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Magnetic Cycle Dependence of the Cosmic Ray Diurnal Anisotropy

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Abstract

The two components of the solar diurnal variation observed with two detectors characterized by linearly independent coupling functions have been used to estimate the free space anisotropy vector during the period 1968-1995 using Least-Square Method (LSM). The values of R_c show ~20-year magnetic cycle with the lowest values at solar activity minima for positive polarity (qA>0). A good correlation is obtained between R_c and both the IMF magnitude and the geomagnetic activity index. The amplitude of the radial anisotropy (A_R) shows ~20-year magnetic cycle with the highest values around solar activity minima for qA>0 (1975-1976 and 1995), whereas that of the east-west (A_ϕ) is minimum. This results in shifting the anisotropy vector to the earliest hours. The amplitude of the anisotropy is high around solar maxima and low around solar minima. It is also enhanced during decline phase of solar activity (1971, 1984-1985 and 1991).

1 Introduction:

The cosmic ray anisotropy vector **A** in free space can be estimated by calculating the observed diurnal variation (DV) at certain location and the coupling function (CF) which couple the primary variational spectrum with the observed DV and by assuming an upper limit of the rigidity (R_c) above which the primary spectrum is not modulated. Many investigators have calculated the long term variation of the cosmic ray anisotropy in free space (Bieber and Chen, 1991; Ahluwalia and Sabbah, 1993; Munakata et al., 1997; Sabbah et al., 1998; Sabbah, 1999a) Calculation of the upper cut-off rigidity (R_c) at which the anisotropy vanishes is essential in order to calculate the amplitude of the anisotropy in free space and consequently the values of the cosmic ray gradients.

In this paper, we calculate the free space anisotropy of the DV during the period 1968-1995 using LSM.

2 Cosmic Ray Anisotropy:

In the present analysis we estimate the Anisotropy vector (AV) in free space as well as the applicable upper cut-off rigidity R_c above which the cosmic rays becomes isotropic during the period (1968-1995). We select DR neutron monitor together with vertical UMT located at SOC during the period (1968-1988) after which SOC detector stopped operating. We also select DR with vertical UMT located at SAK during the period 1978-1995. The CFs of the couple DR-SOC or DR-SAK are linearly independent (Sabbah, 1999a). We use LSM and assume a flat rigidity spectrum during the period 1968-1995. Figure 1 displays the parameters of the anisotropy during the period (1968-1995) namely: the upper cut-off rigidity R_c, the amplitude of the radial anisotropy (A_R) along with that of the east-west anisotropy (A_ϕ) and the direction of resultant DA vector obtained from LSM. These parameters exactly fit the observed DV over the years 1968-1995. The amplitude of the resultant anisotropy is plotted in Figure 1 as well. The time of the solar polarity reversal is shown by shaded areas in the bottom panel of the Figure 1. Years of sunspot maxima are indicated with upward pointing arrows while those of sunspot minima are indicated with downward pointing arrows. The upper cut-off rigidities displayed at the top panel of the Figure 1 (open circles) derived from the couple DR-SOC and (triangles plotted at the middle of the bin) derived from the couple DR-SAK. R_c reaches the highest values during the declining phase of solar activity (1982-1984 and 1991). The values of the upper cut-off rigidity R_c show a ~20-year solar magnetic cycle with minimum values around solar activity minima of qA>0 in (1976

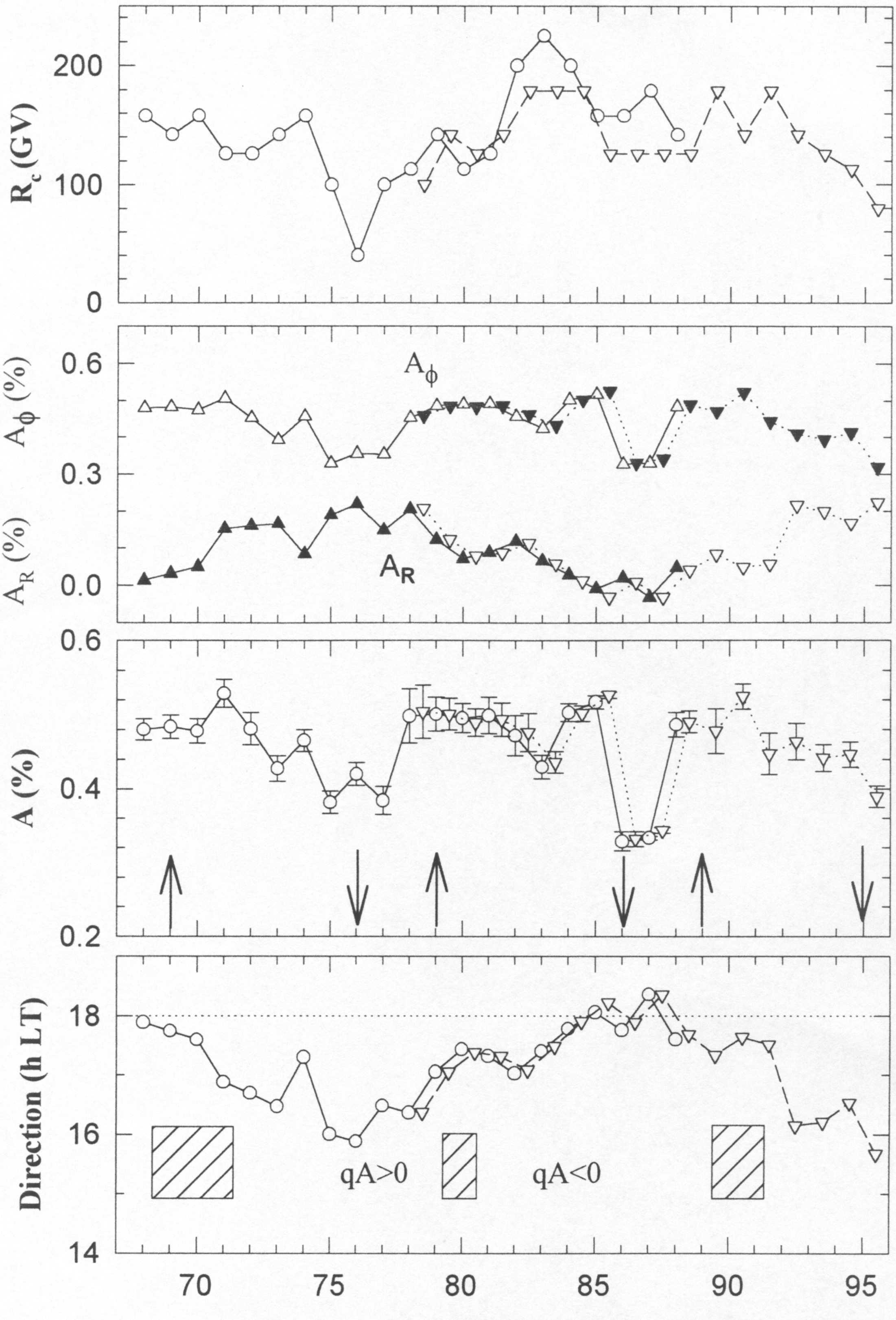

Figure 1: The best fit parameters of the free space anisotropy vector.

and 1995). The value of the anisotropy is low around solar minima indicated with downwards pointing arrows and high around solar maxima indicated with upwards arrows. The lowest values of the amplitude occurred in 1986-1987. The values of A shows a clear 11-year cycle. The amplitudes of the anisotropy calculated from the couple DR-SOC (open circles) are equal (within the statistical error) to those calculated from the couple DR-SAK (triangles plotted at the middle of the bin) during the overlapped years. The amplitude of the east-west component (A_ϕ) of the anisotropy is always higher than that of the radial component (A_R). That is why the behavior of the anisotropy A is very much similar to that of A_ϕ. Note that the values of A_R are negative during 1985-1987, when it is pointed toward the 0 hLT direction. The amplitude of A_ϕ reaches the lowest values around solar activity minima for qA>0 (1976 and 1995). The reverse is true for A_R: it reaches the highest value around 1976 and 1995. The average value of A_ϕ during the 28-years (0.44±0.04)% is almost 5 times that of the radial anisotropy. The average value of the amplitude of A_R during qA>0 increases 4 times of its value (0.04±0.01)% during qA<0. This results in shifting the AV to earlier hours during qA>0 which is consistent with the prediction of the drift model (Sabbah and Potgieter, 1995). The co-rotating anisotropy breaks around years of sunspot minima of qA>0 (1976 and 1995) when A_R reaches the highest values and A_ϕ reaches the lowest values. This results in shifting the AV to the earliest hours around 1976 and 1995 which in turn produce ~20-year solar magnetic cycle (see bottom panel of Figure 3).

3 Correlations of the Upper Cut-off Rigidity:

In Figure 2 we show the values of R_c which were plotted in Figure 1 together with the yearly average values of interplanetary magnetic field IMF magnitude (closed circles). We see a very good correlation between the two parameters: This is not surprising since the cosmic ray anisotropy only arises because particles of a particular rigidity suffer sufficient scattering in the interplanetary medium to remove the density gradient which is otherwise set up to cancel the effect of the overall, conservative electric field (Parker, 1964, Axford, 1965, Stern, 1964). The parallel mean free path must depend on some inverse power of the total magnetic field magnitude. Therefore, as the IMF strength reduces, the upper limit to efficient scattering reduces and the upper limit to the anisotropy (R_c) similarly declines. The IMF magnitude shows 11-year cycle (Sabbah, 1996). It was minimum when the value of R_c was very low in the years of solar activity minima (m), (1976, 1987 and 1995) represented by dotted lines. Both the values of R_c and those of IMF magnitude were high in the years of solar

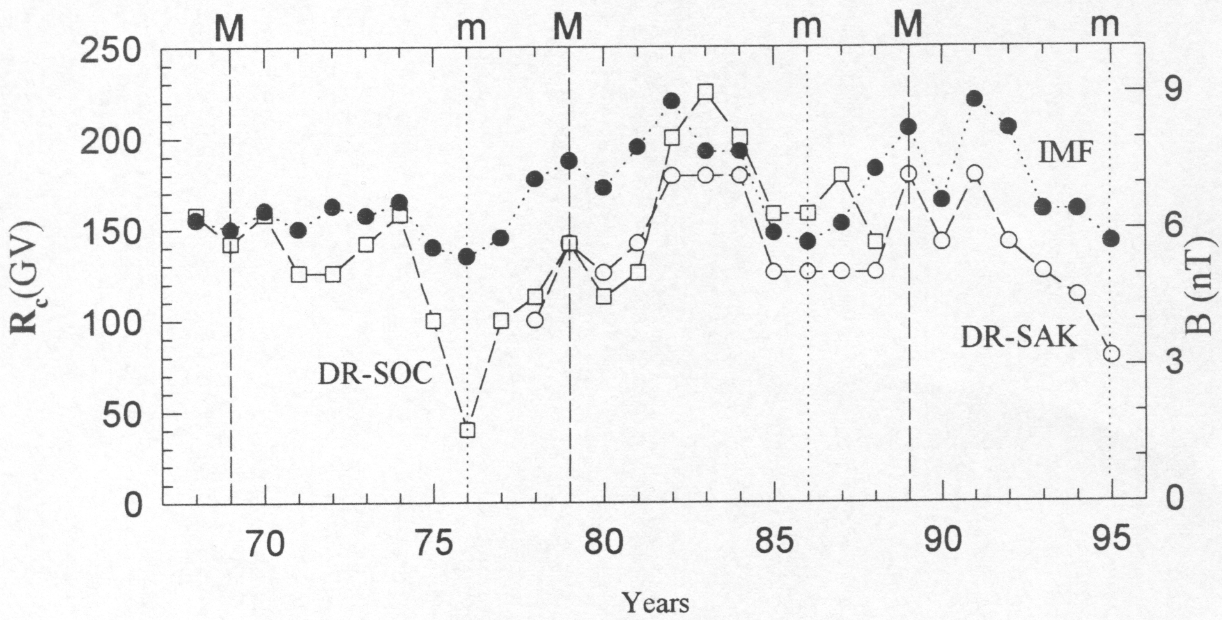

Figure 2: Values of the upper cut-off rigidity together with the values of the IMF magnitude.

activity maxima (M), (1979 and 1989), represented by dashed lines. The IMF magnitude reached the highest value in the years of declining phase of solar activity (1982 and 1991), when the values of R_c were high. The IMF magnitudes show a magnetic cycle variation as well with the lowest values around solar activity minima of qA>0 in (1976 and 1995) when the co-rotating anisotropy breaks and the radial anisotropy reaches the highest values. We got a correlation coefficient r=0.49 between the IMF magnitude and R_c during the entire period (1968-1995). We use R_c calculated from the couple DR-SOC during 1968-1977 and that calculated from the couple DR-SAK during 1978-1995. The upper cut off rigidity calculated from the couple DR-SAK (open circles) is well correlated with the IMF magnitude during the period 1978-1995 with r=0.60. Ahluwalia (1992) obtained a correlation coefficient of 0.62 during the period 1966-1987. However, the values of R_c derived from DR-EM by Ahluwalia and Dorman (1997) are a lot lower than our's and not even correlated with the IMF magnitude any more. This gives us more confidence in our choice of the two detectors DR and SAK after Socorro data was stopped in 1988 to calculate the values of R_c. A good correlation (r=0.6) has also been obtained between R_c and the geomagnetic activity index Ap (Sabbah, 1999b).

4 Conclusions:

In this analysis we use diurnal variation observed with detectors characterized by linearly independent CFs to estimate the anisotropy vector in free space using LSM. Our analysis reveals that:

1. The fact that the values of the anisotropy parameters derived from DR and SOC are well consistent with those obtained from DR and SAK during the overlapped period does validates our choice of the detectors used.
2. The upper cut-off rigidity shows ~20-year magnetic cycle with the lowest values at the sunspot minima of qA>0. R_c reaches the highest value (200-250 GV) during the declining phase (1982-1984) of solar cycle 21.
3. A good correlation is found between the values of R_c obtained from the couple of detectors DR-SAK and IMF magnitude.
4. The average value for the amplitude of the AV for the 1968-1995 period is (0.46±0.03)%. The direction of the anisotropy displays obvious ~20-year magnetic cycle, with the earliest hours at the sunspot minima of qA>0 in 1976 and 1995. This happens since the amplitude of the radial anisotropy (A_R) reaches the highest value during solar activity minima of qA>0 in 1976 and 1995 when that of the east-west anisotropy (A_ϕ) reaches the lowest value which results in shifting the AV more closer to the larger anisotropy component (earliest hours).

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