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

I. FREQUENCY ANALYSIS

by

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I. Frequency Analysis

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Summary

At the end of the last century, Eliot (1895) had drawn attention to a short-period barometric oscillation over the Indian monsoon region. The oscillations were reported to have a five day mean periodicity. The present report, based on the data for the IGY period, makes a comprehensive study of these oscillations on a global scale. The frequency analysis shows that these oscillations are not confined to India or the tropics alone, but are noticed at high latitude stations also. A plot of the mean amplitude shows two humps at about 60 degrees of latitude in both the hemispheres.

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1. Introduction

1.1 In recent years, quite a bit of attention has been drawn to the problem of atmospheric oscillations. It is understandable that the complicated solutions of the hydrodynamical problems involved in the weather prognostication will be much simplified if any of the parameters involved does have a periodic recurrence. However except for the annual cycle and the diurnal/semidiurnal tides, the atmospheric processes have hardly been put to show any strict periodicity. The weather watchers and the statisticians have been always on the look for any periodicity, that might be 'hidden' in the atmospheric phenomena. Summarising the weather regularity in the earlier part of the century, Haurwitz (1937) commented that 'only a period of 19 days seems to be missing in the region of periodicities between 2 and 37 days.' Recently, a number of investigations have been reported on the atmospheric periodicity. Apart from the tidal phenomena, summarised by Chapman et al (1970), atmospheric periodicities ranging from 4 days to twenty six months have been reported in the literature. (Yanai & Maruyana 1966, Reed 1966, Maruyama 1968, Wallace and Kousky 1968, Wallace & Chang 1969, Nitta 1970, Julian & Madden 1971 etc.).

1.2 By the end of last century, Eliot (1895) had reported a simultaneous pressure change over the Indian area and had brought attention to a short period barometric oscillation. Frolow (1942) and Palmer et al (1956) had also reported the same phenomenon in other parts of the tropics. These papers demonstrated that the rise and fall of surface pressure for the tropical stations was simultaneous and somewhat periodic - with a mean periodicity around 5 days.

... 3

1.3 A preliminary study on the subject was undertaken by us, (Ananthakrishnan and Misra 1970 a) wherein we had tried to investigate the possible influence of the solar phenomena on the rise and fall of pressure as reported earlier. The study was made for seven Indian stations for a 12-year period. The investigation did not yield any evidence of a probable solar control on the characteristics of the atmospheric pressure; but on the other hand it was observed that similar pressure tendency oscillations were also conspicuous at the subtropical stations (Ananthakrishnan and Misra 1970 b). Examination of data for a few Soviet and Japanese stations also demonstrated evidence of similar oscillations at these stations (Ananthakrishnan and Misra 1970 c). Around the same time, Wallace and Chang (1969) reported that the 5-day fluctuations of the atmospheric pressure at the equatorial latitudes result from a westward propagating pressure wave of the same period and having a zonal wavelength equal to the circumference of the earth. About the middle of 1970, we studied the behaviour of the pressure tendency oscillations in fuller details as regards their latitudinal extent, the amplitude variation, the phase progression etc. The present report, divided into three parts, intends to submit the results of this investigation. In the first part (the present one), we will give the frequency analysis of the tendency oscillations; the second part will contain the results of the application of spectral methods to the data in the tropical stations and in the third part we will take up a closer investigation of the data in the extra-tropics.

1.4 The 24-hour pressure tendency is determined by subtracting the previous day's pressure from today's pressure. This parameter (plotted as

... 4

$P_{24} P_{24}$ by the India Met. Dept.) has a variation between one thousandth to about one hundredth of the mean pressure value, depending upon the impending weather situation. The tendency can be either positive or negative and in stable cases, zero is also an accepted value. It is an observed fact that any epoch of the tendency does not continue for a long period. For example, if $P_{24} P_{24}$ is negative today, one can always predict that the negative spell will cease after a few days and a positive epoch may start. This is because of the peculiar atmospheric property to conserve the pressure distribution on the earth's surface. The positive spell of the pressure tendency in combination with a following negative spell will constitute what is termed as the pressure tendency oscillation in this report. Thus, a five day period of this oscillation may comprise of one-day rise with a four-day fall, two-day rise and a three-day fall or also a four-day rise and a one-day fall.

2. Data

2.1 The period 1957 July to 1958 December comprising the IGY period offers a set of homogeneous and reliable data for undertaking a global study. The surface and the upper-air data for thousands of weather observing stations around the globe have been carefully collected and condensed into microcard form - by the initiative of WMO. A full set of cards is available with the Office of the Deputy Director General of Climatology, Poona. The cards can be read with the help of a microcard-reader and the relevant material can be easily extracted. The surface data have been also plotted as weather charts by the Deutscher Wetterdienst, Hamburg, Germany, (1963). The isobaric analysis is done by the Central Institute of Forecasting, Moscow, USSR (1958).

2.2 To begin with, a decision has to be taken on the choice of stations. Since Wallace et al (1969) had already reported a zonal propagation of the pressure wave in the tropics, it was decided that it would be more profitable if the stations are selected uniformly spaced in longitude. If the stations in the higher zonal belts are chosen along or around the same longitude, any meridional propagation can also be investigated. Thus the process would be to have a choice of a suitable number of meridional half circles and to group the stations around them for each zonal belt.

2.3 The width of the zonal belt is also a consideration. For the present study, we have chosen the width to be five degrees of latitude on the tropical region 25°N-25°S and ten degrees latitude beyond. So, the zonal belts are twenty-two viz. $0^\circ - 5^\circ$NS; $5^\circ - 10^\circ$NS; $10^\circ - 15^\circ$NS; $15^\circ - 20^\circ$NS; $20^\circ - 25^\circ$NS; 25°-35°NS; $35^\circ - 45^\circ$NS; 45°-55°NS; $55^\circ - 65^\circ$NS; $65^\circ - 75^\circ$NS; $75^\circ - 85^\circ$NS. No consistently reporting stations were available in the last named zonal belt i.e. $75^\circ - 85^\circ$S. Hence we have twenty one zonal belts utilised in the study. The choice of the meridional half circles is arbitrary, however the choice could be so made that the particular longitude line has many weather reporting stations around it. A set of such lines with a uniform spacing is difficult to be obtained. A spacing of 30 in longitude was decided as a not-too-close interval. This also truncates the data valume to a reasonable size. The meridional half circles selected were 10°E, 40°E, 70°E, 100°E, 130°E, 160°E, 170°W, 140°W, 110°W, 80°W, 50°W

... 6

and 20°W. Whenever no station was available around the particular line, which normally is the case in the ocean area, the nearest station to the east was included in the group.

2.4 The IGY surface pressure data are recorded after being reduced to sea level. It is well known that the reduction of the surface pressure to that of the sea level by the hydrostatic relationship allows errors when the station level is at a high altitude. To reduce the pressure reduction errors to the minimum, it is necessary that the station be at a low level. The choice of stations has been done with this as a criterion. For some meridian lines, going through the continental regions one has no choice but to be satisfied with a high altitude station. From among these, the stations reporting for the full period 1 July 1957 to 31 Dec 1958 have only been chosen. This constitutes the data length of 549 days. Daily 12 GMT surface pressure values for 181 stations constitute the data for the study. the geographical locations of the stations are given in fig.1. The WMO index numbers for stations in different zonal belts are tabulated in table I. The stations are arranged in increasing longitude to east in respective belts.

2.5 A few stations amongst the final selection do sometimes have observations missing. The missing data were interpolated with the help of IGY surface maps prepared by the Soviet meteorologists. The interpolation from this global map prepared on comparatively smaller scale could amount to some error. A neighbouring reporting station plotted on the surface charts prepared by the Deutscher Wetterdienst helped to sort out the mistake in many cases.

3. Computation method and Results

3.1 The 24-hour pressure tendency is obtained from the surface pressure data by taking the successive difference on the daily values. As we shall see later, this works as first difference filter and takes away the low frequency trend from the series. One data point is lost in the process and the data length is reduced to 548 days.

3.2 The next process is to scan for the pressure tendency oscillations. As we have put in the first section, the process is to sort out the positive and the negative epochs and to find out their recurrence. From the numerous methods through which this is possible, scanning through the consecutive values by means of a computer appears to be the most convenient. The end of the first negative spell is taken as the starting point of the scan. The scanning is done for a complete cycle at a time. For a cycle, this comprises of a count of days constituting the positive spell and a subsequent count for the negative spell till the new positive value is encountered. When a cipher appears as a data point, it is counted in the spell in which the successive non-zero value goes. Thus, if the value previous to a zero tendency is positive and the subsequent one is negative, the zero value is taken as the first count in the negative spell.

3.3 The oscillation of various periodicities are stored in a 12 x 12 matrix form, where the row number gives the spell of negative pressure tendency of a cycle - the column number giving the corresponding spell of positive pressure tendency. Thus the first element on the matrix, after the full scan is over, represents the total number of oscillations, that are constituted

... 8

by one day positive and a successive one day negative value of pressure tendency. The last element represents the number for a 12-day rise and a 12-day fall.

3.4 The magnitudes of pressure rise and fall were also obtained in a similar manner. For this, the magnitude of pressure rise and fall during the period of a positive or negative spell are first noted and are tabulated against the number of days which has given rise to the sum. The magnitude is rounded to the nearest .5 mb and the total magnitude arising from a given period of spell is computed. Since the maximum period considered for a spell is 12 days, we are left with two tables giving the total number of occasions, in which a 1, 2 or 3 day rise/fall of Δp have occurred and the total amount of their contribution. A division by the number of cases gives an average magnitude during a spell of pressure rise or fall in a period.

3.5 In Table II, we are giving the frequency table for spells of pressure rise and fall - comprising of sixteen elements in 4 x 4 matrix form, available at the top left corner of the original 12 x 12 matrix. The elements in the higher order rows and columns assume non-significant values, the total 'intensity' being concentrated in low values of row and column. In fact, the first sixteen elements, as represented, account for more than ninety percent of the total number of oscillations in most of the cases. For each station, the average magnitude of pressure fall and rise for spells of one day, two days, three days and four days are tabulated next. The order is kept the same as in Table I, the station identification being made complete as regards latitude, longitude and height in all except five

... 9

cases, for which reference is not available in the WMO station reference index, (1971).

3.6 The fact that the higher order elements of the frequency matrix are blank or non-significant, brings a noticeable point that the tendency oscillations are essentially short periodic. The pattern does not change as we go higher in latitude. We get a better idea of this when we group the oscillations according to their periodicity. This is obtained by taking a sum of $\sum a_{ij}$ where $i+j$ can be held to be 2, 3, 4, etc., which are the periodicities of the oscillations. By so doing, we ignore the component spells of the oscillation and full cycle of characteristic periods are brought into picture. In this case, one finds that very little is left behind as we cross 6 days' periodicity.

3.7 The frequency of occurrence for different periods are plotted against the periodicity in fig.2. It was seen earlier from the frequency tables of Table II, that the first element was higher than the others in many cases. However in the plot of fig. 2, the peak for the number of oscillations shows a shift towards the 3 or 4 days periodicity. From the total number of cases about fifty percent of the stations show a peak number at the period of 3 days, about thirtyfive percent give the peak at 4 days and ten percent at two days. The rest five percent have a maximum at the five days' periodicity. There is not much differential property as regards longitude and latitude in this particular behaviour. The three day oscillations however show a trend to be more frequent at the higher latitudes compared to the lower ones.

3.8 The average period of oscillation was then computed with a division of the total number of days with the total number of oscillations at each station. The number of pressure tendency oscillations for the data-length of 548 days gives a fluctuation between 120 to 150. The variation is more random than related to any geographical or other distribution. The average periodicities computed for all the stations are given in Table III. The same order for the stations as in table I is maintained for identification. It is seen from this table that a majority of the stations have an average periodicity within 4 and 5 days. Occasions with less than 4 or greater than 5, though present, are rare. As has been pointed out earlier, there is little geographical variation as regards the average period is concerned.

3.9 Table IV gives the average amplitude of the pressure tendency oscillations for various zonal belts. If the average period of the oscillation is taken to be 4 days, the ideal pattern would be a two-day rise followed by a two-day fall. Since such an ideal pattern is not observed (neither to be expected) we have taken into consideration the composite magnitude of two-day rise and two-day fall for computing the average amplitude. The mean between the magnitudes of pressure rise and fall in two days has been taken as the amplitude at any particular station. This has then been averaged out for each zonal belt. The amplitude has a steady rise from the equator towards the high latitudes having a peak around 60 in either hemisphere. Fig.3 gives a plot of the results tabulated in Table IV. The two humps around 60 on either side of the equator are clearly marked.

4. Conclusion

4.1 The study which is based purely on the observational data covering the globe shows that the pressure tendency oscillations as reported by Eliot are not confined to any particular region as he suggested. The trend for the twentyfour-hour pressure tendency values to have a mean periodicity of recurrence of the order of 4 days is a typical feature with the parameter itself. The amplitude of the oscillations, as observed by Eliot, assumes higher values with latitude progression, the peak at 60 being about ten times higher than the value of 1.5 mb at the equator.

4.2 Alaka (1963) referring to Eliot's oscillations, had called it a peculiar type of atmospheric tide. The previous investigators have assumed this oscillation to be stationary. As we shall see later, the oscillation results due to a westward propagating wave of the same periodicity and a characteristic wavelength equal to the zonal circle. Though no phase progression is observed in the meridional direction, there is an amplitude variation (fig.3) from which the meridional wavelength can be estimated to be 14,000 km. Details on this wave structure will be given in the third part of this report.

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... 13

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TABLE I

Index numbers of stations in different zonal belts covered in the study

Zonal belt.	N. Hemisphere	S. Hemisphere
0°-5°	64500, 62360, 96694, 91610, 91487, 80411, 65592	64503, 63820, 63980, 96253, 97724, 97760, 94085, 91700, 84377, 82191
5°-10°	65271, 63230, 43371, 48568, 98754, 91334, 91376, 78806, 81002, 61866	66160, 63894, 61967, 96745, 97900, 91724, 91920, 84452, 82861, 61900
10°-15°	65073, 63043, 43279, 48455, 98439, 91218, 91250, 78954, 61695	66305, 61974, 96995, 94120, 91543, 91811, 91943, 84691, 83248
15°-20°	61017, 62641, 43003, 48378, 98223, 91245, 91275, 91285, 76654, 78501, 78897, 08583	66422, 67073, 61988, 94203, 91558, 91822, 91942, 85406, 61901
20°-25°	62414, 42867, 46692, 91131, 91165, 76405, 78119, 60096	68110, 67197, 94300, 94374, 91699, 91948, 85442, 88748
25°-35°	62016, 40650, 41640, 47184, 91066, 72295, 72234, 78016, 08521	68816, 68588, 67198, 94649, 94791, 93997, 85469, 85585, 83995, 68902
35°-45°	07761, 17038, 38081, 72594, 72405, 72815, 08506,	68994, ~~94967,~~ ~~93988~~ 67199, 94967, 93986, 85834, 87692, 68906
45°-55°	10147, 27612, 28678, 29865, 31388, 32411, 70398, 72892, 72905, 74098, 03953	84998, 85930, 88890, 88903
55°-65°	01262, 22550, 23552, 23891, 24959, 25821, 25594, 70360, 72934, 72915, 04270, 04018	94986, 89592, 95502, 88959, 88925
65°-75°	01028, 01098, 20667, 20891, 21824, 21695, 21982, 70086, 72925, 72918, 04212, 01001	89664, 89162, 89043, 89022
75°-85°	01005, 20047, 20069, 20292, 21432, 74074, 74084, 04310	

TABLE II

Frequency Tables for spells of rise and fall of pressure in a 4 x 4 matrix form. The average magnitude of the rise and fall during a spell is also given. The first column is for the rise and the second for the fall

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North Hemisphere

0° – 5° N

Libreville 0° 27'N, 9° 25'E, 10 M

31	15	4	2	.8	.8
21	14	3	4	1.4	1.3
13	10	2	3	1.8	1.9
3	1	3	0	2.7	2.9

Mogadiscio 2° 02'N, 45° 21'E 9 M

31	21	7	1	1.0	1.0
22	13	6	2	1.8	1.7
10	8	7	2	2.3	2.2
6	1	1	0	2.7	2.0

Singapore 1° 21'N, 103° 54'E, 10 M

31	16	16	4	.8	.9
17	17	7	2	1.6	1.6
5	6	3	0	2.1	2.1
5	5	1	0	2.4	2.2

Tarawa 1° 21'N, 172° 55'E, 4 M

29	16	7	3	.9	.9
12	15	7	2	1.6	1.7
12	6	1	3	2.5	2.4
4	4	2	1	3.1	2.6

Fanning Is. 3° 54'N, 159° 23'W, 5 M

36	26	5	2	1.4	1.1
21	9	7	2	1.9	1.8
10	7	4	3	2.2	2.4
2	3	0	0	2.6	3.7

Stn.in Venezuela 4° 10'N, 61° 00'W (App.)

25	14	6	1	1.0	1.0
14	11	9	3	1.5	1.8
16	10	4	2	2.4	1.9
2	2	0	2	2.9	1.7

Tabou 4° 25'N, 7° 22'W, 10 M

35	9	7	2	.7	.7
22	13	10	4	1.5	1.5
10	6	5	2	2.2	1.7
3	1	2	0	2.3	2.0

5° – 10° N

Makurdi 7° 41'N, 8° 37'E, 97 M

35	17	4	5	1.1	.9
32	13	9	0	1.8	1.8
10	7	2	2	2.2	2.2
1	3	0	0	3.2	2.5

Galcayo 6° 51'N, 47° 16'E, 302 M

47	15	17	2	1.1	1.1
29	13	3	1	2.1	1.7
14	4	5	0	2.6	2.5
3	2	2	1	2.0	3.1

Trivandrum 8° 29'N, 76° 57'E, 64 M

33	17	11	4	.9	.8
20	12	9	2	1.5	1.5
7	9	5	0	1.9	2.4
1	6	0	0	2.8	1.9

Songkhla 7° 11'N, 100° 37'E, 10 M

30	20	11	0	.8	1.0
16	18	7	2	1.5	1.6
7	11	1	0	2.5	2.0
2	3	3	1	3.0	2.3

Davao 7° 04'N, 125° 36'E, 20 M

47	10	7	4	.9	1.0
13	14	7	2	1.9	1.7
8	8	4	0	2.4	2.0
3	2	2	2	3.2	3.0

Truk 7° 28'N, 151° 51'E, 8 M

14	14	6	6	.9	1.0
13	13	6	2	1.8	1.7
9	9	4	1	2.6	1.7
2	3	2	0	2.0	2.4

Table II (Contd.)

Majuro 7°05'N, 171°23'E, 3 M

16	10	7	5	.9	.8
21	11	7	3	2.1	1.9
9	8	3	0	2.3	1.7
2	4	0	1	2.8	2.6

Howard Afb. 8°58'N, 79°36'W, 9 M

17	12	10	5	1.0	.9
10	10	9	7	1.8	1.9
5	8	4	0	2.3	2.5
5	4	1	0	2.9	3.1

Atkinson 6°30'N, 58°15'W, 28 M

18	13	8	4	.8	.9
13	13	9	4	1.5	1.7
10	6	4	1	2.0	1.8
3	2	1	0	2.4	1.8

Bonthe 7°32'N, 12°30'W, 8 M

29	21	7	4	1.0	.9
18	20	7	1	1.5	1.5
5	6	3	0	2.1	2.0
4	1	3	1	1.7	2.6

10°-15° N

Potiskum 11°42'N, 11°02'E, 414 M

32	16	7	4	1.2	1.1
19	12	4	2	2.4	1.9
8	3	2	4	2.2	2.8
7	2	1	0	3.5	3.1

Assab 13°01'N, 42°43'E, 14 M

46	17	6	5	1.2	1.1
14	15	9	3	2.5	2.2
6	7	6	0	2.6	3.2
3	0	0	1	2.4	3.3

Madras 13°00'N, 80°11'E, 16 M

23	17	7	3	.8	.8
14	11	3	0	2.0	1.9
8	9	6	1	2.9	2.9
8	0	1	2	2.7	2.8

Bangkok 13°44'N, 100°30'E, 12 M

31	12	12	5	.9	1.0
12	16	6	4	2.1	2.1
6	5	5	1	2.7	2.6
4	2	2	0	3.5	3.7

Daet 14°07'N, 122°57'E, 11 M

20	8	11	2	1.0	1.0
12	10	4	5	2.1	2.5
2	9	6	1	3.5	3.0
1	4	2	1	4.4	4.8

Anderson Afb. 13°54'N, 144°55'E, 162 M

29	11	10	2	1.2	1.2
7	9	7	5	2.8	2.7
8	4	5	2	3.3	3.0
3	4	1	0	3.2	5.4

Eniwetok Atoll 11°21'N, 162°21'E, 6 M

14	12	7	2	1.0	.9
14	15	3	3	1.7	1.7
7	7	5	0	2.9	2.5
0	4	4	1	3.2	2.9

Seawell Airport 13°04'N, 59°29'W, 56 M

28	14	9	2	.9	.9
19	15	8	1	1.6	1.6
10	4	6	0	2.4	2.2
4	5	1	2	3.5	1.8

Zinguinchor 12°33'N, 16°16'W, 23 M

26	25	8	2	1.0	1.1
23	22	7	2	2.0	1.9
8	4	4	0	2.5	2.6
5	1	2	0	1.8	2.4

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Table II (contd.)

15° - 20° N

Bilma 18° 41'N, 12° 55'E, 357 M						Port Sudan 19° 35'N, 37° 13'E, 2M					
20	14	4	0	1.2	1.3	20	7	10	1	1.2	1.2
15	19	9	1	2.4	2.5	8	18	11	4	2.5	2.5
9	3	5	1	4.6	3.9	10	7	11	0	3.1	3.0
0	6	1	1	3.5	4.1	2	3	3	1	4.0	4.0

Bombay 19° 07'N, 72° 51'E, 4 M						Phitsanulok 16° 50'N, 100° 16'E, 50 M					
20	22	14	2	1.1	1.0	18	14	7	4	1.4	1.3
17	10	6	0	2.0	1.8	13	12	10	2	2.0	2.2
9	10	6	1	3.0	2.6	9	7	2	1	3.7	3.0
5	3	2	0	4.8	3.5	6	1	2	0	3.6	3.9

Ladag 18° 11'N, 120° 32'E, 5 M						Wake Is. 19° 17'N, 166° 39'E, 4 M					
21	12	13	4	1.2	1.3	17	4	6	2	0.9	1.1
15	10	4	4	3.1	2.4	13	18	5	1	2.0	2.2
8	4	4	2	4.2	4.3	5	9	10	5	3.7	2.8
2	5	2	3	3.5	3.5	1	3	4	0	3.8	2.8

Johnston Is. 16° 44'N, 169° 31'W, 5 M						Hilo 19° 43'N, 155° 04'W, 11 M					
18	14	5	5	1.0	1.2	14	11	3	1	1.0	0.8
7	12	11	3	2.3	1.8	15	13	2	5	2.1	1.5
9	7	5	1	2.4	2.7	9	9	6	4	3.2	3.5
4	8	2	0	4.3	2.6	2	4	5	2	4.1	3.9

Manzanillo 19° 03'N, 104° 20'W, 6 M						Swan Is. 17° 24'N, 83° 56'W, 11 M					
25	12	10	2	.9	1.0	13	11	4	5	1.4	1.3
15	15	10	3	2.1	2.1	15	16	7	1	2.5	2.3
8	8	4	2	3.1	2.7	5	7	6	4	4.0	3.2
5	2	1	1	3.2	2.8	4	4	1	0	3.2	5.1

Raizet 16° 16'N, 61° 13'W, 8 M						Mindelo 16° 53IN, 24° 59'W,					
22	8	7	0	.8	.9	23	18	9	2	1.0	1.0
8	18	8	0	2.2	1.9	21	18	7	5	1.9	1.9
8	9	8	1	2.9	2.5	5	6	4	0	2.6	2.8
4	3	3	1	4.0	3.0	3	1	0	1	2.2	3.7

22° - 25° N

Asswan 23° 58'N, 32° 47'E, 194 M						Nagpur 21° 06'N, 79° 03'E, 310 M					
24	10	10	3	1.1	1.3	21	7	12	4	1.1	1.2
15	14	5	4	3.2	2.1	14	15	7	3	2.6	2.5
3	11	1	3	3.8	4.0	6	5	4	2	3.2	3.5
4	0	3	3	4.6	4.9	4	4	1	0	5.7	4.2

... 4

Table II (Contd.)

Taipei 25° 02'N, 121° 31'E, 9 M

20	15	4	2	2.4	1.6
21	11	5	2	4.1	4.1
11	8	4	2	6.8	5.3
5	2	3	1	7.2	6.4

Pac.Is. 24° 00'N, 154° 00'E, (app.)

18	7	5	4	1.6	1.8
9	11	8	4	3.0	3.2
8	4	5	3	4.8	3.2
3	4	6	1	5.1	5.1

Lihue 21° 59'N, 159° 21'W, 45 M

10	7	7	1	1.1	1.0
9	14	13	3	2.4	2.5
6	6	13	0	3.4	3.9
4	2	2	4	3.3	4.1

Lapaz 24° 10'N, 110° 21'W, 18 M

28	16	7	2	1.5	1.4
11	11	8	1	2.8	2.8
8	8	7	2	3.8	3.3
4	4	4	0	4.5	4.0

Bahamas 21° 27'N, 71° 09'W, 10 M

11	9	3	3	1.0	.8
11	15	5	4	3.5	2.5
12	9	5	3	3.6	3.5
5	4	5	0	5.5	5.0

VillaCisneros 23° 42'N, 15° 52'W, 10 M

20	13	7	6	1.2	1.3
11	12	7	5	2.4	2.3
7	5	4	0	3.7	3.2
4	6	2	0	4.8	4.9

25° – 35° N

Misurata 32° 35'N, 15° 06'E, 6 M

14	9	9	4	3.0	2.2
10	13	5	3	5.8	4.6
8	10	7	2	6.0	7.3
3	5	1	1	8.2	8.2

Baghdad 33° 20'N, 44° 24'E, 34 M

26	19	6	1	2.4	2.4
14	11	7	1	5.4	4.0
9	9	4	0	6.7	5.8
5	2	3	1	11.6	5.8

Lahore 31° 33'N, 74° 20'E, 214 M

29	19	10	2	2.6	1.9
22	12	9	2	4.0	3.8
8	7	6	2	4.8	4.8
3	5	0	0	6.1	6.0

Chejudo 33° 31'N, 126° 32'E, 22 M

15	22	7	1	2.8	3.1
13	17	6	4	6.1	6.2
4	9	3	2	8.5	8.7
2	4	1	3	11.0	11.6

Midway Is. 28° 13'N, 177° 22'W, 13 M

10	10	7	5	2.0	2.7
14	16	6	2	5.4	4.5
10	0	5	5	4.1	5.5
1	5	5	1	8.4	8.3

Los Angeles 33° 56'N, 118° 23'W, 32 M

11	11	3	3	2.9	2.2
19	21	10	5	5.0	4.0
6	8	9	2	6.2	6.2
3	4	1	1	6.5	8.8

Meridian 32° 20'N, 88° 45'W, 94 M

11	12	2	3	3.4	3.6
10	18	7	3	8.0	6.8
5	5	6	1	7.6	7.5
1	5	3	1	13.7	11.5

Kindley field 32° 22'N, 64° 40'W, 5M

14	14	9	4	4.1	4.9
12	11	2	4	7.7	7.6
6	11	7	2	10.5	9.4
3	3	2	2	9.0	13.2

... 5

Table II (Contd.)

Funchal 32°38'N, 16°54'W, 110 M

12	12	0	2	1.9	1.6
13	10	8	1	5.4	4.7
4	5	7	5	6.6	6.2
2	3	4	0	9.4	9.0

35° – 45° N

Ajaccio 41°55'N, 8°48'E, 5 M

10	15	8	2	3.6	3.0
16	11	7	2	6.0	6.9
8	9	5	5	8.6	10.1
0	2	2	3	13.5	16.2

Trabzon 41°00'N, 39°43'E, 37 M

26	18	2	3	4.4	4.1
22	15	8	3	7.6	6.4
6	9	5	0	12.9	11.3
2	5	3	0	11.4	10.5

Tasty 44°48'N, 69°07'E, 200 M

28	17	5	3	5.0	3.8
16	16	3	2	9.9	8.2
11	9	4	2	13.0	11.5
1	7	2	1	15.5	15.1

Eureka 40°48'N, 124°10'W, 18 M

29	13	4	1	4.0	3.5
15	21	8	2	6.9	7.1
9	10	4	1	8.6	9.0
1	5	4	0	15.7	12.7

Washington 38°51'N, 77°02'W, 20M

15	22	4	0	6.9	7.2
19	17	7	4	11.7	11.0
5	9	5	4	14.7	15.3
4	2	3	0	18.5	15.7

Stephenville 48°32'N, 58°33'W, 13 M

26	27	9	4	9.2	11.3
12	15	6	2	16.1	14.1
9	7	5	1	17.0	18.4
2	5	1	1	23.2	23.4

Horta 38°32'N, 28°38'W, 61 M

14	11	7	2	3.3	4.0
8	11	8	2	7.6	6.8
5	7	5	3	10.2	8.9
4	3	0	1	16.2	16.3

45° – 55° N

Hamburg 53°38'N, 10°00'E, 16 M

26	13	6	3	5.9	6.5
11	11	7	4	11.1	10.5
7	6	5	1	17.2	16.7
1	7	1	3	22.7	23.7

Moscow 55°45'N, 37°34'E, 156 M

28	16	6	3	6.3	4.9
16	8	7	4	10.8	11.4
8	6	5	3	15.6	16.0
3	3	1	2	21.5	15.3

Petropavlovsk 54°50'N, 69°09'E, 136 M

27	19	7	2	5.0	6.1
16	14	7	4	13.8	10.4
6	11	2	3	18.2	18.4
3	3	1	0	19.3	16.3

Abakan 53°45'N, 91°24'E, 245 M

19	19	7	1	9.1	7.5
16	16	6	1	13.0	10.8
11	5	4	2	16.5	18.4
3	4	0	1	13.3	12.5

... 6

Table II (Contd.)

Norsky-sklad 52°21'N, 129°55'E 207 M

16	14	8	4	4.8	6.4
19	14	5	8	11.2	11.1
7	5	2	1	15.1	14.7
3	4	5	2	15.3	14.7

Echa 55°42'N, 155°38'E, 4 M

23	16	10	4	5.4	7.4
14	11	7	4	11.7	13.2
3	6	5	1	16.7	18.0
1	4	7	1	19.2	18.7

Annette Is. 55°02'N, 131°34'W, 34 M

34	17	8	4	6.9	6.9
17	9	5	3	10.9	12.2
8	8	3	2	15.8	17.3
4	3	0	1	18.8	14.4

Vancouver 49°11'N, 123°10W, 5 M

40	16	6	1	6.6	6.3
17	14	7	6	10.1	11.6
5	6	8	0	13.8	14.2
3	3	2	1	13.0	11.6

Great whale River 55°17'N, 77°46'W, 20 M

34	34	4	1	8.7	9.2
27	18	5	2	15.4	13.6
6	8	4	2	19.7	20.8
1	2	0	0	19.6	18.0

India House Lake 56°14'N, 64°44'W, 10 M

30	16	6	1	9.9	9.0
22	11	6	4	16.2	16.5
10	5	3	3	22.4	22.5
3	3	3	1	25.1	23.6

Valentia Obsy. 51°56'N, 10°15'W, 14 M

24	15	9	1	5.6	6.9
12	18	3	3	12.2	14.9
4	7	1	1	19.6	16.3
3	4	3	0	19.3	22.4

55° - 65°N

Nordoyan 64°48'N, 10°33'E, 36 M

27	6	8	4	5.8	7.5
16	16	3	0	14.9	13.0
6	8	5	1	16.1	18.4
3	2	2	1	18.0	22.8

Arkhangelsk 64°35'N, 40°30'E, 13 M

28	17	5	0	7.7	7.4
9	11	4	2	14.2	15.0
4	3	5	3	17.8	19.1
5	1	0	0	18.0	25.4

Tarkosale 64°55'N, 77°49'E, 27 M

23	15	9	1	8.6	7.9
15	18	4	5	13.4	13.5
9	7	3	1	16.8	17.0
2	4	0	2	19.8	18.5

Baikit 61°40'N, 96°22'E, 179 M

16	21	7	2	8.0	7.2
14	15	2	3	11.1	12.6
14	3	1	1	24.3	18.2
1	7	6	0	19.0	20.0

Yakutsk 62°05'N, 129°45'E, 103 M

18	13	11	4	5.3	6.2
10	16	10	2	10.1	9.9
3	4	3	4	13.3	14.8
4	3	1	0	18.4	14.0

Nayakhan 61°55'N, 158°59'E, 23 M

16	16	7	2	3.8	5.9
15	12	8	3	8.5	10.7
6	5	5	1	14.3	13.1
2	1	1	1	13.1	13.2

... 7

Table II (Contd.)

Bukhtaprovidenia 64° 26'N, 173° 14'W, 3 M

13	23	8	3	6.0	6.8
15	8	6	2	6.2	11.4
8	5	3	2	20.1	13.7
2	8	6	1	19.0	21.8

Cape St.Elias 59° 48'N, 144°36'E, 18 M

25	11	7	4	6.1	8.0
11	14	6	3	14.4	16.0
3	6	3	3	19.5	21.5
5	2	1	2	22.3	20.0

Fort Smith 60°01'N, 111° 58'W,203 M

32	20	4	1	7.4	8.1
16	18	5	4	14.5	14.1
5	6	1	2	17.3	21.1
0	5	2	0	20.9	23.7

Coral Harbour 64° 12'N, 83° 22'W, 59 M

16	12	7	4	6.3	6.8
11	10	4	3	11.3	13.5
5	6	4	2	17.6	17.8
4	3	2	0	25.2	19.6

Narssarsuaq 61° 11'N, 45° 25'W, 27 M

37	18	10	6	7.5	8.5
18	9	7	2	12.7	15.1
4	4	8	1	18.0	17.8
4	3	2	1	27.2	20.0

Keflavik 63° 59'N, 22° 38'W, 49 M

18	18	5	5	7.5	8.9
15	14	4	3	12.6	13.2
6	5	2	2	21.4	19.5
7	3	0	1	26.0	23.1

65° - 75° N

Bjornoya 74° 31'N, 19° 01'E, 14 M

27	23	9	3	6.0	6.4
16	8	4	1	11.4	14.7
5	6	6	0	17.3	15.1
5	3	11	1	22.8	21.2

Vardo 70° 22'N, 31° 06'W, 15 M

22	14	9	3	6.5	8.6
10	10	3	1	14.3	10.3
8	4	2	2	20.6	17.0
2	5	4	1	16.5	27.9

Ostrov Bely 73° 20'N, 70° 20'E, 6 M

18	12	7	4	6.8	7.8
12	10	5	3	10.0	10.7
6	5	4	1	18.4	18.0
3	6	3	3	26.0	19.9

Khatanga 71° 59'N, 102° 28'E, 24 M

16	16	10	2	6.5	7.4
8	15	6	1	10.6	10.7
6	3	5	3	14.9	17.3
3	2	2	3	26.4	24.8

Bukhta Tiksi 71° 35'N, 128° 55'E, 8 M

20	11	2	4	5.6	5.6
20	8	3	1	9.3	10.0
7	5	5	4	12.6	14.7
1	1	2	2	18.0	16.8

Ost.Chatyrekhstolbovoy 70° 38'N 162° 24'E, 6 M.

17	19	8	3	5.4	5.0
16	13	7	0	9.5	10.1
2	1	3	4	14.6	16.0
5	5	2	3	16.6	15.3

Ostrov Wrangel 70° 58'N, 178° 32'W, 3 M

22	11	7	2	5.3	5.3
10	9	10	3	10.1	10.1
4	7	5	2	14.3	15.9
3	2	3	2	18.0	15.6

Barter Is. 70° 07'N, 143° 40'W

21	12	7	1	5.0	5.5
18	17	5	4	10.5	10.5
6	4	2	1	16.3	18.3
3	7	2	1	19.3	16.8

... 8

Table II (Contd.)

Cambridge Bay 69° 07'N, 105° 01'W, 14 M

21	11	5	6	6.1	6.7
19	9	9	0	11.9	11.0
6	4	3	4	16.1	17.1
4	4	2	1	21.3	18.4

Arctic Bay 73° 00'N, 85° 18'W, 11 M

17	13	9	4	4.6	5.1
11	8	3	1	10.5	10.0
10	5	2	2	14.4	15.1
3	4	3	0	18.5	19.7

Umanak 70° 41'N, 52° 07'W, 7 M

35	18	8	3	7.7	7.2
25	13	5	1	14.2	15.1
4	4	1	2	16.5	17.1
1	2	7	1	22.6	21.3

Jan Mayen 71° 01'N, 8° 28'W, 39 M

31	17	9	2	6.8	4.9
13	12	7	1	14.6	15.8
13	7	2	1	14.4	20.2
4	2	0	1	22.8	18.5

75° – 85° N

Isfjord Radio 78° 04'N, 13° 38'E, 9 M

26	12	5	2	6.5	6.2
16	9	10	2	12.7	11.9
5	3	7	2	17.2	18.3
2	5	3	1	19.9	19.8

Bukhta Tikhaya 80° 19'N, 52° 48'E, 6 M

21	1[illegible]	11	4	4.5	4.5
12	7	4	1	9.0	12.3
9	5	1	3	16.8	12.9
2	1	2	2	21.0	21.2

Ostrov Vize 79° 30'N, 76° 59'E, 18 M

16	13	3	3	5.0	5.5
10	4	4	5	11.1	10.4
7	3	3	1	15.1	13.0
4	2	2	3	18.5	21.0

Mys-chalyuskin 77° 43'N, 104° 17'E, 6 M

18	11	5	4	4.7	4.4
11	9	5	4	11.2	11.2
5	2	2	0	14.8	16.5
4	2	1	1	18.9	20.5

Ostrov Kotelny 76° 00'N, 137°54'E, 10 M

24	14	6	4	5.7	5.4
17	9	7	3	11.1	11.0
4	3	2	1	14.5	13.5
3	3	0	1	19.2	18.9

Isachsen 78° 47'N, 103° 32 'W, 25 M

24	11	3	3	5.1	16.2
18	7	9	2	11.2	8.7
6	6	1	2	14.6	14.2
4	6	1	1	16.2	15.3

Alert 82° 32'N, 62° 20'W, 62 M

28	12	10	2	6.0	6.2
21	10	6	3	11.5	10.4
5	7	3	1	14.6	14.1
6	2	2	2	18.4	20.0

Nord 81° 36'N, 16° 40'W, 36 M

31	20	10	1	4.1	5.2
21	18	7	2	11.2	11.7
8	4	2	1	14.1	14.8
6	2	1	2	20.5	19.0

... 9

Table II (Contd.)

South Hemisphere

0° - 5° S

Mayumba 3° 25'S, 10° 39'E, 34 M

36	10	7	3	.9	.9
20	7	7	1	1.7	1.5
12	6	4	4	1.7	1.9
2	2	1	0	2.5	1.8

Mombasa 4 02'S, 39 37'E, 55 M

17	12	8	1	1.0	1.0
18	15	7	0	1.8	1.8
12	7	6	1	2.2	2.2
2	2	4	0	2.8	2.6

Mahe 4° 37'S, 55° 27'E, 1 M

13	12	7	5	1.0	.9
14	11	1	3	1.3	1.3
13	12	5	1	2.1	1.9
4	1	0	2	2.5	2.4

Bengkulu 3° 25'S, 102° 20'E, 16 M

45	19	12	6	1.3	1.2
15	18	8	2	1.7	1.7
9	8	1	1	2.6	2.4
1	1	0	0	2.9	3.2

Ambon 3° 42'S, 128° 05'E, 12 M

35	15	8	1	.9	.8
14	12	10	1	1.4	1.2
10	11	2	3	1.7	1.8
4	4	0	0	1.9	2.1

Kaimana 3° 40'S, 133° 45'E, 3 M

51	16	7	2	1.3	1.3
17	7	9	0	1.9	2.0
8	6	2	1	2.3	2.2
5	4	2	0	3.5	2.5

Rabaul 4° 13'S, 152° 11'E, 8 M

26	16	6	4	.7	.8
15	14	12	1	1.3	1.0
13	6	2	1	1.6	1.5
4	0	2	1	2.1	2.3

Fizi Is. 2° 30'S, 171° 30'W (app.)

19	10	3	2	.8	.8
20	13	6	3	1.5	1.4
7	10	4	0	1.4	1.8
2	2	1	0	3.0	1.1

Iquitos 3° 45'S, 73° 15'W, 126 M

35	10	11	0	1.3	1.4
15	8	7	6	2.5	2.6
10	9	2	3	3.8	3.1
3	4	0	2	4.8	4.1

Belem 1° 26'S, 48° 29'W, 24 M

14	6	5	6	.9	1.0
14	13	6	2	1.3	1.1
9	7	7	2	2.1	1.9
3	1	3	2	2.0	2.7

5° - 10° S

Luanda 8° 51'S, 13° 14'E, 70 M

45	18	13	2	1.1	1.1
22	11	9	3	1.6	1.8
11	4	4	0	2.3	2.4
3	1	0	0	3.2	2.0

Dar-es-salam 6° 53'S, 39° 12'E, 58 M

31	16	8	3	1.1	.9
12	14	7	3	1.8	1.7
17	6	4	2	2.5	2.3
3	2	2	0	2.6	2.9

Diego-garcia 7° 21'S, 72° 29'E, 2 M

22	12	10	4	.8	.9
14	13	5	3	1.2	1.2
12	8	4	2	1.8	1.8
2	4	0	0	2.1	1.7

Djakarta 6° 11'S, 106° 50'E, 8 M

35	17	16	7	1.0	1.1
15	15	7	3	1.6	1.9
5	9	3	1	2.0	2.0
4	1	2	1	2.4	2.5

... 10

Table II (Contd.)

Saumlaki 7°59'S, 131°18'E, 24 M

33	15	12	2	1.0	1.0
23	11	15	3	1.7	1.8
4	8	3	2	1.8	2.1
0	0	1	2	2.6	1.8

Nukunono 9°12'S, 171°55'W, 3 M

26	19	12	6	1.0	1.0
18	14	6	2	1.9	2.0
10	10	2	1	2.2	2.5
3	2	2	0	3.7	3.9

Taiohae 8°56'S, 140°05'W, 18 M

31	10	11	4	1.1	1.1
15	17	10	4	1.7	1.7
11	2	3	0	2.2	1.8
7	2	1	0	2.6	2.8

Chiclayo 6°47'S, 79°50'W, 37 M

34	16	9	4	1.2	1.3
20	10	4	2	2.0	1.7
9	10	3	3	2.4	2.2
4	2	1	0	3.0	2.8

C.do Araguaia 8°16'S, 49°17'W, 157 M

48	18	11	1	1.4	1.4
22	13	3	1	2.2	2.1
12	7	4	2	2.3	2.5
3	2	2	0	2.5	2.8

Ascension Is. 7°55'S, 14°25'W, 6 M

25	19	13	4	1.0	1.0
16	15	10	3	1.6	1.7
10	7	5	0	1.7	2.0
2	2	0	0	2.1	2.5

10° - 15°S

Lobito 12°22'S, 13°22'E, 3 M

47	21	13	1	1.2	1.0
22	12	6	2	1.3	1.9
12	3	0	4	2.3	2.5
3	0	1	0	2.6	2.8

Agalega 10°33'S, 56°45'E, 8 M

30	17	8	1	.8	.8
16	10	4	7	1.4	1.8
12	6	2	2	2.2	2.0
3	0	2	0	2.8	2.3

Christmas Is. 10°25'S, 105°40'E, 17 M

18	13	11	2	1.4	1.5
12	16	11	4	1.5	1.7
9	7	1	2	2.5	2.5
5	1	0	1	3.5	2.8

Darwin Airport 12°26'S, 130°52'E 6 M

31	16	7	1	.9	.8
20	11	4	4	1.5	1.7
13	12	3	2	2.3	1.9
0	4	3	1	3.0	2.9

Vanikoro 11°49'S, 66°47'E, 2 M

36	17	14	2	.9	1.0
17	8	8	3	1.7	1.7
3	6	3	0	2.3	2.6
5	2	1	0	2.5	3.0

Pukapuka 10°53'S, 165°49'W, 3 M

35	16	12	5	1.0	1.0
15	8	4	3	1.7	1.4
15	7	3	0	2.7	2.8
4	5	2	1	2.7	3.0

Takaroa 14°29'S, 145°05'W, 3 M

24	14	7	2	1.0	.8
23	15	8	2	1.7	1.9
11	6	4	1	3.1	2.5
4	1	1	1	2.2	3.5

Pisco 13°45'S, 76°17'W, 7 M

34	22	11	2	1.3	1.1
21	8	6	2	1.7	2.0
11	7	3	0	2.8	2.8
4	2	1	1	2.7	3.1

... 11

Table II (Contd.)

Salvador 12° 54'S, 38° 20'W, 13 M

29	5	9	2	1.0	1.0
18	14	6	4	2.5	2.2
12	6	1	3	2.9	2.5
6	1	0	2	3.1	3.3

15° - 20° S

Mocamedas 15° 12'S, 12° 09'E, 45 M

48	21	8	5	1.2	1.2
25	7	6	2	2.1	2.2
15	7	2	1	2.5	2.3
2	2	2	0	2.4	2.3

Maintirano 18° 03'S, 44° 02'E, 25 M

24	14	6	5	.9	1.0
16	9	8	2	1.8	1.9
14	9	3	3	3.1	2.9
4	2	1	1	3.4	3.2

Rodrigues Is. 19° 41'S, 63° 25'E, 59 M

15	15	6	3	1.4	1.3
11	15	6	3	1.8	2.2
7	6	7	3	3.1	4.6
5	4	2	0	4.4	4.6

Broome 17° 57'S, 122° 13'E, 9 M

25	7	6	4	1.5	1.3
14	9	14	3	2.1	2.0
9	11	2	0	3.0	3.2
2	3	3	0	2.8	2.8

Vila 17° 45'S, 168° 19'E, 20 M

6	8	11	4	.9	1.1
9	9	3	4	2.2	2.4
5	5	8	2	2.5	2.8
3	3	1	0	4.1	2.8

Niue 19° 02'S, 169° 55'W, 6 M

14	9	2	2	1.1	.9
10	8	5	3	2.5	2.4
6	10	1	1	4.5	3.2
2	4	1	2	4.8	5.4

Nikuneru 17° 33'S, 142° 40'W, 3 M

19	7	8	1	.8	.9
12	22	7	2	2.0	2.2
2	6	5	1	3.7	2.9
33	2	1	3	3.9	3.5

Arica 18° 22'S, 70° 21'W, 35 M

55	23	9	5	1.7	2.1
21	17	4	1	2.6	2.4
11	3	2	1	4.1	3.3
5	3	1	0	4.8	3.5

St.Helena Is. 15° 58'S, 5° 42'W, 6M

30	14	6	5	1.2	1.2
22	11	6	5	1.9	1.9
6	10	3	0	2.3	2.3
4	0	2	1	3.1	3.5

20 - 25 S

Stn.in S.Africa 22 30'E, 15 00'E (app.)

31	21	11	5	1.7	1.7
23	14	7	3	2.4	3.1
7	7	2	3	4.5	3.1
6	1	0	0	5.2	4.5

Fort Dauhin 25 02'S, 46 57'E, 8 M

17	11	4	4	2.8	2.3
15	14	8	4	5.2	4.1
6	4	9	4	5.7	6.7
2	4	4	1	7.1	6.9

... 12

Table II (Contd.)

Camarvon 24° 53'S, 113° 19'E, 4 M

10	7	7	1	2.3	1.9
13	13	9	1	3.4	3.4
10	14	4	2	5.7	5.0
6	5	5	0	7.9	6.4

Rockhampton 23° 23'S, 150° 29'E, 14 M

14	10	3	6	1.6	1.6
16	11	8	2	3.4	3.5
10	4	7	1	5.8	5.5
1	2	2	3	6.7	7.6

Onoilau 20° 40'S, 178° 43'W, 28 M

12	6	6	3	1.1	1.1
10	11	3	6	2.5	2.9
5	10	3	2	4.5	3.9
4	3	2	0	5.7	5.2

Rikitea 23° 07'S, 134° 58'W, 3 M

13	6	7	3	1.3	2.1
11	8	8	5	3.3	3.7
11	3	7	3	5.2	5.0
2	3	0	1	8.5	7.5

Antofagasta 23° 28'S, 70° 26'W, 122 M

49	20	6	3	1.5	1.6
17	15	7	6	2.8	2.6
9	2	1	1	3.2	3.2
4	5	2	0	4.6	3.8

Rio-de-Janeiro 22° 54'S, 43° 10'W 26 M

25	11	4	0	2.8	2.3
9	16	11	1	5.3	5.3
8	10	3	0	7.4	6.9
1	5	3	1	8.8	7.8

25° - 35° S

Cape Town 33° 58'S, 18° 36'E, 49 M

37	11	9	0	3.9	3.6
19	20	7	2	9.0	7.9
12	6	4	2	9.9	9.8
3	4	3	1	13.7	10.6

Durban 29° 58'S, 30° 57'E, 14 M

30	24	8	2	5.2	6.2
22	21	5	2	10.9	9.4
9	8	6	1	10.7	11.4
2	7	1	0	13.8	15.8

Noville Amsterdem 37° 50'S, 77°34'E, 20 M

29	15	7	3	5.2	5.3
19	14	5	3	11.0	10.7
9	2	3	3	16.2	12.3
4	4	4	0	16.8	18.5

Cook 33° 37'S, 130° 24'E, 124 M

30	13	7	3	3.8	4.6
18	8	8	1	9.2	8.4
4	7	5	3	12.4	10.7
2	66	4	2	11.8	13.1

Coffs Harbour 30° 18'S, 153° 08'E, 21 M

13	12	5	5	4.0	3.7
13	8	5	3	7.4	8.4
6	8	4	1	12.0	9.6
3	4	1	0	11.2	12.5

Raoul Is. 29° 15'S, 177° 55'W, 49 M

9	7	6	1	4.6	3.7
14	11	7	3	6.4	5.9
1	6	2	2	9.0	10.4
0	2	5	0	12.8	9.2

Isla de Pascua 27° 09'S, 109° 27'W, 41 M

27	13	8	4	3.0	3.2
15	11	7	3	4.8	4.7
7	0	3	0	6.9	7.0
2	1	3	2	9.7	6.2

Isla de Fernandez 33° 37'S, 78° 52'W, 6 M

25	16	7	4	3.4	4.3
21	10	5	8	6.1	7.1
4	8	2	1	9.3	7.5
3	4	3	1	12.3	8.1

... 13

Table II (Contd.)

Rio Grande 32° 02'S, 52° 06'N, 3 M

19	16	1	1	4.9	4.5
23	16	9	3	8.5	8.7
5	5	2	1	13.8	8.7
2	5	2	1	13.8	14.6

Tristan da Kunha 37° 03'S, 12° 19'W, 23 M

29	19	7	3	6.4	5.7
13	17	4	3	10.6	11.4
5	4	3	2	15.6	12.3
4	5	1	0	15.4	17.4

35° - 45° S

Marion Is. 46° 53'S, 37° 52'E, 26 M

52	20	10	3	11.4	11.7
23	16	4	3	19.5	20.0
10	3	5	2	26.7	24.7
3	3	1	0	22.9	24.6

Port-aux-Francais 49° 20'S, 70° 13'E 14 M

50	22	13	7	11.2	12.0
21	12	1	4	17.4	17.9
6	3	3	0	24.8	24.8
0	1	2	1	24.8	27.3

Cape Bruni 43° 30'S, 147° 09'E, 88 M

23	14	9	7	8.2	8.3
16	9	2	1	14.0	13.0
8	8	5	3	18.9	18.3
5	1	1	3	21.8	25.0

Chatham Is. 43° 58'S, 176° 33'W, 49 M

20	14	4	4	6.8	6.6
16	13	5	5	13.3	13.1
5	6	2	3	18.4	17.4
5	3	1	1	19.9	19.2

Isla Guafo 43° 34'S, 74° 50'W, 140 M

21	13	4	0	7.2	8.2
20	11	10	3	10.9	10.4
9	6	2	1	14.7	14.2
4	6	2	1	17.6	16.7

Mardel Plata 37° 56'S, 57° 15'W, 19 M

25	15	4	1	5.1	5.4
25	15	4	2	9.8	8.4
8	8	5	1	14.6	13.2
3	4	3	2	20.3	15.5

Gough Is. 40° 19'S, 9° 54'W, 7 M

41	17	7	2	8.6	9.2
20	15	5	3	15.5	13.7
15	6	1	2	19.1	18.5
1	3	1	0	21.2	23.1

45° - 55° S

Macquarie Is. 54° 30'S, 158° 57'E, 6 M

36	17	5	3	9.9	10.9
17	14	3	0	20.1	16.6
8	3	5	2	24.4	22.6
5	5	1	1	32.0	30.7

I.Evangelistas 52° 23'S, 75° 07'W, 58 M

35	14	7	0	9.1	9.3
15	9	8	4	16.9	18.1
9	8	0	4	21.1	19.8
5	1	1	1	29.2	23.3

Stanley Is. 51° 42'S, 57° 42'W, 53 M

40	14	10	3	9.3	9.0
19	14	4	2	15.2	16.6
9	8	1	2	18.5	22.0
4	1	1	2	32.8	29.6

Grytviken 54° 16'S, 36° 30'W, 2 M

31	23	8	2	9.9	10.7
18	10	7	5	17.9	20.1
11	5	1	0	27.1	20.9
5	6	2	0	27.1	27.5

... 14

Table II (Contd.)

55° - 65° S

Mawson 67° 36'S, 62° 53'E, 14 M

22	27	10	4	6.5	6.7
20	11	44	2	11.0	12.5
6	9	4	4	16.3	16.4
1	2	0	0	17.0	21.0

Mirny 66° 33'S, 93° 01'E, 30 M

39	22	13	2	7.0	8.2
21	19	9	3	11.9	11.7
10	2	3	0	13.2	17.8
1	2	0	0	15.4	5.7

Dumont-de-Urville 66° 40'S, 140° 01'E, 40 M

27	16	5	6	5.8	7.2
27	22	5	2	14.1	11.8
6	4	2	0	17.0	14.2
3	5	2	1	20.3	19.0

Horse shoe Is. 67° 48'S, 67° 19'W, 9 M

37	16	7	5	8.5	7.2
18	10	4	6	13.6	14.8
6	7	0	0	15.3	17.3
3	5	1	1	19.6	18.8

Signy Is. 60° 43'S, 45° 36'W, 7 M

37	21	10	6	7.9	8.8
26	20	3	2	15.7	15.6
7	2	1	1	19.3	16.5
4	2	1	1	21.2	23.0

65 - 75 S

NAFMc-Murdo 77° 50'S, 166° 36'E, 45 M

29	19	5	5	5.9	6.1
18	25	4	1	13.5	11.0
7	7	4	0	14.3	15.8
3	3	0	0	17.0	22.5

Little America 78° 14'S, 161° 55'W 45 M

31	15	4	4	7.3	8.0
17	14	8	1	14.3	13.5
8	7	4	1	22.2	18.7
3	4	2	1	22.9	23.0

Ellsworth Station 77° 43'S, 41° 07'W, 43 M

27	25	7	1	6.8	7.6
15	21	2	3	12.9	13.1
6	8	1	3	17.4	14.8
7	2	3	2	17.8	17.0

Halley Bay 75° 31'S, 26° 37'W, 30 M

19	24	6	0	5.1	4.6
21	17	6	3	11.7	11.5
9	6	3	0	17.4	17.1
4	3	1	1	18.7	19.2

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TABLE III

Mean periods (in days) of the oscillation in pressure tendencies for the stations given in Table I.

Zonal belt	N.Hemisphere	S.Hemisphere
0° - 5°	4.0, 3.8, 3.9, 4.1, 3.8, 4.2, 3.9	4.1, 4.3, 4.6, 3.6, 3.9, 3.7 4.1, 4.6, 4.1, 4.8
5° - 10°	3.7, 3.5, 3.9, 3.9, 3.9, 4.0, 4.5, 4.5, 4.5, 4.0	3.6, 3.9, 4.3, 3.8, 3.9, 4.0, 4.0, 3.9, 3.5, 4.0
10° - 15°	4.1, 3.7, 4.3, 4.1, 4.7, 4.5, 4.8, 4.1, 4.3	3.5, 4.2, 4.6, 4.4, 3.6, 5.4, 5.1, 4.7, 4.0
15° - 20°	4.5, 4.1, 4.3, 4.4, 4.4, 4.7, 4.5, 4.7, 4.2, 4.6, 4.5, 4.1	3.5, 4.2, 4.6, 4.4, 5.4, 5.1, 4.7, 4.4, 4.0
20° - 25°	4.4, 4.5, 4.3, 4.8, 4.9, 4.2 4.8, 4.5	3.8, 4.5, 4.7, 4.7, 5.1, 5.0, 3.6, 4.5
25° - 35°	4.7, 4.2, 3.9, 4.4, 4.8, 4.5, 4.9, 4.6, 5.1	3.8, 3.7, 4.1, 4.3, 4.9, 5.5, 4.4, 4.2, 4.4, 4.2
35° - 45°	4.7, 4.1, 4.1, 4.1, 4.3, 4.0, 5.0	3.5, 3.5, 4.4, 4.6, 4.4, 4.2, 3.7
45° - 55°	4.4, 4.3, 4.1, 4.3, 4.4, 4.4, 4.0, 3.9, 3.5, 3.9, 4.4	4.0, 4.2, 3.8, 3.9
55° - 65°	4.5, 4.6, 4.3, 4.4, 4.5, 4.6, 4.5, 4.5, 4.0, 4.8, 3.9, 4.4	3.9, 3.6, 3.9, 4.0, 3.6
65° - 75°	4.2, 4.6, 4.7, 4.7, 4.7, 4.6, 4.8, 4.4, 4.5, 4.8, 3.9, 4.1	3.9, 4.1, 4.1, 4.0
75° - 85°	4.4, 4.7, 5.1, 5.0, 4.6, 4.5, 4.2, 3.8	

TABLE IV

Mean amplitude in mb. for the pressure tendency oscillation of 4 days average period. The figures are the averages for the zonal belts in two hemispheres.

Zonal belt	North	South
0 - 5	1.6	1.6
5 - 10	1.7	1.8
10 - 15	2.1	1.8
15 - 20	2.2	2.1
20 - 25	2.9	3.4
25 - 35	5.5	8.3
35 - 45	9.0	14.1
45 - 55	12.4	17.7
55 - 65	12.7	13.3
65 - 75	11.5	12.7
75 - 85	11.1	-

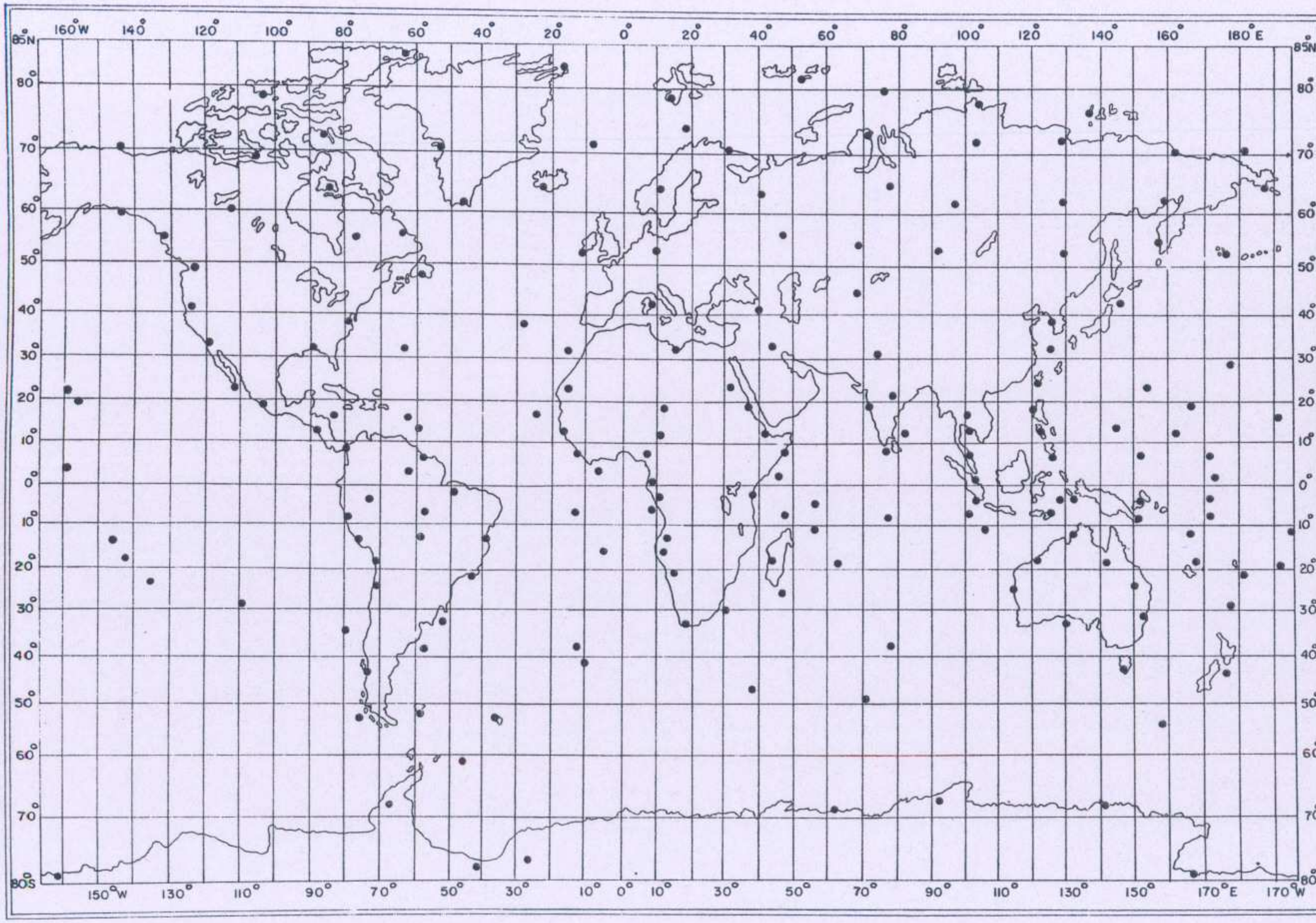

FIG.-1 . GEOGRAPHICAL LOCATIONS OF THE STATIONS.

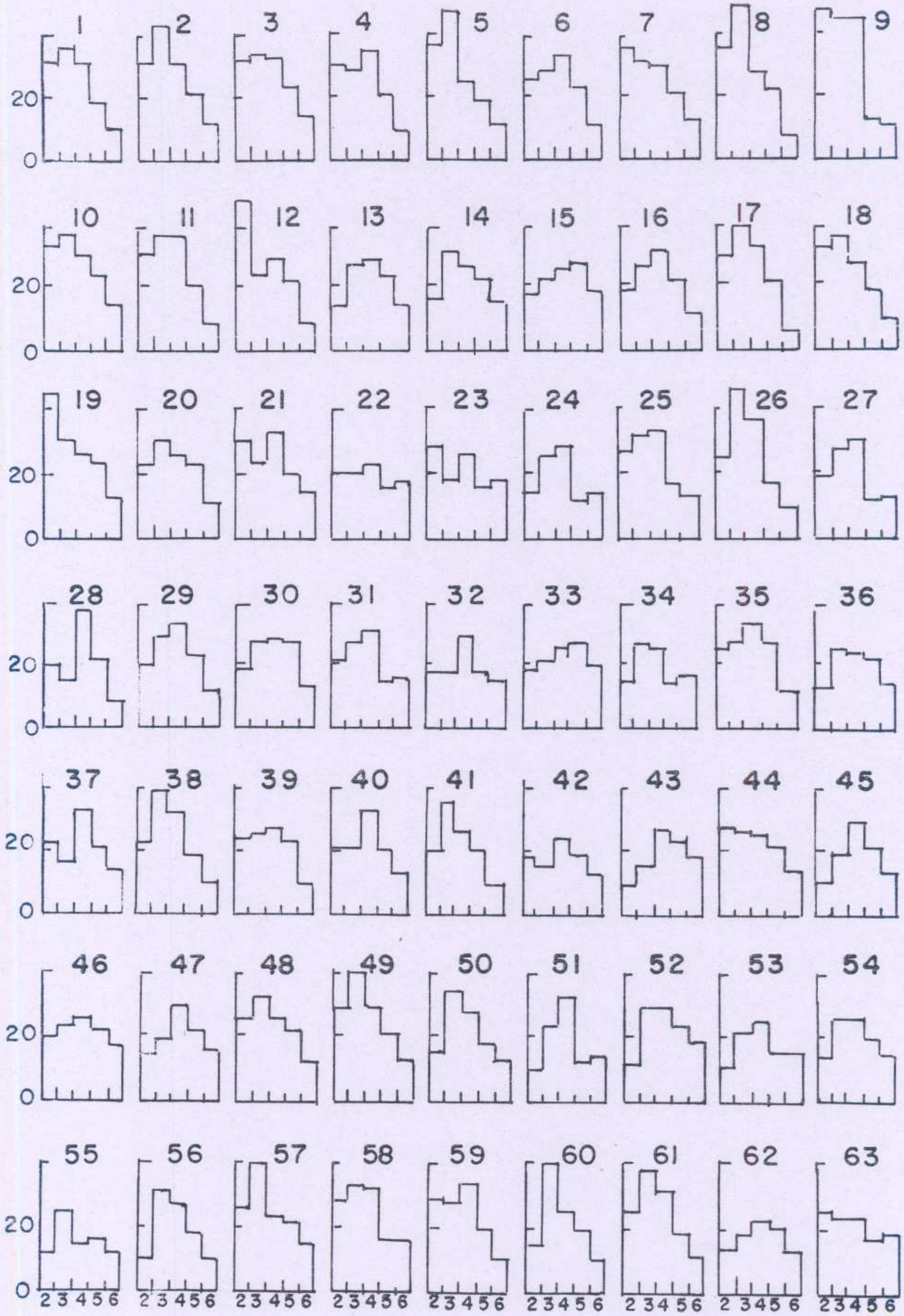
1 2 3 4 5 6 7 8 9
10 11 12 13 14 15 16 17 18
19 20 21 22 23 24 25 26 27
28 29 30 31 32 33 34 35 36
37 38 39 40 41 42 43 44 45
46 47 48 49 50 51 52 53 54
55 56 57 58 59 60 61 62 63
0
20
2 3 4 5 6

FIG. 2 (i)

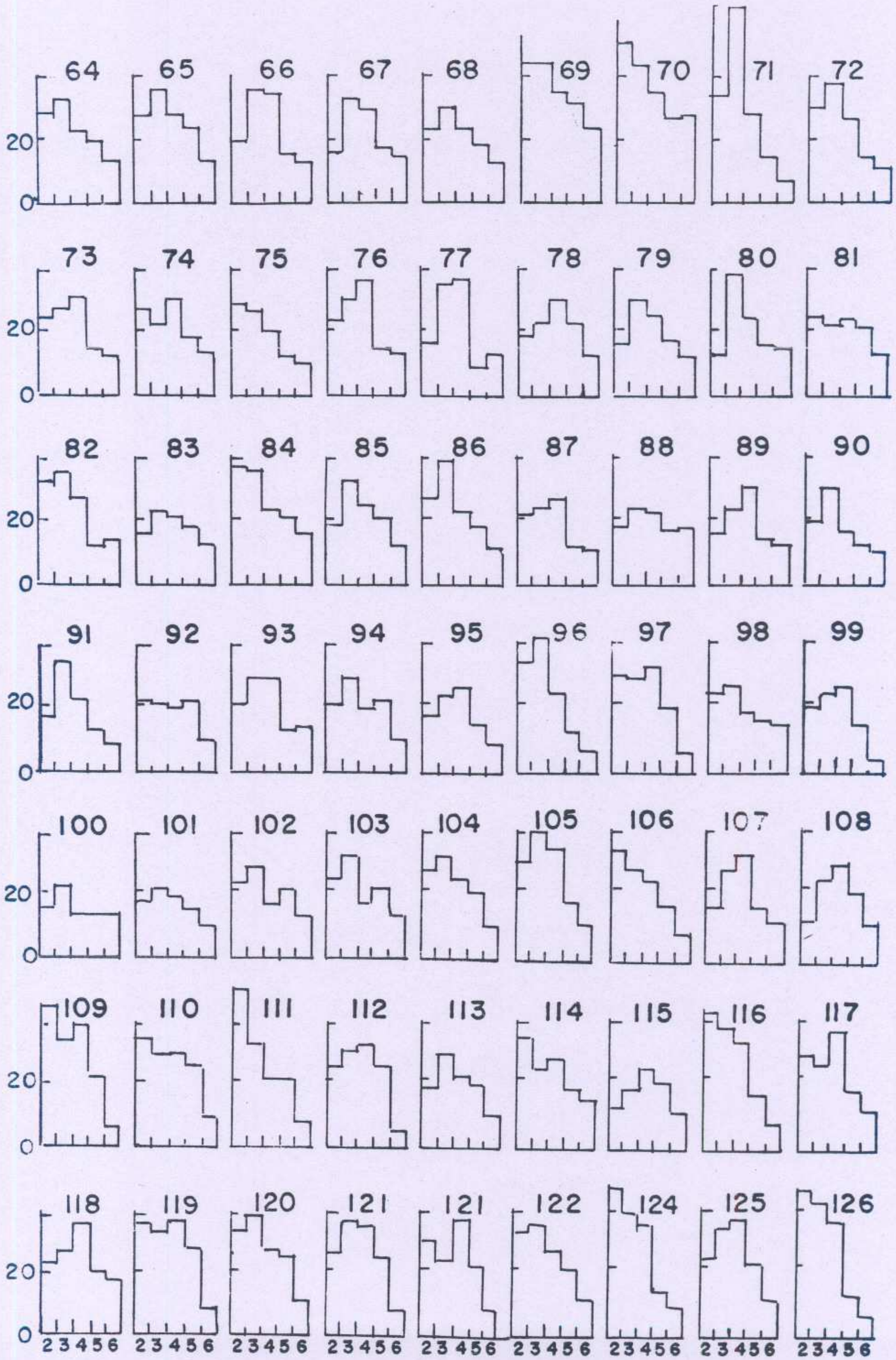
64 65 66 67 68 69 70 71 72
73 74 75 76 77 78 79 80 81
82 83 84 85 86 87 88 89 90
91 92 93 94 95 96 97 98 99
100 101 102 103 104 105 106 107 108
109 110 111 112 113 114 115 116 117
118 119 120 121 121 122 124 125 126
20
0
2 3 4 5 6

FIG. 2 (ii)

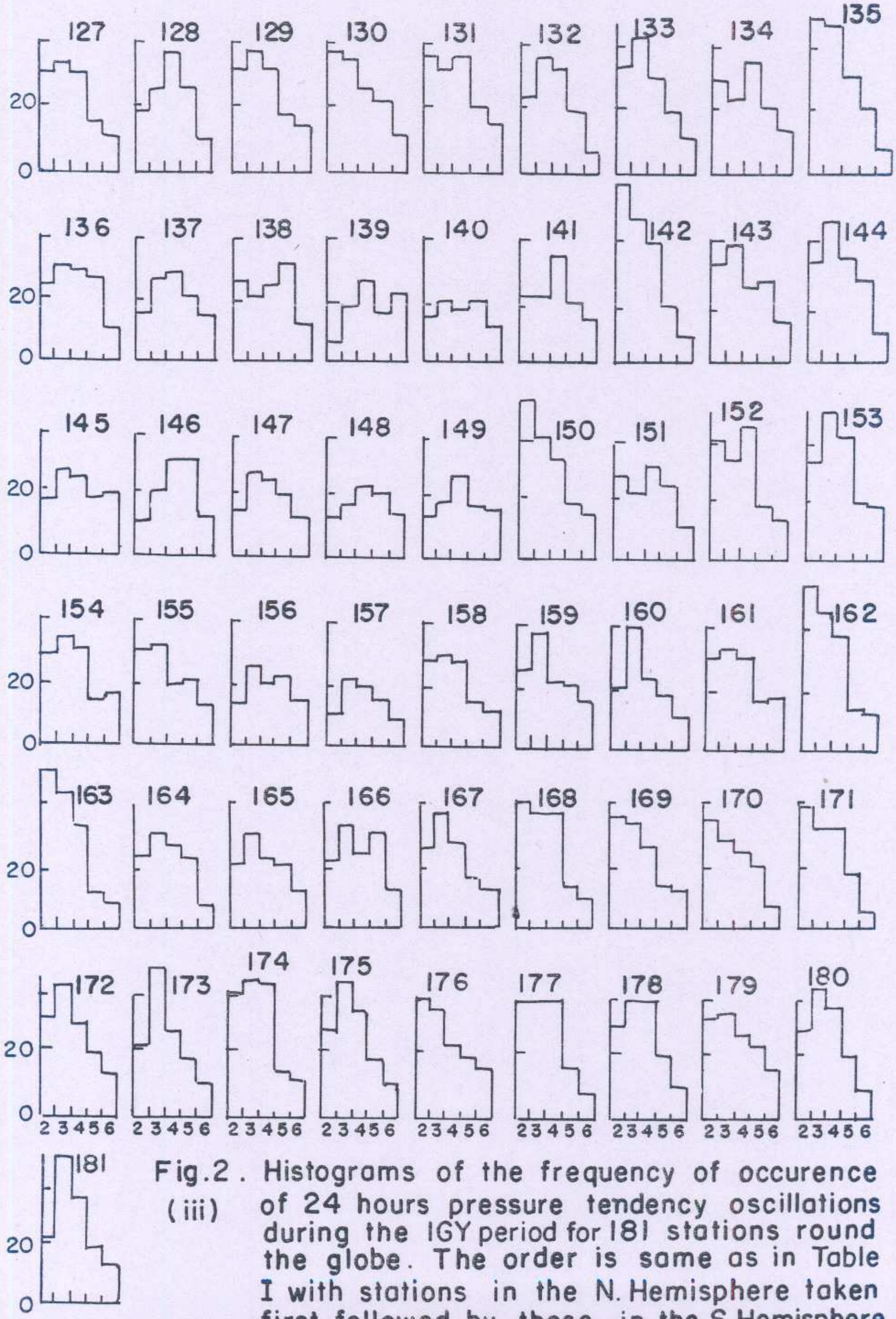

Fig.2. Histograms of the frequency of occurence (iii) of 24 hours pressure tendency oscillations during the IGY period for 181 stations round the globe. The order is same as in Table I with stations in the N. Hemisphere taken first followed by those in the S.Hemisphere.

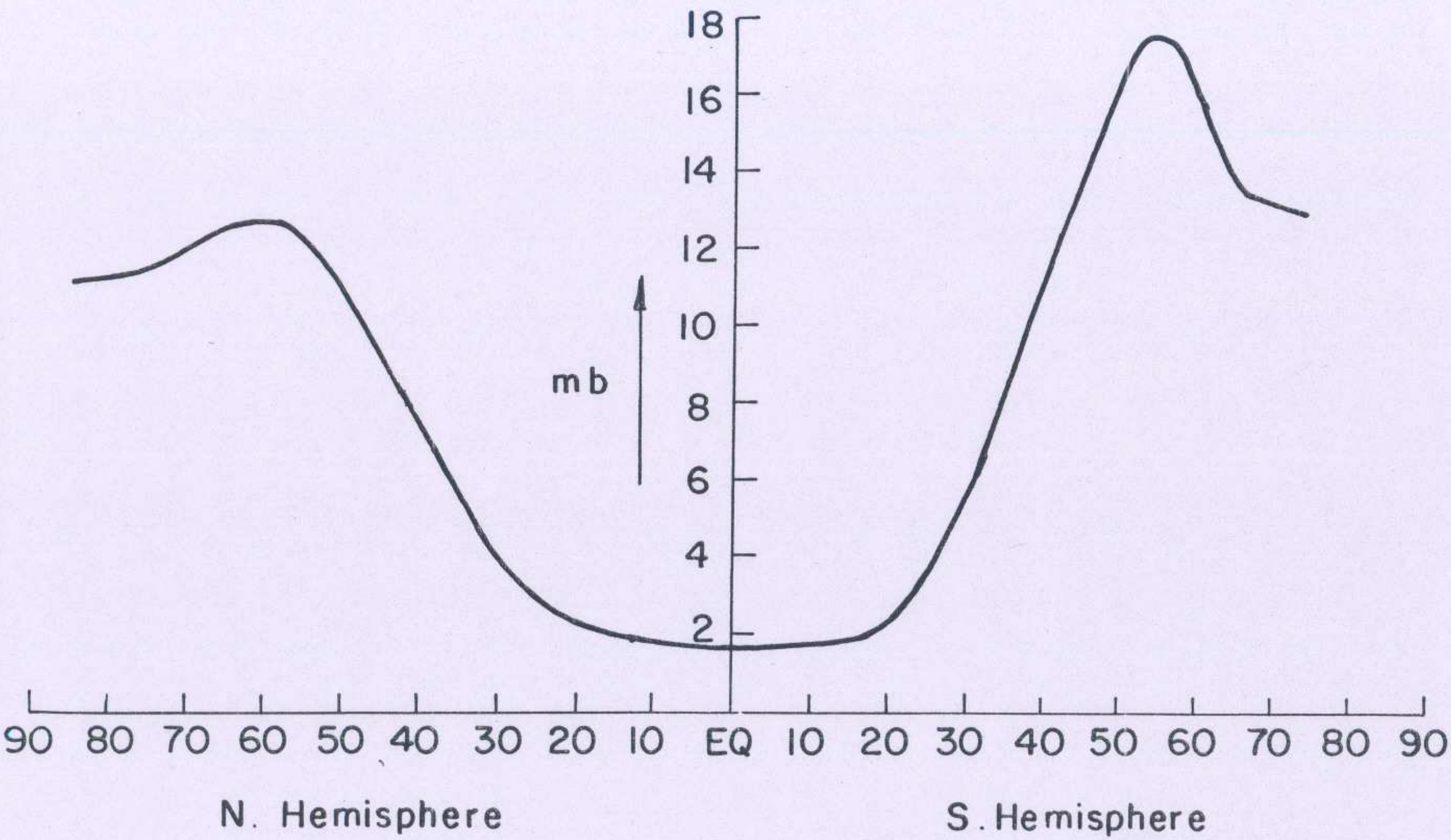

Fig.3 . Zonal variation of mean amplitude of 24 hour pressure tendency oscillation of 4-day period.

On the behaviour of the 24 hour pressure tendency oscillations on the surface of the earth

II. Spectrum analysis for tropical stations

B.M. MISRA

Summary

Spectrum analysis of 24 hour pressure tendency series for 76 stations in the tropics 20 N - 20 S shows a peak in the periodicity of 4-5 days. Cross spectrum for stations grouped in zonal belts shows that the oscillation results due to a westward propagating wave of the same periodicity having a zonal wavelength equal to a zonal circle. The direction of propagation is identical in both the hemispheres and shows no inclination to latitude circles.

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1. Introduction

1.1 In a previous report in this series (Misra, 1973) we have brought attention to a short period oscillation in the 24 hour pressure tendency prevailing almost all over the global surface. The mean periodicity of the oscillation is around 4 days. The mean amplitude is about 1.5 mb in the equational region and increases towards high latitudes - a peak of about 15 mb being reached around 60 degrees of latitude in either hemisphere. In an earlier study (Ananthakrishnan and Misra 1970), we had disproved any causal association of these oscillations with the solar flares, as envisaged by Palmer and Ohmstede (1956).

1.2 From the 181 stations for which the surface pressure data were taken in the previous study (Misra 1973) we will presently concern ourselves to a closer examination of the data for the stations in the tropical area covering 20 N - 20 S. We have eight zonal belts of five degrees width, each containing about ten stations the total number coming to 76. The consideration of isolating the stations in the tropics was arbitrary, more because of the fact that the data for the tropical stations were available with convenience. Later on however the results from the spectral study study justified such sisolation. The results on the extratropical stations will be reported in a subsequent report.

1.3 Excepting a few cases in Africa and South America, the altitudes of most of the stations were below 50 m, above the mean sea level. Another qualification for the group was that the observations had a consistent report this may be due to the extra care taken for the tropical stations during the

IGY period. The data constitute a good homogeneous set for a spectral study. Wallace and Chang (1969) point out that nonalignment of stations on the latitude circles will give rise to errors in the computation of phase through the cross spectrum. As can be well understood, a strict alignment of stations in latitude circles is difficult to be obtained, however the latitude separation between our station is much narrower than used by Wallace et al in their study.

2. Spectrum Analysis as a tool for meteorological study

2.1 A good review on the application of the spectral analysis technique to the meteorological time-series is given in a recent article by Jones (1971). The special advantage of the technique is that it allows the variance partitioning to take place in frequency components of arbitrary size. i.e. the frequency specified may not be an integral number of cycles in the length of the record. This is also its essential difference with the conventional harmonic analysis. The removal of data length as a guiding factor for the computations makes the spectral analysis a better tool suited to the study of time-series of meteorological origin. But the non-stationarity of the meteorological data can evolve spurious results. A compromise method is to remove the long term trend from the data by the use of suitable filters (Holloway 1958). But with all the rigours of filtering procedure the spectral estimation can show artificial results as evidenced by Julian (1971). For obvious reasons more confident results are expected from long sequences of data, but in this case, again, the choice of lag and window can sometimes also produce results which were not originally available.

... 4

2.2 The choice of lag in the spectrum analysis methods is somewhat arbitrary - one fourth to one fifth of the number of points in the data length being used for good resolution. Parzen's criterion of initially employing three lags $M_1 < M_2 < M_3$ such that $M_3/M \sim 4$ and M_3 being about one fifth of the data length and then choosing a suitable lag can be used in many cases. We feel that the best method for a meteorological study is to fix the bandwidth and the resolution from the available data size with a careful consideration of the sampling interval. A comparison of the computed spectra with the histogram of the data can in many cases be a good check on the choice of the lag. A good proposal is always to work with high degrees of freedom, such that one gets more confidence in the results. Many smoothing windows have sidelobe features. So the one to be selected has to conform to the resolution characteristics already established. It is seen that the Parzen window has a slower resolution than the Tukey's. In most practical cases, Tukey's window can be selected with a proper lag. Lastly, if the time-series has undergone a filtering process, it is extremely important to determine the transform of the filter before the implications of the results are investigated.

3. Computation Method

3.1 In the computation of spectra, we will follow the procedure outlined by Jenkins and Watts (1968). The process is analogous to that employed by Munk et al (1959) and Maruyama (1968), with a small difference in the estimation of the covariance functions. A consideration of the mean square error of the covariance estimators, (Parzen 1961) shows that the estimator with divisor N (N = the number of data points) has a less m.s.e. than that with the divisor N-L (L = Lag used). In our computations we will employ N as the divisor in preference to N-L. Jenkins and Watts (1968) also show that the plot of the autospectra in a logarithmic scale facilitates in constructing a constant confidence interval for the whole frequency domain. A logarithmic plot has been adopted because of this convenience.

3.2 In the consideration of phase the bivariate spectral methods have been extended to the multivariate case. In this method, the phases of the wave at different stations are computed with respect to a reference station in the same zonal belt. A plot of the phase difference against the longitude difference determines the propagation characteristics of the wave in the latitude belt. The propagation in the meridional belt is determined by a similar consideration with the stations grouped in a longitude belt. The Tukey window with a lag of 20 has been utilised for the smoothing purpose. This allows the degrees of freedom to be as high as 73, with a bandwidth of 0.067.

4. Results

4.1 The autospectra of all the stations considered in the study are presented in figs. 1 and 2 for the north and south hemispheres respectively. The abscissae are the periodicity in days. The 95% confidence interval and the bandwidth are also shown in both the figures. A peak on the period range of 4-5 days is evidenced almost at all stations considered. The amplitude is also seen to be higher at high latitude stations.

4.2 Plots of phase difference against the longitude difference for the wave of 4.4 day periodicity with various reference stations in the zonal belts are presented in figures 3 and 4. In all cases we see that the phase builds upto while a complete circle round the globe is covered. The property remains unchanged with a change of reference station. Similar behaviour of phase propagation is demonstrated in all the latitude belts considered. The coherency for the 4.4 day wave when referred to various stations vary between 0.2 and 0.7. Since the number of degrees of freedom in this case is 73, the 95% confidence interval for the phase estimates is ± 20 . This consideration of the phase presents a definite evidence of the presence of a westward propagating wave in the whole of the tropical zone 20 N-20 S. The wave has a periodicity of about 4.5 days, during which it moves round the globe once.

4.3 The stations have next been grouped in different meridian belts aligned along previously chosen meridians. The comparison of phases for stations arranged on four meridians separated by 90 degrees i.e. 10 E, 100 E, 170 W and 80 W is given in Table I. The reference station has been chosen as the one which is closest to the meridian considered for the group. As is seen from the tables the phase differences of stations along a meridian line are quite small and all values lie within the 95% confidence interval. This amounts to the evidence that the wave reaches a particular meridian in all zonal belts in practically the same epoch. The propagation, therefore, is purely zonal.

5. Conclusions

The principal conclusions of the study may be summarised as follows :-

(i) The 24 hour pressure tendency shows a peak in the period range of 4-5 days in the whole tropical belt 20 N-20 S.

(ii) The oscillation in 4-5 days results from a westward propagating

... 7

wave of the same periodicity having a zonal wavelength equal to the zonal circle. The behaviour is same in both the hemispheres.

(iii) The propagation of the wave is parallel to the zonal belts, the same epoch being maintained throughout a meridian belt at any instant, throughout the tropical region.

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TABLE I

Phase differences for stations arranged on meridian lines 10° E, 100° E, 170° W and 80° W

(A) 10° East Meridian

Reference – Mayumba 3° 25'S 10° 39'E

Station Name	Latitude	Longitude Difference	Phase Difference	Coherence
Mocamedas	15° 12'S	1° 30'	16	0.27
Lobito	12° 22'S	2° 43'	10	0.31
Luanda	8° 51'S	2° 35'	1	0.45
Libreville	0° 27'N	– 1° 14'	– 12	0.56
Makurdi	7° 41'N	– 2° 2'	– 9	0.33
Potiskum	11° 42'N	0° 23'	– 13	0.13
Bilma	18° 41'N	2° 16'	10	0.41

(B) 100° East Meridian

Reference – Phitsanulok 16° 50N 100° 16'E

Station Name	Latitude	Longitude Difference	Phase Difference	Coherence
Cristmas Is.	10° 25'S	5° 24'	– 32	0.20
Djakarta	6° 11'S	6° 34'	2	0.32
Bengkulu	3° 25'S	2° 4'	– 21	0.17
Singapore	1° 21'N	3° 38'	– 13	0.42
Songkhala	7° 11'N	0° 21'	– 16	0.48
Bangkok	13° 44'N	0° 14'	– 8	0.66

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TABLE I (Contd.)

(C) 170° West Meridian

Reference - Niue 19° 2'S 169° 55'W

Station Name	Latitude	Longitude Difference	Phase Difference	Coherence
Pukapuka	10° 53'S	0° 6'	21	0.27
Nukunono	9° 12'S	- 2° 0'	- 13	0.24
Canton Is.	2° 46'S	- 1° 48'	20	0.19
Johnston Is.	16° 44'N	0° 24'	- 6	0.25

(D) 80 West Meridian

Reference - Chiclayo 6° 47'S 79° 50'W

Station Name	Latitude	Longitude Difference	Phase Difference	Coherence
Arica	18° 22'S	9° 29'	9	0,23
Pisco	13° 45'S	3° 33	6	0.44
Iquitos	3° 45'S	6° 35'	34	0.22
Albrock	8° 58'N	0° 14'	21	0.35
Swan Is.	17° 24'N	- 0° 6'	16	0.33

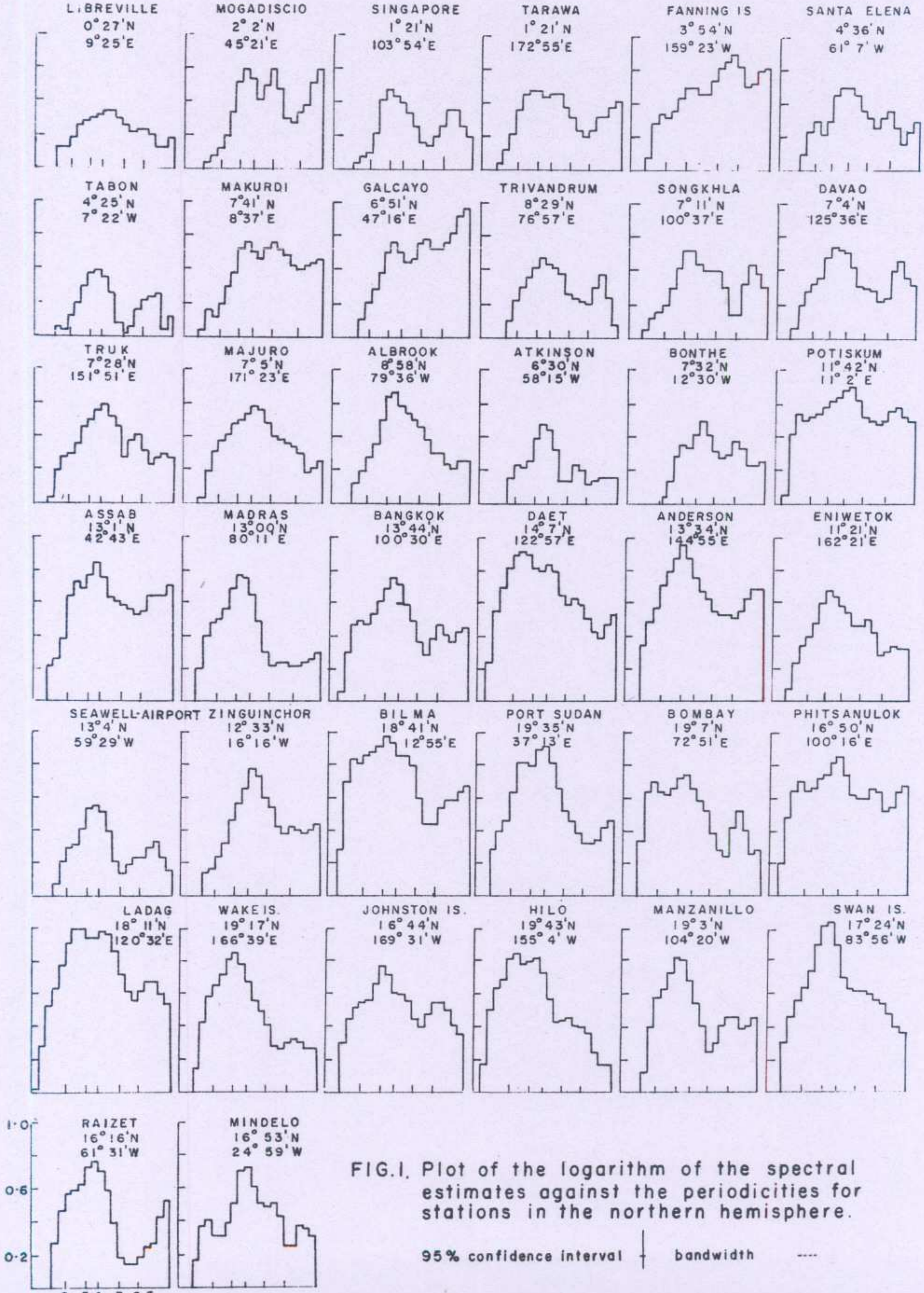

FIG.I. Plot of the logarithm of the spectral estimates against the periodicities for stations in the northern hemisphere.

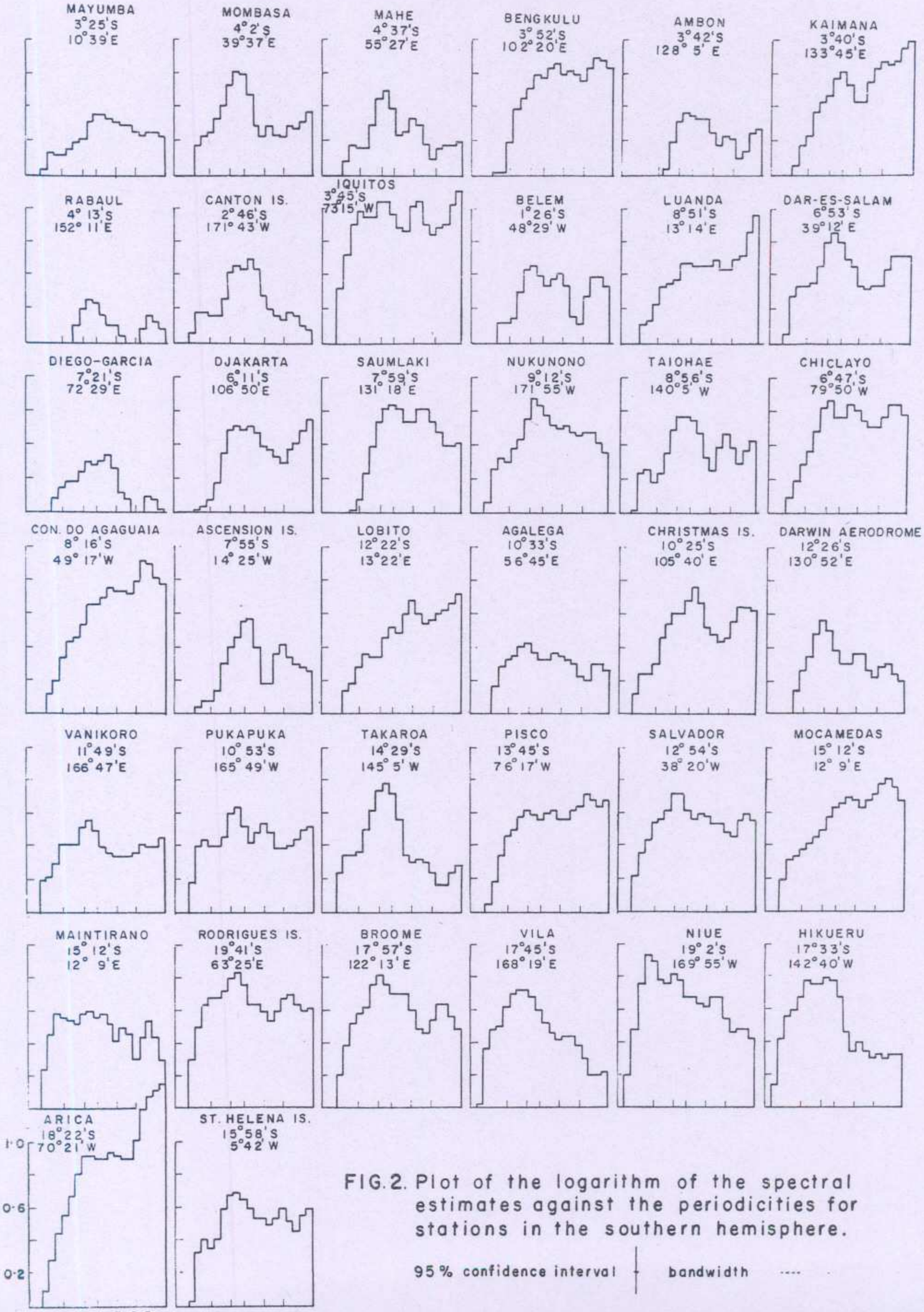

FIG. 2. Plot of the logarithm of the spectral estimates against the periodicities for stations in the southern hemisphere.

95% confidence interval | bandwidth ----

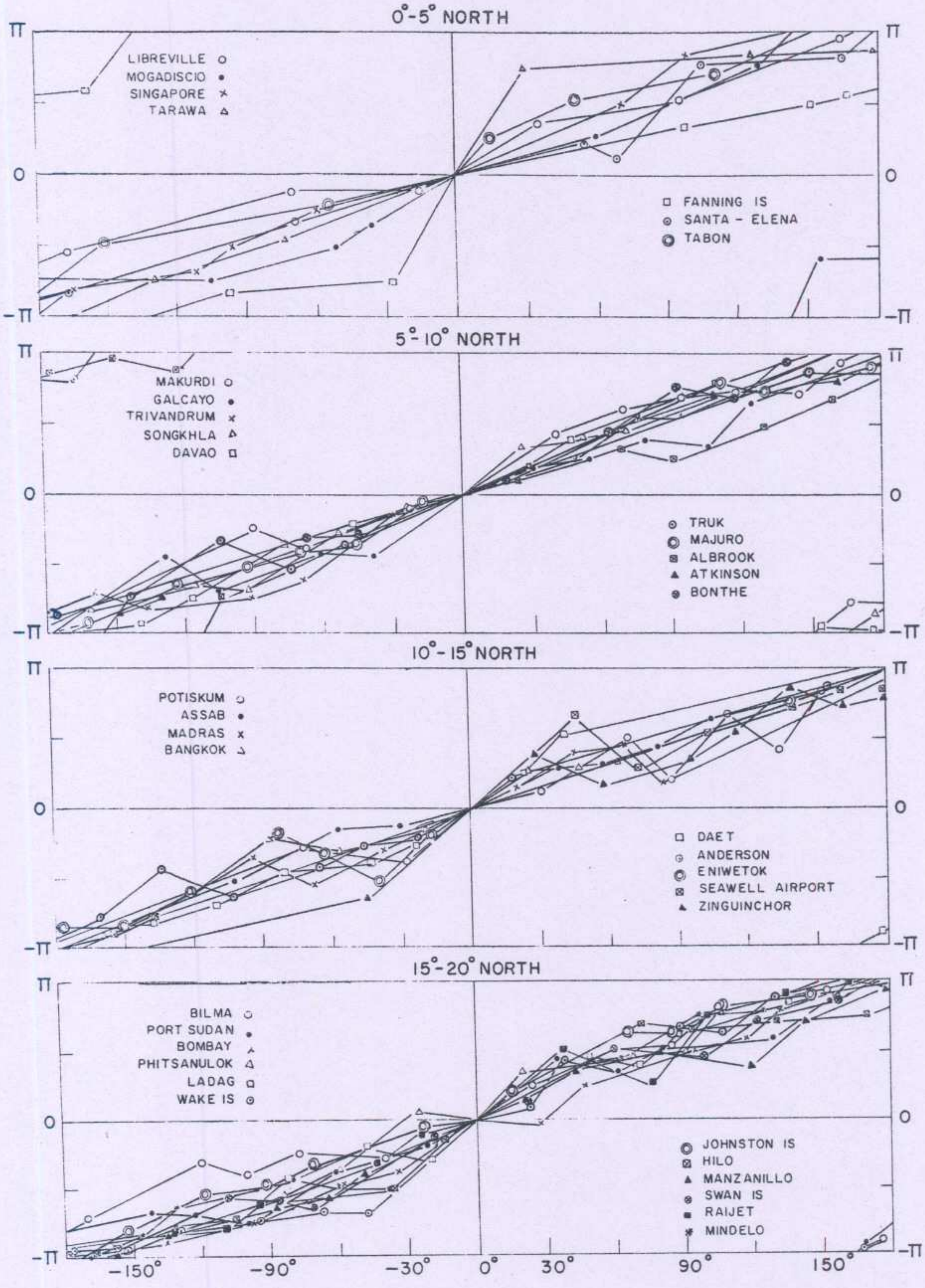

Fig. 3

Plot of the phase difference against the longitude difference for zonal belts in the northern hemisphere (Plotted for the wave of periodicity 4.4 days). Different markings of points denote the phases of different stations in the belt with respect to a particular station as indicated.

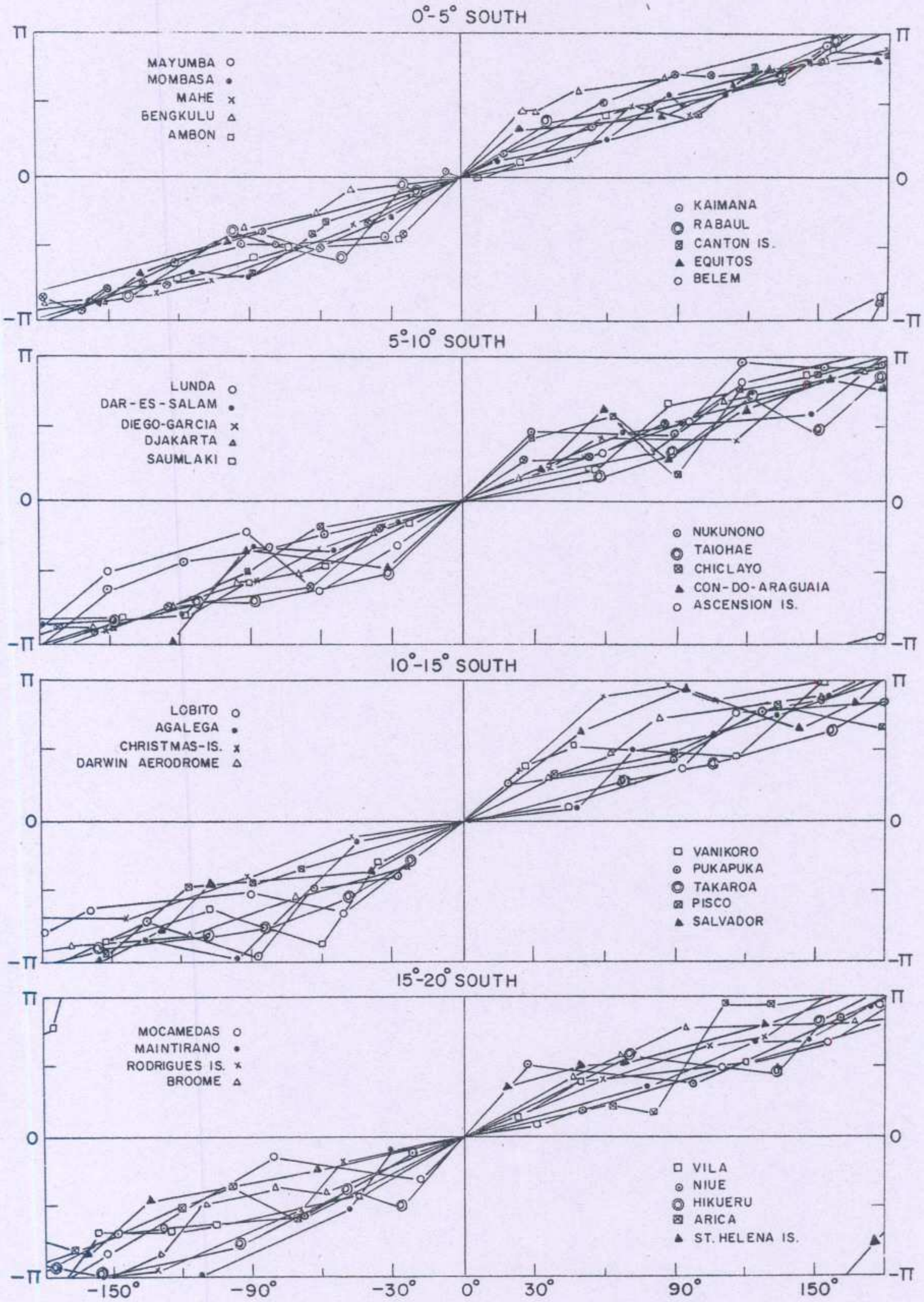

Fig. 4

Plot of the phase difference against the longitude difference for zonal belts in the southern hemisphere (Plotted for the wave of periodicity 4.4 days). Different markings of points denote the phases of different stations in the belt with respect to a particular station as indicated.