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NORTH-SOUTH ANISOTROPY AND ANTICIPATORY INCREASE OF INTENSITY ASSOCIATED WITH THE COSMIC-RAY STORM OF FEBRUARY 11, 1958

by
Dr. V. Sarabhai and R. Palmeira

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NORTH-SOUTH ANISOTROPY AND ANTICIPATORY INCREASE OF INTENSITY ASSOCIATED WITH THE COSMIC-RAY STORM OF FEBRUARY 11, 1958

Dr. V. Sarabhai*
Physical Research Laboratory, Ahmedabad, India
and
R. Palmeira**
Centro Brasileiro de Pesquisas Físicas

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The time variations of cosmic rays have been measured during the International Geophysical Year with standard instruments at a large number of places on the Earth, and several studies have been made of the energy dependence of the primary

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* Sometime guest of the Massachusetts Institute of Technology.

** This work was performed when one of the authors (R.P.) was at the M.I.T.

variations and the anisotropy which is often associated with primary variations of intensity. From an examination of Forbush--type decreases, Fenton, Fenton and Rose[1] have come to the conclusion that the cause of the transient intensity decreases is variable in its energy dependence from a few BeV. to more than 30 BeV. The variation in response to transient decreases observed with similar equipment at different stations suggests that a primary anisotropy is present at these times. Lockwood[2] has examined the detailed structure of several Forbush-type decreases in the intensity of local neutrons during 1955-58. He finds that in most of the decreases there was a magnetic storm at the onset. Flare activity during the preceding 30 hr. was high and there was some indication of an intensity maximum during the 12-hr. period preceding the start of the decrease. He comments that such an anticipatory effect might be due to the albedo of the moving magnetic gas cloud, but that further results are needed to substantiate any anticipatory effect. McCracken and Parsons[3] have made a very interesting analysis of a Forbush-type event which occurred on October 21, 1957. They found that there was a preliminary depression prior to the commencement of the Forbush decrease and they comment that it was not due to the arrival of solar matter at the Earth since it occurred before the magnetic disturbances. They conclude from studies made at several stations that the preliminary depression must be attributed to a cause located at some distance from the Earth, and since it is not observed simultaneously at all stations its explanation requires

Table 1. CHRONOLOGY OF EVENTS ASSOCIATED WITH THE FORBUSH DECREASE OF FEBRUARY 11, 1958

ΔC and ΔH respectively indicate the change of cosmic-ray intensity (CR) and of the horizontal component of geomagnetic field at Virginia

Date	U.T.	Solar event	U.T.	Terrestrial effect:	Cosmic ray features
9-2-58	0207	*2$^+$ Flare		Radio fade-out	
	2053-2120	Type III and Type I radio bursts			
	2139	*2+ Flare E04.S20		Radio fade-out	
10-2-58	1325	*2+ Flare with major burst radio noise W67, S12		Radio fade-out	
			2100	CR maximum	(1) Anticipatory increase at equator only related to high energy
				$+ \Delta C \approx +1$ per cent	
11-2-58			0120	S.C. storm	
			0126	$+ \Delta H, - \Delta C$	(2) Decrease starts at high latitudes
			0130	Aurora	
			0154	$+ \Delta H, - \Delta C$	
			0300	CR minimum	(3) 0300 minimum at equator
					(4) 0500 minimum in mesons
			0622	X-ray $\Delta H = 0$	
			0635	Maximum absorption, galactic noise of 18 Mc./s.	
					(5) 0700 minimum at high latitudes
			0730	X-ray ends	
			0850	X-ray and ΔH	(6) Increase commences
			1000	Maxima aurora	
			1100	CR maximum	Seen in instruments with high and low energy response. Not observed in stations in 120° E. belt, nor in the southern hemisphere

some rather special form of short-lived primary anisotropy. McCracken[4] has analysed the anisotropy of a number of Forbush-type decreases which were preceded by decreases. Yoshida and Wada[5] have directed attention to increases of intensity which occur after the onset of cosmic-ray storms. They believe that the increases are mainly isotropic and have an energy-dependence nearly the same as that of the decreases.

In conexion with the Forbush-type decrease in cosmic-ray intensity which occurred on February 11, 1958, we have fortunately a large number of other solar and terrestrial observations which give us a unique set of data for following the event from the time it occurred on the Sun. These have been summarized by Trotter and Roberts[6]. During its second passage on February 9, 1958, a region 58-B at 15° S. heliographic latitude, then at the central meridian, suddenly underwent very rapid changes in plage brightness and sun-spot growth. The region flared rapidly throughout the day; half a dozen of the flares were Class 1 + or greater. Five of these caused complete short-wave radio fade-outs of considerable duration. In addition, these events were associated with unusual solar radio noise burst activity on 2,800, 470 and 167 Mc./s. The flux density on 167 Mc./s. was very high during February 7-9. An extremely large number of high-speed dark surges were observed on the solar disk, most of them in association with small flares. The mean integrated coronal (5303 A) intensity was low during the period. Region 58-B, which had very intense activity during the second passage in February, persisted with pronounced activity

Table 2. Particulars of Cosmic-Ray Neutron Monitor Stations Used in Analysis

Code	Station	Geog. Lat.	Geomag. Lat.	Long.	Investigator
A	Murchison Bay	80° N.	76° N.	18° E.	Dr. A. E. Sandstrom, Sweden
B	Churchill	59° N.	69° N.	94° W.	Dr. D. C. Rose, Canada
C	Leeds	53° N.	57° N.	0°	Dr. J. G. Wilson, England
D	Sulphur Mt.	51° N.	58° N.	115° W.	Dr. D. C. Rose, Canada
E	Weissenau	48° N.	49° N.	9° E.	Dr. A. Ehmert, Germany
F	Ottawa	45° N.	57° N.	76° W.	Dr. D. C. Rose, Canada
G	Mt. Norikura	36° N.	26° N.	137° E.	Dr. Y. Miyazaki, Japan
H	Kodaikanal	10° N.	1° N.	77° E.	Dr. V. Sarabhai, India
I	Makerere College	0°	2° S.	32° E.	Dr. D. M. Thomson, Uganda
J	Lae	6° S.	16° S.	147° E.	Dr. A. G. Fenton, Hobart
K	Huancayo	12° S.	1° S.	75° W.	Dr. J. A. Simpson, Chicago
L	Hermanus	34° S.	33° S.	19° E.	Dr. A. M. Vanwijk, Hermanus
M	Mt. Wellington	41° S.	45° S.	147° E.	Dr. A. G. Fenton, Hobart
N	Invercargill	46° S.	52° S.	168° E.	Dr. N. V. Ryder, New Zealand
O	Mawson	67° S.	73° S.	62° E.	Dr. A. G. Fenton, Hobart

1	H, I, K	Equator	0-2°	
2	B, C, D E, N, O	High latitude	49-73°	
3	D, F, K	West longitude		75-115°
4	C, E, I	O-Longitude		0- 32°
5	J, M, N	East longitude		147-163°
6	A, E, G	Northern hemisphere	26-76° N.	
7	L, M, O	Southern hemisphere	33-73° S.	

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during the third and fourth passages in March and April respectively.

The strongest geomagnetic storm with sudden commencement (s.c.) of the present solar cycle began early on February 11, and almost simultaneously a very spectacular aurora that persisted throughout the night lit up the northern sky as far south as the 35th parallel. It was visible on the following night as well. In Table 1, the important events observed on the Sun and on the Earth are summarized in chronological order.

We have examined the effect in cosmic rays from data of the high counting-rate meson detector at the Massachusetts Institute of Technology and from a grid of neutron monitor stations distributed (1) in two belts corresponding to the equator and the middle geomagnetic latitudes, (2) in three meridional sections corresponding to 75-115° W., 0-32° E. and 147-168° E., and (3) in the northern and southern hemispheres. In Table 2 are indicated the stations which are included in the grid, particulars of their location and the name of the principal investigator at each station through whose kindness the data have been made available to us. Assuming that the variations can be dependent on the primary energy response, on local time or longitude and on the hemisphere, we have grouped stations so as to study one variable at a time with, so far as possible, an equal contribution in each group due to the other two variables. The stations from which data have been combined for the various analyses are indicated in Table 2.

Fig. 1 shows the percentage deviations in the bi-hourly counting-rates of the neutron monitors during successive bi-hourly periods in U.T. from February 9-12, the deviations in each case being taken with respect to the mean intensity on February 10, which represents a period of 24 hr. immediately preceding the onset of the Forbush decrease early on February 11. It is clear from Fig. 1A that the variation is strongly dependent on primary energy. It will be noticed that the meson detector at the middle latitude exhibits a variation which is intermediate between the variation of the neutron monitor intensity at the equator and at the middle latitude stations. The middle latitude stations have a much larger percentage decrease than the stations at the equator. A minimum intensity is reached at 0300 U.T., at 0500 U.T. and at 0700 U.T. at the equator, with the meson detector and at the middle latitude stations respectively. Moreover, about 12 hr. after the initial decrease, at the equator the intensity returns almost to normal before it decreases again; on the other hand, the recovery occurs only partially at middle latitude stations.

A most interesting aspect of the present event is the increase of intensity at 2100 U.T. on February 10, observed at equatorial stations only, about 4 or 5 hr. before the arrival of the solar plasma at 0120 U.T., indicated by the storm with sudden commencement and a number of other terrestrial effects. The second increase, or the recovery of intensity at 1100 U.T. on February 11, is seen to be much more significant at the equatorial stations and in the meson detector at Cambridge than at the middle latitude stations. It would thus appear that both events, which

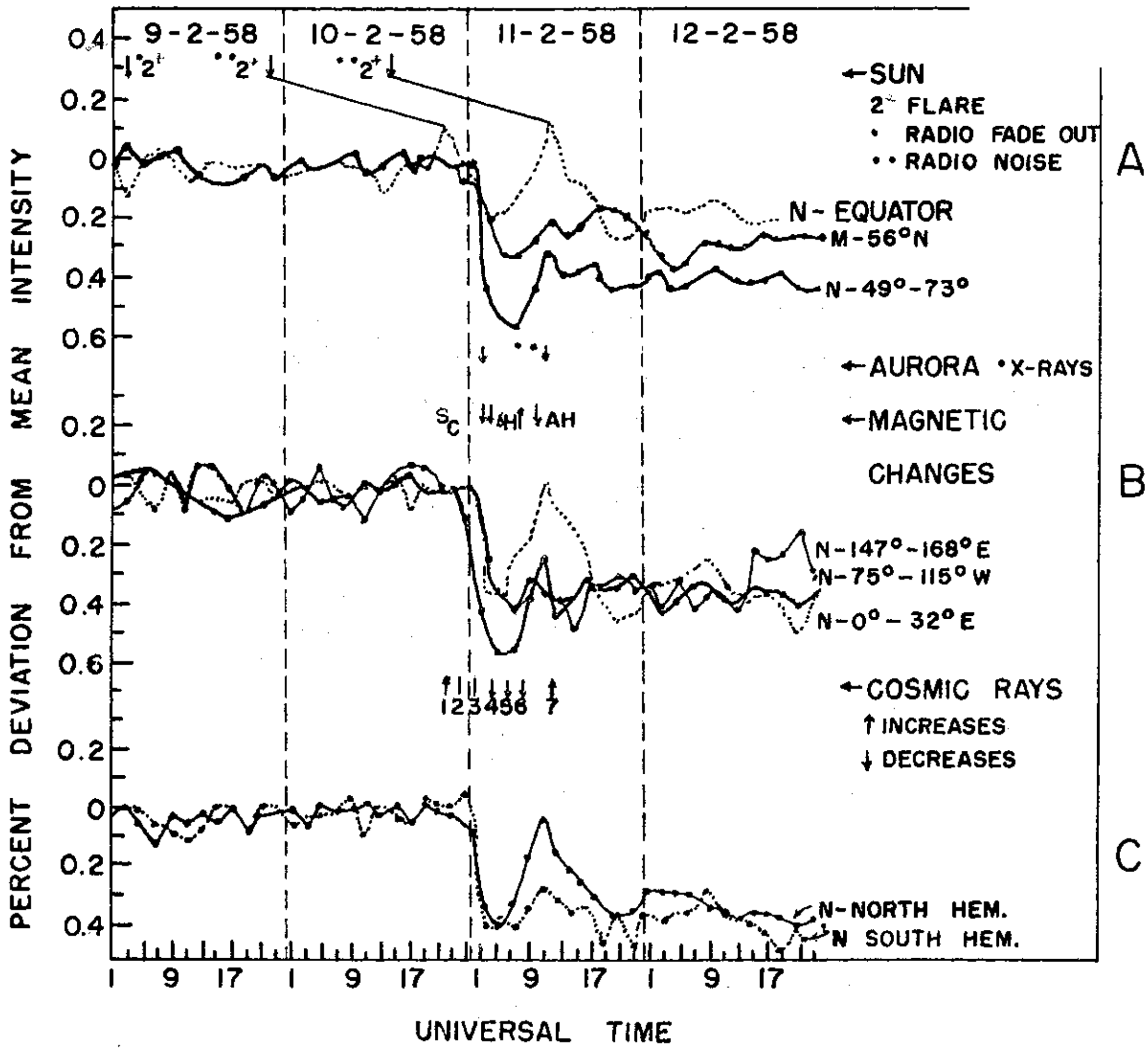

Fig. 1. Cosmic-ray intensity changes and associated solar and terrestrial effects for the cosmic-ray storm of February 11, 1958. Relationships of changes are indicated separately in A for low and medium latitudes and primary energy response, in B for meridional sections and in C for hemispheres.

appear to be increases, are particularly characteristic of the high-energy component of the primary radiation. In contrast, the first minimum of the Forbush event is larger and occurs later for low-energy than for high-energy primaries.

In Fig. 1B the variations of intensity at stations in the three meridional belts are compared. It is seen that there are significant differences in the initial decrease, indicating the existence of an anisotropy. The most remarkable feature is the complete absence of the second increase at 1100 U.T. on February 11 at stations in the east meridional section (147° E. to 168° E. longitude), as also at stations in the southern hemisphere for which a comparison with the northern hemisphere is shown in Fig. 1C. The second increase of intensity is thus characterized by a strong anisotropy not only parallel to the ecliptic, but also perpendicular to it. This is perhaps the first evidence for an anisotropy of the latter type. In contradiction to the view of Yoshida and Wada, we believe that the second increase is mainly anisotropic and has an energy dependence different from the mainly isotropic Forbush decrease.

The main event observed early on February 11 in cosmic rays, in geomagnetism, in the aurora and in X-rays at high altitudes is undoubtedly related to the major solar outburst from region 58-B between 2053 and 2139 U.T. on February 9. We would like to suggest here that solar plasma reached the interaction distance of the geomagnetic field at about 0120 U.T. on

February 11, but that for several hours prior to that, there was a cosmic-ray effect which involved an increase of the radiation. During the second increase of cosmic-ray intensity on February 11, we have an increase of cosmic-ray intensity occurring with a strong aurora and change of the horizontal component H of the geomagnetic field. This contrast with the association of the aurora and the change in magnetic field with the large decrease of cosmic-ray intensity about 10 hr. earlier. From other geophysical evidence it is believed that the main plasma outburst streamed past the Earth in 10-12 hr. and it appears that the second increase of cosmic-ray intensity is related to the departure of the plasma cloud. There was a 2^+ flare with major burst of radio noise at 67°W. heliographic longitude, which occurred at 1325 U.T. on February 10. It is worth while examining whether the second increase is related to the arrival of fresh solar particles from this flare. If, in order to explain the terrestrial influence of a solar event far removed from the central meridian to the west, one postulates the presence of a guiding path of solar magnetic lines of force stretched out to the Earth by earlier streams or an outward solar wind, it would be difficult to explain the 24-hr. delay for solar particles of even a few MeV. energy. We are thus inclined not to associate the second event with the solar outburst on February 10.

We believe that in the two increases and the meain decrease observed with the cosmic-ray storm of February 11, 1958, we have essentially three types of modulation process. One is directly associated with the moving plasma, probably related to the magnetic fields in the shock front and gives increases as well as decreases of intensity along with anisotropy. The second gives decreases of intensity and is related to a process which has a sharp onset but a relatively long time constant of recovery. The first is often more effective for high primary energies than low, but the second is much more effective for low than for high energies.

The large anisotropy parallel to the north-south and east-west directions in the second increase poses an important problem. The different motions of solar particles trapped by the geomagnetic field have been discussed by Gold[7], and before average conditions are established round the globe there is probably a basis for major differences in conditions over the hemisphere and at different meridional sections immediately following the arrival of a new cloud of solar particles. But the time involved is very short compared to the observed effect which shows up over periods of several hours. Moreover, even though changes in the Van Allen radiation belts could perhaps provide an adequate mechanism for the perturbation of the geomagnetic field, and through it alter cosmic-ray intensity, a quantitative evaluation of the effect has not so far been undertaken.

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