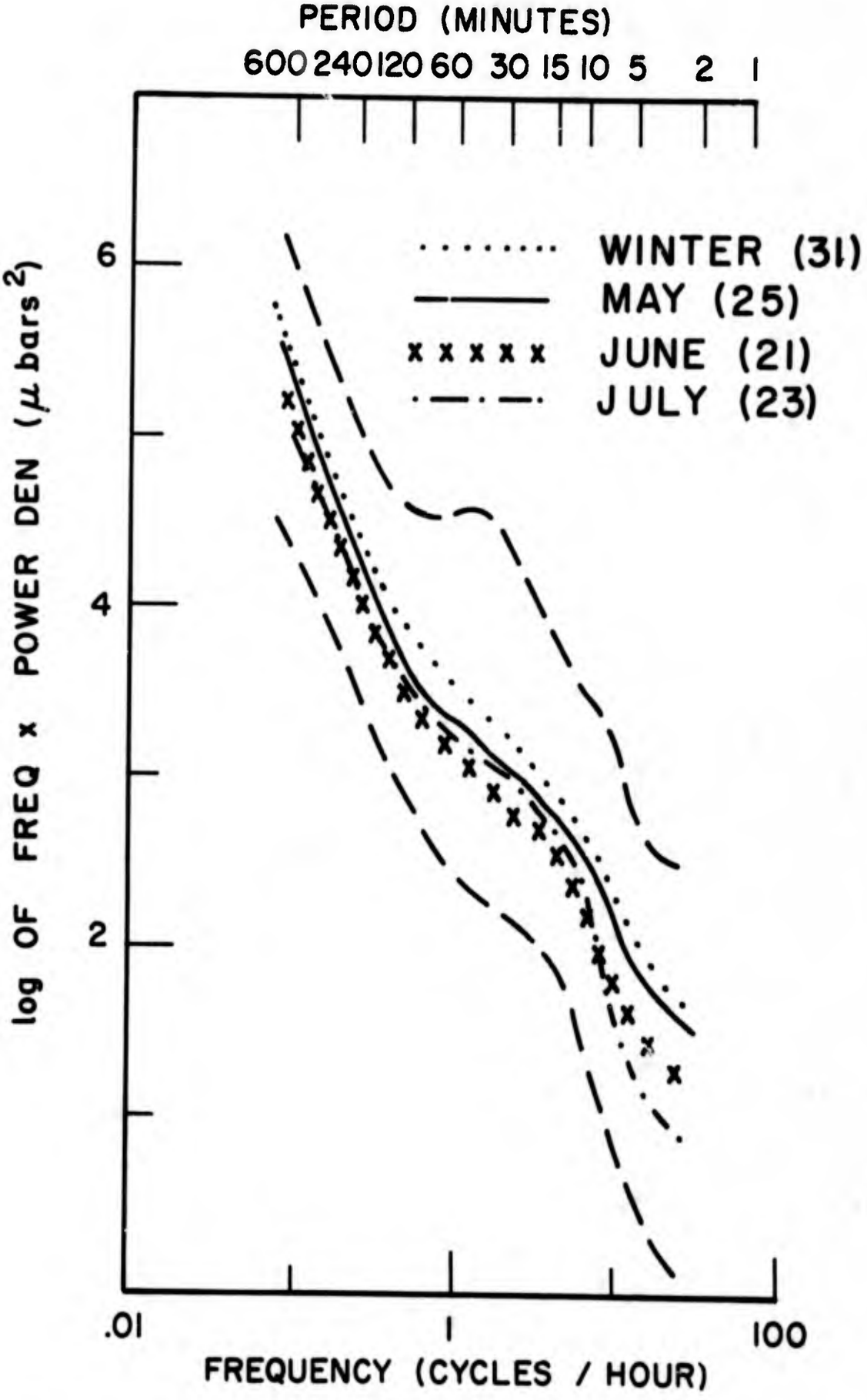


Fig. 16. Average logarithm of power spectra at Hudson Laboratories for a number of months. Number of 24-hour spectra used for each month is given by number in parentheses. Dashed lines indicate extreme cases encountered during that period.

months. During the months of February and March we had, unfortunately, less data available (various reasons contributed to this, including recalibration of all our sensors and installation of new ones). As a result, the data for December, January, February, and March all went into the "winter" curve. It is not possible to say for sure, at this point, which month had the highest background of pressure fluctuations. But we do appear to have systematically higher winter levels. This difference is small compared to the possible extremes (e.g., within a given month), but it is real and corresponds to a factor of 2 to 5 in power. As one would expect, it becomes more pronounced toward the shorter periods, suggesting a possible correlation with local weather conditions.

The average spectra which we obtain are quite similar to Gossard's results obtained on the West Coast.[2]

2. Cross-Spectrum Analysis: Cross-spectrum analyses have been performed upon data from many pairs of stations in the array, yielding measurements of phase angle and coherence. Some typical results are shown in Figs. 17 and 18.

These show that, for 24-hour samples, the coherence at longer periods is high between sensors of the small array located 5 or 10 km apart, at least for long periods. For shorter periods, the coherence will usually drop and will not infrequently show peaks of the type appearing in Fig. 17. For bigger spacing between stations (Fig. 18), coherence is lost quite rapidly, at least for such long samples (24 hours).

Figure 19 shows the results of an analysis in which many coherence values, from station paths of various separations, were averaged for periods

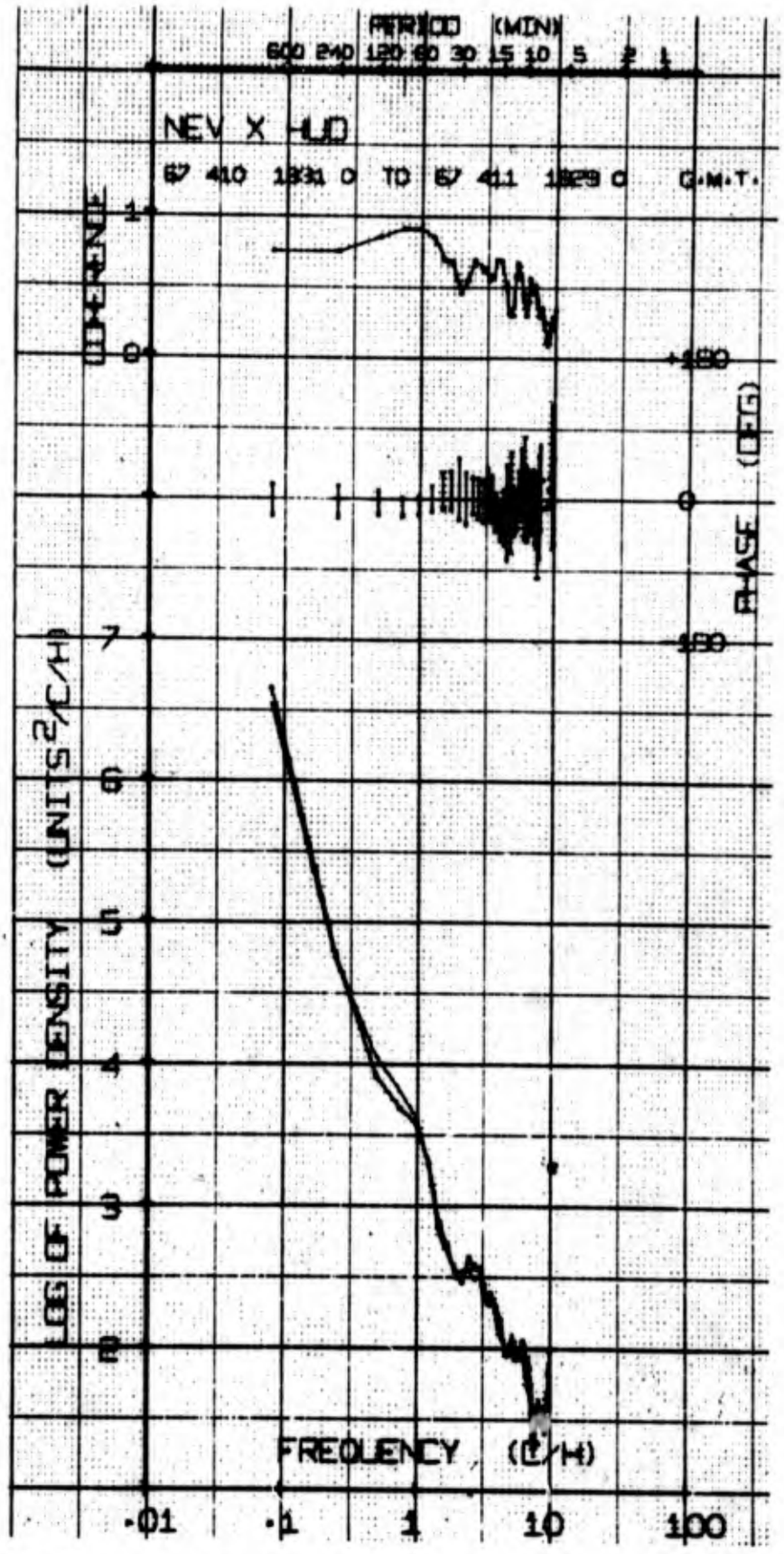


Fig. 17. Coherence, phase, and power spectra for Nevis and Hudson Laboratories microbarographs on April 10, 1967. These stations are close to each other ($\simeq 1.8$ km) and the coherence is quite high, especially at longer periods (coherence $\simeq 0.9$ at T = 100 min ).

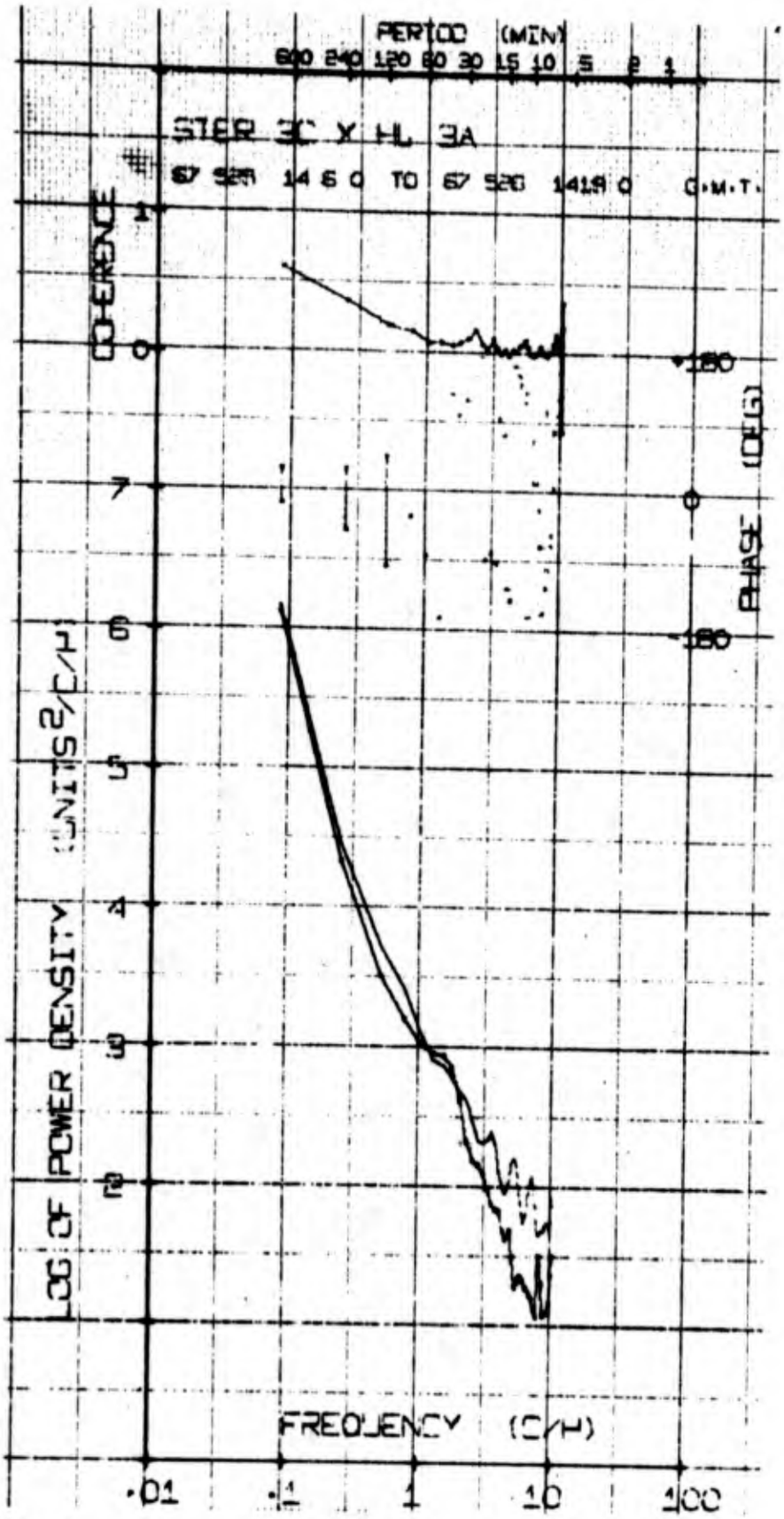


Fig. 18. Same as Fig. 17, but for the pair of stations Sterling Forest and Hudson Laboratories. Here the distance between stations is much larger (36 km) and the coherence is negligible.

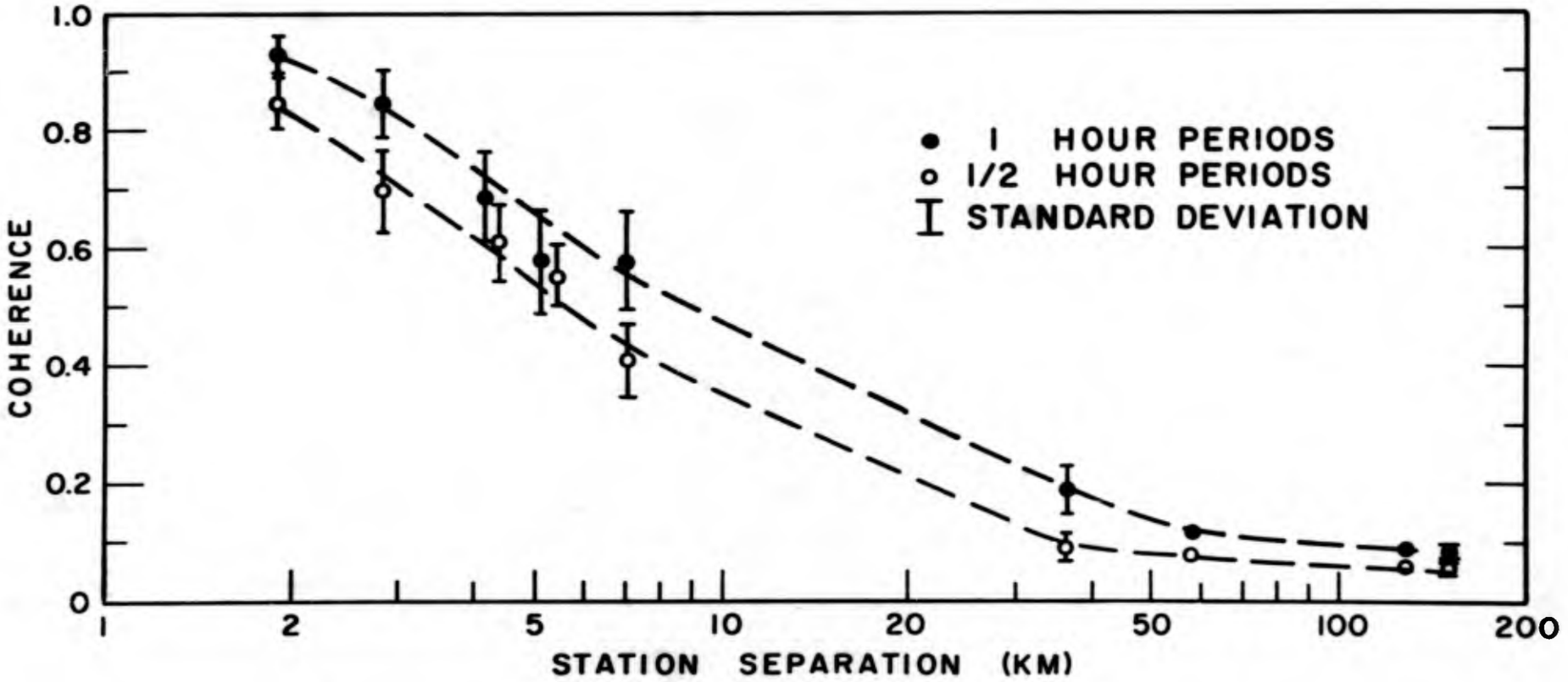


Fig. 19. Showing coherences versus station separation for periods of 1 hour and 1/2 hour. These correspond to average of many points from coherence curves of the type shown in Figs. 17 and 18.

$T = 1$ hour and $T = 30$ min . Beyond a station separation of the order of 40 km, the coherence generally drops to values no longer implying a similar source for the signals. Of course, the coherence for any chosen spectral component is partly a function of the record length being analyzed. We are now searching for signal correlations at greater station separation using shorter record lengths (compatible, of course, with the problem of spectral estimate stability versus frequency resolution).

3. Moving Cross-Spectrum Analysis: A computer program has been developed which performs a "moving" cross-spectrum analysis upon various pairs of signals from the array, giving phase angles between the signals. A cross-spectrum analysis is first performed on a short section of record, usually a 4-hour section. This 4-hour window is advanced by 2 hours along the records, and the analysis repeated. A moving record of the phase angles is obtained. Whenever the coherence between the signals of the array is above a specified value, the program makes a least-squares adjustment of the phase angles and computes the true direction and true speed of the signal across the array. This type of analysis is being performed on many sets of records from the small-scale array (Nevis, HL, BTI, and LGO, Fig. 1) and a spectrum of speeds and directions is being obtained for atmospheric pressure perturbations.

Some of the results of this analysis, performed upon one single 24-hour section of the array records, using a 4-hour window, are shown in Fig. 20. This is a polar plot giving speed and directions in which the disturbance is moving. The points correspond to periods of 6 to 48 min. From the limited amount of data analyzed so far, it would seem that most

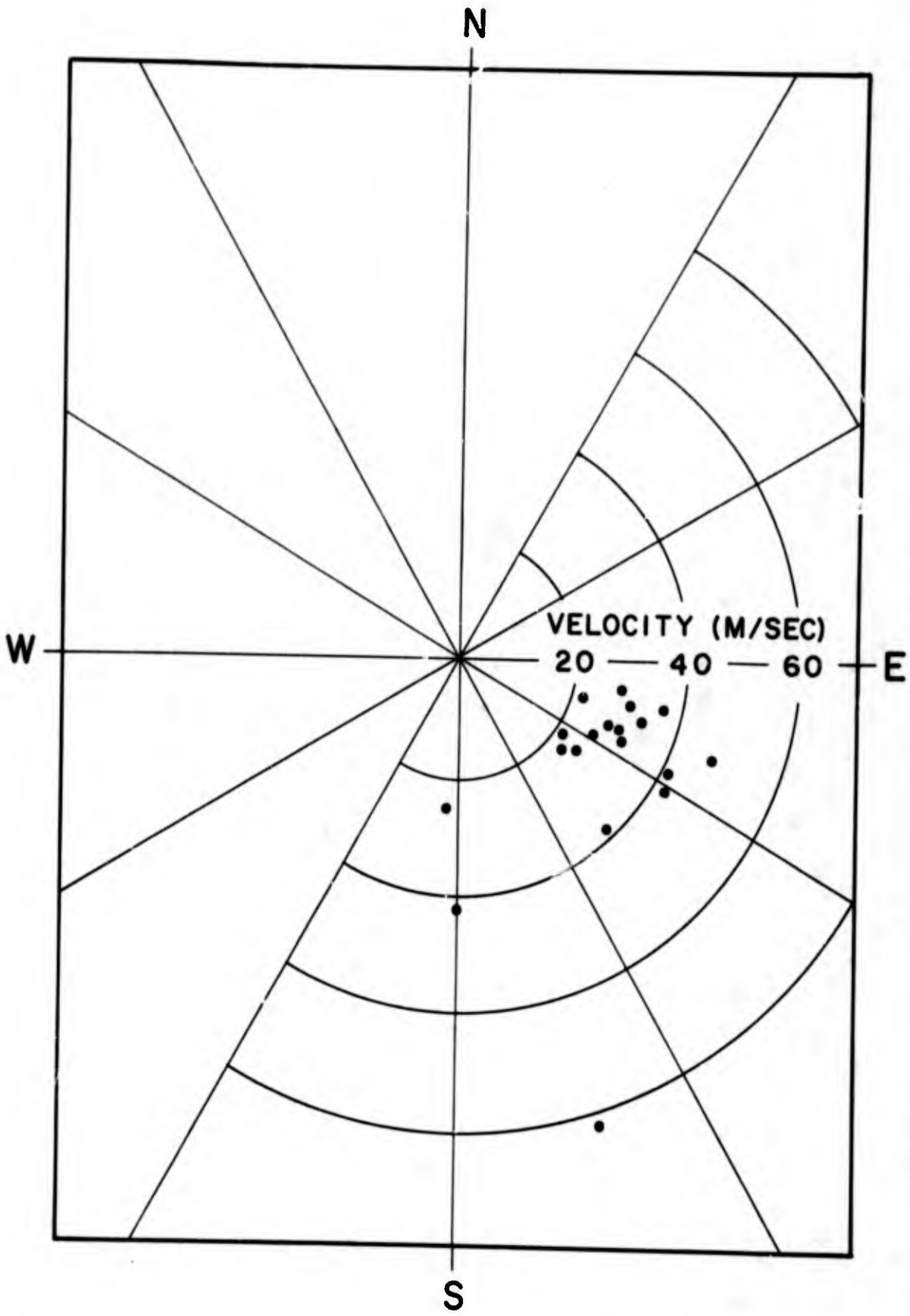


Fig. 20. Direction of travel and velocity of propagation of disturbances on one 24-hour sample, using a moving 4-hour cross-spectrum window. Note the very definite bunching of points, indicating motion toward the SE, at velocities in the 20 to 40 m $sec^{-1}$ range.

disturbances move at speeds of 15 to 60 m $sec^{-1}$ towards the SE. An investigation is in progress to determine whether the moving disturbances are propagating waves or advective features carried by the high-level winds. The observed speeds are certainly too high for the disturbances to be carried by ground-level winds.

Other types of information on the traveling disturbances are also given by our array-steering routine. Thus, Fig. 21 shows a sum-and-delay display for a typical disturbance (included in the first 4-hour window to be used in connection with Fig. 20), and Fig. 22 shows the corresponding directional properties by means of a polar plot of P over the duration of the major part of the disturbance.

Systematic measurements of this kind will be continued, both on the small-scale array data and on the larger scales. The latter should provide interesting data on longer period and faster traveling disturbances.

## IV. THEORETICAL STUDIES

Studies of a fundamental theoretical nature have been pursued, dealing with problems in wave propagation, concomitant questions in ionospheric motion, and some aspects of statistics and signal processing.

1. A thorough study has been underway concerning the use of simplified, approximate models of the atmosphere in describing the propagation of long-period internal gravity wave modes. In particular, the solutions for a single-layer atmospheric model have been discussed in detail in a recently published paper.[3] In this paper, the particle motion due to the

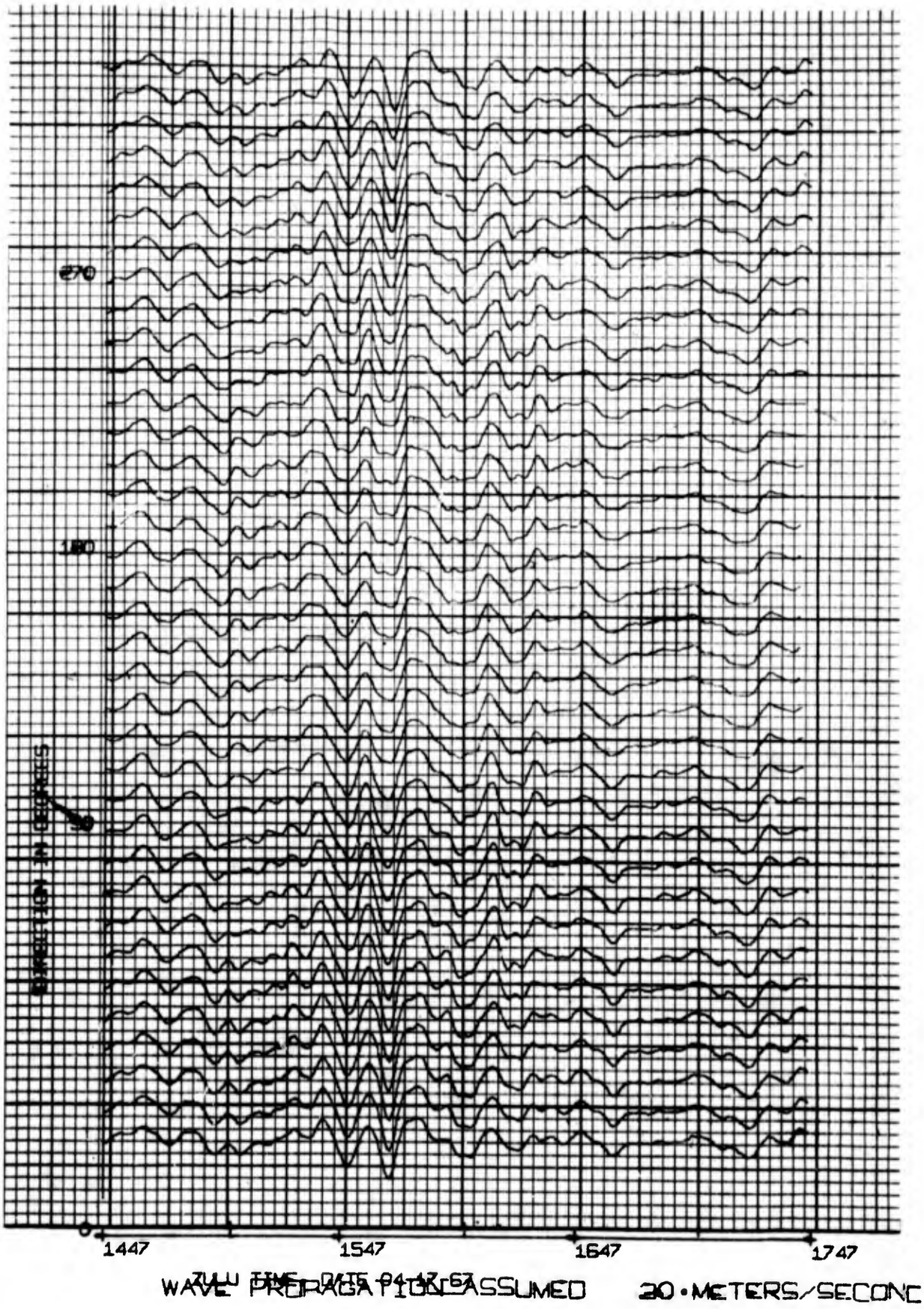


Fig. 21. Sum-and-delay display of one typical disturbance on small array (see Fig. 1). Amplitudes are clearly maximized around 60°, indicating travel direction into the NE.

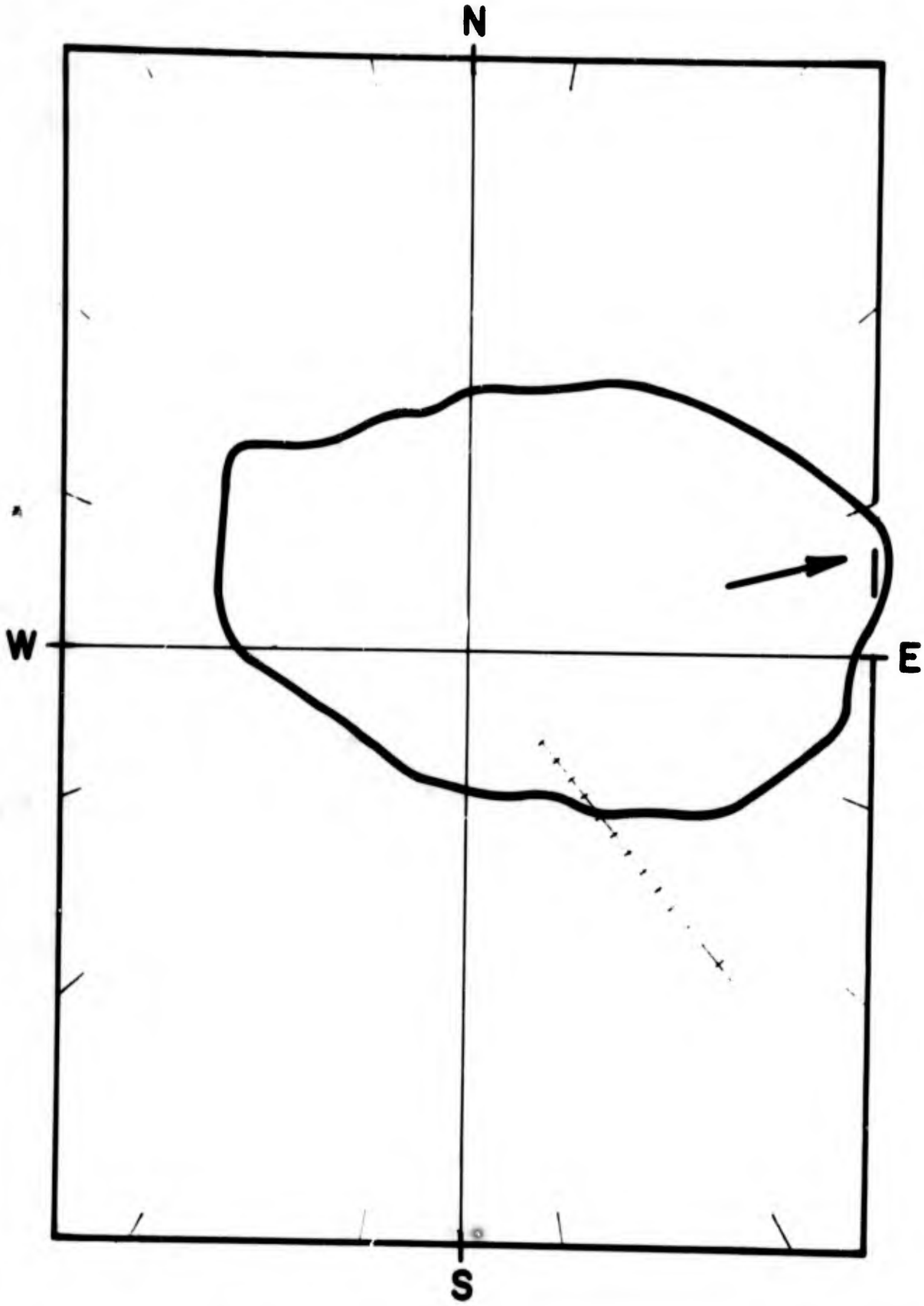


Fig. 22. $\int_{t_i}^{t_2} p^2\,dt$ directionality plot corresponding to Fig. 21.

passage of an internal gravity wave system is considered to be incompressible, and the atmosphere is therefore treated as an incompressible fluid with an exponential density variation in a constant gravity field, i.e., with a constant "average" value of the Väisälä frequency of the order of 7 min. It is shown that these results are at least qualitatively meaningful for periods longer than 20 min and shorter than 3 hours. An interesting feature of this model is that, under certain conditions, it may be treated as having a free surface at a height $H$ of the order of 300 to 500 km (the exact value of $H$ depends upon both the wavelength and our assumptions concerning the upper atmosphere, but the theory is not very sensitive to it anyway). That is, we may assume a model of the kind shown in Fig. 23a. This is allowed because, near the height $H$, the mean free path $\ell$ of the molecules is of the order of the vertical gravity wave wavelength $\lambda_z$. Above this height $\lambda_z \ll \ell$ and we have, effectively, a vacuum. Of course between the vacuum region $\lambda_z \ll \ell$ and the region $\lambda_z > \ell$ for which the equations of continuous mechanics apply, there exists a <u>transition layer</u> in which, strictly speaking, one should use Boltzmann's equations. But the thickness of the region in which the density varies by an order of magnitude is of the order of 100 km so that, as long as $\lambda_z \gg 100$ km, the damping effect of this transition layer is probably not severely limiting. This type of model clearly predicts the existence of a sort of "surface gravity wave." In the limit of long periods ($T > 20$ min) this mode is only weakly dispersive, the phase and group velocities being about equal at 420 m $sec^{-1}$. A more accurate estimate of such a velocity has been made recently by Tolstoy and Engelhardt[4] by means of a numerical study of a two-layer model (Fig. 23b), giving close to 680 m $sec^{-1}$. Both of these

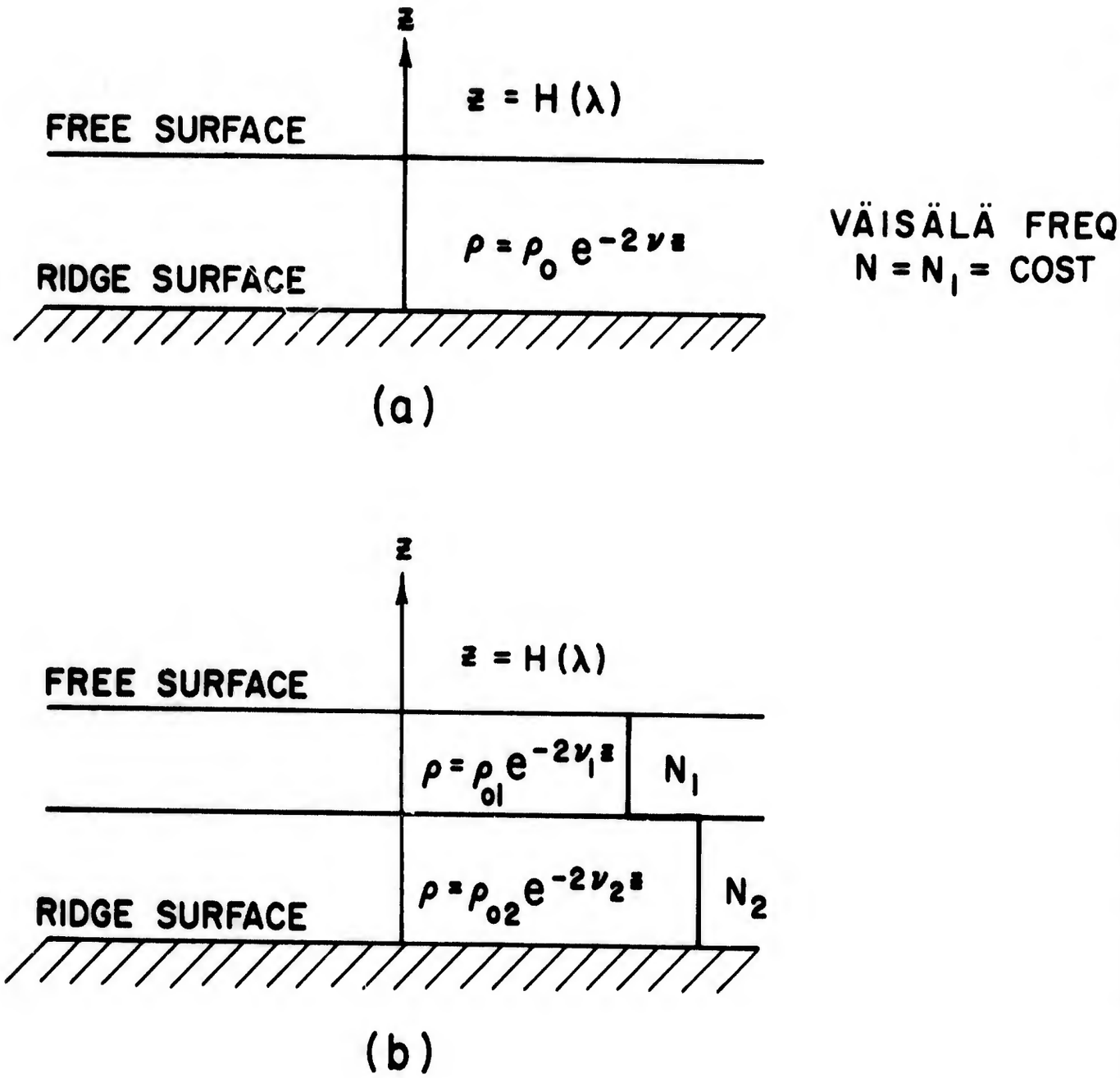


Fig. 23. Some simplified theoretical models.

models also give some simple approximations to the propagation velocities of the internal gavity modes, which turn out to be quite comparable to the more detailed calculations of Harkrider,[5] Press and Harkrider,[6] Pfeffer and Zarichny:[7] what we have are actually approximations to their more complex calculations of the general type discussed by Meecham.[8] Asymptotic values of the propagation velocities for long periods of some of the modes of these two models are enumerated in the following table:

TABLE 1

| Mode | Model a | Mode | Model b |
|---|---|---|---|
| Surface, m=0 | 420 m $sec^{-1}$ | Surface, m=0 | 680 m $sec^{-1}$ |
| Internal, | | Internal, | |
| | | m=1 | 625 m $sec^{-1}$ |
| | | m=2 | 600 m $sec^{-1}$ |
| | | m=3 | 525 m $sec^{-1}$ |
| | | m=4 | 475 m $sec^{-1}$ |
| m=1 | 370 m $sec^{-1}$ | m=5 | 390 m $sec^{-1}$ |
| m=2 | 340 m $sec^{-1}$ | m=6 | 340 m $sec^{-1}$ |
| m=3 | 300 m $sec^{-1}$ | m=7 | 300 m $sec^{-1}$ |

2. There is reason to believe that, for the longer periods of interest to us here, the effects of the earth's rotation are not entirely negligible, at least not for high latitudes. A numerical study of these effects is underway.

3. A theoretical treatment of the transient excitation of internal gravity waves is in progress. In this study, applied to the model of Fig. 23a,

simple solutions for a concentrated $\delta(t)$ force are obtained in integral form by means of the method of normal coordinates.[9] The integrals are then evaluated by the method of stationary phase, and interesting time-history curves are obtained for the internal gravity modes. The effect of the earth's rotation can also be introduced into this solution without too much difficulty.

This study is well on the way, and is of interest not only because it represents a fairly simple solution of the transient problem, but because it represents the only real study of the internal gravity wave excitation problem for a point source: the rather detailed studies by Pierce[10] or Harkrider[5] have used a source which discriminates against internal gravity waves. These writers used a compressional point source, which is a good source only for the acoustic modes but is quite inefficient in the excitation of long-period internal gravity waves. As is well known,[11] the latter are quite insensitive to the elastic properties of the medium.

4. Theoretical studies of some of our data processing problems have also been pursued by Hinich[12,13] and Hinich and Clay.[14]

5. A preliminary study of the equations allowing us to predict the motions of the electrons in the E and F layers of the ionosphere connected with the passage of internal gravity waves in the upper atmosphere has been performed by Bugnolo.[15,16]

## V. PROGRAM FOR THE COMING YEAR

1. On the experimental and instrumental side, we are in the process of installing and checking out a Packard Bell digital magnetic tape data

recording system. Three of our distant stations have fully digitized data transmission links (modems) to the master station at HL capable of handling up to eight channels apiece. At these stations we have a Pace microbarograph and three magnetometers. We are also including Texas Instruments absolute gauges (see Clay and Kraft[1]) and, soon, at least one Doppler shift sounder for recording motions in the E and F layers. There will also be an eight-channel modem at HL to digitize Pace microbarograph signals arriving from single sensor stations of the type used in 1967. The digitized data (up to 32 channels) are multiplexed and recorded on IBM digital tape. To handle this outflow of data we have replaced our 1130 by an IBM 1800 system. The finishing touches are being put on the software, and we should have a smoothly operating system by December. At that time at least most of our additional instrumentation (Doppler system and Texas Instruments gauges) should be operating (the magnetometers are already installed and in running condition).

Clearly, among our first experimental studies will be:

a) Search for low-frequency coherence between the Doppler shift information, the magnetometer channels, and the pressure fluctuations. All the software required for a systematic study of these possible effects is already available (for example, cross-spectrum routines with moving and adjustable length windows to look for coherence, array-steering routines to check directionality and velocities of magnetic micropulsations, etc.).

b) Further systematic studies of the pressure background. In particular, we will continue to investigate intensively the direction and speeds

of various size disturbances. By means of our three available array scales we should be able to cover the range of $\lambda$ from 1500 km to a few km. Much more is needed in the way of seasonal studies of these effects (and of simple power spectra) to obtain solid information on the nature and type of noise we are dealing with at the long periods.

2. Our theoretical program will involve:

a) Continued study of propagation problems in simplified models. In particular, the concentrated $\delta(t)$ internal gravity wave source problem, with and without the effects of rotation, will be completed shortly.

b) We are interested in the propagation of stability waves in shear flows: these waves are probably highly relevant to atmospheric studies, but their properties qua waves are largely unknown at this point. Hydrodynamicists have limited themselves to examining the implications of these perturbations to the theory of stability. Much more relevant to our studies are the propagation characteristics of such perturbations, which have remained virtually unknown.

## REFERENCES


1. C. S. Clay and D. W. Kraft, Microbarographs for Measurements of Atmospheric Waves, Hudson Laboratories Technical Report No. 135 (1967).
2. E. E. Gossard, "Spectra of atmospheric scalars," J. Geophys. Res. 65, 3339-3351 (1960).
3. I. Tolstoy, "Long-period gravity waves in the atmosphere," J. Geophys. Res. 72, 4605-4622 (1967). (HL Contrib. No. 294.)
4. I. Tolstoy and J. Engelhardt, "Improved approximation for long-period gravity waves in the atmosphere," in process.
5. D. G. Harkrider, "Theoretical and observed acoustic-gravity waves from explosive sources in the atmosphere," J. Geophys. Res. 69, 5295-5321 (1964).
6. F. Press and D. G. Harkrider, "Propagation of acoustic-gravity waves in the atmosphere," J. Geophys. Res. 67, 3889-3908 (1962).
7. R. L. Pfeffer and J. Zarichny, "Acoustic gravity wave propagation in an atmosphere with two sound channels," Geofis. Pura Appl. 55, 175-199 (1963).
8. W. C. Meecham, "Simplified normal mode treatment of long period acoustic gravity waves in the atmosphere," Proc. IEEE 53, 2079-2087 (1965).
9. M. A. Biot and I. Tolstoy, "Formulation of wave propagation in infinite media by normal coordinates with an application to diffraction," J. Acoust. Soc. Am. 29, 381-391 (1957).

10. A. D. Pierce, "Propagation of acoustic-gravity waves from a small source above the ground in an isothermal atmosphere," J. Acoust. Soc. Am. 35, 1798-1807 (1963).

11. I. Tolstoy, "The theory of waves in stratified fluids including the effects of gravity and rotation," Revs. Modern Phys. 35, 207-230 (1963). (HL Contrib. No. 157.)

12. M. Hinich, "Estimation of spectra after hard clipping of Gaussian process," Technometrics 9, 391-400 (1967). (HL Contrib. No. 237.)

13. M. Hinich, "Detection of an unknown waveform randomly recurring in Gaussian noise," Information and Control 10, 394-408 (1967). (HL Contrib. No. 278.)

14. M. Hinich and C. S. Clay, "The direct use of the fast Fourier transform in the estimation of power spectra of geophysical data," to appear in J. Geophys. Res. (1967). (HL Contrib. No. 305.)

15. D. S. Bugnolo, Ionospheric Motion and Internal Gravity Waves, Hudson Laboratories Tech. Rept. No. 132 (1967).

16. D. S. Bugnolo, The Interaction of Internal Gravity Waves with the Ionosphere at the $F_1$ and $F_2$ Levels, Hudson Laboratories Tech. Rept. No. 140 (1967).

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13. ABSTRACT

This report summarizes the work performed during FY 1967. After a brief description of the system and its characteristics, a number of background studies are described. Particular attention has been given to microbarographic pressure fluctuation levels (power spectra) and cross-spectral properties such as coherence and phase lags between pairs of instruments. It is found that an important fraction of the background, in the 5 to 50 min period range, consists of slowly traveling disturbances (20-40 m/sec$^{-1}$) probably associated with the jet stream. This part of the background is coherent over distances of a few km, and decorrelates rapidly for distances greater than 10 km. This report also discusses briefly immediate plans for FY 1968.

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| Internal gravity waves in the atmosphere. | | | | | | |
| Background power spectra at low frequencies in the atmosphere. | | | | | | |
| Coherence at low frequencies in the atmosphere. | | | | | | |

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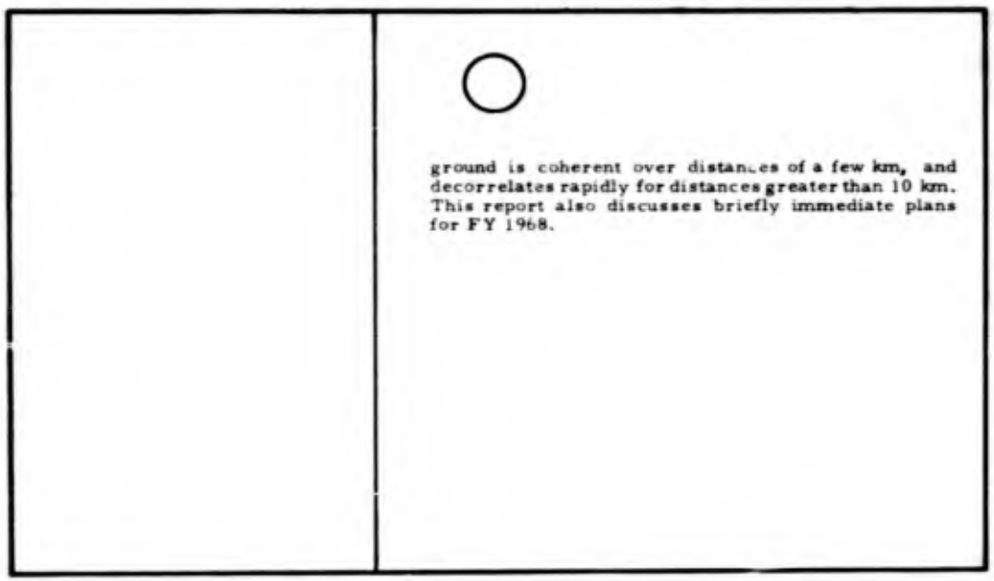

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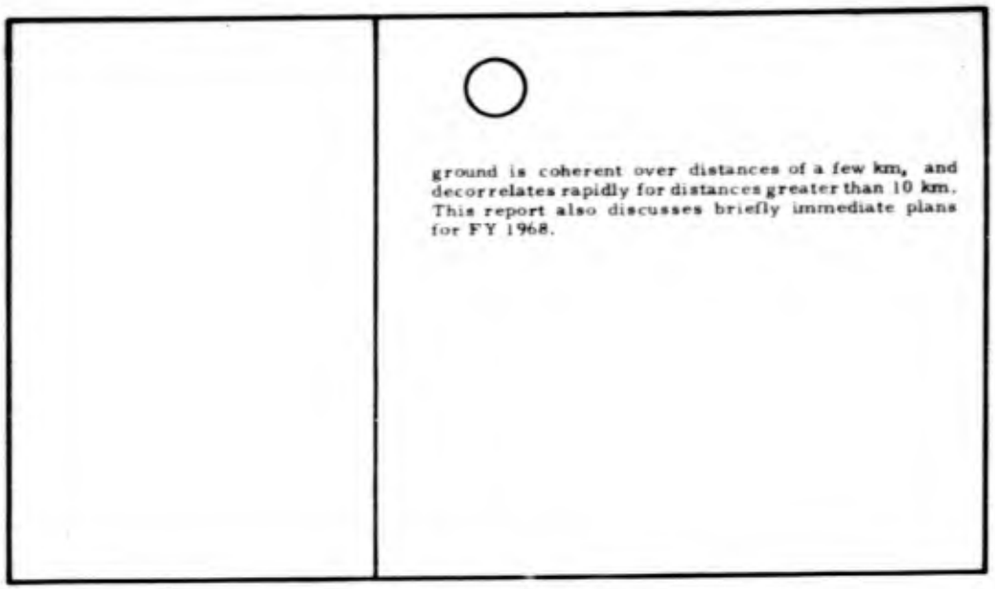

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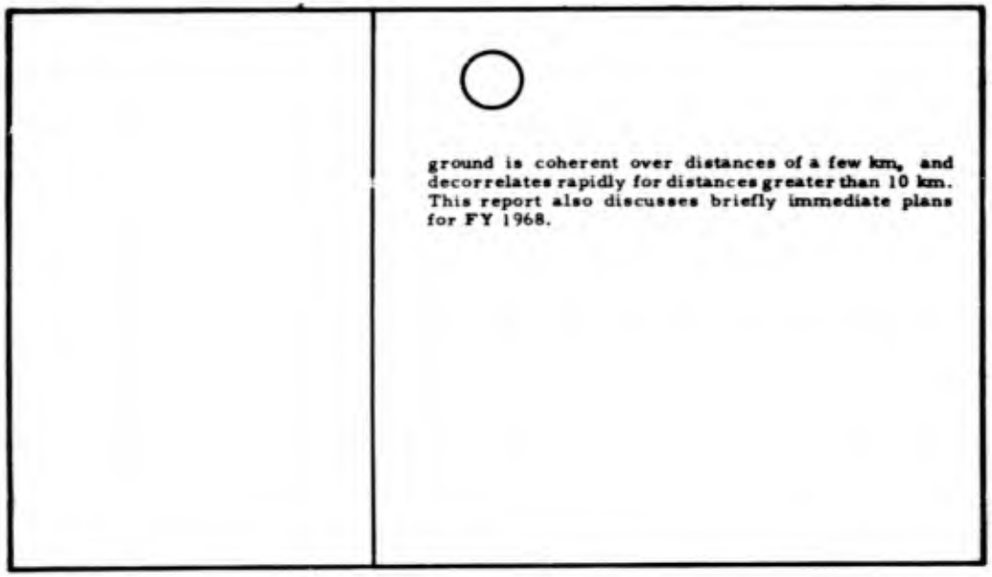

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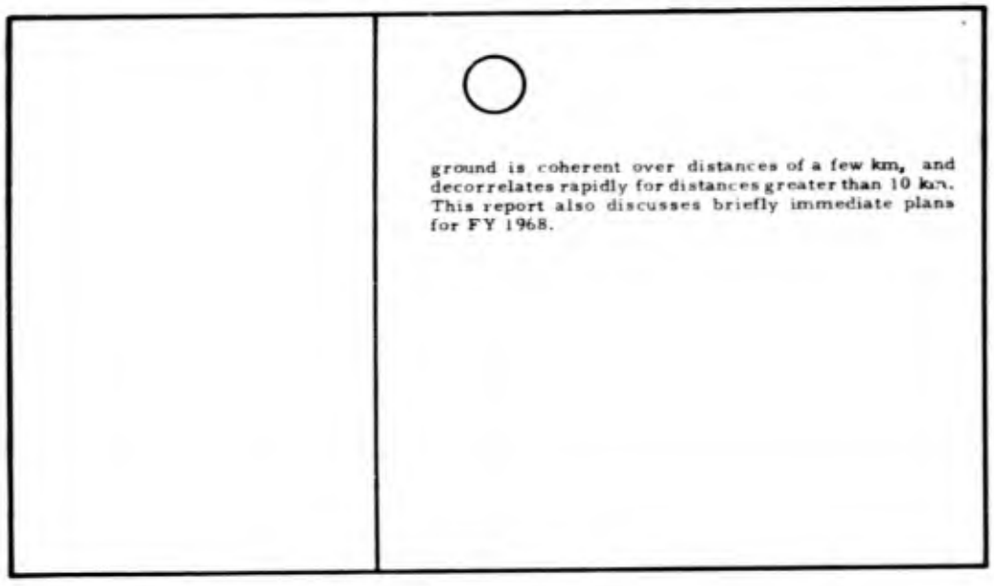

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