

A REPORT ON COSMIC RAY DAILY VARIATION

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Introduction

The diurnal variation of cosmic ray intensity has been investigated by several workers [1-4]. On a long-term basis, the diurnal variation has two significant components of the variability of 11 and 22-year period of solar activity. In the present analysis we have derived the yearly mean amplitude and phase of the diurnal variation of cosmic ray intensity for the period of 1989-2000, which represents the maxima of solar activity cycle 22 to next maxima of solar activity cycle 23. As such, we discuss various characteristics of long-term diurnal variation of cosmic ray intensity for the period of 1989-2000. The following are the previous observations :

1. The neutron monitor observations have generally indicated that the average diurnal anisotropy is time invariant during 1958 to 1970[1,2].
2. However, based on longer database, the phase change with 11 year and 22 year periods stand out, with a phase shift to earlier hours during solar cycle minima (1965, 1976, 1986 and 1996).[3,4,].
3. The recent neutron monitor observations have again shown that the average characteristics of the diurnal anisotropy has significantly changed during the period 1994 onwards [5,6] and these variations are not accountable by a reasonable change in the value of rigidity spectrum or R_{max} . (the upper cutoff rigidity up to which the diurnal anisotropy exists).

Observational Results & Discussion

The earlier results of the statistical relationship between A_p and $r_i - \phi_i$ on a day-to-day basis had shown drastic changes (reversal) during the years 1968 and 1973 [4]. As such, we have looked for the relationship between A_p and diurnal variation for the recent periods. To obtain the relationship between the A_p index and the diurnal variation on day-to-day basis, we have taken two stations Kiel and Tokyo, one the high latitude neutron monitor station and the other low latitude. The vector average of diurnal variation has been obtained for each year, by dividing all good days in five of A_p values. The following are the observational results:

1. The days are divided in five groups according to increasing value of A_p index (0-8,9-17, 18-26,27-53, and $A_p > 54$). However, days with large U.T. associated cosmic ray effects have not been included.
2. From the Fig.1, the change in diurnal variation with A_p for the station Kiel (geomagnetic cut-off rigidity range $\approx H 2.32$ GV), which when compared with Tokyo station demonstrates exactly similar variation except for some years.
3. Further it reveals a complete reversal of the vector from 1 to 4 as the period of maxima to minima approaches. The vector average values for each group and for each year from 1989-2000 for Kiel are plotted in the figure. It is observed that for low A_p groups, the dispersion from, one period to another is least in both the diurnal amplitude and phase. However, the

dispersion is found to be large for the last two Ap index groups (Ap 27-53 and Ap>=54). It is also noticed that the observed simultaneous increases in diurnal amplitude with Ap are consistent with the earlier findings [7].

4. Figure 2 depicts the annual average vectors of diurnal variation for the period of 1989-2000, using the Kiel cosmic rays data. Similarly Fig 3 shows the average diurnal vectors for Tokyo station. In these two figures, the annual average values for diurnal vectors have been plotted end-to-end for the entire period of study in the form of vector addition diagram. The overall value are shown in the figures by the dashed lines for both the stations (Kiel and Tokyo).

5. From these figures we see very clearly that the diurnal phase has continuously changed to earlier hours from 1992 to 1997, with some what decreasing amplitudes. the overall average vectors for the entire period for Kiel and Tokyo station have been deduced and are found to be:

$$\text{Kiel } r_{\text{avg}}(1989-2000)=0.25\%; \phi_{\text{avg.}}(1989-2000) = 192^{\circ}$$

$$\text{Tokyo } r_{\text{ave}}(1989-1997)=0.126\%; \phi_{\text{avg.}}(1989-1997) = 143^{\circ}$$

The change of diurnal vector during the 11 – year solar cycle is not very different from that reported for earlier solar cycles. In fact larger changes during the 11- year period has been observed earlier during alternate solar cycles [5-14]. It has also been reported that the amplitude of the diurnal variation is enhanced and phase shifts to earlier hours during days of high geomagnetic activity [13,14].

6. Fig4 depicts the frequency of occurrence for each year, for the diurnal amplitude for Kiel station (left hand side), whereas similar histogrammic distribution for diurnal phase is shown on the right hand side. A well defined peak around 0.3% can be easily seen for the amplitude in most of the years, except for 1995

to 1997, where there is a leftward shift, with maximum frequency around 0.2%. Since U.T. affected days have already been removed from the data set, hence normally we do not encounter diurnal amplitude values greater than 0.2%. Eventhough, there is a skewness at lower amplitude values, however, the distribution is fairly normal. The peak is much more defined with less skewness in the case of diurnal phase in almost all the years. Our earlier findings from the annual average behavior that the phase shifts to earlier hours can be confirmed from this distribution even on a day-to-day basis. The phase values represented earlier and here are all in local time. Similar sets of distribution are shown in fig.5 for Tokyo.

7. A critical comparison of the values shown in fig.5 for Tokyo, and that shown in fig.4 for Kiel, brings out that distribution of the diurnal amplitude has the peaks of much lower values than that for Kiel. Similarly, all the peaks of phase distribution are also shifted to earlier hours, with greater magnitudes, than that for Kiel. In each case, the peaks are narrow and well defined. The notable difference in the distribution of diurnal phase is observed to be in the years 1993 and 1994, where Kiel and Tokyo show different trends when compared with 1992.

8. Finally as such the analysis for the most recent period, once again reveals the predominance of eleven year changes in the diurnal variation of cosmic rays with characteristics similar to the observed earlier, both on a day-to-day basis as well as on an average basis.

9. Nevertheless, it is clear from a comparison of data from two or more stations, that the diurnal vectors associated with high Ap values, generally having larger amplitudes, though associated with larger scatter, are composed of real extra-terrestrial anisotropy. Moreover, the contamination of the variation being of

terrestrial origin, which could be due to universal time variations, cut-off rigidity changes correlated with Dst variations, and /or due to inadequate atmospheric pressure correction insignificant. During the years 1989-92 as well as during 1997 to 2000 , the diurnal time of maximum is found to shift to earlier hours quite significantly with the increasing value of Ap index, which is in complete agreement with earlier findings[7]. Nevertheless, the findings can be qualitatively explained by considering the differential response of cosmic rays due to the effect of varying interplanetary parameters, which are mostly produced by the two types of high-speed solar wind streams emanating from solar flares and coronal holes. Further analysis of more recent data for declining phase of solar activity is expected to provide confirmatory evidences.

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