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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3B-3. Cosmic Ray Increases Associated with Solar Flares

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Neutron intensity changes associated with optical flares on the sun have been studied using the data recorded on Sulphur Mountain during 1959 and 1960. A small positive correlation exists in the measurements which appears greater for flares associated with ionospheric disturbances than otherwise.

Introduction

Thirteen enhancements in cosmic ray intensity, correlated with solar flares, have been recorded at ground level in recent years. Other evidence of energetic solar particles in the neighbourhood of the earth has been obtained from balloon flights and rocket measurements, again apparently correlated with optical flares on the sun but without noticeable effects at ground level. At still lower energies the emission of charged particles from the sun has been detected at the earth using techniques measuring enhanced ionization in the ionosphere in polar cap absorption and auroral phenomena.

The often spectacular increases in cosmic ray intensity measured by conventional neutron monitors at the surface of the earth have prompted several investigations of the possible correlation of all important solar flares with intensity increases of cosmic radiation. Firor (1954) calculated proton trajectories from the sun to the earth under the influence of the earth's magnetic field and showed the existence of preferred areas for the arrival of the particles on the earth, called impact zones. He then analyzed neutron data from Climax for 1952—53 and was able to show, using the Chree method of superposition of epochs in his study and correcting for the diurnal variation, that an average increase of about 1% occurred in neutron intensity following the onset of solar flares of importance at least 1+ when Climax was in an impact zone whereas flares occurring at other times produced no noticeable effect. Following Firor, Towle and Lockwood (1959), Kolomeets (1959), Ghielmetti *et al* (1960) and Maeda and Potel (1961) have made similar analyses of cosmic ray data. All these authors considered flares of importance≥2 and used the Chree method of analysis.

Towle and Lockwood, using neutron data from Mt. Washington for the summer months of 1956 and 1957 and Ghielmetti *et al* using neutron data from Mawson and Mt. Wellington 1957-58, found no increases in intensity with solar flares in the impact zones after correcting for the diurnal variation of intensity. On the other hand, Kolomeets using neutron data from four medium latitude stations and considering 41 flares in the period July to November 1957 found correlated increases of about 1%. The data was restricted to a sixteen hour period in each day and no mention has been made of correction for diurnal variation. Maeda and Patel used meson data from polar stations where no theoretical impact zones exist and where the amplitude of the diurnal variation is small and found a positive correlation with solar flares of the order of 0.4%.

It is clear that the question of correlated effects has not been unambiguously resolved but the magnitude of the effect is certainly small. It is well known that the large scale cosmic radiation increases measured both on the ground and high in the atmosphere are strongly energy dependent, the intensity varying approximately as E^{-6}. If small increases accompany all flares then they should be most readily discernible in data from monitors sensitive to the lowest energy primaries. The present study utilizes neutron data from Sulphur Mountain (Geomagnetic Latitude 58°N.) from January 1959 to July 1960.

Method of Analysis

All solar flares of importance≥2 during the period were considered with the following exceptions. The large cosmic ray flare of May 4, 1960 was not included; flares which occurred during the onset phase of a Forbush decrease or within six hours of a previous important flare were omitted. These exceptions were made to exclude cases where the intensity was varying rapidly and with magnitude greater than the scale of the events under consideration and to avoid overlap of flare effects. The position of the flare on the solar disc and associated ionospheric effects were noted in each case. The neutron intensity for the period of each flare was corrected for pressure variations and for the solar diurnal variation. The latter variation was computed in three-month intervals to reduce the effects of changes in amplitude and phase of the variation.

Results

A total of 226 flares was considered in the nineteen month period. The average intensity for the period of each flare is plotted in bi-hourly values in Fig. 1 for the eight hours preceding and twelve hours following the flare; the zero interval represents the two-hour interval containing the onset time of the flare. The same data have been plotted in Fig. 2 for flares (a) accompanied by short wave fadeout (SWF) and (b) without SWF. A further subdivision of the intensity corresponding to flares with SWF is shown in Fig. 3 where the effects (a) of sudden SWF and (b) slow and gradual SWF are presented.

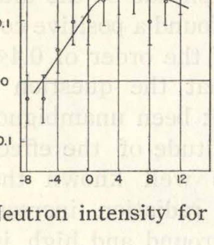

Fig. 1. Neutron intensity for all flares.

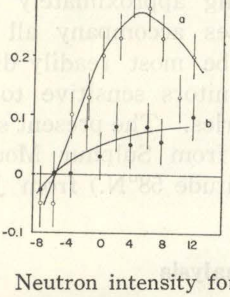

Fig. 2. Neutron intensity for flares.
(a) with SWF.
(b) without SWF.

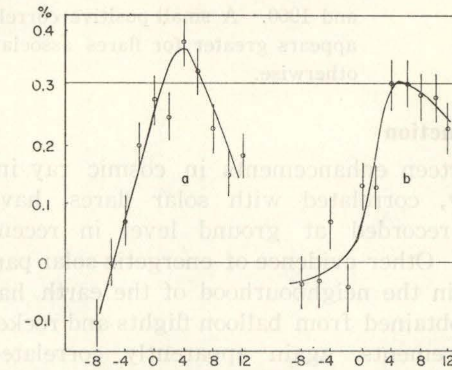

Fig. 3. (a) Neutron intensity for flares with S-SWF.
(b) Intensity for flares with s-SWF & g-SWF.

Table I.

Class	1	2	3	4	5	Total	Ratio (1+2)/(4+5)
Flares with SWF	34	17	10	10	11	82	2.4
Flares without SWF	43	22	26	22	31	144	1.2

The pre-onset level for each flare has been calculated by taking the average intensity from two to eight hours before the flare onset period. This level has been compared with the intensities in the four two-hour periods, including the zero interval, immediately following the flare, *i.e.* 0, +2, +4 and +6 hours. The results are collected in Table 1. Class 1 refers to events where all four of the post-flare intensity levels are higher than the pre-onset level; Class 2 to events where three of the four are higher; Class 3 where two of the four are higher; Class 4 where one is higher and Class 5 where all four intensities are below the pre-onset level.

Discussion

From Figs. 1 and 2 it seems clear that small increases in neutron intensity accompany solar flares; the effect appears to be greater for flares which also produce ionospheric effects although the type of SWF appears to be of little significance, and the results of Table 1 and Fig. 2 suggest that most of the intensity increase is due to cosmic ray production in flares which are strong sources of ultra-violet and X-radiation. The amount of the increase, however, is only about 0.3% while for all flares it is about half this value.

The small magnitude of the effect observed at Sulphur Mountain appears consistent with the negative results obtained by Towle and Lockwood and Ghielmetti *et al.* whose observations derive from higher energy primaries. The data of Kolomeets is less readily comparable since the corrections applied to the data for the diurnal effect are not known. However, the minimum energies of the primary particles at the latitudes of the European stations considered are much higher than at Mawson, Mt. Wellington, Mt. Washington and Sulphur Mountain and consequently the results are difficult to reconcile. The present study shows little agreement with the results of Maeda and Patel using the meson component. Increases noted in the meson component during large cosmic-ray flares when large neutron increases have occurred have always been much smaller or absent, reflecting the higher energy of the primary particles responsible for the component. It is difficult to explain the presence of a larger effect in the meson component than in the neutron component.

Analysis of the flare position on the solar disc shows little evidence of east-west differences in importance. 103 of the 188 flares in Class I, II, IV and V originate on the eastern half; 60 of these produce increases in intensity (Classes 1 and 2) compared to 54 of the 85 flares located on the western half of the disc.

A feature of the increases is the time delay in attaining the maximum. The primary particles contributing to the increase are detected for several hours following the onset of the flares. Such a delay is also characteristic of the polar cap absorption phenomenon, considered to be due to the arrival at the earth of 10—100 Mev protons from the sun (Obayashi and Hakura, 1960). This suggests that the storage mechanism responsible for this type of event may continue to be effective for cosmic rays with energies up to at least 400 Mev, the cut-off energy at Sulphur Mountain.

Reference

1) J. Firor: Phys. Rev. **94** (1954) 1017.
2) H. Ghielmetti, J. C. Anderson, J. M. Cardosa, J. R. Manzano, J. G. Roederer, and O. R. Santiochi: Nuovo Cimento **15** (1960) 87.
3) E. V. Kolomeets: Soviet Physics. JETP **36** (1959) 960.
4) K. Maeda, and V. L. Patel: Journal of Geophys. Res. **66** (1961) 1288.
5) T. Obayashi, and Y. Hakura: Journal of Geophys. Res. **65** (1960) 3143.
6) L. C. Towle and J. A. Lockwood: Phys. Rev. **113** (1959) 641.

Discussion

Chasson, R. L.: (1) What percentage of your total group of flares was accompanied by a short wave radio fadeout?

(2) Did you chree-analyze for the group not accompanied by a fadeout?

Wilson, B. G.: (1) About 40%.

(2) Yes, see Fig. 2.

Ney, E. P.: If you include one flare with an obvious cosmic ray neutron increase *e.g.* May 4. Would it control the whole thing?

Wilson: Yes, however, an inspection of the data used indicates that in fact more than half of the flares contribute to the increase, although the individual contributions are not statistically significant.

Sarabhai, V. A.: It might be good to test that the distributions of intensity deviations at the hours corresponding to the increase and at the preflare hour, are different at a statistically significant level.

Wilson: Yes, however, the small increases reported appear to extend over several hours.

Lüst, R.: How many Flares had to be excluded since they followed each other within 6 hours? This class of Flares might be important.

Wilson: About 20%. The emission appears necessary in order that the preonset level in the Chree analysis is not raised by overlapping of flare effects.

Sandström, A. E.: (1) How did you account for the diurnal variation?
(2) The diurnal variation shifts considerably when single days are considered.
(3) The amplitude sometimes shifts by a factor of 2 or 3.

Wilson, : The diurnal variation was computed for three month periods throughout the period of analysis using days free from large fluctuations in intensity. It is recognized that the corrections are inexact but this will be true for any method of correction or for no correction.

Biermann, L.: One significant difference of the Sulphur Mt. observations as compared to those reported in the preceding papers appears to the low cut-off energy of the former, of only 400 Mev.

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II-3B-4. On a Maximum of Cosmic-Ray Intensity Prior to a Prebaisse-Effect

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From an analysis of the neutron monitor data of the Nov. 1960 events it was found that the cosmic ray intensity increased by about 3% on Nov. 5[1]. At that date the center of activity in which the series of three cosmic ray flares was produced, turned onto the visible hemisphere of the sun. One might think that this coincidence occurred not just accidentally, and that a connection exists between cosmic-ray intensity and the position of some important activity centers on the solar disc.

Such a connection appears also from an analysis of the prébaisse-effects, as introduced by the second author[2]. It turned out that on the average 2 days before the occurrence of a prébaisse a representative number of stations recorded a maximum of the cosmic-ray intensity (cf. Fig.). The phenomenon seems to be of a general nature so that a further discussion of its significance is needed.

In deciding whether there is a real connection between these cosmic-ray events and certain solar phenomena, the superposed epoch method appeared to be not very appropriate. So instead of combining for one station the observations of a number of events, which is done when using the superposed epoch analysis, the observations of one and the same event, made by a number of stations were combined in order to increase the statistical reliability. The results of this analysis are presented in this paper. The events taken in consideration were chosen to be the prébaisse-effects. The dates