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COSMIC RAY PHENOMENA DURING THE NOVEMBER 1960 SOLAR DISTURBANCES

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ABSTRACT

A preliminary analysis of Cosmic Ray data obtained with some neutron monitors during the Nov. 1960 solar disturbances is presented. The first increase on Nov. 12 is attributed to generation of particles on the sun, following a class 3^+ flare. A second increase on Nov. 12 is interpreted as the arrival at the earth of 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 Nov. 15 is attributed to a new generation of high energy particles by another class 3^+ flare which occurred on the same solar active region. The characteristics of the solar flare increases are shown to be in agreement with the conclusions of McCracken and Palmeira, regarding the propagation of solar particles in the interplanetary space. Data from low latitude stations are used to investigate the Forbush decreases, and their relation with the other solar and terrestrial events.

* * *

I - INTRODUCTION

This paper is based on an exchange of data and ideas at the Symposium on Space Research 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, the results presented here are of preliminary character.

However, the data already available indicate the importance of these events, principally that of November 12, where a chance superposition of the flare increase and a Forbush decrease offers an unique opportunity for studying the interaction of the two mechanisms responsible for these two effects on the cosmic ray intensity.

Table I shows the principal solar and terrestrial events which occurred in the period Nov. 10 - Nov. 15, 1960. All flares here presented, with the exception of the Nov. 13 flare, occurred in the region 5925 which had its central meridian passage on Nov. 12. The indicated association of the sudden commencement magnetic storm and the Forbush decreases with a particular solar flare seems to us the most plausible one

Fig. 1 shows hourly cosmic ray percentage intensity variations refered to a quiet prestorm level, recorded with neutron monitors at the south-american continental stations Chacaltaya (13.5 BV geomagnetic cutoff rigidity, 5.200 m above s.l.), Rio de Janeiro (11.5 BV, s.l.), (Data from Buenos Aires (10.7 BV, s.l.) coincide within statistical fluctuations with the latter), Mina Aguilar (12.5 BV, 4000 m above s.l.), and Ushuaia (5.9 BV, 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 Fig. 2 quarter-hourly neutron monitor intensity data recorded at Ellsworth, Antarctica are represented. A double--peak increase occurs on the 12th; the increases on the 15th has a simpler structure. A more detailed picture of the intensity behaviour is shown in Fig. 3, where [illegible]-minute data are shown for Ellsworth. Notice the "fine structure" in intensity variations, which also appeared at other stations which detected these increases.

II - 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 flares of the 12th we find Ellsworth lying in the 09 zone. Other stations, however, like Yakutsk, Uppsala and London, which reported increases, do not fit into the picture of impact zones.

This is what to be expected according to McCracken and Palmeira (1960) and 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 1030 UT.

Considering the close time association between this Forbush decrease and the start of the second solar increase of the 12th we may tentatively assume this additional radiation, to be an almost isotropic low energy flux of solar particles, trapped by the magnetic cloud, and therefore detected only when this cloud engulfes the earth.

In Fig. 4 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 the time elapsed from the begining of the first increase. We can divide the period into three intervals, according to the peculiar intensity time behaviour:

a) Nov. 12, 1345 - 1900 UT, corresponding to the first increase, and showing a time behaviour which varies from station to station. Taking coupling functions given by Webber and Quenby (1959) and cutoffs rigidities given by Quenby and Webber (1959) we get from the latitude effect at the maximum (1700 UT) a primary variation spectrum relative to the normal spectrum, of the form:

$$\delta j/j \propto p^{-(6.0\pm0.5)}$$

where p is the magnetic rigidity. This form changes rapidly in time during this interval.

b) Nov. 12, 1900 - Nov. 13, 0315 UT: corresponding to the second increase and following intensity decay. All stations show a remarkable parallel time behaviour, the ratio of intensities of any pair of different stations remaining constant throughout this interval. Assuming that no appreciable change in the magnetic cutoffs occurred, we get for the form of the relative variation spectrum of the additional radiation:

$$\delta j/j \propto p^{-(4.5\pm0.5)}$$

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 cut-offs were appreciably changed by the plasma cloud, (Obayashi and Hakura, 1960 b) so to invalidate the above calculation.

A further argument for this cutoff decrease is the fact that magnetic field intensity at higher latitudes showed an important increase coincident with the second cosmic rays intensity peak on Nov. 12.

c) Nov. 13, after 0315 UT: the intensity time dependence shows again a strong local character.

In Fig. 5 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 occuring around 2300 UT, Nov. 12. At 1100 UT on Nov. 13, a sharp decrease of the intensity occurs, coincident with the arrival of a second magnetic cloud.

III - THE INTENSITY DECREASE AT LOW AND INTERMEDIATE LATITUDES

The correlation diagram of hourly values between Mina Aguilar and Ushuaia is given in Fig. 6 for the whole period. No change in the slope of the difference vectors is revealed. According to Roederer et al. (1960), this is an indication that no change occurs in the primary variation spectrum, i.e. that the same Forbush-type mechanism is responsible, 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 Fig. 7. The increase of the 12th falls outside. Notice that at 1100 UT on the 13th, the intensity of the high latitude stations falls sharply into the region around the "Forbush line". The same behaviour is observed in the correlation diagrams of Mina Aguilar with the other high latitude stations. This is a proof that the solar particles disappear at about 1100 UT, in coincidence with the arrival of the cloud responsible for the galactic intensity decrease.

We suggest that this cloud responsible for the S. C. at 1021 UT, and which may have been expelled by the sun in association with the 3^+ flare of the 12th, being emitted into the previous magnetic region of depressed galatic flux but full of low energy solar particles, sweeps away these solar particles, bringing the intensity at high latitude 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 galatic 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 II), we obtain the curve of Fig. 8. The change in slope disappeared, and the solar flux time dependence from Nov. 12, 1900 UT, can be fitted quite well with a power law of the type I $t^{-2.3}$ where t = time in hours elapsed after Nov. 12, 1345 UT.

IV - PARTICLE INJECTION ON NOVEMBER 15

It can be seen from Fig. 2 that the flare increase on Nov. 15, has a faster rise time and is of a shorter duration than the Nov. 12 event. Considering the higher western heliographic longitude of the producing 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 the cosmic ray flare increase. There are however considerable short-time fluctuations during the beginning of this increase.

According to preliminary data received from same 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 4th flare increase.

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Flare					Associated Storm	
Importance	Time	Heliographic Position	Mayor Radio Burst	Solar Cosmic Rays	SC Magnetic Storm	Forbush Decrease
3	Nov. 10, 10:00-14:00	28° N, 28° E	yes	none	Nov. 12, 13:48	Nov. 12, 19:30
3^+	Nov. 12, b 13:25-19:22	26° N, 04° W	Type IV	starting 13:30	Nov. 13, 10:21	Nov. 13, 10:30
2^+	Nov. 13, 13:15-13:50	23° N, 59° E	none	none	none	none
2	Nov. 14, b 00:15-01:00	31° N, 14° W	none	none	none	none
2^+	Nov. 14, 02:46-05:20	27° N, 19° W	Type IV	none	Nov. 15, 13:04	Nov. 15, 13:30
3^+	Nov. 15, 02:07-04:27	26° N, 33° W	Type IV	starting 02:30	none	none

TABLE I: Solar and terrestrial events in the period November 10 - 15, 1960.

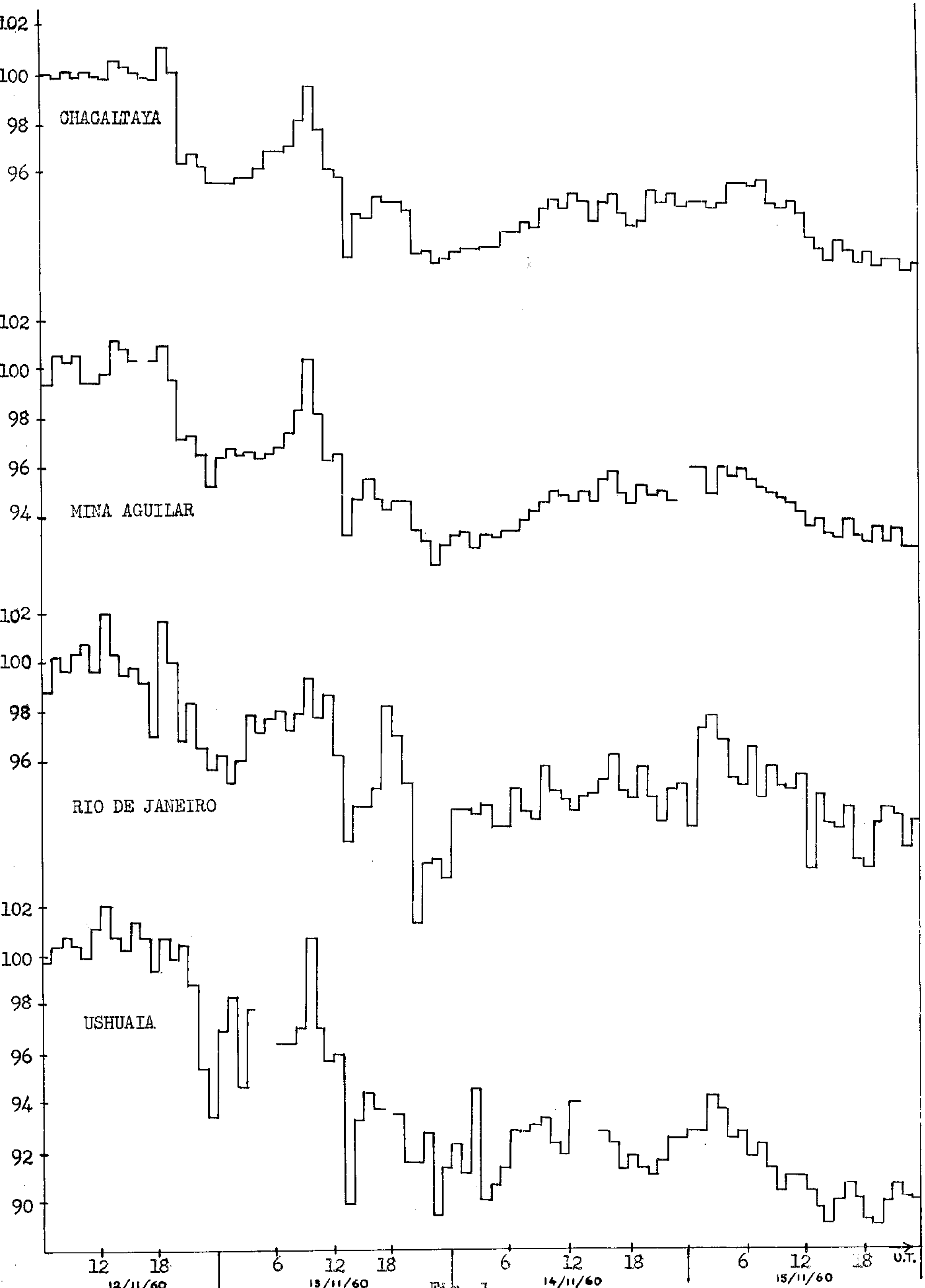
CHACALTAYA
MINA AGUILAR
RIO DE JANEIRO
USHUAIA
102
100
98
96
94
92
90
12
18
6
U.T.
12/11/60
13/11/60
14/11/60
15/11/60

Fig. 1

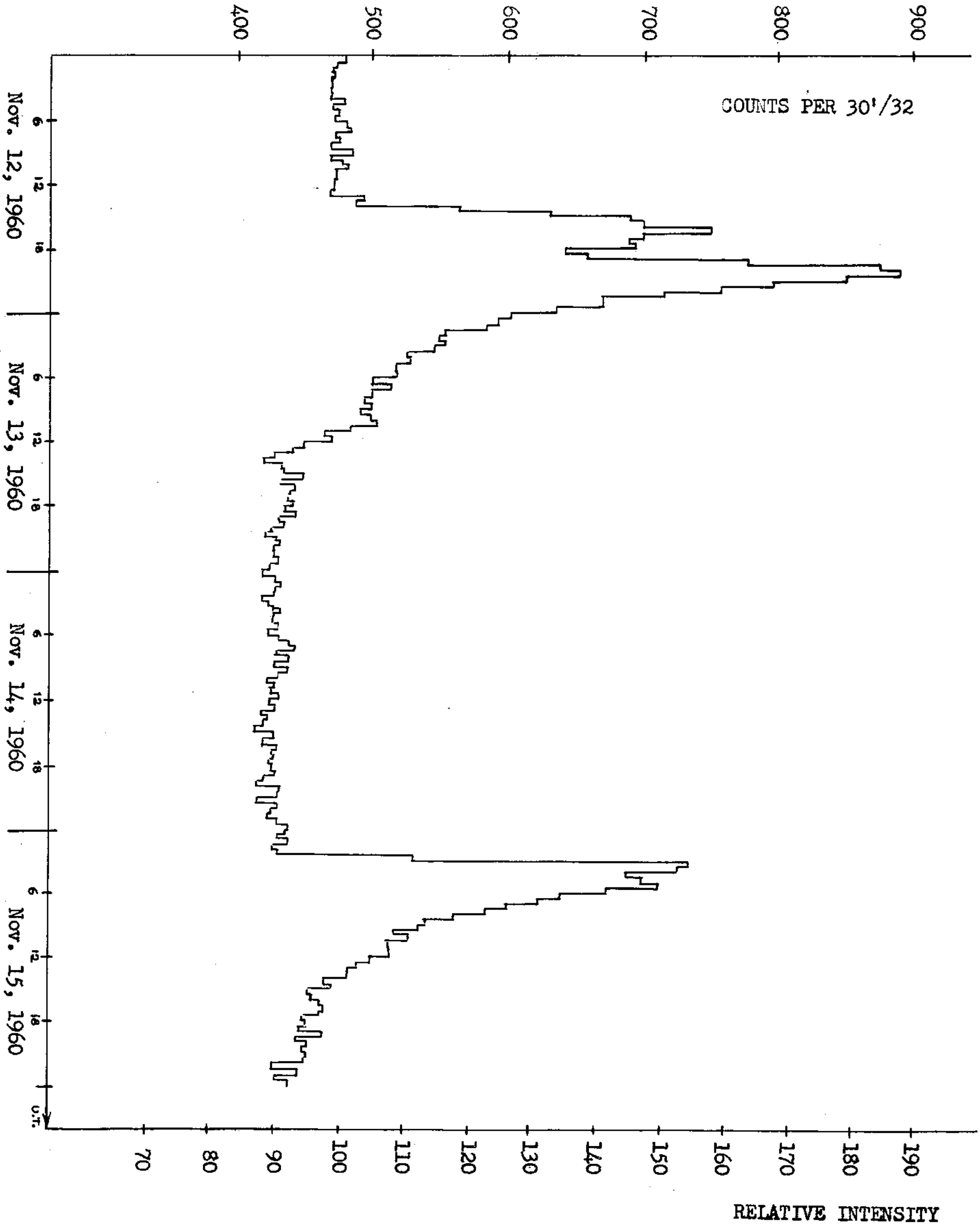
COUNTS PER 30'/32
400
500
600
700
800
900
Nov. 12, 1960
Nov. 13, 1960
Nov. 14, 1960
Nov. 15, 1960
U.T.
70
80
90
100
110
120
130
140
150
160
170
180
190
RELATIVE INTENSITY

Fig. 2

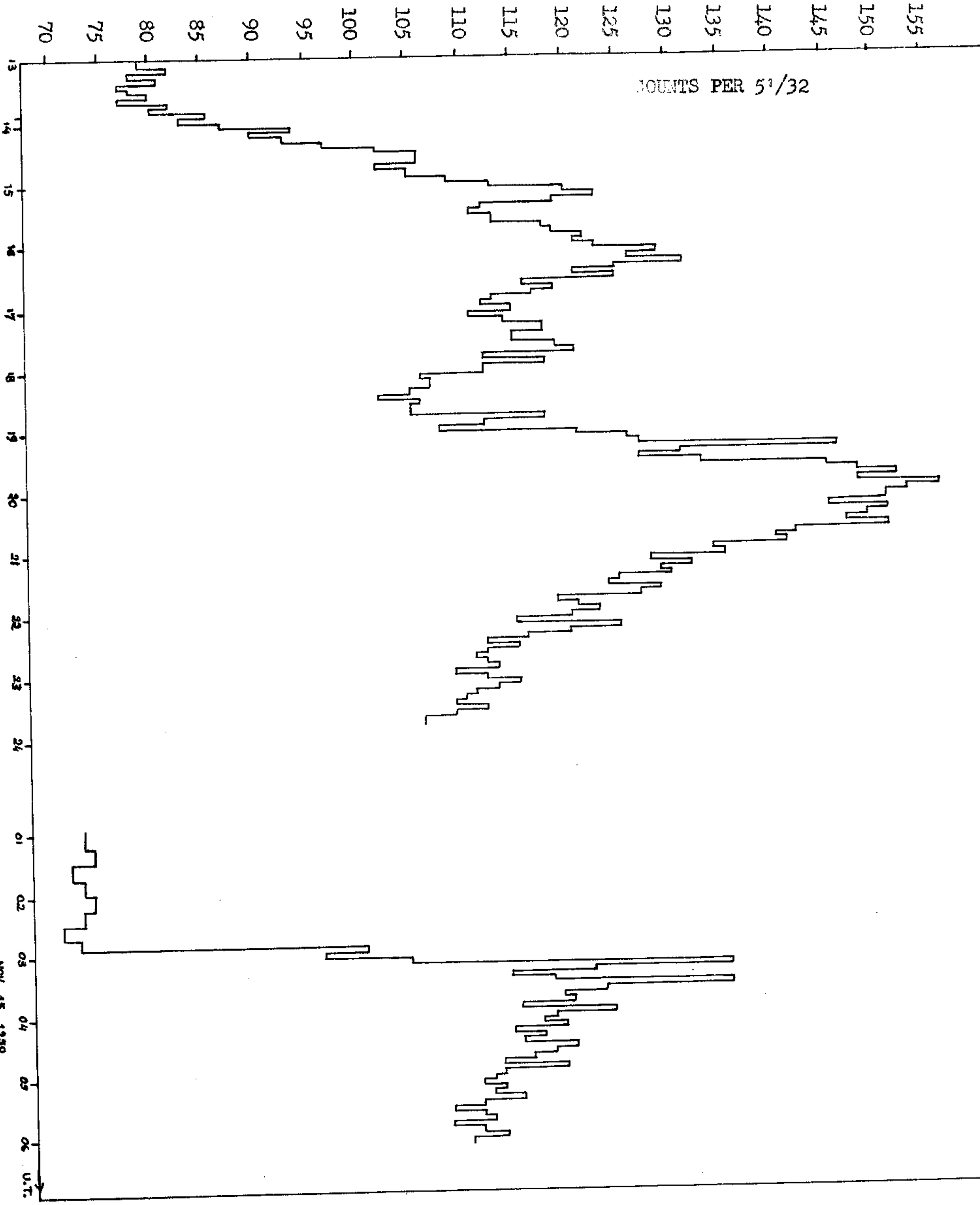
OUNTS PER 5¹/32
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
NOV. 12, 1960
U.T.

Fig. 3

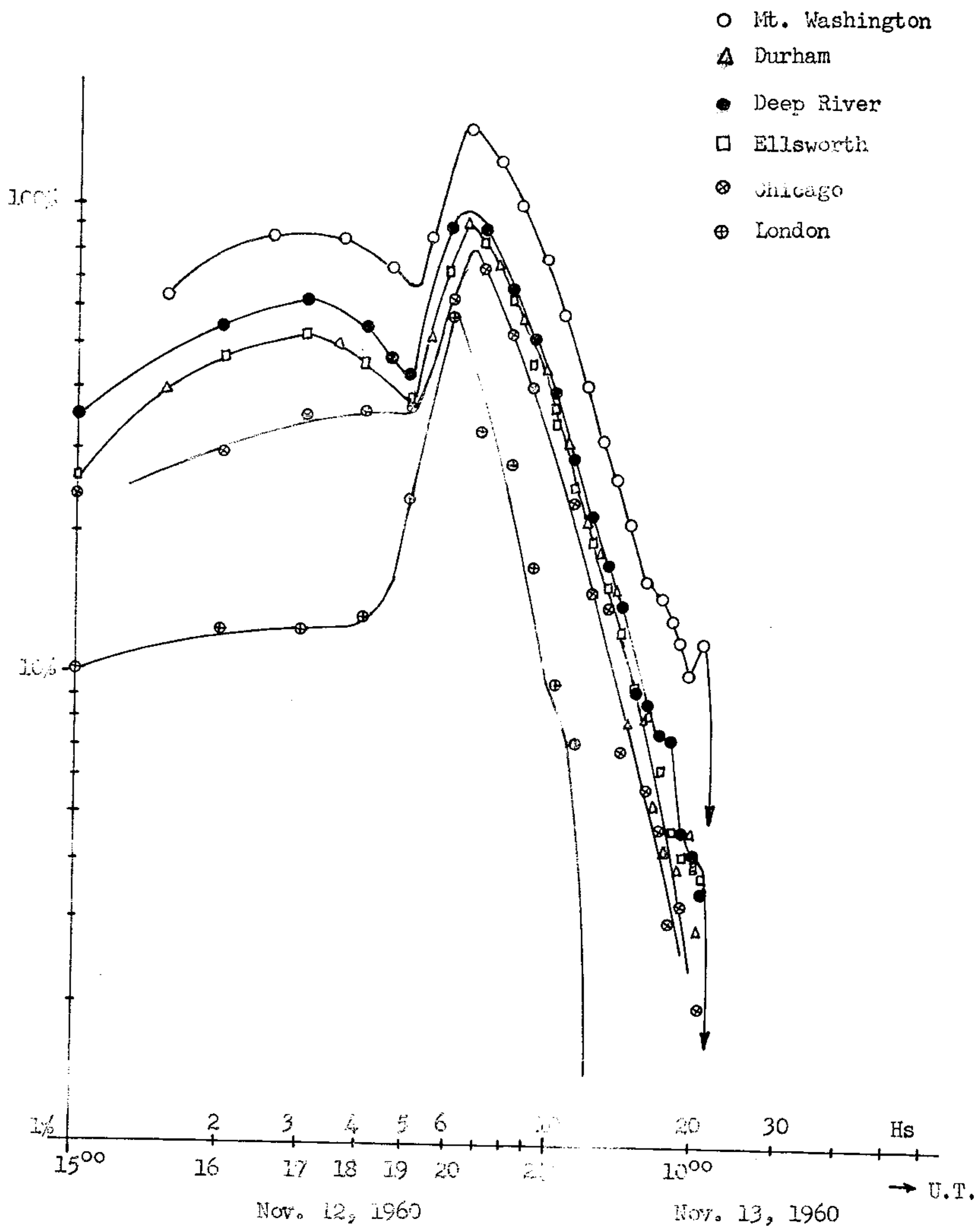
Mt. Washington
Durham
Deep River
Ellsworth
Chicago
London
100%
10%
1%
2
3
4
5
6
20
30
Hs
15⁰⁰
16
17
18
19
20
10⁰⁰
→ U.T.
Nov. 12, 1960
Nov. 13, 1960

Fig. 4

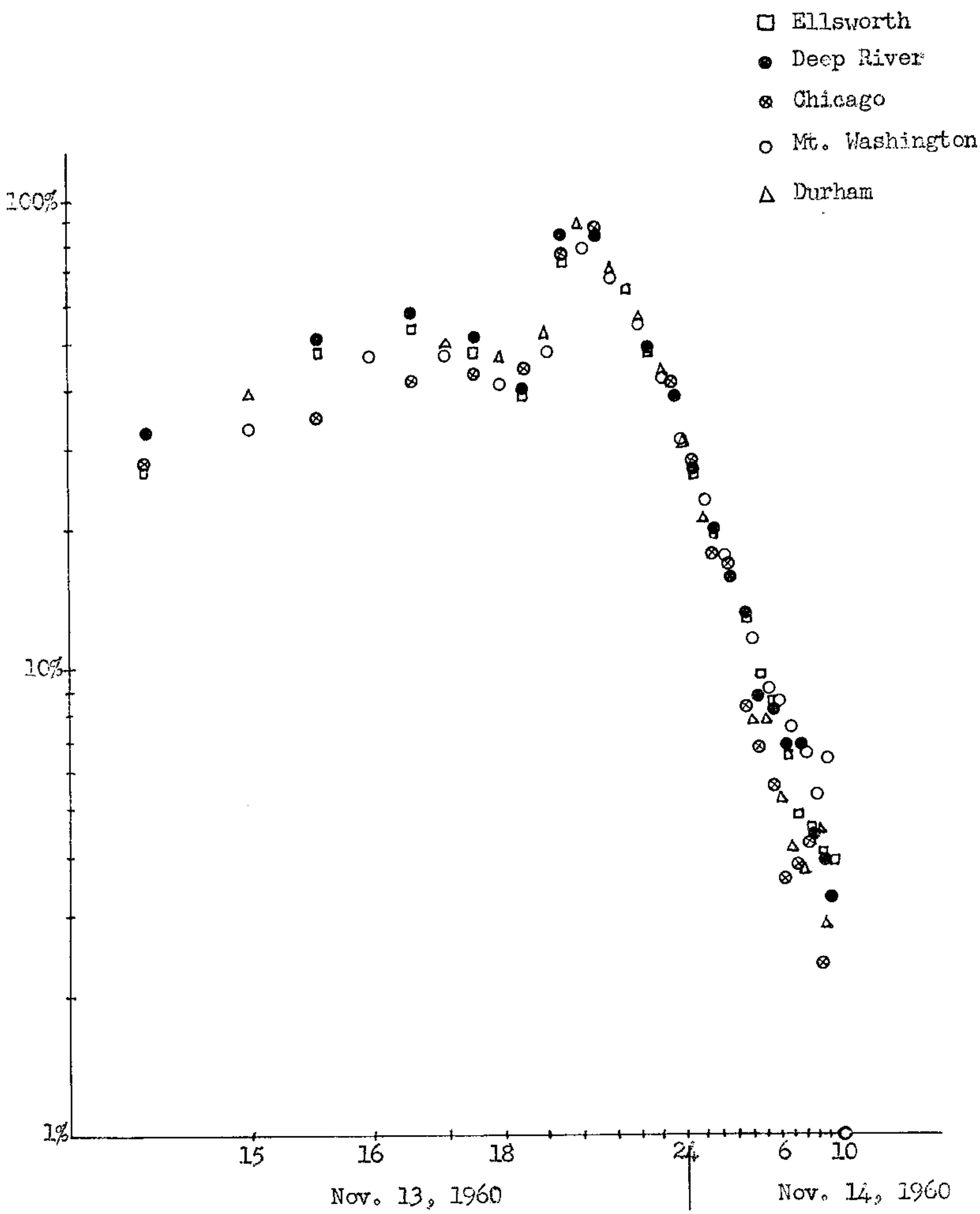
Ellsworth
Deep River
Chicago
Mt. Washington
Durham
100%
10%
1%
15
16
18
24
6
10
Nov. 13, 1960
Nov. 14, 1960

Fig. 5

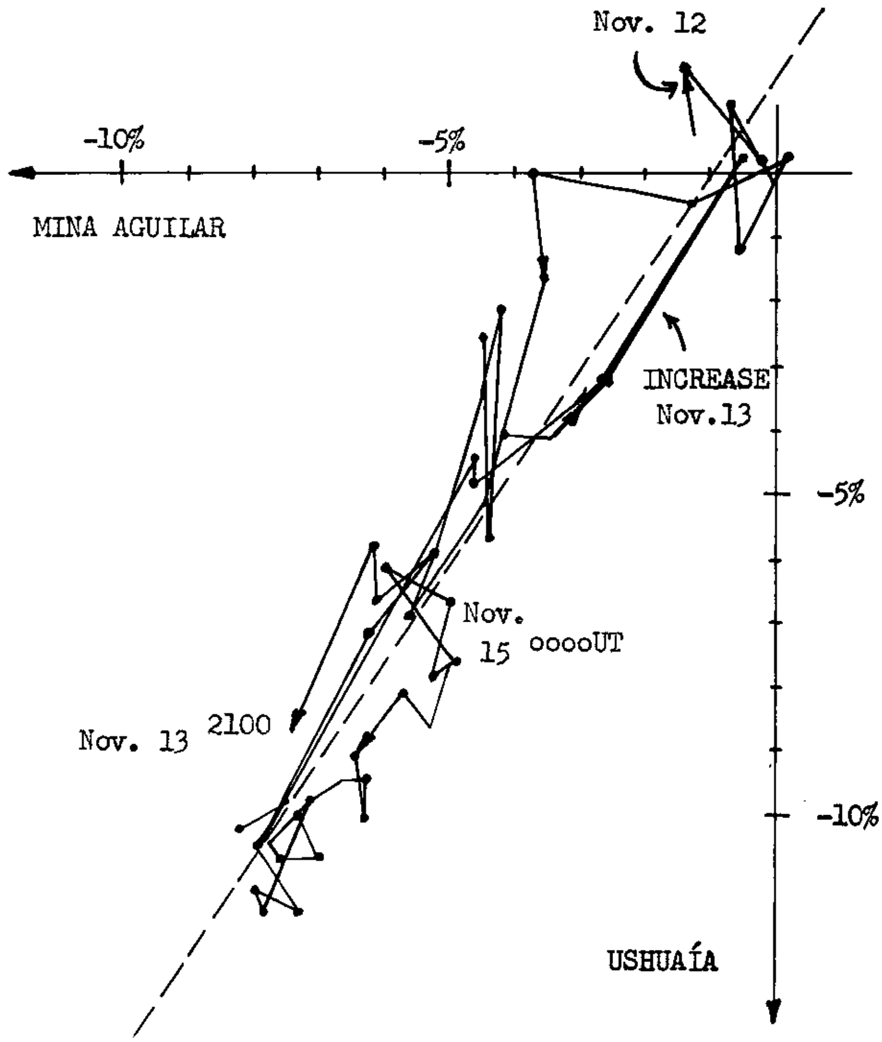
Nov. 12
-10%
-5%
MINA AGUILAR
INCREASE
Nov.13
-5%
Nov.
15 0000UT
Nov. 13 2100
-10%
USHUAÍA

Fig. 6

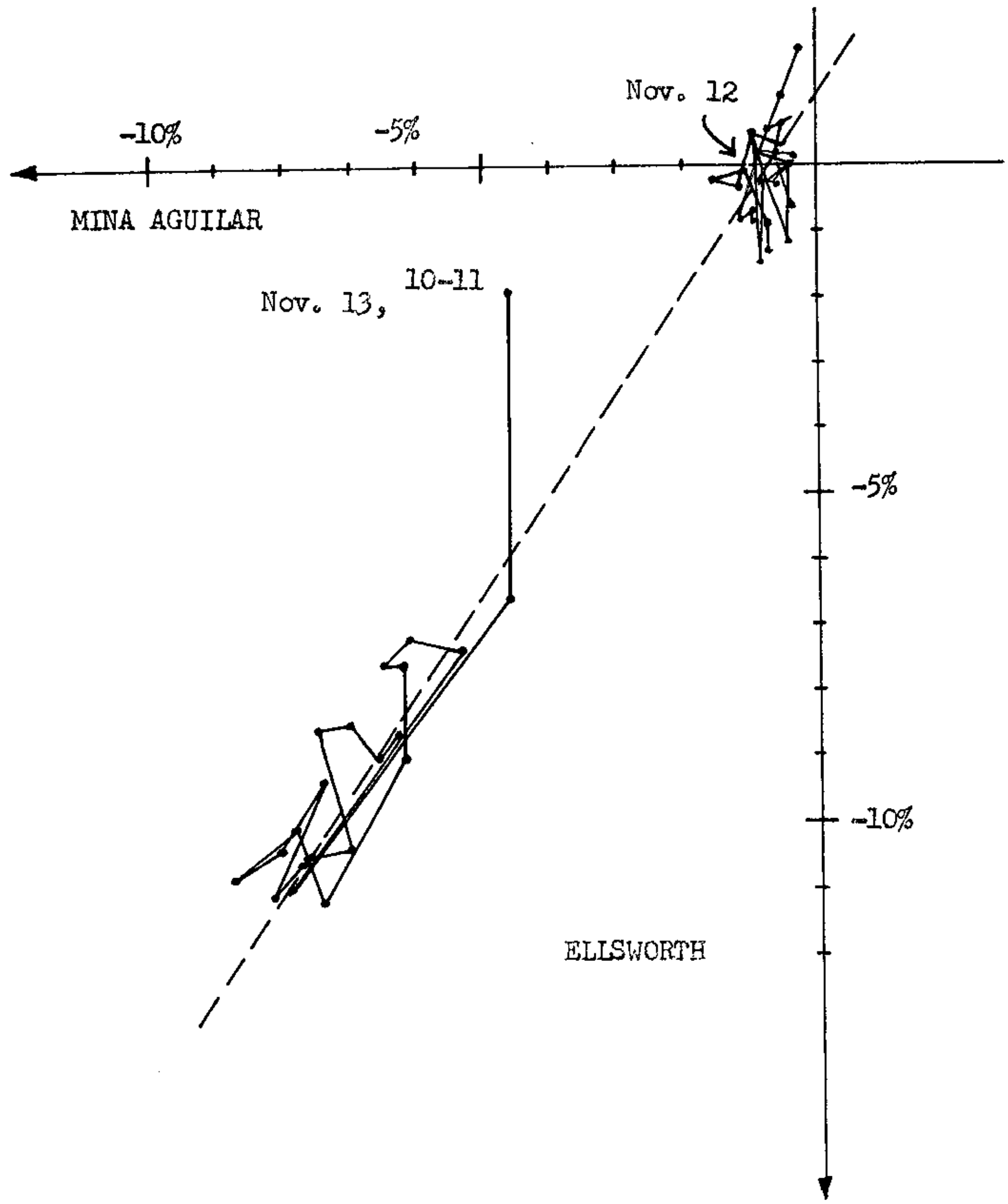

Fig. 7

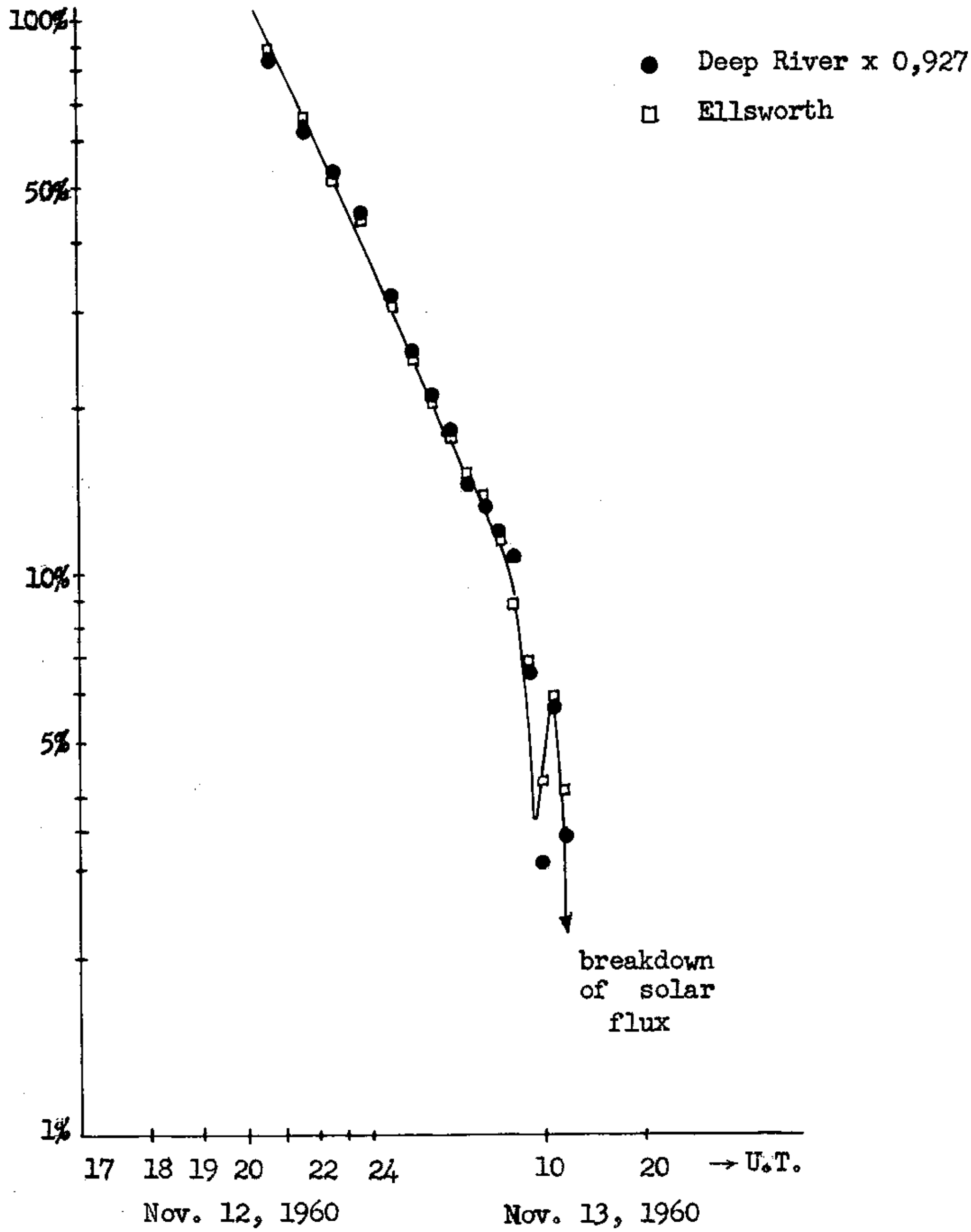
100%
50%
10%
5%
1%
Deep River x 0,927
Ellsworth
breakdown of solar flux
17 18 19 20 22 24 10 20 → U.T.
Nov. 12, 1960
Nov. 13, 1960

Fig. 8

FIGURE CAPTIONS

Fig. 1 - Hourly percentage intensity values for 4 south-american neutron monitors.

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

Fig. 3 - Ellsworth neutron monitor 5-minutes intensity values for the increases of Nov. 12 and Nov. 15.

Fig. 4 - Hourly-values of relative intensity, plotted on a logaritmic scale, for the Nov. 12 increase, for high latitude neutron monitors.

Fig. 5 - Same data as for fig. 4, normalised during the decay period.

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

Fig. 7 - Correlation diagram of percentage intensity variations between Mina Aguilar and Ellswort.

Fig. 8 - Decreasing part of the solar flux of Nov. 12, corrected for Forbush decrease, plotted on a logaritmic scale.

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