RESEARCH REPORT

RR-011 A

ON THE BEHAVIOUR OF THE 24 HOUR PRESSURE TENDENCY OSCILLATIONS ON THE SURFACE OF THE EARTH

by

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III Spectrum Analysis for the extra-tropical stations

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Summary

Spectral examination is done of the variation of the 24 hour surface pressure tendency oscillations in the extra tropical latitudes. A spectral peak at 5 days period is available at most of the stations. A wave number one retrogression can be traced in the subtropical latitudes, but it is difficult to trace it in the higher latitudes. The characteristics of the pressure tendency oscillations with 5 days period and wave number one westward propagation identifies it as the principal free mode of the earth's atmosphere.

1. Introduction

In a previous report in this series (Misra 1973 a) we have analysed the surface pressure data for the IGY period for the stations around the globe and have seen that the 4-5 day fluctuations in the atmospheric pressure is not confined to the tropics alone, but are available at the high latitude stations also. By applying a cross spectral technique to the station data in the tropics (Misra 1973 b), we found that the oscillations result due to a westward propagating pressure wave of the same period and zonal wavelength equal to the full zonal circle. Presently, we will extend the scope of the spectral investigation to the high latitude stations in either hemisphere. From the amplitude distribution of spectral power, we will see that the characteristics of these oscillations match with the free oscillation mode discussed by Matsuno (1966) and Longuet-Higgins (1968) for an equivalent depth consistent with the earth's atmosphere.

2. Spectral Results for the high latitude

The part II of this report covered the data of stations in the tropics 20°N-20°S from a global data assembly. The auto-spectra for the pressure tendency series of the IGY period for the high latitude stations in the north and the south hemispheres are given in figs. 1 and 2. The stations have been arranged as per their increasing latitude and the station identifications are given in separate pages. The computations

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have been done on the same lines as for the station data in the tropics (part II). This consists in estimating the covariance matrix with the total number of data points as the divisor and subsequently plotting the cosine transforms of the covariances in a logarithmic scale. The advatange of the logarithmic scale is that it allows a constant confidence interval for the whole domain as per the chi-quare distribution for the appropriate number of degrees of freedom. We use a Tukey window with a lag of 20, giving 73 degrees of freedom.

Before we discuss the power spectral distribution, we give in fig.3, the collective representation of the station locations where a maximum in the histogram analysis took place (please refer to the histograms in fig.2 of the part I of this report). The figure shows some marked zones for the occurrence of maxima in different period ranges. 2 days maximum is more dominant in the southern hemisphere than the northern. In the south hemisphere, they occur systematically on the west coast of south American and that of African continent, also in the belt of 40°- 60°S where many oceanic stations are affected. Stations in the Indonesian belt and a few

Pacific ocean stations in the southern hemisphere show maximum frequency of oscillations to occur at 2 days period. Most of these stations are situated either on or against an elevated topography. Four stations in the northern hemisphere which show a maximum frequency to occur at 2 days periodicity also fall to the same criterion. In the southern hemisphere, they occur at the west coast of United States and a few stations in the western Europe.

In contrast to the shortest period, the maximum at 3 to 4 days are more a characteristic of the tropical belt and the high latitude stations where the station altitude is not high. It is again interesting to see that the 3 day maxima occur mostly around these stations which had given a 2 day maximum earlier. In the tropical belt, it is again mostly found in the west African coast and the west coast of south America. Most of the stations in the 40°- 70° latitude in the north hemisphere give a maximum frequency at 3 day period, except for a small zone between 90°E to 150°E, which is the area of maximum pressure on the north hemisphere. The period that is favoured here for the maximum frequency is that of

4 days. Beside this zone, the 4 days period is a characteristic feature of the tropical oceanic areas extending to sub-tropics in some regions. It is interesting to see that north Africa has a favoured period of 4 days for the oscillations to occur even though the general elevation is of the same order as for the west Africa and west South America, where 2 days period is preferred.

Among the stations that prefer a 5 day maximum are those in the west coast of Australia. It is interesting to note that all other Australian stations give a maximum frequency at 3 days period. No distinguishing characteristic can be noticed for this difference. Other stations that give a maximum at 5 days period are embedded in a zone where the maximum frequency mostly occurs at 4 days period.

The distribution of spectral power in fig. 1 and 2, divides the stations into three broad categories

1) the stations that have a spectral power maximum at about 5 days period

2) the stations that have a relative minimum at 5 days period

3) the stations that give a uniform power distribution between 8 days to 2 days.

In fig. 4, we give the geographical distribution of these three categories of variation of spectral power. In this figure a ✓ , a o and a x have been utilised to indicate the three categories respectively. It is easily understood that the nature of the spectral power distribution diagram is somewhat different from the frequency maximum diagram. It is natural that the spectral power distribution is more stable and does summarise the total probabilistic information in some sense. What clearly emerges from fig. 4, is that the stations which do not show a maximum in the period range of 4-5 days, have a system of organisation in them. The most preferred zones for them are in the 40°- 60° latitude belt in the south hemisphere and around the 70°W longitude where the north hemispheric stations also fail to show the 4-5 day maximum. The zone in which a broad band occurs, lies on the west coast of Africa and the west coast of south America, whereas a minimum occurs in the 40°- 60°S and 70°W belt.

In fig. 5, we give the distribution of logarithmic spectral amplitude in the 4-5 day spectral band. The spectral amplitude is minimum at the equator and goes on increasing with increasing latitude till about 60° in either hemisphere, after which the amplitude falls. The plot follows the same trend as given in fig. 3 of the part I of this report.

3. Phase and coherence in zonal belts

Fig. 6 to fig. 10 gives the plots of phase difference against longitude difference for a 4.4 day period (the same period that was used for the tropical area in the part II of this report) on the subtropical and polar latitude belts in the two hemispheres. The zonal belts are 20°- 25°N, 25°- 35°N, 35°- 45°N (fig.6); 45°- 55°N, 55°- 65°N, 65°- 75°N (fig. 7); 75°- 85°N (fig. 8); 20°- 25°S, 25°- 35°S, 35°- 45°S (fig. 9); and 45°- 55°S, 55°- 65°S, 65°- 75°S (fig. 10). The stations in these latitude belts as used in figs. 1 and 2 have been used in drawing the phase lines. Four stations have been chosen as references in each zonal belt more or less uniformly distributed in longitude, a station around 10°E, 100°E, 170°W and 80°W have been used as references, wherever possible. The reference stations have been noted below each figure. While plotting the phases, a dark circle indicates a station where a significant coherence

(95 percent) obtains in the analysis. The stations not showing a 95 percent significant coherence with the reference stations have a phase marked with a •.

In the north hemisphere, the phase propagation is systematically westward upto about 35°N, completing a wavenumber one progression. Between 35°- 55°N, the phase propagation is more disorderly and hence no smooth pattern can be fitted to the 4,4 days period. Beyond 35°N, towards the polar latitudes, it appears that the phase propagation is more or less eastward covering a wavenumber 2. In the south hemisphere, the westward propagation with wavenumber one is seen only in the 20°- 25° belt. As happens in the north hemisphere, the phase propagation is more disorderly between 25°- 55°S. In some cases in these latitudes an eastward propagation of phase is also seen. However the polar latitudes in the south hemisphere do again show a westward propagation for the 4.4 days period.

A comparison of figs. 6-10 with figs. 3 and 4 of the part II of this report brings home the great difference between the phase propagation in the tropical and the middle latitudes. It is only natural, since we know that the middle latitude pressure systemes have a different dynamics than the tropics. However, it is relevant here to reproduce a diagram from Madden and Julian (1972), who have plotted the wave number one one anomaly only on a global map for the grid point data during the IGY period. This is done in fig. 11. A westward propagation associated with wavenumber one is evident from this figure. The more interesting point is the positioning of the maximum anomaly in the middle latitudes in two hemispheres. An elegant picture of this characteristic emerges from the day 2 of the propagation diagram. We further see in this diagram that the increase in amplitude from the equator to the middle latitudes is about twice, while the fig. 5, plotting the logarithmic spectral power, gave one order of magnitude higher for the middle latitude amplitude maximum. It only means that our analysis takes all the contributions to a 5 day period into account while the fig. 11 gives the contribution from the wavenumber one only.

In a tables 1, 2, 3 and 4, we give the coherences and phases of a 4.4 days period wave between the tropical and extra-tropical latitude stations for the longitudes 10°E, 100°E, 170°W, 80°W for the north and south hemispheres respectively. A reference station is chosen in the 25°- 35° belt in all the occasions. It is seen that at 10°E, the tropical stations are coherent with the subtropical ones, but are inchoherent with the 55°- 65° latitude belt. Coherence increases again at high latitudes. This is true for both the hemispheres. For 100°E, the tropical and subtropical stations are coherent in the north hemisphere, but are incoherent in the south hemisphere. The belt 55°- 65° is incoherent with the tropics in the north, while it is coherent in the south. Incoherence between tropical and subtropical stations also occurs for 170°W, while the midlatitude stations are coherent with the tropical ones. At 80°W, the tropical and subtropical stations are coherent, but are incoherent with the stations in the middle and high latitudes. For all the stations, which show a large coherence with the reference station, the phase difference obtained is of the same sign and order as the longitude difference. However in view of the result that the middle latitudes are affected by wave characteristics of different space scales, the phases between stations in the tropics and extratropics may not carry much inference.

4. Schematic model of the propagating pressure wave

Fig. 12 gives a schematic picture of the circulations associated with the propagating pressure wave. It is interesting to note that the circulations depicted matches with one of the equatorial modes (n = 1) discussed by Matsuno (1966). The circulation for n = 1, equatorial mode for half a wavelength is reproduced from Matsuno's paper in fig. 13. Matsuno's solution is on an equatorial beta plane and hence will not be valid on a sphere. But it is interesting to find that the Rossby speed for the n = 1 mode given by

$$\frac{-\beta}{k^2 + \frac{\beta}{c_g}(2n+1)}$$

where $\beta = \frac{\partial f}{\partial y}$, k the wavenumber and c_g the speed of pure gravity wave, gives a retrogression of 90° longitude per day for a wavenumber one progression.

Lastly in fig. 14, we give the pressure and wind characteristics for a westward propagating wave-number one solution from the eigensolutions over a sphere deduced by Longuet-Higgins (1968). The figure corresponds to an equivalent depth of 8.8 km in a barotropic fluid. As Madden and Julian (1972) have already noted, there is a striking resemblance between the pressure variation observed in the Longuet-Higgins's paper and the wavenumber one anomaly. The winds deduced by Longuet-Higgins is only qualitative and no examination has yet been done on how the pressure wave shows itself in the wind field.

5. Discussion

The study divided into three parts has brought out that the short period pressure fluctuations, discussed by Eliot (1895), are global in character. They have a mean period ranging between 4-5 days. The pressure fluctuations in the tropical areas has an amplitude of about 1 mb, while that in the middle latitudes can be about 8-10 mb. These fluctuations in the tropics can be ascribed to a westward progressing pressure wave of wavenumber one. To trace the wave from the total pressure field in the extratropics is difficult, but the wavenumber one anomaly shows a westward propagation in about 5 days' time.

The characteristics of this wave matches with the properties of wavenumber one free mode in a non-divergent barotropic fluid. It is possible that the pressure wave discussed in this report could be the fundamental free oscillation for the earth's atmosphere.

Acknowledgement

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Station Identification for Fig.2 (Southern Hemisphere)

	Station Name	Latitude	Longitude
1.	Ono-i-lau	20° 40'	178° 43'W
2.	South African Stn.	22° 30'	15° 00'E
3.	Rio-de-Janeiro	22° 54'	43° 10'W
4.	Rikitea	23° 07'	134° 58'W
5.	Rockhampton	23° 23'	150° 29'E
6.	Antofagasta	23° 28'	70° 26'W
7.	Carnarvon	24° 53'	113° 19'E
8.	Fort Dauphin	25° 02'	46° 57'E
9.	Isla de Pascua	27° 09'	109° 27'W
10.	Raonl Is.	29° 15'	177° 55'W
11.	Durban	29° 58'	30° 57'E
12.	Coff's Harbour	30° 18'	153° 08'E
13.	Rio Grande	32° 02'	52° 06'W
14.	Isla de Fernandez	33° 37'	78° 52'W
15.	Cook Is.	33° 37'	130° 24'E
16.	Cape Town	33° 58'	18° 36'E
17.	Tristan da Kunha	37° 03'	12° 19'W
18.	Nouville Amsterdam	37° 50'	77° 34'E
19.	Mar del Plata	37° 56'	57° 35'W
20.	Gough Is.	40° 19'	9° 54'W
21.	Cape Bruni	43° 30'	147° 09'E

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23.	Tasty	44° 48'	69° 07'E
24.	Stephenville	48° 32'	58° 33'W
25.	Vancouver	49° 11'	123° 10'W
26.	Valentia Obsy.	51° 56'	10° 15'W
27.	Norsky-sklad	52° 21'	129° 55'E
28.	Hamburg	53° 38'	10° 00'E
29.	Abakan	53° 45'	91° 24'E
30.	Petropavelovesk	54° 50'	69° 09'E
31.	Annette Is.	55° 02'	131° 34'W
32.	Great Whale River	55° 17'	77° 46'W
33.	Echa	55° 42'	155° 38'E
34.	Moscow	55° 45'	37° 34'E
35.	Indian House Lake	56° 14'	64° 44'W
36.	Cape St. Elias	59° 48'	144° 36'W
37.	Fort Smith	60° 01'	111° 58'W
38.	Narssarssuaq	61° 11'	45° 25'W
39.	Baikit	61° 40'	96° 22'E
40.	Nayakhan	61° 55'	158° 59'E
41.	Yakutsk	62° 05'	129° 45'E
42.	Keflavik	63° 59'	22° 38'W
43.	Coral Harbour	64° 12'	83° 22'W
44.	Bukhta Providenia	64° 26'	173° 14'W
45.	Arkhangelsk	64° 35'	40° 30'E

46.	Nordoyan	64° 48'	10° 33'E
47.	Tarko-sale	64° 55'	77° 49'E
48.	Cambridge Bay	69° 07'	105° 01'W
49.	Barter Is.	70° 07'	143° 40'W
50.	Vardo	70° 22'	31° 06'E
51.	Ostrov Chetyre	70° 38'	162° 24'E
52.	Umanak	70° 41'	52° 07'W
53.	Ostrov Wrangel	70° 58'	178° 32'W
54.	Jan Mayen	71° 01'	8° 28'W
55.	Bukhta Tiksi	71° 35'	128° 55'E
56.	Khatanga	71° 59'	102° 28'E
57.	Arctic Bay	73° 00'	5° 18'W
58.	Ostrov Bely	73° 20'	70° 20'E
59.	Bjornoya	74° 31'	19° 01'E
60.	Ostrov Kotelny	76° 00'	137° 54'E
61.	Mys Chelyuskin	77° 43'	104° 18'E
62.	Isfjord Radio	78° 04'	13° 38'E
63.	Isachsen	78° 47'	103° 32'W
64.	Ostrov Vize	79° 30'	76° 59'E
65.	Bukhta Tikhaya	80° 19'	52° 48'E
66.	Nord	81° 36'	16° 40'W
67.	Alert	82° 32'	62° 20'W

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LEGENDS TO FIGURES

Fig. 1. : Plot of logarithm of spectral estimates against period of 24 hour surface-pressure tendency field for extra-tropical stations in the north hemisphere. Station identifications as per serial number (increasing with north latitude) in the figure is given in the attached page. Kindly refer to part II of this report and Fig. 1 terein for the confidence interval and band-width of spectral estimates.

Fig. 2. : Same as Fig. 1 except for extra-tropical stations in the south hemisphere. Station identifications (increasing with south latitude) are given in the attached page. Kindly refer to part II of this report and Fig. 2 therein for the confidence interval and band-width of spectral estimates.

Fig. 3. : Presents a summary of information derived from frequency analysis, described in part I of this report. The figure depicts the maximum frequency occurrence for different periodicities.

Fig. 4. : Presents a summary of information derived from spectral analysis for all the station-data, as given in Fig. 1 and Fig. 2 of part II of this report and Fig. 1 and Fig. 2 of the present article.

Fig. 5. : Gives the logarithm spectral amplitude distribution for a period of 4.4 days over the whole earth as obtained from spectral analysis, earlier referred to. A spectral amplitude maximum around 60° latitude is noticed. The distribution compares with Fig. 3 of the part I of this report.

Fig. 6 to Fig. 10. : Plot of longitude difference against phase difference for 4.4 days period (as used in Fig. 3 and Fig. 4 of part II of this report) for the stations in various zonal belts in the hemispheres as indicated in each figure. Kindly refer to Table II of part I for the station identifications in the zonal belts. (a), (b), (c) and (d) stand for different stations, whose identifications have been given at the bottom of each plot. Phases for the stations showing significant coherence with the reference station, have been indicated as black circles. Phases for stations which do not have a significant coherence are marked by a cross. Phase-line is constructed among the stations which show significant coherence. The phase line is marked dashed, when it depicts a wavenumber two progression or an eastward propagation.

Fig. 11. : Reproduced from a paper by R.A. Madden and D.R. Julian (1973) as given in the reference. This depicts the propagation of wavenumber one anomaly as derived from the grid-point values of surface pressure for the IGY period.

Fig. 12. : A schematic model of the propagation of pressure wave discussed in this report. The meridional alignment of high pressure cells should be noted.

Fig. 13. : Reproduced from the paper by T. Matsuno (1966) on the equatorial wave disturbances. The figure which corresponds to $\eta = 1$ mode (n, a degree of Hermite polynomial) in the equatorial latitudes, has a great similarity to the pressure wave discussed in this report.

Fig. 14. : A figure deduced from the pages by M.S. Longuet-Higgins (1968) on the eigen-solutions of the Laplace's tidal equations over a sphere. The figure gives the geopotential, zonal and meridional wind speed distribution for a westward propagating mode with wavenumber one against latitude for an equivalent depth of about 8.8 km for earth's atmosphere. Such a mode has also a characteristic period of about 4.8 days. The geopotential field characteristics matches with the amplitude of the surface pressure wave observed.

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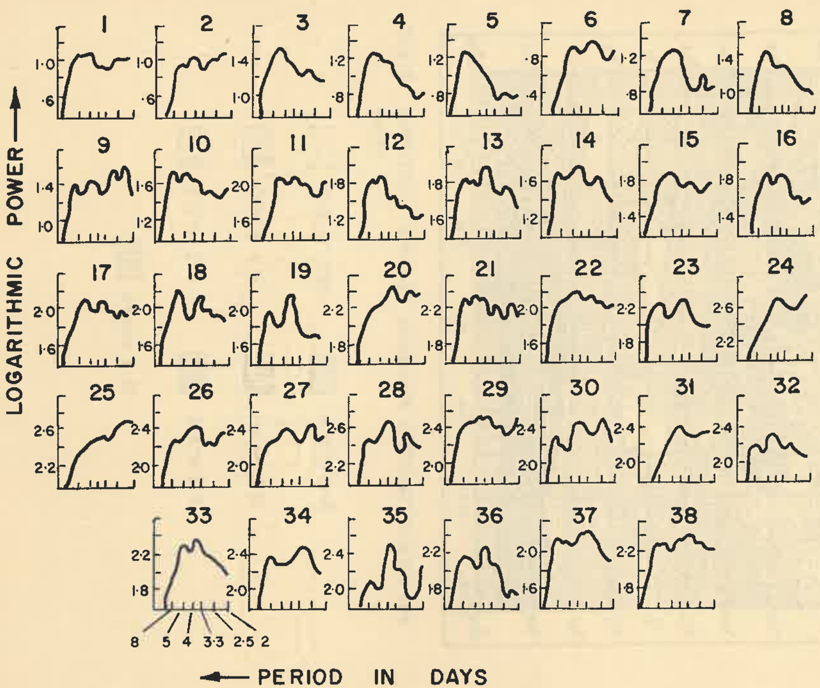

LOGARITHMIC POWER
PERIOD IN DAYS

Fig. 2

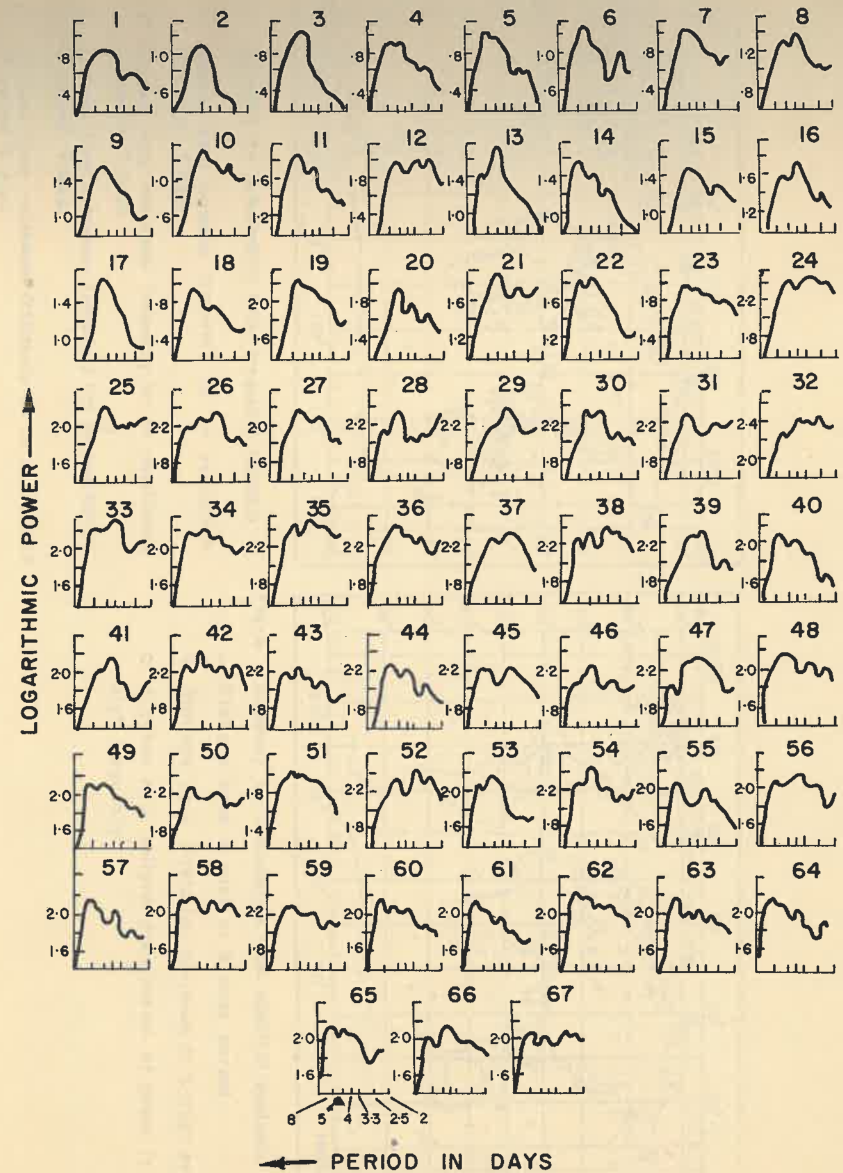

LOGARITHMIC POWER
PERIOD IN DAYS

FIG. 1

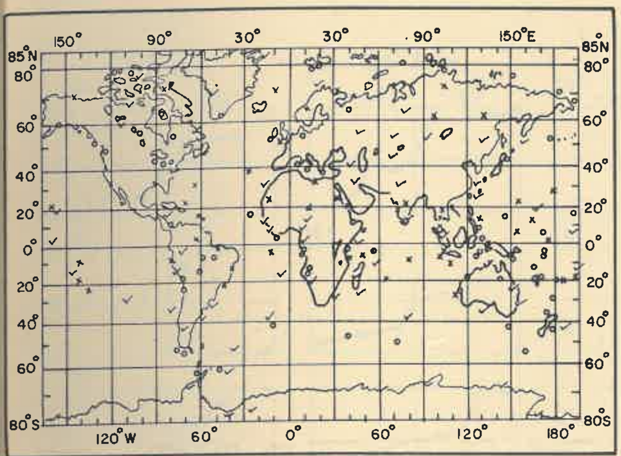


Fig-3: Summary of information from frequency analysis.

- o Stations have maximum frequency for an oscillation of period 2 days.
- ✓ Stations have maximum frequency for an oscillation of period 3 days
- X Stations have maximum frequency for an oscillation of period 4 days.
- □ Stations have maximum frequency for an oscillation of period 5 days.

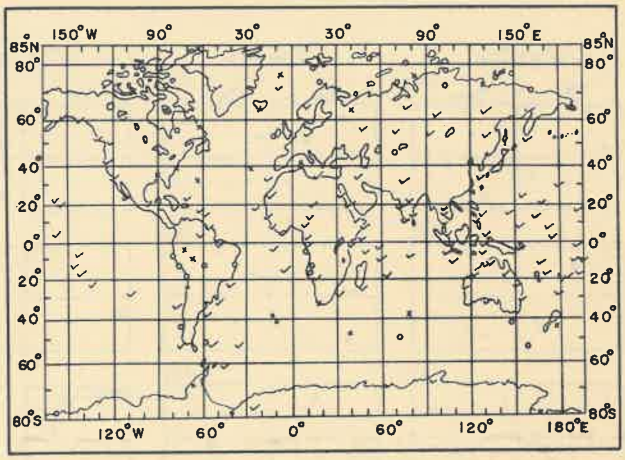


Fig-4 Summary of information from spectral analysis.

- ✓ Stations have a peak at 5-days period.
- X Stations have a relative minimum at 5-days period.
- O Stations have uniform distribution of power in the high frequency.

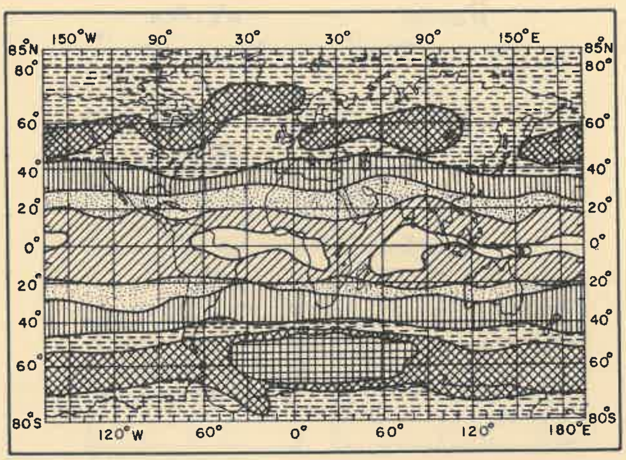
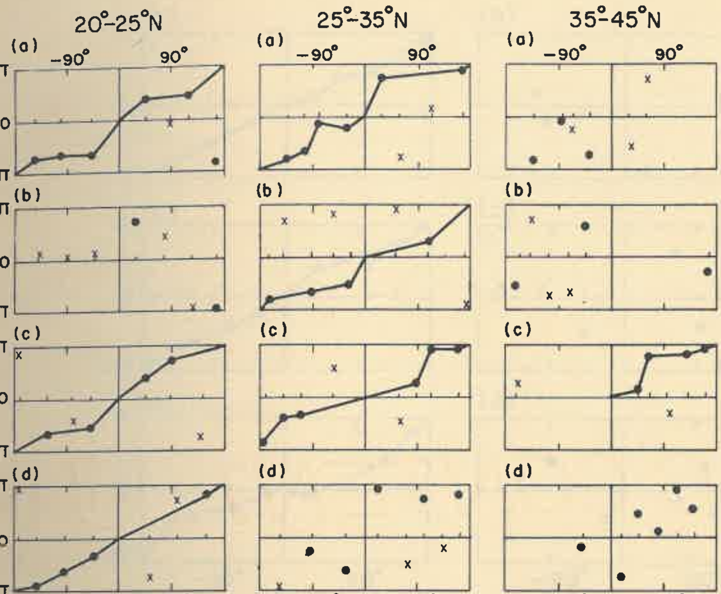


Fig.-5: Logarthmic spectral amplitude distribution over the earth.

- 0·4 or less.
- 0·4 to 0·8
- 0·8 to 1·4
- 1·4 to 2·0
- 2·0 to 2·4
- 2·4 to 2·6
- above 2·6



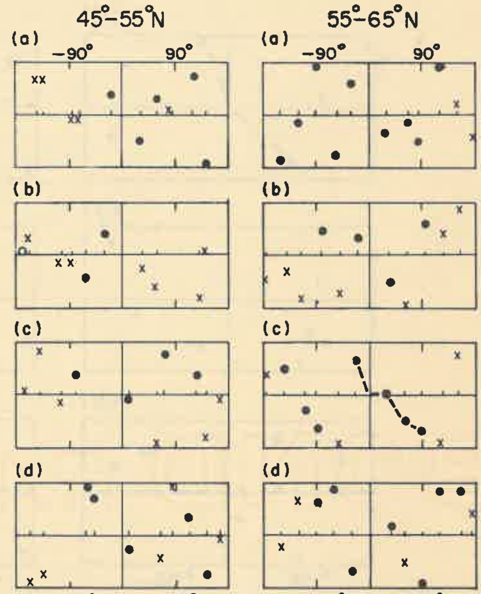
(a) Asswan 23°58'N 32°47'E
(b) Taipei 25°02'N 121°31'E
(c) Lihue 21°59'N 159°21'W
(d) Bahamas 21°30'N 71°00'W

Ref. —

(a) Misurata 32°35'N 15°06'E
(b) Chejudo 33°31'N 126°32'E
(c) Midway 28°13 N 177°22'W
(d) Meridian 32°20'N 88°45'W

(a) Ajaccio 41°55'N 8°48'E
(b) Tasty 44°48'N 69°07'E
(c) Eureka 40°48'N 124°10'W
(d) Washington 38°51'N 77°02'W

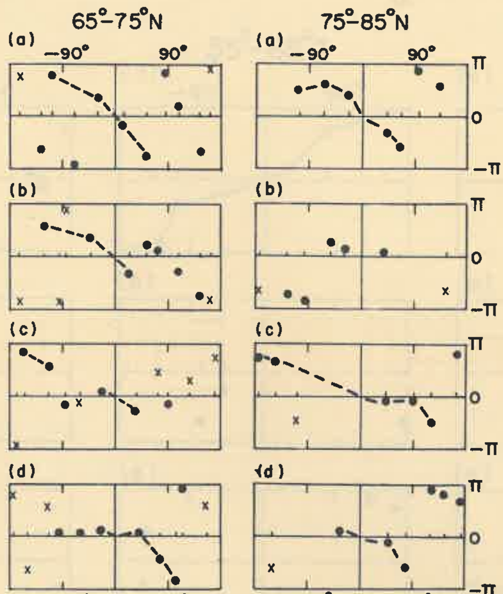
Fig.-6



(a) Hamburg 53°38'N 10°00'E
(b) Abakan 53°45'N 91°24'E
(c) Annette 55°02'N 131°34'W
(d) Whale River 55°17'N 77°46'W

(a) Nordoyan 64°48 N 10°33'E
(b) Baikit 61°40'N 96°22'E
(c) B.Providenia 64°26'N 173°14'W
(d) Coral Harbour 64°12'N 83°22'W

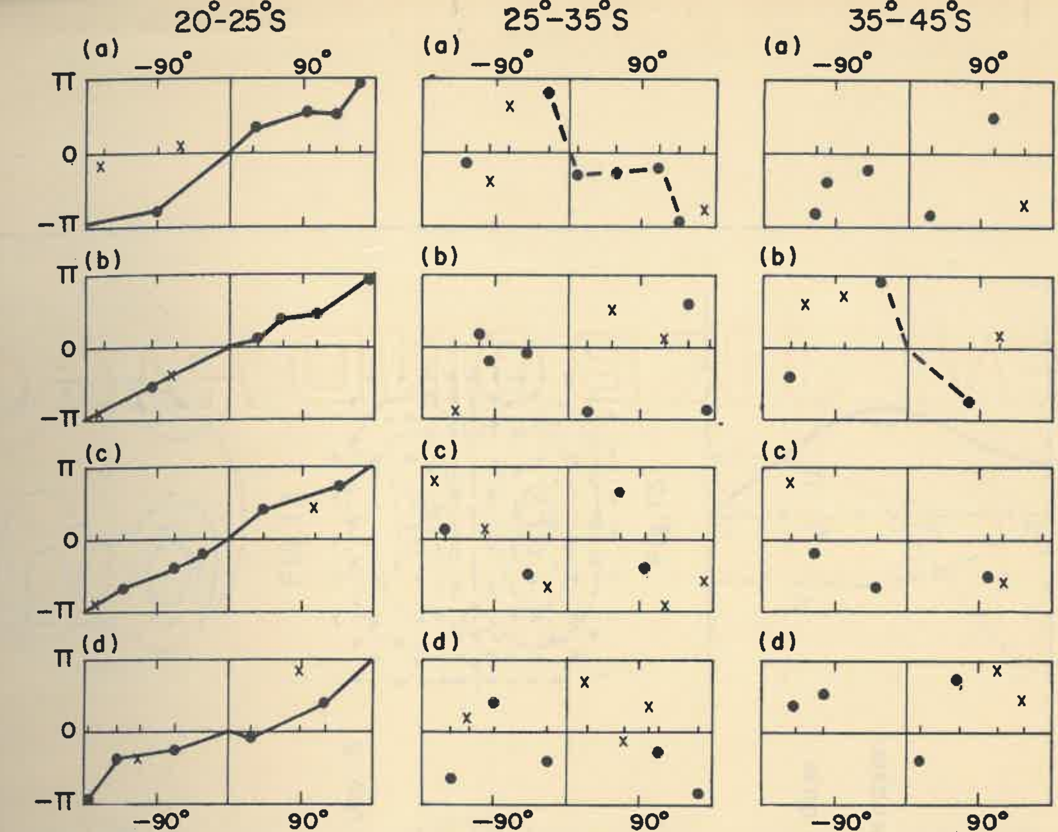
Fig.-7



(a) Bjornaya 74°31'N 19°01'E
(b) Khatanga 71°59'N 102°28'E
(c) O.Wrangel 70°58'N 178°32'W
(d) Arctic Bay 73°00'N 85°18'W

(a) Isf. Radio 78°04'N 13°38'E
(b) Myscheiyuskin 77°43'N 104°17'E
(c) Isachsen 78°47'N 103°32'W
(d) Alert 82°30'N 62°20'W

Fig.-8



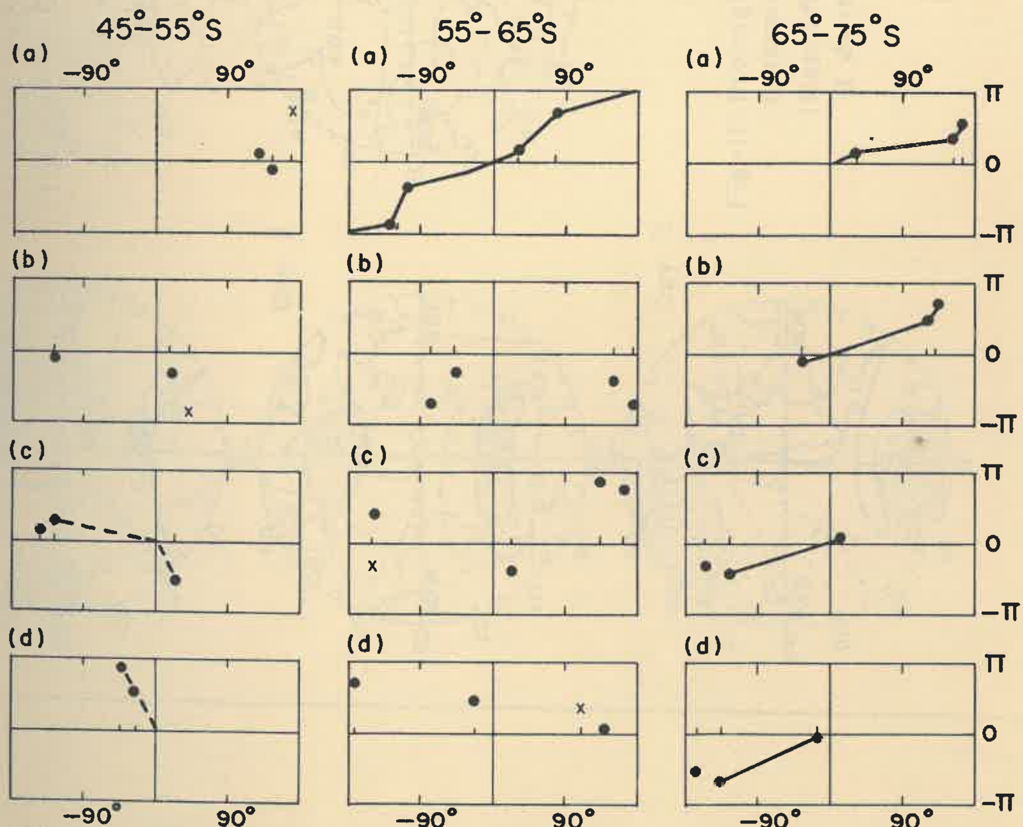
Ref :-

(a) S. Africa 22°30'S 15°00'E
(b) Carnarvon 24°53'S 113°39'W
(c) Ono-i-Lau 20°40'S 178°43'W
(d) Antofagasta 23°28'S 70°26'W

(a) Cape Town 33°58'S 18°36'E
(b) Cook 33°37'S 130°24'E
(c) Raoul 29°15'S 177°55'W
(d) Is. de Fern. 33°37'S 78°52'W

(d) Marion 46°53'S 37°52'E
(b) P.a. France. 49°20'S 70°13'E
(c) Chatham 43°53'S 176°53'W
(d) Is. Guafo 43°34'S 74°50'W

Fig. 9.



(a) Macquarie 54°30'S 158°37'E
(b) I. Evangelistas 52°23'S 75°07'W
(c) Stanley 51°42'S 57°52'W
(d) Grytviken 54°16'S 36°30'W

(a) Mawson 67°36'S 62°53'E
(b) D. de. Urville 66°40'S 140°01'E
(c) Horse Shoe 67°48'S 67°19'W
(d) Signey 60°43'S 45°36'W

(a) Macmurdo 77°50'S 166°36'E
(b) Little America 78°14'S 161°55'W
(c) Ellsworth 77°43'S 41°07'W
(d) Halley Bay 75°31'S 26°37'W

Fig. 10.