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CANADA

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AN ANALYSIS OF THE DATA SAMPLING REQUIREMENTS FOR THE MAST VERSION OF THE BREWER BUBBLER OZONESONDE

BY

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ABSTRACT

Data from the Mast ozonesonde are subjected to a power spectrum analysis. The resulting power spectra are then used to suggest an optimum sampling frequency for use in the preparation of profiles of the vertical distribution of ozone.

ANALYSE DES BESOINS EN ÉCHANTILLONNAGE DE DONNÉES POUR LA VERSION MAST DE LA SONDE D'OZONE BREWER BUBBLER

par

E. G. Morrissey

RÉSUMÉ

Les données provenant de la sonde d'ozone Mast sont soumises à une analyse du spectre de puissance. Les spectres de puissance obtenus sont ensuite utilisés pour établir une fréquence d'échantillonnage optimale qui sert à la préparation de profils de la répartition de l'ozone.

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E. G. Morrissey

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1. Introduction

The Mast version of the Brewer Bubbler Ozonesonde used by the Meteorological Service of Canada uses an ink on paper trace for output. Each output trace consists of a series of frequency observations taken at 15 second intervals, the partial pressure of ozone being linearly proportional to the frequency. Since the average ozonesonde flight lasts about 100 mins, about 400 observations of ozone are made during each ascent. Because of the large number of measurements and computations it is preferable to use machine methods to obtain the ozone profile from this record.

The purpose of this study was to examine the time series of frequency measurements using power spectrum analysis to find an optimum sampling frequency (interval between readings) both for archiving and for computation of ozone which would keep the amount of data transferred to a computer compatible medium at a minimum, without loss of information.

2. Data

The data selected for this study were taken from six ascents of the Mast sonde made at Resolute Bay on a daily basis between the 9 March and 14 March 1966. These ascents were made at a time of the high total ozone amount. The individual observations were made at 15 second intervals and this allowed an average of 460 observations to be obtained for each of the six time series.

Forty ascents made at Goose Bay using Regener Sonde were used for comparison. These observations were available at 30 second intervals and each series contained an average of 175 observations.

3. Theory

Muller (1966), has given a detailed account of the application of power spectrum analysis to meteorological problems. As a result, the discussion of the theory below is limited to a statement of the formulae used together with references to the above paper.

The procedures used were as follows:

(a) The autocorrelation coefficients, C(l), for lags, l, from 0 to 10 minutes were computed for all the ascents used in this study.

(b) The resulting autocorrelation curve was subjected to a Fourier transform of the form (Muller 1966 p. 7-8)

$$C(l) = P(f_o) + \sum_{n=1}^{m} P(f_n) \cos \frac{2\pi n \ell}{2m}$$

when m = maximum lag in units of observation interval, 40 for Resolute Bay data and 20 for Goose data, and $f_n = n/2m$.

(c) The resulting power spectrum series was then smoothed by 'Hanning' (Muller 1966 p. 13-16) so that the resulting spectral estimates would have greater statistical stability. The smoothing function was of the form:

$$P_H(f_n) = 0.25\, P(f_{n-1}) + 0.50\, P(f_n) + 0.25\, P(f_{n+1})$$

$$P_H(f_o) = 0.25\, (P(f_o) + P(f_1))$$

$$P_H(f_m) = 0.25\, (P(f_m) + P(f_{m-1}))$$

(d) In addition, the data series were subjected to a high pass triangular filter. The response curve (Muller 1966 p. 54-72) of this filter is shown in figure (1). The purpose of this filter was to subdue the power in the low frequencies while allowing the power in the higher frequencies to pass with little modification. The filtered series was then subjected to a similar power spectrum analysis to that described above. By increasing the proportion of the normalized spectra contained in high frequencies, the high pass filter removed most of the effects due to the spreading of spectral power.

4. Instrumental Modification of the Time Series

The Mast Sonde has a time constant of approximately 20 seconds, and, therefore, has the effect of applying an exponential filter upon the data, (Muller, 1966, p. 57-63). The effect of the time constant is shown in figure 2. R^2 (f) is the effect of the filter on the squared amplitude and $\phi(f)$ the effect on the phase. Figure 2 was obtained from the equations:

$$R^2 (f) = (1 + 4\pi^2 \lambda^2 f^2)^{-1}$$

$$\phi (f) = \arctan(-2\pi f \lambda)$$

where λ is the time constant of the instrument, assumed here to be 20 seconds.

Figure 2 shows that the effect of the time constant is to reduce the amplitude as well as to alter the phase. Although the effect appears to be rather large, it was found that most of the variance of the time series occurred at frequencies much lower than $(1/\lambda)$ sec^{-1}. Hence, no attempt was made to restore the series by refiltering. However, this could have been done for frequencies below $(1/\lambda)$ sec^{-1}.

The time constant of the Regener Sonde is approximately 1 millisecond, hence, it effects only frequencies 15,000 times higher than those which can be detected by the sampling frequency. It should be noted, however, that the time constant and sampling frequency used in this method of measuring the variation of ozone with height could have given rise to severe aliasing (Muller, 1966, p. 24-41) if the power spectrum of atmospheric ozone did not decrease rapidly with increasing frequency.

5. Results

Figure 3 shows the average of the normalized power spectra (I) of the six ascents made at Resolute Bay with the Mast Sonde. 95% of the power occurred in frequencies of less than 0.1 cycles per minute. The application of the high pass filter (II) reduced the power of zero frequency to zero, that of 0.05 cycles per minute by 63% and 0.10 cycle per minute by 15%. This meant that it removed approximately 98% of the variance. Although the removal of the power in this frequency range was done to amplify the power in the higher frequencies, 95% of the power of the remaining series occurred at frequencies of less than 0. 80 cycles per min.

Figure 4 shows the average results from the 40 Goose Bay Ascents. The results are similar to those obtained from the Resolute Bay data.

The application of the high pass filter to the Goose Bay data reduced the power at 0.1 and 0.2 cycles per min. by 60 and 11% respectively. This together with the complete removal of the power at zero frequency accounted for 92% of the total variance. Of the remaining power, 90% occurred at frequencies below 0.6 cycles per min.

A comparison of the Resolute Bay and Goose Bay results shows that the differing time constants had little effect upon the final spectrum. Most of the power occurred in the lower frequencies and these were only slightly modified by the long time constant of the Mast Sonde. Again, since the six Resolute Bay ascents produced a spectrum which was similar to the one obtained from the Goose Bay data, it is reasonable to assume that a larger sample of Resolute data would not have greatly altered the shape of the spectrum.

Usually, the vertical profile of ozone shows most variation in the region between the tropopause and the ozone maximum. The region is characterized by an increase in the partial pressure of ozone with height and by rapid fluctuations in the ozone content. In order to investigate the variance in this portion, the Resolute Bay data was subjected to the high pass filter, then the autocorrelation coefficients were computed using only the data which was obtained from this region. The extent of this subset, which varied from ascent to ascent, was determined subjectively. An average of 154 observations were used for each ascent, and the maximum lag used to calculate the spectrum was 3 minutes or 12 observational intervals.

The average power spectrum which resulted from this data subset is shown in figure 5. It can be seen that the power is spread into higher frequencies more than in the cases given above. However, an average of 93% of the variance occurred at frequencies below 0.5 cycles per minute.

The results discussed above refer to average values of the power spectra. Figure 6 gives the spectra for each ascent at Resolute and figure 7 shows the spectra for a selection of the Goose Bay ascents. It must be remembered that the differences between the average and the individual spectra occur only in respect to a small fraction of the total variance since the spectra shown in figures 6 and 7 are those of the series after they have been subjected to the high pass filtering.

Figure 8 shows some of the spectra obtained from the part of the Resolute Bay ascents which lay between the maximum values of the partial pressure of ozone. The spectra for the 11, 12 and 14 March were similar to those of the 9 and 10 March and were not included in the diagram. The only ascent that was not similar was that of 13 March which shows a relative shift of power to the higher frequencies. In this case, 84% of the variance occurred in frequencies below 0.5 cycles per minute as opposed to an average of 94% for the other five ascents.

6. The Selection of a Suitable Sampling Frequency

The above discussion gave an indication of the partitioning of the spectral power in the time series. The problem now is to decide how much of the variance should be retained when the data are digitized and converted to computer compatible form, and how much aliasing can be allowed to accompany the digitizing. If the data were sampled at 5-minute intervals, it would be possible to describe the variance due to frequencies from zero to 0.1 cycles per minute. This would account for an average 98% of the observed variance in the case of Resolute Bay data. The remainder would be folded into the lower frequencies. However, the removal of most of the power in the lowest frequencies revealed that the remaining power was still red, that is biased toward low frequencies. In order to retain 95% of this remaining power, a folding frequency of 0.8 cycle per minute would be required. This would require a sampling frequency of 1.6 observations per minute; that is, using every third observation of the present series. However, at this stage there would be a need to correct for the time constant effects shown in figure 1. If the observation frequency was one per minute, the folding frequency would be 0.5 cycles per minute. In the Mast Sonde, cases considered above this would have accounted for an average of 99.94% of the total variance with individual values varying between 99.87 and 99.98%. This sampling frequency would reduce the number of pieces of data transferred to a computer compatible medium by a factor of 4 while folding in less than 1% of the total power. The folding frequency of 0.5 cycles per minute is approximately equivalent to a vertical space 'period' of 2000 ft, since the balloon rises at about 1000 ft min^{-1}. In addition, the sampling would be more than adequate for use in the computation of the vertical profile of ozone which is carried out to convert the 'raw' data into a form suitable for publication.

There remains the possibility that this sampling frequency could remove some of the details of the vertical variation of ozone. This was demonstrated by the investigation of the power spectrum obtained from those parts of the Resolute Bay ascents which occurred between the ozone maximum and ozone minimum. To ensure that at least 90% of this power is contained in frequencies below the folding frequency it would be necessary to increase the sampling frequency to 2.0 observations per minute. If this is done, it would be desirable to restore the amplitude and phase of the higher frequencies as suggested in section 4.

From the results obtained in this study, it would seem unlikely that an instrument with a shorter time constant than the Mast Sonde is desirable, since there appears to be little spectral power at high frequencies. Indeed, it is probable that shortening the time constant would do little but increase the aliasing if the lower time constant was not accompanied by a higher sampling frequency.

7. Conclusions

It appears that a sampling frequency of two observations per minute is suitable for archiving purposes. The data should be filtered to remove the effects of the asymetric response of the time constant. This restoration should be used in respect to frequencies below one cycle per minute which is the folding frequency for a sampling rate of two observations per minute.

8. Acknowledgement

I am grateful of F. B. Muller for many helpful discussions during the course of this study.

APPROVED,

J. R. H. Noble,
Director,
Meteorological Branch.

9. Reference

(1) Muller, F. B., 1966: Mesometeorological and Short Range Forecasting Report No. 1, Notes on Power Spectrum Analysis, Canada, Meteorological Branch, Department of Transport, Meteorological Memoir No. 24.

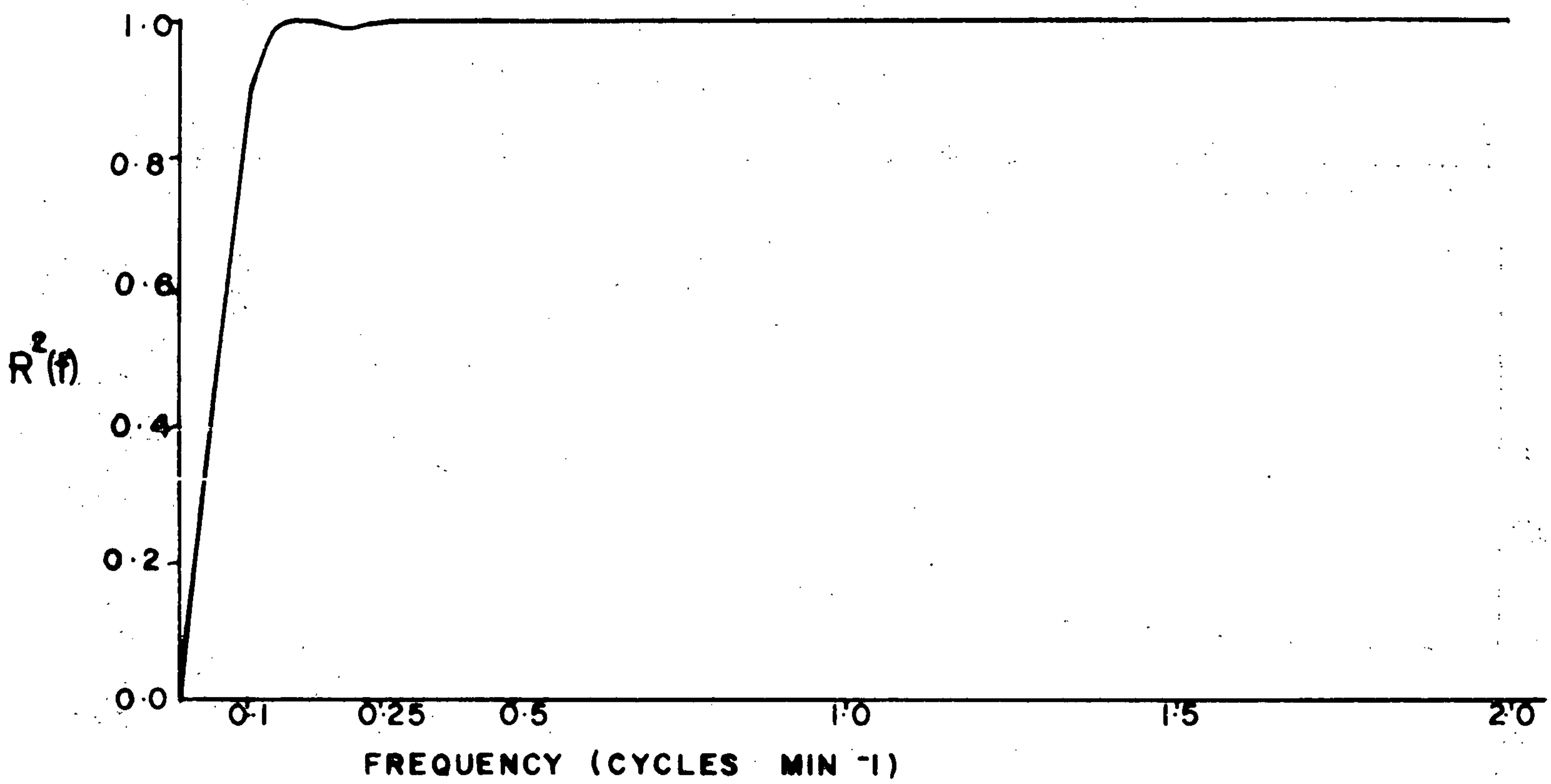

Figure 1
The Response of the High Pass Filter in the Frequency Domain.

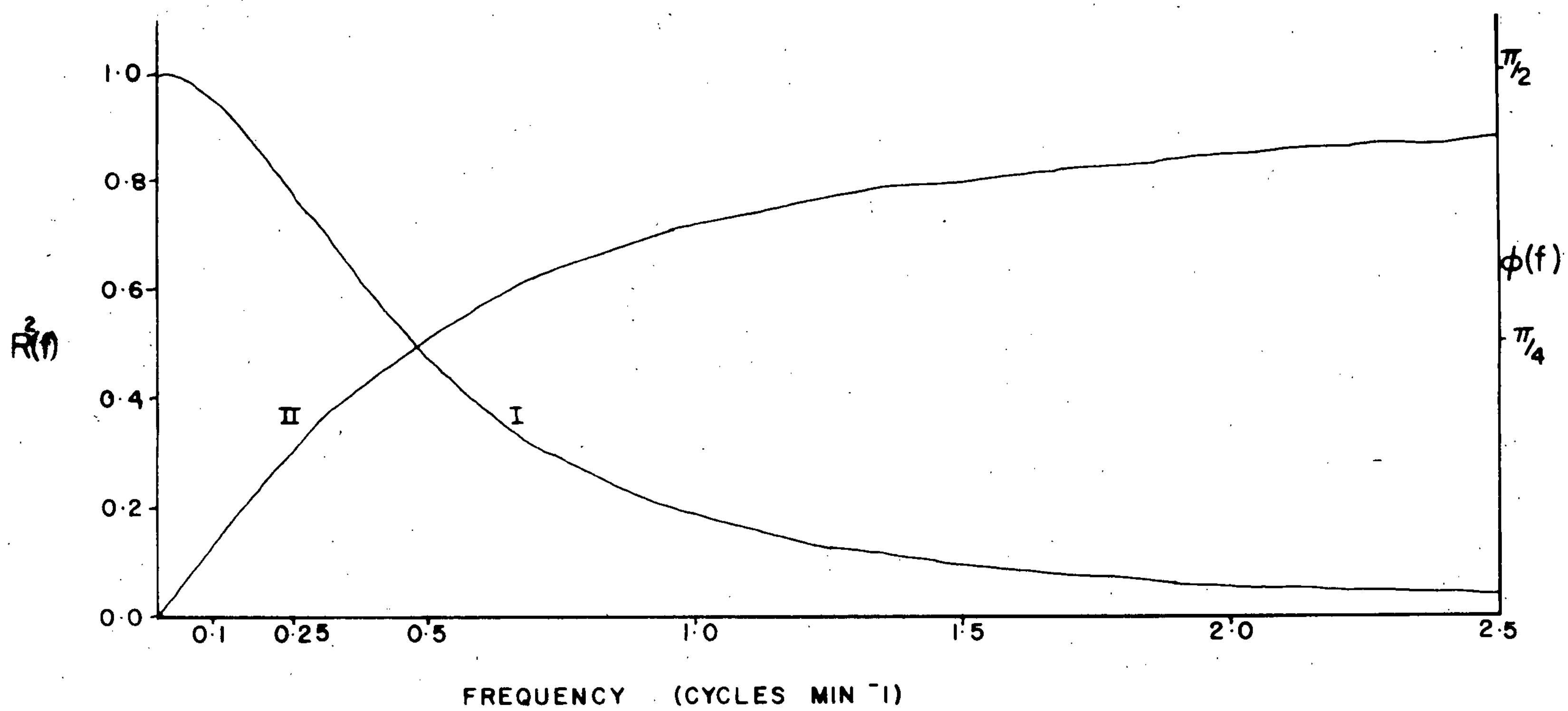

Figure 2
The Effect of the Exponential Weighting Function, Implied by the Use of a Sensor With a Fixed Time Constant of 20 Records, in the Frequency Domain.
Curve I Shows the Effect on the Squared Amplitude and Curve II shows the Effect on the Phase.

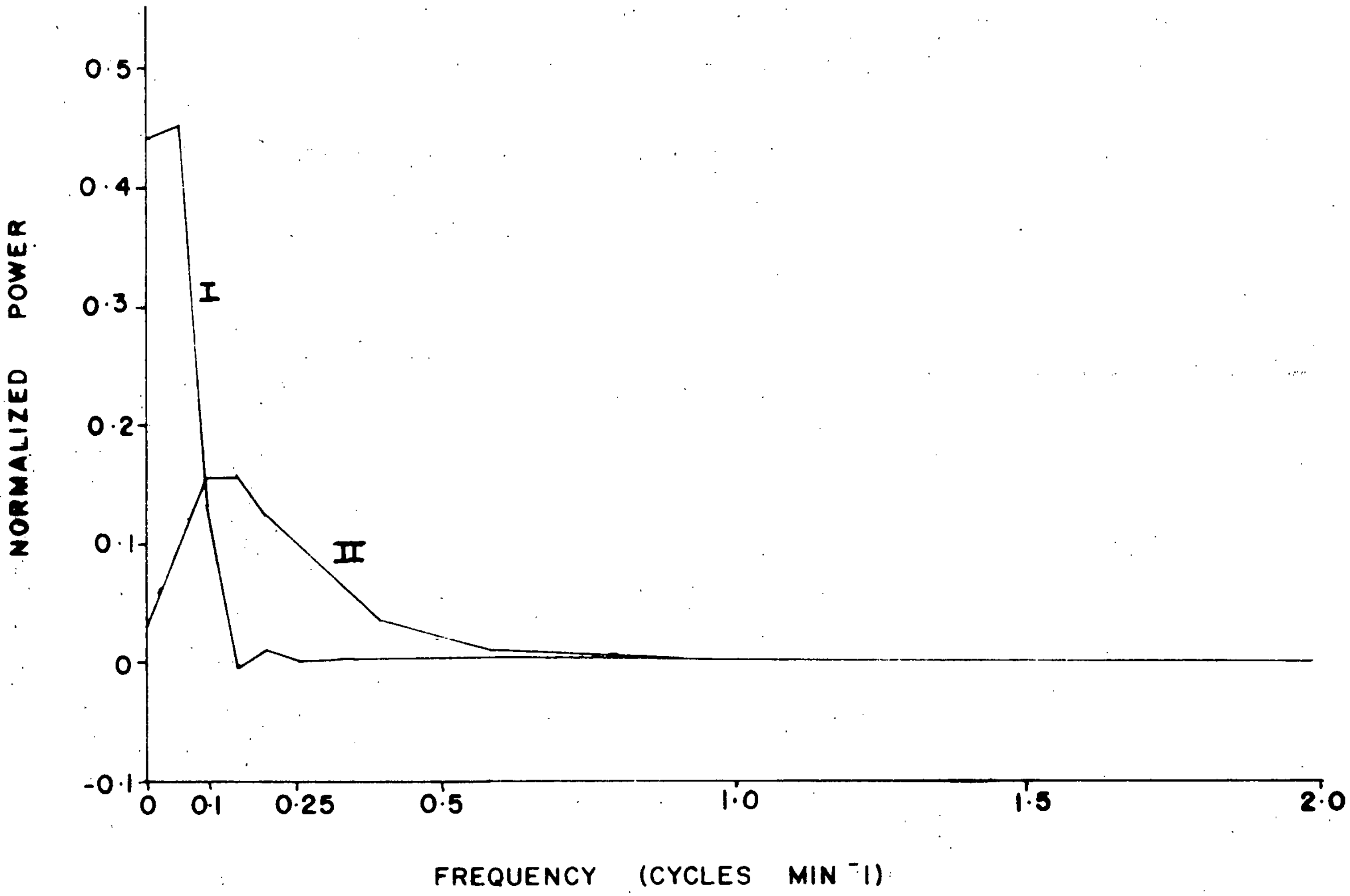

Figure 3
The Average of the Normalized Power Spectra for Six Ascents Made at Resolute Bay. Curve I Shows the Average Spectrum Obtained From the Unfiltered Data and Curve II Shows That Obtained From the Data After the Application of the High Pass Filter.

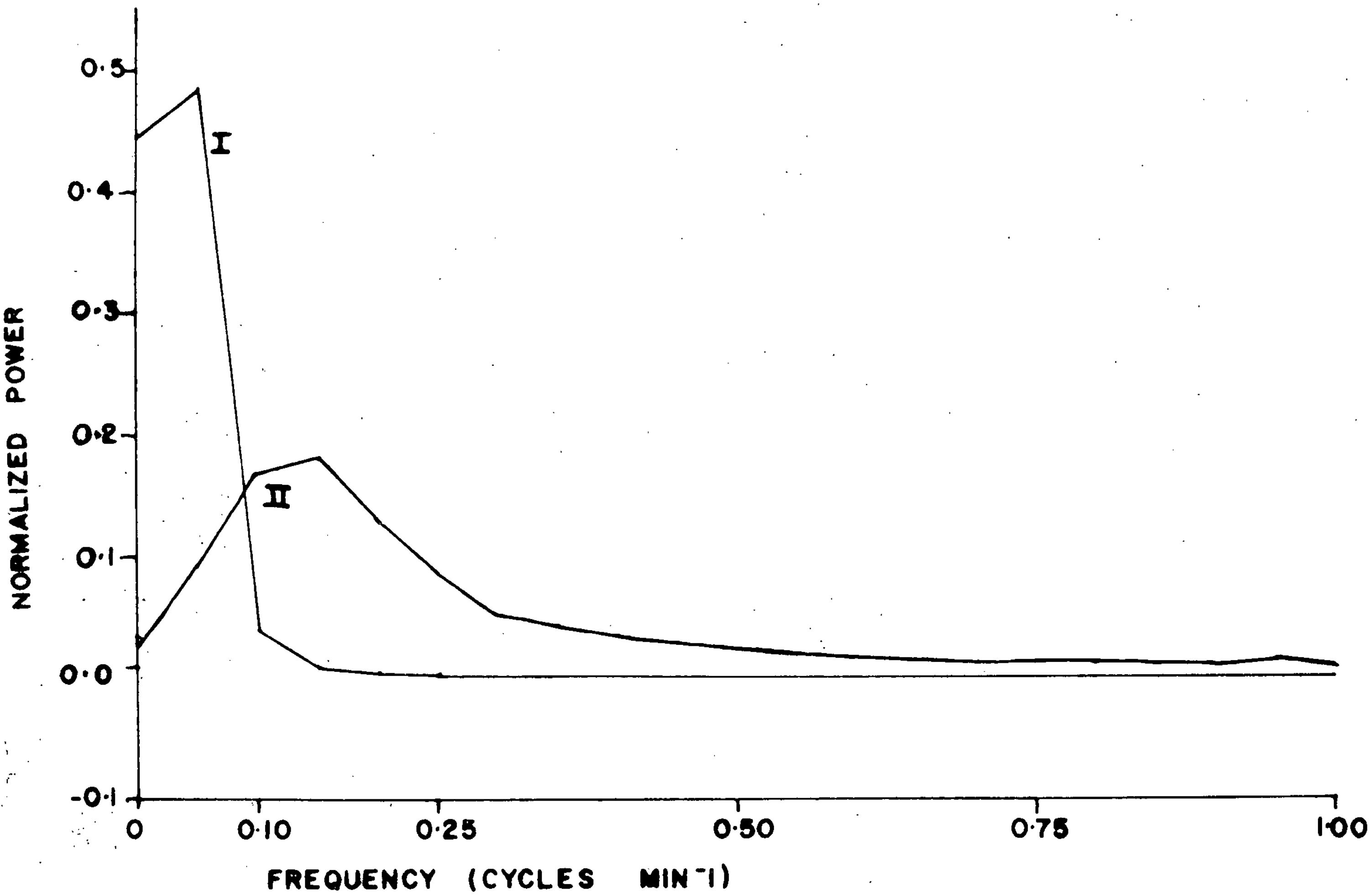

Figure 4
The Average of the Normalized Power Spectra for 40 Ascents Made at Goose Bay.
Curve I Shows the Average Spectrum Obtained From Unfiltered Data and
Curve II shows That Obtained From the Data After the Application of the High Pass Filter.

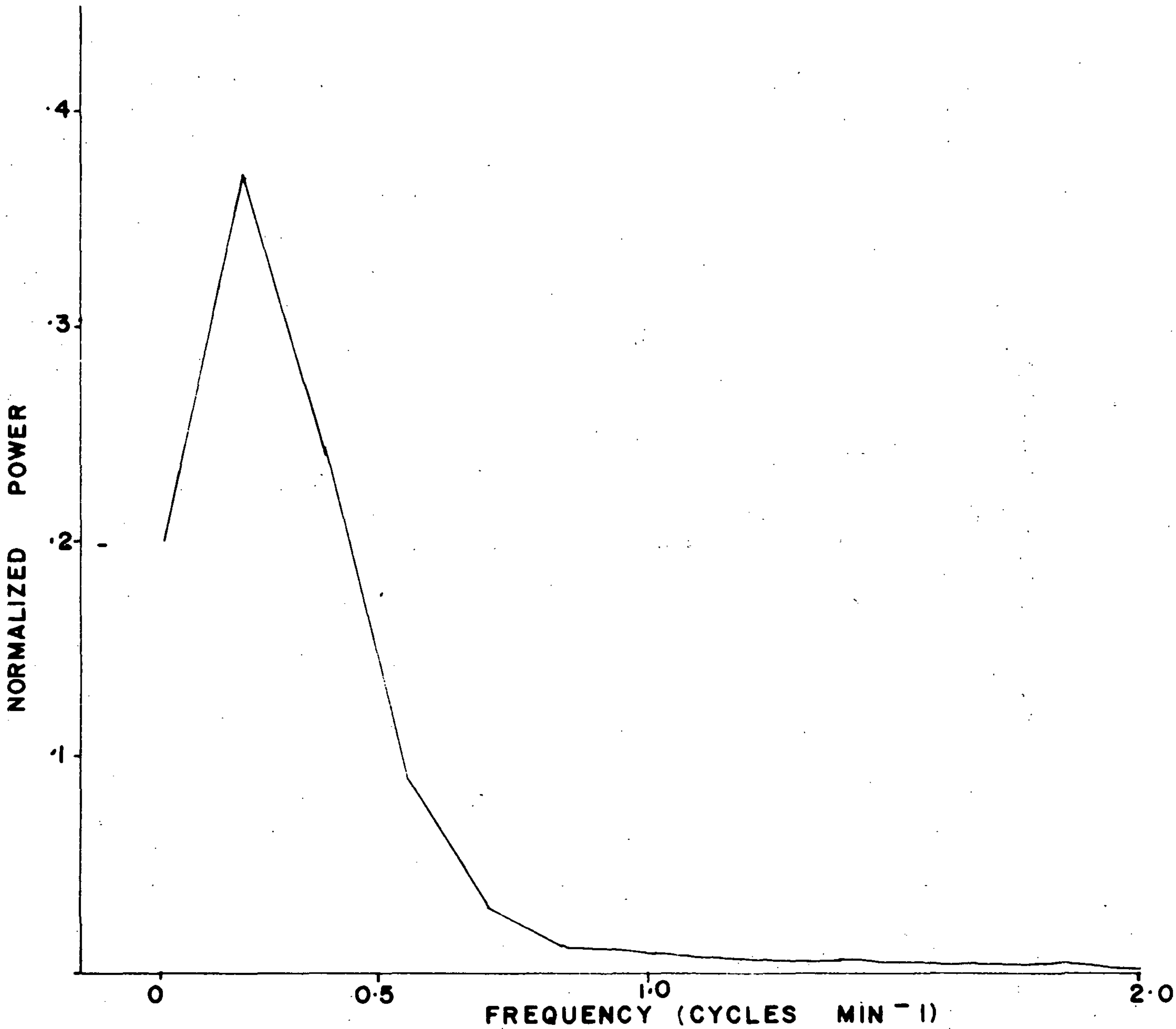

Figure 5
The Average of the Normalized Power Spectra Obtained from Data for the Portion of the Resolute Bay Ascents Which Occurred Between the Ozone Minimum and the Ozone Maximum, After the Application of the High Pass Filter.

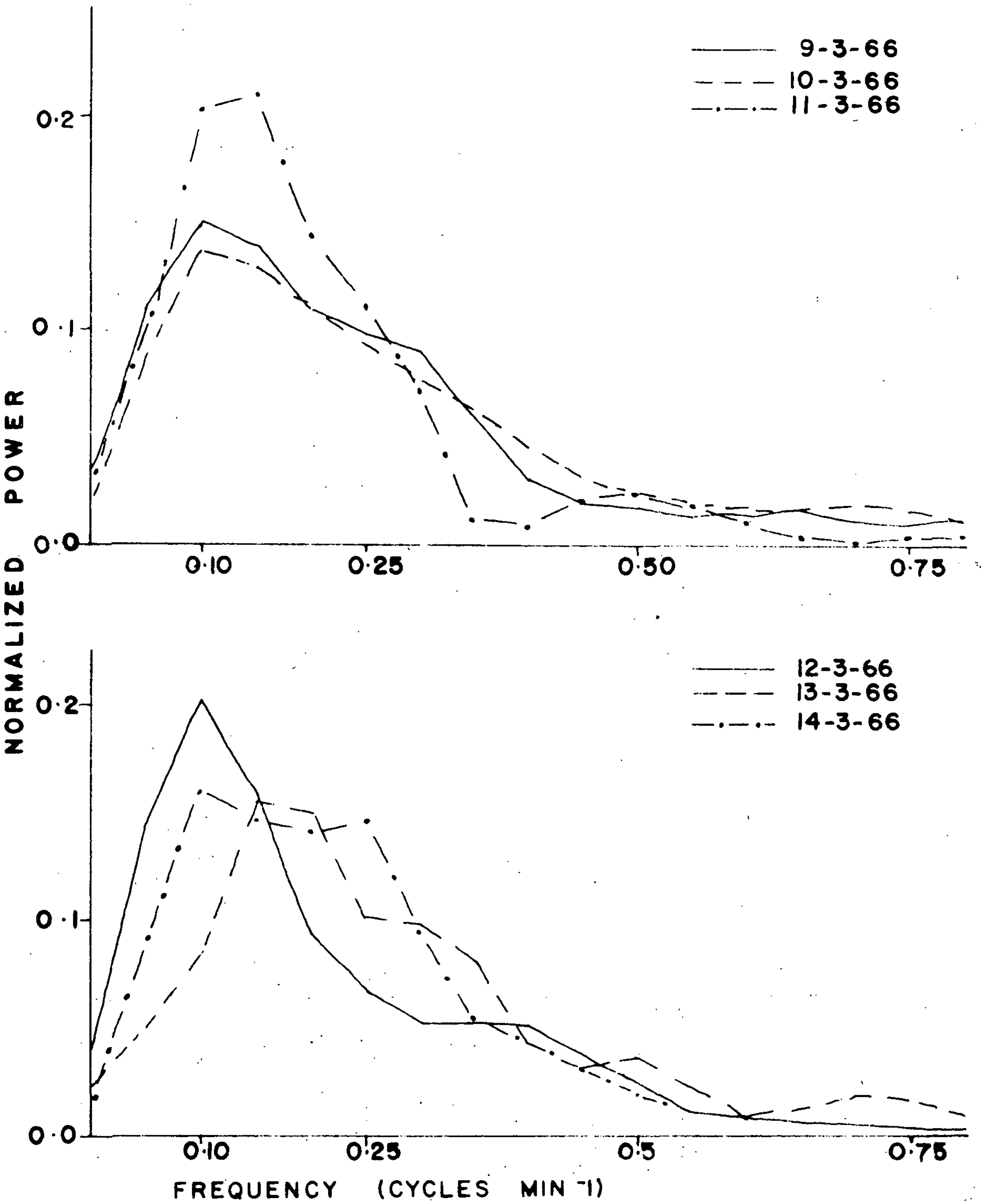

Figure 6
The Normalized Power Spectra for the Six Resolute Bay Ascents Which Resulted After the Application of the High Pass Filter.

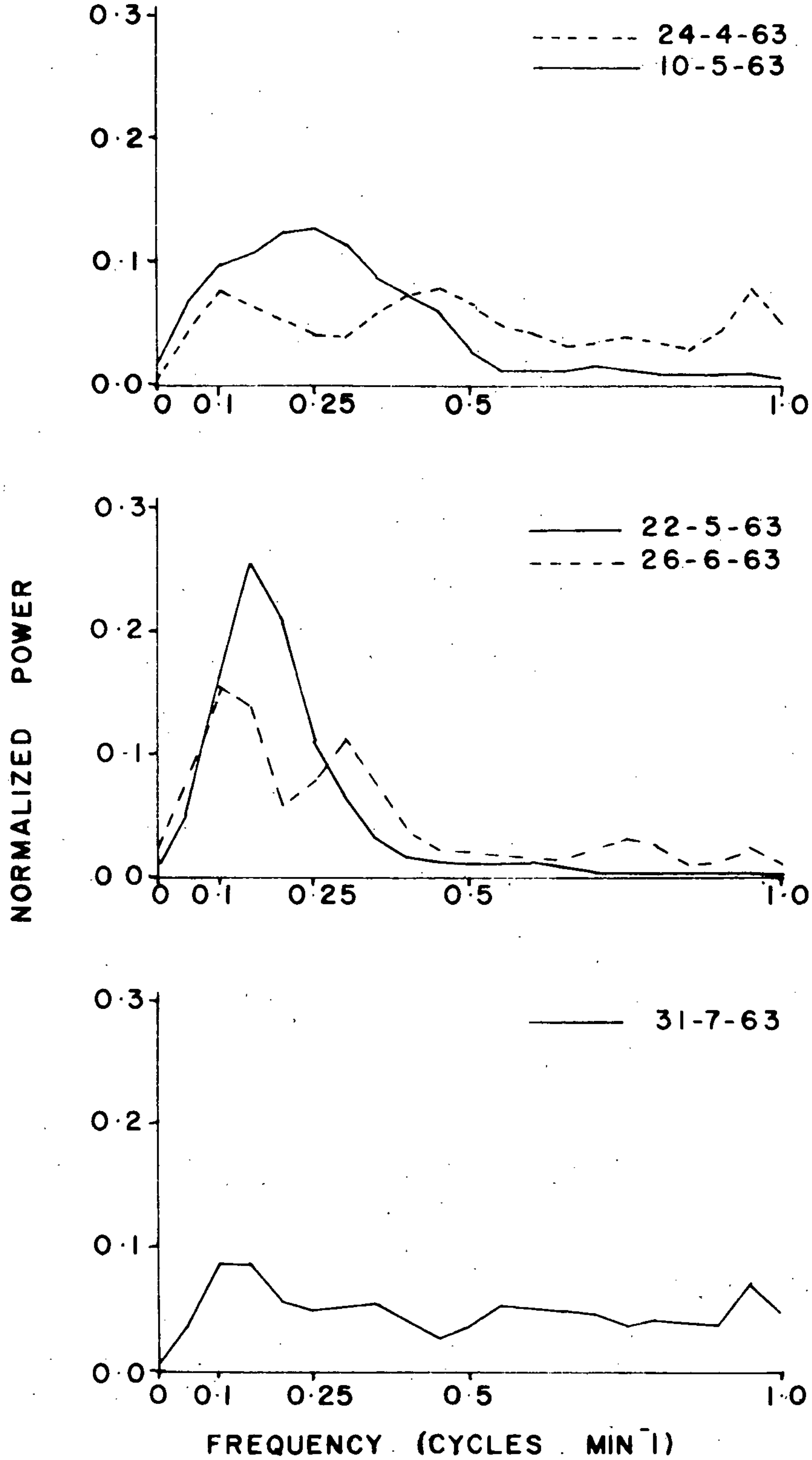

Figure 7
Examples of the Normalized Power Spectra Obtained From the Goose Bay Data After the Application of the High Pass Filter.

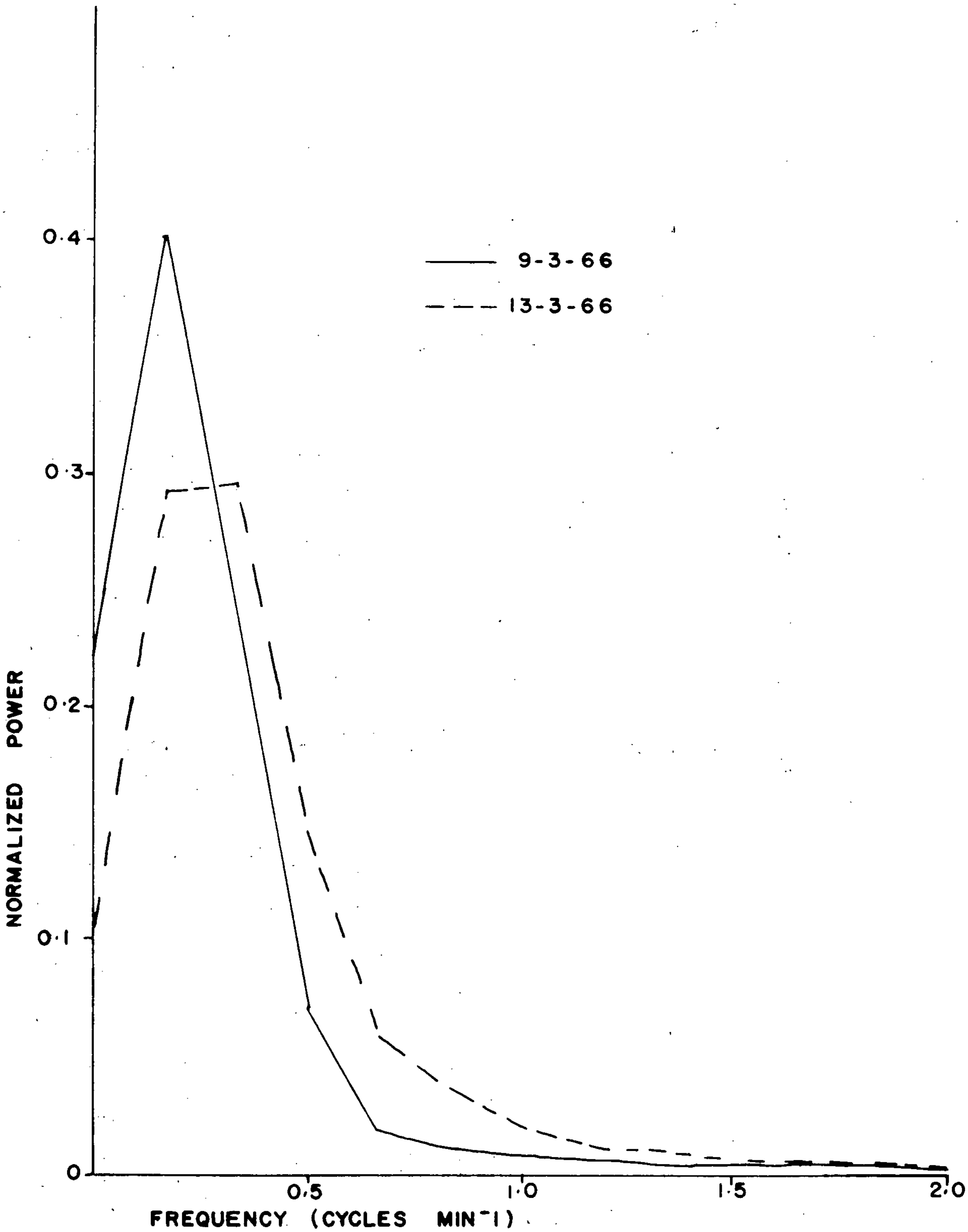

Figure 8
The Normalized Power Spectra of that Part of the Resolute Bay Data That Occurred Between the Ozone Maximum and the Ozone Minimum for the Dates Shown.

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6 pps. 8 figs. 1 ref.

Subject reference: 1. Brewer Bubbler Ozonesonde
2. Power Spectrum Analysis

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TEC-664
13 October 1967.

CANADA - DEPARTMENT OF TRANSPORT - METEOROLOGICAL BRANCH
315 Bloor Street, West,
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Amendment to Circular -4530, TEC-637 -

SEA ICE GROWTH IN ARCTIC CANADA

by

D. M. Leahey

1. The following changes are to be made to the above mentioned circular:

(a) Page 2: The equation $K_S \frac{(\theta_i - \theta_s)}{\delta} = - Q$
should be identified as equation (1)

(b) The legend on Figure III, should be reversed so that 0 - calculated values of Q and X - climatic values of Q.

APPROVED.

C. M. [signature]
for J. R. H. Noble,
Director,
Meteorological Branch.

UDC: 551.311.18