29th International Cosmic Ray Conference Pune (2005) **00**, 101-104

The changes of diurnal anisotropy in cosmic rays and geomagnetic activity

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We have studied the data strings for the cosmic ray intensity registered by Deep River neutron monitor, the interplanetary magnetic field (IMF) intensity (B), geomagnetic activity index (Ap), sunspot numbers (Rz) as well as solar wind velocity for the period 1981-1994. Our analysis brings out some of the steady state characteristics of the long-term changes in cosmic ray intensity and other data strings and their interrelationships. It is noticed that the amplitude of the diurnal anisotropy seems to increase during solar activity maximum years; whereas the diurnal time of maximum remains in the corotational direction for the high amplitude anisotropic wave train events (HAE). The interplanetary magnetic field (B_{HAE}), solar wind velocity (SWV_{HAE}) and geomagnetic activity index (Ap_{HAE}) are positively correlated with solar activity.

1. Introduction

It has been realized that solar activity controls and modulates most phenomena studied in the interplanetary medium. The sunspots are distinguishing visible features of the Sun; they are the sites of intense magnetic fields on the photosphere, which extend into the corona and are drawn into the space by the solar wind. Hedgecock [1] reported evidence for an inverse correlation between the low frequency turbulence in IMF and the modulation of cosmic rays.

Ahluwalia [2] has suggested that the diurnal anisotropy is unidirectional during 1957-1970 having a maximum in the corotation direction (1800 hours) and during 1971-1978 the anisotropy consists of two components, one in the corotation direction (1800 hours) and the other in the radial (1200 hours) direction, similar to the concept proposed by Quenby and Hashim [3].

The average diurnal anisotropy vector has been explained as a consequence of the equilibrium established between the radial convection of the cosmic ray particles by solar wind and the inward diffusion of particles along the interplanetary magnetic fields due to the radial gradient [4-6]; the anisotropy is simply visualized as corotation of particles with the solar system magnetic fields [7, 8].

2. Data Sources and Analysis

The anisotropic events are identified using the hourly plots of cosmic ray intensity recorded at ground based Deep River neutron monitoring station and selected 38 unusually high amplitude anisotropic wave train events (HAEs) during the period 1981-94. The days having abnormally high amplitude for five or more consecutive number of days have been selected as HAE. High amplitude wave train events of continuous days have been selected when the amplitude of diurnal anisotropy remains higher than 0.4% on each day of the event for at least five or more days. The pressure corrected hourly neutron monitor data after applying trend correction is harmonically analysed to obtain amplitude (%) and phase (Hr) of the diurnal anisotropy of cosmic ray intensity for HAE. The data related with interplanetary magnetic field (IMF) and solar wind plasma (SWP) parameters have also been investigated.

3. Experimental Results and Discussion

To investigate the cosmic ray diurnal variation during 1981-94 the following parameters were

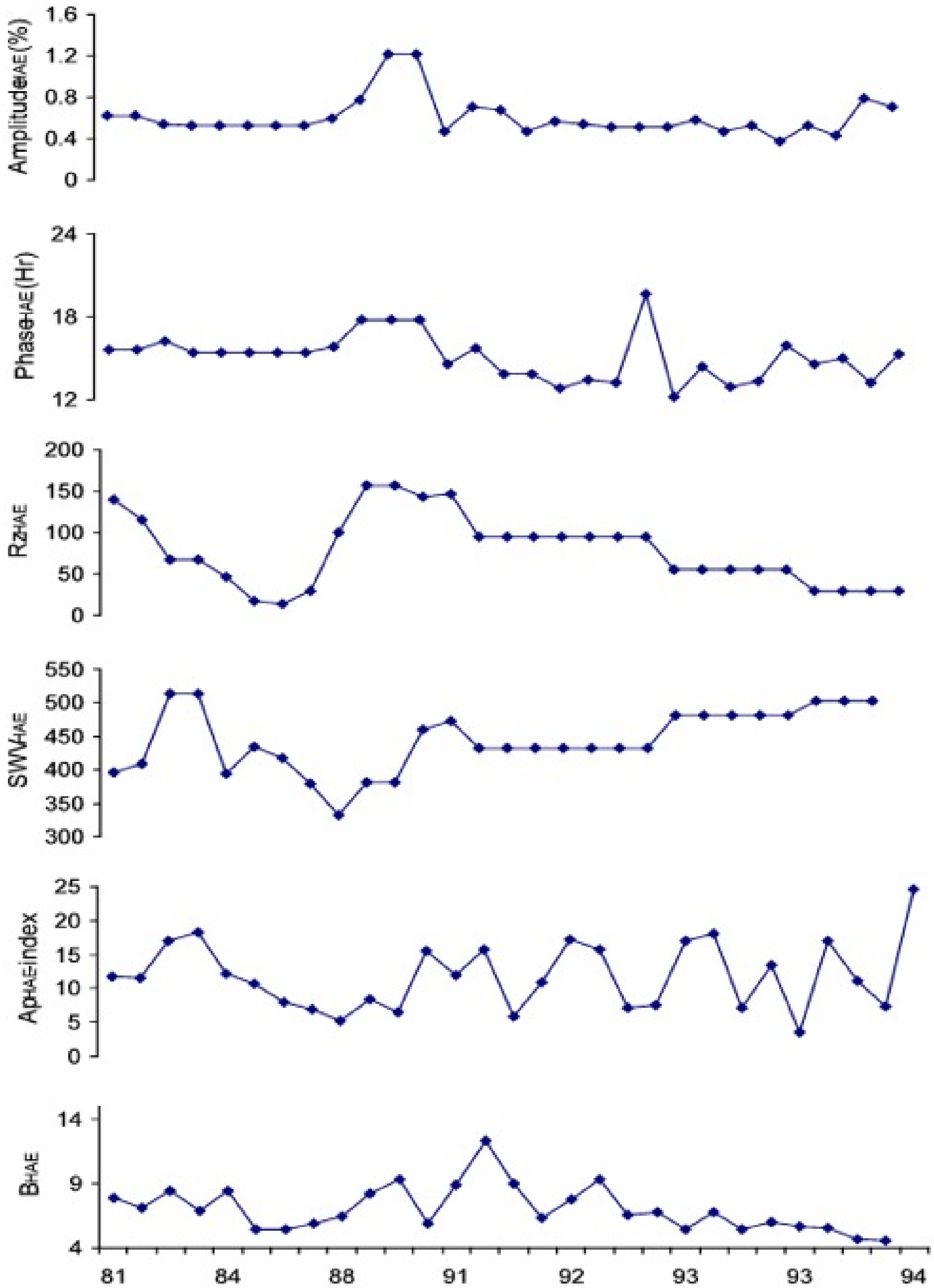

Figure 1: The long-term variation of cosmic-ray diurnal anisotropy amplitude (%) and the time of maximum (hr) for each HAE event is shown as a function of solar cycle represented by sunspot number (Rz_{HAE}), solar wind velocity (SWV_{HAE}), geomagnetic activity index (Ap_{HAE}) and interplanetary magnetic field ($\mathbf{B}_{HAE}$) for the period 1981-1994.

studied: the cosmic ray intensity registered by Deep River neutron monitor, sunspot number (Rz_{HAE}), geomagnetic activity index (Ap_{HAE}), and the interplanetary medium parameters: solar wind velocity (V_{HAE}), module of the interplanetary magnetic field (B_{HAE}) during high amplitude days. The amplitude (%) and time of maximum (Hr) along with the interplanetary and solar wind parameters for all the HAE has been plotted in Figure 1.

As depicted in Figure 1 the amplitude (%) of cosmic ray diurnal anisotropy consistently remains constant during the entire period. However, it does not indicate a one to one correlation with the sunspot numbers (Rz). It is evident from the figure that the amplitude distribution shows peaks (1.2%) during solar activity maximum years (1989 and 1990); whereas the sunspot distribution also shows peaks during these years. The diurnal time of maximum (Hr) as depicted if Figure 1 does not show any correlation with Rz but indicate a significant shifts towards earlier hours as compared to the corotational/18 Hr direction for most of the period. This is in good agreement with the earlier results [9, 10] where they concluded that the amplitude of the diurnal anisotropy is well correlates with the solar cycle but the direction of the anisotropy is not correlated with the solar cycle and shows a systematic shift to earlier hours. Further, the phase remains in the corotational direction during solar activity maximum years (1989-90).

One can clearly seen from the Figure 1 that frequency of days with diurnal time of maximum in the 1600 Hr direction significantly remains constant and the frequency of days with diurnal phase in the 1300 Hr direction shows significant decrease during 1992-1994. This clearly shows that during 1981-1994, the variation in the direction of the diurnal anisotropy vector has been caused by two kinds of flow of cosmic ray particles; one having a maximum in the 1600 Hr direction and another in the 1300 Hr direction. During 1989-1990 the phase shift of diurnal anisotropy has been caused by streaming of particles in the 1800 Hr direction and during the rest of the, in addition to the 1300 Hr component, the presence of excess streaming in the 1600 Hr direction caused a shifting of the diurnal time of maximum to wards earlier hours. Thus the diurnal anisotropy seems to be completed dominated by three components in the 1300 Hr, 1600 Hr and 1800 Hr direction.

It is clear from the figure the as the sunspot number (Rz) seems to decrease during solar activity minimum years (1986-87) and the solar wind velocity, Ap-index and IMF **B** also decreases significantly during this period. Further, with the increase in the sunspot number (Rz) during solar activity maximum years (1991) the solar wind velocity, Ap-index and IMF **B** also seems to increase significantly. The sunspot number (Rz), Solar wind velocity and IMF **B** remain statistically constant during 1992-1994. The Ap-index deviates quite frequently during the entire period. Thus it is observed that solar wind velocity and IMF **B** positively correlated with the solar activity.

In general there is a correlation between the long-term variations of Ap and the observed GCR modulation [11, 12 and references therein]. In an earlier analysis [13] it was noted that a subsidiary maximum appears in the annual mean solar diurnal anisotropy data, "when (the solar wind bulk velocity) V>470 km/s or when B has large values. It is shown that Ap is most responsive to the changes in the fine structure of B [14]; this point has been emphasized also by Lockwood et al. [15].

Thus we have observed from the plot that the diurnal amplitude (%) increases quite significantly during solar activity period; whereas the diurnal time of maximum remains in the corotational/azimuthal direction for all the HAE events. The solar wind velocity (SWV_{HAE}), sunspot numbers (Rz_{HAE}) and interplanetary magnetic field (B_{HAE}) seems to increase during solar activity maximum years; whereas the geomagnetic activity index (Ap_{HAE}) seems to unaffected during this period. However, the amplitude (%) seems to remain constant during solar activity minimum years; whereas the direction of the diurnal time of maximum remains in the 1600 Hr direction. The solar wind velocity (SWV_{HAE}), sunspot numbers (Rz_{HAE}) and geomagnetic activity index (Ap_{HAE}) seems to decrease during solar activity maximum years; whereas the interplanetary magnetic field (B_{HAE}) seems to unaffected during this period. It is also evident from the plot that the amplitude (%), diurnal time of maximum, solar wind velocity (SWV_{HAE}), sunspot numbers (Rz_{HAE}) and interplanetary magnetic field (B_{HAE}) remains statistically constant for the rest of the period; whereas the geomagnetic activity index (Ap_{HAE}) fluctuates quite frequently.

4. Conclusions

From the above discussion of observations and results we conclude that:
The long-term behaviour of the time of maximum of the diurnal anisotropy vectors could be explained in terms of corotation component and two additional components produced in the 1600 hours and 1300 hours direction.
The diurnal amplitude (%) increases quite significantly and the diurnal time of maximum remains in the corotational direction during solar activity maximum years for all the HAEs and thus shows a positive correlation between them.
The interplanetary magnetic field (**B**), solar wind velocity and geomagnetic activity index (Ap) are positively correlated with solar activity during HAE.

5. Acknowledgements

The authors are indebted to various experimental groups, in particular, Prof. Margret D. Wilson, Prof. K. Nagashima, Miss. Aoi Inoue and Prof. J. H. King for providing the data.

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