

A STUDY OF THE DIURNAL AND SEMI-DIURNAL VARIATIONS
OF COSMIC RAY NUCLEONIC INTENSITY AT VICTORIA
FOR THE PERIOD SEPTEMBER 1964 - AUGUST 1966

by

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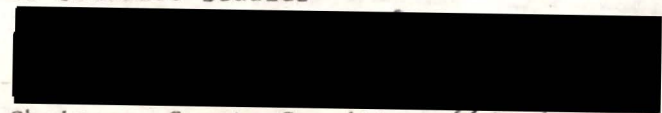
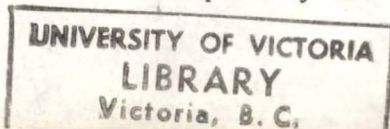


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ABSTRACT

An analysis is given of the solar daily variation of cosmic ray nucleonic intensity recorded by the neutron monitors at Victoria and other stations during 1965. The variabilities of amplitude and time of maximum of daily variation of cosmic radiations at Victoria have been investigated on a day-to-day basis from September 1964 to August 1966.

A geomagnetic-latitude dependence of the diurnal hour of maximum is observed and a barometric coefficient of -0.74 per cent per millibar is obtained from semi-diurnal components of pressure and uncorrected neutron counts; these are in agreement with other workers. Day-to-day analysis of diurnal variation of corrected neutron counts at Victoria for the period September 1964 to August 1966 reveals that there exists enhanced amplitudes of diurnal variation in preferred directions, and in a few instances those amplitudes can be associated with cosmic ray storms. There is a general increase in diurnal amplitudes in the summer months with no corresponding increase in the daily total cosmic ray counting rate. Finally, the mean diurnal hour of maximum is found to be 16 hours local time.

An attempt has been made to find out if the semi-diurnal variation is just the residual error after correction for pressure, but without satisfactory result.

CONTENTS

	<u>page</u>
I. Introduction.....	1
II. Instrumentation.....	5
III. Method of Analysis.....	9
1. The yearly mean diurnal and semi-diurnal variation.....	9
2. Fourier analysis.....	10
3. Harmonic dial.....	11
4. Determination of the barometric coefficient	12
IV. Diurnal Variation.....	15
1. Brief account of some important theories of diurnal variation.....	15
2. Some properties of diurnal variation of pressure-corrected cosmic ray intensity....	21
3. Diurnal variation on a day-to-day basis....	25
V. Semi-diurnal Variation.....	54
1. Dilemma associated with semi-diurnal variation.....	54
2. Is the semi-diurnal variation of the pressure- corrected counts a residue of inadequate pressure correction of the cosmic ray intensity?.....	56
3. Investigation on how far the supposition that the pressure-corrected semi-diurnal effect can be taken as residual error is true, using monthly data of Victoria.....	65

4. Day-to-day variability of the semi-diurnal component.....	<u>page</u> 77
VI. Conclusion.....	94
Appendix I Discussion of errors.....	96
Appendix II Barometric constant of Victoria station determined from least squares regression of each month's pressure and uncorrected neutron data.....	98
Bibliography.....	100

LIST OF FIGURES AND TABLES

	<u>page</u>
Table I. List of stations.....	22
Figure 1. Harmonic dial for the diurnal variation of corrected neutrons at 11 stations during 1965.....	23
Figure 2. Geomagnetic latitude dependence of time of maximum of diurnal variation of corrected neutrons.....	24
Figure 3. Amplitude of diurnal variation of corrected neutrons versus geomagnetic latitude.....	26
Table II. Diurnal variation of nucleonic component corrected for pressure.....	27
Figure 4. Scatter of asymptotic direction of maximum of anisotropy estimated from observed times of maximum at various stations.....	28
Figure 5. Relative amplitude predicted from the theory of asymptotic cone of acceptance for a rigidity independent anisotropy.....	29
Figure 6. Histograms of hour of maximum of diurnal variation of corrected neutrons at Victoria	31
Figure 7. Time of maximum of daily diurnal variation of corrected neutrons at Victoria from September 1, 1964 to August 31, 1966.....	34
Figure 8. Amplitude of diurnal variation of corrected neutrons at Victoria from September 1, 1964 to August 31, 1966.....	41
Figure 9. Daily total pressure-corrected nucleonic intensity at Victoria from September 1, 1964 to August 31, 1966.....	49
Figure 10. Amplitude of diurnal variation of corrected neutrons plotted against the corresponding time of maximum at Victoria.....	51
Table III. Deviation of semi-diurnal variation of uncorrected counts from 180° antiphase w.r.t. pressure semi-diurnal variation and the residual semi-diurnal effect.....	57

	<u>page</u>	
Figure 11a,b	Harmonic dial for semi-diurnal variation of pressure & uncorrected counts at eight stations during 1965.....	58
Figure 11c.	Harmonic dial for semi-diurnal variations of pressure, uncorrected neutrons and pressure residual effect at Lae.....	66
Figure 12.	Semi-diurnal amplitude of the barometric pressure versus uncorrected nucleonic intensity for nine stations during 1965.	61
Table IV.	Yearly mean daily variation of corrected neutrons of Victoria using different barometric coefficients for pressure correction.....	64
Figure 13.	Monthly mean semi-diurnal variation of corrected neutrons at Victoria for the period September 1964 to August 1966....	67
Figure 14.	Monthly mean semi-diurnal variation of pressure at Victoria for the period September 1964 to August 1966.....	68
Figure 15.	Monthly mean semi-diurnal variation of uncorrected neutrons at Victoria for the period September 1964 to August 1966....	70
Figure 16.	Monthly mean semi-diurnal variation of uncorrected-minus-corrected neutrons at Victoria for the period September 1964 to August 1966.....	75
Figure 17a.	Barometric coefficient determined from linear regression of monthly mean semi-diurnal amplitudes of pressure and uncorrected-minus-corrected neutrons....	74
Figure 17b.	Barometric coefficient determined from linear regression of monthly mean semi-diurnal variation of pressure and uncorrected counts.....	74
Table V.	Monthly mean semi-diurnal variation of pressure, pressure-corrected neutron counts, uncorrected neutron counts and uncorrected-minus-corrected neutron counts at Victoria.....	78

	<u>page</u>
Figure 18.	Histograms of hour of maximum of semi-diurnal variation of corrected neutrons at Victoria..... 80
Figure 19.	Amplitude of semi-diurnal variation of corrected counts at Victoria from September 1, 1964 to August 31, 1966.... 84
Figure 20.	Time of maximum of semi-diurnal variation of corrected neutrons at Victoria from September 1, 1964 to August 31, 1966.... 88
Figure 21.	Amplitude of daily semi-diurnal variation of corrected neutrons plotted against the corresponding time of maximum at Victoria..... 92

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CHAPTER 1

INTRODUCTION

The earth's atmosphere is subject to continuous showers of highly energetic cosmic ray radiation, the intensity of which shows time variations greater than statistical fluctuations. Some of the intensity time variations are non-periodic, such as cosmic ray storms, Forbush decreases, and solar-flare increases, while others are periodic, such as the 11-year variations associated with solar activity, 27-day recurrences, sidereal daily variations and solar daily variations.

Among the periodic variations, the solar daily variation plays an important role. It is a world-wide local time phenomena, but the amplitudes and hours of maximum vary from place to place on the earth's surface. This phenomenon was first discovered by Lindholm (1928)¹ using ionization chambers, and was subsequently confirmed by many observers (Compton et al (1932)², Hess and Graziadei (1936)³, Schonland et al (1937)⁴, Lange and Forbush (1948)⁵). It has been well established that solar daily variation of the primary particles can be decomposed into two components:

- 1) the diurnal variation with a period of 24 hours, amplitude about 0.3 percent for the nucleonic component, hour of maximum in afternoon; and

- 2) a semi-diurnal variation with a period

of 12 hours, amplitude about 0.05 per cent, hours of maxima in early morning and afternoon. After corrections for atmospheric attenuation and for geomagnetic deflection have been applied, the remaining diurnal variation has been considered to be of extra-terrestrial origin. The existence of semi-diurnal variation is still unsettled.

The study of the daily variation is a difficult task because its amplitude is only a few times larger than the standard deviation of the measured cosmic ray intensity. It depends on meteorological factors such as temperature, pressure and water vapour distribution in the atmosphere. There is not a complete theory for these processes, which are greatly complicated by the dependence of the cross-sections on the cosmic ray energy. As a result, the corrections usually employed are mainly empirical. Unfortunately the experimental data available to study this dependence are very scanty.

Cosmic rays being charged particles are affected by geomagnetic disturbances, changes in the cut-off rigidity and changes in interplanetary field conditions. It is uncertain whether geomagnetic conditions and interplanetary field conditions constitute disturbances which should be eliminated in the study of the daily variation or whether they form an integral part of the ultimate causes of the observed daily variation. If they are to be eliminated, then there are insufficient direct measurements of cosmic ray

intensity in the extra-terrestrial regions where the cosmic rays are considered to be generated. Usually data obtained from ground level, and from high altitude stations are used to deduce, or rather guess what is happening in places very far away from the earth, and to compare with theoretical predictions. There are scarcely any independent means which have been devised to test the validity of mechanisms put forward to explain the daily variation.

For more than thirty years, cosmic ray physicists have continued to investigate this complicated problem, using world-wide data for both meson and nucleonic components. The daily variation has been correlated with both terrestrial and extra-terrestrial phenomena. Many theories and mechanisms have also been proposed to account for the observed daily variation. The general aims are to locate the source and to gather information about the anisotropy of primary cosmic ray flux and interplanetary conditions.

The following analyses deal with diurnal and semi-diurnal variations using data recorded by the Victoria super-neutron monitor NM-64 and neutron monitor of some other stations situated in different parts of the world. The latter information was obtained from the World Data Centres of the IQSY. The minimum solar activity

period 1964-66 has been chosen so that disturbances due to other intensity time variations associated with solar activity are minimized. One of the advantages of the nucleonic component is that correction is necessary only for pressure; temperature, water vapour and other meteorological factors have negligible effect on cosmic ray intensity (Simpson et al (1955)⁶).

To minimize standard deviation, yearly average diurnal amplitudes are usually computed. However, with the improved statistics of the NM-64 monitors, the study of diurnal and semi-diurnal variation is possible on a day-to-day basis and gives more information about their natures and origin.

CHAPTER 2

INSTRUMENTATION

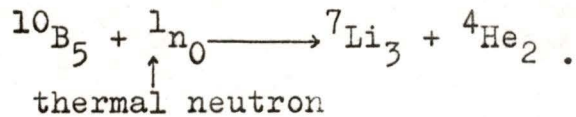
The University of Victoria neutron monitor consists of three units of 6 NM64 counter assemblies, developed by Atomic Energy of Canada Ltd. in 1964.⁷ Each assembly has a boron-tri-fluoride filled proportional counter enriched to 96 percent ^{10}B to detect thermalized neutrons, and a polyethylene enclosure called the inner moderator, to moderate the neutrons and for mechanical protection of the thin-walled counters. An air gap is left between the stainless steel counter wall and the polyethylene moderator for optimum operation. A transistor amplifier and discriminator is installed into each assembly. The operating voltage is 2800 volts negative with the counter wire at ground potential; and the slope of the plateau is about one percent per 100 volts over a range of more than 500 volts.

The counter assembly is enclosed by heavy circular lead rings which provide a local production of energetic evaporation and cascade neutrons. Six counter assemblies surrounded by lead ring tubes, separated by lead blocks-- an arrangement devised for optimum operation -- are placed in a rectangular polyethylene enclosure called the reflector. The function of the reflector is to absorb and reflect spurious low energy neutrons

in the vicinity of the monitor and to reflect as well as to moderate evaporation neutrons trying to escape.

For one incoming nucleon in the energy range 200 mev to 300 mev, eight evaporation neutrons (mean energy about 2 mev) are produced on the average, per interaction in the lead (Bercovitch (1960)⁸). These evaporation neutrons are slowed down to thermal energy by collisions with the moderating material. Some of these escape or are captured uselessly by the moderating material. About six percent of the evaporation neutrons are being detected by the counters.

Neutrons on entering the counter react with $^{10}\text{B}_5$ to give lithium fragments and alpha particles:



The alpha particles produced are very energetic (about 1.46 mev). The lithium fragments can exist in two states: about 94 percent are left in the 480 kev excited state and 6 percent in the ground state. The alpha particle together with the lithium fragment in the excited or the ground state have a total kinetic energy of 2.3 mev and 2.78 mev respectively. These fragments produce ionization in the counter, giving sharp pulses. The energy spectrum of the output pulses has two monoenergetic peaks: one at 2.3 mev and a small one at

2.78 mev. The full width at half height of the prominent 2.3 mev peak is about 8.5 percent.⁷ Gamma rays and spurious background effect may also be detected, but they have energy so low that they can be easily discriminated against.

The average detected multiplicity, (that is, observed counting rate per event), is 1.41 (Hatton and Carmichael (1964)⁹). A large value of multiplicity implies greater efficiency of detecting incoming nucleons.

The efficiency of detecting a nuclear disintegration by the NM-64 monitors has been calculated by Pearce and Fowler (1964)¹⁰; values in the range 30 to 60 percent were obtained and it was found to be 1.23 as efficient as the IGY neutron monitor developed by Simpson and co-workers.

The monitor is operated with a dead-time of about 20 μ sec. and the counting rate per channel is about 125,000 counts/hour. Consequently, dead-time counting rate losses are negligible.

The following information is recorded automatically by tape punch continuously at five minutes intervals:

- 1) counting rate from three scalers;
- 2) barometric reading to the nearest 0.1 mm. Hg; and

3) universal time.

The results are processed by the University of Victoria
digital computer.

CHAPTER 3

METHOD OF ANALYSIS

§1. The yearly mean diurnal and semi-diurnal variation.

The mean percentage deviation of the i^{th} hour counting rate from the mean station counts is given by

$$\delta N_i = \frac{100 \sum_{j=1}^J (N_{ij} - \bar{N})}{J \times \bar{N}} \quad (1)$$

where \bar{N} is the mean station counting rate and N_{ij} , the counting rate of the i^{th} hour on j^{th} day. Also J represents the total number of days in the period under consideration.

As a matter of convenience, the mean station counting rate \bar{N} has been replaced by the average counting rate of the 24^{th} hour (i.e. by \bar{N}_{24j}). Since the percentage deviation is small compared with \bar{N} or \bar{N}_{24j} , using either \bar{N} or \bar{N}_{24j} in the denominator will not introduce any significant error. Replacing \bar{N} by \bar{N}_{24j} in the numerator only shifts the reference level. In this way, the daily variations of different stations are normalized to the same reference level, namely zero percentage deviation at the 24^{th} hour.

δN_i is composed of two parts, the diurnal and semi-diurnal deviations. The semi-diurnal percentage deviations are given by

$$\delta S_i = (\delta N_i + \delta N_{i+12})/2, \quad i = 1, \dots, 12 \quad (2)$$

while the diurnal percentage deviations are given by

$$\begin{aligned}\delta D_i &= \delta N_i - \delta S_i, & i &= 1, \dots, 12 \\ \delta D_i &= \delta N_i - \delta S_{i-12}, & i &= 13, \dots, 24\end{aligned}\tag{3}$$

The amplitude and the hour of maximum are determined graphically from the 24-hour graphs of δD_i and δS_i . The diurnal and semi-diurnal variations of corrected counts are obtained by applying corrections for pressure to the hourly data before taking an average over the total number of days.

The above treatment enables correlation between corrected counts, uncorrected counts and pressure daily variations to be detected easily. Alternatively the amplitude and the hour of maximum can be determined by the Fourier analysis outlined in the following section.

§2. Fourier analysis.

Assuming that only the first two harmonics of Fourier analysis of the daily variation are significant, the counting rate as a function of time t can be written as

$$N(t) = A_0 + A_1 \sin(\omega t + \alpha_1) + A_2 \sin(2\omega t + \alpha_2)\tag{4}$$

where A_0 is an arbitrarily fixed counting level, A_1, A_2 are the maximum amplitudes of the first and second harmonics, and α_1, α_2 are the phases of the first and second harmonics. The circular frequency ω in this case is

$2\pi/24$ radian per hour.

By expanding the sine terms, equation (4) can be written as

$$N(t) = A_0 + p_1 \cos \omega t + q_1 \sin \omega t + p_2 \cos 2\omega t + q_2 \sin 2\omega t \quad (5)$$

$$\text{where } p_1 = A_1 \sin \alpha_1, q_1 = A_1 \cos \alpha_1, p_2 = A_2 \sin \alpha_2, q_2 = A_2 \cos \alpha_2 \quad (6)$$

p_1, q_1, p_2, q_2 are known as harmonic coefficients.

The harmonic coefficients are determined from a number of discrete data points. In the case of hourly data, the number amounts to 24 (on day-to-day basis). In a manner similar to the determination of Fourier coefficients, the harmonic coefficients can approximately be represented by the following expressions,

$$p_1 = \frac{2}{24} \sum_{K=1}^{24} N_K \cos(K-1)\omega, \quad q_1 = \frac{2}{24} \sum_{K=1}^{24} N_K \sin(K-1)\omega \quad (7a)$$

$$p_2 = \frac{2}{24} \sum_{K=1}^{24} N_K \cos 2(K-1)\omega, \quad q_2 = \frac{2}{24} \sum_{K=1}^{24} N_K \sin 2(K-1)\omega \quad (7b)$$

where N_K is the counting rate of the K^{th} hour.

From equation (6),

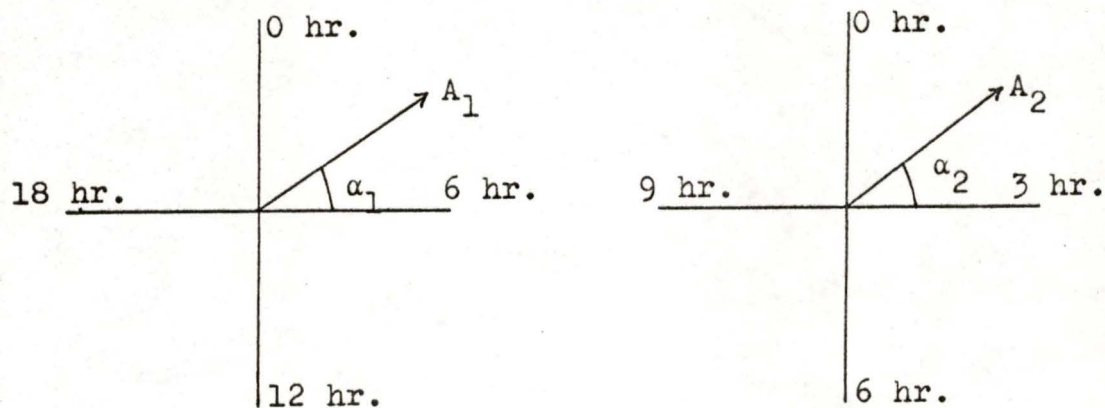
$$A_1 = \sqrt{p_1^2 + q_1^2}, \quad \alpha_1 = \tan^{-1} (p_1/q_1) \quad (8a)$$

$$A_2 = \sqrt{p_2^2 + q_2^2}, \quad \alpha_2 = \tan^{-1} (p_2/q_2) \quad (8b)$$

§ 3. The harmonic dial.

The first and second harmonics of daily variation

can be represented in vector diagrams or "harmonic dials" as shown in the following diagram.



a) First harmonic.

b) Second harmonic.

The magnitude of the vectors represents the amplitude and the direction of the vectors indicates the time of maximum. The time of maximum of the first harmonic is given by

$$T_1 = (\pi/2 - \alpha_1)/\omega \quad (9)$$

and that of the second harmonic ,

$$T_2 = (\pi/2 - \alpha_2)/2\omega \quad (10)$$

§ 4. Determination of the barometric coefficient.

The barometric coefficient β of the cosmic ray intensity is defined by

$$\frac{dI}{I} = - \beta dp \quad (11)$$

where I is the intensity of the cosmic ray, and p is the pressure.

Assuming that β is a constant, equation (11) is integrated to give

$$\ln I = \beta(p_0 - p) + \ln I_0 \quad (12)$$

where I is the observed cosmic ray intensity at pressure p (often referred to as uncorrected counts); and I_0 is the cosmic ray intensity at some standard pressure p_0 (often referred to as pressure-corrected counts). The barometric coefficient β is determined from least square regression of the pressure and the logarithm of the uncorrected counts. The observed pressure values are grouped together in intervals of 0.1 mm. Hg. The corresponding uncorrected counts are also grouped together. The mean is then taken and the frequency recorded.

The least square regression is done as follows: A straight line given by $y = b(p_0 - p) + c$ is fitted to the data points specified by $p_i = p_0 - p$ and $y_i = \ln I$. The slope b is then an approximation to the barometric coefficient β . Let

$$S = \sum_i n_i d_i^2 \quad (13)$$

where $d_i = y - y_i$ and n_i is the weight of y_i . Then b and c can be determined by requiring S to be a minimum, i.e.

$$\frac{\partial S}{\partial b} = 0, \quad (14a)$$

and
$$\frac{\partial S}{\partial c} = 0. \quad (14b)$$

Thus equation (14a) gives

$$\frac{\partial}{\partial b} \left\{ \sum_i n_i d_i^2 \right\} = \frac{\partial}{\partial b} \left\{ \sum_i n_i [(bp_i + c) - y_i]^2 \right\} = 0$$

i.e.

$$b \sum_i n_i p_i^2 + c \sum_i n_i p_i - \sum_i n_i p_i y_i = 0. \quad (15)$$

Similarly, equation (14b) gives

$$b \sum_i n_i p_i + c \sum_i n_i - \sum_i n_i y_i = 0. \quad (16)$$

Therefore, from equations (15) and (16),

$$b = \frac{(\sum_i n_i)(\sum_i n_i p_i y_i) - (\sum_i n_i p_i)(\sum_i n_i y_i)}{(\sum_i n_i)(\sum_i n_i p_i^2) - (\sum_i n_i p_i)^2} \quad (17)$$

Finally, equation (12) can also be expressed as

$$I = I_0 \exp[-\beta(p - p_0)] \quad (18)$$

which is often referred to as the exponential correction for air mass.

CHAPTER 4

DIURNAL VARIATION

§1. Brief account of some important theories of diurnal variation.

From directional measurements of solar daily variation of cosmic rays notably by Alfven and Malmfors (1943)¹¹, Malmfors (1949)¹², Elliot and Dolbear (1950,^{13a} 1951^{13b}), Roa and Sarabhai (1961)¹⁴, it has been well established that the first harmonic is of extra-terrestrial origin. The diurnal variation was found to be different for north and south directions, as well as for east and west directions. The amplitudes of diurnal variation in the north and south direction were practically the same, but there was a difference of 5.5 hours¹³ between the times of maximum intensity. A difference of about 6 hours in diurnal time of maximum for the east and west direction was observed to occur on many days at Ahmedabad, a low latitude station.¹⁴ The residual variations in both cases (that is, north minus south, west minus east) were large in comparison to standard errors. Meteorological variations were automatically eliminated in the difference between the variations in north and south directions or west and east directions, since the cosmic rays passed through the atmosphere under the same conditions. .

After being corrected for meteorological variations, the observed diurnal variation is believed to be due to the magnetic field either of the earth or of the sun, or to anisotropy of primary radiation; the combined action of both two effects is also possible.

Direct measurements of interplanetary field conditions and cosmic ray intensity in space are limited even with the advent of satellites and space crafts in the past few years. The general problem of charged particle trajectories in the interplanetary plasma has not been solved both because of insufficient knowledge of the fields and because of mathematical difficulties. There has been considerable qualitative work, but theoretical models developed usually contained many free parameters to fit observations from world-wide ground-level stations and high - altitude stations.

The solar dipole field theory of diurnal variation has been investigated by Janossy (1937)¹⁵; Alfven (1947)¹⁶; Kane, Shanley and Wheeler (1949)¹⁷; Dwight (1950)¹⁸; Firror, Jory and Treiman (1954)¹⁹ and other workers. According to simple Stormer theory for trajectories of charged particles in the solar dipole field, there are allowed directions and forbidden directions of approach, fixed relative to the earth-sun line, for particles above certain cut-off rigidities.

As the earth rotates on its axis, a station scans different directions of the sky, and records maximum and minimum intensity within one solar day. The simple theory was modified by including the possibility of particles being scattered into forbidden orbits of the sun's field by the magnetic field of the earth with the result that the predicted amplitude of diurnal variation was reduced and a better agreement with observed amplitude was expected. The phase and amplitude of daily variation depend on the value assumed for solar magnetic dipole moment, the direct measurement of which is inaccessible, and also on the relative number of particles scattered into forbidden cones. This theory attempts to explain the increase of amplitude of diurnal variation from the equator to high latitudes up to about 60° N. and S. and the scatter of the time of maximum observed by stations situated at different geomagnetic co-ordinates.

The form and ultimate cause of anisotropy of cosmic ray radiation responsible for the diurnal effect is still an unsettled problem. The anisotropy may be a function of asymptotic latitude, asymptotic longitude and the rigidity spectrum of primary radiation and it may vary from day to day or have long term variations.

Anisotropy of cosmic ray radiation can be interpreted as a radial drift of cosmic rays bound to the

sun's rotation coupled with a tangential component due to the earth's rotation (Brunberg and Dattner (1954)²⁰). If the tangential component is directed towards the source, the energy of cosmic rays will appear to increase, and the number of cosmic ray particles arriving per unit time will increase in a direction approximately 90° with respect to the earth-sun line towards afternoon. This would be the 18 hour direction, giving rise to a diurnal effect with amplitude of about 0.5 percent.

To account for various components of diurnal variation Dattner and Venkatesan (1959)²¹ proposed a few mechanisms based on Alfven's model of frozen-in solar magnetic field, the effect of gradient in the distribution of cosmic rays, or diffusion of the interplanetary plasma in the solar system. An earlier hour diurnal maximum of 0.03 percent was predicted in periods of minimum solar activity as a result of the earth's being situated outside the region of the solar system taking part in the solar rotation. The medium around the earth is at rest relative to the earth's orbit. As the earth moves in its orbit, it receives more particles on its morning side than the evening side.

Anisotropy in the 18-hour direction may arise as a result of co-rotation of solar wind or magnetic frozen-in field in a spiral pattern with the

sun and inward diffusion of cosmic ray particles (Ahluwalia and Dessler (1962)²², Parker (1964²³, 1965²⁴)). The angular velocity overtakes the earth's orbital motion with relative velocity about 400 km/sec. directed parallel to the earth's orbit. The interaction of cosmic rays with the co-rotating plasma, superimposed on the isotropic motion of cosmic ray particles gives rise to a predicted diurnal variation of amplitude 0.39 percent and a shift of the time of maximum to later hours towards afternoon. The rigid co-rotation or azimuthal streaming of low energy cosmic rays may be caused by magnetic irregularities in large scale field.

A two-anisotropy model has been postulated by Japanese cosmic ray physicists Nagashima et al (1961)²⁵. This model has been used to interpret some of the observed latitude effects of cosmic ray diurnal variation by Kitamura et al (1965)²⁶. The anisotropy has a maximum in the 20-hour and 8-hour directions and may be caused by diffusion of cosmic ray particles from galactic space into interplanetary space in the presence of a quasi-radial magnetic field.

Using asymptotic cone of acceptance* to make

*It is the solid angle containing the asymptotic direction of approach, outside the influence of geomagnetic field, that contributes significantly to the counting rate of the detector.

allowance for the geomagnetic bending, Rao et al (1963)²⁷ have supposed the diurnal variation to originate from a rigidity-independent anisotropy, fixed relative to the earth-sun line. The scatter in asymptotic time of maximum among different stations is expected to be small for a rigidity-independent anisotropy fixed relative to the earth-sun line. However the observed amplitudes and times of maximum of diurnal variation produced by such a cosmic ray anisotropy vary greatly from station to station only because different stations have different asymptotic cones of acceptance. The local time of maximum intensity at a station whose geographic longitude L is given by the expression²⁷

$$\frac{180+C+L-\gamma}{15} \text{ hours.}$$

where γ is the allowance for geomagnetic bending, and C is the asymptotic direction of viewing from which a maximum of anisotropy is seen (measured east of the earth-sun line).

To conclude, theories concerning physical processes causing diurnal variation are diversified. Until direct measurements of field and cosmic ray intensity in space are available to test the qualitative theories put forward and to enable quantitative models to be constructed, it is rather premature to assert which one represents more closely what is happening in reality.

§2. Some properties of diurnal variation of pressure-corrected cosmic ray intensity.

Analyses in this section show some interesting properties of diurnal variation of pressure-corrected cosmic ray neutron intensity. In most cases, agreement with the results analyzed by other workers is obtained.

The diurnal variations of neutron intensity, corrected for pressure, for 11 stations situated at geographic co-ordinates given in Table I, are shown in a harmonic dial in Fig. 1. The results shown were obtained from analysis on the University of Victoria Computer. Local times of maximum are spread between noon and 18 hours.

Local times of maximum, T_{\max} , are plotted versus geomagnetic latitude in Fig. 2. There is a systematic increase of local times of maximum from equator to pole as pointed out by Schwachheim (1960)²⁸, Katzman et al (1960)²⁹, Rao et al (1963)²⁷, Kitamura (1965)²⁶ and others. From the present analysis the relationship may be represented by $T_{\max} = (13.2 + 0.03\Lambda)$ hour, where Λ is the geomagnetic latitude.

The variation of amplitudes of diurnal variation with geomagnetic latitude is not as systematic as the local times of maximum. Amplitudes are relatively large at mid-latitude stations and relatively small but comparable at the two low-latitude stations, Lae and

No.	Station	Geographic Co-ordinate		Geomagnetic Co-ordinate		Altitude meters	Cut-off Rigidity BV
		Lat.	Long.	Lat.	Long.		
1	Victoria	48.5°N	123.4°W	54.3°N	292.7°	71	1.86
2	Calgary	51.1°N	114.1°W	57.9°N	300.4°	1128	1.09
3	Sulphur Mountain	51.1°N	115.5°W	57.9°N	300.4°	2283	1.14
4	Climax	39.4°N	106.2°W	48.1°N	315.5°	3500	3.03
5	Huancayo	12.0°N	75.3°W	1.6°S	353.8°	3313	13.49
6	Lae	6.4°S	147.0°E	16.0°S	217.4°	sea level	15.52
7	Mt. Washington	44.3°N	71.3°W	55.8°N	357.0°	1909	1.24
8	Leeds	53.8°N	1.5°W	56.7°N	83.6°	sea level	2.20
9	Mt. Norikura	36.1° N	137.5°E	25.6°N	203.5°	2770	11.39
10	Ottawa	45.4°N	75.7°W	57.0°N	351.3°	101	1.08
11	Resolute	74.7°N	94.9°W	83.1°N	287.7°	17	< .05

TABLE I
List of Stations

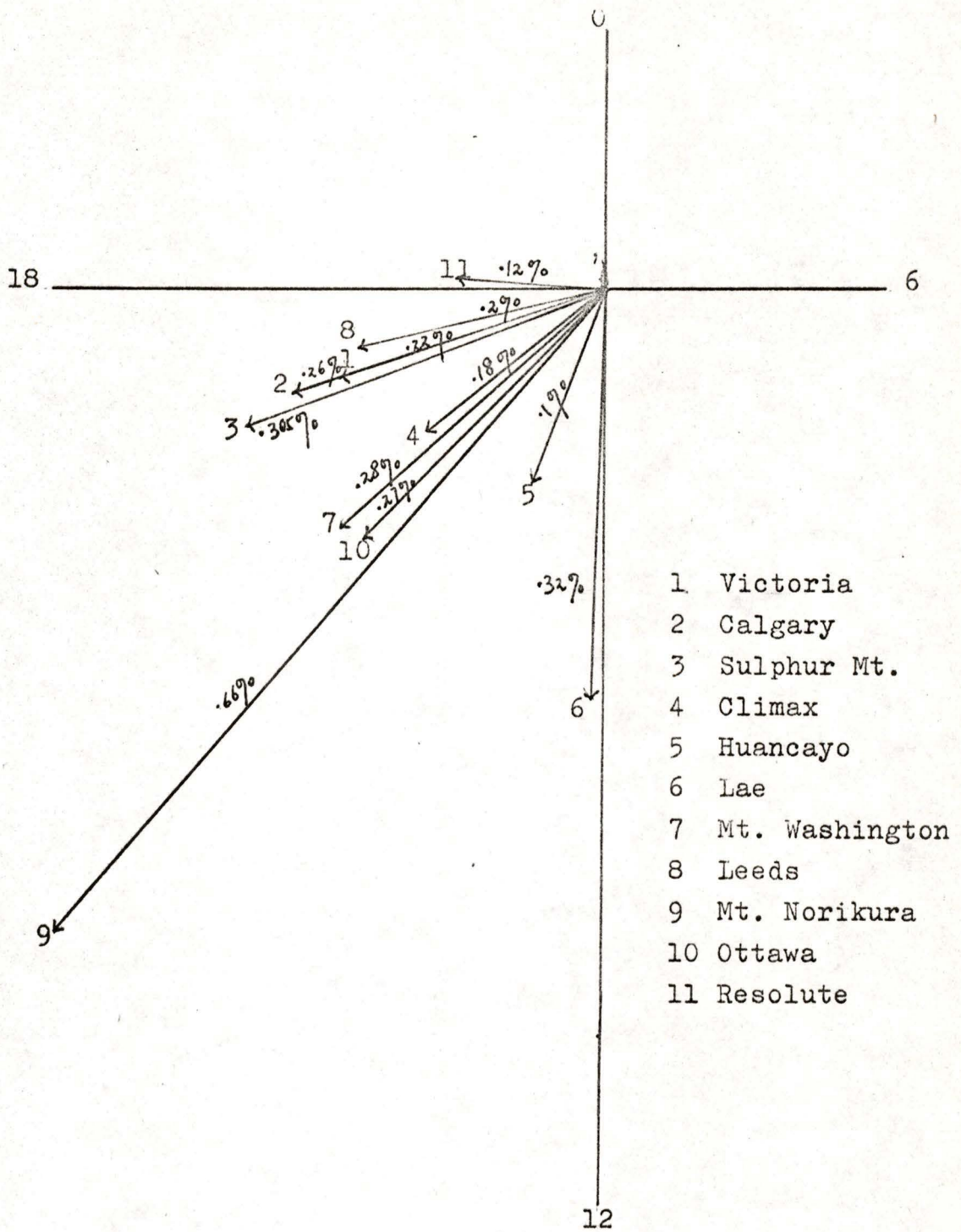


Fig. 1 Harmonic dial for diurnal variation of corrected neutrons at 11 stations during 1965.

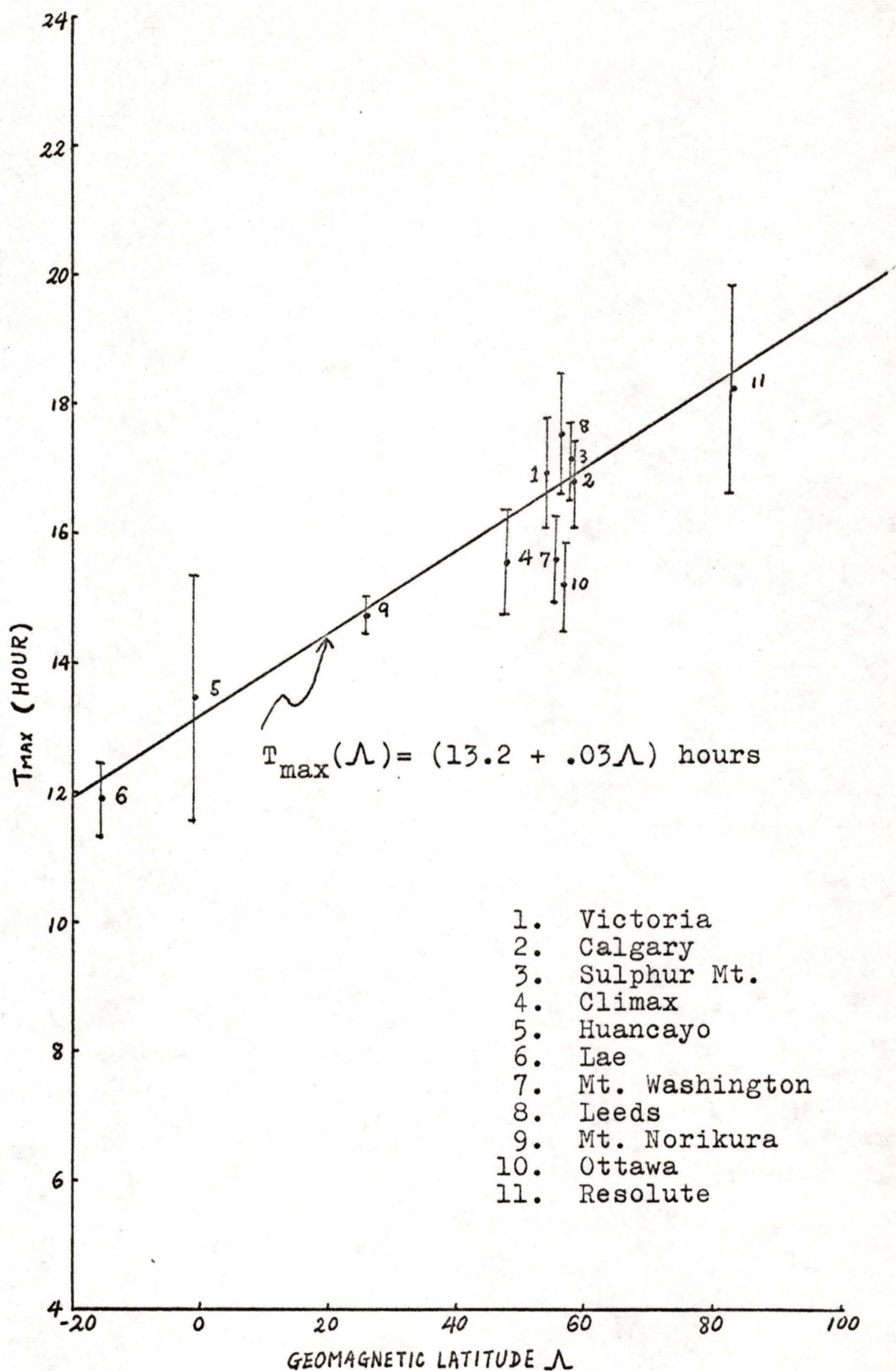


Fig.2 Geomagnetic latitude dependence of time of maximum of diurnal variation of corrected neutrons. (T_{\max} is the diurnal time of maximum in local time.)

Huancayo; and there is a relatively small amplitude at Resolute, a polar latitude station (Fig. 3).

Corrections for geomagnetic bending based on data published in IQSY Instruction Manual No. 10³⁰ have been applied to the observed local times of maximum of 11 stations (Table II). Points shown in Fig. 4 represent the asymptotic directions of viewing the maximum of the anisotropy. A rigidity independent anisotropy has been assumed. A mean direction of 93° east of the earth-sun line (near 18-hour direction) is obtained, though the scatter in asymptotic times of maximum among stations is still large.

Relative amplitudes of the first harmonic of daily variation caused by a rigidity independent anisotropy of 11 stations, predicted by Rao et al (1965)³⁰ are plotted versus geomagnetic latitude (Fig. 5). There is reasonably good agreement with experimental results in the present analysis (see Fig. 3 and Table II).

§3. Diurnal variation on a day-to-day basis.

Victoria hourly neutron counting rates have been corrected for pressure using an experimentally determined barometric coefficient of 1.0101 percent per mm. Hg. The corrected counts in the periods September 1964-August 1965 and September 1965-August 1966, hereafter referred to as Period I and II respectively, have been Fourier analyzed as outlined in Section 3.2. Days with

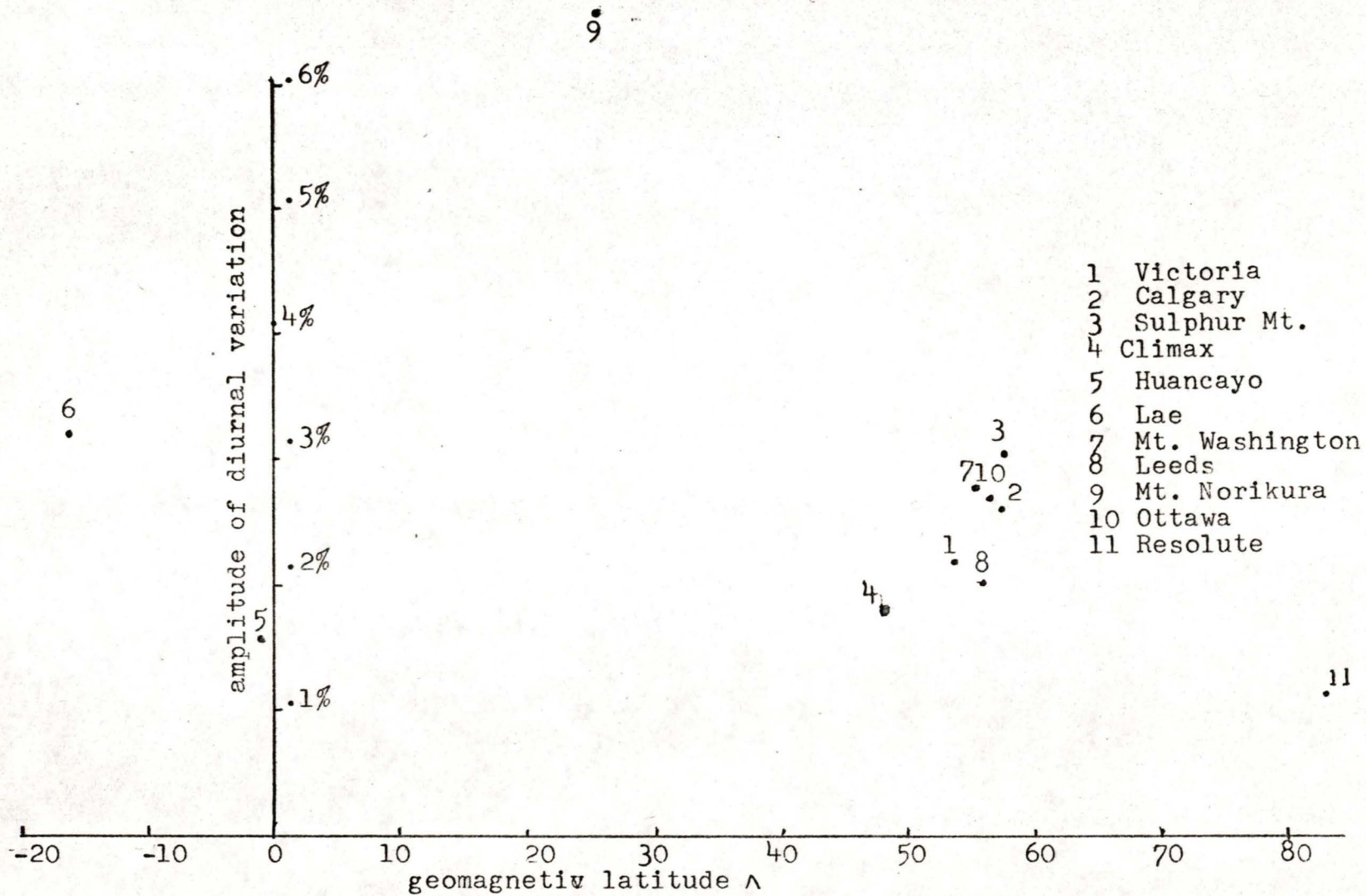


Fig. 3 Amplitude of diurnal variation of corrected neutrons versus geomagnetic latitude.

Station	Diurnal Variation		Barometric Coefficient (% per mb)	Correction for geomagnetic bending * (hrs)	Asymptotic time of maximum after 12 noon (hrs)	Predicted relative amplitude*
	Amplitude (%)	Local time of maximum (hrs)				
1. Victoria	.22	16.8	-0.7770	1.99	6.79	82.91
2. Calgary	.26	16.8	-0.7718	1.58	6.38	85.09
3. Sulphur Mountain	.30	16.7	-0.7665	1.73	6.43	84.61
4. Climax	.18	15.4	-0.7385	3.24	6.64	71.18
5. Huancayo	.16	13.4	-0.7385	3.56	4.96	63.56
6. Lae	.32	12.0	-0.7363	3.68	3.68	64.09
7. Mt. Washington	.28	15.3	-0.7564	2.90	6.20	82.14
8. Leeds	.20	17.1	-0.7685	3.52	8.62	74.61
9. Mt. Norikura	.66	14.7	-0.6538	3.91	6.61	57.83
10. Ottawa	.27	15.0	-0.7190	2.43	5.43	84.22
11. Resolute	.12	18.1	-0.7270	0.61	6.71	34.56

* Data taken from IQSY Instruction Manual No. 10³⁰

TABLE II

Diurnal variation of nucleonic component corrected for pressure. (Rigidity independent anisotropy is assumed for the last three columns.)

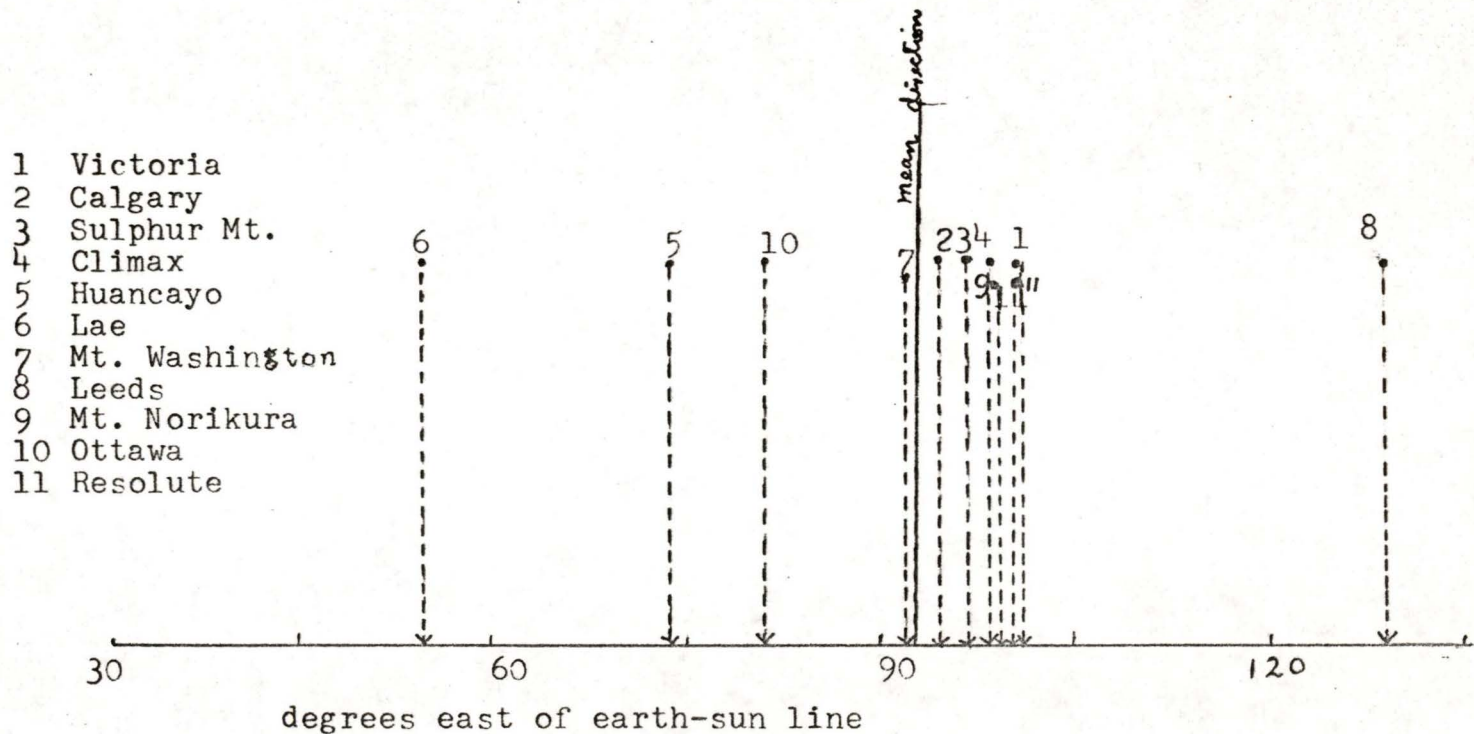


Fig.4 Scatter of asymptotic direction of maximum of anisotropy estimated from observed times of maximum at various stations.

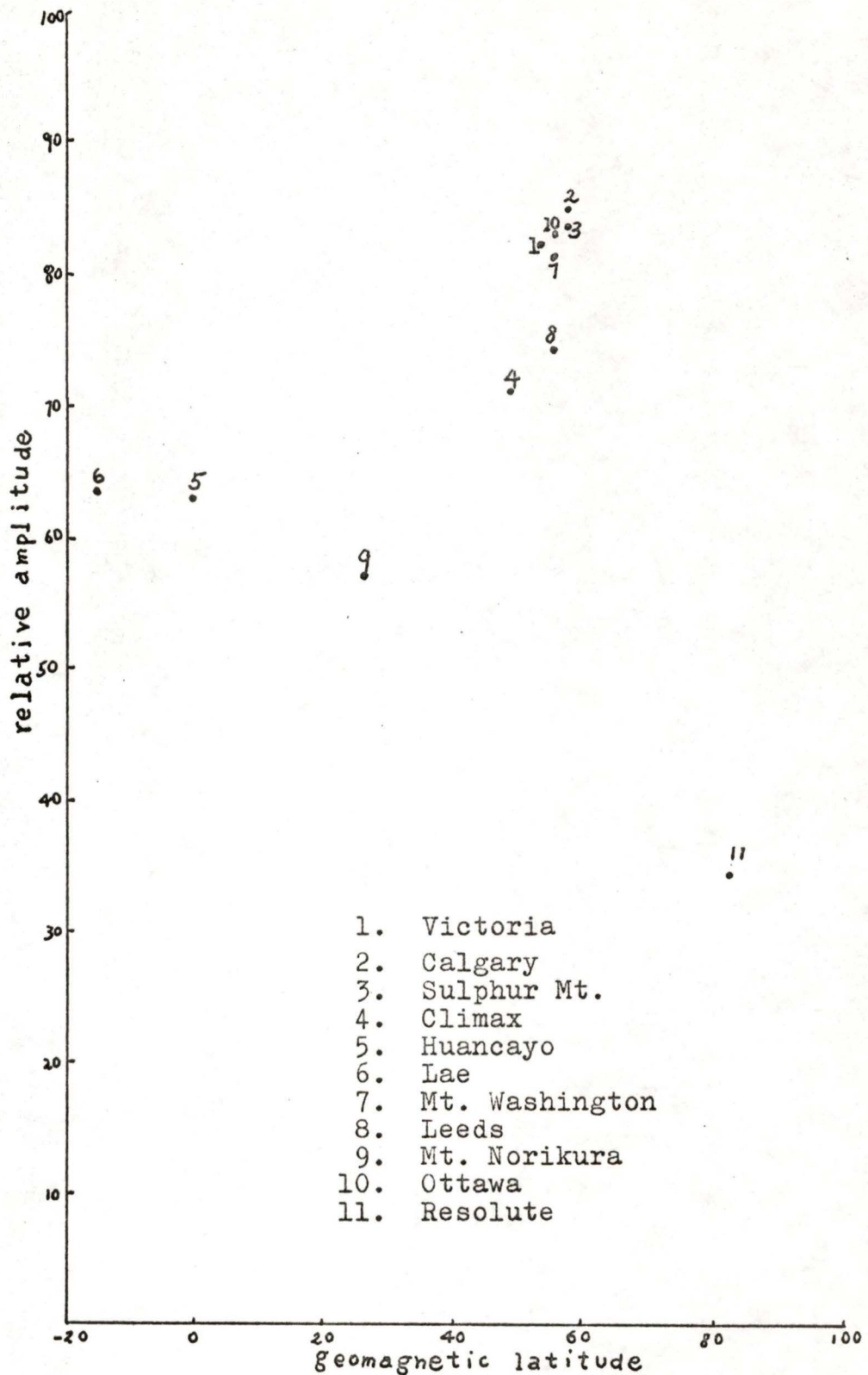


Fig. 5. Relative amplitude predicted from the theory of asymptotic cone of acceptance for a rigidity independent anisotropy; data taken from the IQSY Instruction Manual No. 10.

incomplete 24 hourly data of pressure and uncorrected counts due to recording failure have been excluded from the analysis ; and days with any hourly uncorrected counts deviating more than 5 percent from the daily average uncorrected counts also have been excluded.

Frequency distribution of times of maximum in Period I and Period II is plotted separately in Figs. 6a and 6b, and frequency distribution of times of maximum extending over the two periods is plotted as well in Fig. 6c. Frequency distributions of times of maximum of diurnal variation on a day-to-day basis of Period I and Period II are seen to agree with each other, with probable time of occurrence of maximum at 16 hour local time. This probable value agrees with yearly average time of maximum of diurnal variation within limits of error.

Times of maximum of the diurnal variation are plotted versus days of the year in Fig. 7a to 7f. It appears that the times of maximum occasionally tend to shift from the probable time of maximum, (i.e. 16 hour), to earlier hours, (i.e. 8-10 hours local time), in cycle or multiples of 27 days --the rotation period of the equatorial part of the sun. After making correction for geomagnetic bending, this corresponds to a shift from 6 hour after noon to noon, i.e. within the quadrant to the east of the earth-sun line. The correction for geomagnetic bending at Victoria for a rigidity independent

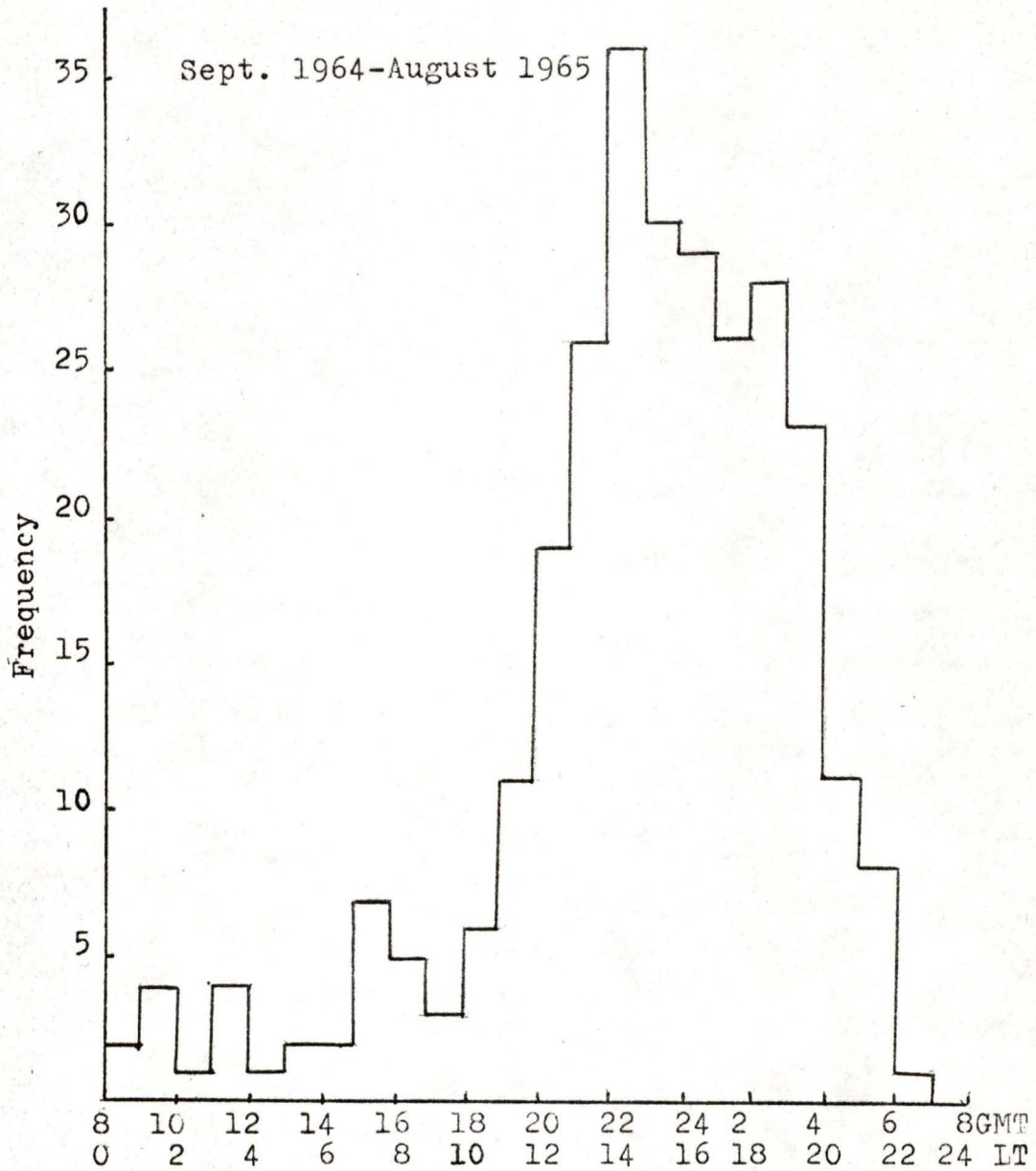


Fig. 6a Histogram of hour of maximum of diurnal variation of corrected neutrons at Victoria

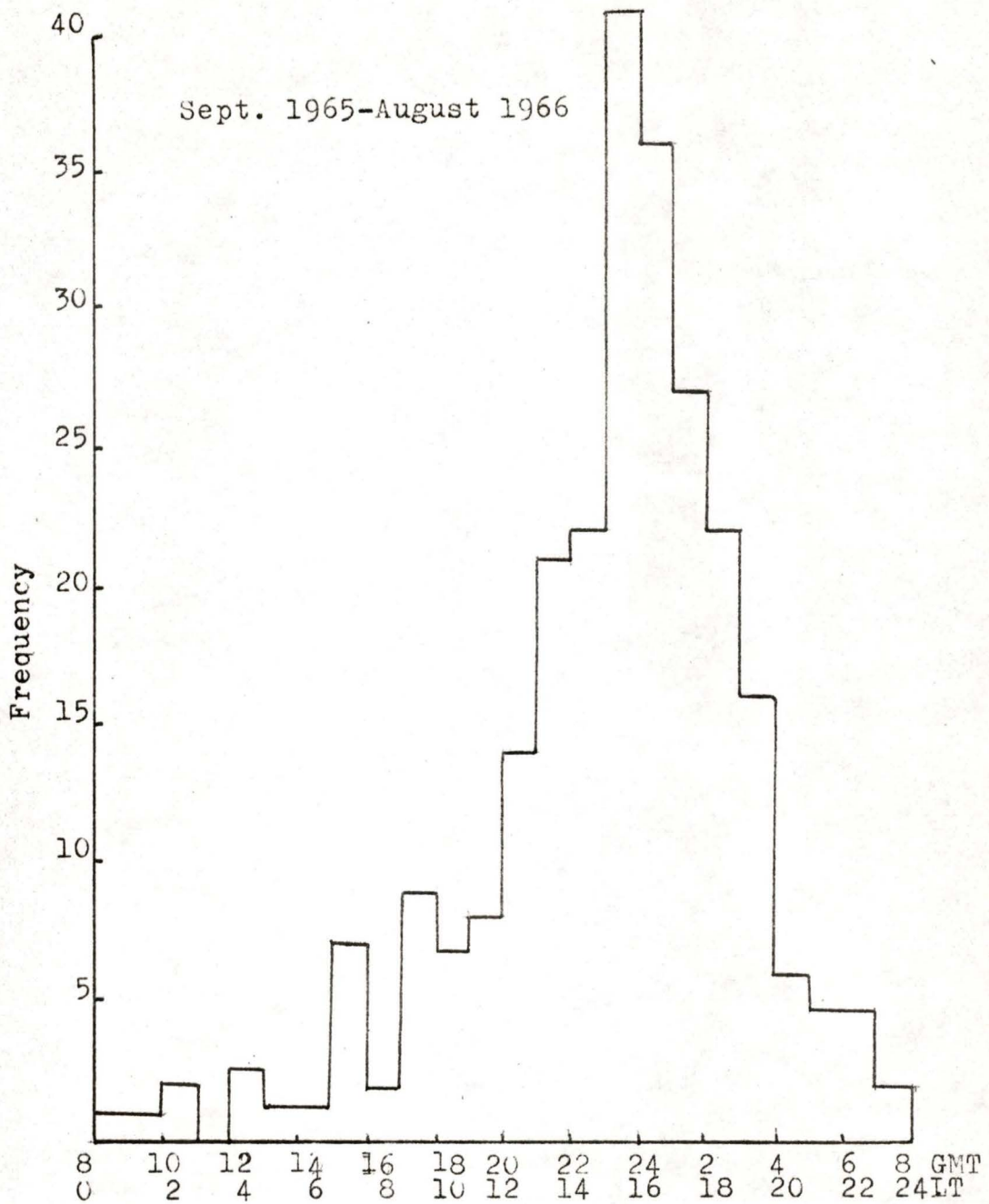


Fig. 6b Histogram of hour of maximum of diurnal variation of corrected neutrons at Victoria.

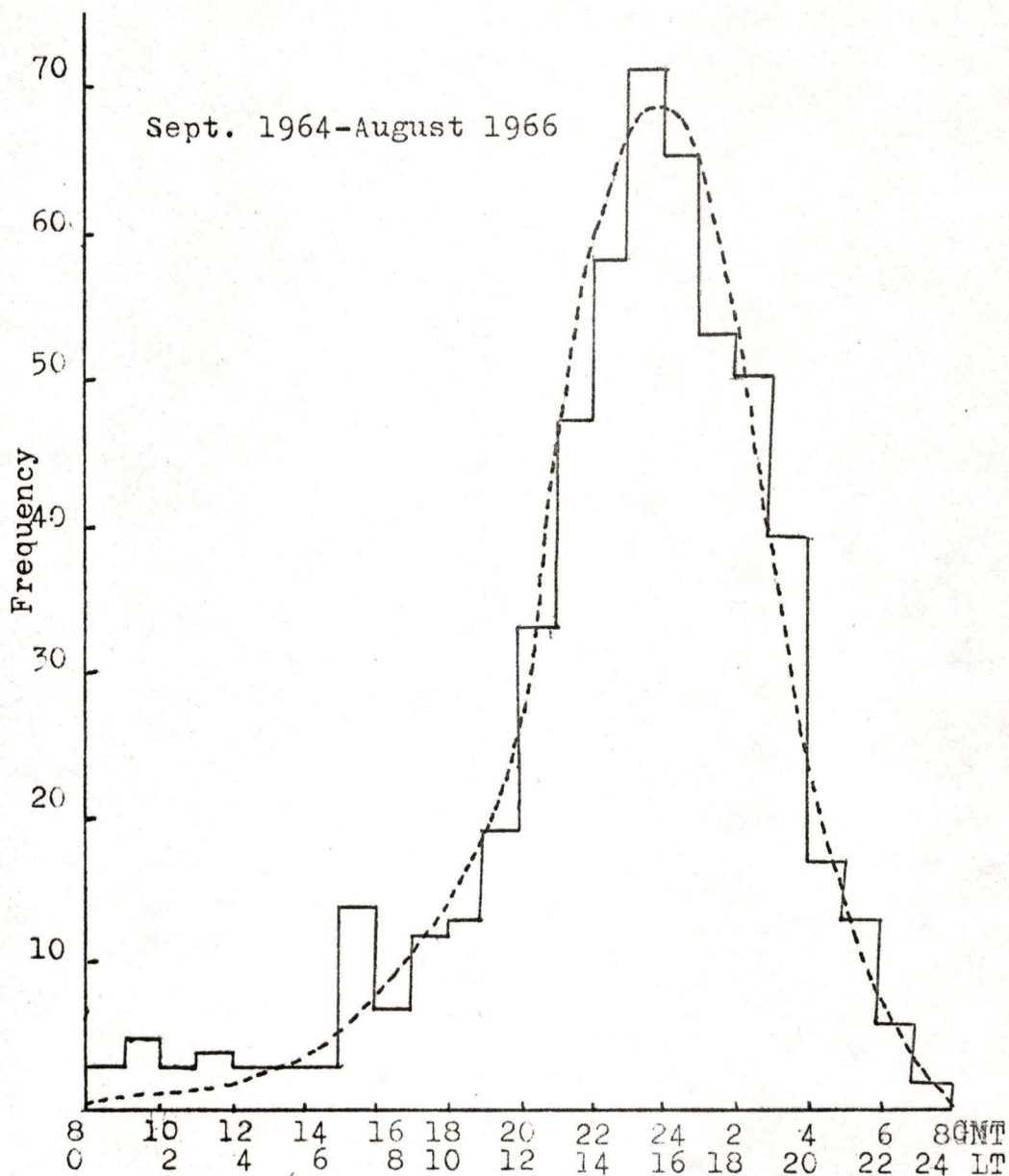


Fig. 6c Histogram of hour of maximum of diurnal variation of corrected neutrons at Victoria.

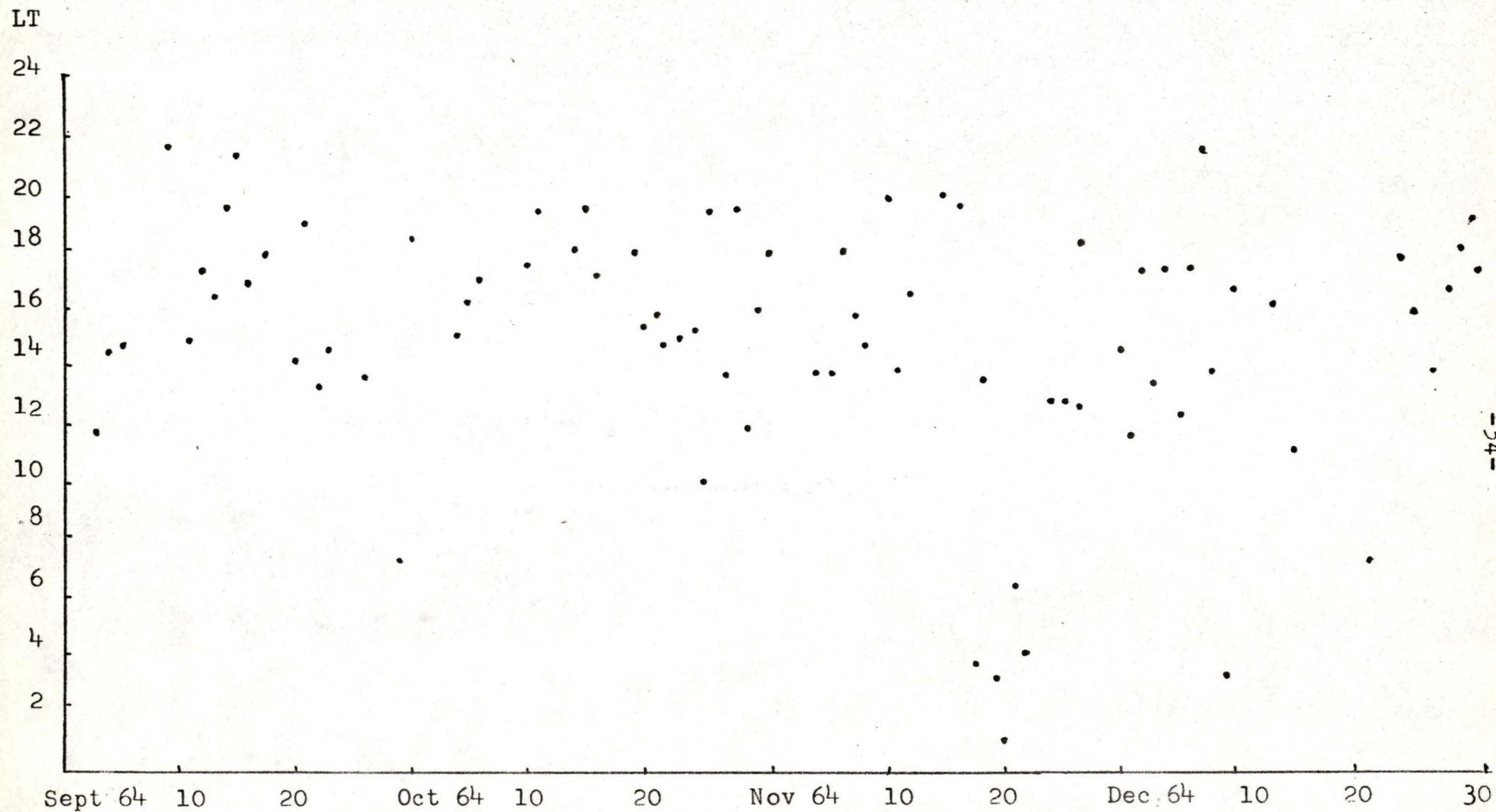


Fig. 7a Time of maximum of daily variation of corrected neutrons at Victoria

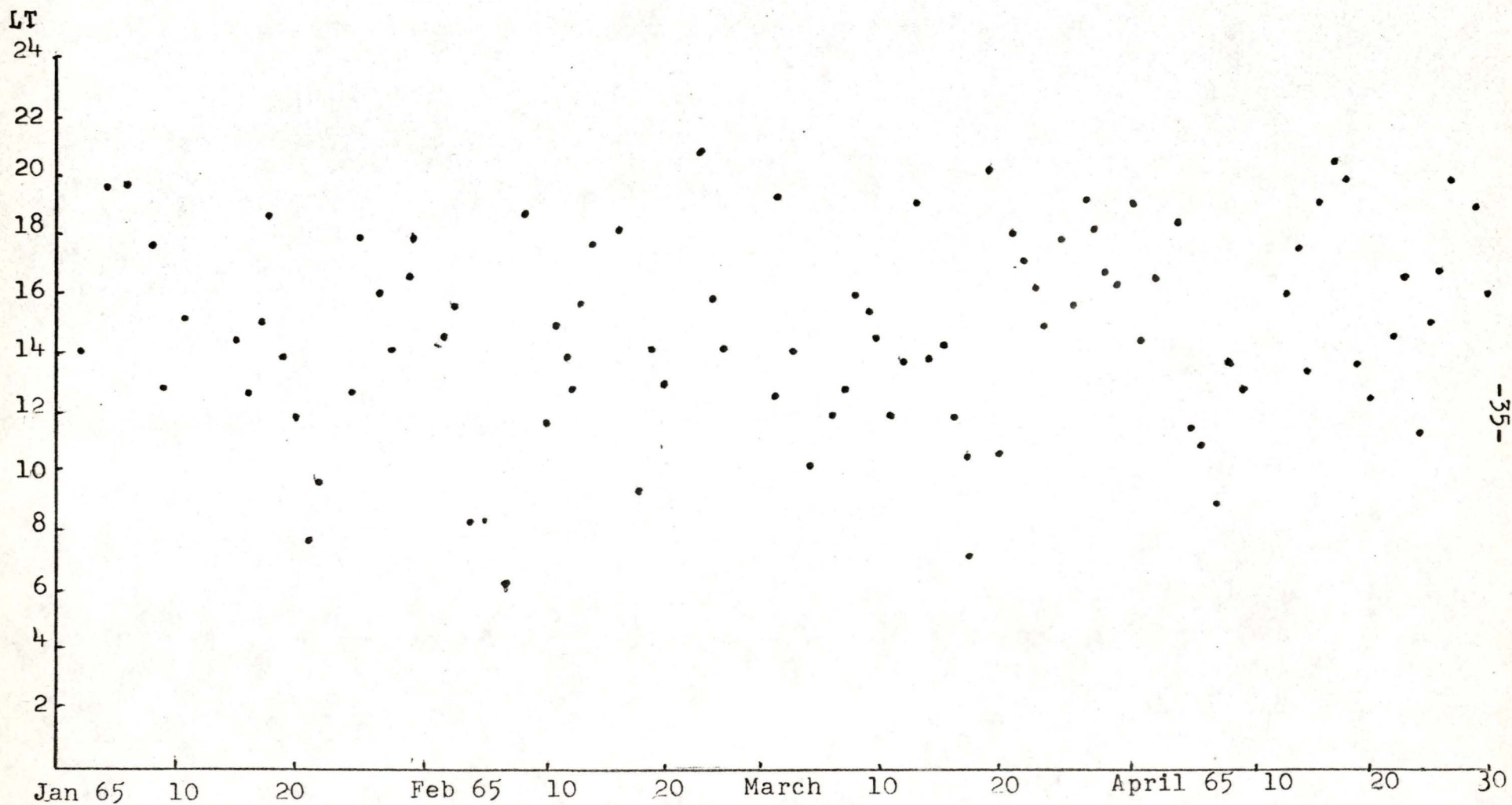


Fig. 7b. Time of maximum of daily diurnal variation of corrected neutrons at Victoria

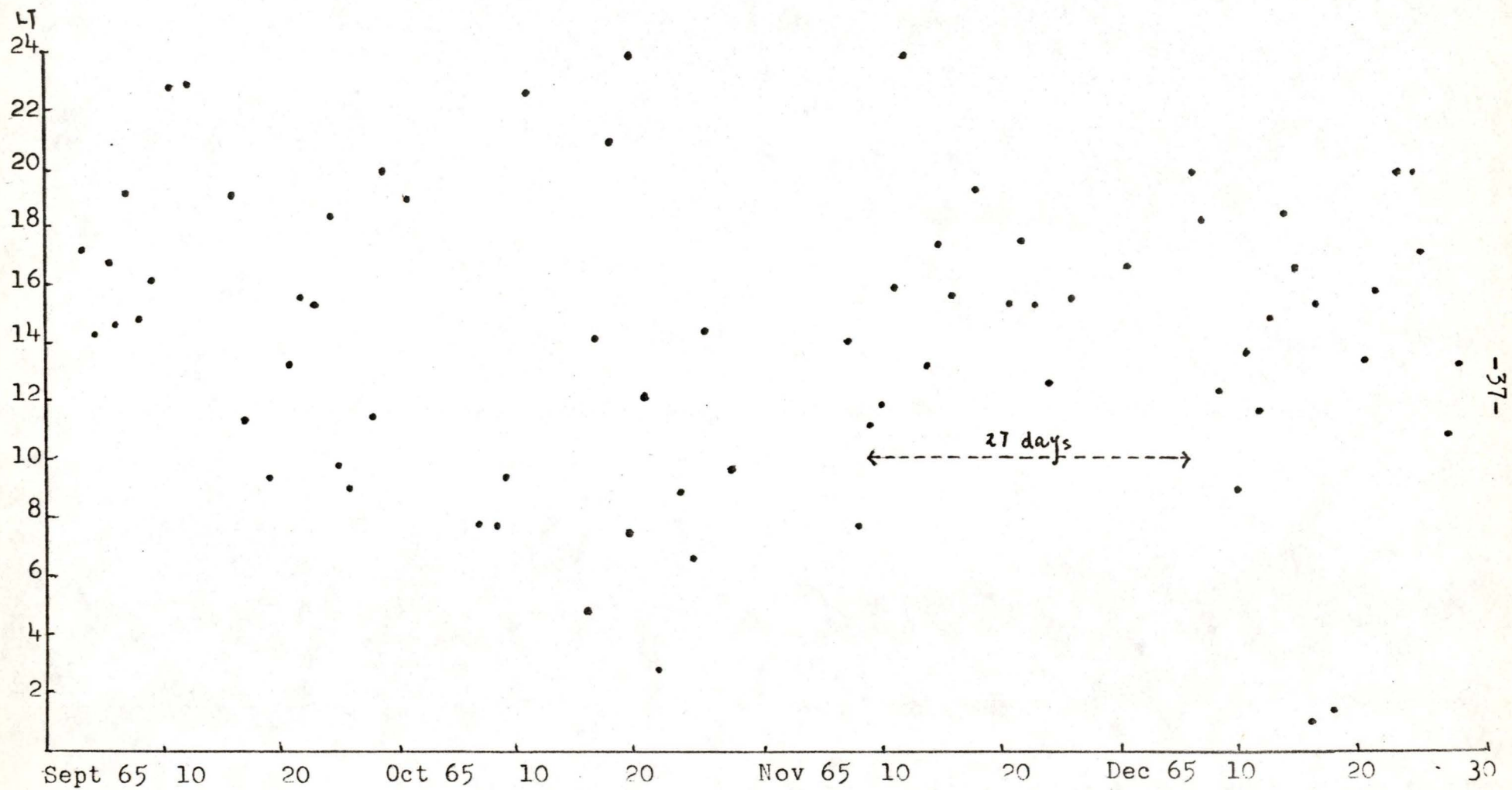


Fig. 7d Time of maximum of daily diurnal variation of corrected neutrons at Victoria

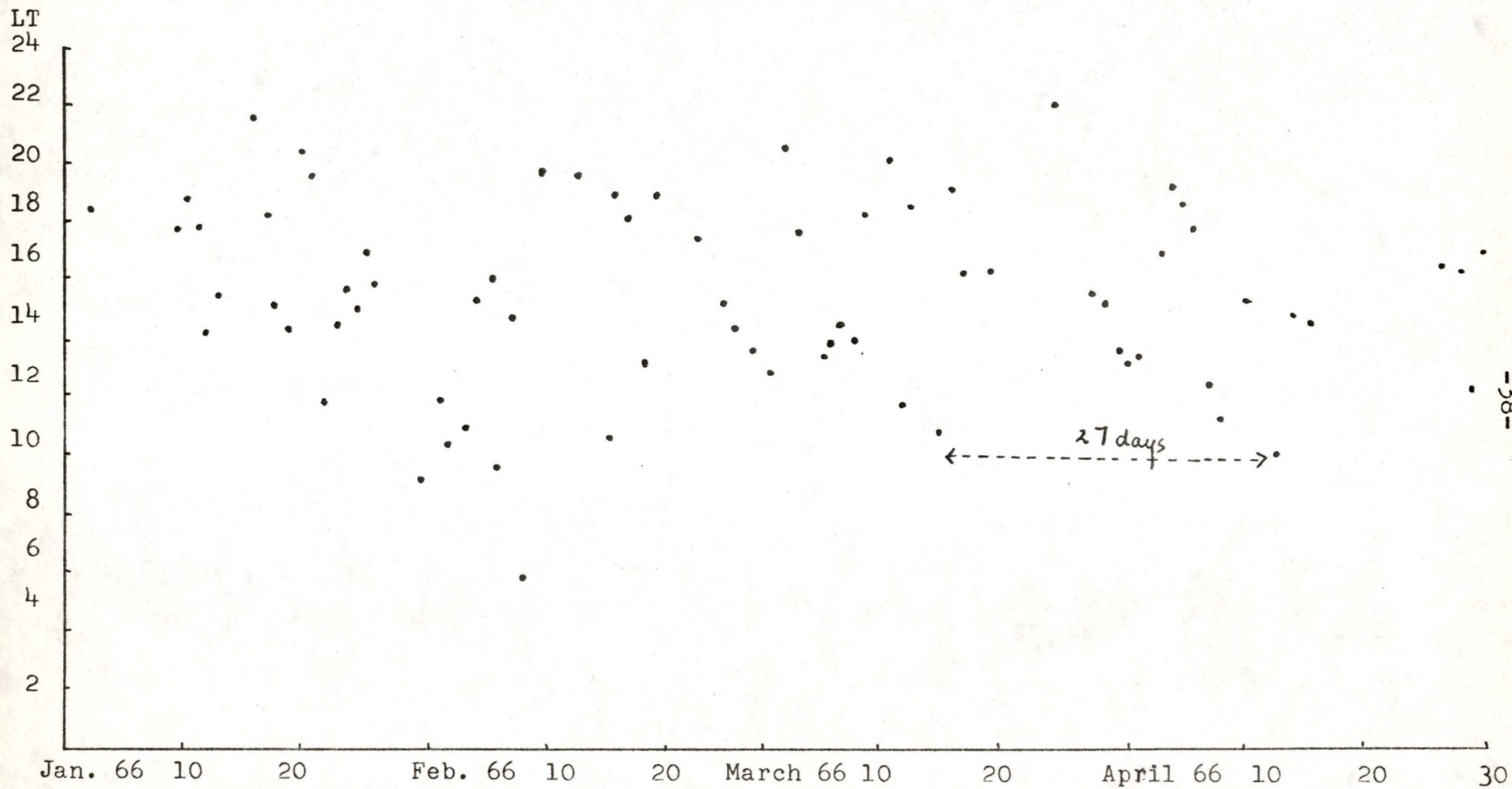


Fig. 7e Time of maximum of daily diurnal variation of corrected neutrons at Victoria

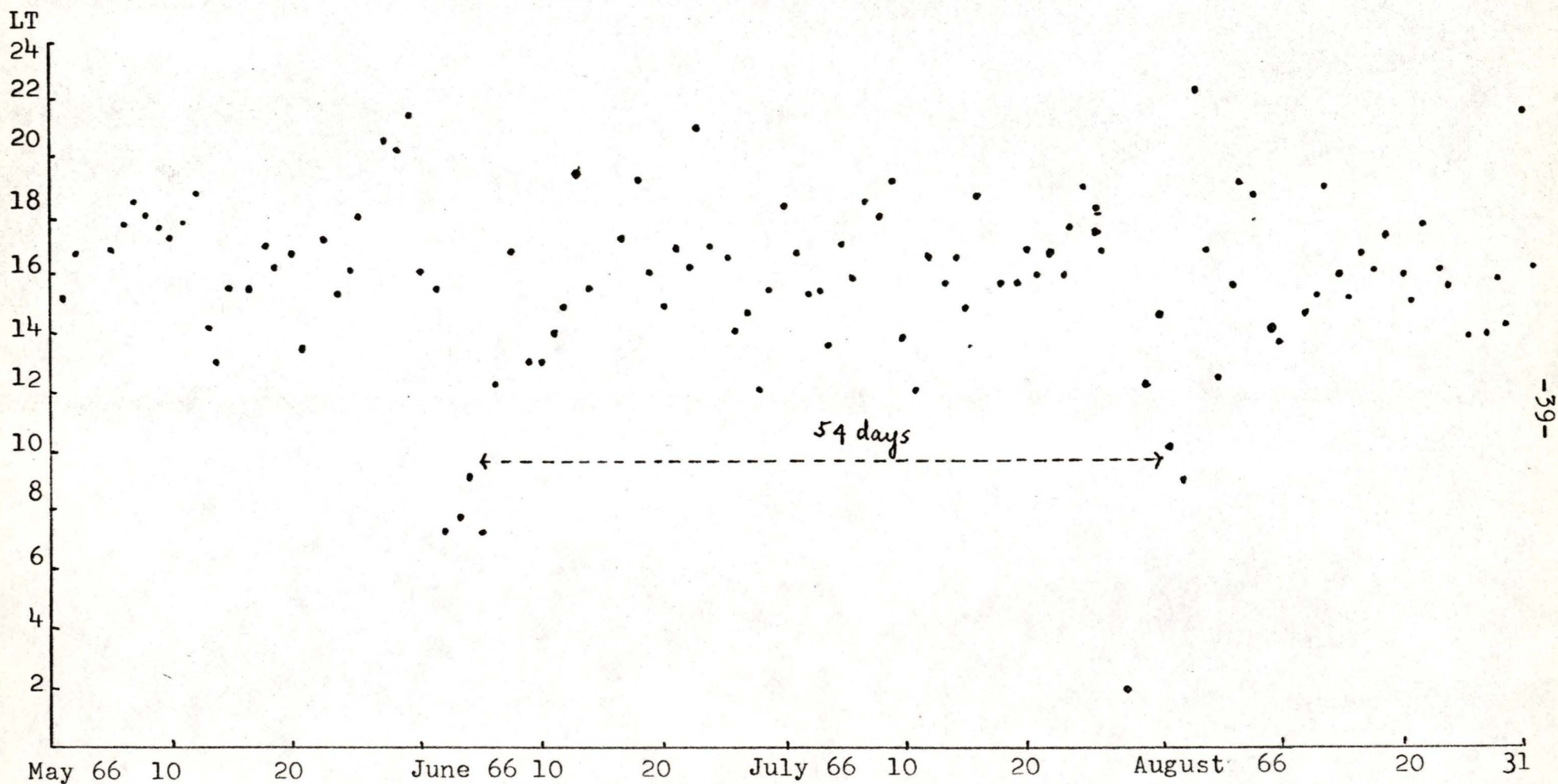


Fig. 7f Time of maximum of daily diurnal variation of corrected neutrons at Victoria

anisotropy is 1.99 hour (Rao et al (1965)³⁰).

Amplitudes of the diurnal variation are plotted versus days of the year in Figs. 8a to 8f. Amplitudes of the diurnal variation are seen to vary irregularly from 0.1 percent to 0.6 percent over short periods of time. On many days the amplitudes are enhanced, i.e. two to three times larger than the mean average yearly diurnal amplitude of about 0.2 to 0.3 percent. In some instances, notably in periods 10 January to 8 February 1966, 22 March to 20 April 1966, and 23 May to 14 June 1966, the enhanced diurnal amplitudes are associated with cosmic ray storms, (a decrease in daily mean total cosmic ray intensity followed by slow recovery to pre-decrease level), and the corresponding times of maximum tend to shift to earlier hours (see Fig. 7, 8, 9). There is a slight increase of amplitude in the summer months observed in both periods; there is no corresponding increase in daily total cosmic ray intensity (see Fig.9). No attempt has been made in this present analysis to find out whether the increase in amplitude is a seasonal effect or due to increase in solar activity or due to other causes.

Correlation of times of maximum and amplitudes is displayed in Figs. 10a and 10b with the former as x co-ordinates and the latter as y co-ordinates. At a fixed time of occurrence of maximum, the magnitude

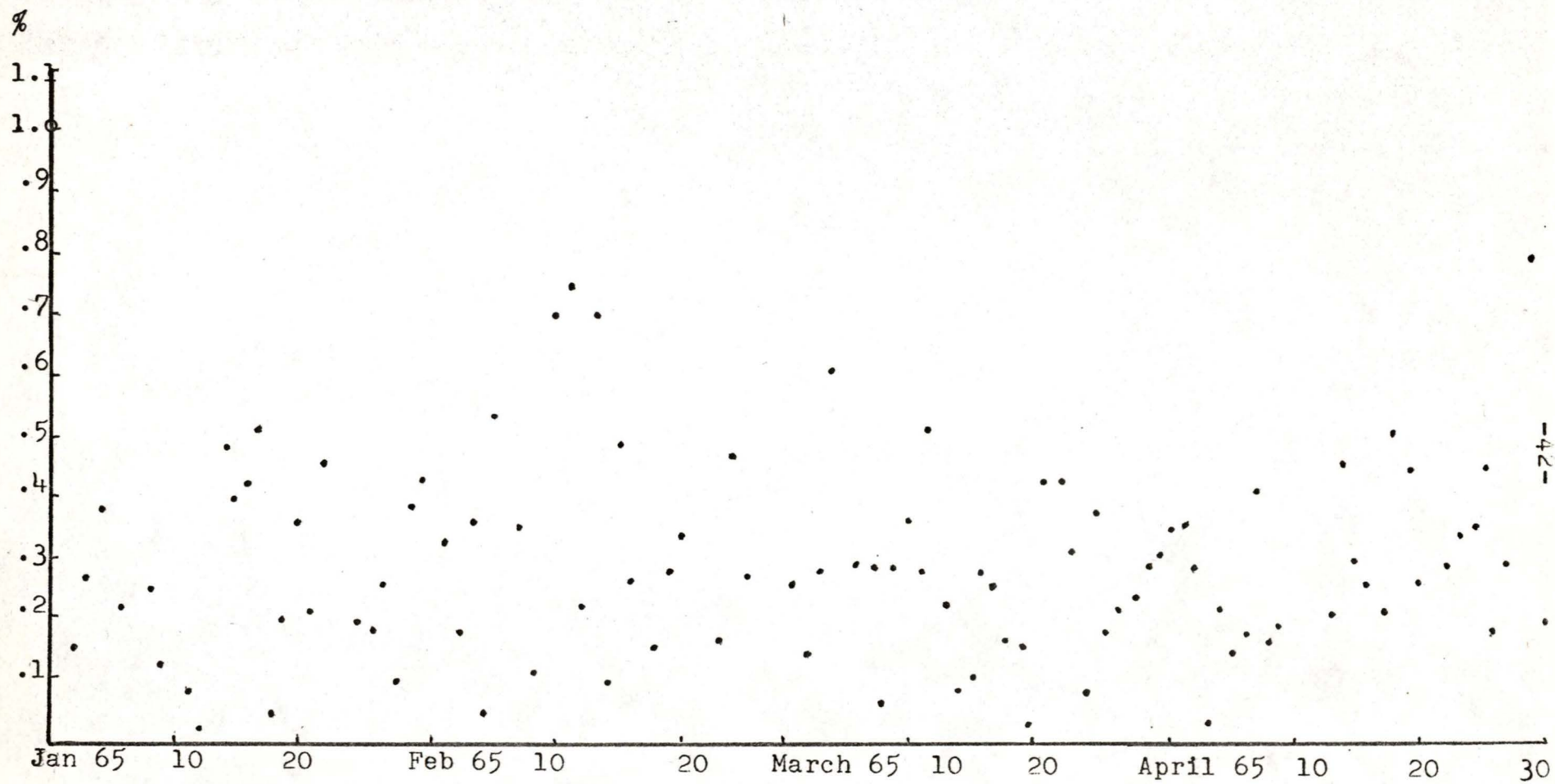


Fig. 8b Amplitude of diurnal variation of corrected neutrons at Victoria

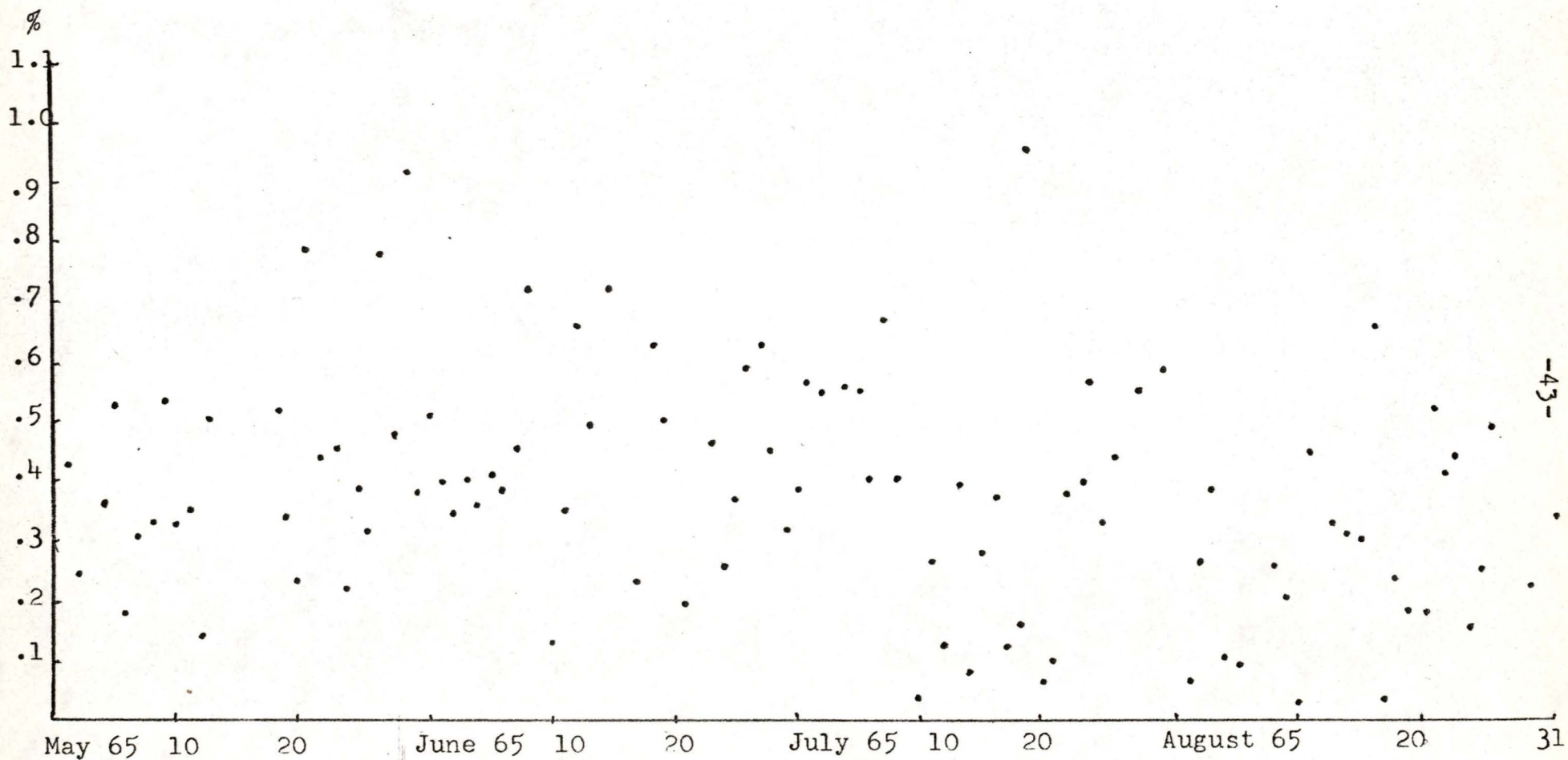
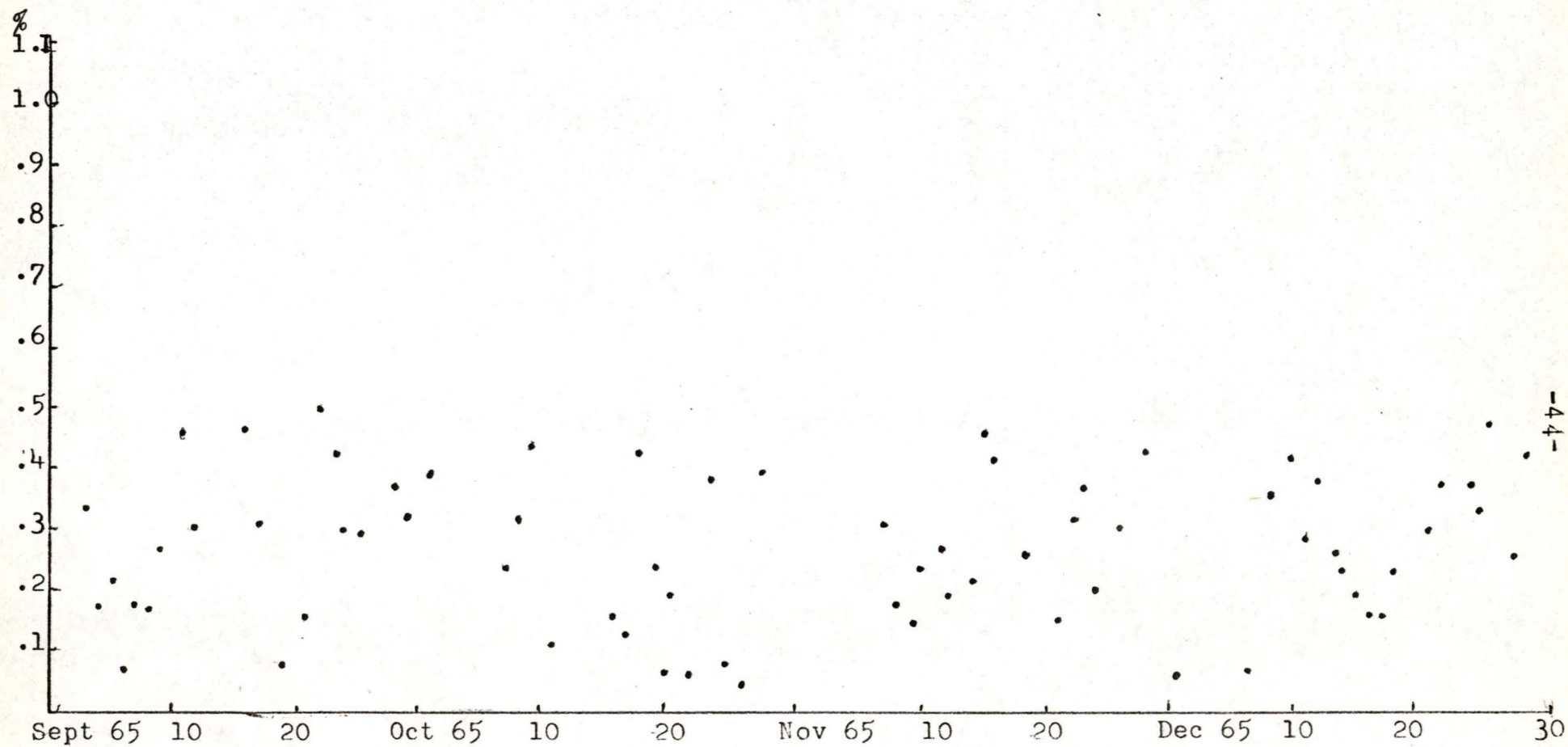


Fig. 8c Amplitude of diurnal variation of corrected neutrons at Victoria



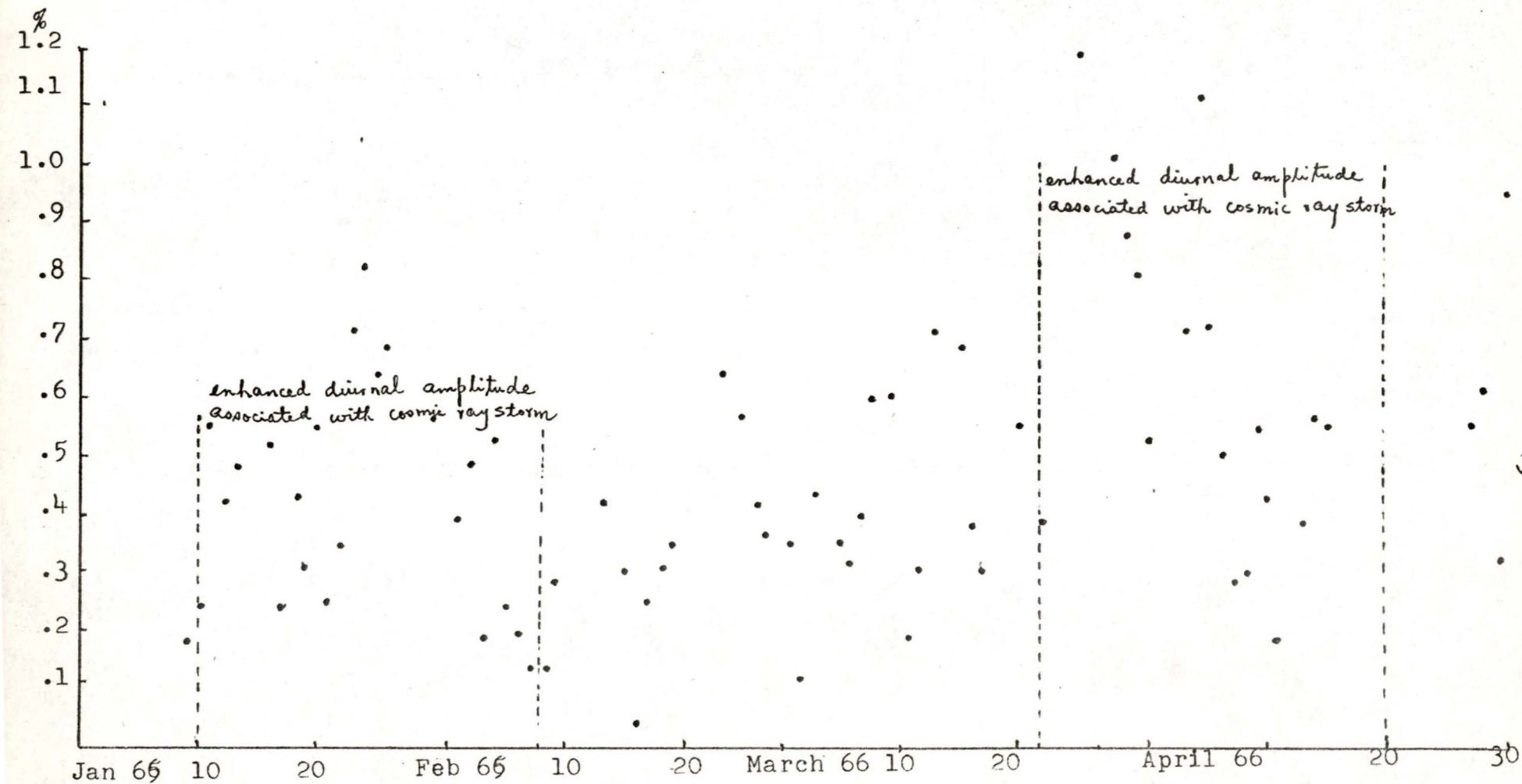


Fig. 8e Amplitude of diurnal variation of corrected neutrons at Victoria

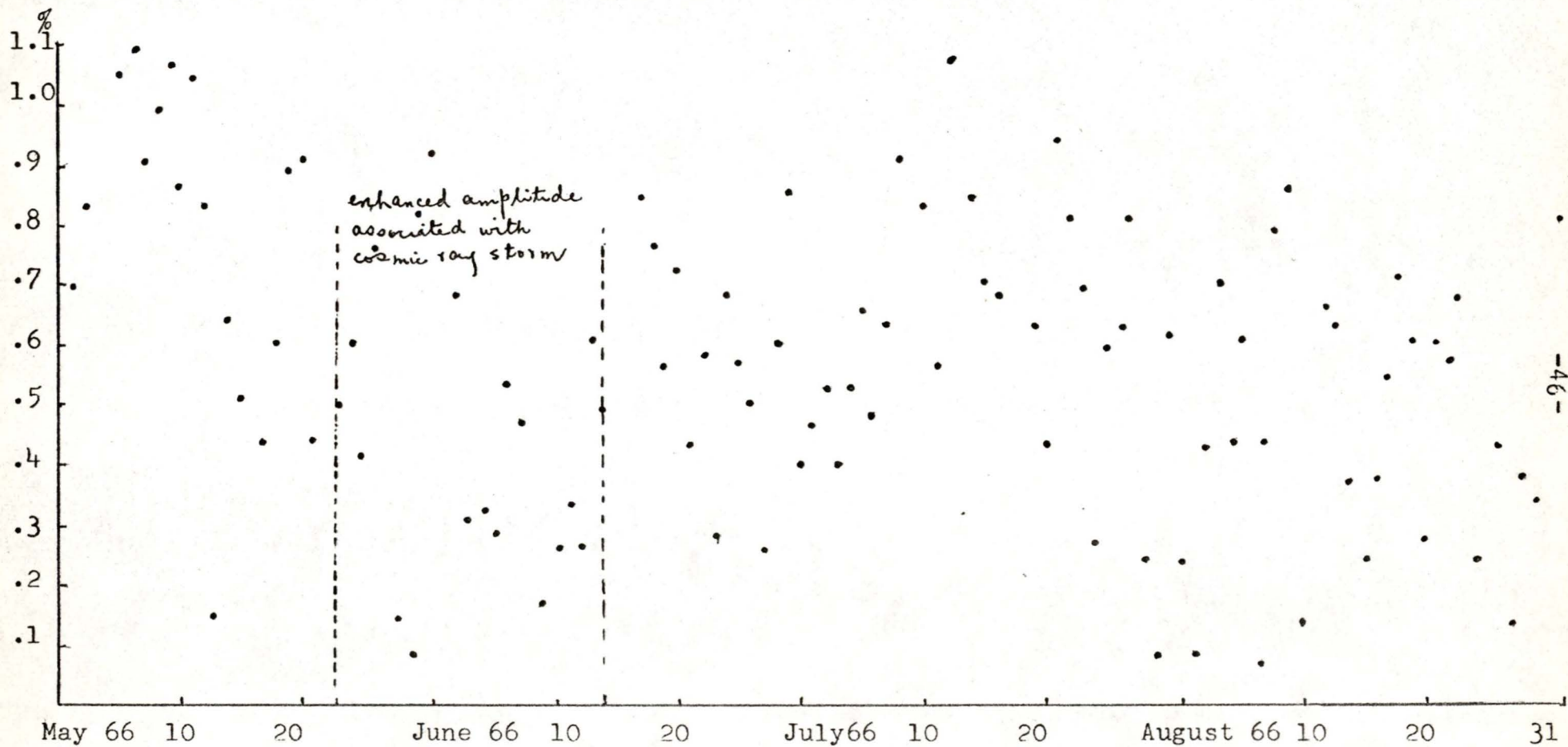


Fig. 8f Amplitude of diurnal variation of corrected neutrons at Victoria

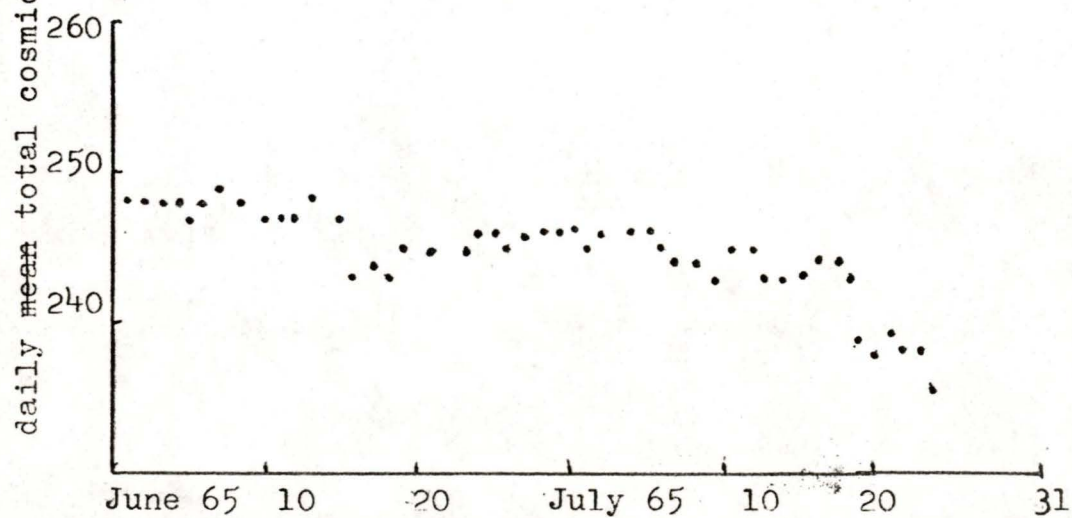
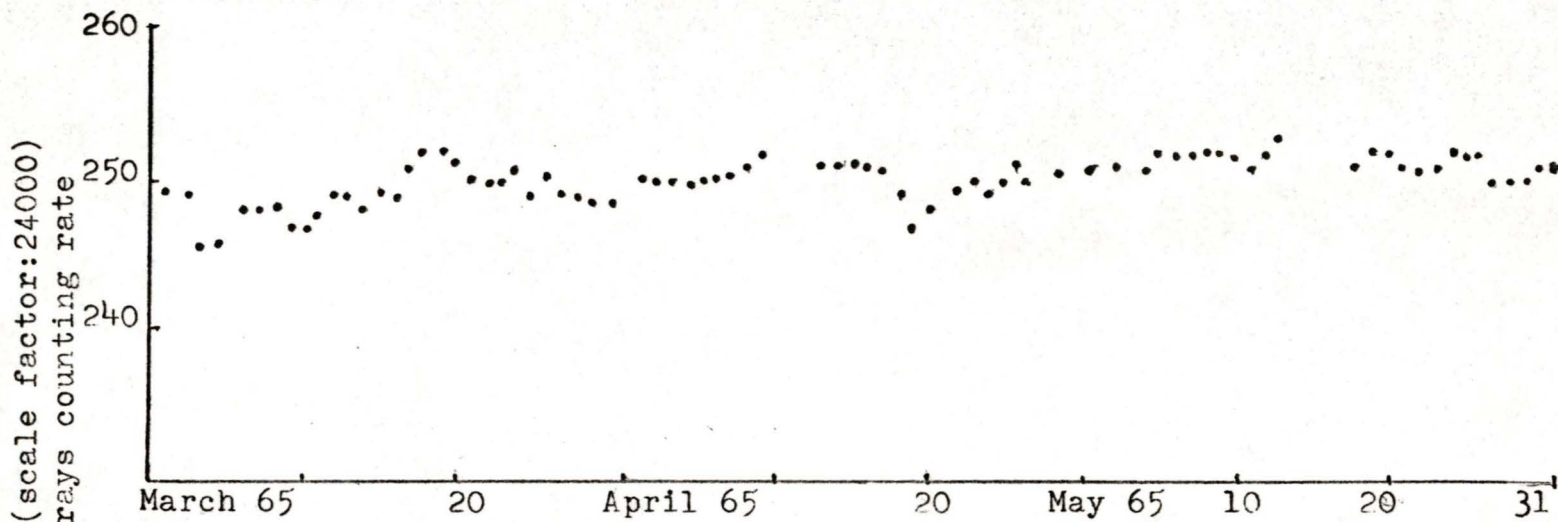


Fig. 9b Daily total pressure corrected nucleonic intensity at Victpria

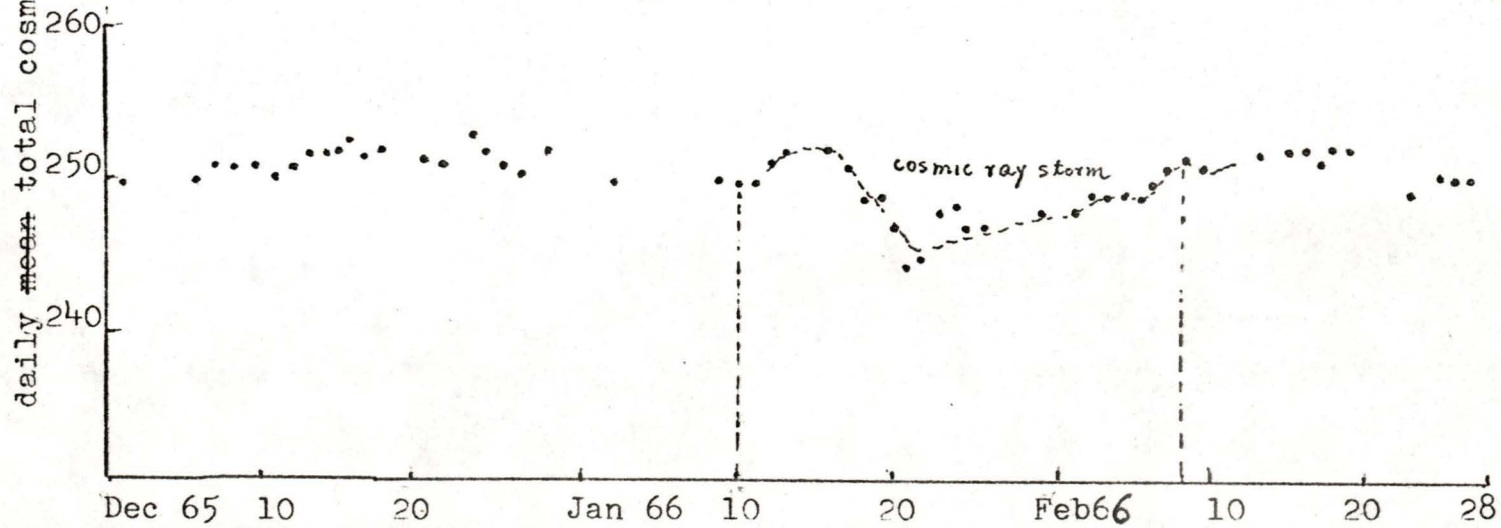
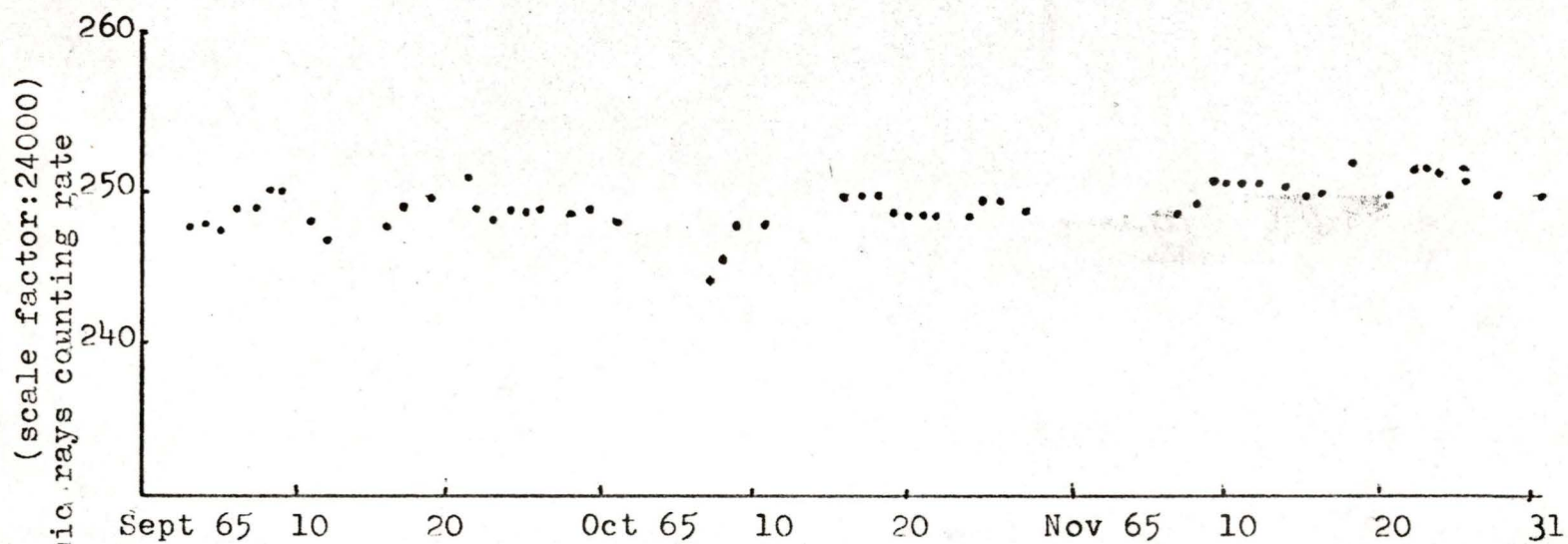


Fig. 9c Daily total pressure corrected nucleonic intensity at Victoria

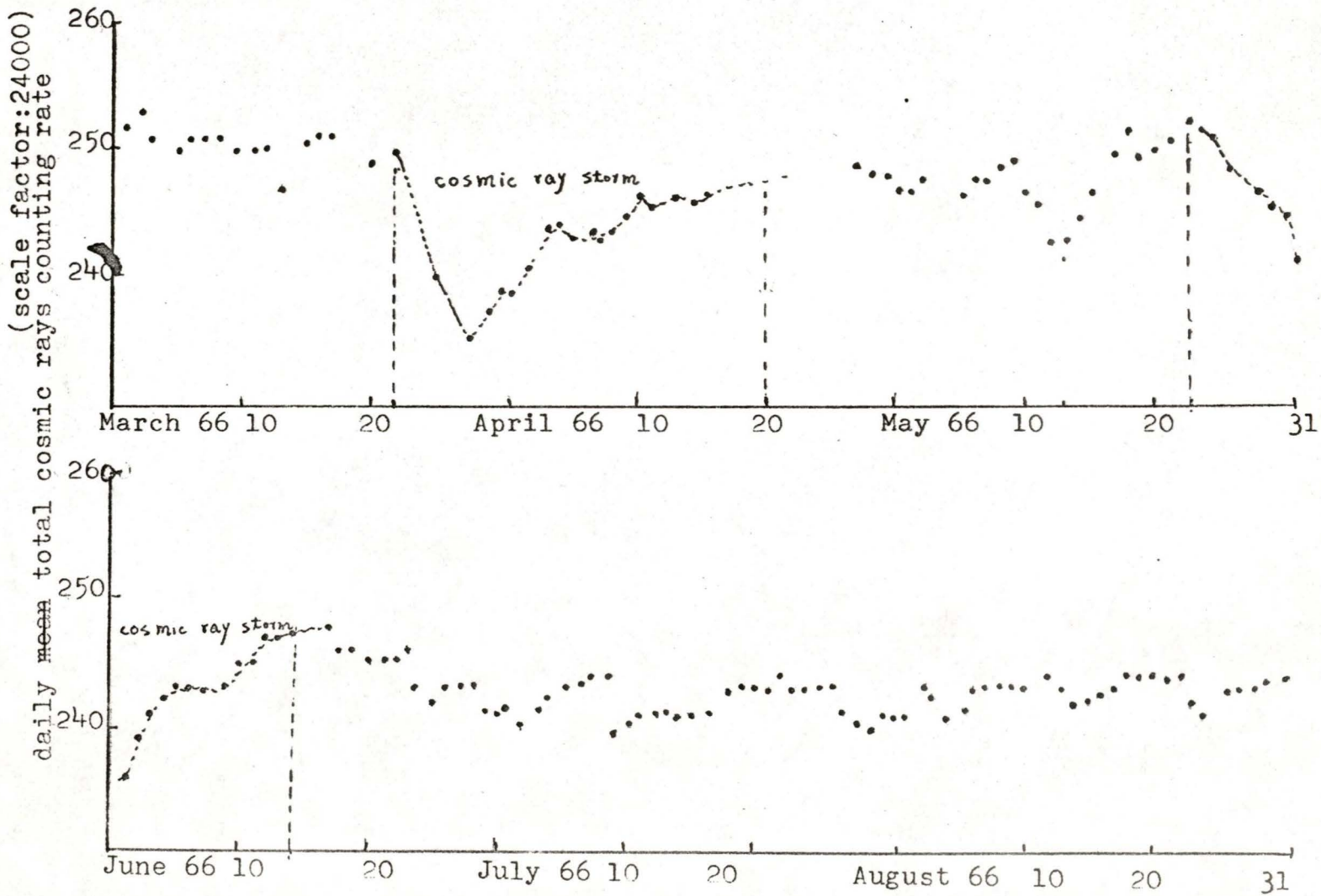


Fig. 9a Daily total pressure corrected nucleonic intensity at Victoria

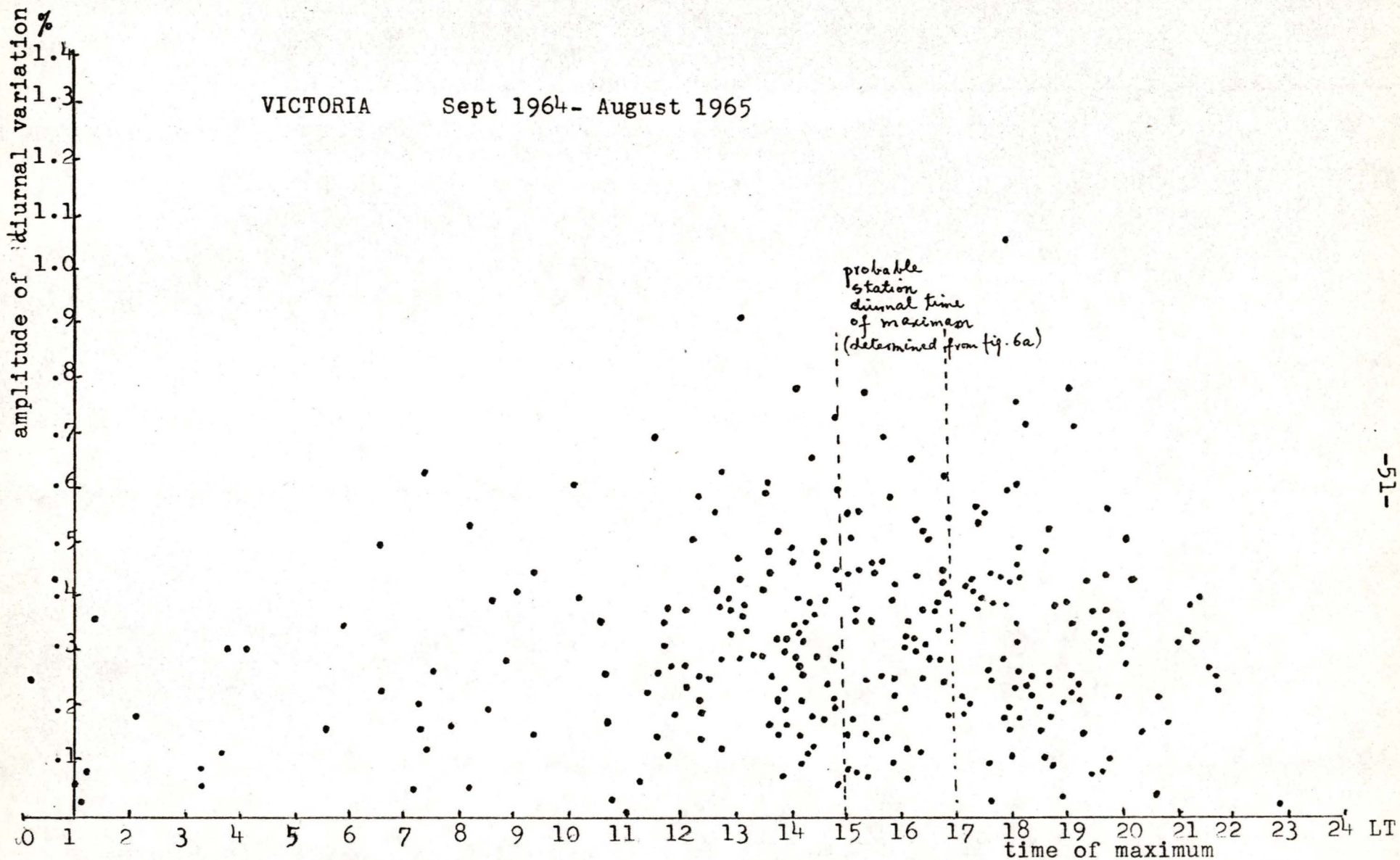


Fig. 10a amplitude of diurnal variation of corrected neutrons plotted against the corresponding time of maximum

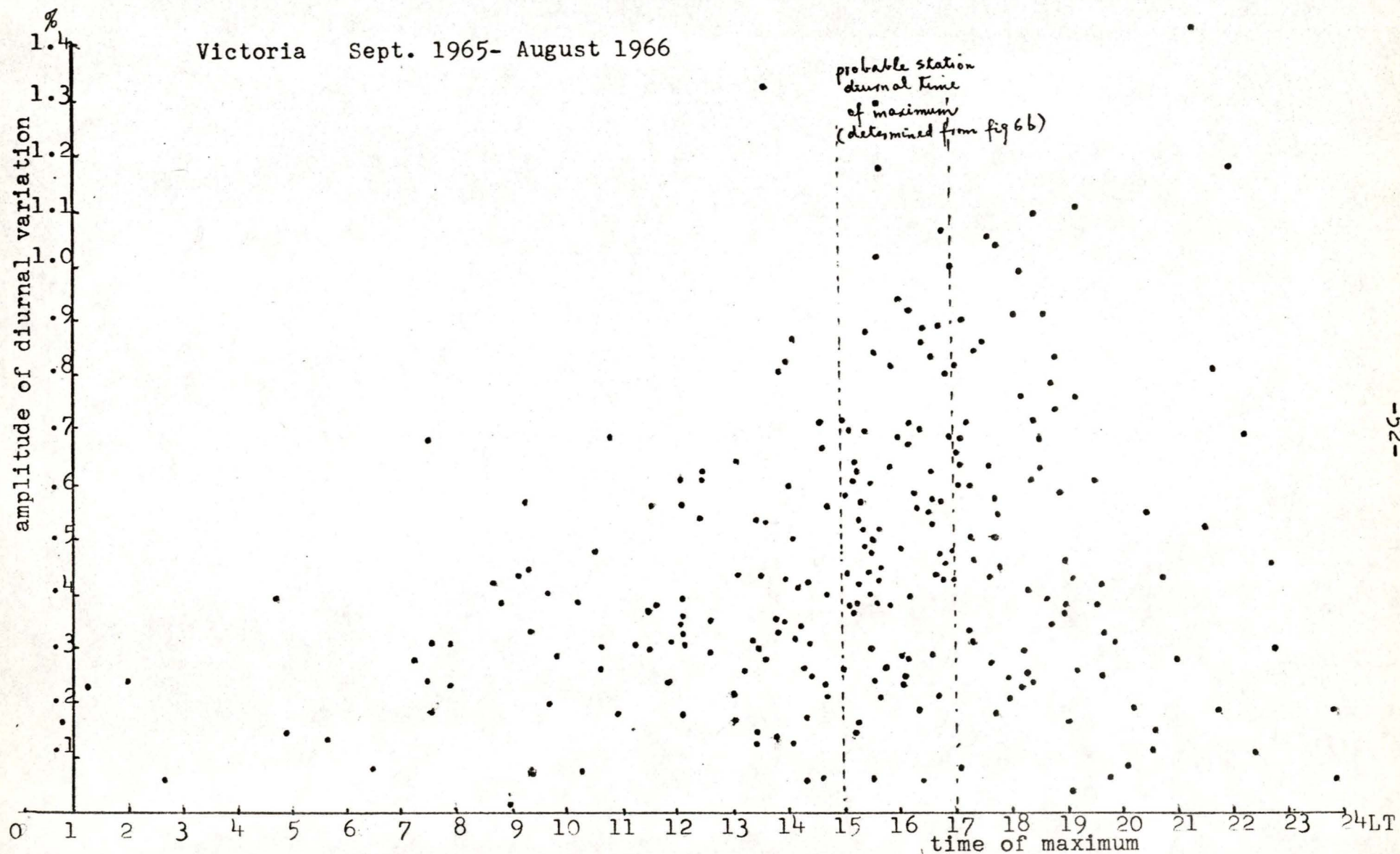


Fig. 10b Amplitude of diurnal variation of corrected neutrons plotted against the corresponding time of maximum

of diurnal variation varies within wide limits. For instance, within ± 1 hour of the probable hour of maximum, the amplitudes vary between 0.1 percent and 0.6 percent. But there is a tendency for the enhanced amplitudes to occur near the probable diurnal time of maximum. Amplitudes of diurnal vector with times of maximum remote from the probable values are relatively smaller.

CHAPTER 5

SEMI-DIURNAL VARIATION

§1. Dilemma associated with semi-diurnal variation.

The interpretation of the semi-diurnal variation has been a controversial subject. After corrections have been applied for pressure, the second harmonic of the daily variation of the nucleonic components has an amplitude of about 0.05 percent which is comparable to the uncertainty in accuracy of neutron monitors. Cosmic ray physicists such as Katzman and Venkatesan (1960)²⁹ have doubted the establishment of the pressure-corrected residual second harmonic and asserted that the semi-diurnal variation of uncorrected counts is a pressure effect. In their analysis, semi-diurnal components of pressure and uncorrected counts were found to be nearly 180° out of phase as expected. The slight discrepancy in the anticorrelated phases (about 24 minutes) might be accounted for by errors in recording barometric pressure. A barometric coefficient of -0.72 percent per millibar has been determined from the semi-diurnal components of pressure and uncorrected counts; that is comparable to the usual barometric coefficient determined from regression of pressure and uncorrected counts. However, they found a few equatorial stations such as Lae that had relatively

large residual semi-diurnal variations after the application of pressure correction to the intensity of nucleonic component.

Elliot and Dolbear (1950^{13a}, and 1951^{13b}) found that the semi-diurnal variations recorded by meson telescopes were different in the north and south directions. The phase shift between the semi-diurnal vectors determined from the two directions, however, was not as prominent as in the case of diurnal vectors. The difference in amplitudes between the two vectors cannot be considered significant as both vectors were small and liable to inaccurate determination. Ahluwalia (1962)³¹ investigated the semi-diurnal variation on geomagnetically disturbed days using data from low latitude stations, and found that the apparent small amplitudes of semi-diurnal variation averaged over geomagnetic disturbed days were due to the variability of phase of semi-diurnal variation on individual days. These experimental evidences suggest that the semi-diurnal variation is perhaps of extra-terrestrial origin.

Cosmic ray physicists have formulated qualitative anisotropic models to account for semi-diurnal variation. It is more difficult to visualize the physical processes causing a second harmonic component of primary radiation than a first harmonic. The former cannot be attributed simply to the streaming of interplanetary corpuscles or fields coupled with the earth's rotation without involving

some complicated interactions. The fact that the semi-diurnal component is significant only at equatorial latitudes is a puzzling problem. If the interpretation of anisotropy is correct, the observed amplitude should decrease at low latitudes due to relatively large asymptotic cones of acceptance at low latitudes (Rao et al (1963)²⁷). Some semi-diurnal anisotropic models have been formulated, but the predicted amplitude is so small and the scatter of time of maxima for different stations is so large that no conclusive results can be drawn.

§2. Is the semi-diurnal variation of the pressure-corrected counts a residue of inadequate pressure correction of the cosmic ray intensity?

Station barometric pressure is taken to be a measure of air mass above the detector. Changes of pressure alter the absorption mean free path of nucleons, and consequently affect the number of nucleons entering the monitor. Hence neutron intensity is anticorrelated with station pressure.

Correlation between semi-diurnal variation of pressure and uncorrected counts has been investigated using neutron monitor data of nine stations situated at different geographic co-ordinates (see Tables I and III). From the harmonic dial shown in figure 11a and b, it is observed that the semi-diurnal vectors for pressure and for uncorrected counts are nearly 180° out of phase, i.e., they are anticorrelated as expected from theory. On

Station	Mean Station Pressure (mb)	Pressure S.D.*		Uncorrected Counts S.D.*		[(T ₁ -6)~T ₂] (hrs)	Pressure Corrected Counts S.D.*	
		Amplitude (mb)	Local time of maximum, T ₁ (hrs)	Amplitude (%)	Local time of maximum, T ₂ (hrs)		Amplitude (mb)	Local time of maximum (hrs)
1. Victoria	984	0.23	10.8	0.25	5.4	0.6	0.06	4.2
2. Calgary	883	0.20	10.0	0.22	3.8	0.2	0.07	2.4
3. Sulphur Mountain	995	0.19	10.3	0.14	4.3	0.0	0.03	2.3
4. Climax	655	0.33	10.2	0.28	3.6	0.6	0.05	2.8
5. Huancayo	673	1.14	10.4	0.85	4.4	0.0	0.03	2.0
6. Lae	1008	1.25	10.2	1.05	4.1	0.1	0.18	3.0
7. Mt. Washington	786	0.25	9.5	0.22	4.1	0.6	0.06	4.5
10. Ottawa	1008	0.42	9.8	0.30	3.2	0.6	0.08	1.4
11. Resolute	1015	0.10	5.7	0.10	11.7	0.0	--	--

*S.D. = Semi-diurnal variation

Mean = 0.3

TABLE III

Deviation of semi-diurnal variation of uncorrected counts from 180° antiphase w.r.t. pressure semi-diurnal variation and the pressure corrected counts semi-diurnal variation.

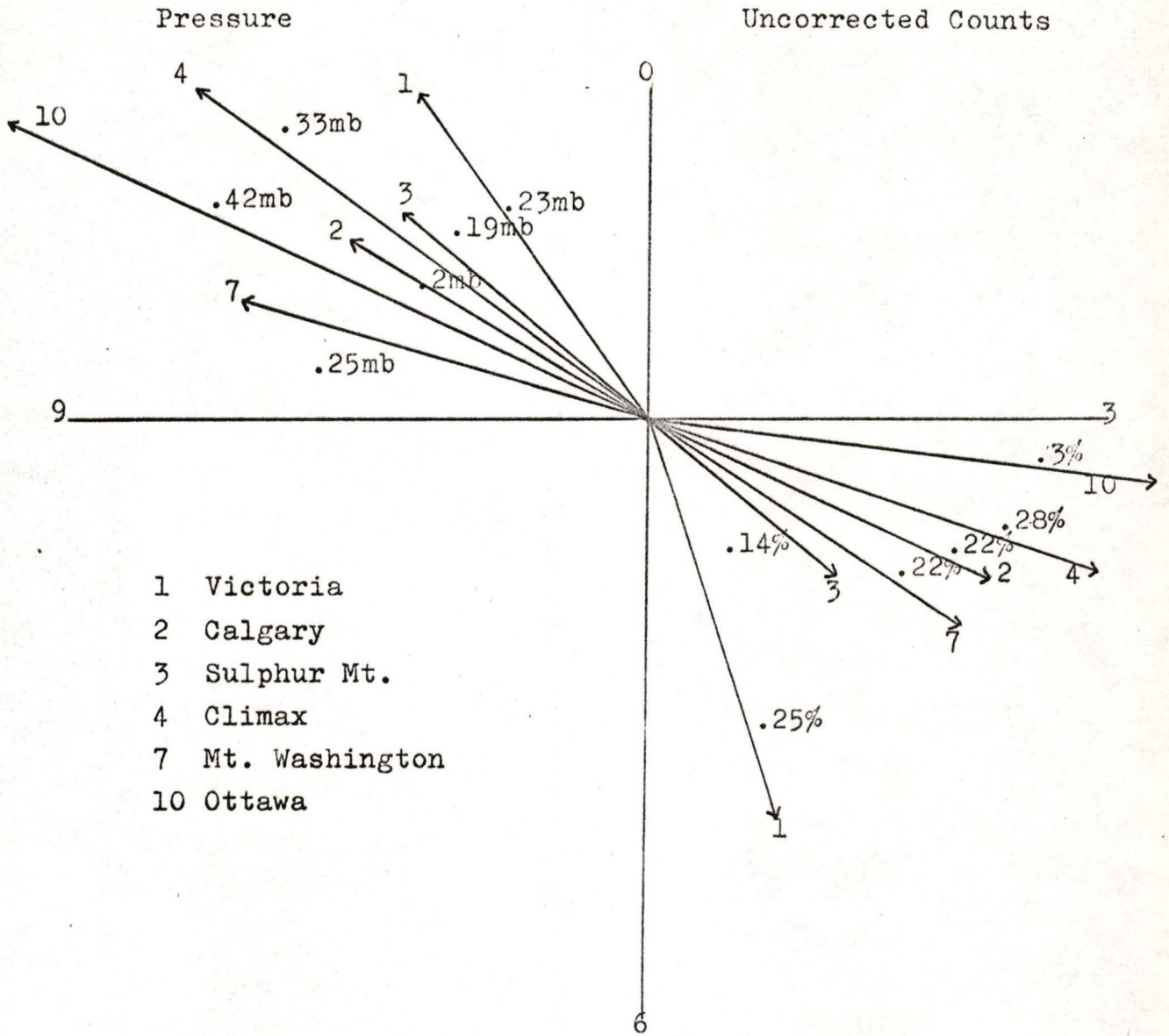


Fig. 11a Harmonic dial for semi-diurnal variation of pressure & uncorrected counts at 6 stations during 1965.

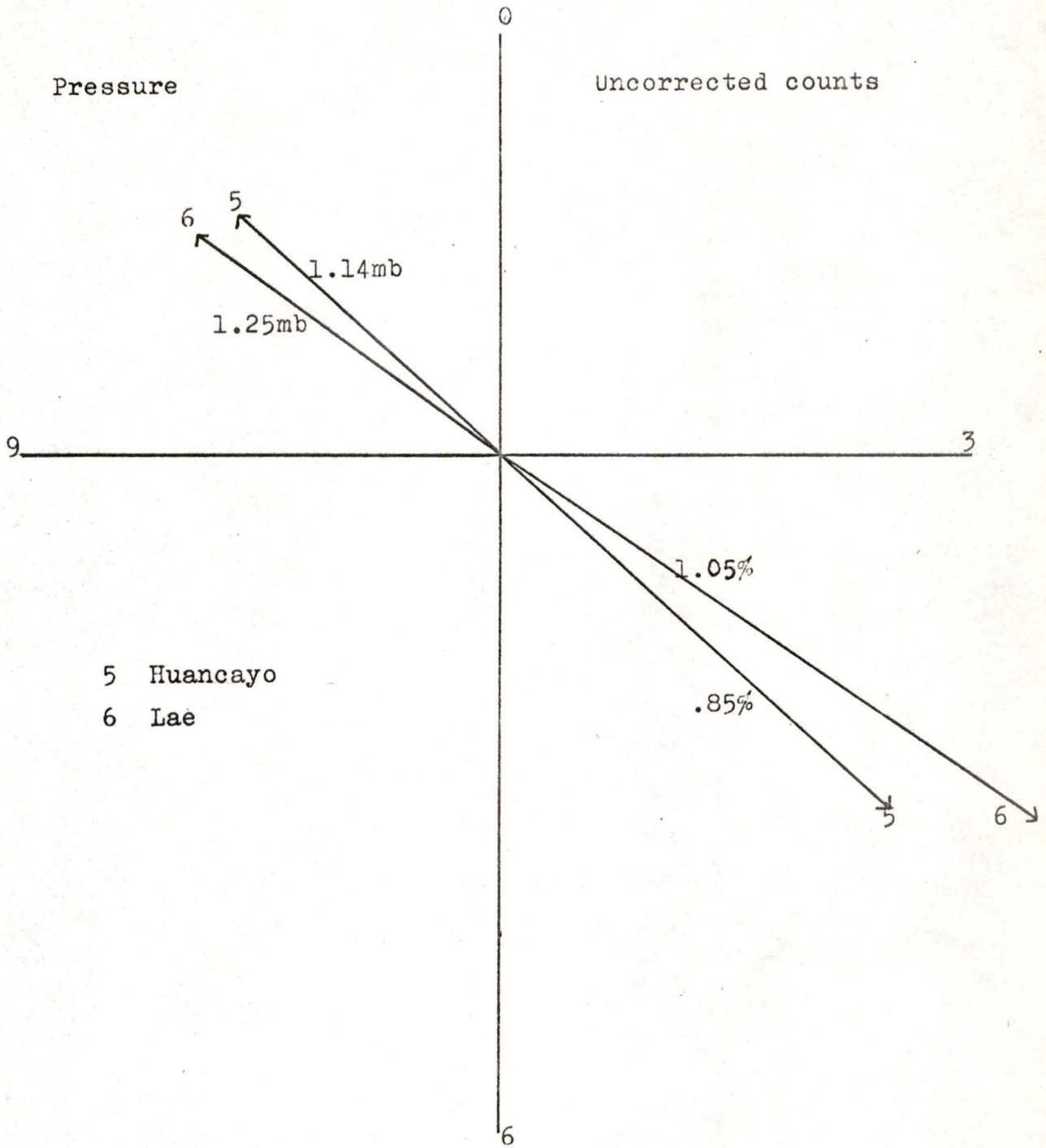


Fig. 11b Harmonic dial for semi-diurnal variation of pressure & uncorrected counts at two low latitude stations during 1965.

the average, an alteration of 9° (0.3 hour) in either pressure or uncorrected counts vector would give exactly 180° phase difference (Table III). A barometric coefficient of 0.74 percent per millibar has been determined from a linear regression of semi-diurnal amplitudes of uncorrected counts in percent and atmospheric pressure in millibar (Fig. 12). It is uncertain whether the semi-diurnal variation of uncorrected counts has components due to causes other than the meteorological factors.

The slight discrepancy in antiphase between pressure and semi-diurnal variation may well be due to several errors. It is doubtful whether the pressure recorded by barometer represents precisely the air mass above the detector. Uncertainty may arise from turbulence in atmosphere, wind velocity, instrument error; for example, error associated with pressure recording has been discussed in detail by Katzman and Venkatesan (1960)²⁹. An inaccuracy of 0.3 to 0.5 mb. has been estimated due to frictional error, clock mechanism of barograph, adjustment of microbarograph pen etc. This will introduce an error between 0.02 percent and 0.03 percent in the corrected counts and mask the true nature of the residual semi-diurnal variation, which has an amplitude only slightly greater than the error superimposed.

An anomaly in the variation of barometric coefficient as a function of altitude has been reported by

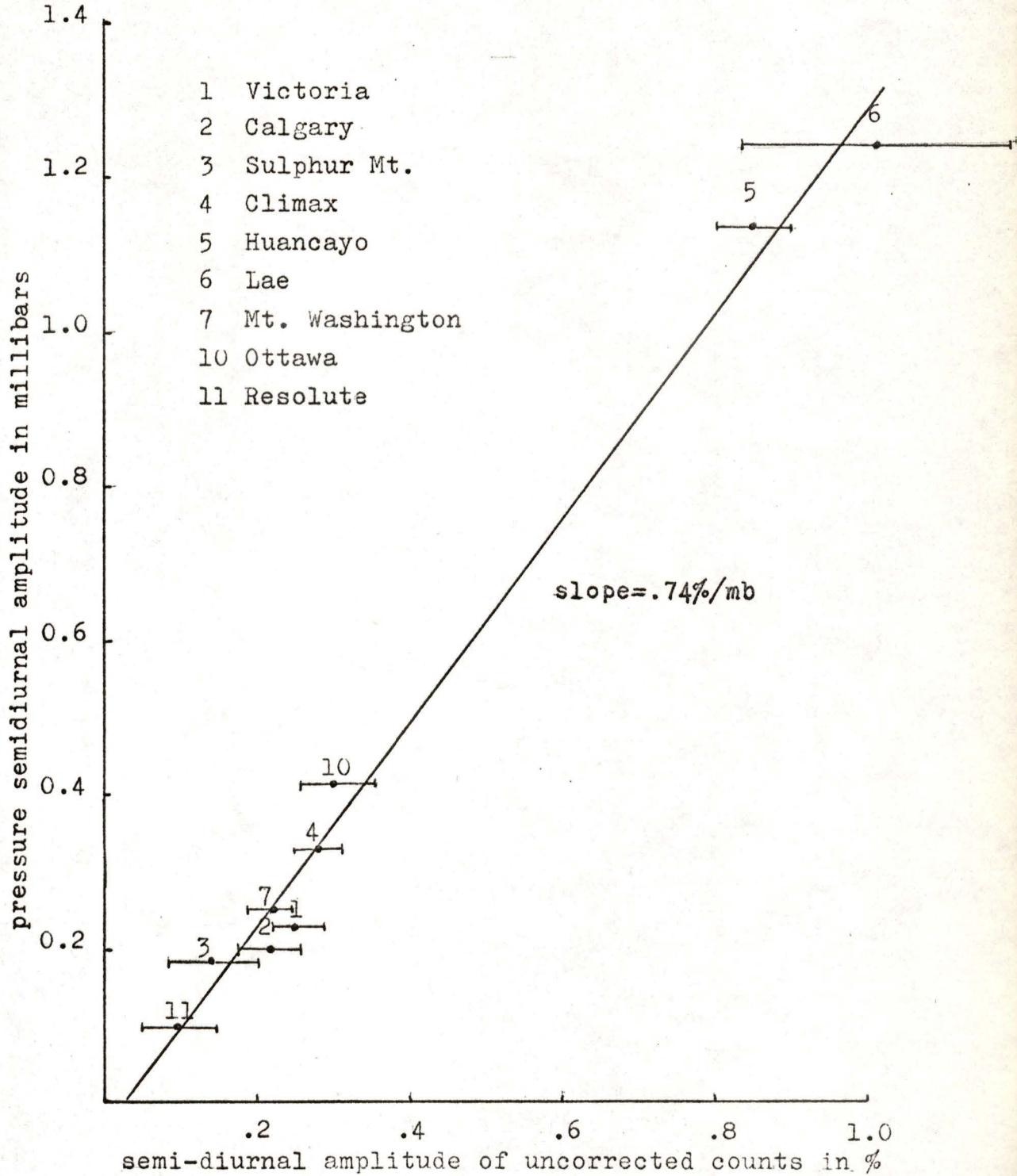


Fig. 12 Semi-diurnal amplitude of the barometric pressure versus uncorrected nucleonic intensity for 9 stations during 1965.

Bachelet et al (1965)³², Lapointe (1964)³³, Kisselbach et al (1965)³⁴. The barometric coefficient appears to be larger in lower pressure ranges on a high altitude station than a sea level station. A maximum in the barometric coefficient as a function of atmospheric depth was found at about 600 mm. Hg. This is in contrast to the increase of air mass attenuation length of the nucleonic cascade at aircraft and balloon altitudes where the average energy of nucleonic cascade is higher. Since the barometric coefficient is inversely proportional to the attenuation length, the barometric coefficient is expected to decrease with altitude in the lower atmosphere. This reveals the fact that precise theoretical analysis concerning the physical processes of how air mass will affect the low energy nucleonic component should be revised. Lack of precise correlation of pressure with counting rate may introduce additional error.

Moreover, an uncertainty of 5 percent in a determination of barometric coefficient may arise due to the dependence of atmospheric attenuation coefficient on multiplicity, dead-time and the neglect of positive temperature effect of meson-linked neutrons detected by neutron monitors. But it is found that pressure corrected diurnal and semi-diurnal variations of nucleonic component of Victoria are unaffected by a variation of ± 5 percent around the experimentally determined mean

station barometric coefficient (Table IV). Monthly mean barometric coefficients of Victoria determined in the manner described on page 12 are shown in Appendix II.

Among the data treated, semi-diurnal variations of two low latitude stations, Lae and Huancayo are of special interest. In low latitude regions, according to a theory of atmospheric oscillation outlined by Pekeris (1937)³⁵, (1939)³⁶ and developed in detail by Weekes and Wilkes (1947)³⁷, the pressure semi-diurnal variations at ground level have larger amplitudes than those at mid-latitudes and have maximum between 9.5 and 10 hours local time (a.m. and p.m.). At latitudes above 70° the hour of maximum occurs between 11:00 and 12:00 G.M.T. The anti-correlation between pressure and cosmic ray intensity causes the semi-diurnal variation of cosmic rays at low latitudes to have correspondingly larger amplitudes.

No direct correlation can be found between semi-diurnal variation of pressure uncorrected and pressure corrected counts. After applying the usual exponential correction due to mass effect, Lae has a large residual pressure effect of about .18 per cent, but Huancayo has an amplitude of about .05 per cent (Table III). It is observed that the phase difference between the pressure and uncorrected counts semi-diurnal variations is nearly 180° . The uncorrected semi-diurnal vectors and the residual vectors are plotted on a harmonic dial in

Barometric Coefficient used for Pressure Correction	Diurnal Variation of Corrected Counts		Semi-Diurnal Variation of Corrected Counts	
	Amp. %	Local time of max. in hrs.	Amp. %	Local time of max. in hrs.
.9595%/mm Hg	.22	17.1	.06	4.2
.9898%/mm Hg	.22	16.8	.06	4.4
1.0101%/mm Hg*	.22	16.6	.06	4.3
1.0303%/mm Hg	.22	17	.05	4.3
1.0606%/mm Hg	.21	16.8	.05	4.3

* mean station barometric coefficient

TABLE IV

Yearly Mean Daily Variation of Corrected Neutrons of Victoria
using Different Barometric Coefficient for Pressure Correction

figure 11c . At Lae, it seems that the residual vector shifts the uncorrected counts by 15 minutes and reduces the magnitude of amplitude by a factor of 10 per cent. The significance of such alteration is doubtful in view of the error associated with determination of pressure and neutron intensity semi-diurnal vectors. There is a possibility of considering the pressure corrected residual amplitude at Lae to be negligible when compared with the large semi-diurnal amplitude of uncorrected counts caused by the relatively large pressure semi-diurnal variation at equatorial regions.

§3. Investigation on how far the supposition that the pressure corrected semi-diurnal effect can be taken as residual error is true, using monthly data of Victoria.

A slight discrepancy in antiphase between pressure and uncorrected neutrons semi-diurnal variations has been observed in the analysis given in section 5.2. The discrepancy is further investigated in this section, using the monthly mean semi-diurnal variation of pressure-corrected counts, pressure, pressure uncorrected counts of the Victoria station for the period September 1964 to August 1966 (Figs. 13, 14a, 14b, 15a, 15b). The directions of semi-diurnal vectors of uncorrected counts indicate times of minimum to show the anticorrelation with pressure semi-diurnal variation.

In the period September 1964 to August 1965, times

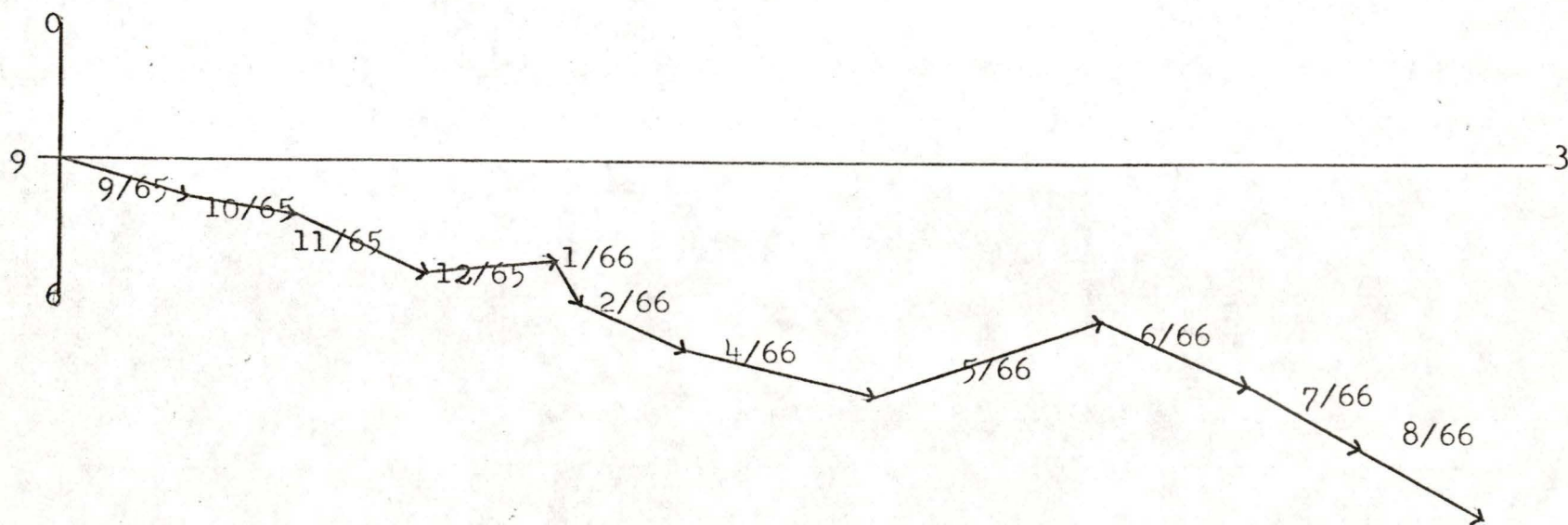
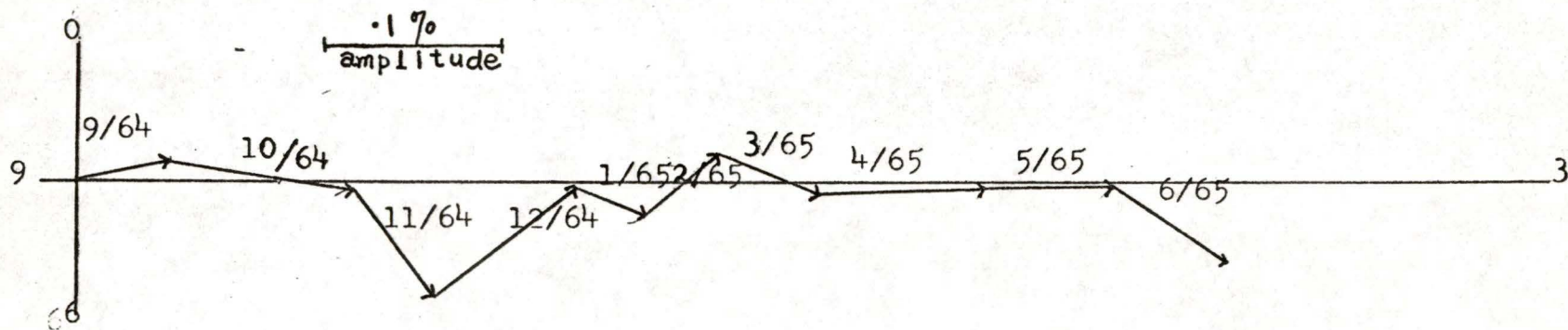


Fig. 13 Monthly mean semidiurnal variation of corrected neutrons at Victoria for the period Sept. 1964-August 1966

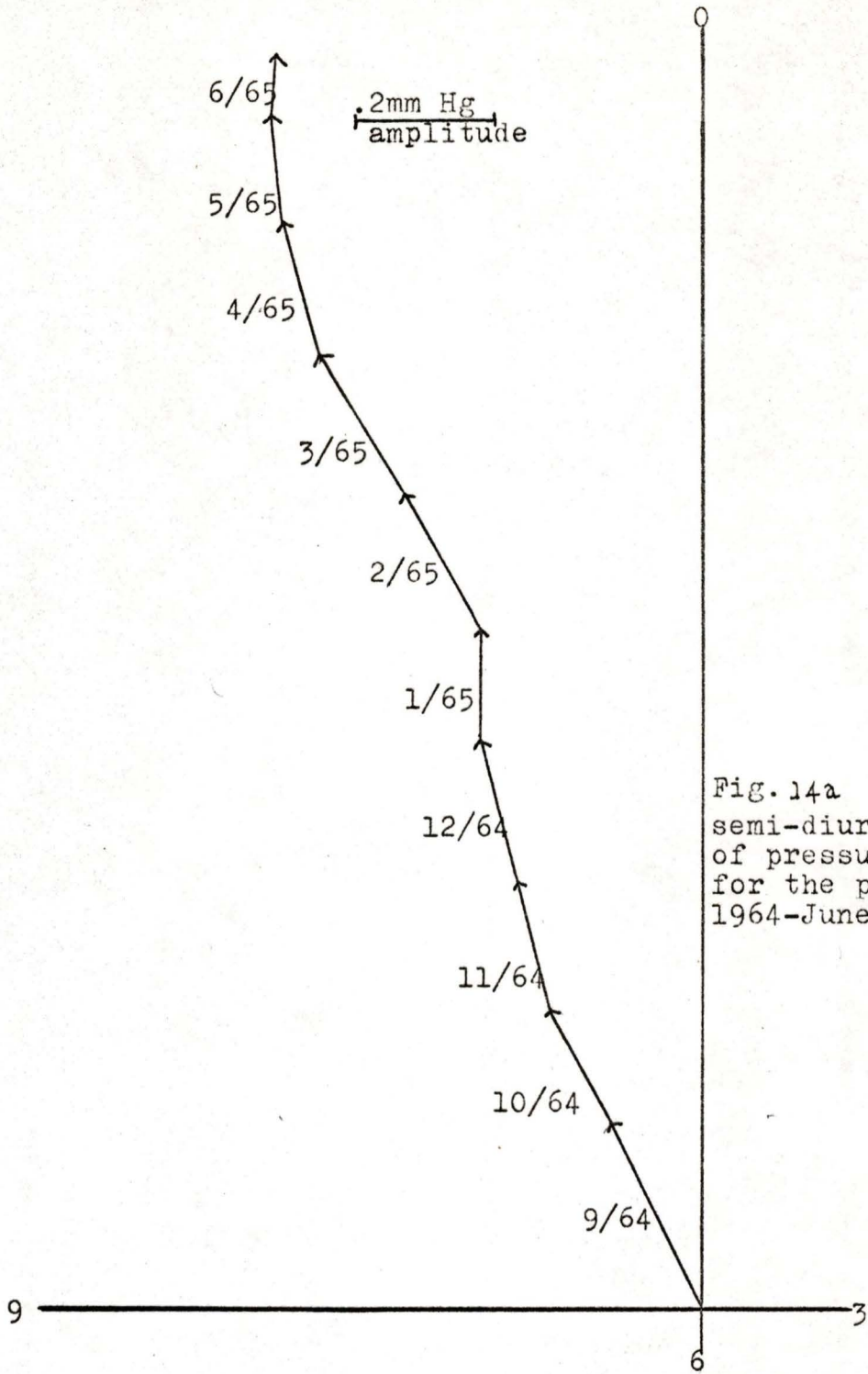


Fig. 14a Monthly mean semi-diurnal variation of pressure at Victoria for the period Sept. 1964-June 1965.

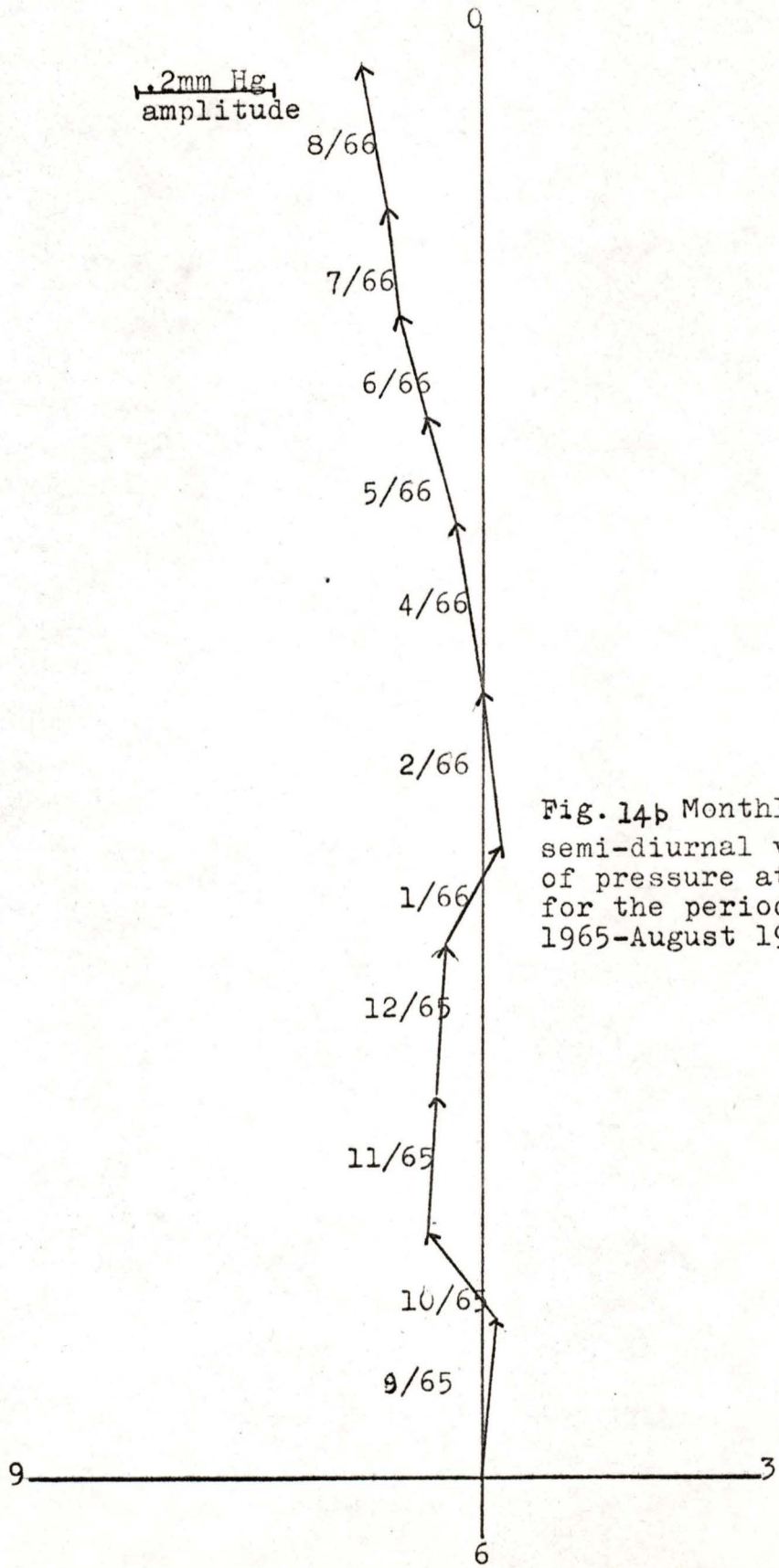


Fig. 14b Monthly mean semi-diurnal variation of pressure at Victoria for the period Sept. 1965-August 1966.

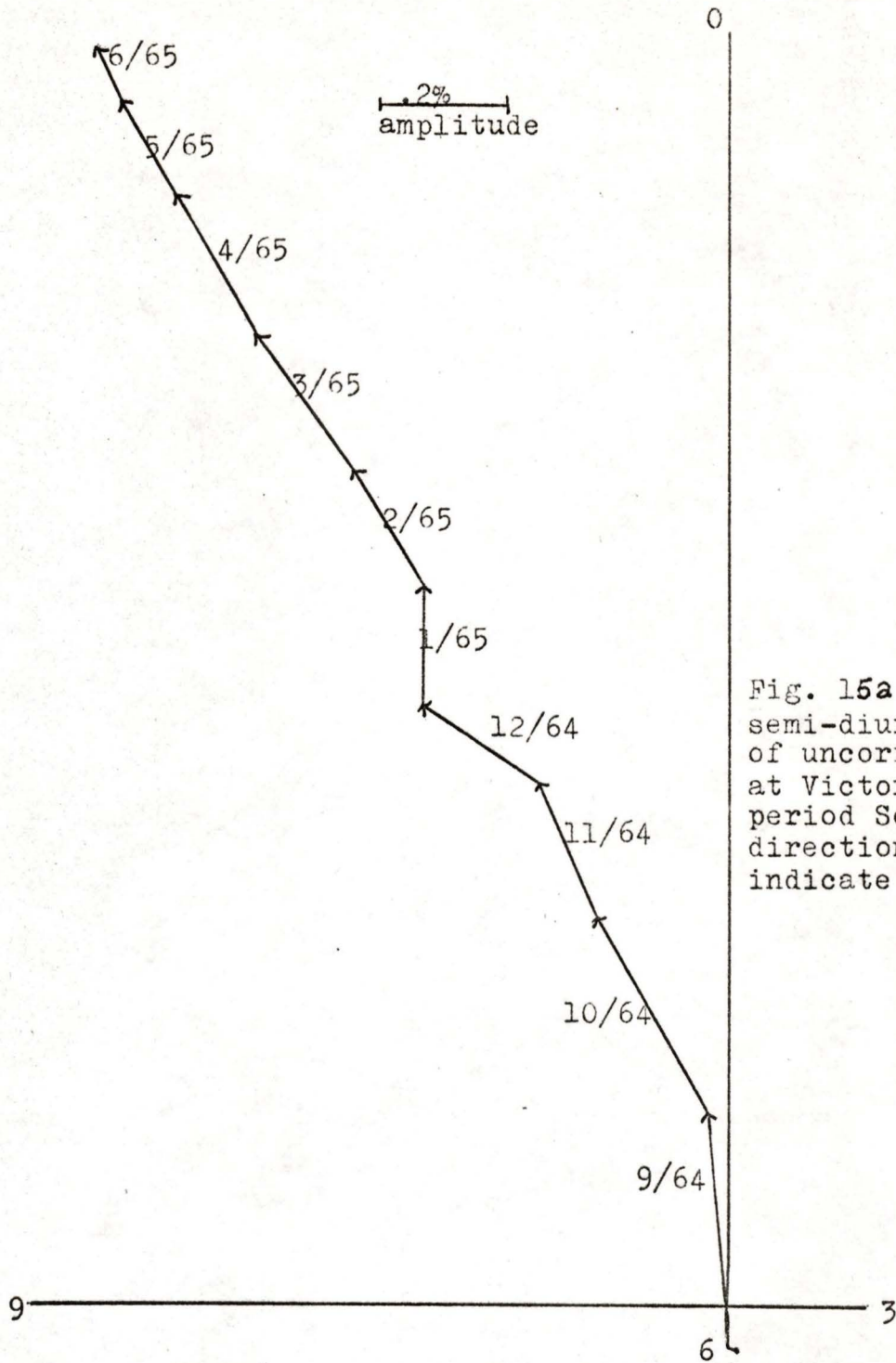


Fig. 15a Monthly mean semi-diurnal variation of uncorrected neutrons at Victoria for the period Sept '64-June '65; directions of vectors indicate time of minimum

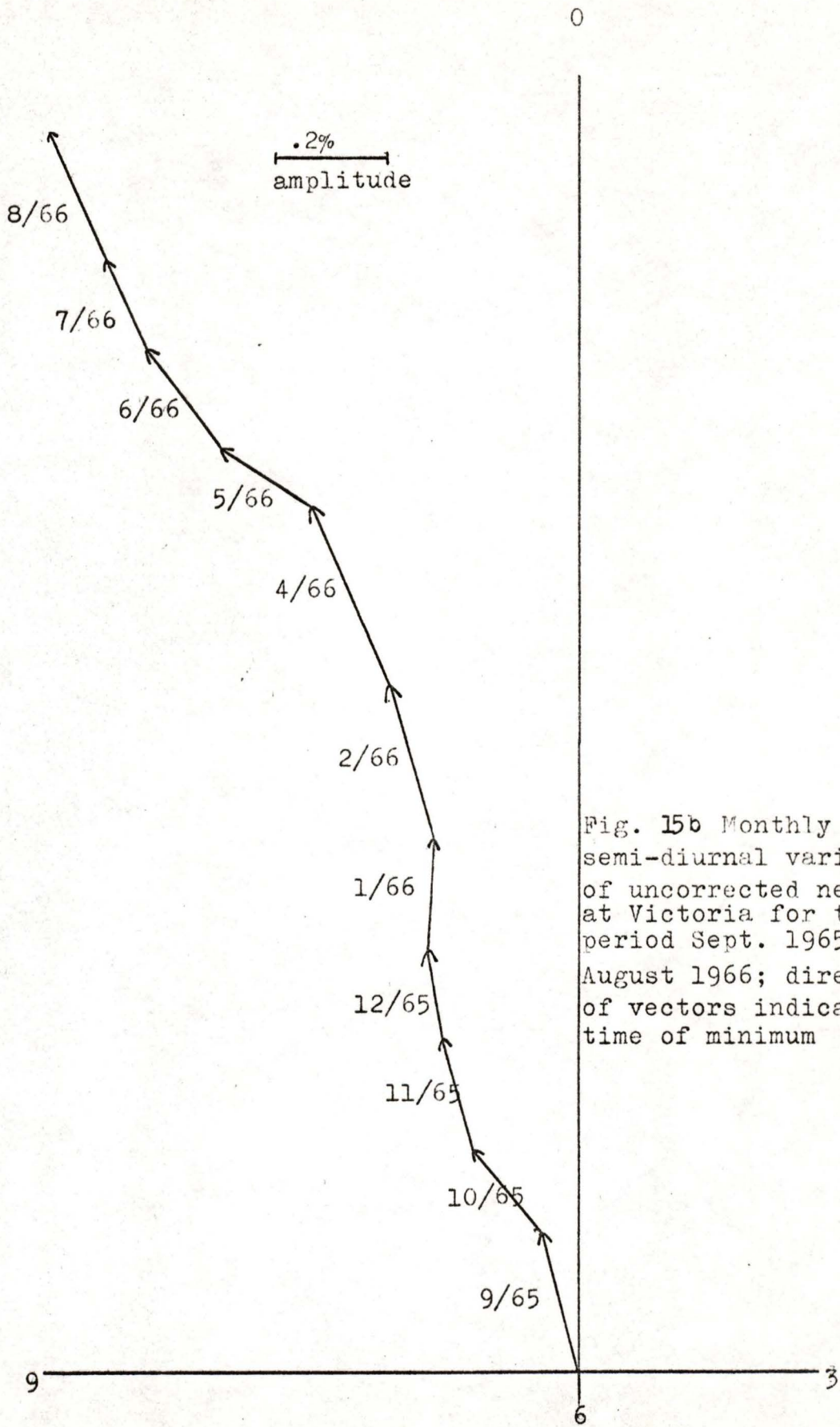


Fig. 15b Monthly mean semi-diurnal variation of uncorrected neutrons at Victoria for the period Sept. 1965-August 1966; directions of vectors indicate time of minimum

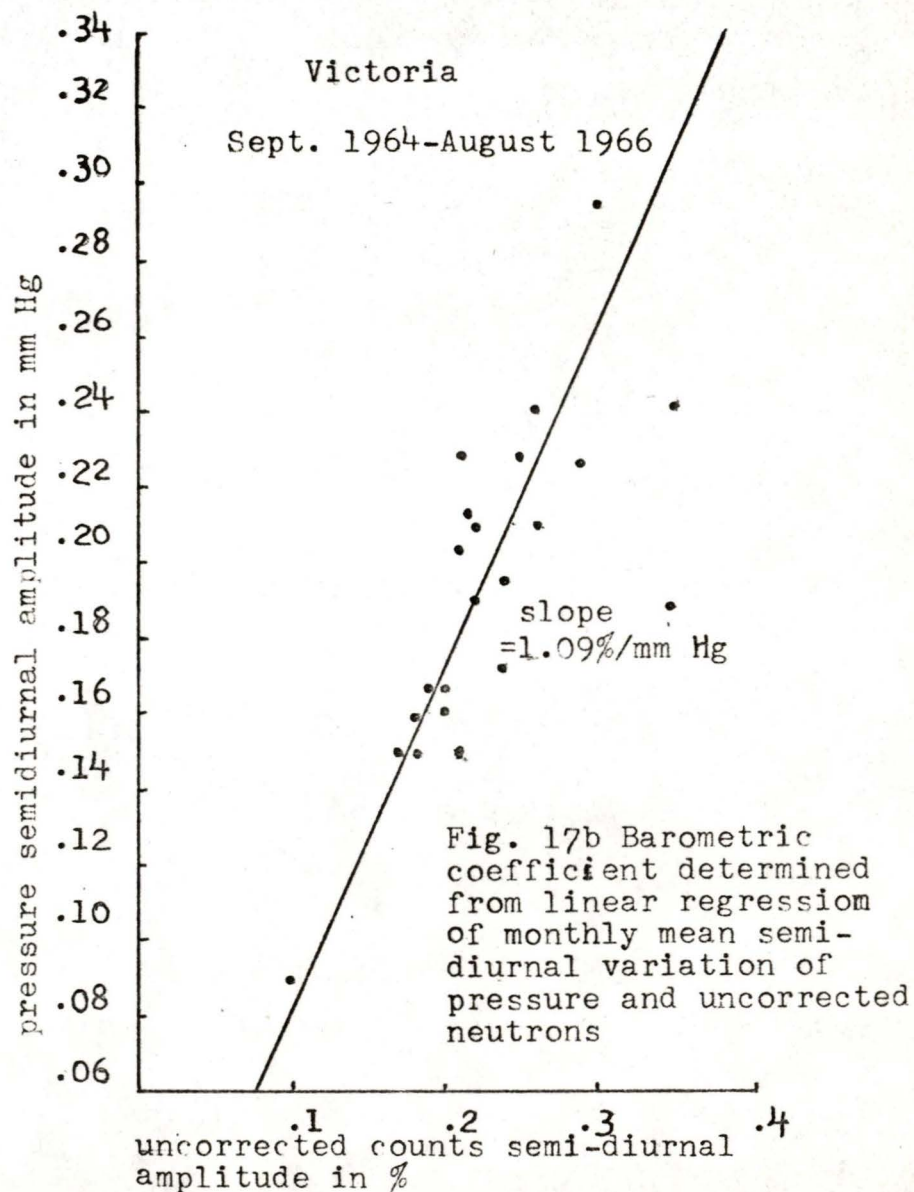
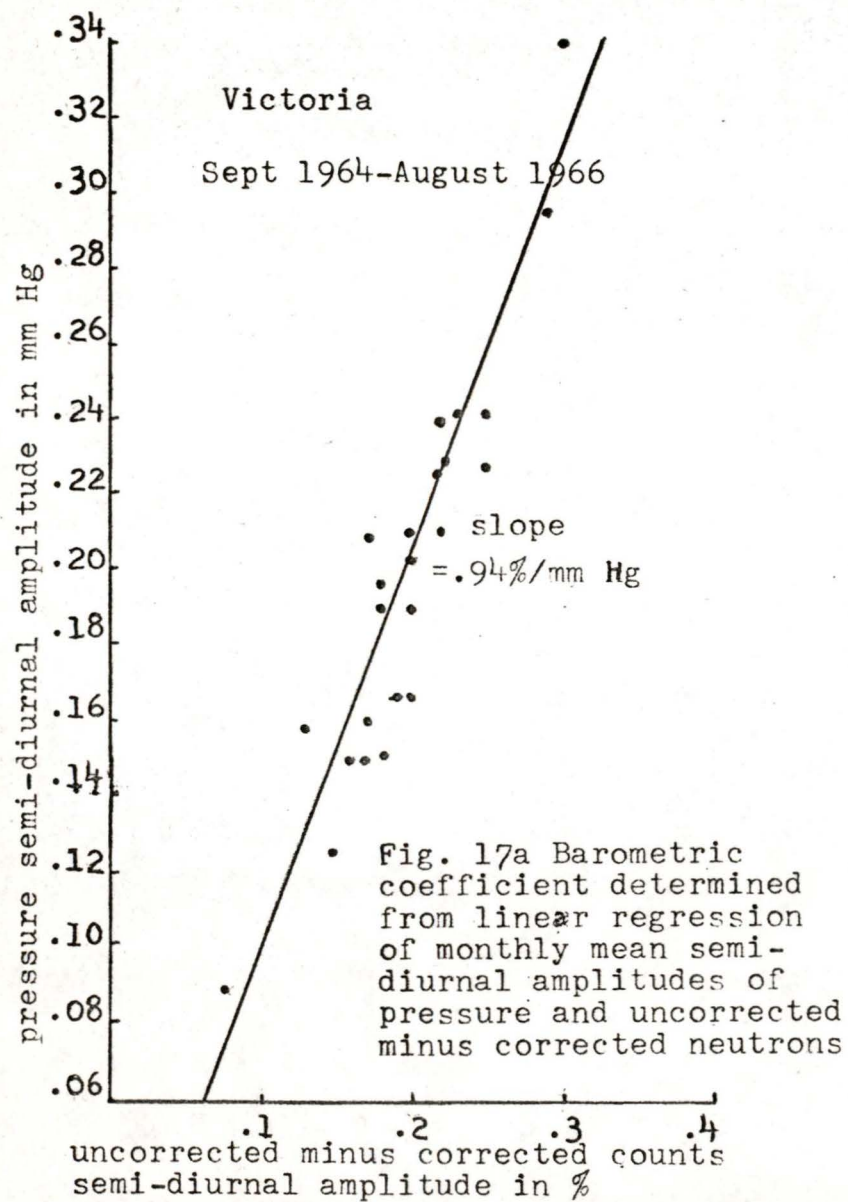
of maximum of pressure-corrected counts semi-diurnal variation are scattered about the three hour direction and amplitudes vary between 0.05 per cent and 0.1 per cent. Times of maximum of pressure, and times of minimum of uncorrected counts semi-diurnal variation are scattered about the 11-hour direction, (Figs. 14a, 15a).

In the period September 1965-August 1966, the average phase of uncorrected counts semi-diurnal variation remains unchanged (time of minimum about 11 hours), but there is a general shift of phase of semi-diurnal variation of pressure to 0.6 hour later. The time of maximum of semi-diurnal variation of corrected counts, on the average, is also shifted 0.5 hour later (Figs. 14b, 15b).

The semi-diurnal component of pressure is caused by atmospheric oscillation, giving rise to a variation with more or less definite phase. The shift in phase of semi-diurnal pressure vectors between the two periods under consideration may possibly be due to a time lag in the pressure recording instrument. Average shift of times of maximum of pressure and times of minimum of uncorrected counts is about 0.6 hour. Bearing in mind that the inaccuracy in the determination of times of maximum or minimum of cosmic ray semi-diurnal variation amounts to ± 2 hours or more (see Appendix I), it is uncertain whether the discrepancy is in fact due to a semi-diurnal component of primary

radiation. The pressure semi-diurnal vectors in per cent are converted to millimeter Hg by multiplying by the monthly mean station pressure. The barometric coefficient, determined from a linear regression of monthly semi-diurnal amplitudes of uncorrected counts and millimeter Hg is found to be 1.09 ± 0.18 per cent / mm. Hg for the period September 1964-August 1965 (Fig. 17b). The deviation from the mean station barometric coefficient 1.0101 ± 0.05 per cent / mm. Hg is 0.08 per cent / mm. Hg within the limits of error.

It is uncertain whether the semi-diurnal variation of corrected counts is a residual error after correction for pressure or is a real semi-diurnal variation, possibly due to a second harmonic in anisotropy of the primary radiation. If the semi-diurnal variation of corrected counts is not merely a random uncertainty, the vector difference of uncorrected counts and corrected counts semi-diurnal variations (hereafter referred to as semi-diurnal variation of uncorrected-minus-corrected counts) might follow more closely the anticorrelation with pressure semi-diurnal variation. To check this, monthly semi-diurnal variation of uncorrected-minus-corrected counts at the Victoria station in the period September 1964-August 1966 is plotted in Fig. 16a and 16b and compared with Figs. 14a, 14b, 15a and 15b. It is observed that the phases of individual monthly semi-diurnal vectors of pressure



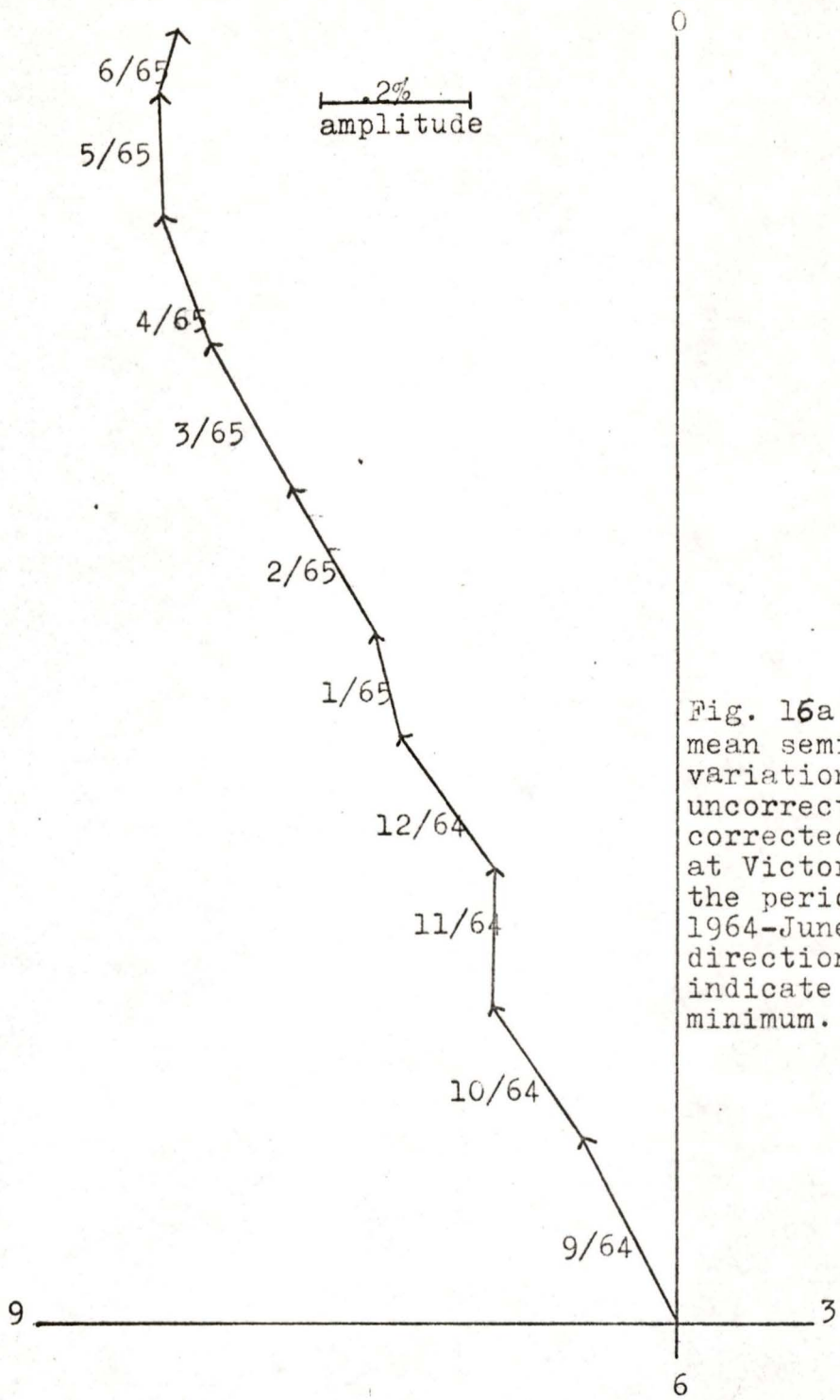


Fig. 16a Monthly mean semi-diurnal variation of uncorrected minus corrected neutrons at Victoria for the period Sept. 1964-June 1965; directions of vectors indicate time of minimum.

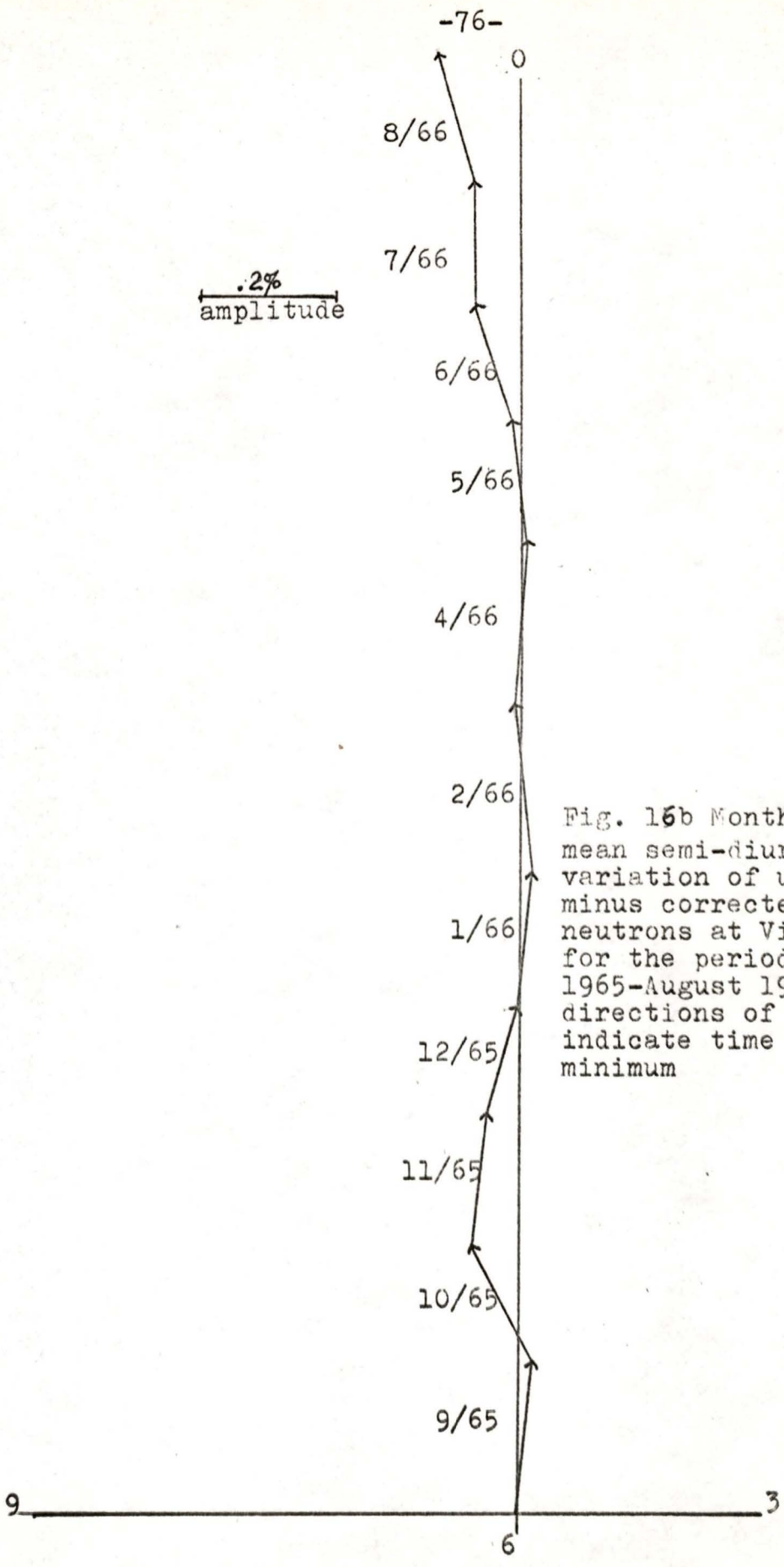


Fig. 16b Monthly mean semi-diurnal variation of uncorrected minus corrected neutrons at Victoria for the period Sept. 1965-August 1966; directions of vectors indicate time of minimum

and uncorrected-minus-corrected counts follow more closely with each other than the phases of monthly semi-diurnal vectors of pressure and uncorrected counts in both periods (Table V a, b). Mean deviation from 180° antiphase in the former case amounts to 0.26 hour and in the latter case amounts to 0.6 hour. The barometric coefficient, determined from a linear regression of monthly semi-diurnal amplitudes of uncorrected-minus-corrected counts and of pressure, is found to be 0.94 ± 0.17 %/mm. Hg (Fig. 17a). Deviation from the mean station barometric coefficient (1.0101 %/mm. Hg) is 0.07 %/mm. Hg.

The above analysis fails to give any conclusive result. It can only be said that incomplete elimination of the relatively large semi-diurnal variation due to meteorological factors (e.g. atmospheric oscillation) renders investigation of the small residual variation after correction for pressure obscure.

§4. Day-to-day variability of the semi-diurnal component.

Semi-diurnal variation at Victoria on a day-to-day basis was investigated in a manner similar to that for the diurnal variation (see section 4.3). Frequency distributions of the times of maximum of semi-diurnal variation of periods September 1964 - August 1965 and September 1965 - August 1966 are similar, with peak values at about 2 hours local time (Fig. 18a, b, c).

Amplitudes of semi-diurnal variation also vary

Month	Press. S.D.		Uncorrected Counts S.D.		Uncorrected - Corrected Counts S.D.		$T_1 \sim T_2$	$T_1 \sim T_3$	Residual Pressure S.D.		
	Amp. (mm Hg)	L.T. of max. T_1 (hr)	Amp. (%)	L.T. of min. T_2 (hr)	Amp. (%)	L.T. of min. T_3 (%)	(hr)	(hr)	Amp. (%)	L.T. of max. (hr)	
Sept. 1964	.29	11.1	.30	11.8	.29	11.1	.7	0	.05	2.7	
Oct. 1964	.19	11.0	.35	10.0	.20	10.9	1.0	.1	.10	3.2	
Nov. 1964	.19	11.5	.22	11.2	.18	12.0	.3	.5	.07	4.7	
Dec. 1964	.21	11.5	.22	10.0	.22	10.8	1.5	.7	.10	1.7	
Jan. 1965	.16	12.0	.18	12.0	.13	11.6	0	.4	.04	3.7	
Feb. 1965	.22	11.0	.21	11.0	.22	11.0	0	0	.05	1.5	
Mar. 1965	.24	10.9	.26	10.8	.22	11.0	.1	.1	.06	3.6	
Apr. 1965	.19	11.5	.24	11.0	.18	11.3	.5	.2	.10	3.0	
May 1965	.15	11.8	.18	11.0	.16	12.0	.8	.2	.07	3.0	
June 1965	.09	12.2	.10	11.2	.08	12.6	1.0	.4	.07	4.1	
July 1965	.13	11.7	results discarded								
Aug. 1965	.24	12.0	results discarded								

S.D. = semi-diurnal variation

L.T. = local time

Mean=.59 Mean=.26

TABLE Va

Monthly Mean Semi-diurnal Variation of Pressure, Pressure Corrected Neutron Counts, Uncorrected Neutron Counts and Uncorrected-Minus-Corrected Neutron Counts of Victoria.

Month	Press. S.D.		Uncorrected Counts S.D.		Uncorrected—Corrected Counts S.D.		$T_1 \sim T_2$ (hr)	$T_1 \sim T_3$ (hr)	Residual Pressure S.D.	
	Amp. (mm Hg)	L.T. of max. T_1 (hr)	Amp. (%)	L.T. of min. T_2 (hr)	Amp. (%)	L.T. of min. T_3 (%)			Amp. (%)	L.T. of max. (hr)
Sept. 1965	.22	12.1	.25	11.5	.22	12.1	.6	0	.07	3.5
Oct. 1965	.16	10.7	.20	10.7	.20	11.1	0	.4	.06	3.3
Nov. 1965	.20	12.1	.21	11.5	.20	12.2	.6	.1	.08	3.8
Dec. 1965	.21	12.2	.24	11.7	.17	12.5	.5	.3	.08	2.8
Jan. 1966	.16	13.0	.19	12.1	.19	12.2	.9	.8	.03	5.0
Feb. 1966	.22	11.8	.29	11.4	.25	11.8	.4	0	.06	3.8
Mar. 1966	.34	12.0			results discarded					
Apr. 1966	.24	11.7	.35	11.3	.25	12.1	.4	.4	.10	3.4
May 1966	.16	11.5	.20	10.1	.17	11.8	1.4	.3	.14	2.4
June 1966	.15	11.5	.21	10.7	.17	11.4	.8	.1	.09	3.8
July 1966	.15	11.8	.17	11.2	.18	12.0	.6	.2	.07	3.9
Aug. 1966	.21	11.7	.26	11.2	.20	11.5	.5	.2	.08	4.0

S.D. = semi-diurnal variation
L.T. = local time

Mean=.6 Mean=.26

TABLE Vb

Monthly Mean Semi-diurnal Variation of Pressure, Pressure Corrected Neutron Counts, Uncorrected Neutron Counts and Uncorrected Minus Corrected Neutron Counts of Victoria.

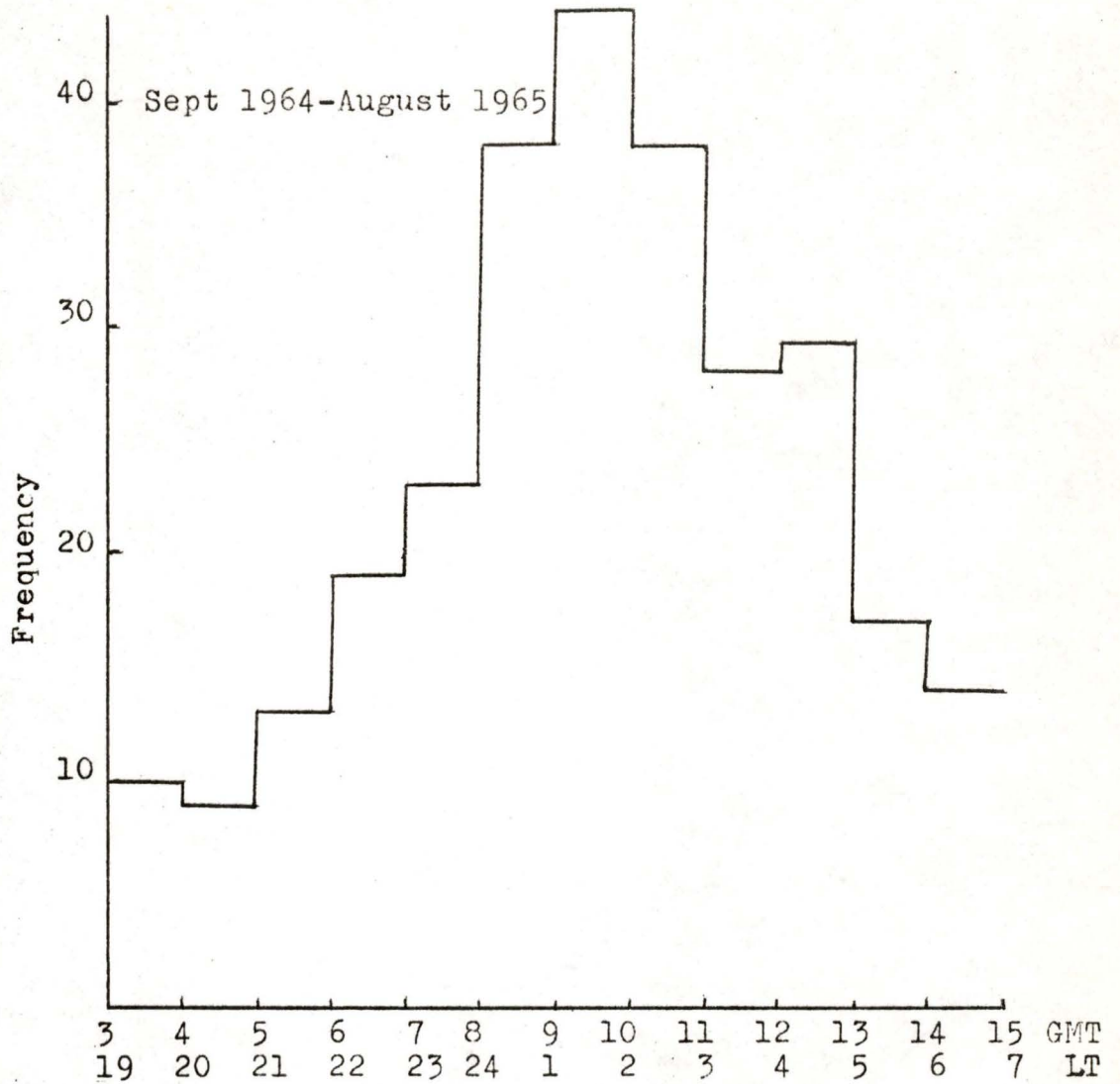


Fig. 18a Histogram of hour of maximum of semi-diurnal variation of corrected neutrons at Victoria

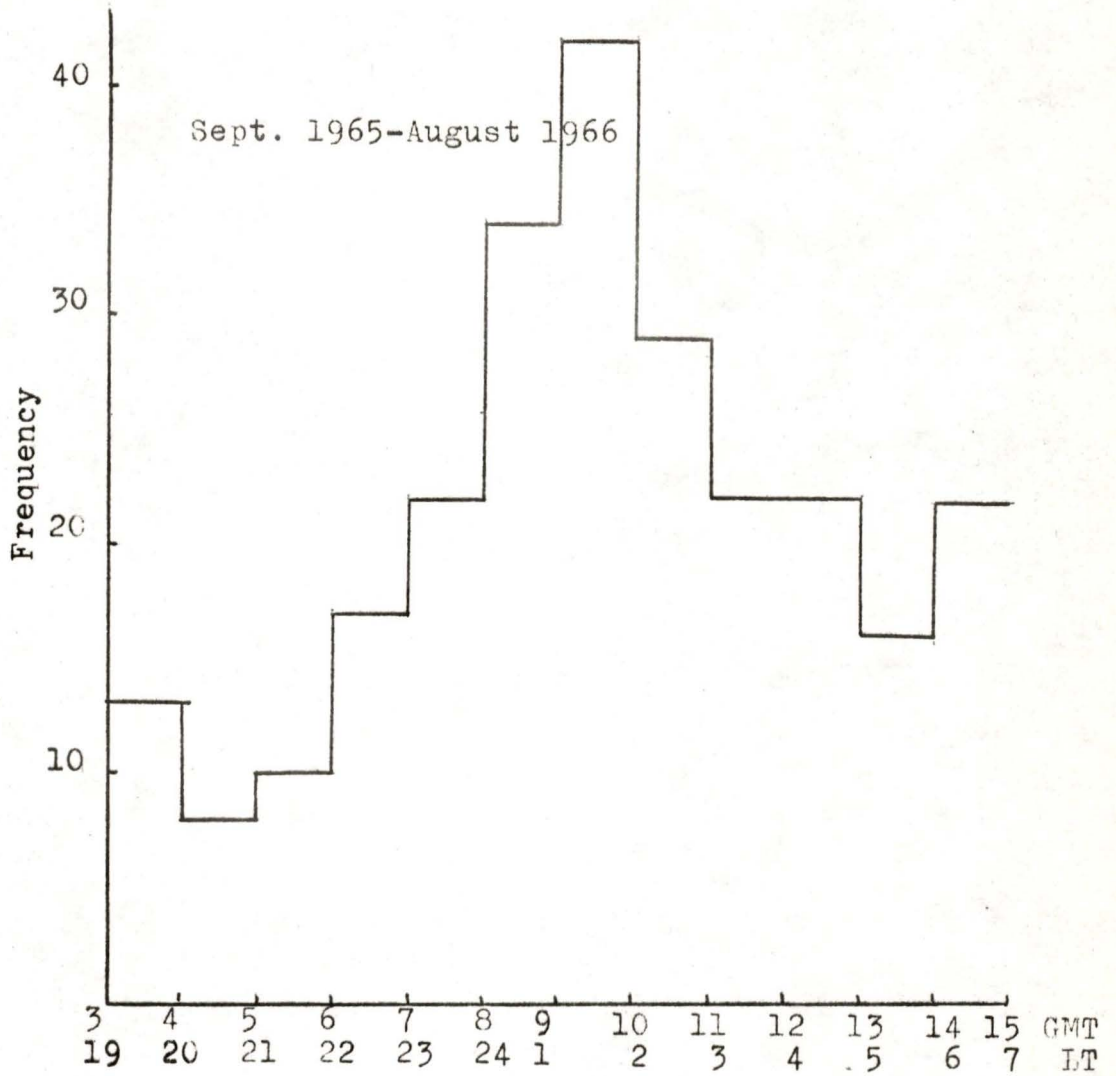


Fig. 18b Histogram of hour of maximum of semi-diurnal variation of corrected neutrons at Victoria

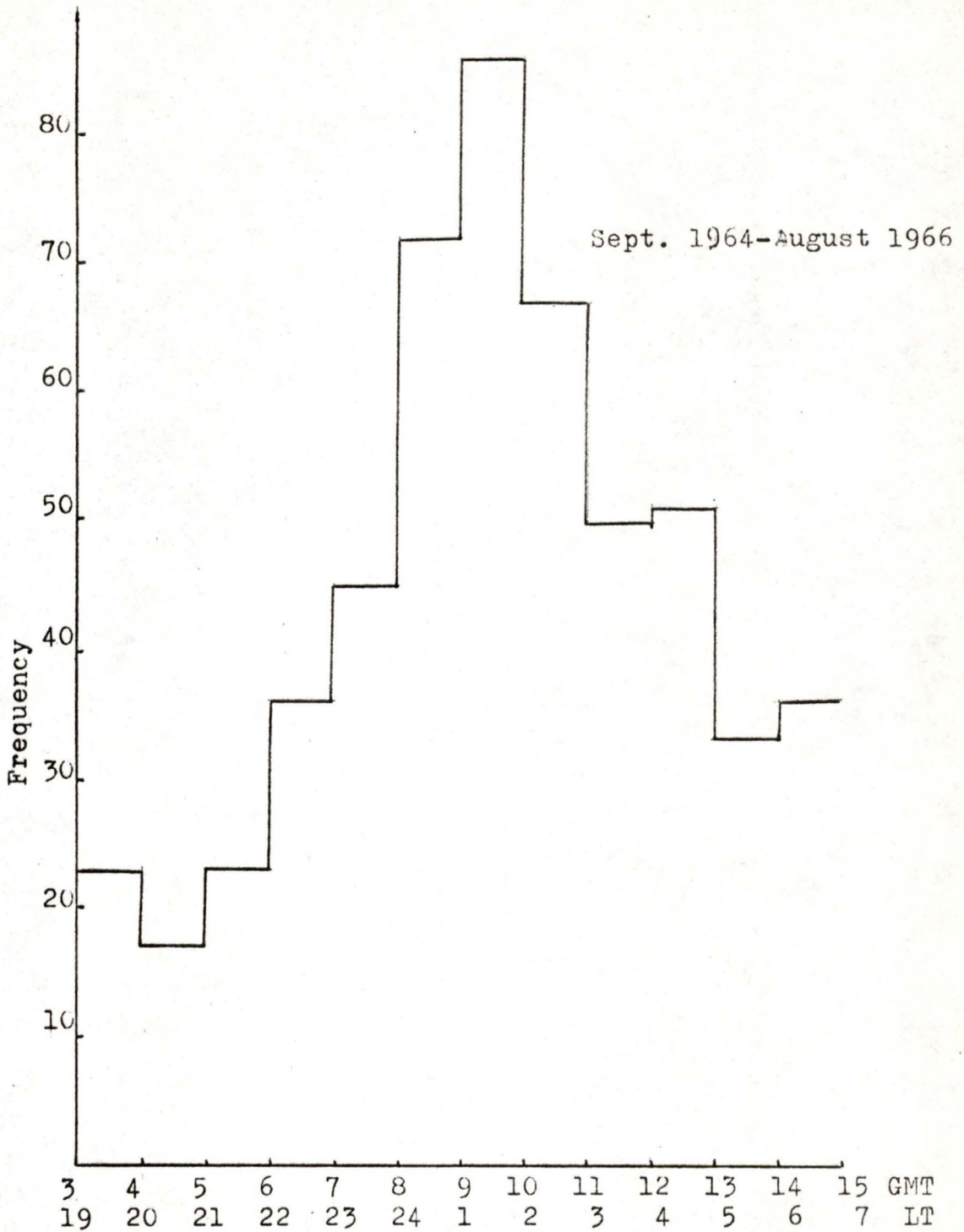


Fig. 18c Histogram of hour of maximum of semi-diurnal variation of corrected neutrons at Victoria

irregularly over short periods of time from 0.05 to 0.3 per cent. In general the amplitudes on a day-to-day basis seem to be larger than the average monthly or yearly semi-diurnal variations (Fig. 19a, b, c, d). Twenty-seven day recurrences are not evident in the times of maximum of semi-diurnal variation (Fig. 20a, b, c, d).

The amplitudes of the semi-diurnal component vary in a manner independent of the occurrence of times of maximum, and the amplitudes span more or less over the same range of values (Fig. 21a, b).

Results similar to diurnal variation on a day-to-day basis can also be seen in semi-diurnal variation; for instance, the variability of amplitudes, and the preferred time of maximum exhibited in the frequency distribution of times of maximum. This suggests that extra-terrestrial origin of semi-diurnal variation is possible.

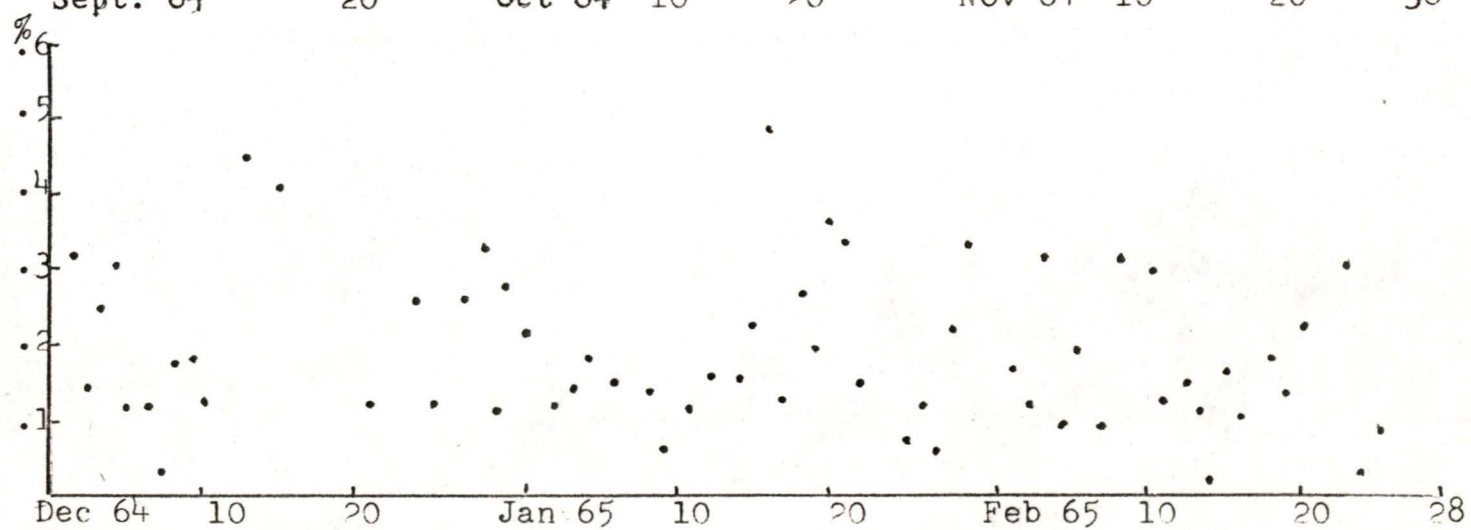
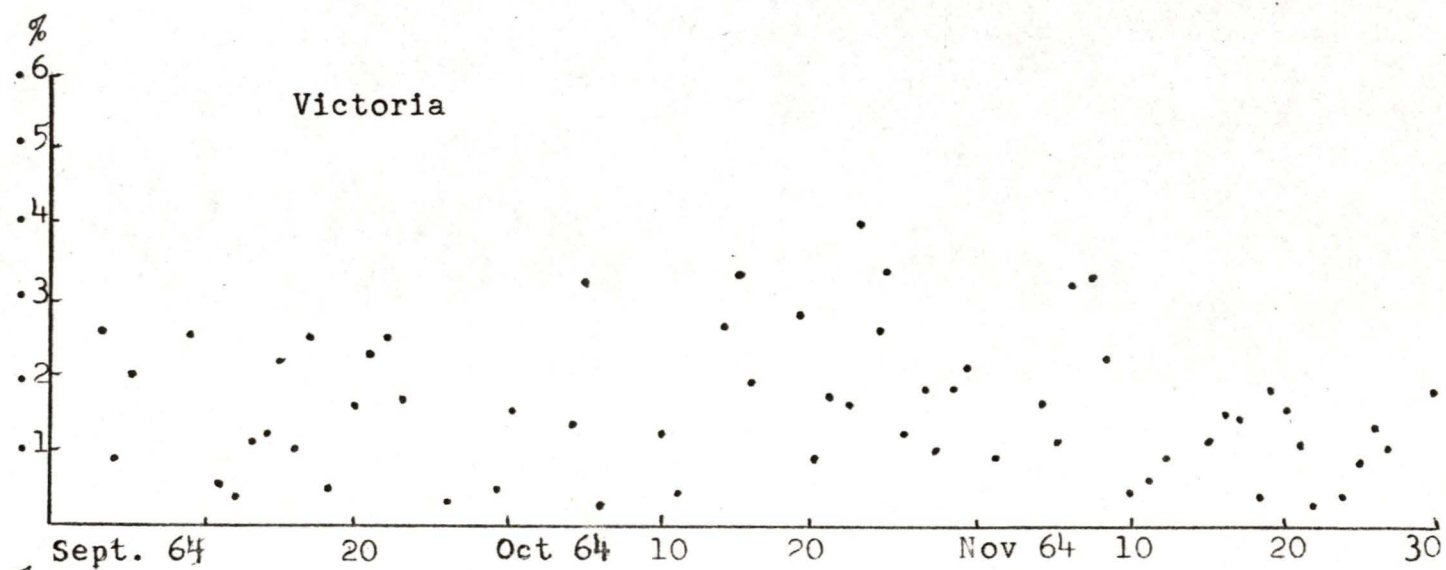


Fig. 19a Amplitude of semidiurnal variation of corrected counts

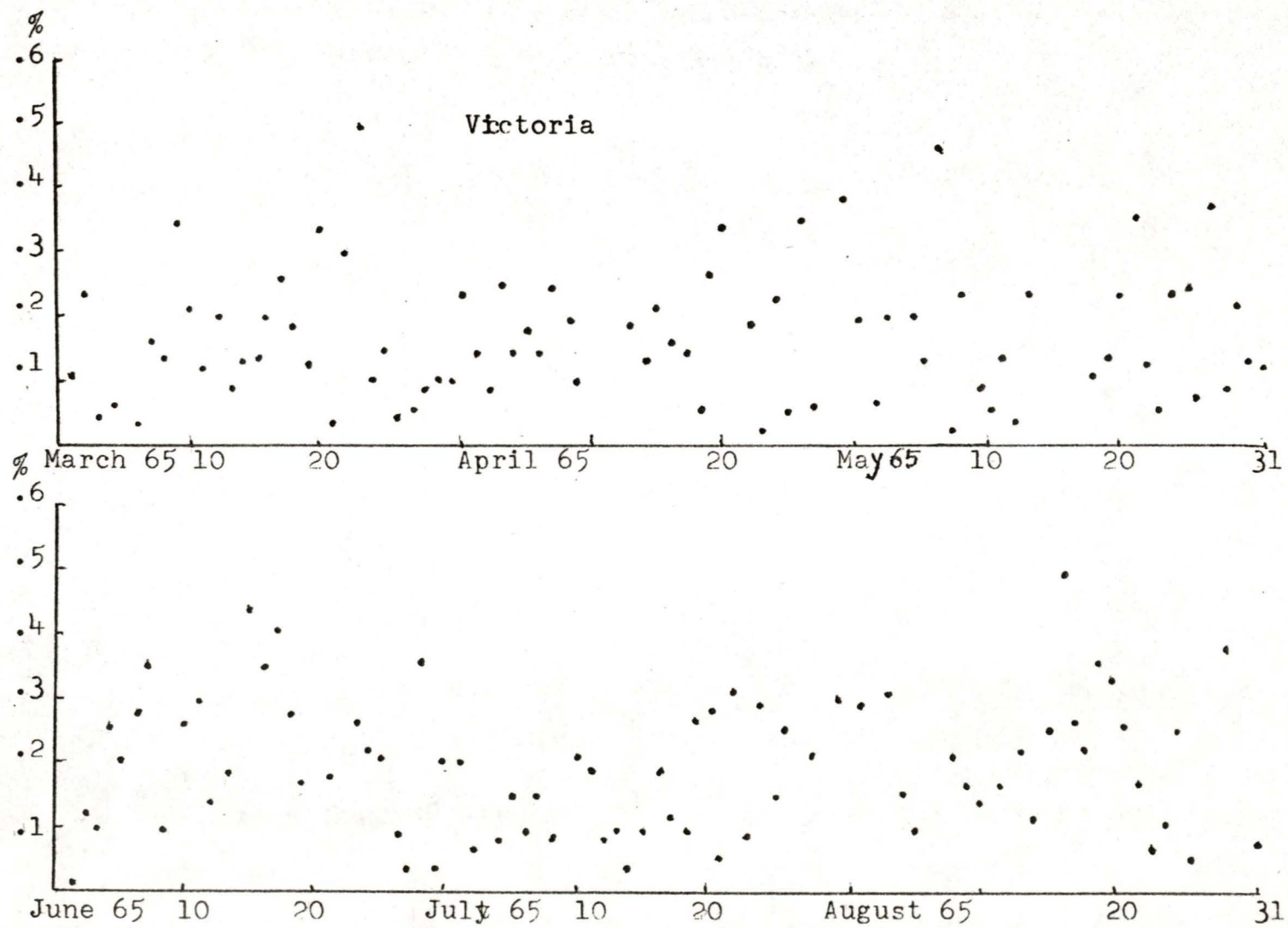


Fig. 19b Amplitude of semidiurnal variation of corrected counts

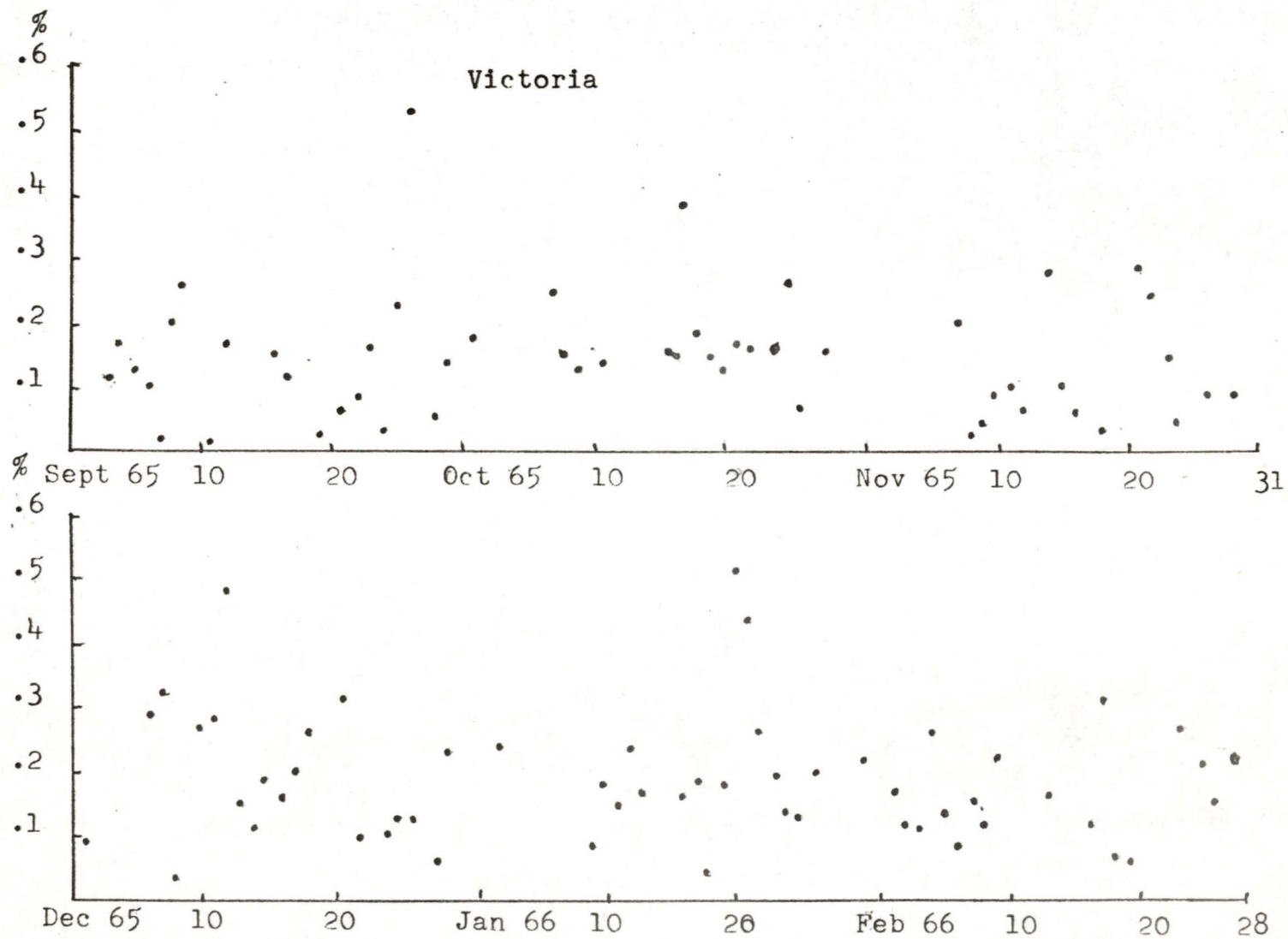


Fig. 19c Amplitude of semidiurnal variation of corrected counts

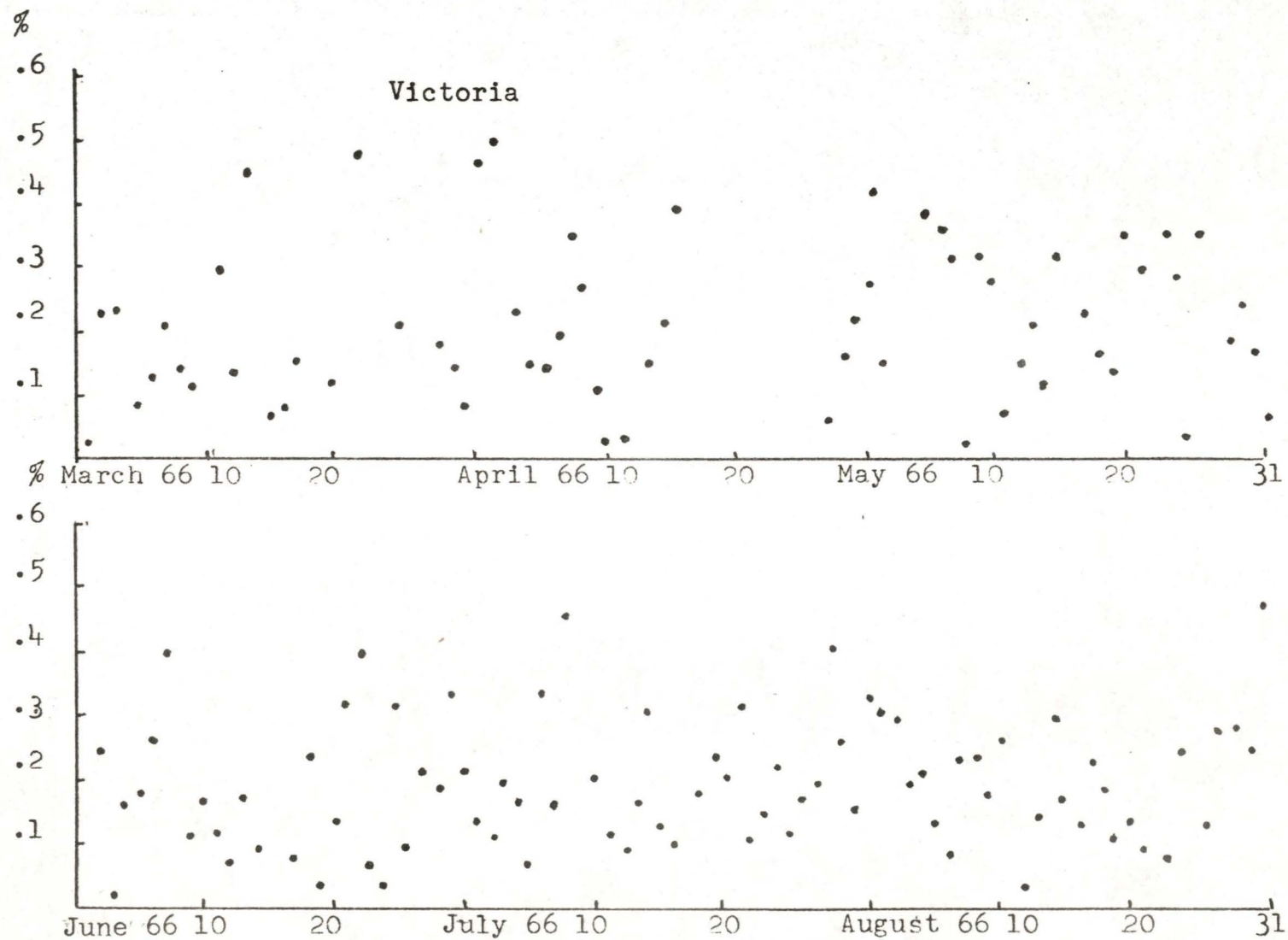


Fig. 19d Amplitude of semi-diurnal variation of corrected counts

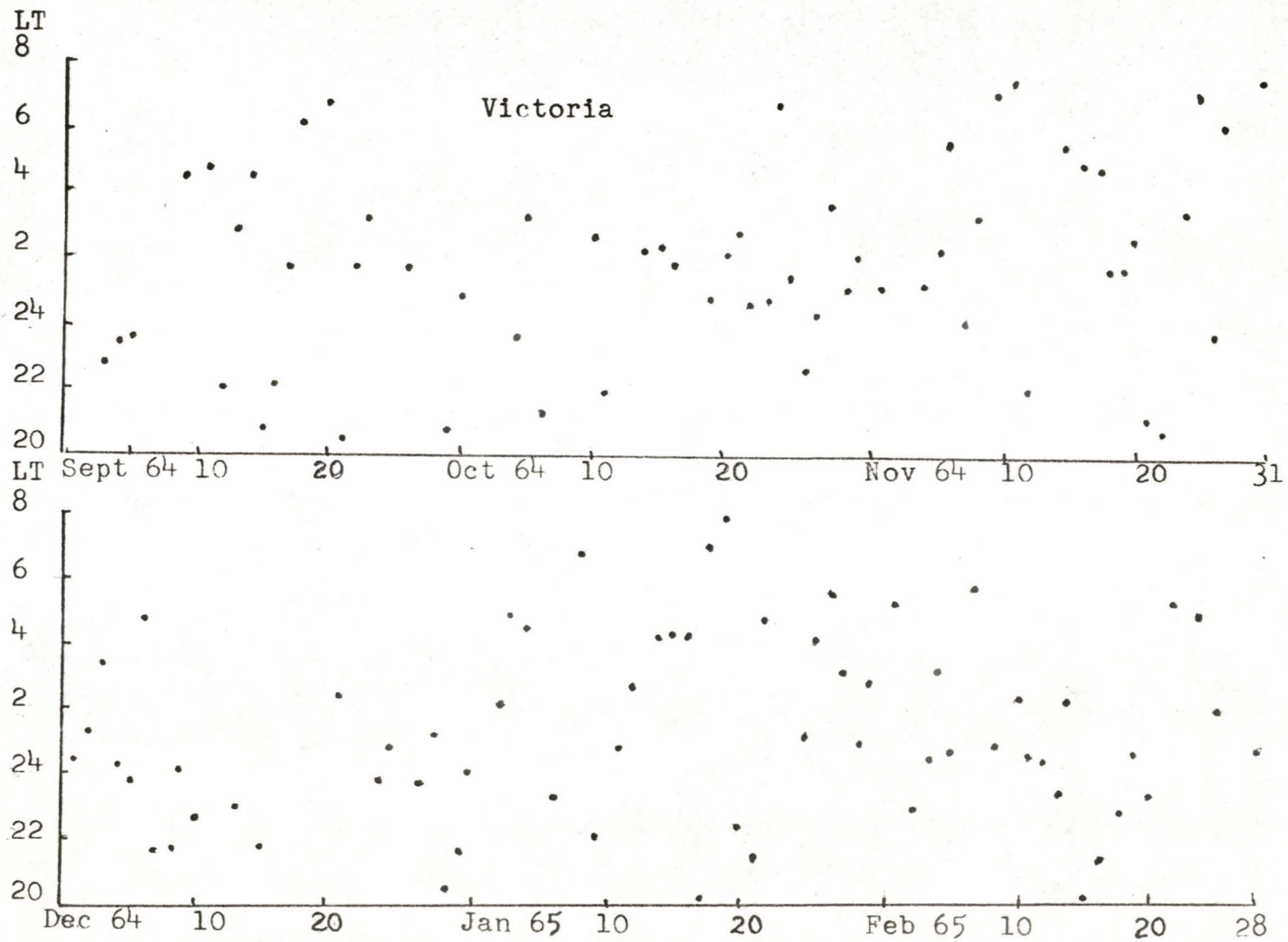


Fig. 20a Time of maximum of semidiurnal variation of corrected neutrons

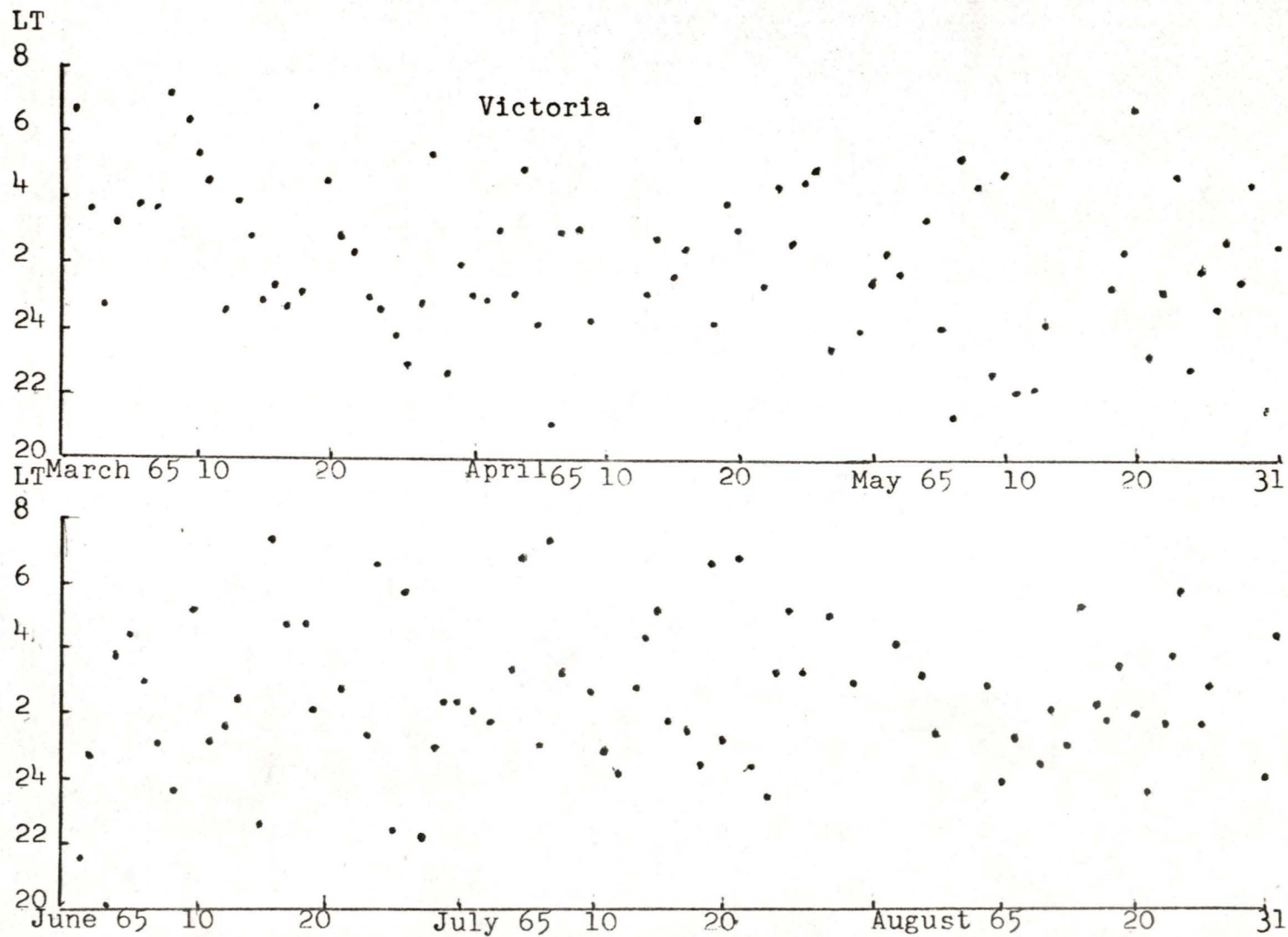


Fig. 20b Time of maximum of semidiurnal variation of corrected neutrons

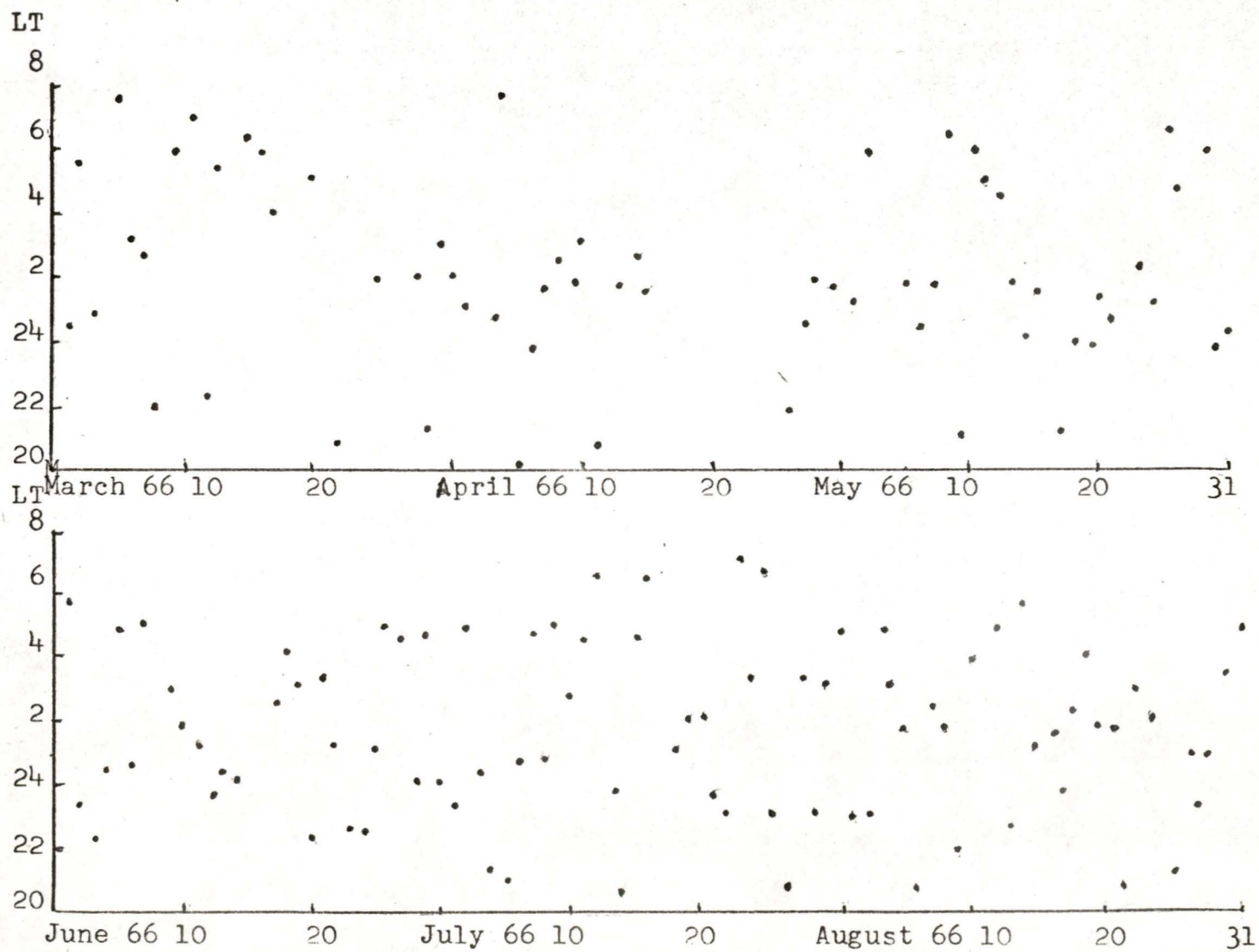


Fig. 20d Time of maximum of semi-diurnal variation of corrected neutrons

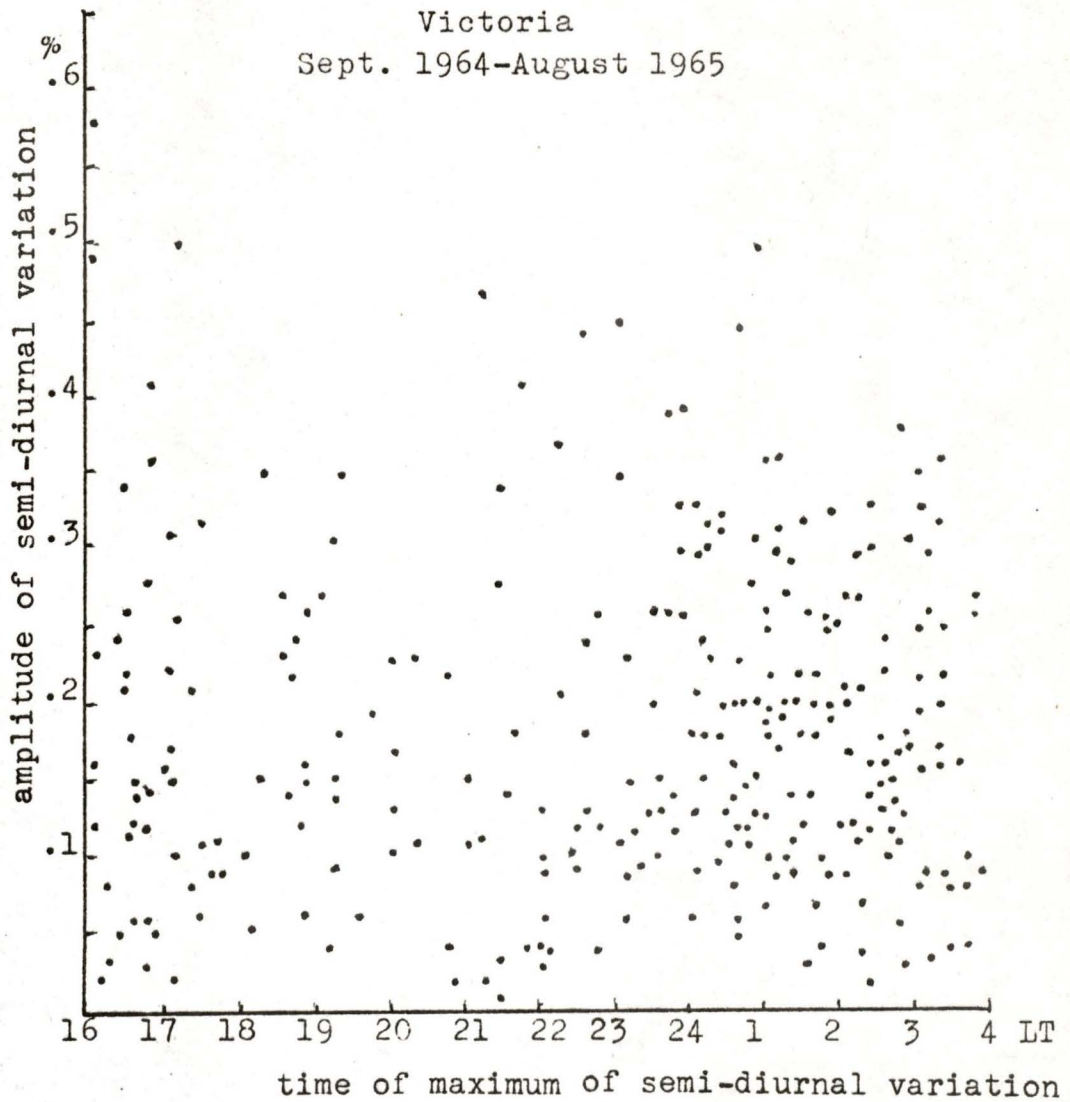


Fig. 21a Amplitude of daily semi-diurnal variation of corrected neutrons plotted against the corresponding time of maximum

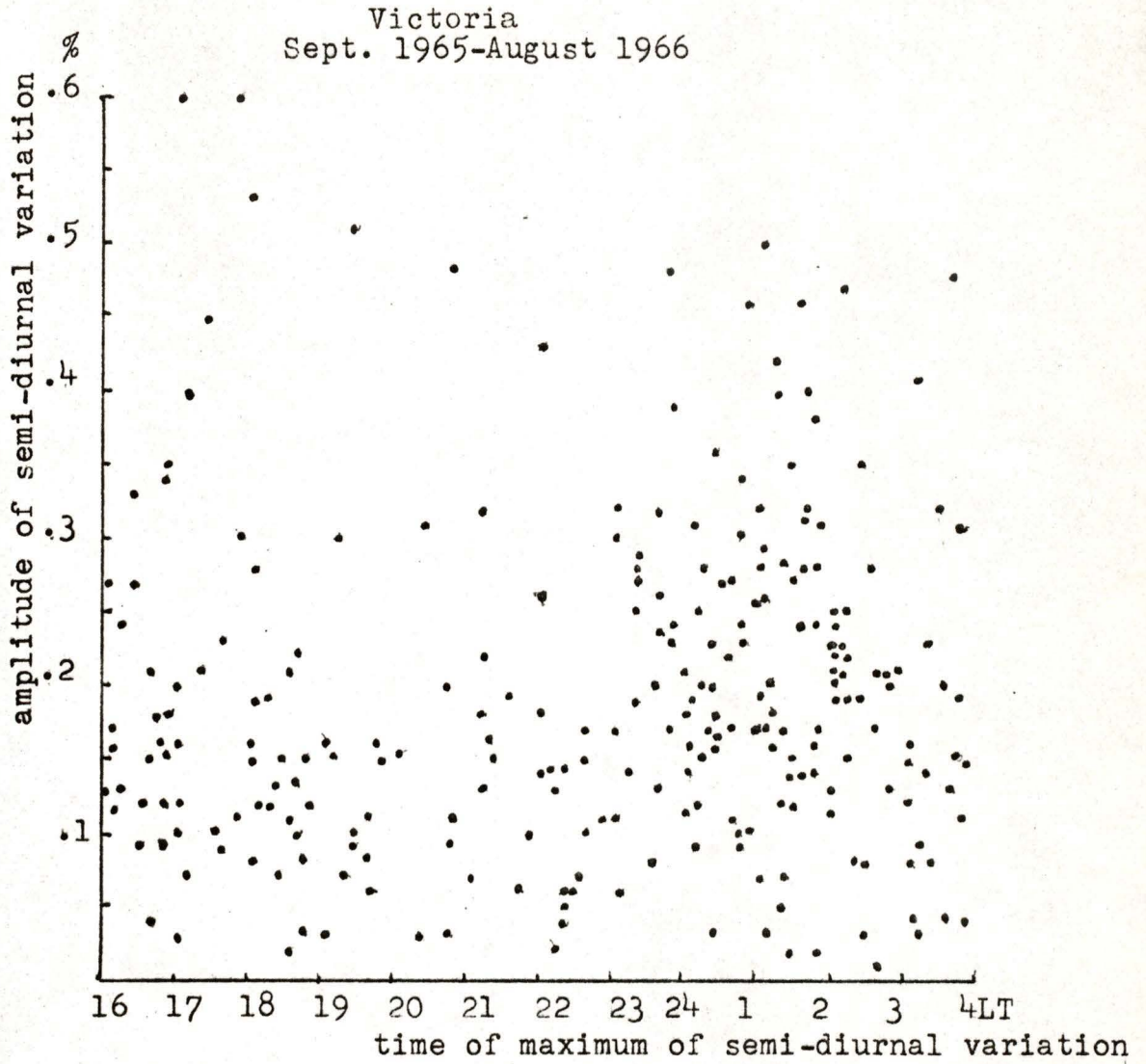


Fig. 21b Amplitude of semi-diurnal variation of corrected neutrons plotted against the corresponding time of maximum

CHAPTER 6

CONCLUSIONS

From a study of the pressure-corrected nucleonic component of 11 stations at the solar minimum 1965, the geomagnetic latitude dependence of the time of maximum, T_{\max} , of cosmic ray diurnal variation, expressed by $T_{\max} = (13.2 + 0.03\lambda)$ hours, has been observed as shown in figure 2. After applying corrections for geomagnetic bending, we have found that the average direction of maximum of anisotropy is 93° to the east of the earth-sun line; but the spread in asymptotic times of maximum among stations is wide, especially among the low latitude stations.

The day-to-day study of pressure-corrected diurnal variation of cosmic ray neutron intensity at Victoria station in the period, September 1964 - August 1966, reveals that the maximum of anisotropy lies in an asymptotic direction of $90^\circ \pm 10^\circ$ to the east of the earth-sun line as shown in figure 6c. Occurrence of early time of maximum is not frequent. An occasional shift of time of maximum to earlier hours in cycles of 27 days or of the multiples of 27 days is observed (see Fig. 7). Both the amplitude and the time of maximum show short term variations. Enhanced amplitudes with corresponding times of maximum in preferred directions, coincident with station diurnal

times of maximum, have been observed (see Fig. 8). In a few instances, the enhanced amplitudes can be associated with cosmic ray storms. A general increase in amplitude of diurnal variation in the summer months has been detected, while the daily total cosmic ray intensity remains more or less constant (see Fig. 8,9).

A second harmonic of extra-terrestrial origin cannot be excluded because of the following reasons. Firstly the pressure-corrected semi-diurnal variation of cosmic ray neutron intensity at Victoria station in the period, September 1964 - August 1966, shows variabilities of amplitude and times of maximum in short periods, and also shows a preferred direction in the histogram of the time of maximum. These results are similar to those of the diurnal variation on a day-to-day basis. Secondly, there seems to be a better anticorrelation of the cosmic ray uncorrected counts with the pressure semi-diurnal variation, when the pressure corrected residual effect has been eliminated from it.

APPENDIX I

DISCUSSION OF ERRORS

Uncertainty in amplitude and phase of the first and second harmonics of cosmic ray daily variation has been discussed by Sandström (1965)³⁸.

Assuming a random distribution of counting rate, the variance of amplitude is given by

$$\sigma_A^2 = (2/\gamma_c) n_d \quad (20)$$

where σ_A is the standard deviation of amplitude, and n_d and γ_c are respectively the 24-hour mean counting rate and the number of counting intervals during each day.

Hence the fractional standard deviation has an amplitude given by

$$\frac{1}{n_d} \sqrt{\frac{2 n_d}{\gamma_c}} \quad (21)$$

Because the average multiplicity is greater than unity, the above expression often under-estimates the associated error and a factor of 3 should be introduced to account for the dependent events of counting rate. Therefore, the fractional standard deviation in harmonics is

$$\frac{3}{n_d} \sqrt{\frac{2 n_d}{\gamma_c}} \quad (21a)$$

and is independent of the order of harmonics.

The phase standard deviation is given by

$$\sigma_{\alpha} = \sigma_A / A \quad (\text{radians}) \quad (22)$$

where A is the amplitude.

Substituting $\gamma_c = 24$ (for hourly data), and $n_d = 250,000 \times 24$ into equation (21a), the fractional standard deviation is of the order of 5×10^{-4} (i.e. .05 %).

From equation (22), it is obvious that the uncertainty of the phase of the second harmonic with small amplitude is larger than that of the first harmonic. For the first harmonic, A is about 0.3 per cent, then σ_{α} is about 10 degrees on the harmonic dial (i.e. 40 minutes in time). For the second harmonic, A is about 0.05 per cent; then σ_{α} is about 60 degrees on the semi-diurnal harmonic dial (i.e. 2 hours).

APPENDIX II

Barometric constant of Victoria station determined from least squares regression of each month's pressure and uncorrected neutron data.

$$* \text{ Barometric constant} = \frac{1}{\text{barometric coefficient}}$$

Month	Barometric constant* in mm Hg	Standard deviation of barometric constant in mm Hg	Average pressure in mm Hg
Sept. 1964	99.56	1.24	757.68
Oct. 1964	97.99	.53	758.12
Nov. 1964	100.47	.27	755.69
Dec. 1964	99.74	.28	751.63
Jan. 1965	96.82	.29	755.52
Feb. 1965	98.66	.28	758.02
March 1965	99.08	.38	759.36
April 1965	99.29	.48	754.71
May 1965	94.82	1.31	758.66
June 1965	95.28	1.74	757.48
July 1965	92.76	4.43	758.20
Aug. 1965	101.11	5.40	755.86
Sept. 1965	99.90	1.54	757.74
Oct. 1965	100.43	.68	757.22
Nov. 1965	99.50	.66	751.69
Dec. 1965	106.37	1.12	753.13

Month	Barometric constant* in mm Hg	Standard deviation of barometric constant in mm Hg	Average pressure in mm Hg
Jan. 1966	94.77	.29	754.38 ^o
Feb. 1966	98.49	.37	756.30
March 1966	100.33	.47	753.39
April 1966	102.01	1.97	758.82
May 1966	104.84	1.09	757.67
June 1966	102.11	1.10	756.58
July 1966	106.88	1.05	756.34
Aug. 1966	91.96	1.45	756.81
Sept. 1966	85.77	1.83	756.64
Oct. 1966	95.41	.45	758.12
Nov. 1966	101.56	.24	754.66
Dec. 1966	93.70	.31	752.80
Jan. 1967	93.80	.33	754.13
Feb. 1967	94.94	.58	759.56
March 1967	98.48	.49	753.39
April 1967	100.64	1.21	754.45
May 1967	112.23	1.48	760.08
June 1967	94.37	1.86	755.34

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