Anomalous Increase of Solar Anisotropy above 150GV in 1981-1983

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Abstract

An analysis was carried out of the observed data with Nagoya(surface), Misato(34mwe) and Sakashita(80mwe) multi-directional muon telescopes, for the solar activity maximum period of 1978-1983. These data respond to primaries extending over the median rigidity range 60GV to 600GV.

The observed amplitude at Sakashita station in 1981-1983 increased, especilly in 1982; the amplitude is twice as large as that in 1978-1980, when those at Nagoya and Misato stations are nearly the same as those in 1978-1980.

Uni-directional anisotropy is derived by the best fit method by assuming the flat rigidity spectrum with the upper cutoff rigidity Pu. The value of Pu obtained is 270GV in 1981-1983 and 150GV in 1978-1980.

1. Introduction

Earlier analyses (e.g., Rao et al.; 1963, Jacklyn et al.; 1970) have shown that the steady-state solar diurnal anisotropy of cosmic rays is rigidity independent up to the upper cutoff rigidity Pu which varies from 50GV to 100GV according to the characters of solar-controlled electromagnetic conditions in the heliomagnetosphere. So far, the obtained values of Pu were dependent on the rigidity range of the data used. To investigate the year-to-year changes of Pu, an analysis over a wide range of rigidities is most necessary during various levels of solar activity.

Since 1978, Sakashita underground multi-directional muon telescope has been in routine operation at the depth of 80mwe and 6-year data have been accumulated. The following observed fact is obtained that the amplitude increases for the period of 1981-1983, especially in 1982. This shows a very remarkable contrast to rather invariant variations at Nagoya and Misato for these years. On the other hand, the observed phases are gradually recover to the 18 hr direction from 1978 due to systematic changes by 22-year modulation.

In the present report, we try to derive the solar diurnal anisotropy responsible for the observed variations showing the above mentioned characteristics.

2. Data and Analysis

In the present analysis, the observed data from Nagoya, Misato and Sakashita stations are exclusively used, then these data are hereafter abbreviated as NAMS by picking up the top letter of these NAgoya, Misato and Sakashita stations. The observed variations are corrected for the Compton-Getting effect due to Earth's orbital motion (.046%,6hr in space), and the corrected variations are used as the basic data in the present analysis.

In Table 1, 3 year averages of the observed solar diurnal variations of NAMS are shown, together with some characteristics of the component

Table 1 NAMS solar diurnal variations corrected for Compton-Getting effect due to earth's orbital motion and the characteristics of NAMS telescopes. Errors in the amplitudes are determined by the dispersion of yearly vectors.

		Zenith & Azimuth		Geographic Direction		Median Rigidity	Counting Rate	3 Years Averages of Amplitude(%) & Phase(hr) of Solar 1st Harmonics	
STATION	TELESCOPE	Z	A	λ	ψ	P_{ME}(GV)	$\times 10^4$/hr	'78-'80	'81-'83
NAGOYA 0mwe	V	0°	-	35°N	137°	60	276.0	.218±.035 12.0	.207±.014 13.3
	N	30°	0°	65°N	"	66	125.0	.204±.063 10.8	.189±.031 12.0
	E	"	90°	30°N	172°	67	120.0	.225±.072 10.6	.221±.034 11.9
	S	"	180°	5°N	137°	64	123.0	.214±.024 12.7	.212±.028 14.1
	W	"	270°	30°N	102°	63	126.0	.182±.016 13.3	.170±.030 14.8
MISATO 34mwe	V	0°	-	36°N	138°	145	28.0	.136±.015 13.4	.145±.024 14.9
	N	33°	39°	57°N	177°	155	10.7	.131±.042 11.4	.152±.018 12.8
	E	"	129°	12°N	164°	143	14.2	.151±.032 12.3	.175±.018 13.9
	S	"	219°	9°N	117°	155	10.7	.124±.025 15.3	.157±.048 16.9
	W	"	309°	51°N	95°	156	9.8	.090±.010 14.5	.091±.012 15.9
SAKASHITA 80mwe	V	0°	-	36°N	138°	331	39.0	.066±.015 14.2	.091±.013 15.8
	N	41°	346°	73°N	104°	401	6.2	.030±.026 12.8	.037±.015 15.6
	E	"	76°	35°N	188°	384	7.6	.064±.027 12.3	.086±.014 13.5
	S	"	166°	5°S	147°	387	6.7	.061±.014 14.8	.097±.015 15.7
	W	"	256°	18°N	96°	444	5.6	.046±.013 16.4	.068±.008 19.2
	NN	60°	346°	77°N	26°	595	2.4	.017±.028 12.4	.002±.031 6.9
	SS	"	166°	23°S	151°	540	2.7	.028±.011 14.0	.065±.029 16.1

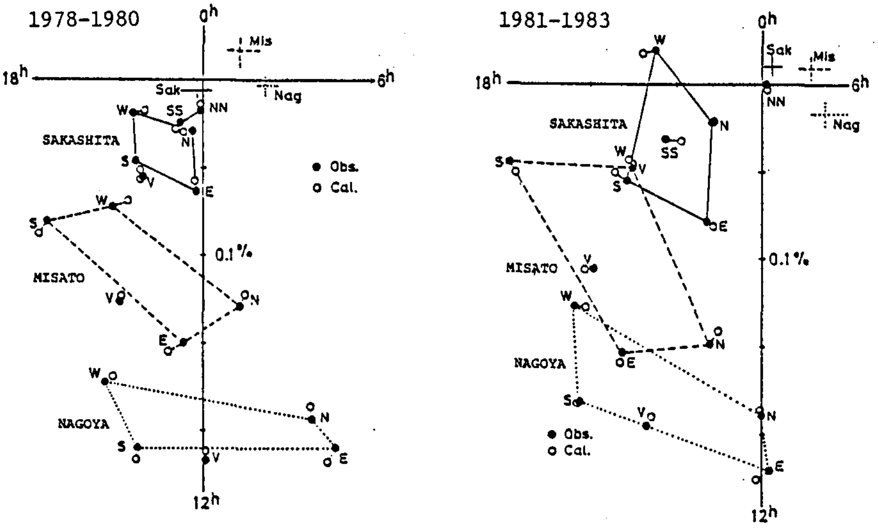

Fig.1(a)

Fig.1(b)

Fig.1 Solar diurnal variation of NAMS in the period of 1978-1980 (Fig.1 a) and of 1981-1983(Fig.1 b).
Solid circles represent the vectors observed, and open circles are those reproduced from the best fit anisotropies. The three kind of cross are respectively the common vectors of each station calculated by the least squares method.

telescopes used and are plotted in Fig.1(a) for 1978-1980 and in 1(b) for 1981-1983 with dotted circles(●).

The solar diurnal anisotropy responsible for the observed variations was determined. Space harmonic vector(X,Y) responsible for the diurnal variation is related to the observed harmonic vector(a_{ij}, b_{ij}) of the j-th component telescope at the i-th station by the following equation with coupling coefficients c_{ij} and s_{ij}.

$$a_{ij} = (c_{ij}X + s_{ij}Y) + a_{ci}, \quad b_{ij} = (-s_{ij}X + c_{ij}Y) + b_{ci} \qquad (1)$$

where (a_{ci}, b_{ci}) represents the unknown vector common to all the components for i-th station. By the least squares method with equal weight for each component, the unknown quantities(X,Y) and (a_{ci}, b_{ci}) were determined for the flat rigidity spectrum with the upper cut-off rigidity Pu, which is taken every 10GV from 50GV to 200GV and so on. The coupling coefficients were referred to the table presented by Fujimoto et al. (1984).

Table 2 Best-fit quantities of anisotropy

	1978-1980	1981-1983
Amplitude in space	0.377 ± 0.016 %	0.320 ± 0.010 %
Direction of anisotropy	15.8 ± 0.2 hr	17.0 ± 0.1 hr
Upper cut-off rigidity	150 ± 10 GV	$270 \pm ^{35}_{20}$ GV

The best-fit parameters are obtained for two periods; 1978-1980 and 1981-1983 and these are shown in Table 2. Also in Figs. 1(a) and 1(b), the reproduced vectors for each component in the best fit case computed by eq.(1) are shown with open circles(○), where the cross marks (··┼··, --┼--, ─┼─) represent the common vector (a_{ci}, b_{ci}) for each station. As is shown in Figs. 1(a) and 1(b), a good agreement between the observed and the reproduced vectors is clearly seen, suggesting uni-directional anisotropy having the characteristics given in Table 2, is well consistent with the present observations.

Year-to-year basis calculation was also performed by the same method. Best-fit quantities

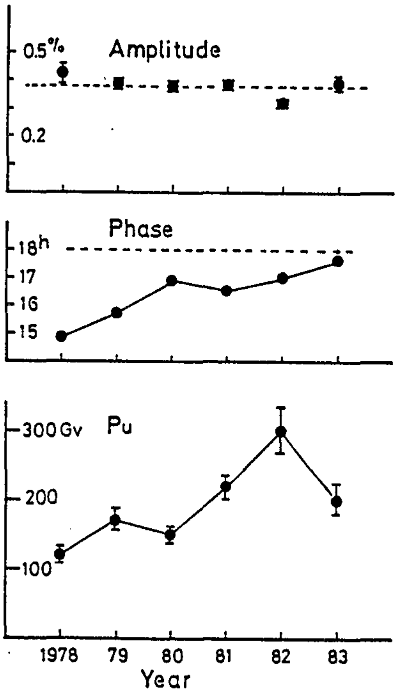

Fig.2 Year-to-year variations of the obtained amplitude, the phase and the upper cutoff rigidity of the solar diurnal anisotropy. Errors in P_U are replaced from the errors of the amplitudes of the anisotropy obtained by the least squares method.

of the anisotropy are shown in Fig.2 as a function of time from 1978 to 1983. As seen in the figure, the amplitude of the anisotropy remains invariant with time for these 6 years. The direction of the anisotropy gradually recovers to 18 hr level. The upper cutoff rigidity varies with time from 100GV to 300GV, particularly Pu in 1982 is extremely higher than those so far reported (Davies et al., 1977, Fenton et al., 1983).

3. Discussions

The increase of solar diurnal variation around 1982 has been observed at London(Thambyahpillai; 1983), Socorro(Swinson; 1983) and Takeyama (Wada et al.; 1985), by the underground muon telescopes at the depth deeper than 60mwe, where the amplitudes are nearly twice as large as in 1978-1980 similar to that at Sakashita station. The origin of the increase of Pu from 150GV to 300GV is yet unknown, but it may be considered to be due to some effect of strong solar activity or the influence of the field reversal resulted in the transition of the heliomagnetosphere from positive state to the negative.

Solar activity of the cycle 21 reaches its first maximum at the end of 1979 and increases again with the second maximum at about Sep. 1981. The cosmic ray intensity minima observed by neutron monitors which correspond to the solar activity maxima are in the middle of 1980 and much lower in July of 1982. In 22-years ago after the period of the maximum solar activity since the start of the cosmic ray observation and at the same phase of the field reversal as in 1981-1983, the cosmic ray neutron intensity had the double minima in Apr. 1958 and in July 1959. At that time, the solar diurnal variations did not increase at London(60mwe, Thambyahpillai et al.; 1965). These facts are very important for the interpretation of the increase of Pu and also for the study of the heliomagnetosphere.

4. Summary

1. The solar diurnal variations observed at Sakashita station remarkably increased in 1981-1983, especially 1982.
2. Uni-directional anisotropy is well consistent with the observed variations, the direction of which gradually recovers to 18 hr level from 1978 to 1983.
3. The upper cutoff rigidity is obtained as 300GV in 1982.

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