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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-4-12. The Recovery Characteristics of Forbush Decreases and the Configuration of the Associated Solar Emission*

I. ESCOBAR, N. W. NERURKAR, O. TRONCOSO
and M. ZUBIETA

Laboratorio de Física Cosmica, Universidad Mayor de San Andres, La Paz, Bolivia

Forbush decreases (F.D.) range from a few fractions of a percent (meson intensity underground) to as high as 30% (neutron intensity at mountain altitudes in high latitudes). The time taken to reach the bottom likewise varies from few minutes[1),2),3)] to about a day, while a greater degree of variability is seen in the recovery time which fluctuates from few minutes to fifteen days. We have attempted to present in the following a systematic study of the recovery times of F.D. in relation to the characteristics of the accompanying M.S. and to the heliographic position of the preceding solar outbursts.

From a great number of M.S. of sudden commencement type observed during I.G.Y. and I.G.C. we have selected for the first part of our study only those which are accompanied by only one F.D. and which in addition are not preceded or followed for about a week by any geomagnetic or strong solar activity. We call those as "single" storms and have listed them in Table I together with the intensity of the magnetic disturbance of the accompanying M.S. The latter are classified as strong if the disturbance raised the planetary index K_p to 8 or higher number for at least two times (in periods of three hours) or otherwise as weak. We have include in addition in the same table the heliographic coordinates of the associated solar emissions.

At the first glance it is seen that the origin points of solar emissions of M.S. are distributed over all solar longitudes. However one fact prominently stands out that, when magnetic disturbance is strong the associated solar emission has its origin near C.M. and when the origin is far away from C.M. the magnetic disturbance is weak. Similar results have been reported by other workers also[1),4)].

The recovery characteristics of the cosmic ray intensity observed during strong and weak storms listed in Table I are shown in Figs. 1 and 2, respectively. Data presented corresponds to the mean variation in neutron monitors at seven stations (four in the northern hemisphere *viz.* Sulphur mountain, Mt. Washington, Climax and Chicago and three in southern hemisphere from Mt. Wellington, Buenos Aires, Mawson, Ushuaia and Hermanus) for M.S. during I.G.Y. and at four stations (Kiel, Dee River, Ellsworth and Ushuaia) for other storms.

Assuming that the recovery from F.D. is exponential with characteristic time τ, we have indicated in Figs. 1 and 2 and also in Table I the best fitting values of τ for each storm. It is seen that τ for strong M.S. with the associated solar emission near central meridian (C.M.) is about two or three days while for weak storms with solar emissions far from C.M. it is ten days or more.

When the solar emission takes place far from C.M., it must be in a wide cone in order to reach the earth. If similar type of emission is supposed to occur always[1)], when it is near C.M. the earth will be engulfed by its central part. In such a case its recovery from F.D. is always likely to be slow. This prediction is not in agreement with the above experimental result that the recovery from F.D. is fast with strong M.S. whose solar emission is near C.M. It appears therefore that there are two distinct types of F.D., which in consequence implies two different configurations of solar emissions containing magnetic fields.

Assuming that the intensity of magnetic

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disturbance depends on the density and the momentum of the arriving solar gas and identifying the recovery rate of F.D. with the volume of the space disturbed by the solar emission we suggest that, in broad terms, there are two types of emissions of solar matter: in narrow cones and omnidirectionally.

In the former case, the emission being confined to a small volume, the densities and momenta are relatively high thus producing strong magnetic disturbances. In addition, the interplanetary space where magnetic field structure is disturbed is small and in consequence needs a short time to restore to its original state. This leads to a fast recovery of the F.D.

In the latter case, the solar gas is spread over a wide range of directions. Its density and the momentum near the earth are comparatively small and hence the magnetic disturbance is weak. Moreover, it disturbs the magnetic field configuration over a fairly large portion of the interplanetary space with

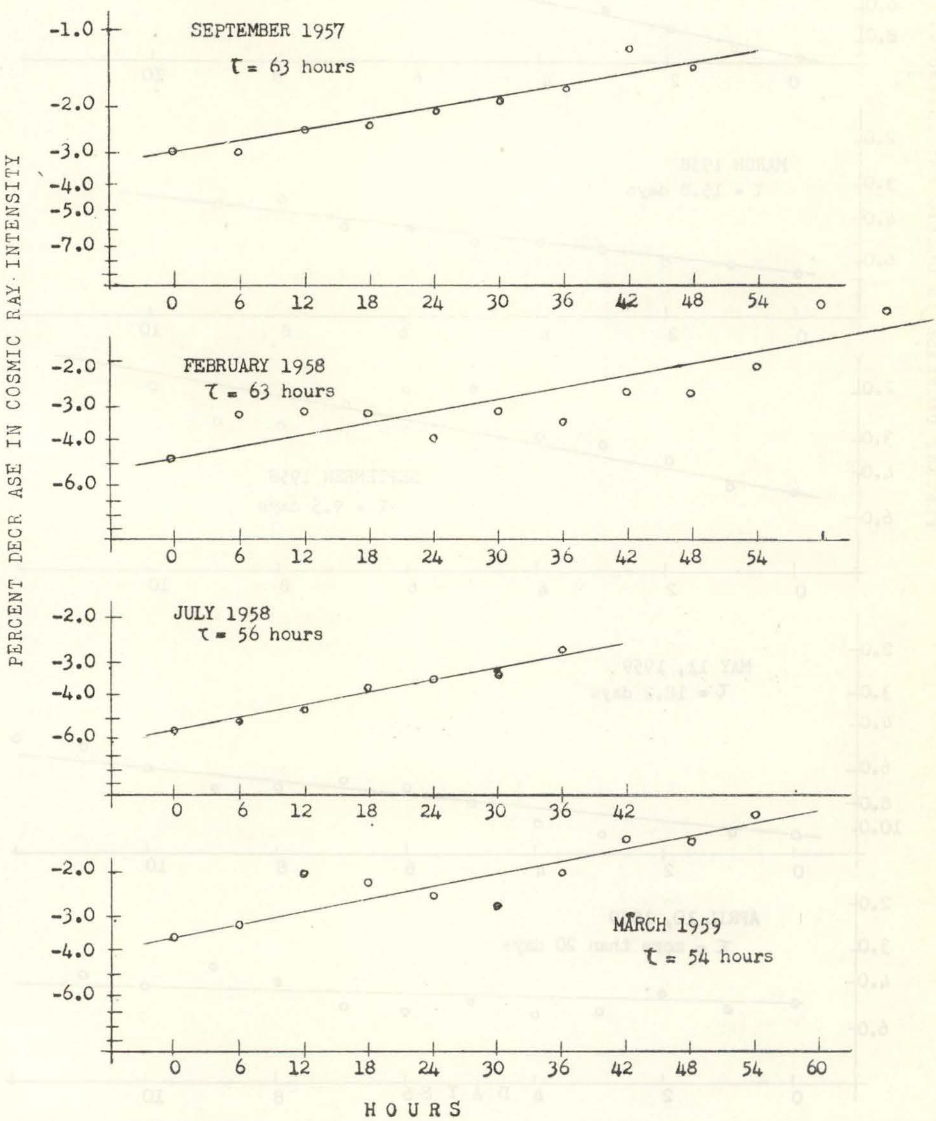

Fig. 1. Cosmic ray intensity, measured by neutron monitors in middle latitudes during recovery of Forbush effect associated with strong magnetic storms has the characteristic time if the recovery is assumed to be exponential.

the result that it will take relatively long time to recover to its predisturbance state and the Forbush recovery is slow.

The above pictures raises two new questions. The first is that an emission taking place far from C.M. can reach the earth when it is in narrow cones. What experimental evidence can be forwarded to support such interpretation?

Since no effect is registered on the earth

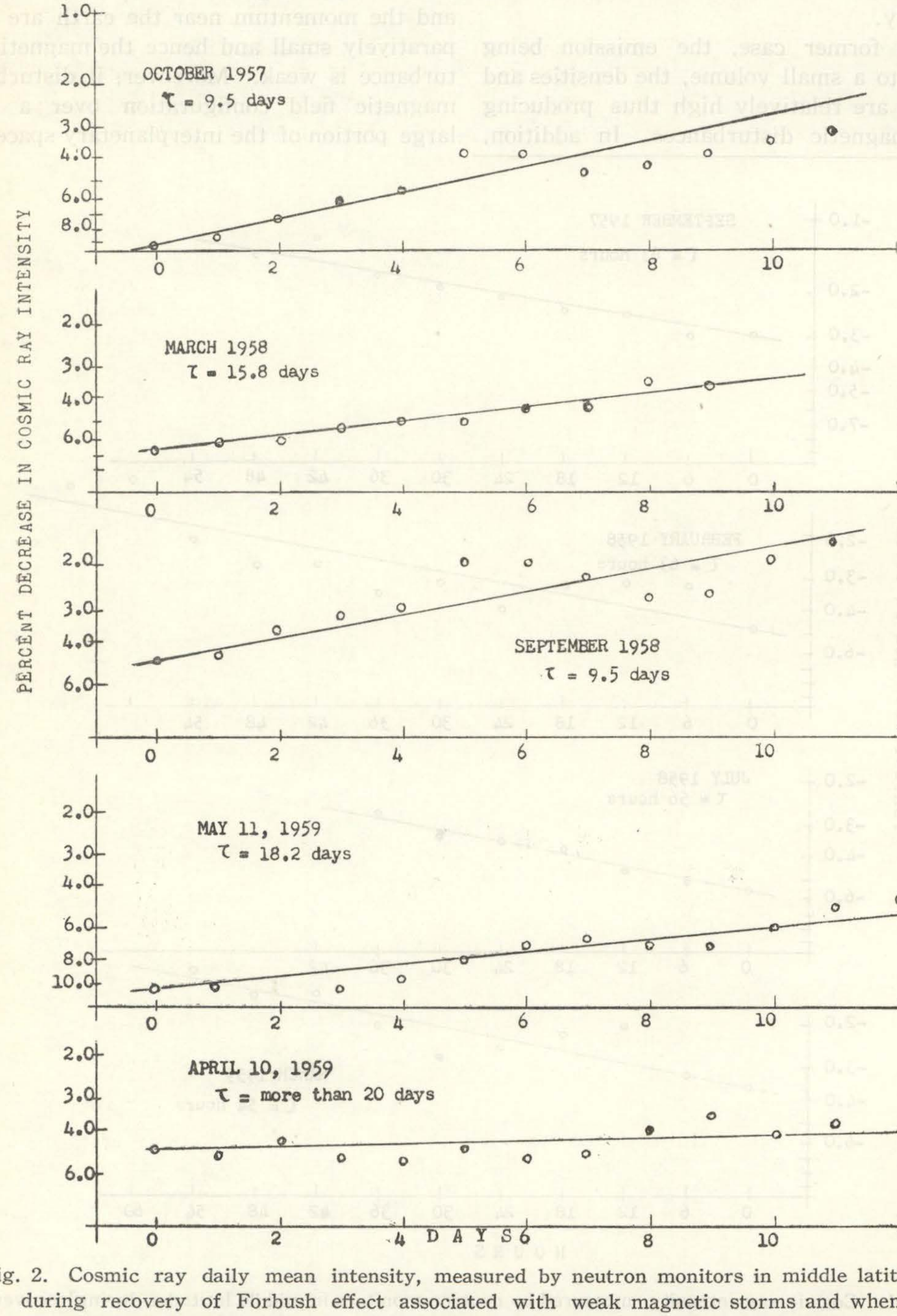

Fig. 2. Cosmic ray daily mean intensity, measured by neutron monitors in middle latitudes during recovery of Forbush effect associated with weak magnetic storms and when the solar matter is emitted from a region far from central meridian has the characteristic time if the recovery is assumed to be exponential.

in the latter case the experimental evidence has to be indirect. If we assume that each flare of type 3 or more give rise to an emission of solar matter, there are many solar flares of type 3 or more which when originated far from C.M. do not give rise to M.S. on the earth. This fact suggest that the associated emission has missed the earth. The above assumption is however ad hoc, although we do not know of any cases of solar flares of type three with origin near C.M. which have failes to produce a M.S. on the earth. On the other hand, very large solar disturbances, associated with which particles are accelerated to cosmic ray energies on the sun, can safely be assumed to

Table I. The Intensity of the magnetic disturbance, the heliographic position of the solar emission and the characteristic times of the recovery of cosmic ray intensity associated with (I) single storms and (II) first of the mixed storms.

Magnetic Stories		Heliographic Coord		Characteristic Time
Date	Disturbance	Latitude	Longitude	
		I) Single Storms		
Sept. 1957	Strong	N 10	W06	2,6 days
Oct. 1957	Weak	S 15	E 37	9,5 days
Feb. 1958	Strong	S 20	E 04	2,6 days
Mar. 1958	Weak	S 14	E 76	15,8 days
July 1958	Strong	N 26	W08	2,3 days
Sept. 1958	Weak	S 20	E 50	9,5 days
March 1959	Strong	N2 0	W02	2,2 days
Apr. 1959	Weak	N 25	E 76	more than 20 ds.
May 1959	Weak	N 19	E 46	18,2 days
		II) First of Mixed Storms		
Feb. 11, 1959	Weak	Far from C. M.		more than 20 ds.
Jul. 11, 1959	Weak	Far from C. M.		11 days
Jul. 15, 1959	Strong	Near C. M.		2,4 days

Table II. Summary of the magnetic effects and cosmic bay recovery rates accompanying forbush decreases due to solar emiseions in narrow cones or omnidirectional.

Type of Emission	Narrow Cones		Omnidirectional	
Heliographic Longitude Magnetic Storm Cosmic ray Recovery	Near CMP Strong rapid	Far from CMP No (emission misses the earth)	Near CMP Weak Slow	Far from CMP Weak Slow
Examples:	1) Sept. 1957 2) Feb. 1958 3) July 1958 4) Mar. 1959 5) July 1959 15, 17 6) Aug. 1959 7) Apr. 1960 8) May 1960 9) Nov. 1960 13, 15	1) May 4, 1960 C. R. Increase Type IV noise No M. S. 2) Nov. 15, 1960 C. R. increase Type IV noise No M. S. 3) Mar. 7, 1942 C. R. increase No M. S. 4) Nov. 19, 1949 C. R. increase No. M. S.	1) Solar flare May 26, 1960 N15, W15 Magnet. storm May 28, 1960 Ap—54 2) Solar flare Jun. 25, 1960 N20, E06 Magnet. storm Jun. 27, 1960 Ap—65 3) Solar flare Jun. 27, 1960 N23, W23 Magnet. storm Jun. 28, 1960 Ap—36	1) Oct. 1957 2) Mar. 1958 3) Sept. 1958 4) Feb. 1959 5) Apr. 1959 6) May 1959 7) July 1959 11

emit a large cloud of solar gas. When such disturbances were registered far from the C.M. in March 1942, November 1949 and May 1960 no M.S. or F.D. were recorded subsequently on the earth, which fact can be taken as proof that the solar emission being in narrow cones missed the earth.

The second question is that if omnidirectional emisson takes place near C.M., what will be the magnetic and cosmic ray effects on the earth? Unless such an emission has a dense core, the M.S. will be weak and the recovery of F.D. will be slow. Examples of this type are F.D. in Deep River neutron monitor on May 28, 1960 and June 28, 1960.

All these results together with examples of other cases are summarised in Table II.

The solar emissions need to contain magnetic fields within them to cause F.D. These fields are most likely to be derived from the sunspots where the gas originates. Their configuration in the gas when emitted in narrow cones is considered by Gold[5] who pictures it as an elongation of the sunspot field in the form of a bottle. We assume that such elongations temporarily displaces the existing interplanetary magnetic fields over the volume occupied by the gas. The F.D. is identified with the earth engulfed by these elongations and the recovery of F.D. with their disruption into turbulent eddies which eventually may contribute to the weak interplanetary magnetic fields.

During periods of high solar activity it often happens that a new solar emission reaches the earth before the effect of the previous one has been over. We see then two F.D. one superimposed on the other or a modification of the first Forbush pattern. Such events are called "mixed" storms. We shall now see how the characteristics of the mixed F.D. can be explained in terms of the above picture.

The recovery characteristics during mixed storms depend on the nature of the two emissions and the manner in which they intermingle and the time separation between them. Nevertheless until a substantial interference occurs, the recovery rate of the first F.D. must correspond to the picture derived for the single stroms. Examples to show that this is true are given in Table I part II.

To understand the recovery times of the second F.D. we consider two main types of interfences; one when two emissions are originated in the same solar region and the other when they originate from two different solar regions.

First we study the case when two emissions originate in the same solar region and we assume the second emisson to be emitted inside the volume occupied by the first one.

a) Narrow cone emission followed by another narrow cone emission. The effect of the first emission is fast recovery of F.D. The second emission being guided by the field lines of the first, will be compressed in a narrower cone and thus occupy less volume than it would normally have occupied in absence of the first emission. The recovery of the second storm will then be very fast. At the same time due to the pressure exerted by the second emission the first magnetic bottle will inflate. The final recovery rate will then correspond to the modified state of the two emissions and hence will be medium fast.

The examples of the above types of interferences are the mixed storms of (1) July 15 and 17, 1959 and (2) November 13 and 15, 1960. The recovery rates of the first storms 3 days. The recovery rates of the second storm, in the beginning, are 1 day, suggesting a very fast recovery while the final recovery rates are 6 days.

If however the second emissions is not very strong, the subsequent solar activity not being very high, it will not modify to a large extent the volume of the first one but it will contribute in lengthening the F.D. The final recovery will then be, with some delay, the same as or slightly slower than that of the first emission. F.D. of September 3, 1960 is an example of this case, when the recovery is delayed for about 3 days and the final recovery rate is 4 days.

b) Omnidirectional emission followed by a narrow cone emission. The effect of the first emission is slow recovery. The effect of the second emission is fast recovery. The second emission will modify to a negligible extent the magnetic field structure of the first one so that the cosmic ray recovery structure will be a sum of the effects of the two emissions only.

Examples of this case are the mixed storms (1) February 11, 14 and 16, 1959 and (2) July 11, 15 and 17, 1959.

We now consider the cases when two solar emissions originate in two different solar regions.

a) Narrow cone emission followed by a narrow cone or omnidirectional or *M*-type emission. Since the recovery rate of F.D. of the first emission is of the order of 3 days, the second emission must be within that period to have its effect registered. The interference effect will be to displace or disrupt the first magnetic bottle resulting in a very rapid recovery rate of the first F.D.

Example of this nature in the F.D. of May 8, 1960 when the recovery rate is less than a day and second emission is of *M*-type.

b) Omnidirectional emission followed by a narrow cone or a wide cone of *M*-type emission. The recovery rate of the first emission is slow *i.e.* of the order of ten days or more. The interference due to second emission will be different depending on the time separation between the two. The general effect will be to disrupt the magnetic field lines of the first emission causing the original slow recovery to turn fast. We have not noticed any example of this type.

Conclusion

Forbush decreases accompanying single magnetic storms are found on the average to recover fast of slow depending on whether the latter are strong or weak. In addition, the recovery rates of the mixed Forbush decreases appear to be related with the volume occupied in space by the emission associated with magnetic storms. This emission is therefore suggested to occur either in narrow cones or omnidirectionally. It is shown that it not only explains satisfactorily a wide range of recovery rates of Forbush decreases *viz.* few hours to two weeks but also helps in understanding the total absence of magnetic storms after some large solar disturbances.

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Discussion

Kondō, I.: I understand that your result is as follows. Is it correct? There are two types of solar stream or cloud.

1) Narrow type 2) Wide type

Did you find any correlation between these types and types of solar events (type of solar radio outbust or importance of solar flare)?

Escobar, I.: Our results pertain to different recovery times observed for Forbush decreases. The two types of solar emission are assumed to explain the two types of recovery observed.

In general the Forbush decreases are only observed for major flares. We have not attempted as yet to correlate the fast and slow recovery with solar radio noise emission.