Journal of
GEOPHYSICAL RESEARCH

VOLUME 66 JUNE 1961 No. 6

Cosmic Ray Phenomena During the November 1960 Solar Disturbances

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Abstract. A preliminary analysis of cosmic-ray neutron monitor intensity data during the November 1960 solar disturbances is presented. The first increase on November 12 is attributed to generation of particles on the sun, following a class 3^{+} flare. A second increase on November 12 is interpreted as the arrival at the earth of solar particles trapped in the gas cloud emitted by the sun in connection with a previous flare. It is shown that the arrival of a further cloud sweeps away the remaining solar particles. The increase on November 15 is attributed to a new generation of high-energy particles by another class 3^{+} flare that occurred on the same solar active region. The characteristics of the solar flare increases are shown to agree with the conclusions of McCracken and Palmeira regarding the propagation of solar particles in interplanetary space. Data from low latitude stations are used to investigate the Forbush decreases and their relation with other solar and terrestrial events.

1. *Introduction.* This paper is based on an exchange of data and ideas at the Symposium on Space Research held in Buenos Aires from November 28 to December 3, 1960, during a session devoted to the November 1960 disturbances. In view of the limited amount of data available at that time, the results presented here are of preliminary character. The data already available, however, indicate the importance of these events, principally that of November 12, where a superposition of the flare increase and a Forbush decrease offers a unique opportunity for studying the interaction of the two mechanisms responsible for these two effects on the cosmic-ray intensity.

Table 1 shows the principal solar and terrestrial events that occurred in the period November 10–15, 1960. All flares here presented, with the exception of the November 13 flare, occurred in the region 5925, which had its central meridian passage on November 11. The indicated association of the sudden-commence-

TABLE 1. Important Solar and Terrestrial Events in the Period November 10–15, 1960

Solar Flares Importance	Solar Flares Time	Heliographic Position	Major Radio Bursts	Solar Cosmic Rays	Associated SC Magnetic Storms	Forbush Decreases
3	Nov. 10 10:00–14:00	N28, E28	Yes	None	Nov. 12 13:48	None
—	Nov. 11 03:05–	—	Type IV	None	Nov. 12 18:46 (SI)	Nov. 12 19:30
3^+	Nov. 12 13:25–19:22	N26, W04	Type IV	Starting 13:40	Nov. 13 10:21	Nov. 13 10:30
2^+	Nov. 13 13:15–13:50	N23, E59	None	None	None	None
2	Nov. 14 00:15–01:00	N31, W14	None	None	None	None
2^+	Nov. 14 02:46–05:20	N27, W19	Type IV	None	Nov. 15 13:04	Nov. 15 13:30
3^+	Nov. 15 02:07–04:27	N26, W33	Type IV	Starting 02:30	None	None

ment magnetic storms and the Forbush decreases with a particular solar flare seems to us the most plausible one.

Figure 1 shows hourly cosmic-ray percentage intensity variations referred to a quiet prestorm level, recorded with neutron monitors at the South American continental stations Chacaltaya (13.5 bev geomagnetic cutoff rigidity, 5.200 m above s.l.), Rio de Janeiro (11.5 bev, s.l.)—data from Buenos Aires (10.7 bev, s.l.) coincide with the latter except for statistical fluctuations —Mina Aguilar (12.5 bev, 4000 m above s.l.), and Ushuaia (5.9 bev, s.l.). Three cosmic-ray intensity decreases are revealed, starting on the 12th at around 2000 UT, on the 13th at about 1100, and on the 15th at 0800. A remarkably sharp intensity increase or recovery is shown at all stations on the 13th, between 0700 and 1030 UT.

In Figure 2 quarter-hourly neutron monitor intensity data recorded at Ellsworth, Antarctica, are represented. A double-peak increase occurs on the 12th; the increase on the 15th has a simpler structure. Notice the 'fine structure' in intensity variations during the first peak, which also appeared at other stations that detected these increases.[1]

[1] Note added in revision: Ellsworth also detected a 7 per cent increase on November 20, starting at 2140 UT. This event may be linked with a recently reported west limb flare.

2. *The particle injection on November 12.* Computing impact zones according to *Firor* [1954] for particles originating at the sun simultaneously with the start of the 3^+ solar flare of the 12th, we find Ellsworth lying in the 09 zone. Other stations, however, such as Yakutsk, Uppsala, and London, which reported the first increase on November 12, do not fit into the picture of impact zones. This is to be expected, according to *McCracken and Palmeira* [1960] and to *Obayashi and Hakura* [1960*a*], taking into account the presence near the earth of the magnetic cloud responsible for the subsequent Forbush decrease starting at about 1930 UT on the 12th.

Considering the close time association between this Forbush decrease and the start of the *second* solar increase of the 12th, we may tentatively assume the following picture of events in interplanetary space: shortly before 1900 UT on the 12th, the earth is 'sitting' in a solar gas cloud responsible for the magnetic storm which started at 1348 UT. No strong magnetic field should be present in this cloud (no Forbush decrease associated with this storm). A second, strongly magnetized cloud is approaching the earth, causing the sudden impulse at 1946 UT and the Forbush decrease of galactic radiation. Furthermore, the magnetic field lines linked with this cloud form a 'magnetic bottle' carrying the remainder of a trapped

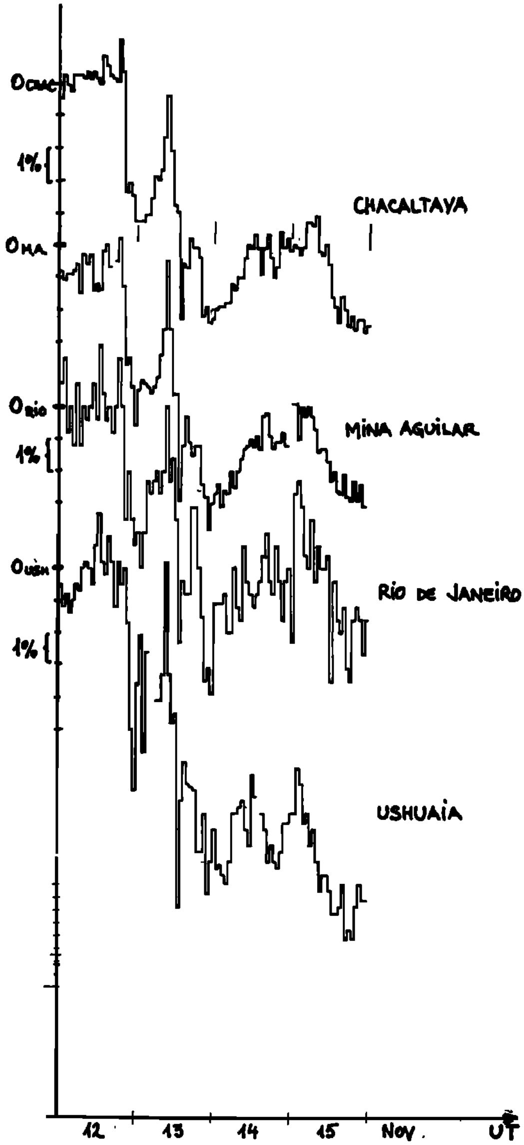

Fig. 1. Hourly percentage intensity values for four South American neutron monitors.

flux of solar particles, injected 6 hours before, during the 3^+ flare.[2]

According to this picture, the first increase of the 12th, between 1345 and 1900 UT, should be interpreted as a radiation leakage from the magnetic bottle, detected at the earth before it entered the bottle. Once the earth was inside, low-energy cosmic-ray intensity sharply rose to the trapped radiation level, whereas the high energy galactic radiation dropped to the Forbush decrease level.

In Figure 3 we plotted on a logarithmic scale the hourly percentage intensity variations, referred to preflare level, of different high latitude neutron monitors as a function of time elapsed from the beginning of the first increase. We can divide the period into three intervals, according to peculiar intensity time behavior:

(*a*) November 12, 1345–1900 UT: corresponding to the first increase, and showing a time behavior that varies from station to station. Using coupling functions given by *Webber and Quenby* [1959] and cutoff rigidities given by *Quenby and Webber* [1959], we get from the latitude effect a primary variation spectrum relative to the normal spectrum, of the form:

$$\frac{\delta j}{j} \sim P^{-(6.0\pm0.5)}$$

at the peak (around 1700 UT). After this time, the spectral form changes rapidly in time. This may be explained by a change in cutoff rigidities during the main phase of the magnetic storm (*Obayashi and Hakura*, 1960*b*).

(*b*) November 12, 1900 UT—November 13, 0315 UT: corresponding to the second increase and following intensity decay. All stations show a remarkable parallel time behavior, the ratio of intensities of any pair of different stations remaining constant throughout this interval. Assuming that at this time cutoffs were normal again, we get for the form of the relative variation spectrum of the additional radiation

$$\frac{\delta j}{j} \sim p^{-(4.5\pm0.5)}$$

which is appreciably harder than that of the previous increase. As this result does not fit into the idea of magnetic trapping of solar particles, which rather should give a softer spectrum, we may assume that during that period magnetic cutoffs were still appreciably different from normal values, simulating a hardening of the energy spectrum by an increase of geomagnetic origin of the intensity at lower latitudes.

(*c*) November 13, after 0315 UT: the inten-

[2] Note added in revision: J. F. Steljes, H. Carmichael, and K. G. McCracken (to be published) support a similar model for the interpretation of the second increase on the 12th.

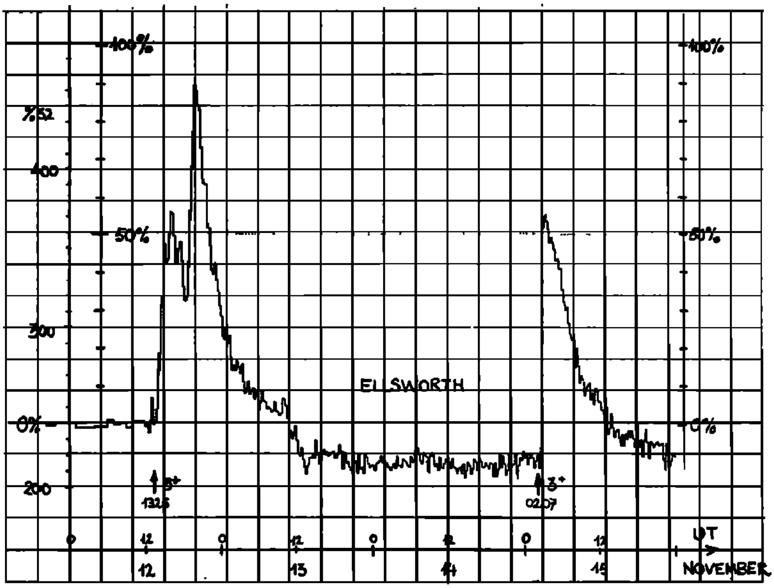

Fig. 2. Ellsworth neutron monitor quarter-hourly intensity values.

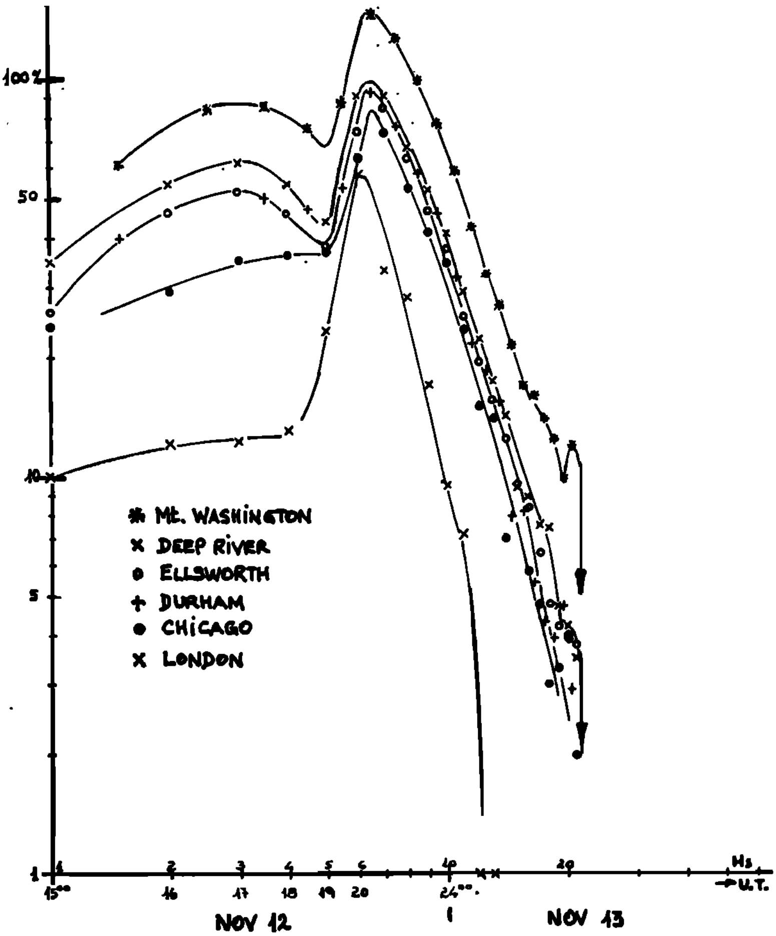

Fig. 3. Hourly values of relative intensity, plotted on a logarithmic scale, for the November 12 increase, for high latitude neutron monitors.

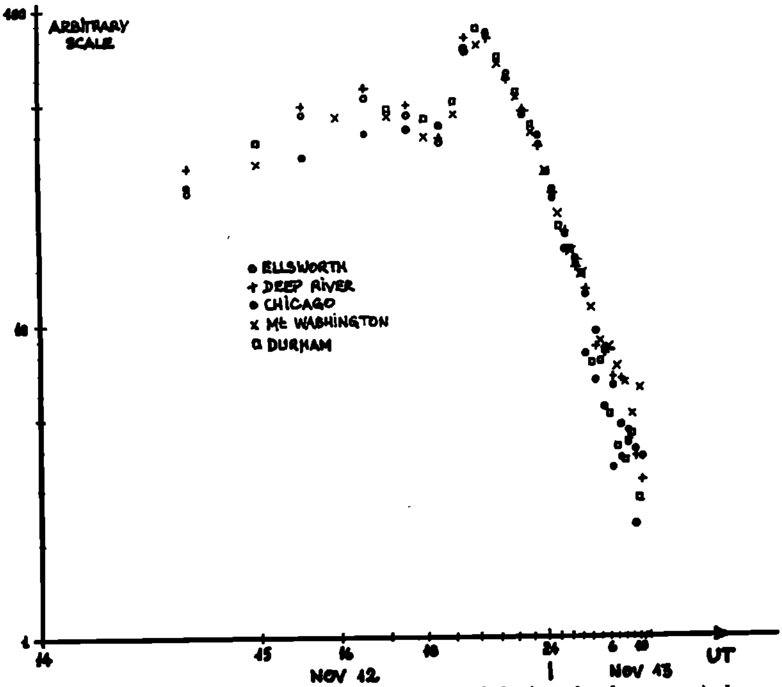

Fig. 4. Same data as for Fig. 3, normalized during the decay period.

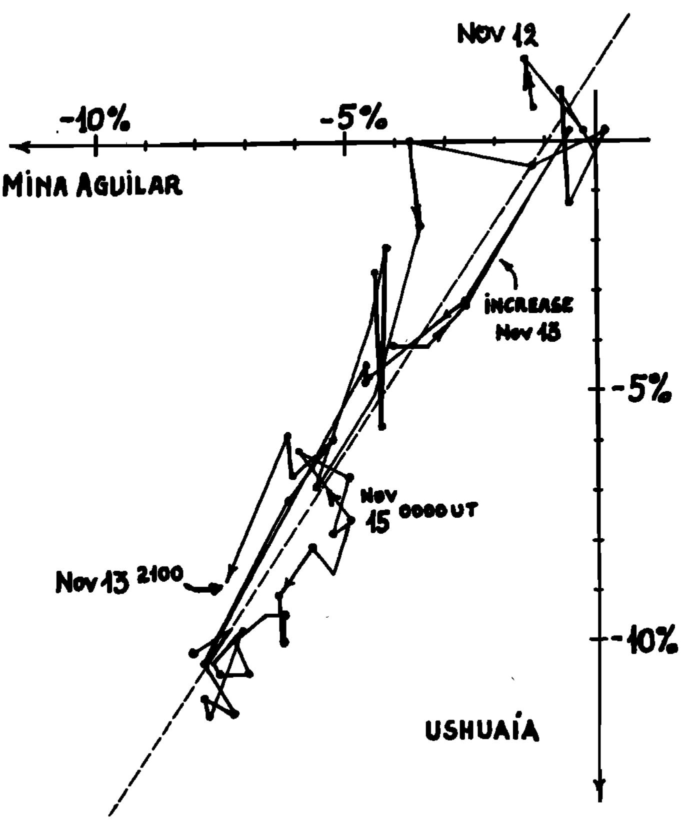

Fig. 5. Correlation diagram of percentage intensity variations between Mina Aguilar and Ushuaia.

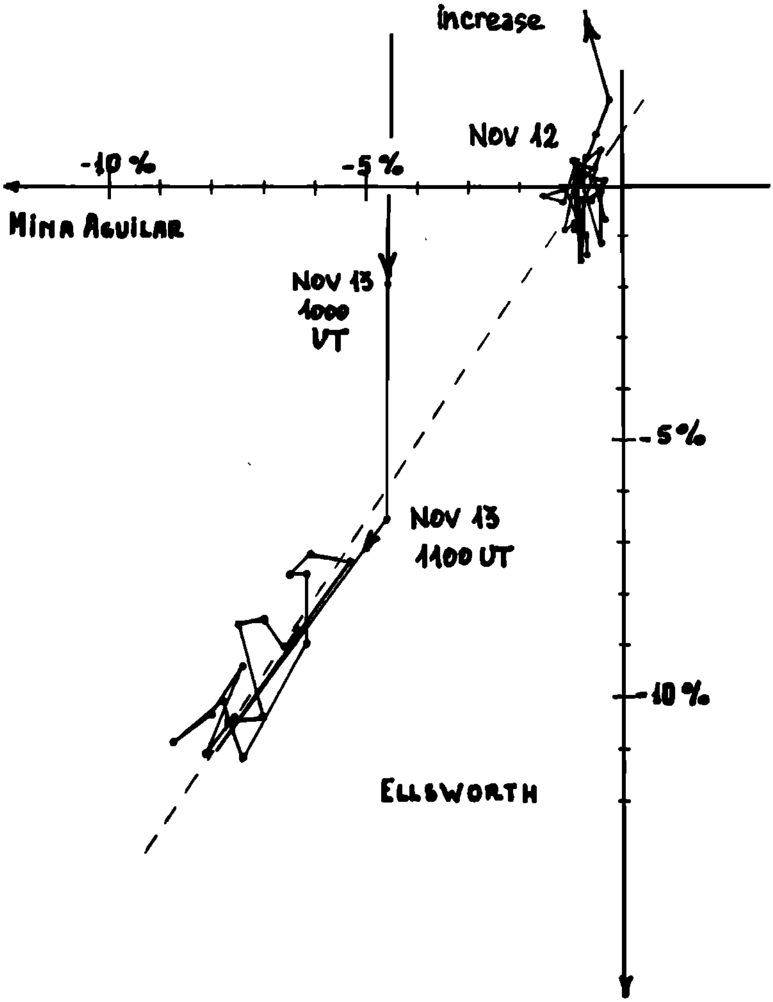

Fig. 6. Correlation diagram of percentage intensity variations between Mina Aguilar and Ellsworth.

sity time-dependence shows again a strong local character.

In Figure 4 we have normalized the intensity of different stations during interval (*b*). In this way we get an even clearer picture of the three different intervals. All stations coincide remarkably during the main decay period. Notice the change in slope occurring around 2300 UT, November 12. At 1100 UT on November 13, a sharp decrease of the intensity occurs, coincident with the arrival of a second magnetic cloud.

3. *The intensity decreases at low and intermediate latitudes.* The correlation diagram of hourly values between Mina Aguilar and Ushuaia is given in Figure 5 for the whole period. No change in the slope of the difference vectors is revealed. According to *Roederer, Santochi, Anderson, Cardoso, and Manzano* [1960], this is an indication that no change occurred in the primary variation spectrum, i.e., that the same Forbush-type mechanism was responsible for all variations including the sharp increase on the 13th. With respect to the high latitude station Ellsworth, which showed the solar increases, correlation diagram with the equatorial station Mina Aguilar is shown in Figure 6. The increase of the 12th falls outside. Notice that at 1100 UT on the 13th, the intensity of the high latitude station falls sharply into the region

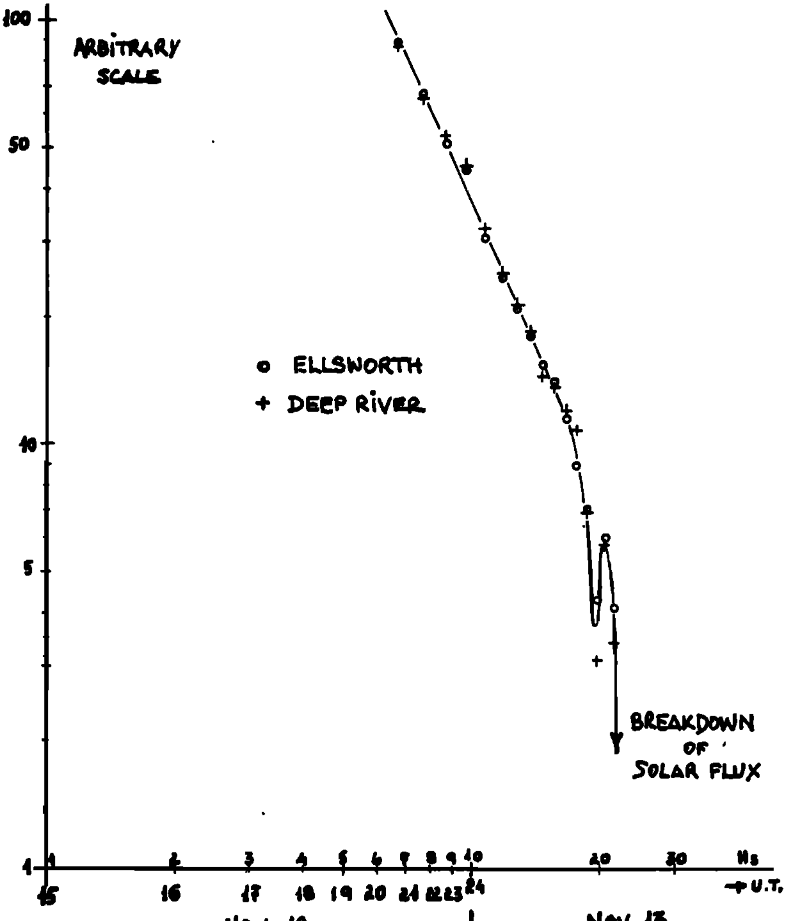

Fig. 7. Decreasing part of the solar flux of November 12, corrected for Forbush decrease and normalized, plotted on a logarithmic scale.

around the 'Forbush line.' The same behavior is observed in the correlation diagrams of Mina Aguilar with other high latitude stations. This is a proof that solar particles suddenly disappear at about 1100 UT, in coincidence with the arrival of the cloud responsible for the sharp intensity decrease at all stations.

We suggest that this cloud—responsible for the SC storm at 1021 UT, and which might have been expelled by the sun in association with the 3^+ flare of the 12th, being emitted into the previous magnetic bottle of depressed galactic flux but full of low energy solar particles—sweeps away these solar particles, bringing the intensity at high latitudes down to the Forbush-decrease level.

If we then suppose that the intensity at high latitudes is a linear superposition of the Forbush-type modulated galactic radiation, plus low-energy solar particles, we may eliminate the Forbush-decrease contribution, obtaining the pure solar injection. This has been done for Ellsworth and Deep River, estimating the Forbush-decrease contribution from Mina Aguilar data and taking into account the latitude dependence of the decrease. Normalizing the Deep River and Ellsworth curves in the interval (b) (section 2), we obtain the curve of Figure 7. The change in slope disappeared, and the solar flux time dependence from November 12, 1900 UT, to November 13, 0315 UT, can be fitted quite well with a power law of the type

$$I \sim t^{-2.3}$$

where t is the time in hours elapsed after November 12, 1345 UT. Extrapolating the curve to earlier hours, we may get an idea of the order of magnitude of the increase that would have been detected if the earth was sitting in the magnetic bottle already at the time of the flare. A peak as high as of about 6000% would have been registered at Ellsworth.

4. *The particle injection on November 15.* It can be seen from Figure 2 that the flare increase on November 15 has a shorter rise time and a shorter duration than the November 12 event. Considering the higher western heliographic longitude of the flare, this is in agreement with the conclusions of *McCracken and Palmeira* [1960] and *Obayashi and Hakura* [1960*a*] regarding the shape and duration of cosmic-ray flare increases.

According to preliminary data received from some stations around the world, there is evidence for the existence of well defined impact zones on the earth for this event. These impact zones, however, are not consistent with particles coming from the direction of the sun. We can get a better agreement if we consider the impact zones for particles coming from a direction making an angle of 60–70 degrees west of the sun-earth line. Similar conclusion was reached by McCracken and Palmeira (unpublished) for the May 4, 1960, flare increase, suggesting the presence of a twisted interplanetary magnetic field at the time of the increase.

Acknowledgments. We wish to express our gratitude to the Argentine National Commission for Space Research for the invitation to the Symposium on Space Research, during which this paper was conceived. We also want to thank the following investigators who promptly supplied us with their cosmic-ray data: J. A. Simpson, T. Thambyahpillai, H. Carmichael, and J. A. Lockwood. In addition we would like to thank the following participants of the Buenos Aires Symposium who presented further data on the November events: W. Rense, A. Shapley, T. Hatanaka, J. Hernandez, N. Mesterman, and S. Radicella. The prompt transmission of Ellsworth data was possible only because of the efficient collaboration of Mr. R. Rastelli.

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(Manuscript received February 9, 1961; revised March 17, 1961.)