The Development of the Forbush Decrease and the Geomagnetic Storm Fields+

by

S. Yoshida* and S.-I. Akasofu

December 1965

Department of Physics and Astronomy
University of Iowa
Iowa City, Iowa

*Geophysical Institute, University of Alaska, College, Alaska.

+Research supported in part by grants from the National Aeronautics and Space Administration to the University of Alaska (NsG 201-62) and to the University of Iowa (NsG 233-62).

ABSTRACT

Relationships between the development of Forbush decreases and characteristics of associated geomagnetic storm fields are examined. It is shown that the onset of a significant Forbush decrease is more closely related to the development of successive sudden impulses or world-wide geomagnetic micropulsations during geomagnetic storms than to a simple step function-like storm sudden commencement. The magnitude of the main phase decrease shows no obvious relation with the magnitude of the Forbush decrease.

1. INTRODUCTION

A considerable amount of work has been done in the past on the characteristics of the Forbush decrease during geomagnetic storms [cf. Dorman;(1) Sandström;(2) Roederer(3)]. They have confirmed that the Forbush decrease begins at about the onset time of a geomagnetic storm (namely, of the storm sudden commencement). Unfortunately, however, little attention has been paid to the problem as to how the development of the Forbush decrease is related to the geomagnetic storm fields that develop after the sudden commencement. Since characteristics of geomagnetic storms differ greatly from one to the other,(4) it is worthwhile to examine in detail this problem for individual cases.

2. THE FORBUSH DECREASE AND INTENSE ACTIVITY OF SUDDEN IMPULSES

In this section, we demonstrate that a significant Forbush decrease develops if geomagnetic storms are accompanied by intense activity of sudden impulses (abbreviated by si). For this purpose, we have chosen here geomagnetic storms whose onsets are characterized by a simple step function-like storm sudden commencement (abbreviated by ssc) and are then followed by intense si activity.

a. The Forbush decreases during the geomagnetic storm of April 23/24, 1959

The storm began with a fairly simple ssc at $10^h\ 36^m$ UT on April 23 and reached the maximum epoch at about 21-22 UT. A little before the maximum epoch, $19^h\ 30^m$ UT, intense si activity began; their world-wide occurrence can be seen in Figure 1a which shows a collection of magnetic records (the H component) from seven stations widely separated in longitude. Figure 1b shows the variation of the cosmic ray (neutron) intensity during the storm at five stations from the polar region, Thule, Resolute Bay, Murchison Bay, Mawson, and Hiffiss Is ; the reason for choosing the polar stations is that their records are less seriously affected by the deformation of the magnetosphere due to the growth of the ring current.(5) Further, in order to eliminate the effects of the abnormally enhanced daily variation,(6) their average variation is obtained to examine only its world-wide variations.

The average variation of the cosmic ray intensity thus obtained indicates that the Forbush decrease associated with the ssc at $10^h\ 36^m$ UT was very weak. However, the decrease was notably enhanced after $19^h\ 30^m$ UT, when the intense si activity began.

b. The Forbush decrease during the geomagnetic storm of June 27/28, 1960

The geomagnetic storm of June 27/28, 1960, was also accompanied by intense si activity well after its onset (Figure 2). The variation of the cosmic ray intensity corresponding to the same period is obtained by averaging the neutron intensity measured by Deep River(7) ($P_c \simeq 1.3$ BV) and Uppsala(8) ($P_c \simeq 1.3$ BV). The Forbush decrease associated with the ssc (at $01^h\ 45^m$ UT on June 27) reached the maximum intensity ($\sim 2\%$) at about $10^h \sim 11^h$ UT on June 27 and began to recover at 12^h UT. However, a new Forbush decrease began at about $16^h\ 10^m$ UT, simultaneous with the onset of intense si activity; it became more intense after 21^h UT, reaching its maximum intensity at about 02^h UT on June 28. The magnitude of the maximum decrease after the si activity was much greater (6.5%) than that associated with the very clear ssc (2%).

There are a number of other excellent examples of this type; among them are the geomagnetic storm of January 21, 1957; September 2, 1957; September 28, 1957; February 10, 1959; January 11, 1960; May 8, 1960; July 14, 1960; and December 1, 1961.

We note that in most of the earlier studies of the Forbush decrease only the onset time of ssc was noted, so that the Forbush decrease during geomagnetic storms was simply associated with the storm sudden commencement; for example, in the second example, the 6.5% decrease was considered to be associated with the ssc at $01^h\ 45^m$ UT, and no consideration has been made to examine how the various geomagnetic storm fields that follow the ssc are related to the decrease.

3. THE FORBUSH DECREASE AND INTENSE GEOMAGNETIC PULSATIONS

In this section, we are concerned with much more rapid changes of the geomagnetic field than si's. When quick-run magnetic records are examined, such changes appear to be oscillatory (rather than a succession of si's), so that they are called geomagnetic micropulsations.

a. The Forbush decreases during the geomagnetic storms of September 21/22, 1946

Figure 3 shows three successive geomagnetic storms which occurred on September 21/22, 1946, and associated changes of the cosmic ray intensity.(9) The first storm was characterized by a fairly simple ssc (17^h 13^m UT on September 21) and an initial phase, but without any significant main phase; the second storm developed the main phase after the ssc (04^h 23^m UT on September 22). The third storm began at 10^h 12^m UT on September 22, a little after the maximum epoch of the second storm. The third storm field was characterized by intense geomagnetic micropulsations; note that in the San Juan record the H magnetic trace between 13^h 30^m and 15^h 00^m is not clearly seen because of extremely intense pulsations. The same micropulsation activity was recorded at other stations, such as Greenwich and Kakioka (Japan), so that it had a world-wide extent.

The cosmic ray variation during the storms shows that the first two storms were not associated with a clear-cut Forbush decrease, but a significant decrease occurred during the third storm.

b. The Forbush decrease during the geomagnetic storm of May 12, 1949

The geomagnetic storm of May 12, 1949, was accompanied by intense fluctuations of the geomagnetic field at about the maximum epoch of the main phase, $15^h\ 50^m$ UT (Figure 4). The simultaneous cosmic ray intensity variation (meson)[9] shows that the decrease associated with the micropulsations is more significant than that associated with the ssc ($06^h\ 40^m$ UT). The geomagnetic storm of July 17, 1959, is also an excellent example of this type; it was accompanied by intense micropulsations of period of order 4 minutes.

4. THE FORBUSH DECREASE AND THE MAIN PHASE DECREASE

As early as 1938, Forbush[10] noted that the intensity of the decrease has no relation with the magnitude of the main phase. This can be demonstrated in two ways. First of all, it is not difficult to show that geomagnetic storms without any significant main phase decrease are often associated with a large Forbush decrease (the geomagnetic storms of May 11, July 11, and August 20, 1959; the first storm will be discussed in the next section). Secondly, there are a number of geomagnetic storms which are not preceded by ssc but have a significant main phase; thus, they can be used to examine relationships between the main phase decrease and the Forbush decrease without 'contamination' of the ssc effect.[11] For this purpose, twelve well developed Sg storms (the main phase decrease of more than 50 γ) during the IGY were examined, and none of them were found to be associated with any appreciable Forbush decrease. It may be noted also that one of the most intense Sg storms, the storm of April 23, 1960, was not associated with the Forbush decrease, although the magnitude of the main phase decrease was as large as 200 γ.[11] The following table shows the characteristics of the twelve Sg storms.

Storm Onset		Maximum Dst Decrease
02 UT	August 13, 1957	73 γ
18	October 1, 1957	51
04	October 10, 1957	57
18	October 20, 195	53
09	November 3, 1957	50
00	March 12, 1958	79
12	March 30, 1958	66
11	April 4, 1958	71
11	May 26, 1958	52
19	June 29, 1958	83
12	November 2, 1958	82
09	November 25, 1958	79

5. DISCUSSION

It is not difficult to infer from the above study that when the onset time of a large Forbush decrease coincides approximately with the ssc of the associated geomagnetic storm, the ssc is often followed by either intense si activity or micropulsations, or by both. The May 11, 1959, storm provides an interesting example; the Forbush decrease began at about the time of the ssc and reached the maximum decrease of order 12% (Figure 5). First of all, the storm was caused by an intense flare at $20^h\ 55^m$ UT on May 10 at 47° E, 23° N on the solar disk. As Sinno(12) and Haurwitz, Yoshida, and Akasofu(13) have shown, the decreases of more than 10% are mostly caused by eastern flares and central flares, but not by far western flares. Secondly, the ssc was soon followed by si and micropulsation activities and was not a step function like ssc. Thirdly, the storm was not associated with a significant main phase decrease, so that this is another way to prove that the main phase decrease is not related to the Forbush decrease. Finally, the Forbush decrease lasted until as late as May 23 or for about 10 days, although the magnetic activity was much reduced at the end of May 12.

Intense si activity contains frequent and rapid world-wide changes (both positive and negative) of the horizontal component of geomagnetic field; Nishida and Jacobs[14] have shown that they have essentially the same characteristics as those of ssc. Since ssc is now interpreted as a sudden compression of the magnetosphere by an enhanced solar plasma flow, intense si activity may be interpreted as an indication of 'turbulent' flow; embedded in such a turbulent flow, the magnetospheric cavity expands or contracts, causing fluctuations of the magnetic field inside the cavity. Intense geomagnetic pulsations discussed in this paper may be interpreted as an indication of 'vibration' of the magnetosphere by a 'turbulence'.[15]

However, the fact that the Forbush decrease lasts much longer than the duration of si activity or micropulsation suggests that the 'turbulent' region of the plasma flow acts as a barrier and reduces the cosmic ray intensity behind the barrier for a long period after it passes the vicinity of the earth. The kind of interplanetary field discussed originally by Parker[16] and later by Haurwitz Yoshida, and Akasofu[13] may sometimes contain 'turbulence' which reduces the cosmic ray intensity more efficiently than a simple barrier.

ACKNOWLEDGEMENTS

We would like to thank Dr. S. Chapman and Dr. J. A. Van Allen for their encouragement during the preparation of this paper. The work presented here was supported in part by grants from the National Aeronautics and Space Administration to the University of Alaska (NsG 201-62) and to the University of Iowa (NsG 233-62).

REFERENCES

1. L. I. Dorman, Progress in Elementary Particles and Cosmic Ray Physics 1, ed. by J. G. Wilson and S. A. Wouthuysen, North-Holland Pub. Co., Amsterdam (1963).
2. A. E. Sandström, Cosmic Ray Physics, North-Holland Pub. Co., Amsterdam (1965).
3. J. G. Roederer, Research in Geophysics, ed. by H. Odishaw, The MIT Press (1965).
4. S.-I. Akasofu and S. Chapman, J. Geophys. Res. 68, 125 (1963).
5. S. Yoshida and M. Wada, Nature 183, 381 (1959).
6. S. Yoshida, Nuovo Cim. 4, 1410 (1956).
7. H. Carmichael, Weekly Report, Deep River, Canada.
8. A. E. Sandström, Pub. Uppsala Univ., Institute of Physics (1961).
9. I. Lange and S. E. Forbush, Cosmic Ray Results, Dept. Terr. Mag., Carnegie Institution of Washington, Pub. No. 175, Washington, D.C. (1957).
10. S. E. Forbush, Terr. Mag. 43, 203 (1938).
11. S.-I. Akasofu, Planet. Space Sci. 13, 297 (1965).
12. K. Sinno, J. Phys. Soc. Japan 17, Suppl. AII, 396 (1962).

13. M. W. Haurwitz, S. Yoshida, and S.-I. Akasofu, J. Geophys. Res. 70, 2977 (1965).

14. A. Nishida and J. A. Jacobs, J. Geophys. Res. 67, 525 (1962).

15. J. W. Dungey, Pub. Ionosphere Res. Lab., Pennsylvania State Univ., No. 69 (1954).

16. E. N. Parker, Interplanetary Dynamical Processes, Interscience Pub., 1963.

FIGURE CAPTIONS

Figure 1a. The horizontal component magnetic records on April 23/24, 1959, from magnetic stations widely distributed in longitude. Note intense si activity during the recovery phase of the storm.

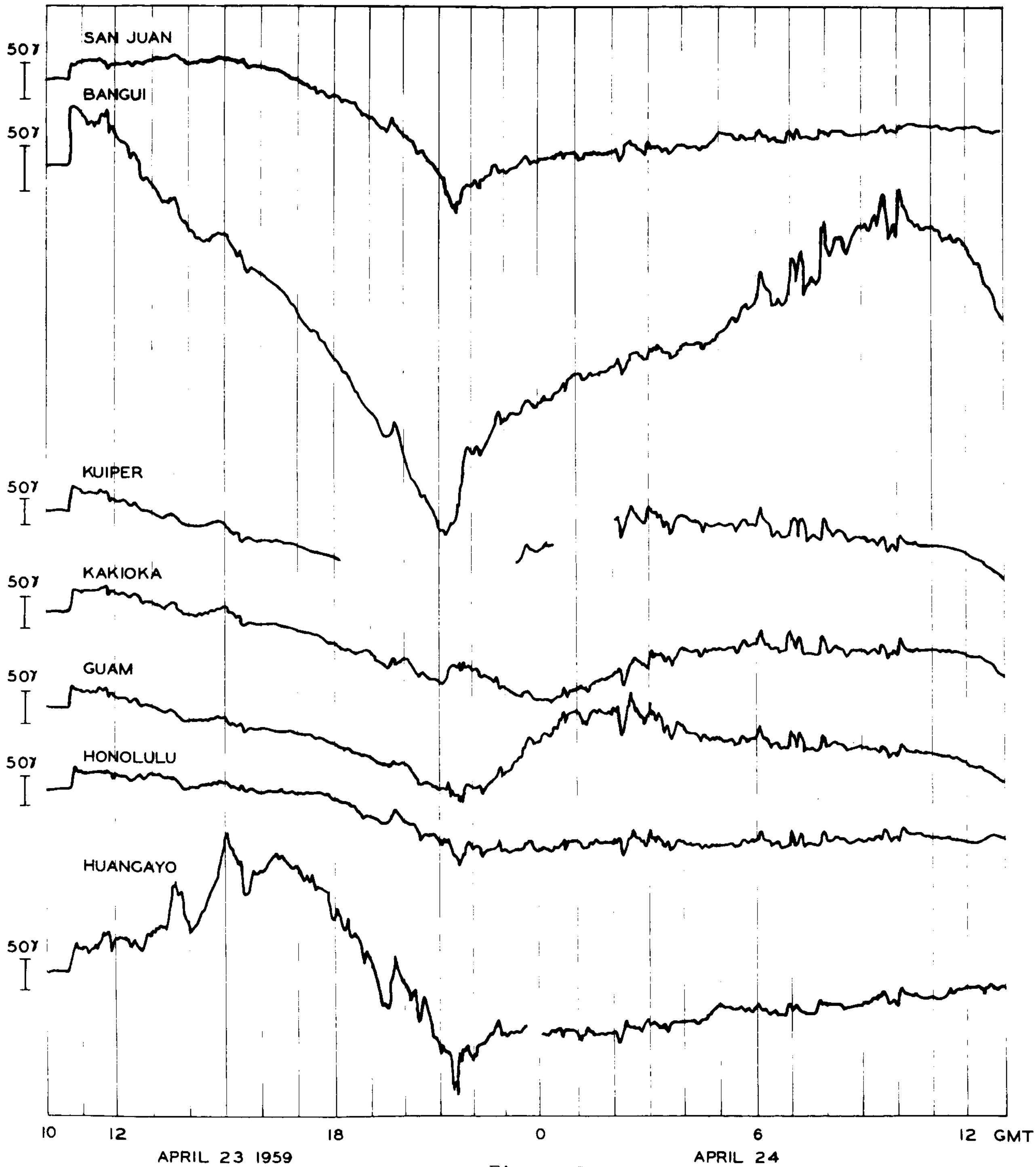
Figure 1b. The magnetic record (H, Z, D) on April 23/24 from Honolulu and the variation of the cosmic ray (neutron) intensity at Thule, Resolute Bay, Murchison Bay, Mawson, and Hifiss Is during the same period; the average (world-wide) variation of the cosmic ray intensity is shown at the bottom.

Figure 2. The Honolulu (H, Z, D) and San Juan (D, Z, H) magnetic records of the July 27/28, 1960, magnetic storm (note that in the Honolulu record, a downward change is positive in the horizontal component) and the average variation of the neutron intensity (Deep River and Uppsala) during the same period.

Figure 3. The San Juan magnetic record (Z, D, H) of the September 21/22, 1946 magnetic storms and the average variation of the meson intensity (Huancayo and Cheltenham) during the same period.

Figure 4. The San Juan magnetic record of May 12, 1949, storm and the average variation of the meson intensity (huancayo and Cheltenham) during the same period.

Figure 5. The San Juan magnetic record (Z, D, H) of the May 11/12, 1959, magnetic storm and the average variation of the neutron intensity (Deep River and Uppsala) during the same period.



SAN JUAN
BANGUI
KUIPER
KAKIOKA
GUAM
HONOLULU
HUANGAYO
50γ
50γ
50γ
50γ
50γ
50γ
50γ
10
12
18
0
6
12 GMT
APRIL 23 1959
APRIL 24

Figure 1a

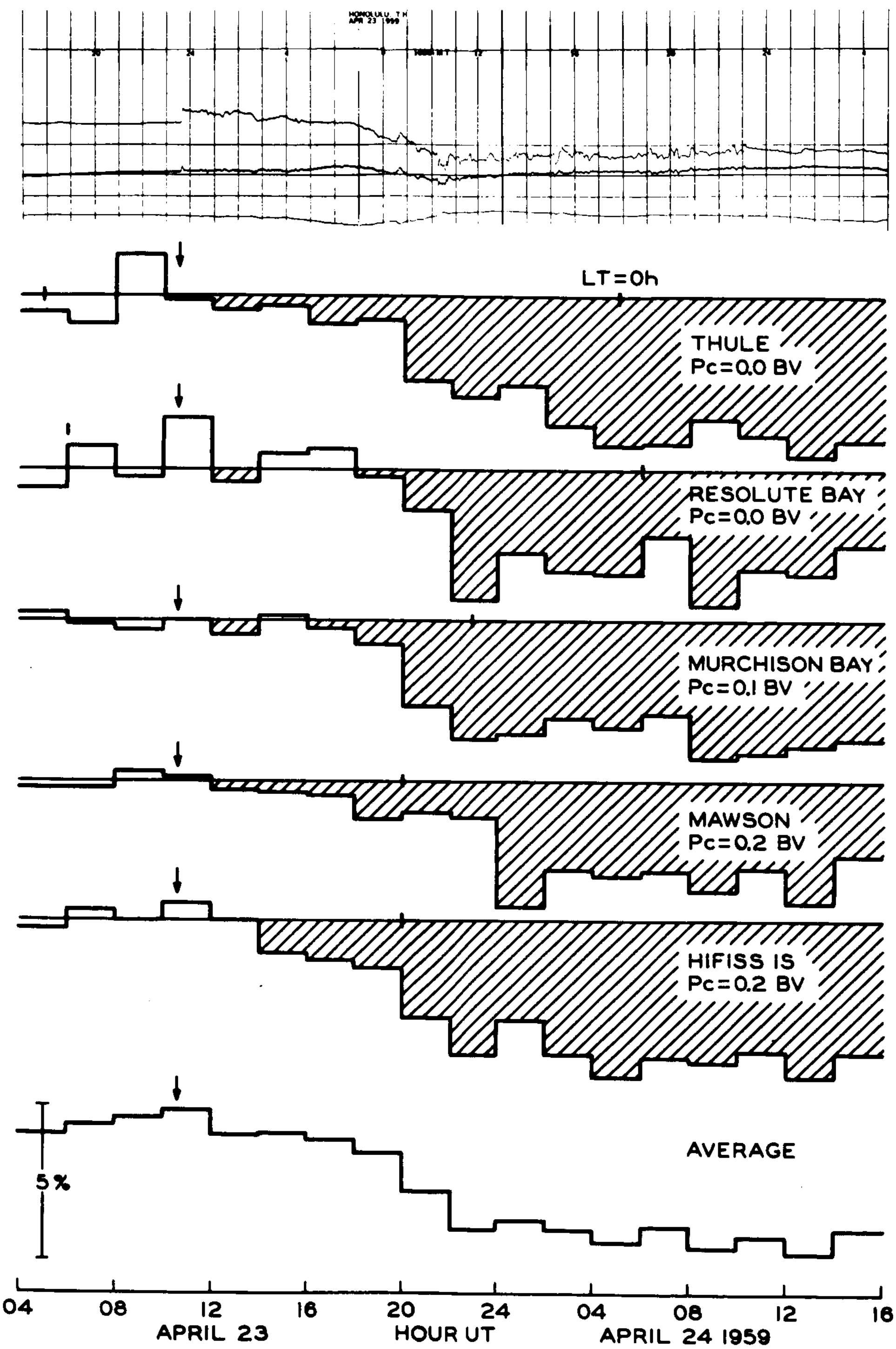
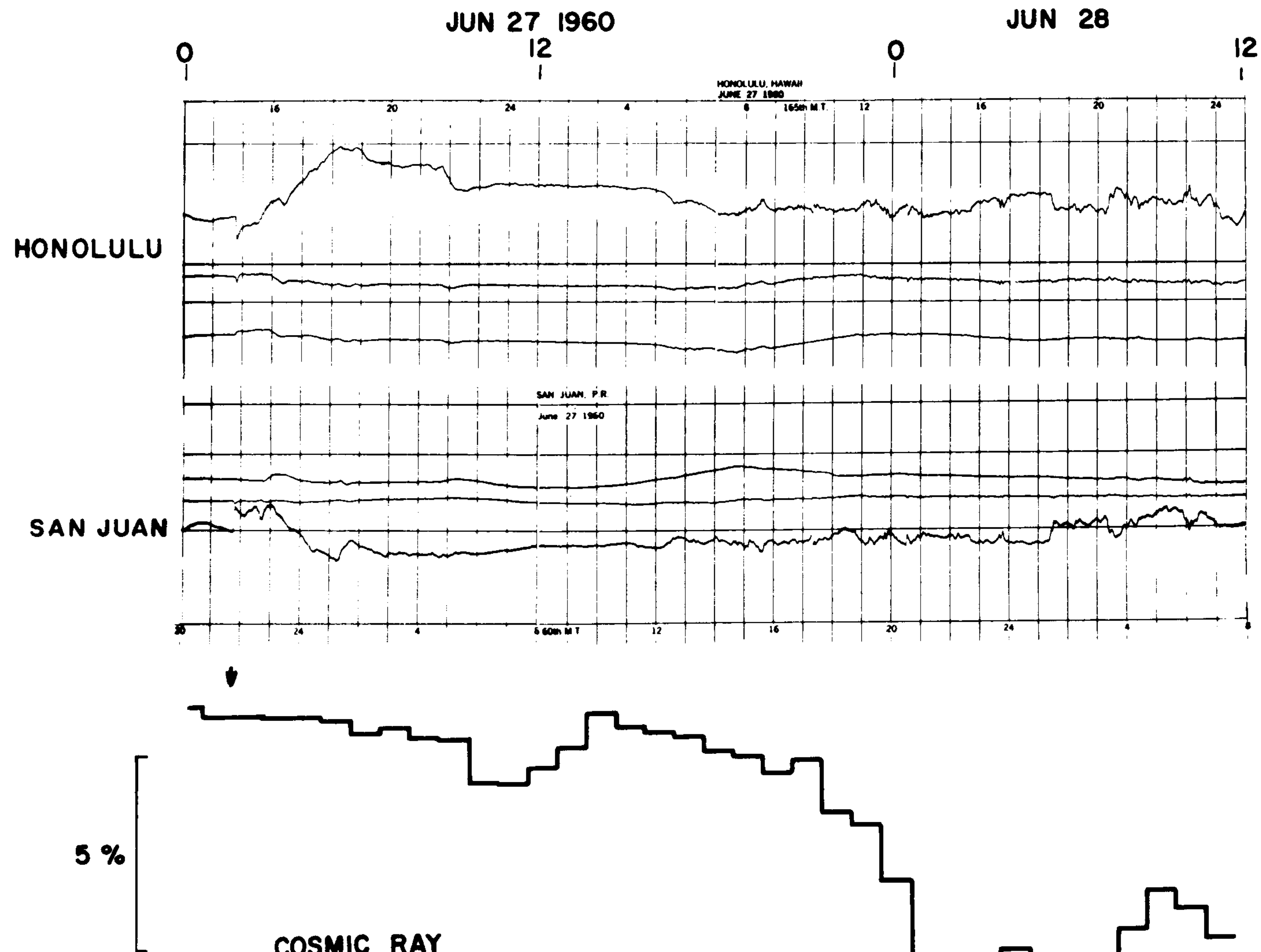

LT=0h
THULE
Pc=0.0 BV
RESOLUTE BAY
Pc=0.0 BV
MURCHISON BAY
Pc=0.1 BV
MAWSON
Pc=0.2 BV
HIFISS IS
Pc=0.2 BV
AVERAGE
5%
04
08
12
16
20
24
04
08
12
16
APRIL 23
HOUR UT
APRIL 24 1959

Figure 1b



JUN 27 1960
JUN 28
0
12
0
12
HONOLULU
SAN JUAN
HONOLULU, HAWAII
JUNE 27 1960
165th M.T.
SAN JUAN, P.R.
June 27 1960
5 %
COSMIC RAY

Figure 2

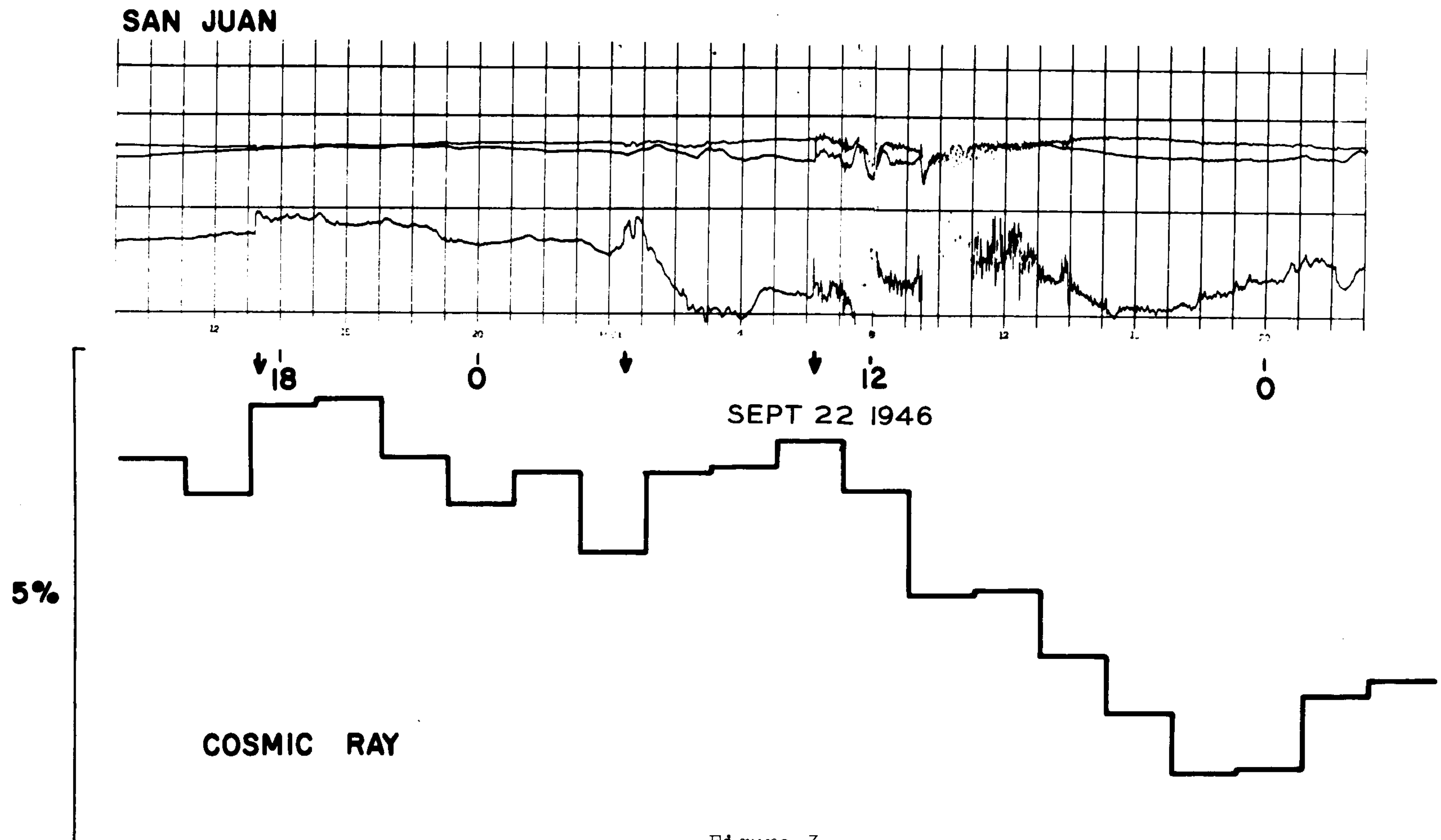


Figure 3

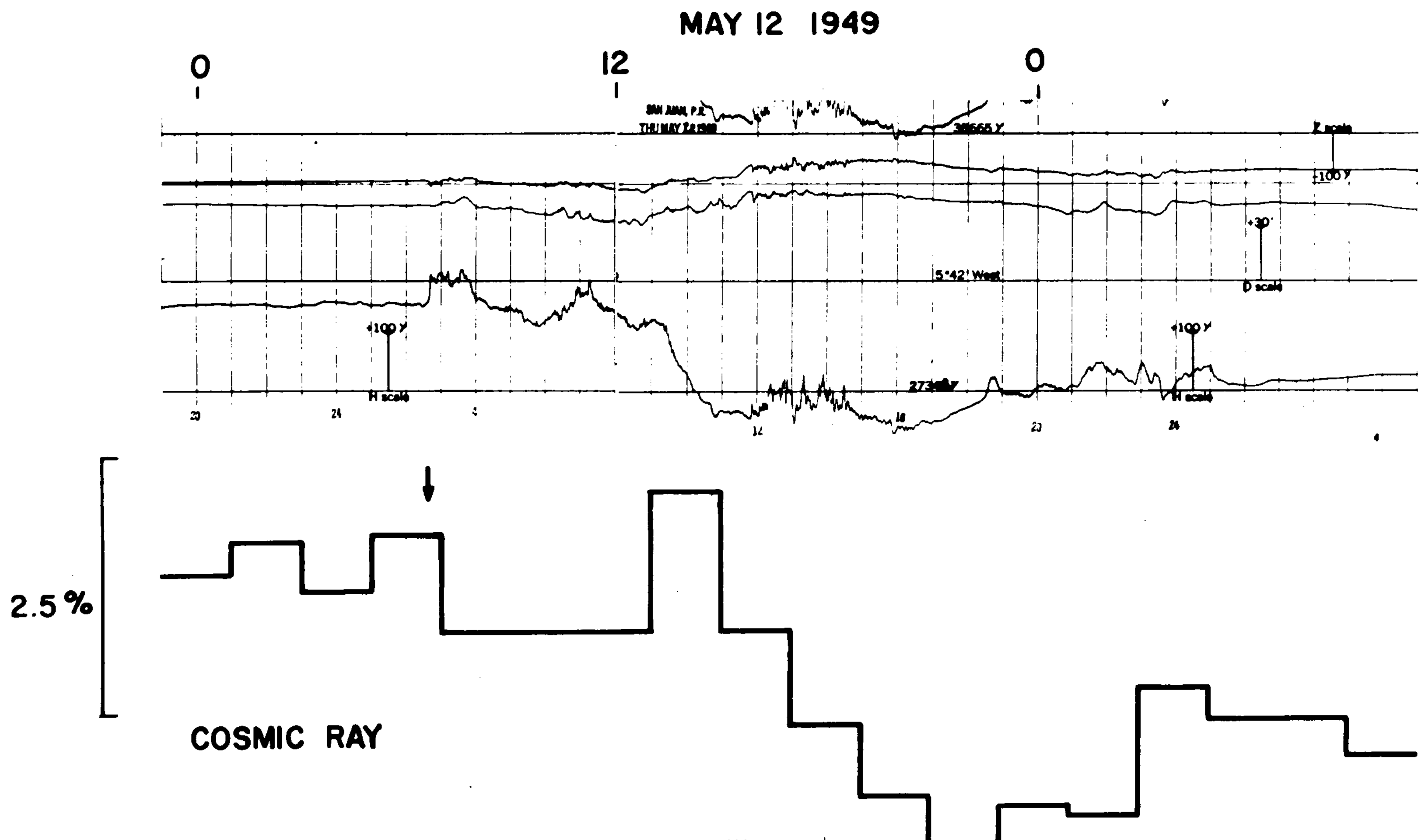

MAY 12 1949
0
12
0
Z scale
+100 γ
+30'
D scale
5°42' West
+100 γ
H scale
+100 γ
H scale
2.5 %
COSMIC RAY

Figure 4

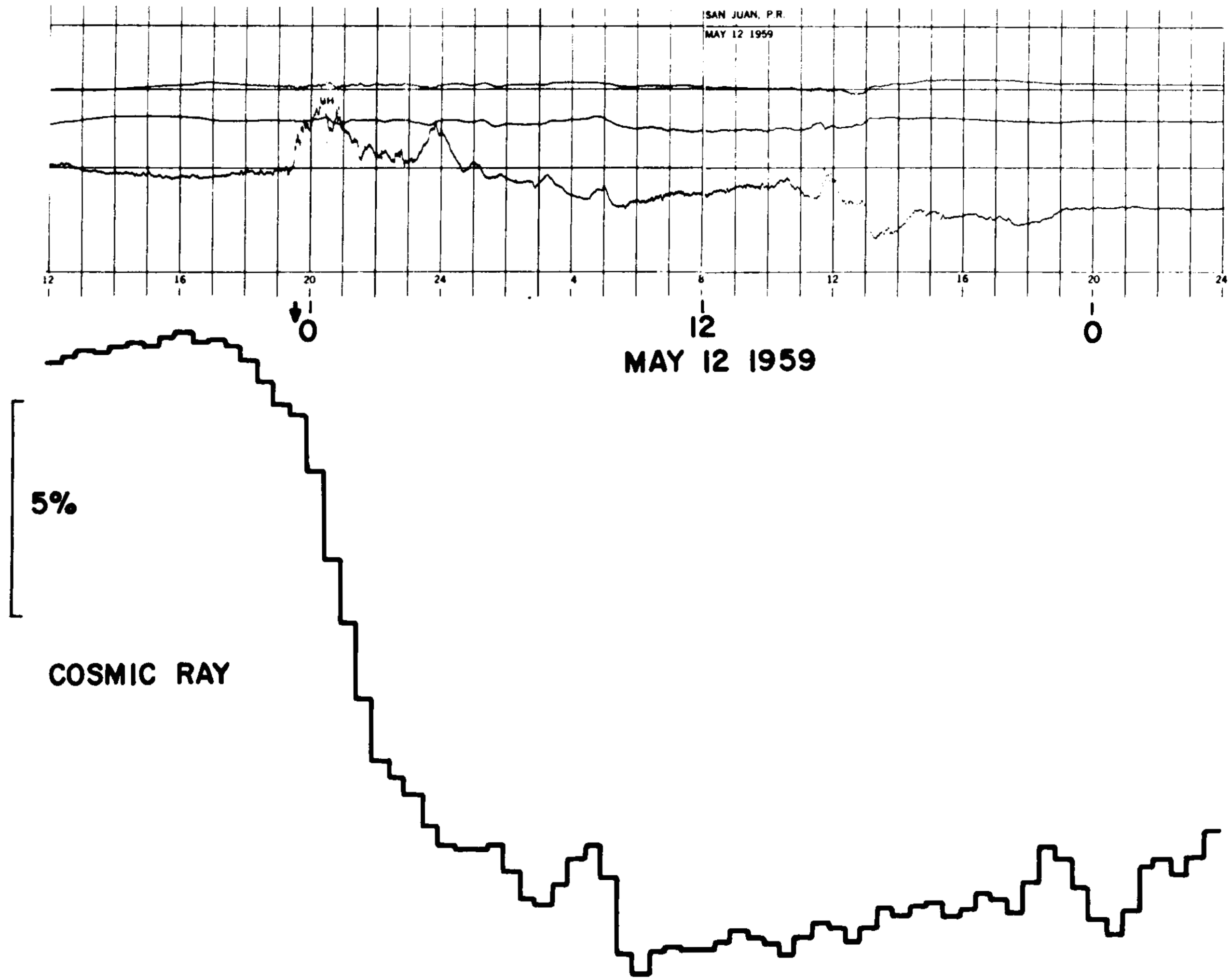

SAN JUAN, P.R.
MAY 12 1959
12
16
20
24
4
8
12
16
20
24
0
12
0
MAY 12 1959
5%
COSMIC RAY

Figure 5