SH 4.3-15

THE COROTATING VARIATION OF THE NORTH-SORTH ANISOTROPY OF COSMIC RAYS

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Correlation analysis on the relation of the north-south (N-S) anisotropy of cosmic rays, observed by the Nagoya multi-directional meson telescope, with the IMF as well as the solar wind velocity within solar Carrington rotation for the period 1971-1976.

It is found that the N-S anisotropy of cosmic rays correlates quite well with the Bx component of the IMF. The correlation coefficient nearly equalsto 0.8.

1. Introduction. Since the cosmic ray N-S anisotropy was discovered, a number of studies about it have been published. The drift due to the radial gradient of cosmic ray density n derives the N-S anisotropy in the presence of the IMF intensity $\underline{B}$, as interpreted by Swinson[1]. The correlation of the cosmic ray anisotropic index GG([4], [5]) with the daily average direction of the IMF was studied by Yasue et al.[2], and a good correlation coefficient (~0.75) was obtained. But they did not give the quantitative analysis between the GG and magnetic field intensity. Fujimoto et al.[3] pointed out that the GG value decreased, as the IMF sector boundary changes its polarity from toward to away the sun, and vice verse. Munakata et al.[4] found that N-S anisotropy correlated somewhat with the solar wind velocity, as well as the Bx component of the IMF.

We made the correlation analysis between the N-S anisotropy and solar flare, and found the flare of importance $\geqq 2$ with duration $\geqq 1.5$ hours could change significantly the anisotropy[5]. The present paper studies the relation of the corotating variation of cosmic ray N-S anisotropy with solar wind velocity, as well as the parameters of the IMF with the sun.

2. Data and Method. The cosmic ray data used are the daily average values taken from the multi-directional meson telescope at Nagoya for the period 1971-1976[6]. The cosmic ray N-S anisotropic indexes A and AA are defined below,

$$A=(N-S)/2 \tag{1}$$

$$AA=(N-S)+(N-E) \tag{2}$$

Another parameter I is defined as

$$I=(N+S)/2 \tag{3}$$

Each term from formula (1) to (3) denotes a directional component of the cosmic ray intensity having its central direction of the viewing cone pointing toward the zenith angle of 30° in the north (N), the south (S), and the east (E)-directions, different from that adopted by Munakata et al.. The solar wind velocity and the IMF data are taken from that compiled by King, J. H.[7].

Analysis of cosmic ray data are made by applying Chree superposed epoch method with reference to their ordinal day in a solar rotation[8]. An accurate Carrimgton rotation period is divided into 27 round days. It avoids not only the drifting error caused by adopting Bartel's rotation, but also the difficulty produced by decimal Carrington rotation. Such a converted round day is called the "Carrington Day", with length approximately equal to 1.01 calender days. After taken the nearest whole number, the day at which the zero Carrington longitude crossing the solar central meridian is regard as the beginning day of each Carrington rotation.

In all figures of this paper the absissas represent the Carrington ordinal day from the first day to the 27th day corresponding the solar longitude from 360° to 0°. The ordinates show the parameters concerned, i.e. A, AA and I, as well as the solar wind velocity V, IMF total intensity B, its components Bx and By and its azimuthal angle φ in the ecliptic plane. In order to making the figures more clear, the values of the first three days are drawn repeatedly after the 27th day

3. Analysis and results. The distributions of cosmic ray N-S anisotropy and IMF Bx component in the Carrington rotation have been calculated. Simply shown are the results for 1973 and 1974 in Fig. 1. In Fig. 1b, two steady corotating structures of the IMF can obviously be seen. Also noted are the variations of A and AA being similar to that of Bx component. In other years, the steady corotating structures still exist, but not as clear as in 1974. Because the correlation coefficient between the A and AA is almost closed to 1, only the AA is discussed in following.

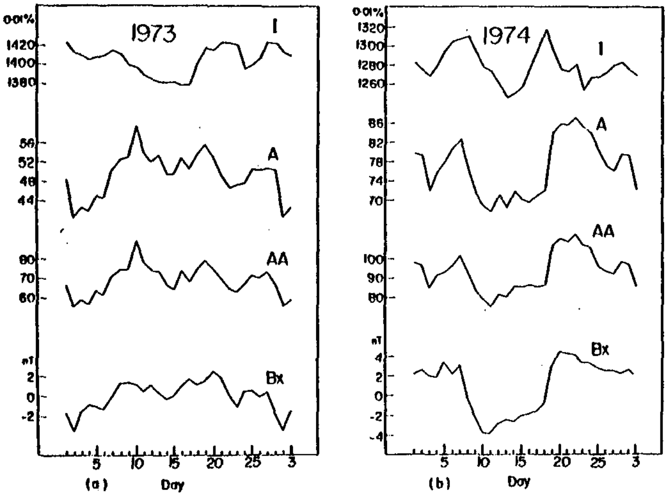

Fig. I. Corotating variations of I, A, AA and Bx.

The single and bi-correlation between AA and Bx and By can be expressed as the following formulas,

$$AA=a_{01}+a_{1x}B_x \qquad (4)$$

$$AA=a_{02}+a_{1y}B_y \qquad (5)$$

$$AA=a_0+a_{11}B_x+a_{12}B_y \qquad (6)$$

Table 1 summarizes the yearly coefficients in formula (4) to (6) and respective correlation coefficients r_x, r_y and r_{xy}, as well as the I and AA. It is striking that AA correlates quite well with the Bx component with a high correlation coefficient r_x 0.8 The r_y is negative, its magnitude is a bit less than r_x. The bi-correlation coefficient r_{xy} is a little higher than r_x. The r_x obtained here is much higher than that by Munakata et al.. This is because the present correlation coefficients are calculated on a yearly beses, while the previous ones using five year data altogether, and the change of the AA following the solar cycle reduced

Table 1. Values of various coefficients, as well as the I and AA during 1971-1975

year	a_{01}	a_{1x}	r_x	a_{02}	a_{1y}	r_y	a_0	a_{11}	a_{12}	r_{xy}	I	AA
1971	14	4.2	0.86	14	-4.1	-0.80	14	3.0	-1.4	0.87	1705	3
1972	38	4.2	0.71	39	-4.1	-0.63	39	3.1	-1.7	0.74	1557	38
1973	69	4.0	0.73	70	-4.3	-0.69	69	3.4	-0.8	0.73	1400	64
1974	90	3.4	0.88	92	-3.6	-0.88	91	1.8	-1.6	0.88	1294	91
1975	114	3.3	0.82	113	-3.3	-0.78	114	3.5	-0.3	0.82	1187	97

the statistical accuracy. Meanwhile the superposed epoch method has filtered the short term vaviation and raised also the statistical accuracy. The coefficients a_{1x}, a_{1y}, a_{11} and a_{12} do not change very much, but a_{01}, a_{02} and a_0 increase approximately from 14 to 114 with the decreasing solar activity during 1971-1975. This fact illustrates that the variation of N-S anisotropy is due to not only $\underline{B}\times v_n$, but other factor, for example, the variation solar general magnetic field.

We have also calculated the distributions of cosmic ray N-S anisotropy, solar wind velocity and the IMF parameters in the Carrington rotation for this period. For simplicity only the results for 1971 and 1974 are shown in Fig. 2. Table 2 summarizes the correlation coefficients of the AA with the V, φ and B respectively. The magnitude of r_V, r_φ and r_B are much lower than those of Bx and By. Hence it is the best to study the correlation of AA with IMF component.

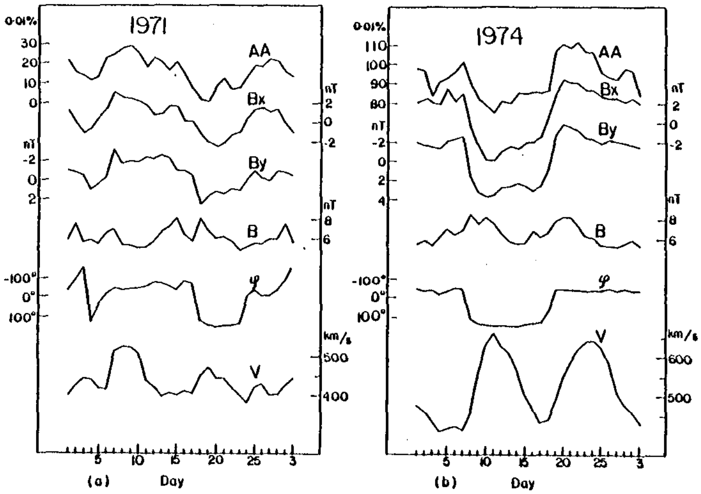

Fig. 2. Corotating variations of AA, Bx, By, B, φ and V.

It is well known that the solar activity weekens from 1971-1974, the solar modulation of cosmic rays increases, and the omnidirectional intensity of cosmic rays increases every year. The present results show the AA follows a similar trend, however, it is unexpected that the I decreases from year to year, quite different from the variation of omnidirectional intensity.

Table 2. The r_V, r_φ and r_B for 1971 and 1974

Year	r_V	r_φ	r_B
1971	-0.33	-0.61	0.29
1974	0.21	-0.75	0.02

4. Conclusion.

The cosmic ray N-S anisotropy correlates quite well with the IMF components Bx and By with a correlation coefficient nearly equal to 0.8, a positive one for the Bx component and negative for the By. The bi-correlation coefficient with both Bx and By is almost closed to 0.8. The variation of the regressive coefficients illustrates that the cosmic ray N-S anisotropy, in addition to the gradient drift effect, is controlled by some kinds of long term variayion of the solar cycle.

5. Acknowledgements. The authors are grateful to Prof. K. Nagashima for providing the valuable Nagoya multi-directional meson telescope data.

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