Cosmic-Ray Diurnal Variation with Phase Inverse to Usually Observed Phase

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Abstract

The phase of the diurnal variation of cosmic-ray intensity occurred on Dec. 23, 1957 is directed to the anisotropy near 6 hr. in local time. After the investigation of similar five examples, it is concluded that these diurnal variations with inverse phase appear on the geomagnetically quiet days after the occurrence of Type IV solar radio outburst.

1. Introduction

Most of the diurnal variations of cosmic rays observed during the IGY was that the time of amplitude maximum appeared after the noon, that is, the phase was directed to the anisotropy in the direction near 18 hr. in local time. During this period, however, there were a few examples of the diurnal variation being quite different in their phase from ordinary one, and especially, the diurnal variation occurred on Dec. 23, 1957 was the most remarkable, which phase really showed the anisotropy in the direction opposite to 18 hr. Anomalous diurnal variations, in general, appear so often in the early stage of cosmic-ray storms (Sekido, Yoshida and Kamiya, 1952) that the inverse phase may well be considered as the event accompanied by cosmic-ray storm. However, the diurnal variation with inverse phase on Dec. 23, 1957, did not show any evidence of the cosmic-ray storm effect, because the intensity itself was increasing on that day and four days have passed since the occurrence of the cosmic-ray storm.

Generally the theories on the diurnal variation have been applicable only to the anisotropy near local time 18 hr. or 12 hr. Therefore, the study of the inverse phase diurnal variation seems to be suggestive for the modulation mechanism of cosmic rays in the interplanetary space. In this viewpoint, we tried to look for another examples of diurnal variations with inverse phase as was observed on Dec. 23, 1957, for a period from July, 1957 to February, 1959, in order to investigate their relation with other geophysical or solar phenomena. As the result of study through five examples, it was found that those diurnal variation of inverse phase appeared by chance on geomagnetically calm days just after the occurrence of Type IV solar radio outbursts.

2. The event on Dec. 23, 1957.

At first, let us show the most typical diurnal variation with inverse phase occurred on Dec. 23, 1957. As the intensity of cosmic rays varies with time in complicated

manner, so it is necessary to get the component related with diurnal variation (diurnal component) out of the variation of total intensity itself. In order to do so, following two methods were used. (The first method) (1) If we assume that the diurnal component varies harmonically within a day and that the other component varies independently of the local time of each station where detector is situated, it is possible to get the world-wide variation by averaging the intensities observed with the same kind of detectors situated at the same latitude but distant at equal angle in longitude from each adjacent detector. Then, we can obtain the diurnal component of the intensity observed at a station by the subtraction of the above obtained world-wide variation from the intensity observed at that station. However, the above method seems to be unsatisfactory, because the diurnal variation deduced by the above-mentioned procedure has a little different mode in the case where the amplitude and phase vary so rapidly within a day. For example, when the amplitude of the diurnal component is increasing, the apparent times of intensity maximum and minimum appear later than the true times. Therefore, another method is necessary to evaluate the maximum time of diurnal variation. (The second method) (2) Assuming that the world-wide component varies monotonically with time, we can get the diurnal component of a

Table I The list of stations.

(a) For the analysis in Fig. 1.	Geographic		Geomagnetic	
	Latitude	Longitude	Latitude	Longitude
Pole Neutron (P.N.)				
Mawson	67°36' S	62°53' E	-73° .1	103° .8
Resolute	74°41' N	94°54' W	82° .9	289° .3
High Latitude Neutron (H.L.N.)				
Zugspitze	47°25' N	10°59' E	48° .2	92° .4
Yakutsk	62°01' N	129°43' E	51° .0	193° .8
Sulphur Mt.	51°12' N	115°36' W	58° .2	300° .3
Low Latitude Neutron (L.L.N.)				
Mt. Norikura	36°07' N	137°33' E	25° .6	203° .6
Mina Aguilar	23°12' S	65°42' W	-11° .7	3° .1
High Latitude Meson (H.L.M)				
Weissenau	47°48' N	9°30' E	49° .0	91° .5
Yakutsk	62°01' N	129°43' E	51° .0	193° .8
Ottawa	45°24' N	75°54' E	56° .8	351° .1
(b) For the analysis in Fig. 2.				
High Latitude Neutron (H.L.N.)				
Zugspitze	47°25' N	10°59' E	48° .2	92° .4
Alma-Ata	43°12' N	76°56' E	33° .0	150° .8
Yakutsk	62°01' N	129°43' E	51° .0	193° .8
Mt. Wellington	42°55' S	147°14' E	-51° .5	224° .5
Sulphur Mt.	51°12' N	115°36' W	58° .2	300° .3
Mt. Washington	44°20' N	71°40' W	55° .6	356° .0

station by subtracting 24 hours running average of the intensities in reference to a certain time of observation, from the intensity at that time, and the diurnal components of six stations distributed on the different longitudes were compared. This method is applicable when the world-wide variation gives almost the equal effect on the intensity at each station, even if the world-wide variation is so sudden.

Above two methods were applied to investigate the diurnal variation occurred on Dec. 23, 1957. The results calculated by the first and the second method are shown in Fig. 1, and Fig. 2. The data used for the calculation are tabulated in Table I (a) and I (b). The results obtained by both methods are quite consistent with each other.

Now we can find out following characteristics from Fig. 1, and Fig. 2.

(2—a): Amplitude of the diurnal variation suddenly increased and then vanished within a day, while the world-wide component of the intensity was increasing. For instance, the magnitude of the amplitude increase for the neutron detector at the high latitude is as large as 2% and the increment of the world-wide component is about 5% above the preceding day level. Such large amplitude can not be seen so often even in the period of the IGY.

(2—b): The most remarkable character is the phase of the diurnal variation. Fig. 2 clearly shows that the time of intensity maximum (T_m) of the diurnal variation is located at about 3 hr. in local time, on Dec. 23, 1957.

(2—c): Comparing the amplitudes in different latitudes in Fig. 1, we can expect by theoretical calculation (Murakami 1961) that the primary energy spectrum of this diurnal component is (Kinetic energy) $^{-0.2 \sim -0.3}$ times the spectrum of the ordinary cosmic rays, and then, that the anisotropy outside of the geomagnetic field is nearly in the direction of 7 hr. seen from the earth. This direction is considered to be very curious.

Fig. 1. Variations of Cosmic ray intensities and Horizontal component of Geomagnetic field.

Fig. 2. Diurnal variations obtained by the second method.

3. Another examples of the diurnal variation with inverse phase and the relation with geomagnetic and solar event.

In order to find out the characteristic feature of the diurnal variation with inverse phase and to study the relation with solar and geophysical phenomena, the following procedure was applied to pick up examples of inverse phase diurnal variation. Firstly, the diurnal component of Zugspitze neutron was calculated in a period from July, 1957 to February, 1959 by the first method mentioned in § 2, and then, examples of diurnal variation with inverse phase were selected from the result calculated above under the condition that each variation has more than 2% in range in a day and the position of amplitude maximum (T_m) is situated at early half morning. Thus, five examples, including Dec. 23, 1957, were obtained, as shown in Table II and Fig. 3.

Table II Examples of the diurnal variation with inverse phase and the data of related phenomena.

	Date	1 st harmonics T_m Amp.	Type IV Solar radio outburst	Type IV Heliographic Position	H (Kakioka) 30000+ γ	ΣKp (daily sum)
1	1957 July 26	3h 0.5%	July 24	27°W 24° S	152	7
2	Dec. 18	1h 0.9%	Dec. 17	26° E 16° N	136	20
3	Dec. 23	4h 1.9%	Dec. 22	38°W 18° N	141	8
4	1958 May 30	1h 0.8%	May 27	29°W 16° N	128	22
	31	1h 0.7%			119	41
5	1959 Jan. 23	1h 0.6%	Jan. 22		182	15
	24	0h 1.0%			176	8

Fig. 3. Five Examples of inverse phase diurnal variations.

In the previous section, it was noticed that the inverse phase diurnal variation occurred when the intensity of cosmic rays increased world-widely. But, as easily seen in the other examples in Fig. 3, that increase seems unimportant, for we can not notice such increase in the other examples. The following points, however, should be emphasized as common phenomena through all examples.

(3—a): Those diurnal variation of inverse phase appear within a few days following the occurrence of Type IV solar radio outburst.

(3—b): Within a few days following the inverse phase diurnal variation, cosmic-ray intensity decrease or geomagnetic storm occurred. This fact (3—b) might be

recognized as the natural result from (3—a), and then, (3—b) would be reckoned as one of the circumstantial evidence for (3—a). The correlation among cosmic rays, geomagnetic storms and Type IV solar radio outburst was studied by Kamiya and Wada (1959).

As to the geomagnetic disturbance in those days on which the inverse phase diurnal variation was observed, the intensity of geomagnetic horizontal component at Kakioka was rather high, and the daily sums of Kp in Table II show that those days were rather geomagnetically calm. May, 1959 event occurred during the cosmic-ray storm just after the recovering period of the geomagnetic storm and before the next geomagnetic storm. Although this event may be the anomalous diurnal variation of cosmic-ray storm, it is obvious that the inverse phase likely to appear at the time of geomagnetically calm period.

((3—c): In any case, the inverse phase diurnal variation supposed to be observed by chance on geomagnetically calm days.

4. Summary

It is concluded that the inverse phase diurnal variation occurs only on the geomagnetically calm days following the occurrence of Type IV solar radio outburst, and also the anisotropy related with these variations in nearly in the direction of 3~7 o'clock in local time outside of the earth. However, the condition of geomagnetic quietness following Type IV solar radio outburst does not always cause the diurnal variation with inverse phase, and the diurnal variations with usual phase are often seen in these period, but, that condition seems to be necessary for the inverse phase. Theories for the diurnal variation proposed so far are applicable only for ordinary phase, but not for inverse phase. How to explain those anomalous event would be the next problem.

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