Long Term Changes in the Daily Variation of Cosmic Ray Intensity

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Abstract

Cosmic ray measurements at different stations for the period 1937—55 are analysed. The diurnal variation is found to be a world-wide phenomenon, thus giving the anisotropy of the primary radiation and its correlation with solar and geomagnetic activities.

Introduction

The systematic studies of the long term changes in the daily variation of cosmic ray intensity by the Ahmedabad, Hafelekar, London and other groups appear to suggest an anisotropy of the primary cosmic radiation influenced by the sun, The aim of the present paper is to consider this problem in the light of further work and also to study the changes in the daily variation during the period of minimum solar activity in 1954, when radical changes in the daily variation appear to have taken place.

It would be worthwhile to review the earlier known results for the period 1933—52.

Known results

The studies of THAMBYAHPILLAI and ELLIOT (1953) deal only with the diurnal hour of maximum for the period 1932—52. They have, moreover, combined the data recorded by different equipment without making any allowance for the differences in the magnitude of the effect in the different instruments. However, they have come to the conclusion that the changes in the diurnal hour of maximum follow the 22 years cycle of solar activity.

STEINMAURER and GHERI (1955) from a study of the Hafelekar data for 1932—54 have drawn attention to the fact that the diurnal time of maximum shifts to earlier hours during the minimum solar activity years of 1933, 1944 and 1953—54, the effect being more prominent in 1933 than in 1944, and most prominent in 1953—54. Such behaviour could be reasonably expected since the solar activity during different cycles could be different and hence could give different magnitudes of the effect in different cycles. Their result would therefore suggest an 11 years cycle.

The study of the Ahmedabad group has been more complete than the above two investigations, since this group has looked into the amplitude and the hour of maximum of the diurnal as well as the semi-diurnal components of the daily variation. (SARABHAI and KANE, 1953, SARABHAI, DESAI, and VENKATESAN, 1954, 55) It has been shown by SARABHAI, DESAI, and VENKATESAN (1955) that it is not possible to assume the semi-diurnal variation to be purely of atmospheric origin. There seems to be an intrinsic semi-diurnal component.

The time of maximum of the diurnal component exhibits a positively correlated world-wide variation over the period 1937—52 and is roughly in step with the solar cycle, as represented by the sunspot numbers. Further, it is better correlated with the intensity of the 5303 Å coronal emission which is available for the period 1941—52. (SARABHAI, DESAI, and VENKATESAN, 1954.)

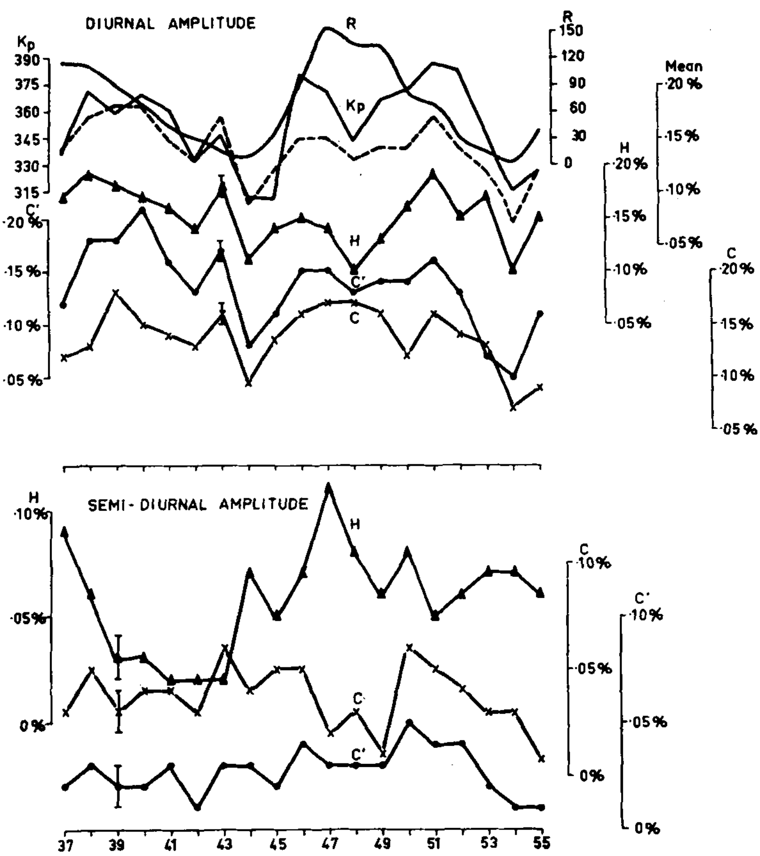

Fig. 1. Changes in the mean annual amplitude of the diurnal (at the top) and semi-diurnal (bottom) components of the daily variation of cosmic ray intensity recorded by the ion chamber at Huancayo (H), Cheltenham (C), and Christchurch (C′). *R* refers to the mean annual sunspot number and K_p to the sum of the K_p values for the 60 most disturbed days in each year. Huancayo is represented by triangles, Cheltenham by crosses, and Christchurch by dots, while the dashed curve represents the mean of all three diurnal components.

The amplitude of the diurnal variation reveals a positive correlation with the solar activity only during the earlier solar cycle (SARABHAI and KANE, 1953) but not in the next solar cycle. (SARABHAI, DESAI, and VENKATESAN, 1954.)

In addition to the long term changes in the diurnal component, significant changes have taken place in the semi-diurnal component also, as pointed out by SARABHAI, DESAI, and VENKATESAN (1955).

Long term changes in the daily variation and the correlation with geomagnetic activity

Although significant changes over the years occur in both the diurnal and semi-diurnal components, there are, nevertheless, essential differences between the two. It might, therefore, be advantageous to discuss them separately. In order to understand the daily variation completely, one has without doubt to consider both components, since in some years the semi-diurnal component is of comparable magnitude. There are, however, certain consistent features which are revealed only in the diurnal variation as will be seen in due course.

It has been pointed out in the previous section that the amplitude of the diurnal variation which, in the earlier cycle, follows solar activity, as revealed by the sunspot numbers, does not do so in the next. We wish to draw

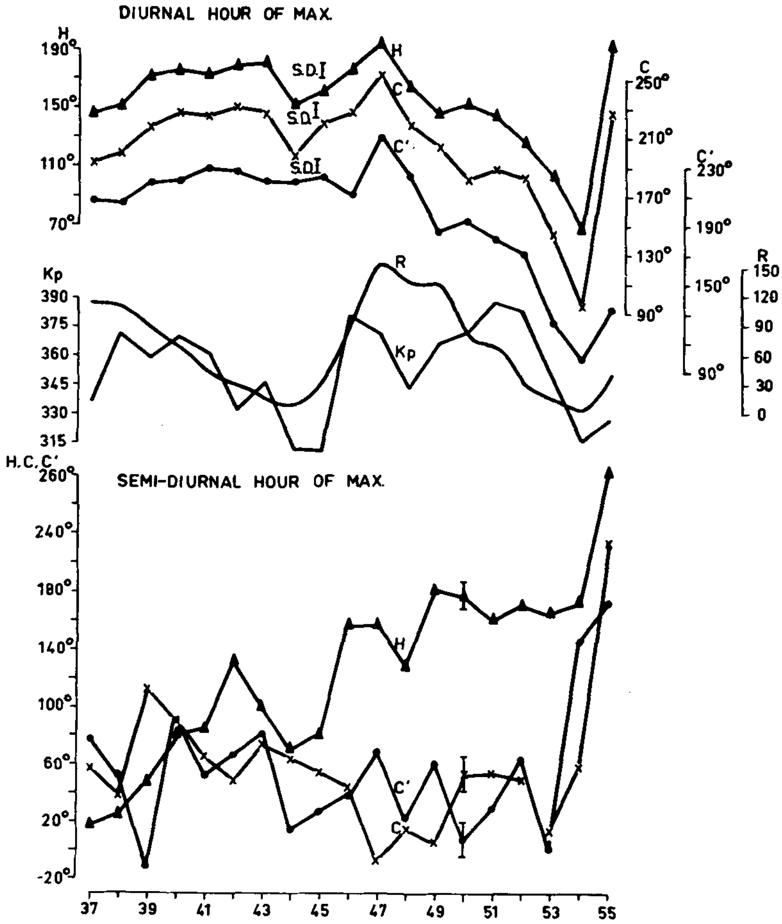

Fig. 2. Changes in the mean annual hour of maximum of the diurnal (at the top) and semi-diurnal (bottom) components of the daily variation of cosmic ray intensity as registered by the ion chambers at Huancayo (H), Cheltenham (C), and Christchurch (C′). *R* refers to the solar activity as revealed by the mean annual sunspot number and K_p to the geomagnetic activity as revealed by the sum of the K_p values corresponding to the 60 most disturbed days in each year. Huancayo, Cheltenham, and Christchurch are represented respectively by triangles, crosses, and dots.

attention to the fact that the relation specifically breaks down in 1946, when radical changes in the interplanetary electromagnetic state seem to have taken place, as pointed out by VENKATESAN (1957). In this connection, it is relevant to mention that the amplitude of the 27-day variation, which appears to follow the solar activity, as revealed by the sunspot number, during the period 1937—46 (MEYER and SIMPSON, 1954) does not do so in 1946 (VENKATESAN, 1957). In fact, as was shown by VENKATESAN, the amplitude of the 27-day variation follows instead the changes in geomagnetic activity, as revealed by the sum of K_p values for the 60 most disturbed days of each year. This points to the fact that in certain phenomena, solar activity is only the indirect cause and the changes in interplanetary electromagnetic state, which is influenced by solar activity, are the direct cause of the phenomena. This again stresses the connection between geomagnetic activity, which reflects conditions near the earth, and the electromagnetic conditions far away. It would therefore be worthwhile to try to find out whether the changes in electromagnetic state in the interplanetary

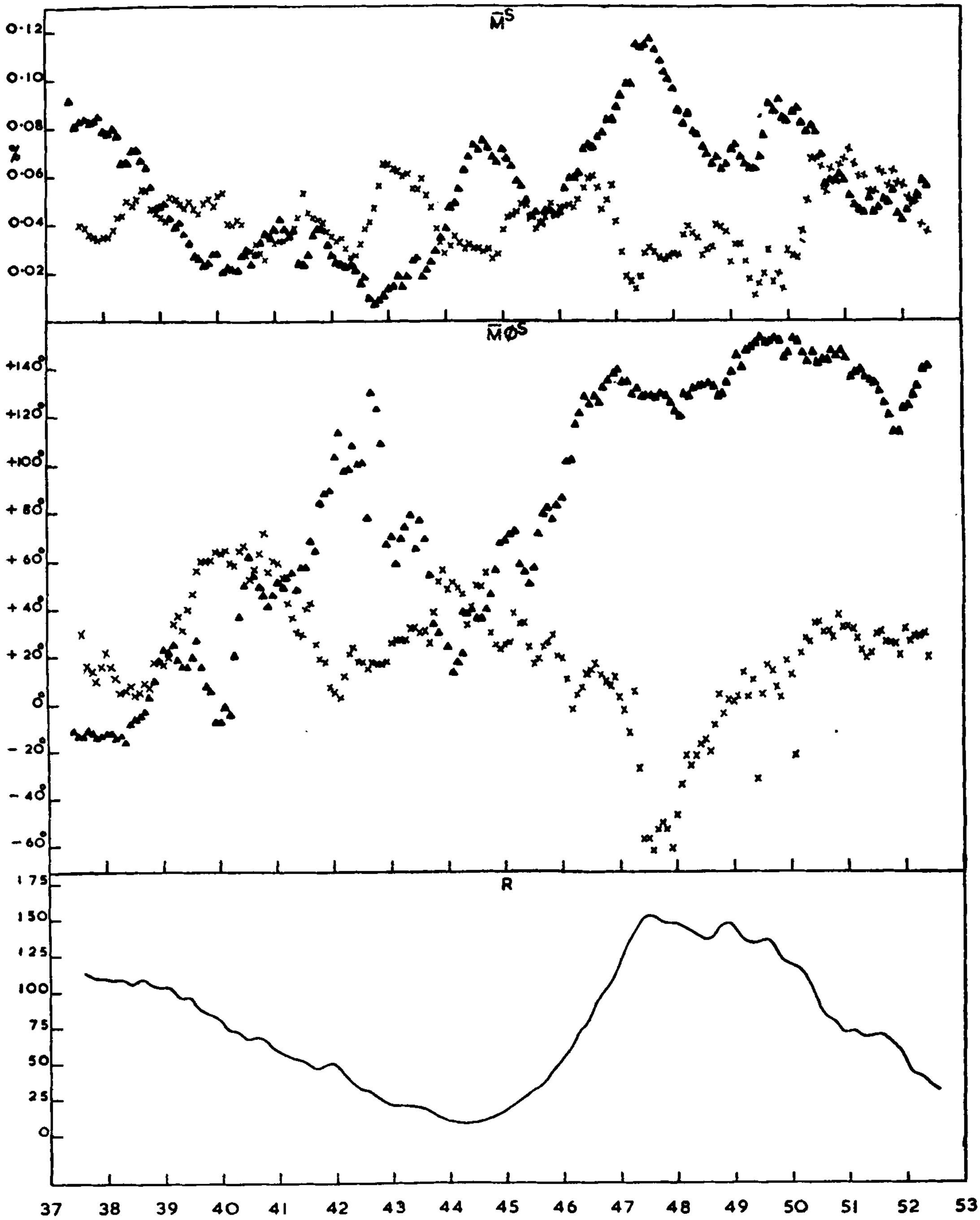

Fig. 3. Time series of the semi-diurnal component of the daily variation of cosmic ray intensity registered by ion chambers at Huancayo and Cheltenham for the period 1937—52. (Taken from the paper by Sarabhai, Desai, and Venkatesan (1955)). *R* refers to the sunspot number. Huancayo is represented by triangles and Cheltenham by crosses. $\overline{M}^S$ refers to the amplitude and $\overline{M\emptyset}^S$ to the hour of maximum.

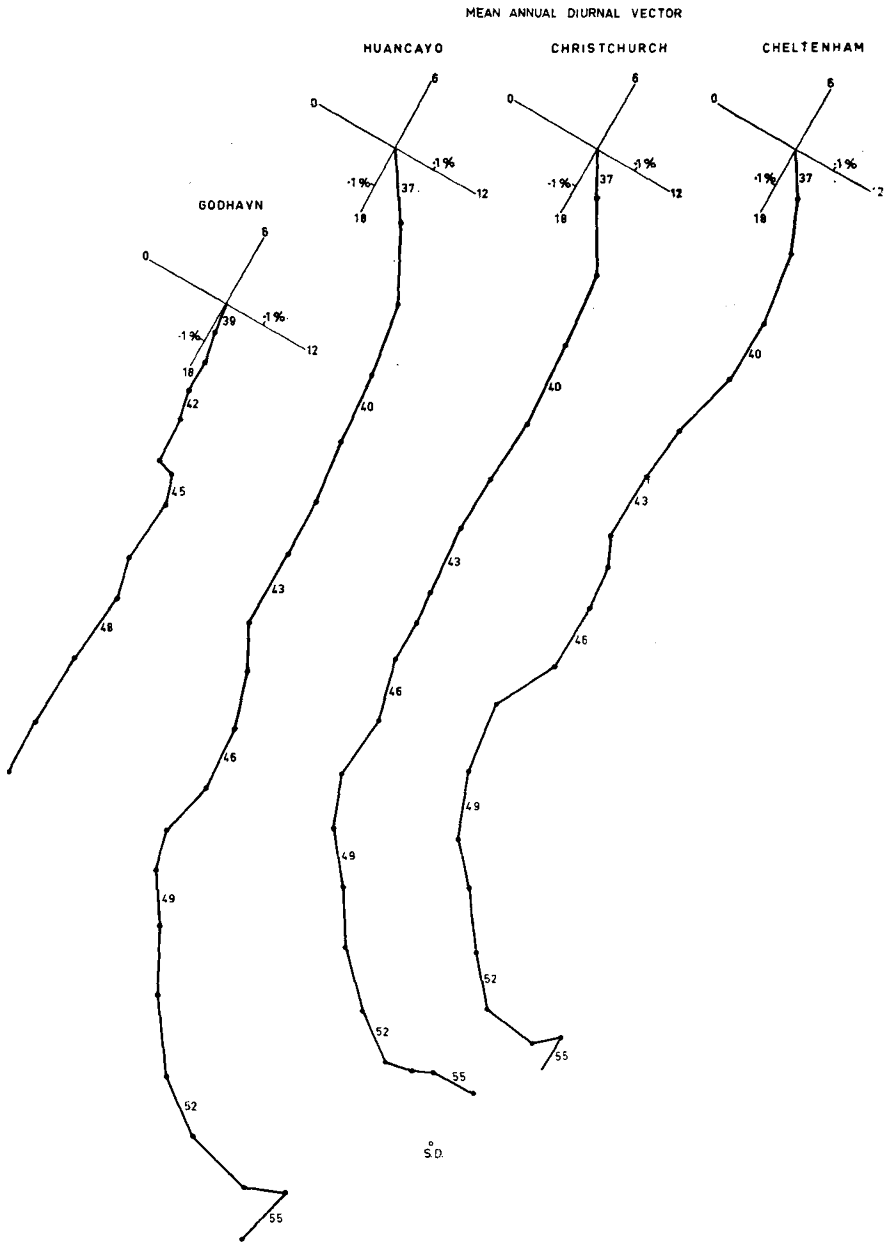

Fig. 4. Mean annual diurnal vectors for the period 1937 to 1955 for Huancayo, Cheltenham, and Christchurch and for the period 1939 to 1950 for Godhavn. The length of the vector gives the amplitude and the angle, with respect to the given axes of coordinates, gives the hour of maximum. The vectors are corrected for geomagnetic deflection, the corrections being 90°, 45°, 45°, and 30° respectively for Huancayo, Cheltenham, Christchurch, and Godhavn as discussed in the text.

space which appear to have taken place around 1946, affect any aspects of the daily variation of cosmic ray intensity.

Fig. 1 shows the changes in the amplitude of the diurnal variation of the cosmic ray intensity, as recorded by the ion chambers at Christchurch, Huancayo, and Cheltenham, and the mean amplitude of the above three stations, along with the changes in solar activity as revealed by the mean annual sunspot number, and the changes in geomagnetic activity as revealed by the sum of the K_p values for the 60 most disturbed days of each year. The study covers the period 1937 to 1955. It should be pointed out that even if we were to consider the K_p sums for all 365 days in each year instead of for the 60 most disturbed days, there would be no difference. The two curves follow each other perfectly and it is therefore reasonable to consider the sum of the K_p values for the 60 most disturbed days to be representative of the year. The changes in the amplitude of the semi-diurnal components of the daily variation at all three stations are also plotted in the same figure.

It can be seen from this figure that the changes in the diurnal amplitude follow the changes in geomagnetic activity more closely than they follow solar activity. The results are especially striking in the cases of Christchurch and Huancayo and, to a slightly lesser extent, Cheltenham. There is a slight anomaly in the years 1948 and 1949 at Cheltenham, which is also observed at another northern station, Godhavn, which needs looking into. As Godhavn data are not available for the whole period they have not been plotted. The strikingly close similarity between the mean amplitude curve and the K_p curve can be observed. Thus it is easily seen that there is a close connection between changes in the geomagnetic activity which prevails in the neighbourhood of the earth, and the interplanetary electromagnetic state which is responsible for the changes in cosmic radiation.

The changes in the amplitude of the semi-diurnal component, on the other hand, are different at the three stations. The significant difference in the semi-diurnal amplitude at Huancayo and Cheltenham can be observed from the figure.

Fig. 2 shows the mean annual diurnal and semi-diurnal hours of maximum at the three stations. While there is a remarkable correspondence in the changes of the diurnal component for all the stations, the striking dissimilarity in the case of the semi-diurnal one is seen. This can also be observed from Fig. 3 which is reproduced from the paper by SARABHAI, DESAI, and VENKATESAN (1955). It can be seen in this figure that the time series at the two stations Huancayo and Cheltenham proceed in opposite directions.

In view of the world-wide positive correlation of the changes in the diurnal component and the dissimilarity for different stations in the case of the semi-diurnal component, it seems appropriate to consider the diurnal component separately, before considering the daily variation as a whole.

Direction of Anisotropy

Fig. 4 gives the mean annual diurnal vector for the three stations Huancayo, Cheltenham, and Christchurch for the period 1937—55 and for Godhavn for the period 1939—50. The length of the vector gives the amplitude and the angle, with respect to the given axes of coordinates, gives the hour of maximum. The vector for each year is drawn from the end of the vector for the previous year. This method of representation, suggested by CONFORTO and SIMPSON (1957), facilitates the study of long term changes. The corrections for geomagnetic deflection have been made, determining them from the curves of BRUNBERG and DATTNER (1954).

If we know the mean energy of the variable component, the angle of correction for the geomagnetic deflection can be determined. Although this energy is not known with any precision, it is expected to be between 20 and 40 GeV. The corrections have been discussed by BRUNBERG and DATTNER (1954). The following corrections have been utilized: Godhavn 30°, Cheltenham 45°, Christchurch 45°, and Huancayo 90°.

It can be seen clearly that there is an agreement between all the four stations and there is a unique direction of anisotropy emerging from all the stations for different periods. It is observed that the direction of anisotropy shows a tendency to earlier hours around 1944 and in the next cycle it shows a systematic shifting to earlier hours. This reveals the world-wide nature of the effect.

Fig. 5 gives the mean annual semi-diurnal vector for all the stations for the same years. The same corrections of 2, 3, 3, and 6 hours have been applied for geomagnetic deflection for the stations Godhavn, Cheltenham, Christchurch, and Huancayo. It is clearly seen that there is no agreement between the various stations. While Cheltenham and Christchurch

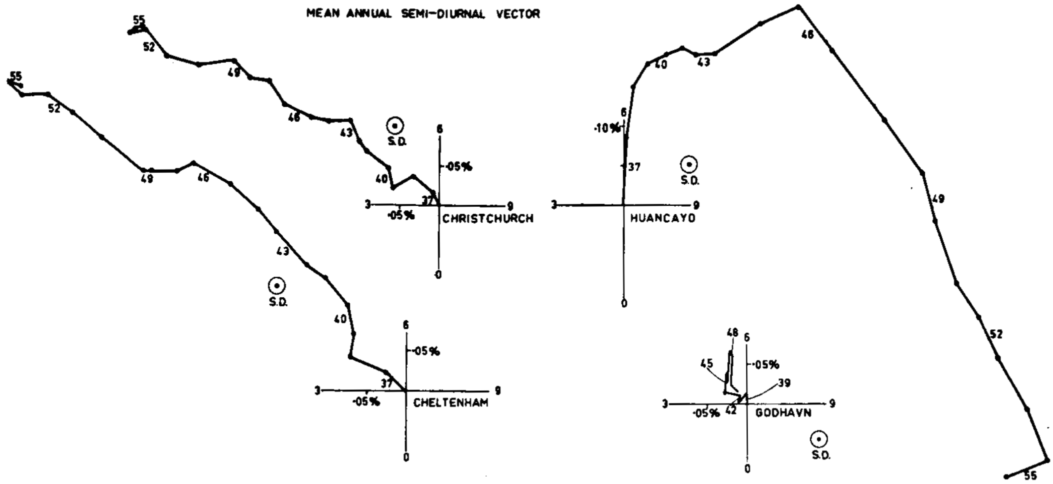

Fig. 5. Mean annual semi-diurnal vectors for the period 1937—55 for Huancayo, Cheltenham, and Christchurch and for 1939—50 for Godhavn. The length of the vector gives the amplitude and the angle, with respect to the given axes of coordinates, gives the hour of maximum. Corrections of 6, 3, 3, and 2 hours have been made for geomagnetic deflection for Huancayo, Cheltenham, Christchurch, and Godhavn respectively.

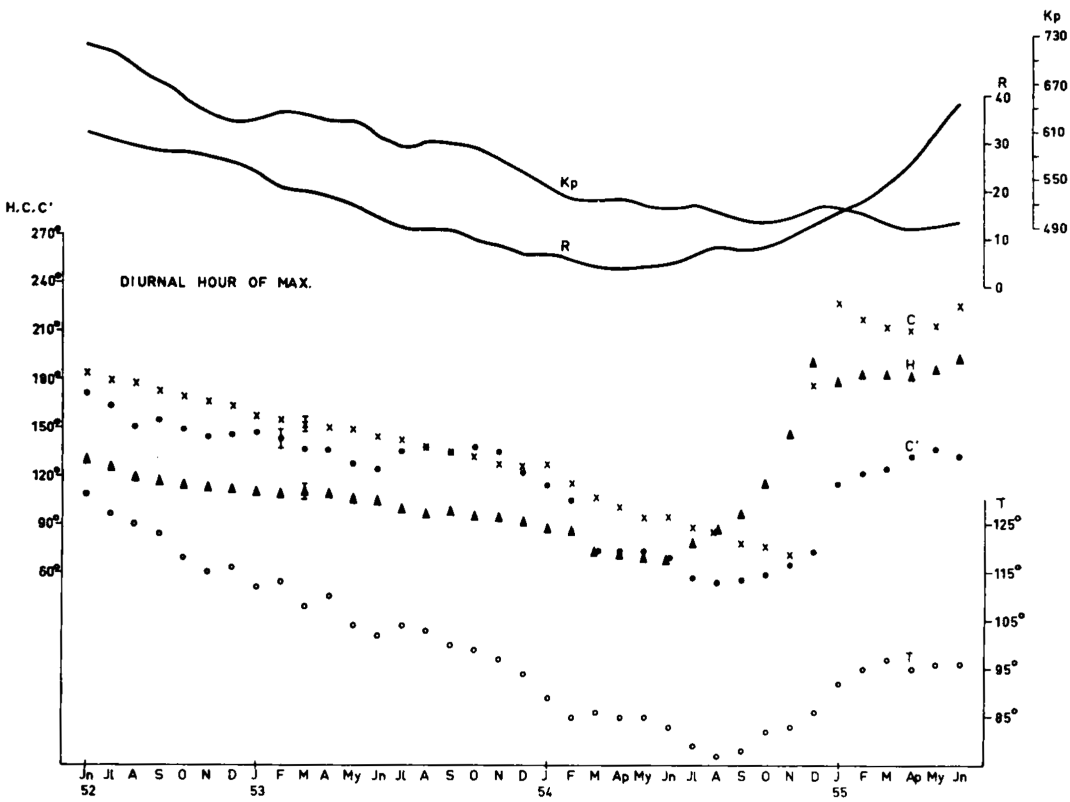

Fig. 6. Time series for the hour of maximum of the diurnal component of the daily variation of cosmic ray intensity for the period 1952—55. Each point refers to the annual mean centred on that month. H refers to Huancayo, C to Cheltenham, C′ to Christchurch, and T to Tokyo. All four are ion chambers. The four stations are represented by triangles, crosses, dots, and circles respectively. R refers to the sunspot number and K_p to the sum of the K_p values for a year.

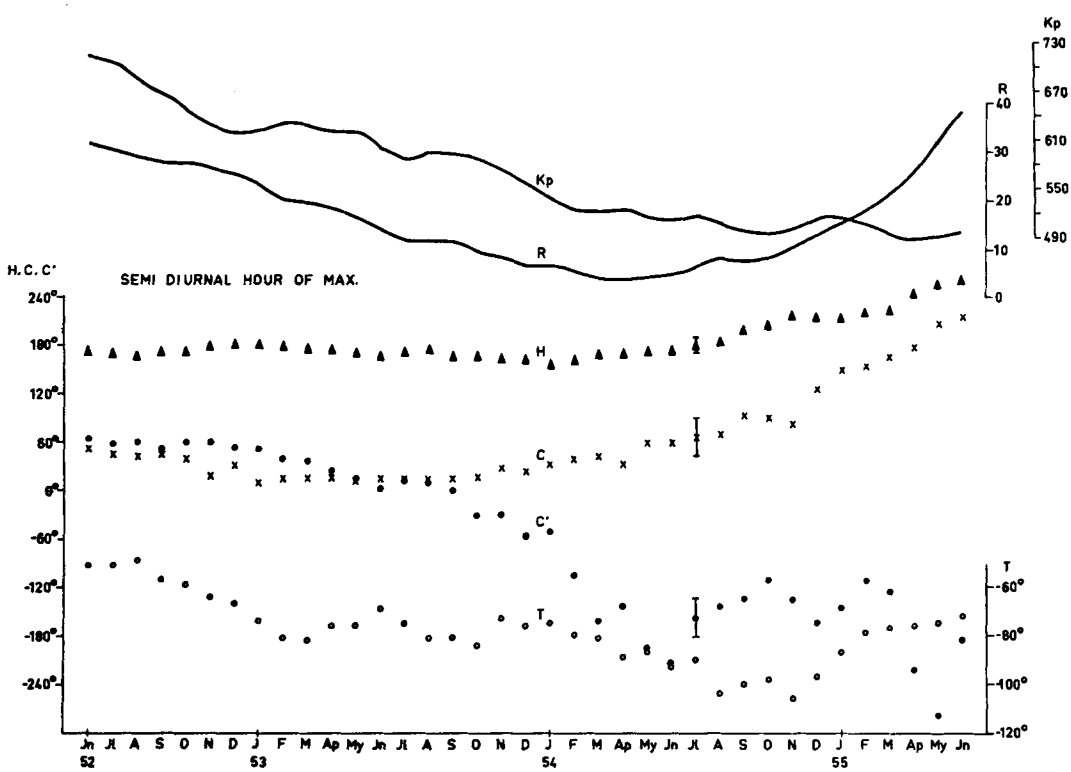

Fig. 7. Time series for the hour of maximum of the semi-diurnal component of the daily variation of cosmic ray intensity for the period 1952—55. H refers to Huancayo (plotted as triangles), C to Cheltenham (plotted as crosses), C′ to Christchurch (plotted as dots), and T to Tokyo (plotted as circles). *R* refers to the sunspot number and K_p to the sum of the K_p values for a year.

have, on an average, been pointing to directions corresponding to 5 and 4-30 hours respectively, Huancayo points in different directions at different periods and it is impossible to fix any direction in the case of Godhavn.

Hence it does not appear feasible to derive any common characteristics from the study of the semi-diurnal component at the various stations, whereas the diurnal variation exhibits a consistent and similar behaviour at the various stations which enables us to determine uniquely the direction for the anisotropy. It therefore appears reasonable to consider the diurnal component of the daily variation separately and to discuss the possible origin of this component. It is needless to point out that the semi-diurnal variation would also have to be explained in order to understand the daily variation completely. In this connection it is necessary to consider the contributions of meteorological origin and to make sure that adequate corrections have been applied for them. It would be of great value to study the semi-diurnal component of the neutron data for a number of stations, since it would then be easier to eliminate the atmospheric effect completely. The differences in the diurnal and semi-diurnal variation could also mean, either that the sources responsible for them are not the same or that it is not appropriate to apply the same correction for the geomagnetic deflection in the two cases.

Changes in the daily variation of cosmic ray intensity during the period 1952—55

The study of the daily variation of cosmic ray intensity by the Ahmedabad group for the period 1937—52 has been extended for the period 1952—55. Running means for successive twelve months are taken and hence each point in figures 6, 7, and 8 refers to the annual mean centred on that month.

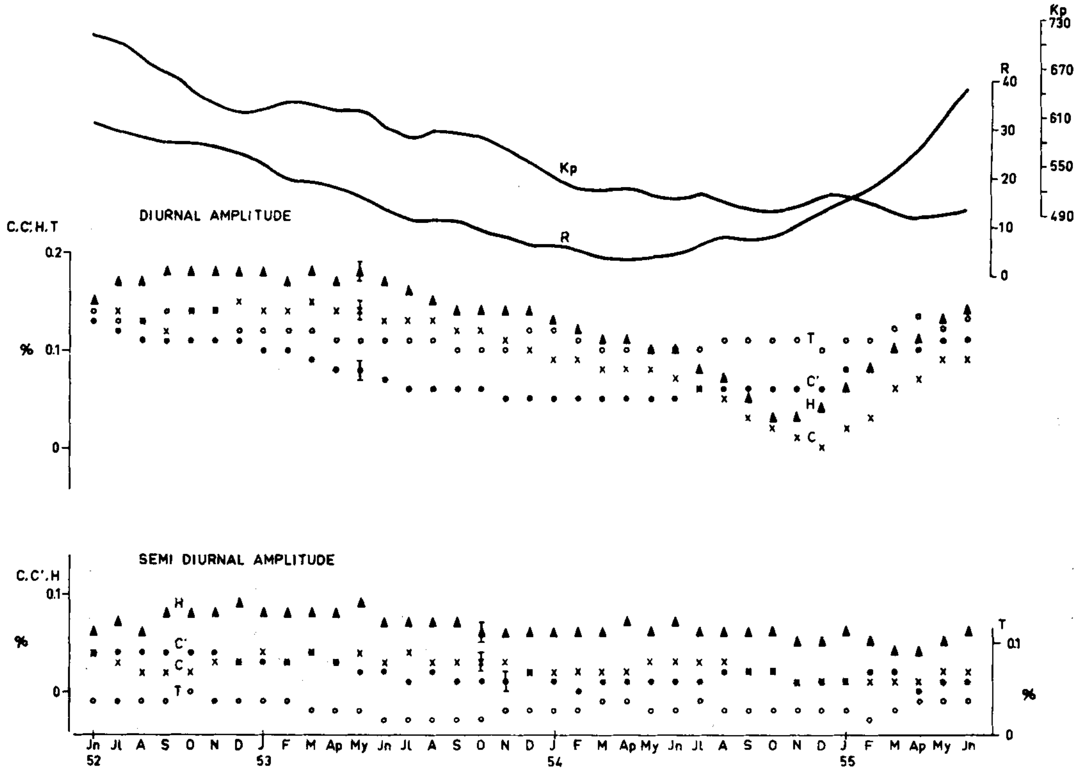

Fig. 8. Time series of the amplitude of the diurnal (top) and semi-diurnal (bottom) components of the daily variation of cosmic ray intensity for the period 1952—55. The triangles refer to Huancayo (H), the crosses to Cheltenham (C), the dots to Christchurch (C′) and the circles to Tokyo (T). R and K_p refer to the solar and geomagnetic activities respectively.

In fig. 6 the solar activity, as revealed by the sunspot number, is plotted at the top, and at the bottom the times of maximum of the diurnal variation at Huancayo, Cheltenham, Christchurch and Tokyo are plotted. The former three stations have identical ion chambers. The instrument at Tokyo is also an ion chamber. No corrections for the geomagnetic deflection have been applied, and direct comparison is therefore possible with the earlier analysis of SARABHAI et al. (1954). The shift of the time of maximum to earlier hours appears to be rather sudden, especially at Cheltenham, in comparison to solar activity as revealed by sunspot number. Nevertheless there is good agreement between the four stations, as has been observed from long term studies.

Fig. 7 shows the changes in the semi-diurnal hour of maximum for all the stations. The disagreement between the stations can be easily seen, and fits in with our earlier studies.

Fig. 8 gives the amplitude of both the diurnal and semi-diurnal components, along with the solar activity, as represented by the sunspot number, and the geomagnetic activity, as revealed by the sum over the year of K_p values. As there is not too great a difference between geomagnetic activity and solar activity during this period, it is not possible to determine whether the amplitude of the diurnal component follows the one or the other. Nothing can be said of the semi-diurnal amplitude, as the variations are too small.

In general it can be seen from this study also that there is a world-wide agreement in the case of the diurnal variation while it is lacking in the case of the semi-diurnal component.

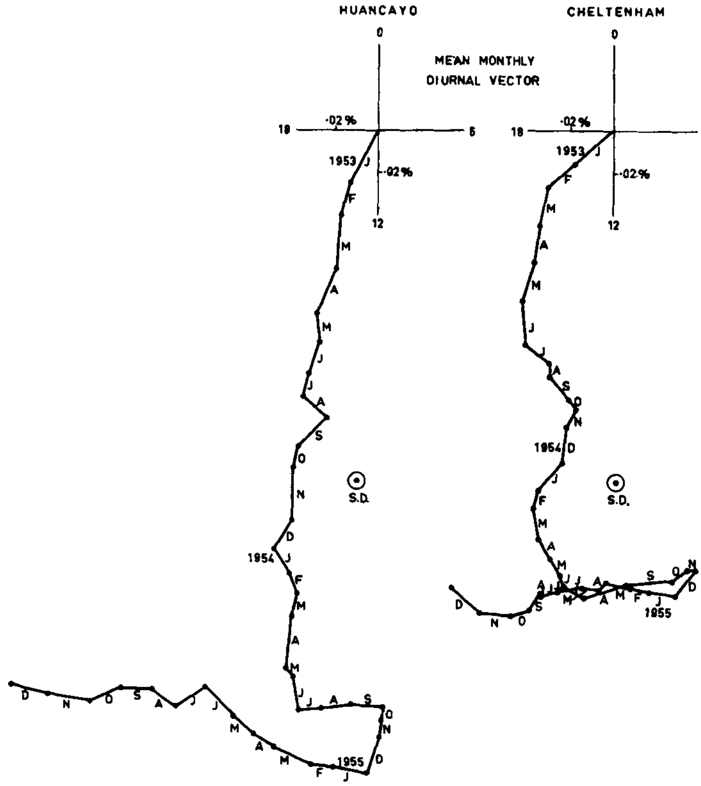

Fig. 9. Mean monthly diurnal vectors for successive months during the period 1953—55 for Huancayo and Cheltenham. The length gives the amplitude and the angle, with respect to the given axes of coordinates, gives the hour of maximum. Correction for geomagnetic deflection has been applied as discussed in the text.

Study of the mean monthly daily variation during the period 1953—55

The year 1954 is noted for the extreme low activity of the sun. In view of the seeming control of the anisotropy by the sun, it would be worthwhile to investigate the changes in the daily variation by considering the mean monthly variation at the various stations.

Figs. 9 and 10 give the successive mean monthly diurnal vectors for the period 1953—55 for Huancayo, Cheltenham, Christchurch, Hobart, and Tokyo for 1953—56. As pointed out earlier, the ion chambers at the Carnegie Institution stations are identical. Hobart data are registered by counter telescope and Tokyo data by an ion chamber. All the data are corrected for pressure. In the case of Tokyo, it is well worth remembering, as pointed out by MIYAZAKI (1954), that as Japan is situated at the edge of the Pacific Ocean, the variation of the temperature is very great, especially accompanied by the passage of fronts or low pressure air masses such as typhoon. One does not know the correction that has to be applied. It is necessary to bear this in mind when discussing the Tokyo results. In the case of Hobart, the vectors are not for each month but for each solar rotation. As the results were available in this form and as they do not materially affect the comparison, we have used them as they are.

As explained earlier the length of the vector gives the amplitude, and the angle, with respect to the given axes of coordinates, gives the hour of maximum. The vector for each month is plotted at the tip of the vector for the previous month in the manner suggested by CONFORTO and SIMPSON (1957). The vectors are corrected for geomagnetic deflection. The angles of correction are 30° for Godhavn,

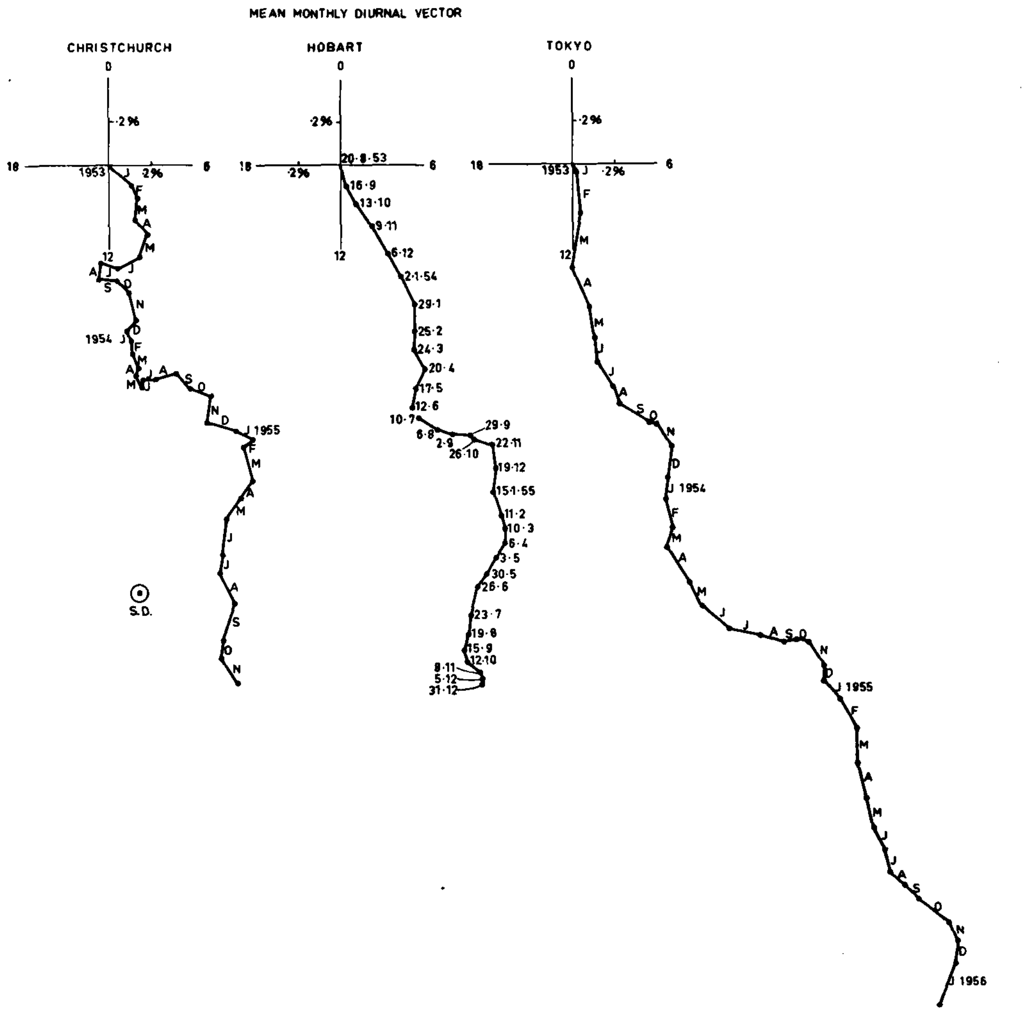

Fig. 10. Mean monthly diurnal vectors for successive months during the period 1953—55 for Christchurch, Tokyo, and Hobart. The length gives the amplitude and the angle, with respect to the given axis of coordinates, gives the hour of maximum. Correction for geomagnetic deflection has been applied as discussed in the text. The first two have ion chambers while Hobart has a counter telescope to register the intensity.

45° for Cheltenham and Christchurch, 90° for Huancayo, 60° for Tokyo, and 45° for Hobart.

It is observed at all the stations that there is a sudden change in the direction of the hour of maximum around June 1954, and again around the end of the year. There is remarkable agreement up to about the beginning of 1955 and then there are certain differences between the stations. The results are summarized in table 1.

The remarkable agreement between the various stations breaks down from the beginning of 1955 as the diurnal hour of maximum at Huancayo, as well as at Cheltenham, is about 18 hours while identical equipment at Christchurch, which is a southern latitude station, gives a value around noon. Again Hobart, which is also a southern station, although a different type of instrument, agrees with Christchurch. Tokyo shows an hour of maximum agreeing with the southern station, and reveals a change in direction in 1956 which, for want of data from other stations, cannot be used for drawing any conclusions.

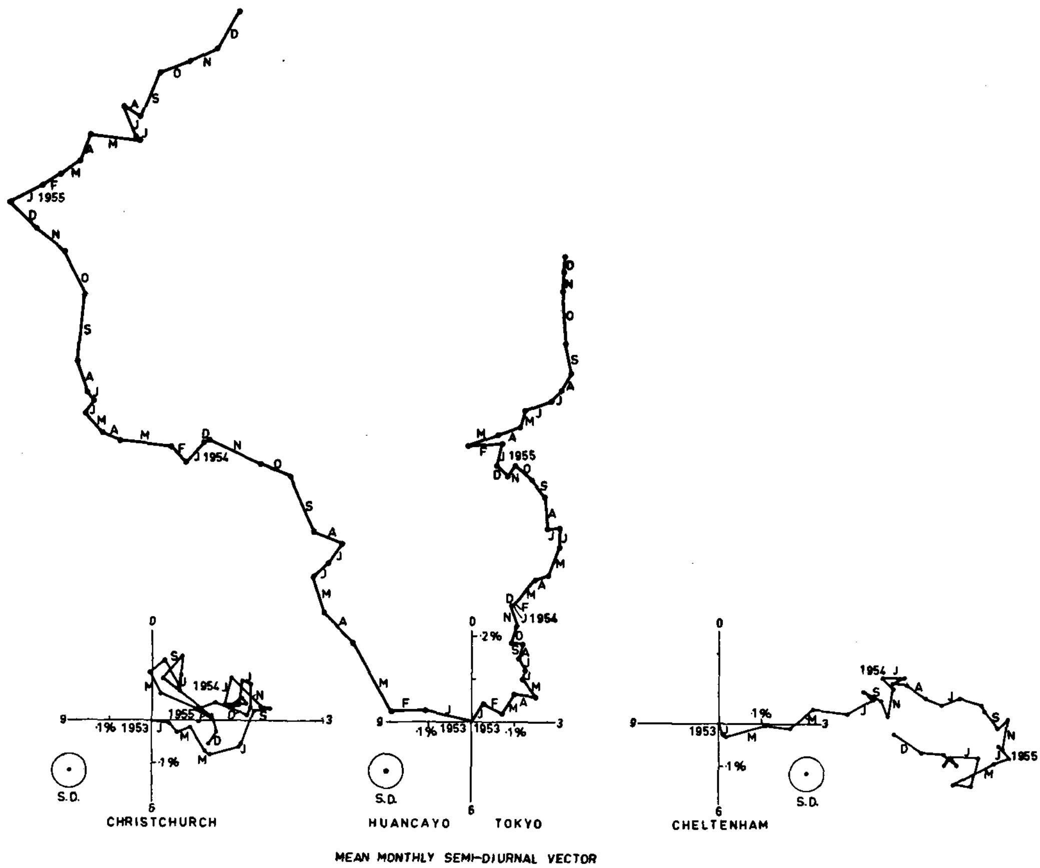

Fig. 11. Mean monthly semi-diurnal vectors for the period 1953—55 for Huancayo, Cheltenham, Christchurch and Tokyo. The length gives the amplitude and the angle, with respect to the given axis of coordinates, gives the hour of maximum. Correction for geomagnetic deflection has been made.

The changes in the monthly semi-diurnal vectors at the four stations, corrected for geomagnetic deflection, are shown in fig. 11. It can be seen that there is no similarity in the changes at the various stations. This is in conformity with the views expressed earlier.

It is possible to interpret the occurrence of the diurnal hour of maximum at around 6 hours during epochs of extremely low solar activity. This and other possible contributions to the diurnal variation are considered separately in another paper (Diurnal Variation—DATTNER and VENKATESAN. Manuscript under preparation).

The differences in the diurnal variation during 1955 at the stations studied here need careful consideration by means of a comparison with data from a large number of stations, before any definite views can be expressed.

CONFORTO and SIMPSON (1957) have pointed out that they observe a regular anticyclic progression of the daily variation vector as deduced from the nucleonic component intensity measured at Huancayo. This is shown in figure 12, which is reproduced from their paper. It should however be pointed out that their vector is not the purely diurnal vector as discussed in our analysis, and hence cannot be directly compared. Their vector amplitude is the ratio of the sum of deviations in the twelve-hour interval of maximum intensity, divided by the standard deviation for the station.

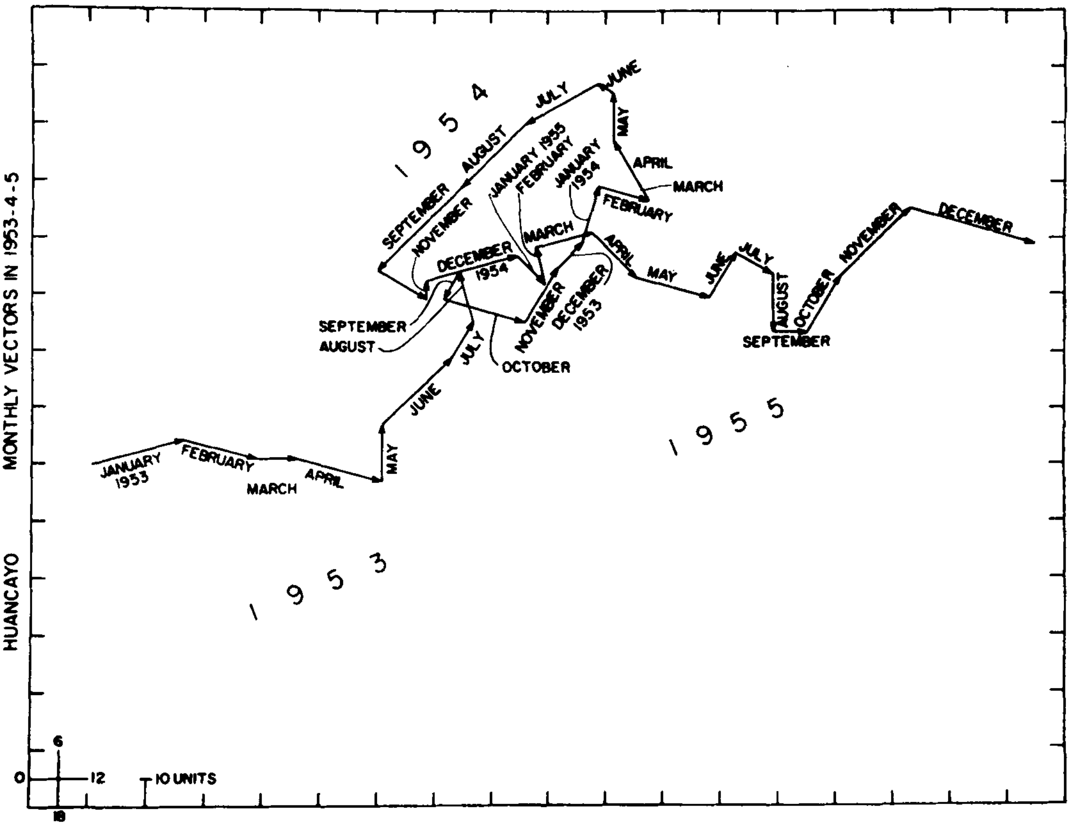

Fig. 12. Monthly average vectors for cosmic ray intensity as registered by a neutron monitor at Huancayo, for the period 1953—55. The vector is different from the ones in the present paper. The amplitude is given by the ratio of the sum of deviations in the twelve-hour interval of maximum intensity, divided by the standard deviation. The phase is determined by the middle of the interval. [Taken from a paper by Conforto and Simpson (1957)].

The phase is determined by the hour at the centre of the twelve-hour time interval. Our diurnal vector for the ionisation component at the same station reveals a regular cyclic progression. Before anything could be said on the differences in the behaviour of the ionising and nucleonic components, it would be necessary to have identical and uniquely defined vectors for both components. It would be interesting to study the changes in the monthly diurnal vector for the nucleonic component and also the changes in the semi-diurnal vector for the nucleonic component, where we are almost sure of correction for atmospheric effects.

Conclusion

The following conclusions emerge from the present study:

1. There are essential significant differences in the long term changes of the diurnal and semi-diurnal components of the daily variation. The changes in the diurnal variation are world-wide and are positively correlated at the various stations. The changes in the semi-diurnal variation, although observed at various stations, nevertheless do not reveal any common features. The semi-diurnal component at the various stations needs greater consideration in view of the striking dissimilarity between the stations and no general conclusions can be drawn about the semi-diurnal component at present. The differences in the changes of the diurnal and semi-diurnal components of the daily variation suggest that it is appropriate to consider the two independently, although it is necessary to consider both in order to understand the daily variation completely.

Table 1

Average direction of the anisotropy, as deduced from the diurnal variation, over the period 1956—55

Station	Period: from	Period: to	Hour of maximum of the diurnal variation
1. Huancayo	Jan. 53	June 54	12—30
2. Cheltenham	Febr. 53 / March 53	»	12—00
3. Christchurch	Jan. 53	»	12—00
4. Hobart	Aug. 53	»	11—30
5. Tokyo	Jan. 53	»	11—30
1. Huancayo	June 54	Oct. 54	06—00
2. Cheltenham	»	Nov. 54	06—00
3. Christchurch	»	Febr. 55	07—00
4. Hobart	July 54	Nov. 54	07—00
5. Tokyo	June 54	Nov. 54	07—00
1. Huancayo	Oct. 54	Dec. 54	13—00
	Jan. 55	Dec. 55	18—30
2. Cheltenham	Dec. 54	Dec. 55	18—00
3. Christchurch	Febr. 55	Dec. 55	12—00
4. Hobart	Dec. 54	Dec. 55	12—30
5. Tokyo	Dec. 54	Dec. 55	11—30
	Jan. 56	Dec. 56	15—00

2. It is possible to determine the direction of the anisotropy uniquely from a study of the diurnal variation corrected for geomagnetic deflection at different stations. The anisotropy tends to earlier hours during years of minimum solar activity. This shifting to earlier hours may be more pronounced in one solar cycle than in another. Though it seems reasonable to expect differences in the magnitude of effects during different solar cycles, it is not possible at present to go into greater detail.

3. The long term changes of the amplitude of the diurnal variation follow the changes in geomagnetic activity more closely than they follow the solar activity. This would indicate that the connection with solar activity is only indirect and that the interplanetary electromagnetic state is the more important link.

We wish to thank Prof. Alfvén and Dr. Herlofsson for their interest in the problem. We are grateful to Dr. S. E. Forbush, Dr. Miyazaki, and Dr. A. G. Fenton for making available the unpublished data from the Carnegie Institution for 1947—55, from the Scientific Research Institute, Tokyo, for 1955—56, and from Hobart for 1953—55. The computation of the Hobart data by Dr. A. E. Sandström was sponsored by the Lars Hiertas Minne Foundation. We are thankful to both. We are thankful to Mrs. Bharathi Venkatesan for computational assistance and to Mrs. Kaj Forsberg for drawing the diagrams. We are thankful to Dr. Conforto and Dr. Simpson for making their manuscript awaiting publication available. One of us (D.V.) is grateful to the Statens Tekniska Forskningsråd for support which has made this investigation possible.

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