JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-II, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3B-22. Review of Some Statistical Studies

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A number of papers presented during the first ordinary session dealt with the statistical aspects of the high energy particle radiation of the sun and its connection with the wave radiation in the optical and the radio frequency range. Preprints of these papers being available, I would like to draw attention, in the present session, only to one or two specific results. Since the occasional large increases of the cosmic ray at sea level were recognized to be due to solar flares, one tried to find at least a statistical increase of the cosmic ray intensity during the larger solar flares. Work reported to this Conferences by Anderson, Chasson and Maeda on one hand, by Wilson and Nehra, on the other hand revealed that no such correlations would be found for stations with geomagnetic cut-off energy of more than 1 Gev, while at Sulphur Mountain, where the magnetic cut-off energy is only 400 Mev, a small but definitely positive correlation was established. This indicates, that during solar flares charged particles are much more often accelerated to energies in the some 100 Mev range than to more than one or two Gev, in accordance with the direct evidence from the observation of individual events from balloons obtained during the last few years.

Another result of Wilson and Nehra was the following: Their measurements indicate that the apparent source of the particles lies in the average about 60° west of the sun in the ecliptic plane. For the events of May 4, and during Nov. 1960 this was found in a different more direct way by McCracken in paper 3B-14, a result which is of considerable interest for the physics of interplanetary space. It may be remarked in this connection that in general sea level stations at high latitude are more useful for investigating the directional properties of cosmic rays because there the disturbing effect of the "Nullbahnen" is absent.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3B-23. Review of Recent High Energy Solar Particle Events Including November 12, 1960

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The eight cosmic-ray increases caused by high energy particles from the sun that have been observed during the years 1959, 1960 and 1961, are illustrated and deductions regarding the propagation and storage of the particles in interplanetary space are reviewed.

Fourteen high energy emissions of particles by the sun have now been observed. By high energy we mean that the effects penetrated the earth's atmosphere to sea level. The dates of these 14 events are indicated in Fig. 1 in relation to the last two cycles of sunspot activity. Several comparatively small events increase the number observed in the 19th cycle-recognition of these is due to the use of neutron monitors. The present world network of neutron monitors, and particularly those operated at high latitudes, provide indispensable data.

It is to be remarked in Fig. 1 that no high energy solar emissions have been detected near the maxima of the solar cycles-none were seen during the IGY maximum but 8 have occurred since. This fact requires explanation since polar cap solar particle events were numerous during IGY.

The 8 high energy events seen during 1959, 60, and 61, were very well recorded and, furthermore, they encompass a quite surprising variety of conditions. Let us consider them individually.

The first increase occurred on July 17, 1959, and is shown in Fig. 2. We have a sequence of three major solar flares, s.c. magnetic storms, and Forbush decreases, well separated from each other. The solar particle increase is seen starting 3 hours after the third flare and taking 6 hours to reach maximum. It was comparatively small and difficult to prove but the comparison of stations seen in Fig. 3 demonstrates its reality. Fig. 4 shows the size of this increase against the cutoff rigidities of Quenby and Webber. It was remarkably isotropic and had an extraordinarily sharp boundary. Any other solar increase on this plot extends to much lower latitudes and decreases asymptotically to zero. This increase, although the flare was on the western half of the sun and although it occurred quite soon after a strong Forbush decrease (see below), must be considered to be anomalous and to have more the character of a polar cap event with partial breakdown of the geomagnetic field. This behaviour may be characteristic of solar increases near the sunspot maximum.

The second increase occurred on May 4, 1960, was characteristic of a *W* limb flare, and was the shortest and the most directional increase that has been observed. The increase is seen in relation to the preceding Forbush decreases in Fig. 5, and its shape is shown in Fig. 6, and again in Fig. 7 in more detail. It started only 15 minutes after the onset of the flare, it reached maximum in 10 minutes, and was nearly over in one-half hour.

It is recognised that the velocities involved

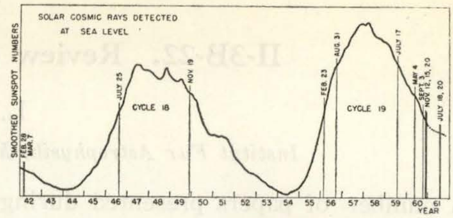


Fig. 1. Sunspot cycles 18 and 19 showing the dates of observation of high energy particles from the sun.

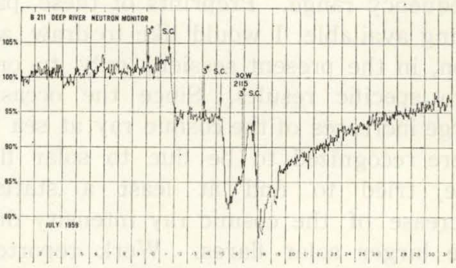


Fig. 2. The sequence of events in July 1959, in relation to the cosmic-ray neutron monitor hourly readings at Deep River, Ontario, Canada.

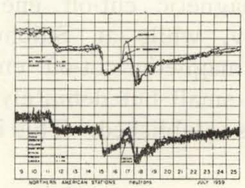


Fig. 3. Comparison of neutron monitor observations in North America in July 1959, demonstrating the occurrence of an increase due to solar particles on July 17.

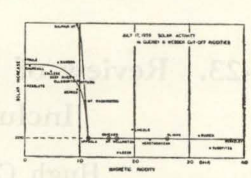


Fig. 4. The latitude effect of the July 17, 1959, solar particle event.

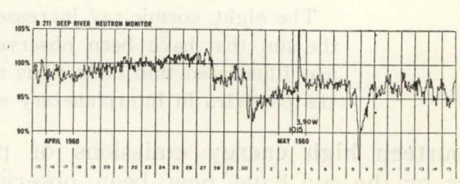


Fig. 5. The Forbush decreases preceding the solar particle event of May 4, 1960.

in the expulsion of gas from the sun (about 1000 km/sec) into the more slowly moving interplanetary gas of the solar wind must produce a hydrodynamic shock. A simple model of the shock wave, using spherical symmetry about the sun, has been recently calculated by Parker. Parker assumes in addition that the general magnetic field of the sun is usually of a radial character dragged out by the solar wind but curved due to the rotation of the sun as shown in Fig. 8. The field is too weak to effect the motion of the gas so that the sudden increase of outward velocity behind the shock produces a shear of the magnetic field as shown. Parker attributes the cosmic ray Forbush decrease to the passage of this sheared field past the earth.

These events are now interpreted in terms of the model strongly advocated since 1958 by T. Gold. This model, as illustrated by Gold, is shown in Fig. 9. A magnetized tongue is assumed to be carried out from the vicinity of a sunspot by the gas cloud ejected by a solar flare. This expanding tongue of magnetic flux can produce a Forbush decrease by turning away the lower energy galactic cosmic rays and it can also trap any solar cosmic rays that may be generated in a *subsequent* solar flare.

We prefer a slightly more elaborate diagram, Fig. 10 which also takes account of the rotation of the sun and provides an additional source of magnetic field-namely the field of the sunspot, which must be dragged out by the plasma cloud. The shock process and the sheering of any previous field in space must preceed the Gold bulge. Loops of magnetic force remain attached to the sun at the sunspot and form an eastwardly curved magnetic bottle in interplanetary space. It is supposed that if the earth is outside the bottle when a cosmic-ray flare occurs, the particles can reach the earth only slowly or be prevented altogether. If the earth is *inside* the bottle, on the other hand, the particles will be guided to the earth rapidly and will come from a direction 50 or 60 degrees west of the earth-sun line.

The May 4 increase has been extensively studied by McCracken, and his analysis is summed up in Fig. 11. The particles arrived most strongly from a direction (represented by $\delta=0^0$) 60°W of the earth-sun line but some

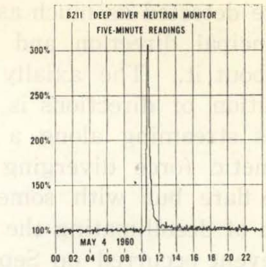


Fig. 6. The May 4, 1960, solar particle event.

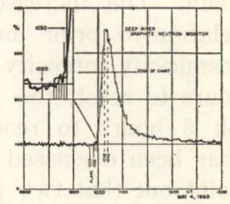


Fig. 7. Superposition of a continuous pen recorder trace upon 5-minute totals of the May 4, 1960, event showing that the increase began at 1029 UT at Deep River, Ontario, Canada. Note that these results and those plotted in Fig. 6 are from independent instruments.

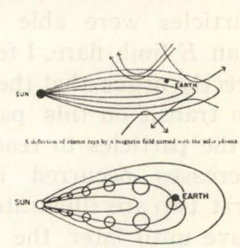


Fig. 8. Artist's sketch after T. Gold.

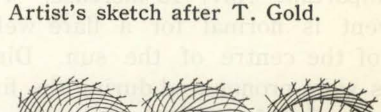


Fig. 9. Artist's sketch after E. Parker.

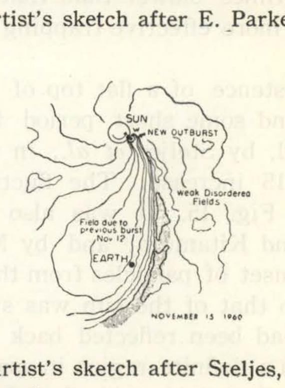


Fig. 10. Artist's sketch after Steljes, Carmichael and McCracken.

particles were detected as much as 80° away from the principal direction and uniformly distributed about it. The axially symmetrical distribution of directions is consistent with particles streaming along a system of lines of magnetic force diverging from the region of the flare but with some irregularities capable of decollimating the particles.

The next event occurred on Sept. 3, 1960, and is the only instance of solar particles reaching the earth from a flare near the *E* limb of the sun. The increase is shown in Fig. 12 in relation to prior and subsequent changes of cosmic-ray intensity. The particles took 3 hours to reach the earth and the increase took 5 hours to reach maximum. This event has been discussed by Winckler *et al.* who point out that two plasma disturbances from another part of the solar disc were in transit to the earth at the time of the flare. Winckler's illustration is shown in Fig. 13, and he argues that these disturbances impeded the arrival of the particles. In as much as this is the only known occasion on which particles were able to reach the earth from an *E* limb flare, I feel one might equally correctly argue that the disturbances that were in transit on this particular occasion *helped* the particles to reach the earth!

Three increases occurred in November 1960; the first two are illustrated in Fig. 14. We shall leave until later the discussion of the important Nov. 12 increase. The Nov. 15 event is normal for a flare well to the west of the centre of the sun. Directional effects were pronounced during the first hour and, as in the May 4, 1900 event, the particles came most strongly from a direction some 50°W of the earth-sun line. The decline was about 10 times slower than that of May 4, indicating more effective trapping of the particles.

The existence of a flat top of two hours' duration and some short period fluctuations were noted, by Steljes *et al.*, in the case of the Nov. 15 increase. The fluctuations are shown in Fig. 15. It was also noted, by Kodama and Kitamura, and by McCracken, that the onset of particles from the direction opposite to that of the sun was sudden as if particles had been reflected back simultaneously from a definite region in space. In the discussion Dr. Gold said that it was more

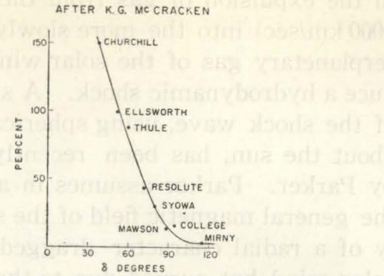


Fig. 11. Strength of the May 4, 1960, solar particle event as a function of the angular distances of the stations from the direction, RA, 23 h 10 m, Dec, +10°, which was 60° W of the earth-sun line.

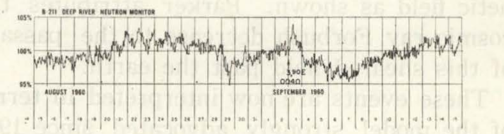
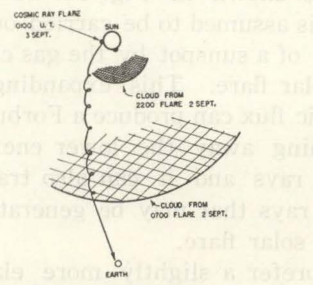


Fig. 12. The Sept. 3, 1960, solar particle event.



Disturbances from two flares in the region approximately 30°W of central meridian were in transit at the time of the cosmic-ray flare. Particles from the cosmic-ray flare on the east limb were propagated through or around the magnetic cloud from the 0700 flare.

Fig. 13. After Winckler, Bhavsar, Masley and May.

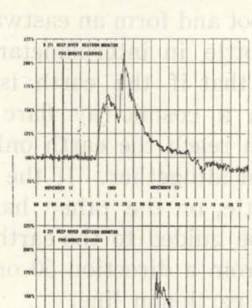


Fig. 14. The solar particle events of Nov. 12 and Nov. 15, 1960, at Deep River, Ontario, Canada.

likely that these particles, arriving suddenly from the rear, left the sun at the same time but came around by the longer path in the bottle.

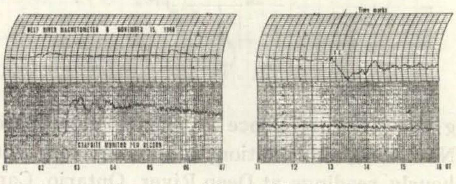


Fig. 15. Detail of the Nov. 15, 1960, solar particle event.

A third increase occurred on Nov. 20 after some days of geomagnetic quiet. By this time the region McMath 5929, responsible for the earlier effects, had passed 20 degrees around the *W* limb of the sun. However, at 2023 UT, a strong outburst of 10.7-cm radio noise occurred coincident with the acceleration of a remarkable high speed luminous cloud from visible elevated portions of a hidden major flare evidently associated with McMath 5925. Half-an-hour later, a small cosmic-ray increase taking about one hour to reach maximum and of several hours' duration was observed. This increase is illustrated in detail in Fig. 16, and the recordings of the North American stations are compared in Fig. 17. This slide is a good example of the data now available from the neutron monitors.

We note from Fig. 17 that the incidence of the particles was isotropic and that the rigidities reached 3 BV. This is the only case of high energy solar particles identified with a flare on the far side of the sun and its occurrence is consistent with our model which provides for easy magnetic guidance of the particles to the earth from flares in the vicinity of the western limb.

Recently, in July 1961, two further solar particle events were observed. These events are shown in detail in Fig. 18, and in relation to the background of galactic cosmic radiation in Fig. 19. The increase on July 18 appears to have been closely preceded by a Forbush decrease. The increase on July 20 originated in a flare on the *W* limb accompanied by a strong outburst of 10.7-cm radio noise. The shapes of both increases are normal, in terms of the model, for flares well to the west of the centre of the sun, and

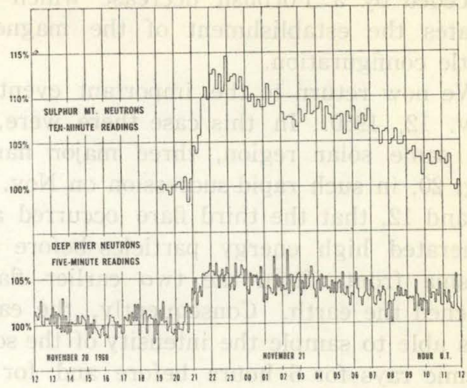


Fig. 16. The Nov. 20, 1960, solar particle event.

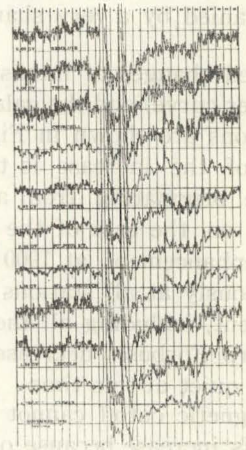


Fig. 17. Nov. 1960 neutron monitor observations from ten stations in North America. The Nov. 12 and Nov. 15 solar particle events go off-scale on these plots which are scaled to exhibit the Forbush decrease. The solar particle event of Nov. 20 can be seen at each of these stations.

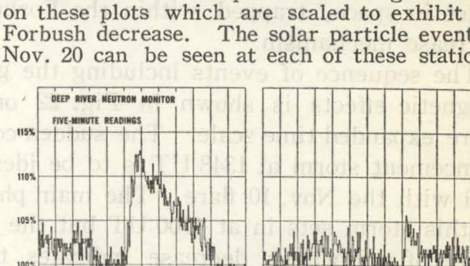


Fig. 18. The solar particle events of July 18 and 20, 1961.

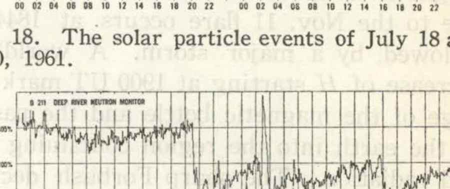


Fig. 19. The solar particle events of July 18 and 20, 1961, in relation to the preceding Forbush decreases.

preceded by a Forbush decrease which indicates the establishment of the magnetic bottle configuration.

We now return to the important event of Nov. 12, 1960. In this case there were, in the same solar region, three major flares, Fig. 20, in such rapid succession on Nov. 10, 11 and 12, that the third flare occurred and generated high energy particles before the plasma fronts from the two earlier flares reached the earth. Consequently, the earth was able to sample the intensity of the solar cosmic rays for 6 hours before and for 15 hours after it was enveloped by a zone in space which generated a major magnetic storm accompanied by a very sharp Forbush decrease.

The observed changes of intensity of both the solar (upper curve) and the galactic (lower curve) radiations are shown in Fig. 21. The earlier part of the increase is typical of a slow increase originating from a flare near the centre or on the east of the solar disc. The sudden enhancement at 1900 UT occurred simultaneously at all stations which detected the event, including all the polar stations. A sharp Forbush decrease followed. The sun was quiet at this time. Breakdown of the geomagnetic cutoff cannot be invoked to explain this increase because of its occurrence at the high latitudes. The earth undoubtedly sampled an increase of solar particles in space, trapped within the Forbush decrease mechanism.

The sequence of events including the geomagnetic effects is shown in Fig. 22 on a more expanded time scale. The sudden-commencement storm at 1348 UT is to be identified with the Nov. 10 flare. The main phase of this storm sets in at 1700 UT but the absence of a Forbush decrease indicates that this plasma cloud does not contain strong magnetic field. The sudden commencement due to the Nov. 11 flare occurs at 1844 UT followed by a major storm. A world-wide increase of H starting at 1900 UT marks the edge of the magnetic bottle and the passage of the earth into the region containing trapped radiation. The sharp Forbush decrease at 1930 UT indicates strong magnetic field within this region. While the edge of the magnetic bottle is passing the earth there are some conspicuous fast fluctuations of the

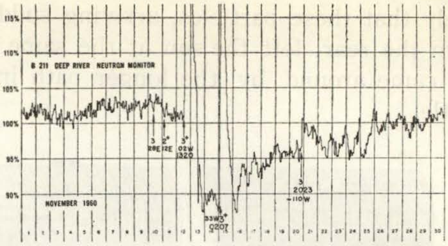


Fig. 20. The sequence of major solar flares in Nov. 1960, in relation to the neutron monitor hourly readings at Deep River, Ontario, Canada.

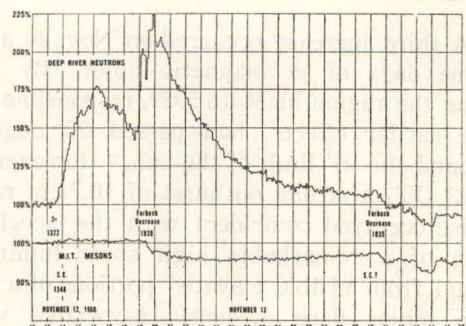


Fig. 21. The Nov. 12 solar particle event and the concurrent Forbush decreases.

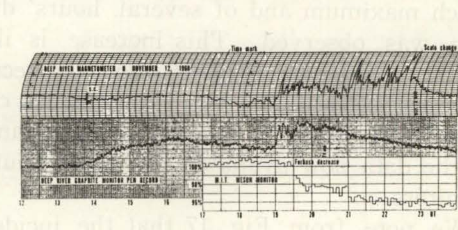


Fig. 22. Detail of the Nov. 12, 1960, solar particle event.

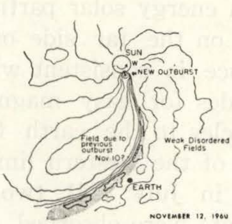


Fig. 23. Artist's sketch after Steljes, Carmichael and McCracken, at the instant of the solar outburst of Nov. 12, 1960. Note that previous outbursts occurred on Nov. 11 and on Nov. 10. Hence, the shaded area may be taken as representing the plasma cloud generated on Nov. 10, and the inner area with magnetic field loops forming a magnetic bottle may be taken as representing the plasma cloud generated on Nov. 11.

intensity of the solar particles.

Fig. 23 shows the model at the instant of the creation of high energy particles at the sun on Nov. 12. The dark shaded area represents the plasma cloud from the Nov. 10 flare just reaching the earth. The loops attached to the sun represent the magnetic bottle within the plasma cloud created by the flare on Nov. 11. This volume of space was rapidly filled with solar particles by the outburst of Nov. 12 but solar particles at this time could reach the earth only with difficulty.

Eventually, a plasma cloud coming from the Nov. 12 flare reached the earth and caused a sudden-commencement storm at 1303 UT on Nov. 13. Roederer has pointed out that this cloud did not itself contain trapped solar particles and, a most interesting observation, that it had a *sweeping-out effect* on the trapped particles in front of it.

The progressive breakdown of the geomagnetic cutoff during the Nov. 12 event has been discussed by Marsden *et al.*, Lockwood and Shea, Bloch *et al.*, Dorman *et al.*, McCracken, and by others. It appears that the effect, Fig. 24, began at 1700 UT coincident with the main phase of the first magnetic storm and increased until 2000 UT when all station with normal cutoffs less than 1.8 GV were essentially deprived of geomagnetic shielding.

Webber has drawn attention to pulses superposed on the decay of the radiation after 2000 UT on Nov. 12, centered at 2110, 2240 and 0030 UT. These pulses were clearly seen only at the European stations near the latitude of London, and at Climax in the U.S.A. They are illustrated in Fig. 25. Noting a correlation with recurrent decreases in equatorial *H*, Webber attributes these pulses to short-lived decreases in the geomagnetic cutoffs at the stations.

As regards the trapping of solar particles in space, there seems to be general agreement with the magnetic bottle hypothesis.

In conclusion, it is of interest to inspect again the first observations of solar particle events, Fig. 26, due to Forbush. Here, the ion-chambers show a very large slow increase on Feb. 28, 1942, followed by a Forbush decrease and then, 7 days later, a sharp increase of the solar *W* limb type. The evidence was already there to be interpreted at that time if we had only been more clever!

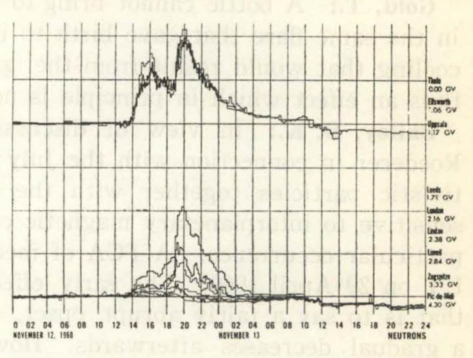


Fig. 24. Observations on Nov. 12 and 13, 1960, at different stations selected to show the progressive breakdown of the geomagnetic cutoff beginning at 1700 UT on Nov. 12.

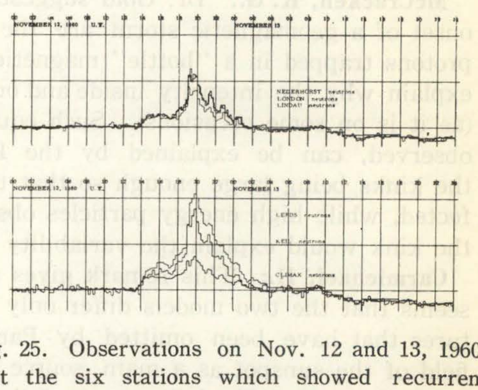


Fig. 25. Observations on Nov. 12 and 13, 1960, at the six stations which showed recurrent pulses between 2100 UT on Nov. 12 and 0100 UT on Nov. 13.

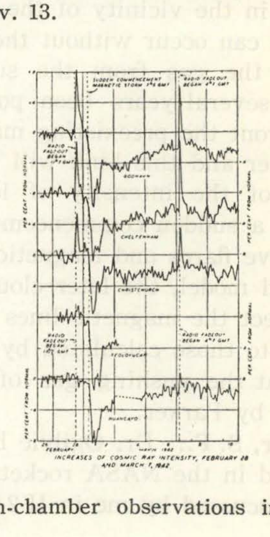


Fig. 26. Ion-chamber observations in 1942 after Forbush.

Discussion

Hultqvist, B.: The sweeping out effect observed mentioned at the end of your paper was not observed for the low energy protons observed by means of riometers.

Gold, T.: A bottle cannot bring to the earth any fast particles that were generated in the same flare that gave birth to it. This is because of the enormous adiabatic cooling that would result from the great expansion. The sweeping cut observed is thus an effect which in principle is not unexpected.

Bailey, D. K.: In view of discussions of the "Sweep-out" effect pointed out by Roederer in connection with the July 1959 and Nov. 1960 events as observed for relativistic particles together with the implications that softer particles might be less sensitive to interplanetary magnetic conditions, it seems worth while to point out a particular occurrence. A PCA of medium size was observed to begin at about 0200 UT on 29 April 1960. The early effects on the ionosphere were reasonably normal, that is to say a fairly abrupt onset, with a maximum effect with 4 to 8 hours, and a gradual decreases afterwards. However during daylight on 30 April the entire remaining effect disappeared very abruptly within about an hour. Those rapid disappearance was unique among the many long-enduring events observed by radio-wave techniques and suggests a "Sweep-out", phenomenon operative for protons with energies very roughly between 3 and 50 Mev.

McCracken, K. G.: Dr. Gold suggests that the low energy protons seen after the onset of a geomagnetic storm are the result of adiabatic cooling of higher energy protons trapped in a "bottle" magnetic regime. It seems hard, on this picture, to explain why the intensity inside and outside the "bottle" should be exactly the same (as it is on some occasions). Such equality, and the fact that equality is not always observed, can be explained by the Parker type magnetic regime, the scale size of the kinks being large enough so that the motion of low energy particles is not affected, while high energy particles observe the kink. Variability of the scale size of the kink would explain the variability of the observed effect.

Carmichael, H.: This remark gives me an opportunity to make a comparison. It seems that the two models differ only in that the Gold model contains several features that have been omitted by Parker. For example, Dr. Gold use the magnetic field of the sunspot as a main source of the fields in planetary space. Parker uses only the quiet field of the sun and thus has no field lines forming loops, attached to the sun in the vicinity of the spot. Whether the observed storage of solar particles in space can occur without these loops is an important question. A shock front proceeding the gas from the sunspot must exist on the Gold model and such a shock has for several years been postulated to explain the sudden commencement. At the shock front the preexisting magnetic lines in space will become kinked as discussed by Parker and this kink will permit the passage of low energy protons and hence a change of the intensity of low energy solar protons should not be expected at the time of a sudden commencement. It should be noted also that we usually see several successive flares and magnetic storms associated with the same sunspot. Here, on the Gold model, the later clouds of gas from the sun will propagate shock fronts that effect the magnetic lines of force established by the earlier flares. Effects quite similar to those calculated by Parker should occur. The observations, however, suggest that the pushing gas often follows more closely upon the shock front than derived by Parker.

Singer, S. F.: Dr. Ogilvie has suggested that the very low energy protons (<1Mev) observed in the NASA rocket during Nov. 1960 might be due to the transfer mechanism discussed by me in II-2-4, *i.e.* by neutron albedo something from the polar cap.