Upper Cutoff in the Proton Spectrum of January 24 and September 1, 1971 Events

by

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In an earlier publication, [Heristchi and Trottet, 1971] arguments have been advanced in favor of the existence of an upper cutoff in the spectrum of solar protons in the case of the events of January 28, 1967 and March 30, 1969. This quantity, even when it is determined in the Earth's environment, is directly related to the Source Spectrum, for, contrary to other parameters of the Source Spectrum, it is almost unaffected by the propagation of particles in the interplanetary medium. When the magnitude of this upper cutoff is of a few GV it can be evaluated from Neutron Monitor (NM) data. As the "Specific Yield Function" for protons (SYF) increases with the rigidity, the neutron monitor is a particularly good means of this measurement. The purpose of this paper is to determine the upper cutoff during the January 24-25, 1971 and September 1-2, 1971 events.

A first method consists in using the world-wide network of NM as a rigidity spectrometer while adding the presence of a maximum rigidity in the proton spectrum [Heristchi and Trottet, 1971]. Mountain stations are ignored and a double correction of the barometric effect is applied. The percentage increase (F) for one NM may be formulated as follows [Palmeira et al., 1970]:

$$F = \frac{A_1}{N_g} \int_{P_c}^{P_m} P^{-\mu} \, S\,(P)\, dP \qquad (1)$$

where P is the magnetic rigidity of the protons, A_1 a constant, N_g the counting rate due to galactic cosmic rays with a standard NM located in a place of magnetic rigidity P_c, P_m the upper cutoff, $P^{-\mu}$ the differential spectrum of the primary solar protons and S(P) the SYF. Here we use for N_g the values obtained by Carmichael et al. [1966], for P_c the values calculated by Shea et al. [1965], and the Lockwood and Webber's [1967] SYF which is represented by power laws in different rigidity bands.

By using for each time interval the percentage increase at several NM stations located in different geomagnetic latitudes and by applying the least square method, it is possible to determine A_1, μ and P_m. By writing equation (1) as a function of energy, we obtain:

$$F = \frac{A_2}{N_g} \int_{E_c}^{E_m} E^{-\gamma} \, S\,(E)\, dE \qquad (2)$$

where E_c corresponds to P_c for protons.

This method is only applicable for an isotropic event. In the case of a noticeable anisotropy or of a lack of data we can proceed as follows [Heristchi et al., 1972]. The ratio R = F1/F2 of the percentage increases at two stations viewing in similar mean asymptotic directions and located in different P_c is calculated. From equation (1) this ratio is computed as a function of P_m for different values of μ. Two examples of the curves $R = f\,(P_m,\mu)$ are shown on Figure 1.

By choosing three or two pairs of stations in different cutoffs, it is possible to determine P_m and μ. We consider three stations with P_{c1}, P_{c2} and P_{c3} ($P_{c1} < P_{c2} < P_{c3}$) in order to have P_m near P_{c3} and substantially larger than P_{c1} and P_{c2}. P_m and μ are determined, from R_1 = F1/F2 and R_2 = F1/F3, by means of an iterative method. Starting from one P_m larger than P_{c3}, μ is determined by using R_1. The knowledge of μ allows one then to find P_m from R_2. This new P_m is used to obtain a new μ and so on. This method is rapidly convergent. Evidently if μ is deduced from other measurements, R_2 is sufficient to evaluate P_m and vice versa.

In order to estimate the magnitude of P_m, it would be possible to search from which cutoff the event is not registered. The preciseness of this procedure is not sufficient to determine P_m, but it can be used to corroborate the results deduced from the preceding methods.

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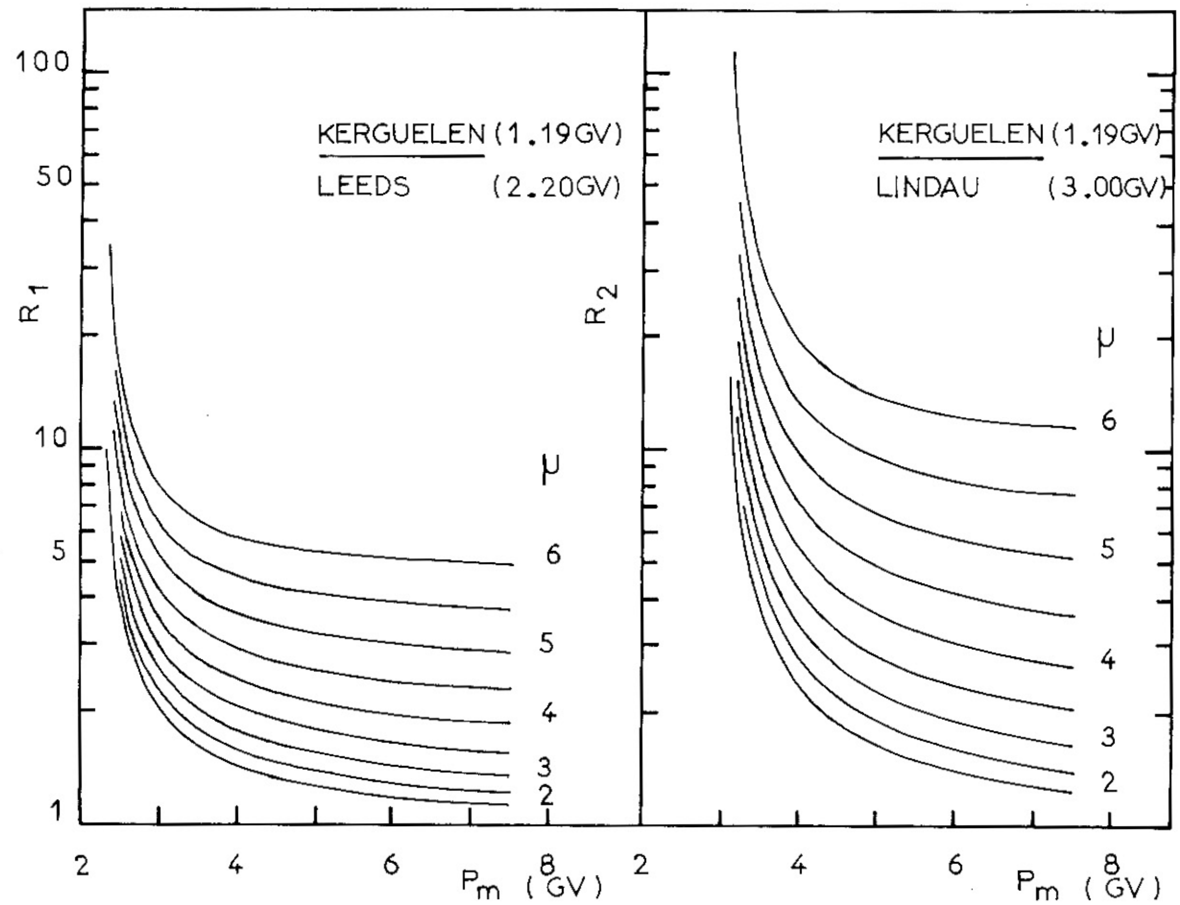

Fig. 1. Expected ratios of relative enhancements of two pairs of stations versus P_m for different values of μ.

<u>January 24-25, 1971 event</u>

The time variations recorded at different NM stations during this event are shown in Figure 2. As this event is not very anisotropic, the first method has been applied to the hourly counting rates of several NM. Since records of low latitude stations show that the galactic background varies during the event, this method has been applied in two different ways:

- The background variations have been neglected (background = mean level before the event).
- A variable background for all the stations has been deduced proportionally to Rome's smoothed variations.

The results are similar in both cases and for different hours.
We obtain:

$$P_m = (3.5 - 4.0) \pm 0.6 \text{ GV} \; ; \; \mu = (3.7 - 3.9) \pm 0.4$$

$$E_m = (2.7 - 3.0) \pm 0.5 \text{ Gev}; \; \gamma = (2.7 - 2.8) \pm 0.4$$

In Figure 3 the percentage increases between 0000 UT and 0100 UT on January 25 is plotted against P_c, and the Figure shows the predicted curves of various forms of the differential spectrum. These curves indicate that the best agreement with the experimental points is obtained with an upper cutoff in the differential spectrum.

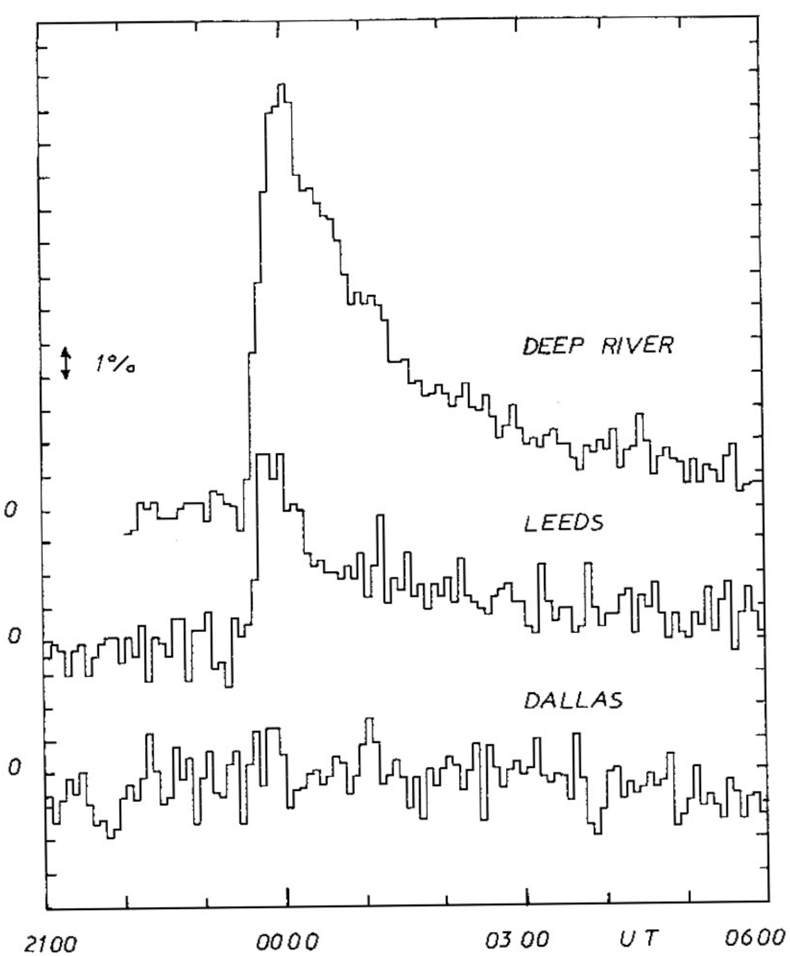

Fig. 2. Time variations of three typical stations on January 24-25, 1971.

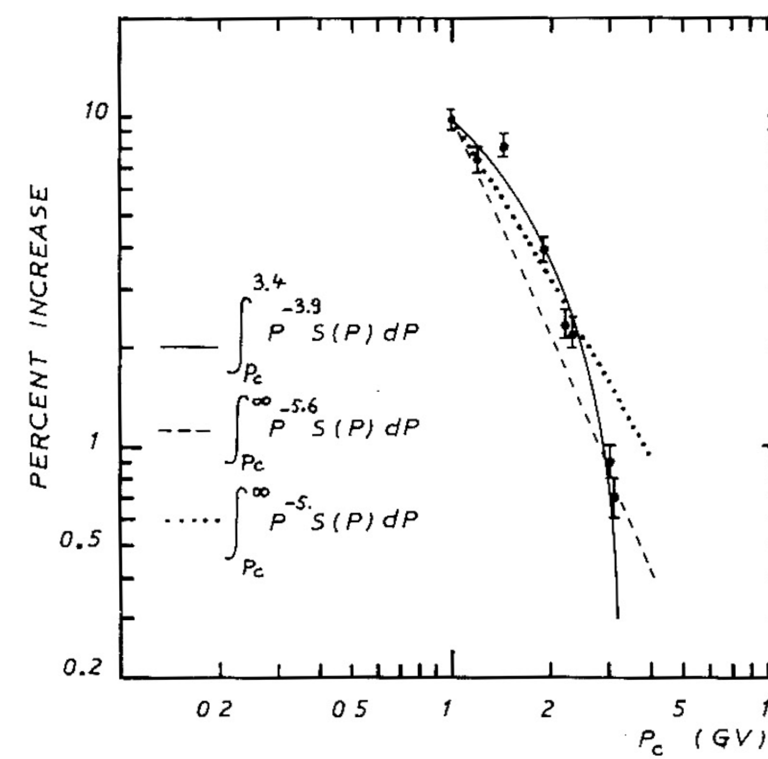

Fig. 3. Percentage increase in the sea level NM at 0100 UT on January 25, 1971, compared with different theoretical curves. The percentage increases of polar stations (1 GV) have been averaged.

Considering that this event is slightly anisotropic the second method has been applied to two groups of three stations. The results are:

- from Kerguelen (1.2 GV), Leeds (2.2 GV), Lindau (3.0 GV).

$$P_m = 4.0 \pm 0.6 \text{ GV} \;;\; \mu = 4.0 \pm 0.4$$

- from Oulu (1.0 GV), Kiel (2.3 GV), Lindau (3.0 GV).

$$P_m = 4.6 \pm 0.6 \text{ GV} \;;\; \mu = 4.6 \pm 0.4$$

Within the errors all these results are in agreement.

However, from balloon measurements in the 100-500 Mev energy band, Charakhchyan [1972] has found γ = 3.8 to 4.2 corresponding to μ = 4.8 to 5.2, values larger than ours. This difference is partly due to the correction which has been applied for the nuclear interaction of 100-500 Mev protons in the atmosphere, and partly to a possible decrease of the P_c of the stations, for the Kp index reaches a value of 4 during the event.

September 1-2, 1971 event

In Figure 4 the counting rates of several NM during the event are plotted against time. Both methods have been applied to the hourly percentage increase and to their sum through 2000 to 2400 UT. Using P_m, so deduced, μ can be evaluated from R_1 = Deep River (1.0 GV)/ Swarthmore (1.9 GV). All the results are shown in Table 1. It follows from this Table:

- The values of P_m and μ, deduced from the different methods, are all consistent:

- E_m and P_m remain substantially constant in time.

- γ and μ increase with time. This can be explained by the propagation of particles in interplanetary space.

Figure 5 is equivalent to Figure 3 for this event. Here again, it is clear that the best agreement with the experimental points is obtained with an upper cutoff in the differential spectrum.

A small increase is visible on Pic-du-Midi's hourly and fifteen minutes records between 2100 and 2200 UT. However, only one of the three sections of this NM shows this increase, so it cannot be due to the event. Moreover, as it can be seen from Figure 4, there is no increase in Dallas's records. It is to be noted that during this event there is an enhanced diurnal variation and that the magnetic activity is very low.

Table 1

Universal time	First method				Second method		
	E_m	γ	P_m	μ	P_m+	μ+	μ++
2000-2100	2.5	1.3	3.3	1.6			
2100-2200	2.4	2.6	3.2	3.5	3.2	3.2	2.6
2200-2300	2.1	2.8	2.9	3.8	2.9	4.2	3.6
2300-2400	2.1	3.2	2.9	4.4			4.0
Sum	2.3	2.7	3.1	3.6	3.0	3.6	3.6

\+ From Kiruna, Leeds and Utrecht.
++ From Deep River and Swarthmore by using P_m from fourth column.

The two events discussed here show upper cutoffs of the same order of magnitude as in the case of the events of 28 January 1967 and 30 March 1969. Preliminary results obtained on other events, recorded by Neutron Monitors, indicate that the upper cutoffs are of a few GV except for the February 23, 1956 event, the P_m of which is larger [Heristchi et al., 1972].

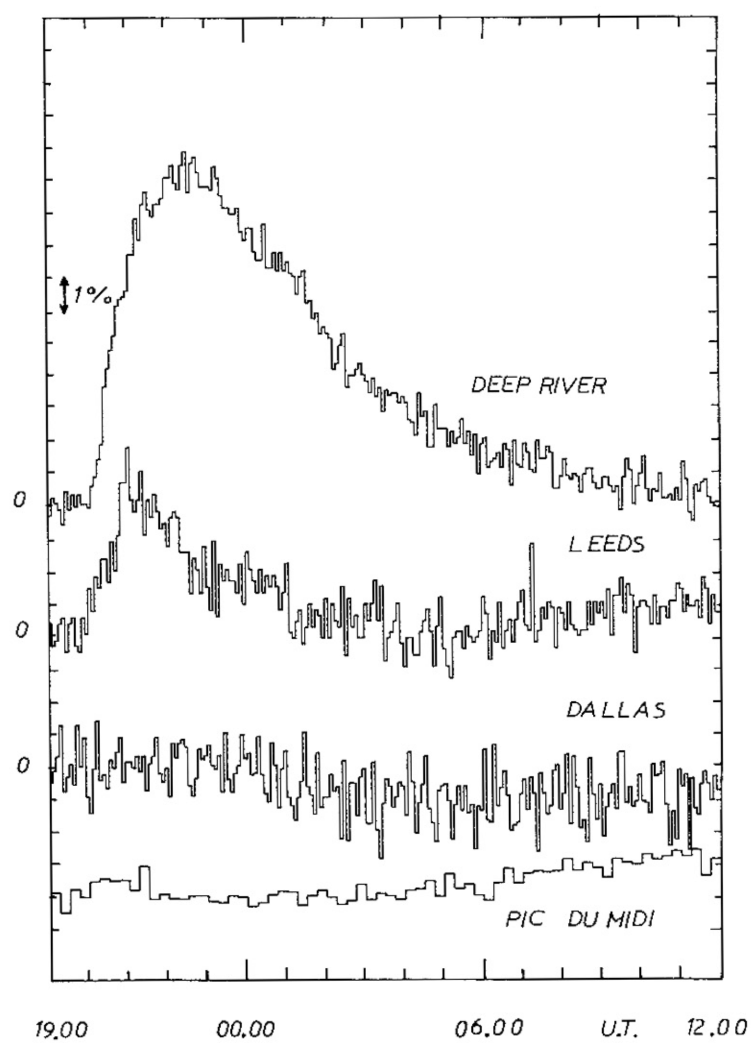

Fig. 4. Time variations of four typical stations on September 1-2, 1971.

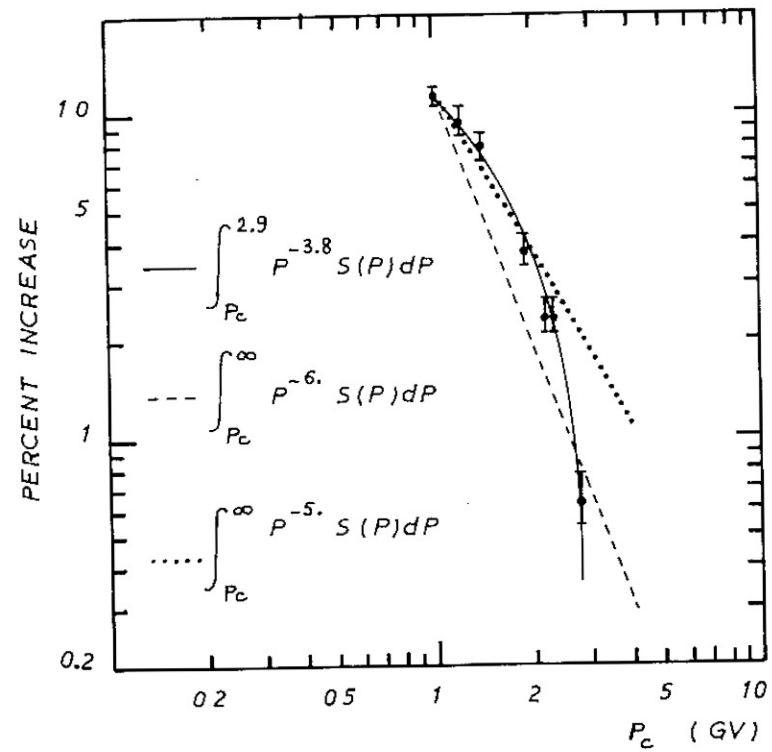

Fig. 5. The same as Figure 3 at 2300 UT on September 1, 1971.

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