OSCILLATIONS IN D-REGION ABSORPTION AT PERIODS OF ONE TO TWO MONTHS

J. L. STANFORD (1)
Department of Atmospheric, Oceanic, and Planetary Physics
University of Oxford OX1 3PU
United Kingdom

and

R. C. SAKSENA (2)
National Physical Laboratory
Hillside Road, New Delhi 110012
India

ABSTRACT

One to two month oscillations in D-region absorption are found in seven years of daily f-min data from low latitude stations at Singapore (1N, 104E) and Rarotonga (21S, 160W). Coherency (cross-spectral) analyses reveal that solar flux variations account for much of the f-min variance at these periods. Over the range of periods from 10 to 200 days, statistically significant linear correlation is found between the f-min time series and contemporaneous 10.7 cm solar flux measurements at periods of 16-19 days, the 26-29 day solar rotation band, and a broad band covering 43-80 day periods.

(NASA-CR-184684) OSCILLATIONS IN D-REGION ABSORPTION AT PERIODS OF ONE TO TWO MONTHS (Oxford Univ.) 14 p CSCL 04A

N89-26308

Unclas
G3/46 0219854

(1) 1988-89 U. S. Fulbright Scholar to the United Kingdom and Faculty Improvement Leave, Physics Department, Iowa State University, Ames, Iowa 50011 USA
(2) Summer Scientific Visitor, 1988, Department of Physics, Iowa State University, Ames, Iowa 50011 USA

I. INTRODUCTION

The minimum frequency, f-min, at which reflection from the ionosphere is recorded on an ionosonde has been used by a number of authors to investigate the relationship between fluctutaions in ionospheric D-region absorption and those in the lower atmosphere. Although there can be problems with f-min data, such as quality control and interference from commericial radio stations, f-min data are widely available for a number of locations and, by exercising proper care, a number of investigators have used such data to good advantage.

The relationship between ionospheric absorption and f-min has been established by PIGGOTT, ET AL. (1957), and slow increases (periods of order 10 days) in f-min were found to be closely related to increases in measured electron density at mesospheric altitudes by GREGORY (1965). Increases of electron density or radiowave absorption with periods of order 10-20 days were found to be strongly correlated to stratospheric temperature changes by GREGORY and MANSON (1970); furthermore, DELAND and FRIEDMAN (1972) analyzed f-min data at several stations and found correlation with stratospheric pressure fields. Particle influxes cause sharper (one day) changes in electron densities (GREGORY and MANSON, 1970), and are not considered to appreciably affect the low frequencies analysed in the present work.

FRASER and THORPE (1976) and FRASER (1977) have utilized f-min measurements to identify a D-region spectral peak with periods near 5 days. Recently, BURNS and FRASER (1988) have investigated f-min, D-region electron density, and satellite-derived radiances representative of stratospheric temperatures in a study of planetary scale waves in both hemispheres. They found that the well-known 5-day wave of the lower atmosphere penetrates up to lower ionospheric levels, with horizontal structure consistent with theoretical predictions.

A one to two month period atmospheric oscillation in the equatorial troposphere reported by MADDEN and JULIAN (1971, 1972) has recently been found in analyses of satellite-derived stratospheric temperatures (GAO and STANFORD, 1987). While the energy source for the tropical oscillation almost certainly involves latent heat release in large scale convection in the tropical troposphere, the details of the mechanism are still poorly understood. Some models predict the propagation of the low frequency oscillations into the stratosphere and possibly beyond. However, to date there has been a dearth of observational evidence for the existence of the oscillations at altitudes above the stratosphere, mostly from lack of suitable measurements at these altitudes.

The original motivation of the present work was to see whether one to two month atmospheric oscillations propagate above the stratosphere. To accomplish this, f-min data were selected for analysis. As will be seen, oscillations were detected on these time scales. However, further investigation using cross-spectral analysis reveals that the oscillations are significantly correlated with solar flux variations.

II. DATA and ANALYSIS

A. Data selection

The selection of f-min station locations was based primarily on two criteria: (i) the availability of data sets sufficiently reliable for spectral analyses and, (ii) the most likely locations to observe such low frequency oscillations. The atmospheric one to two month oscillation is particularly strong in and to the east of the tropospheric Indian Ocean - Indonesian region. If this radiates vertically upwards, f-min data from Singapore and possibly central Pacific locations would be suitable for analyses. In particular, the Singapore measurements are known to be of high quality. Constraints on our time available for analyses was also a factor in how many locations and how much data were obtained. f-min data for Singapore (1N, 104E) and Rarotonga (21S, 160W) covering the seven year period 1 January 1958 - 31 December 1964 were obtained from the World Data Center, Boulder, Colorado. Sampling errors were minimized by using the mean of observed f-min values at 1000, 1100, 1200, 1300, and 1400 hrs local time and provide absorption data representative of the time of daily maximum ionization in the D region.

Daily 10.7 cm solar flux measurements were obtained for the same seven year period from World Data Centre C1, Solar-Terrestrial Physics, Rutherford Appleton Laboratory, U. K.

B. Analysis Methods

Figure 1 shows (a) the unprocessed time series and (b) the detrended/filtered time series for 1958-1964 at Singapore. Fig. 2 gives the series at Rarotonga Island in the south central Pacific. Very long period fluctuations are evident in both station data, as well as annual and semi-annual (6 month) periodicites. The latter is especially strong on the Equator at Singapore; it is in fact the dominant spectral feature there. The broad maximum near days 400-600 (roughly 1959) and broad minimum near days 2000-2200 (roughly 1963) appear to correspond approximately with the solar sunspot maximum and minimum about 1958 and 1965, respectively. A combination of procedures were used to reduce direct contamination of shorter period features by these very slow perturbations:

First, the time series data strings were chosen to be very nearly exact yearly multiples in length, placing the annual and semi-annual oscillations and their harmonics closely on exact analysed Fourier spectral periods. Leakage from these strong components was thereby rendered insignificant.

Second, the time mean and linear trend were removed from each time series, and a cosine taper applied to the first and last 5% of the time series. The latter reduces leakage from components with periods longer than the data series length. The resulting time series were then fast Fourier transformed to obtain estimates of their spectral power vs frequency. The complete computer algorithms were tested by random time series.

The occasional high spikes in the data will contribute mostly white noise at periods much shorter than the one to two month periods of interest in the present investigation.

Standard BMDP (Biomedical Computer Programs) Statistical Software was used for cross-spectral (coherency vs frequency) analysis of the Singapore and Rarotonga f-min time series against 10.7 cm solar flux.

III. RESULTS

A. f-min Spectra

After removal of the mean and linear trends, and application of cosine tapers to each end, the Singapore and Rarotonga time series were Fourier analysed. The resulting unsmoothed periodogram of power spectral density for Singapore is given in Fig. 3. The annual and up through its fifth harmonic have been replaced by the average of the two immediately adjacent spectral points. Apparently enhanced variance is to be noted at periods of about one to two months in Fig. 3. The results for Rarotonga (not shown) are similar.

It can be shown, using red-noise background estimates following the procedure of MITCHELL (1966), that the enhanced variance over the broad band of roughly one to two month periods in Fig. 3 is strong enough to satisfy *a posteriori* statistical significance (see, for example, MADDEN and JULIAN, 1971).

Further corroboration for one to two month oscillations of the D region is provided by the work of OFFERMANN, ET AL. (1987), of whose results we became aware as this paper was being written. They analysed ground based spectral measurements of OH excited states representative of temperatures at 86 km altitude over Sweden during a special observing period in December 1983 - April 1984. They also correlated the OH data with SSU (Stratospheric Sounding Unit) radiance measurements representative of upper stratospheric (about 40-45 km altitude) temperatures for the same location. Although their data cover a limited time span (only about two or three oscillations at these long periods, with consequently low spectral resolution), they reported spectral coherence between the two data series at periods near 40-50 days.

We next address the question of the possible forcing mechanism for these oscillations.

B. Cross-spectra With Solar Flux

In addition to the possibility of forcing from below by atmospheric waves, a second hypothesis for the cause of the one to two month oscillations in D-region absorption is that of forcing by solar flux variations at these periods. To test this latter hypothesis, cross-spectral (coherency vs frequency) analyses were made of the Singapore and Rarotonga f-min time series against contemporaneous 10.7 cm solar flux daily measurements. The coherency and phase results using the Singapore data are presented in Fig. 4(a) and 4(b), while those for Rarotonga are shown in Fig. 5(a) and 5(b).

The null hypothesis that coherency peaks occur due to random fluctuations can be rejected at the 95% confidence level for coherency values above approximately 0.53, indicated by the dashed horizontal line in Figs. 4 and 5. (The combination of tapering and smoothing result in approximately 10 degrees of freedom in our analyses.) That is, coherency values exceeding this level may be considered to indicate significant correlation between the f-min and solar flux times series at these frequencies.

From Figs. 4 and 5 it is clear that a null hypothesis that the f-min data are not linearly correlated with solar flux variations must be rejected for periods of 16-19 days, 26-29 days, and a broad band covering 43-80 days.

IV. DISCUSSION

We have presented evidence for one to two month oscillations in D-region absorption for two low latitude stations. Futhermore, coherency studies indicate that solar flux variations explain a significant fraction of the observed f-min variance at periods of 16-19 days, 26-29 days (the well known solar rotation effects), and, of particular interest in the present study, over a broad band of periods in the 43-80 day range. The one to two month oscillation in the low latitude f-min data must thus be considered primarily due to forcing by the solar flux.

While long period oscillations at mesopause heights are corroborated by OFFERMANN, ET AL., their work suggests that, at least at high latitudes, 40-50 day oscillations of mesopause temperatures are correlated with terrestrial upper stratospheric temperatures. (Similar coherency calculations cannot be performed with the f-min data series used here, since satellite stratospheric temperature data do not exist over the 1958-64 interval.) The results found in the present investigation would suggest primary control of f-min by solar flux variations. How can these two apparently contrasting results be reconciled?

Research since the completion of our f-min study reveals that the one to two month atmospheric oscillation is weak at upper stratospheric altitudes in low latitudes. It has been found that 32-56 day period perturbations in equatorial tropospheric temperatures over the Indian Ocean are strongly correlated with upper stratospheric temperatures at middle/high latitudes, but only weakly correlated at low latitudes (ZIEMKE and STANFORD, 1989). If this is also true of perturbations at the mesospause (representative of the f-min data analyzed here) it would explain the lack, at low latitudes, of strong forcing from below due to atmospheric one to two month oscillations. The various observational results are consistent with a model wherein the D-region response is dominated by solar flux variations in equatorial regions, but at extratropical latitudes forcing from below could become important.

Cross-spectral investigation of stratospheric/mesospheric temperatures, f-min, and solar flux data would provide a clearer picture of the extent to which the extratropical mesopause region is forced extraterrestrially and/or by atmospheric dynamical processes from below.

Acknowledgment

We have appreciated the assistance of J. A. Rickaby, J. R. Ziemke, Dr. M. A. Hapgood, and beneficial conversations with Dr. G. J. Fraser, visitor at Oxford in 1988. We especially appreciate the comments of two referees who pointed out the possibility of correlation between f-min and solar flux on the one to two month time scale. Support for this work was provided through National Aeronautics and Space Administration Grant NAG 5-1060 and National Science Foundation Grant ATM-8722703. The first author was on Faculty Improvement Leave from Iowa State University and U. S. Fulbright Scholar to the United Kingdom, 1988-89.

REFERENCES

BURNS A. G. and FRASER G. J. 1988 J. Atmosph. Terr. Phys. (to appear).

DELAND R. J. and FRIEDMAN R. M. 1972 J. Atmosph. Terr. Phys. 34, 295.

FRASER G. J. 1977 J. Atmosph. Terr. Phys. 39, 121.

FRASER G. J. and THORPE M. R. 1976 J. Atmosph. Terr. Phys. 38, 1003.

GAO X. H. and STANFORD J. L. 1987 J. Atmos. Sci. 44, 1991.

GREGORY J. B. 1965 J. Atmos. Sci. 22, 18.

GREGORY J. B. and MANSON A. H. 1970 J. Atmosph. Terr. Phys. 32, 837.

MADDEN R. A. and JULIAN P. R. 1971 J. Atmos. Sci. 28, 702.

MADDEN R. A. and JULIAN P. R. 1972 J. Atmos. Sci. 29, 1109.

MITCHELL J. M. Jr. 1966 Climate Change Tech Note No. 79, World Meteorol. Organization, Geneva, 36.

OFFERMANN D., GERNDT R., KUCHLER R., BAKER K., PENDLETON W. R., MEYER W., VON ZAHN U., PHILBRICK C. R. and SCHMIDLIN F. J. 1987 J. Atmosph. Terr. Phys. 49, 655.

PIGGOTT W. R., BEYNON W. J. G., BROWN G. M. and LITTLE C. G. 1957 Ann. int. geophys. y. 3, 173.

ZIEMKE J. R. and STANFORD J. L. 1989 (private communication, to be published).

Figure Captions

Fig. 1. Time series f-min data for 1958-1964 at Singapore (1N, 104E). (a) Unprocessed. (b) Detrended, mean removed and high pass filtered (half amplitude response at 70 days period).

Fig. 2. Same as in Fig. 1, but for Rarotonga (21S, 160W).

Fig. 3. Ionospheric D-region absorption unsmoothed spectral power density periodogram (relative units) for Singapore (1N, 104E). Frequency units are 1/(1280 day). Periods (days) are indicated at the top of the graph.

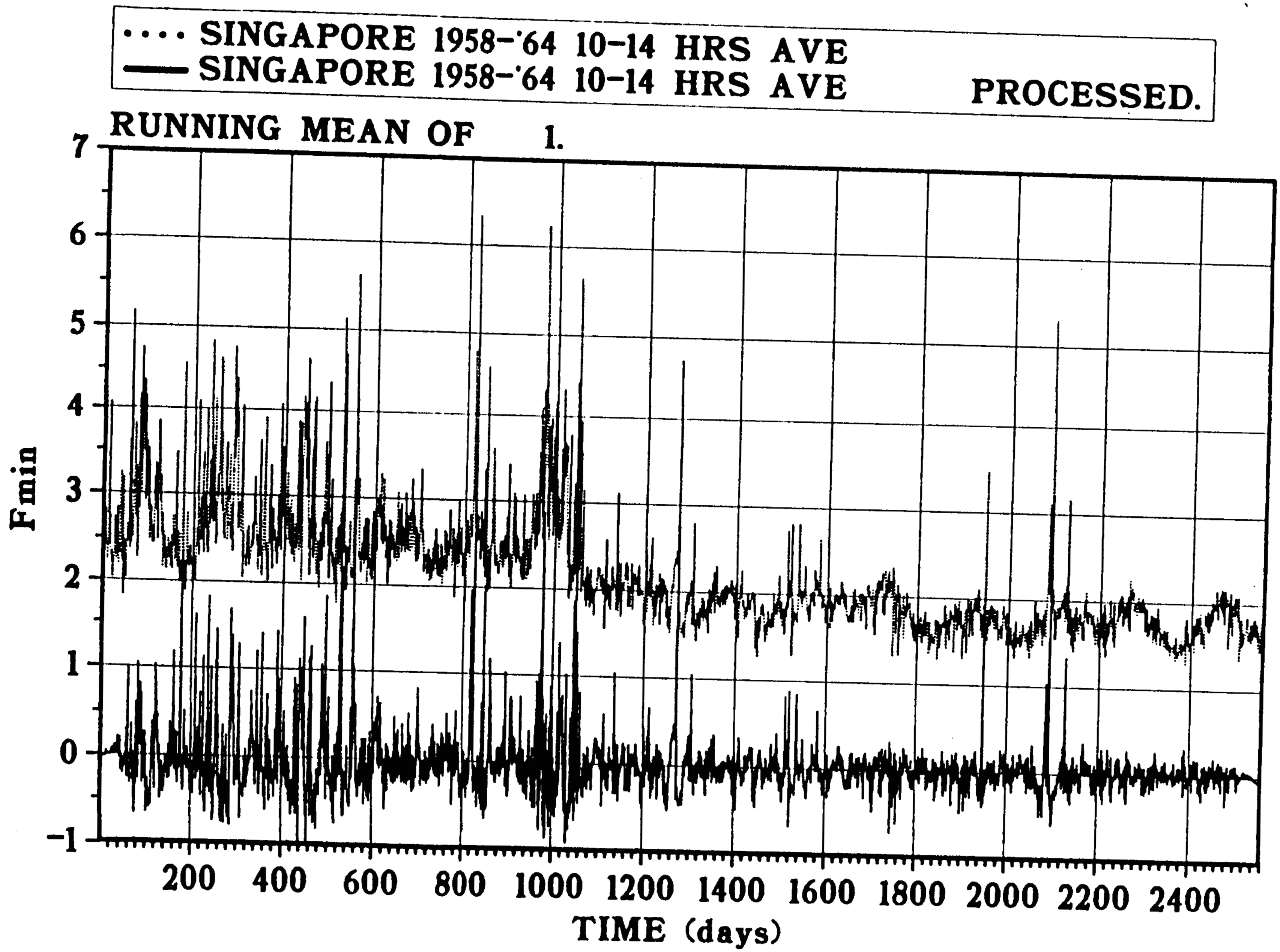
vs frequency of seven years (1958-1964) Singapore daily f-min
ɔoraneous daily 10.7 cm solar flux measurements. Frequency
Bandwidth for the calculation is 0.0059 cycle per day. The
ıcy peaks are the result of chance fluctuations may be rejected
for peaks exceeding about 0.53, indicated by the horizontal

:quency for the coherency plot in (a). Vertical scale units: 2π
y to within plus or minus integer multiples of 2π, and values
ıread of 2π.

4 (a), but for Rarotonga (21S, 160W).

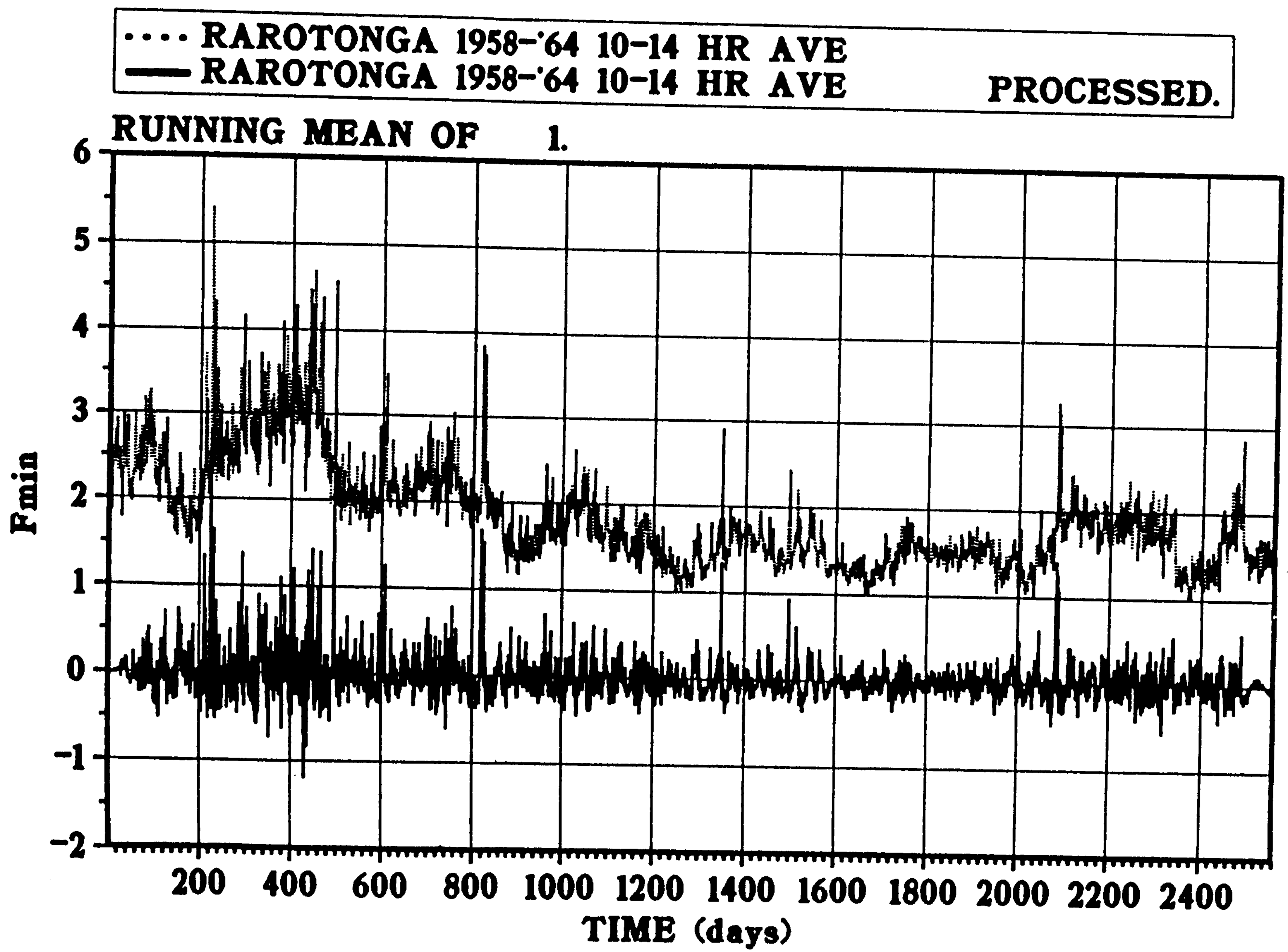
4 (b), but for Rarotonga (21S, 160W).

Fig. 1



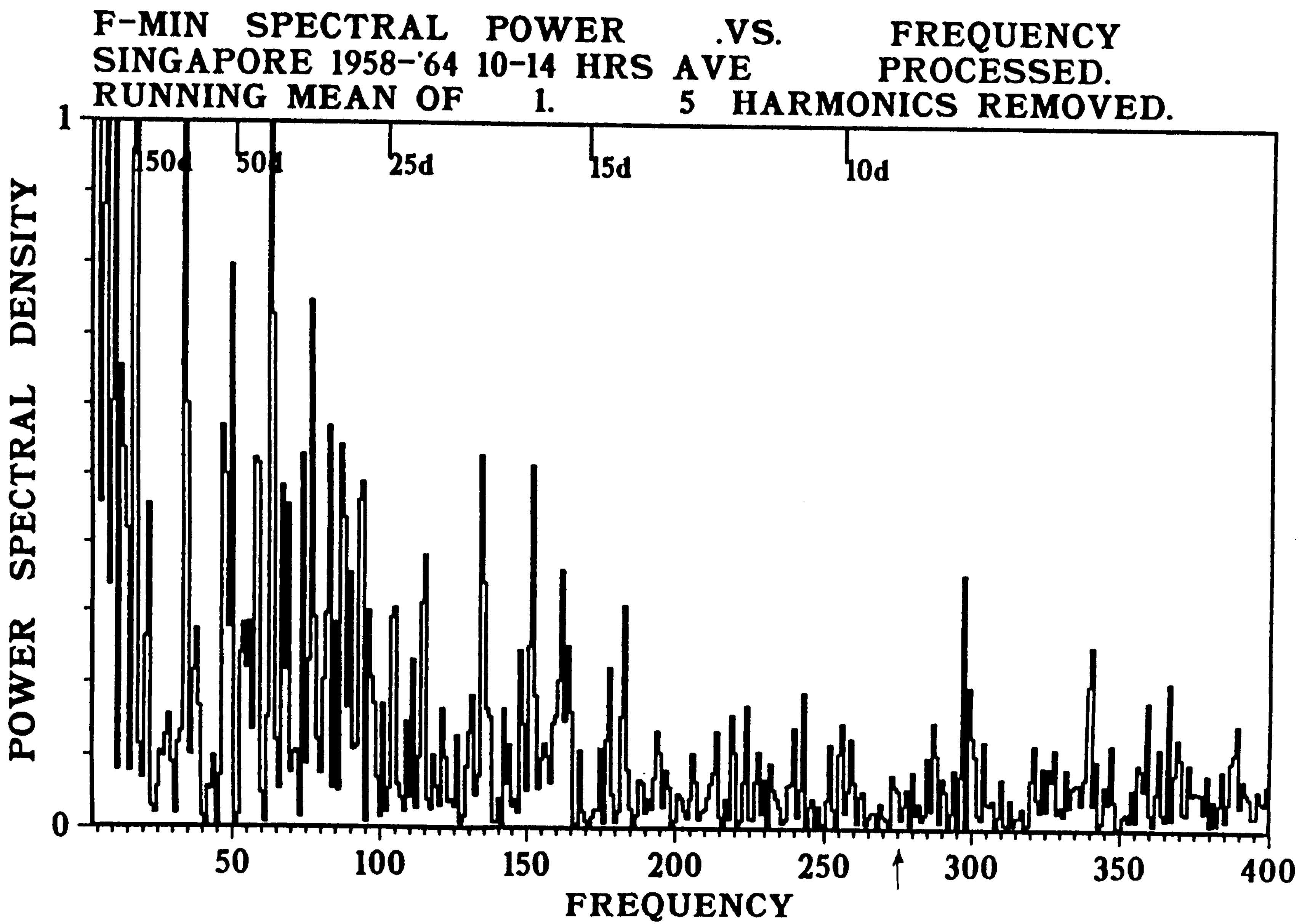
SINGAPORE 1958-'64 10-14 HRS AVE
SINGAPORE 1958-'64 10-14 HRS AVE PROCESSED.
RUNNING MEAN OF 1.
Fmin
7
6
5
4
3
2
1
0
-1
200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400
TIME (days)

Fig. 2



RAROTONGA 1958-'64 10-14 HR AVE
RAROTONGA 1958-'64 10-14 HR AVE PROCESSED.
RUNNING MEAN OF 1.
Fmin
6
5
4
3
2
1
0
-1
-2
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
TIME (days)

Fig. 3



F-MIN SPECTRAL POWER .VS. FREQUENCY
SINGAPORE 1958-'64 10-14 HRS AVE PROCESSED.
RUNNING MEAN OF 1. 5 HARMONICS REMOVED.
150d
50d
25d
15d
10d
POWER SPECTRAL DENSITY
1
0
50
100
150
200
250
300
350
400
FREQUENCY

Fig 4a

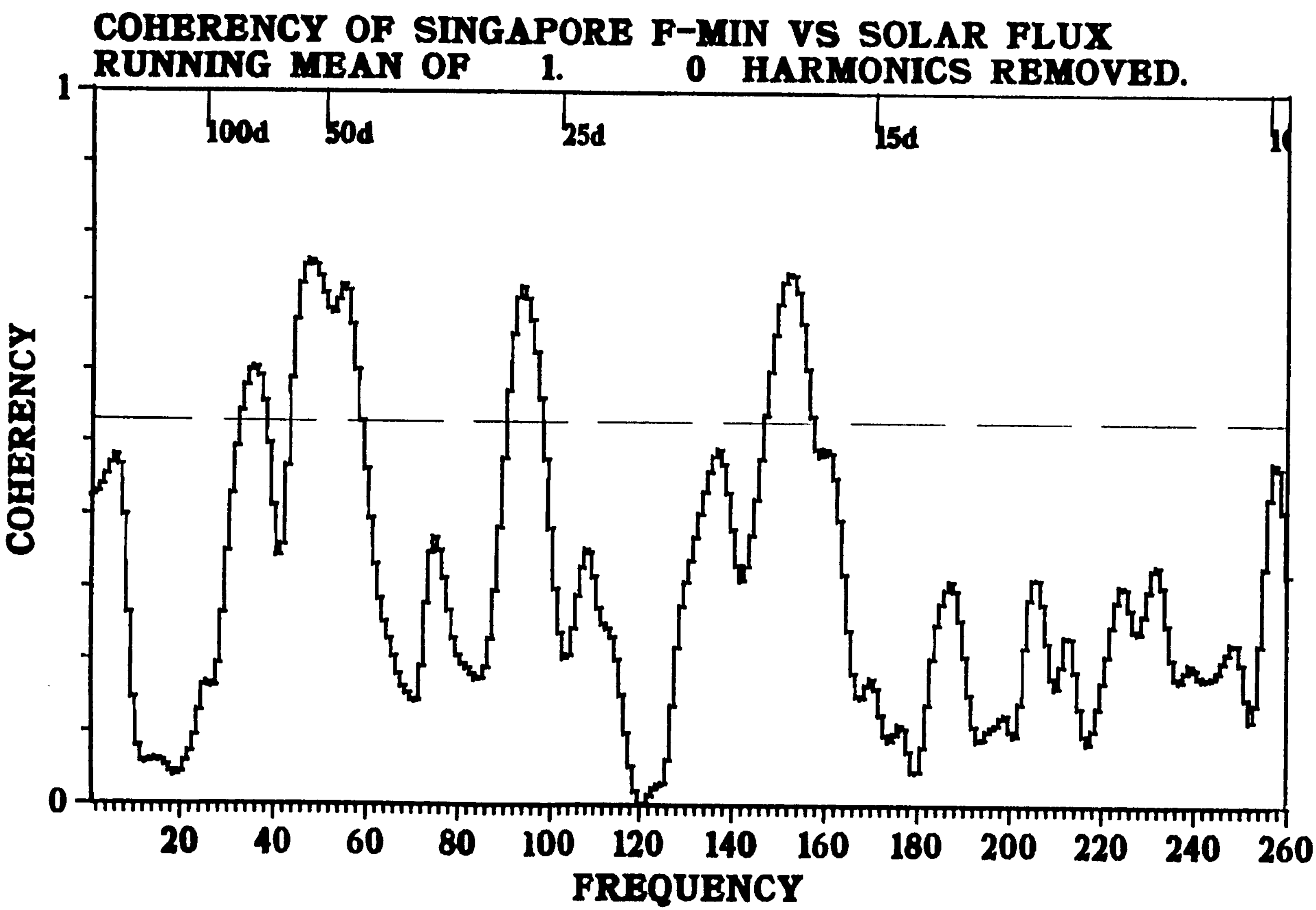

COHERENCY OF SINGAPORE F-MIN VS SOLAR FLUX
RUNNING MEAN OF 1. 0 HARMONICS REMOVED.
100d
50d
25d
15d
1
0
COHERENCY
20
40
60
80
100
120
140
160
180
200
220
240
260
FREQUENCY

Fig. 4(b)

PHASE OF SINGAPORE F-MIN VS SOLAR FLUX
RUNNING MEAN OF 1. 0 HARMONICS REMOVED.

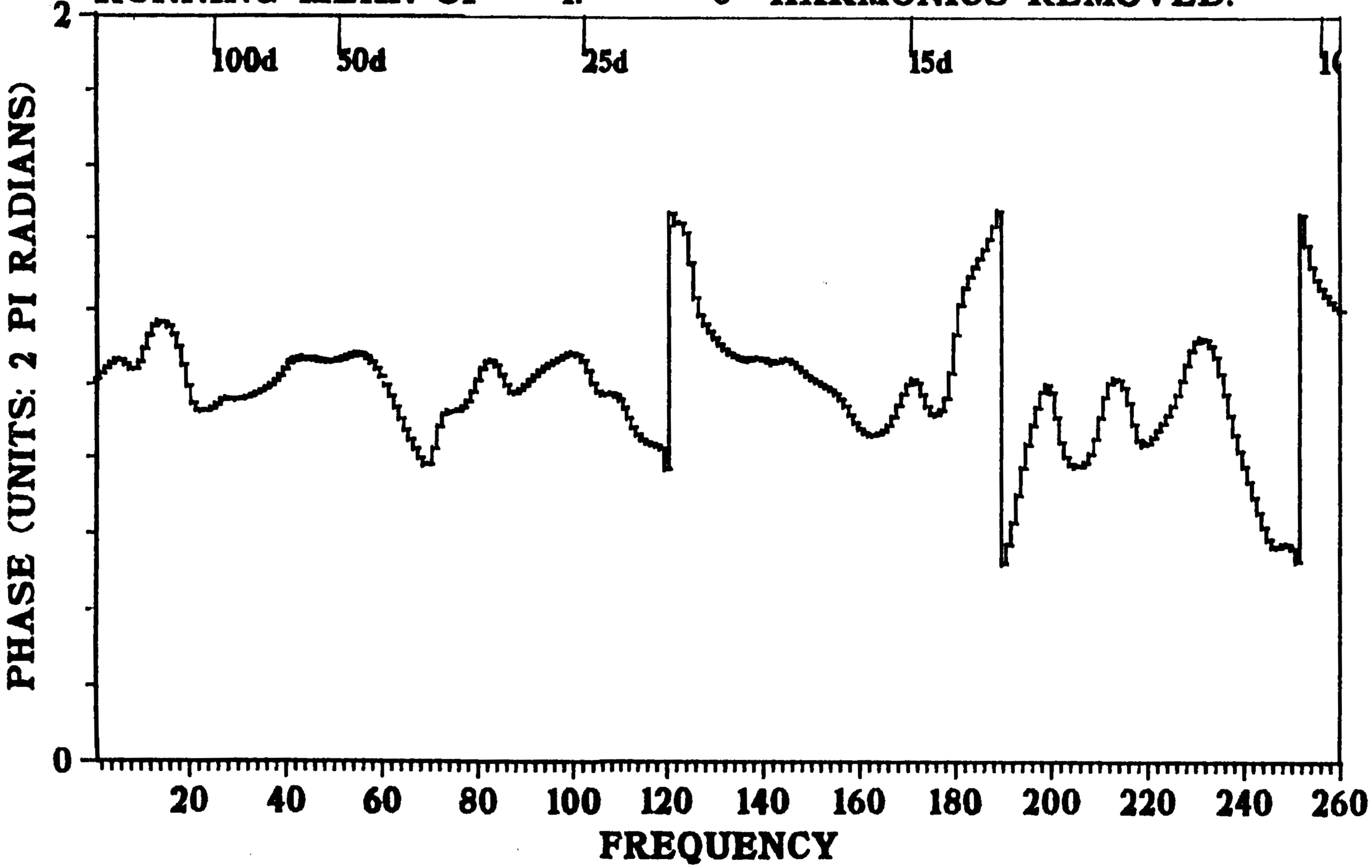


Fig. 5a

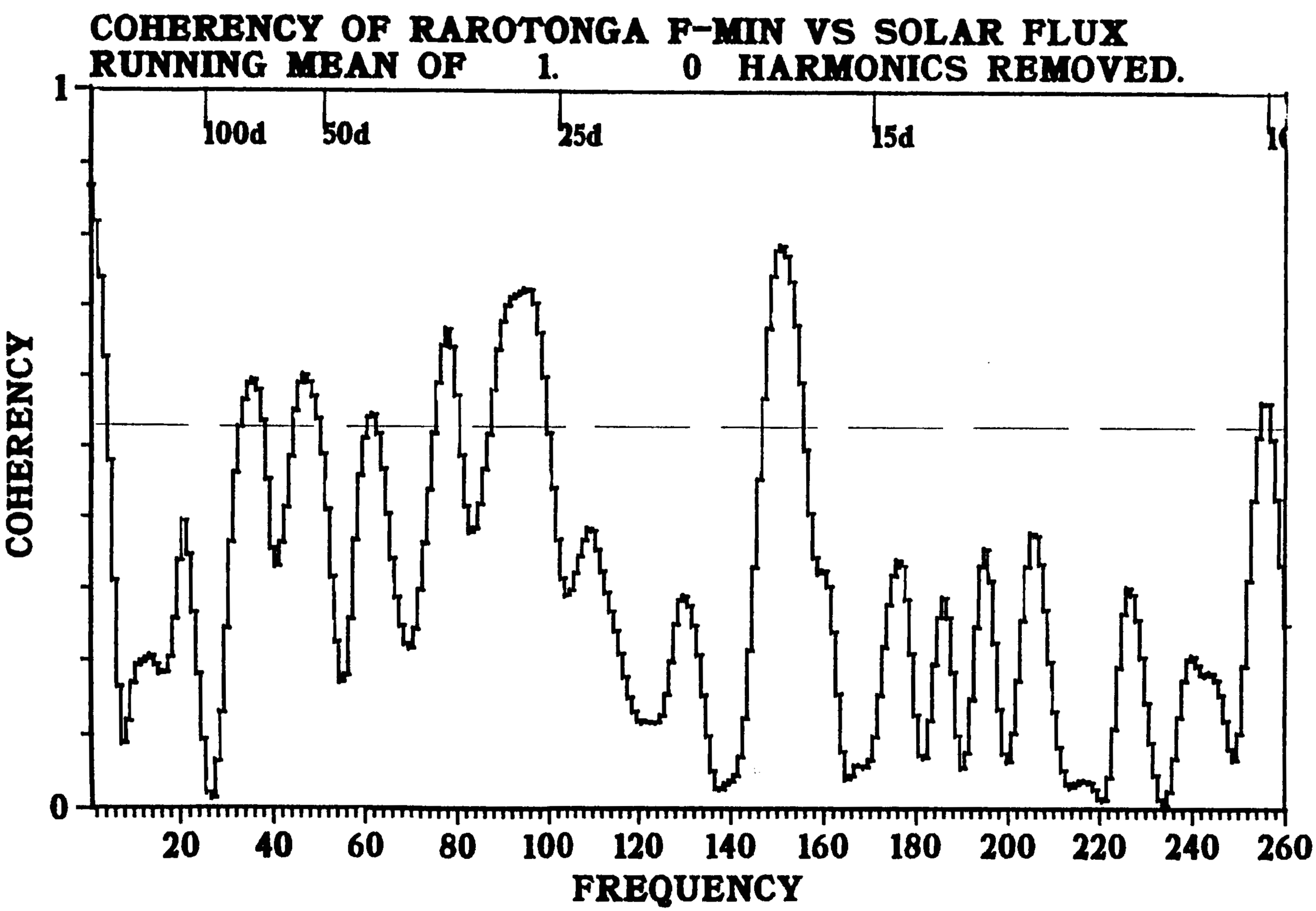
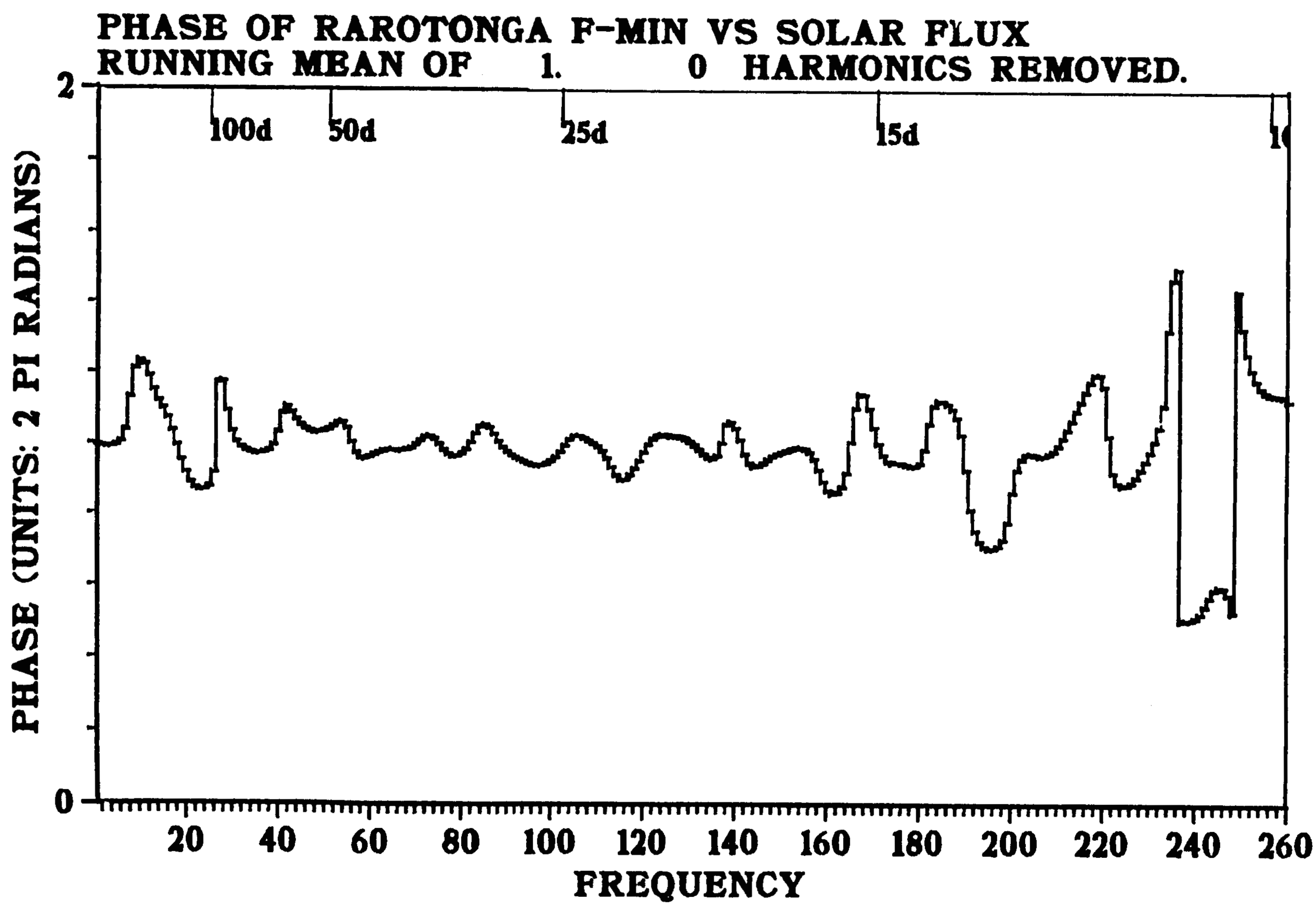

COHERENCY OF RAROTONGA F-MIN VS SOLAR FLUX
RUNNING MEAN OF 1. 0 HARMONICS REMOVED.
COHERENCY
1
0
100d
50d
25d
15d
20
40
60
80
100
120
140
160
180
200
220
240
260
FREQUENCY

Fig. 5



PHASE OF RAROTONGA F-MIN VS SOLAR FLUX
RUNNING MEAN OF 1. 0 HARMONICS REMOVED.
100d
50d
25d
15d
2
0
20
40
60
80
100
120
140
160
180
200
220
240
260
FREQUENCY
PHASE (UNITS: 2 PI RADIANS)