ABSTRACT

A new type of polar geomagnetic disturbance was observed in connection with PCA's of slow onset type. A synoptic analysis of the February 10, 1958 event shows that the distrubance is an intensified S_q^p-field due to an enhanced ionization produced in the ionosphere dynamo region. Protons with energies 0.1 - 1 Mev in the solar cosmic rays may be the cause of the disturbance.

CONTENTS

SLOW ONSET TYPE PCA EVENTS AND ASSOCIATED PRE-SSC POLAR GEOMAGNETIC DISTURBANCES

by

Yukio Hakura*

Goddard Space Flight Center

and

Masao Nagai

Magnetic Observatory

INTRODUCTION

Polar Cap Absorptions (PCA) are classified into two fundamental types according to the delay-time of a PCA onset from an associated flare, i.e. F-type and S-type. The F-type represents a fast-onset in increase of absorption, with its maximum absorption well before the onset of a subsequent geomagnetic storm. The S-type has a slow onset, being delayed several hours or more after the associated flare, and its development is also very gradual.

The main ionizing radiation responsible for PCA is protons with energies 1 to a few hundreds Mev. When they enter the earth's upper atmosphere, they precipitate in the lower ionosphere, in a height region, 30 km - 90 km. Since the region lies below the dynamo layer, PCA is originally an event which occurs without accompanying any geomagnetic disturbance. However, an existence of a polar geomagnetic disturbance has been analytically shown in connection with some of PCA events during the IGY (Hakura, Nagai, and Sano, 1961; Hakura and Nagai, 1964). The present paper shows an affinity between the geomagnetic polar disturbance and the slow-onset type PCA's. Protons with energies 0.1 - 1 Mev precipitate in the dynamo region and may be the cause of the polar disturbance. Production of the low energy protons will be discussed.

SLOW-ONSET TYPE PCA ASSOCIATED WITH A GEOMAGNETIC POLAR DISTURBANCE

An outstanding geomagnetic disturbance was observed on February 1958 with its sudden commencement at 01:26 UT on February 11. The disturbance stemmed from a major solar flare observed around the center of the solar disk at 21:08 UT on February 9. A typical slow-onset type

*Senior research associate of the National Academy of Sciences, on leave of absence from the Radio Research Laboratories, Tokyo, Japan.

PCA was observed in association with the flare which accompanied outstanding solar radio outbursts of type IV. Time variation in the PCA both in the polar region (top) and in the auroral zone (middle) on February 9th through 13th are shown in Figure 1, where variation in geomagnetic K_p index (bottom) is also given. Onset times of the flare and the geomagnetic ssc are indicated at the top of the figure. Two different kinds of onsets were noted in time history of the PCA. In the polar region, the first PCA was observed at 07 UT on February 10, when auroral zone stations did not detect any appreciable PCA yet. The second and intenser PCA started at 12 UT in the auroral zone, and a few hours later in the pole region. Detailed discussions of the two-stepped onset of the PCA were given elsewhere (Hakura and Nagai, 1964). The main interest in the present paper will be concentrated in the second PCA and its association with a peculiar polar geomagnetic storm.

Figure 2 shows storm-time variations of (a) geomagnetic storm-time variation, Dst at 32.5° in geomagnetic latitude, (b) DS-component of geomagnetic disturbance field at Churchill (70.3° in

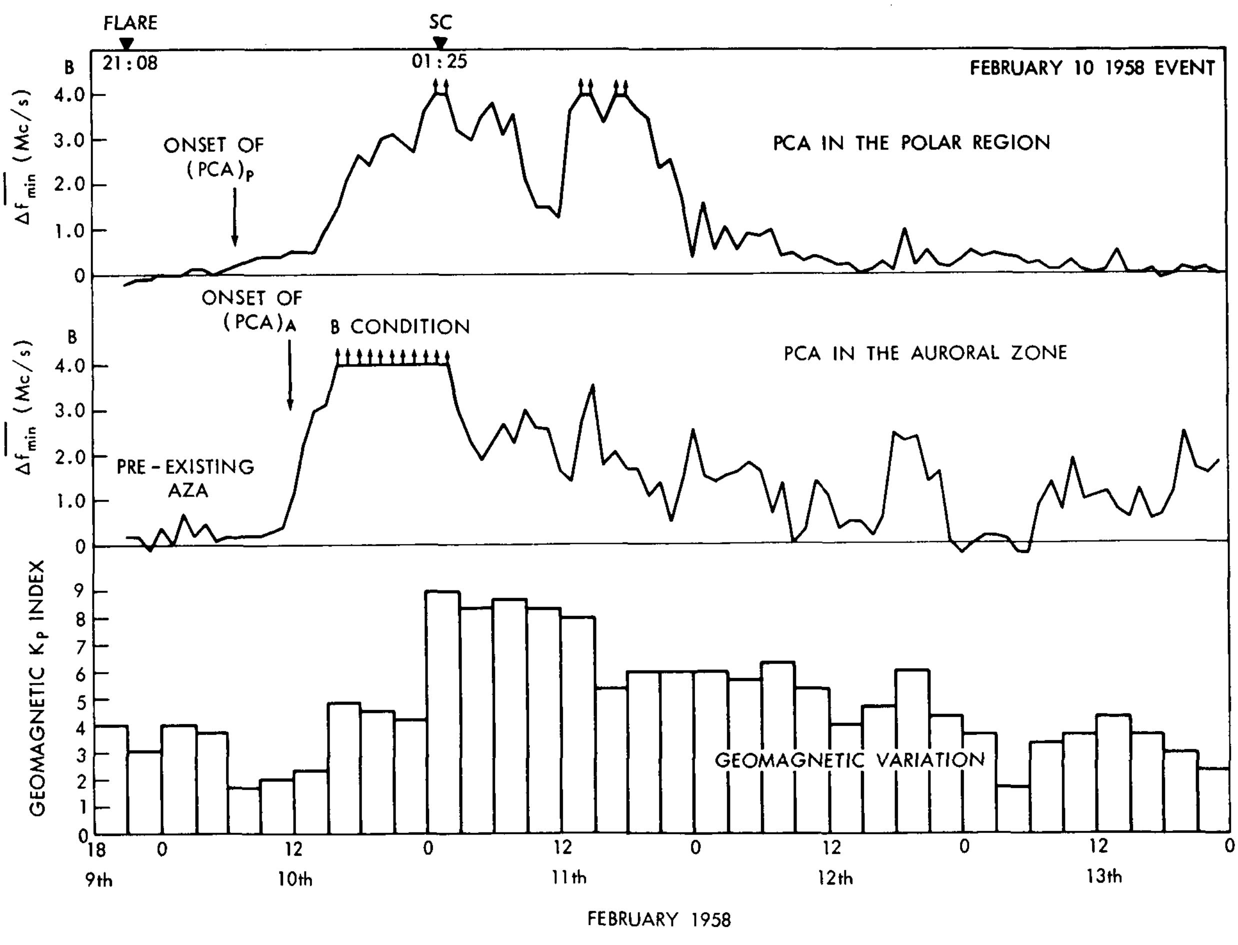

Figure 1—Time variations in PCA both in the polar region (top) and auroral zone (middle), and variation in geomagnetic K_p index (bottom), on 9th through 13th of February, 1958. PCA is expressed by Dst (Δfmin) which is a mean of Δfmin values in several stations. Thule, Alert, Fletchers Ice, Resolute Bay, and Godhavn were selected for Dst (Δfmin) in the pole, while Narsarssaak, Tikhaya Bay, Reykjavik, Churchill, Point Barrow, Arctica I, and Tromsö were picked for computing Dst (Δfmin) in the auroral zone.

corrected geomagnetic latitude), and (c) cosmic noise absorption at Churchill. As indicated by the arrows in the figure, the pre-sc polar disturbance, DP(PreSC), started at -13 hours in storm-time, showing rather surprisingly good time coincidence with the onset of $(PCA)_A$. The $(PCA)_A$ observed at Churchill can never be identified as an auroral zone absorption which usually appears in a zig-zag shape after the onset of an ssc, because of its long duration and smooth variations. Corresponding to the pre-sc disturbances, the Dst field also shows a slight depression. However, it must be noted that the ratio $|DS/Dst|$ at the pre-sc stage is about 3 times higher than that at the post-sc stage. The polar disturbance, DP(PreSC), must be a special disturbance whose origin is connected with the invasion of solar cosmic rays.

During the IGY, 1957-58, when sunspot activity was maximum, five other well defined slow onset type PCA were observed (Hakura, 1968). Table 1 shows some information of all the S-type events, such as year, month, date, and time in UT of the PCA-producing flare, the delay-time Δt_b of the PCA from the flare, and the delay-time Δt_m of the ssc from the flare. Figure 3 shows mean variations in PCA in the pole region, geomagnetic K-index at a pole station (Thule which is located at 86.0° in corrected geomagnetic latitude), geomagnetic K_p index, and equatorial Dst, for the six disturbances shown in the table. The Dst (Δfmin) pole is an average value of Δfmin values observed at several pole stations located in roughly equal longitudinal intervals. The equatorial Dst is quoted from Sugiura (1964). The zero hour in the figure is the time of sudden commencements of the corresponding geomagnetic storms. A gradual increase in Dst (Δfmin) pole in the preSC stage shows an average behaviour of slow-onset type PCA events. Corresponding to the PCA, an enhancement of K-index at Thule

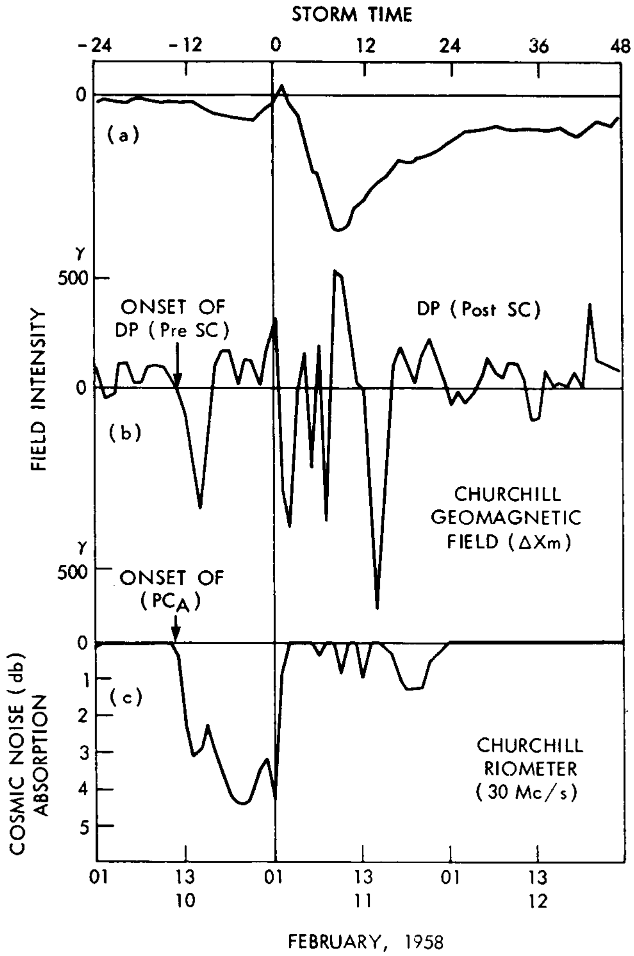

Figure 2—Storm-time variations of Dst (32.5°), Δx_m (Churchill), and cosmic noise absorption at Churchill (D. H. Jelly, 1961).

Table 1

Slow Onset Type PCA Events During the IGY.

Year	Solar flare				PCA	SSC
	Month	Date	h m	Position	Δt_b in hrs.	Δt_m in hrs.
1957	August	28	09:13	30^S35^E	12	34
	September	11	02:43	11^N03^W	29	46
	October	20	16:37	25^S45^W	12.5	30
1958	February	09	21:08	13^S14^W	10	28
	March	23	09:50	14^S77^E	46	54
	August	20	00:43	16^N23^E	38	50

is clearly seen at -12h through 0h, showing the existence of DP(preSC). It must be noted that K(Thule)/K_p ratios at the preSC and postSC stages are 1.8 and 1.0 respectively and that no appreciable disturbance is seen in Dst-variation till the onset of the ssc.

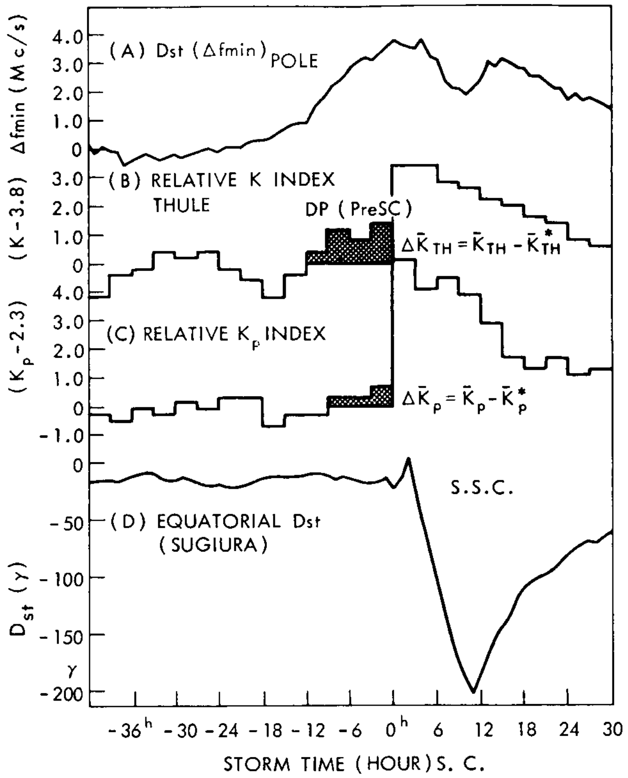

Figure 3—Mean variations in Dst $(\Delta fmin)_{pole}$, K index at Thule, K_p index, and equatorial Dst 6 slow onset type PCA events during the IGY.

SYNOPTIC PATTERNS OF THE PCA AND EQUIVALENT CURRENT SYSTEM OF THE GEOMAGNETIC DP-FIELD

A synoptic analysis will help us in having a further insight into the nature of the polar disturbances. Figure 4 shows a series of onset patterns of the polar absorptions (expressed by contours of Δfmin: hatched region in the upper rank) and equivalent current systems of the geomagnetic DP-field (expressed by arrowed lines in the lower rank).

The first couple (1) of the synoptic charts shows the slight PCA in the polar region, i.e. (PCA)p, and the corresponding current system of geomagnetic variations. The latter consists of two oppositely circulating vortices centered in the polar region and set along the morning meridian. This is essentially identical with the S_q^p current system proposed by Nagata and Kokubun (1962) for explaining an additional geomagnetic daily variation in geomagnetically quiet days. At 12:30 (2), the region of abnormal ionization suddenly began to expand along the auroral zone, (PCA)A. A transition from the S_q^p field to a peculiar polar disturbance field DP(PreSC) was found at this very stage. In the next two couples (3) and (4), are seen more intensified twin current vortices, corresponding to further developed $(PCA)_A$ event.

DISCUSSIONS

Nagata and Kokubun (1962) have explained the S_q^p system as a Hall-current set up by electric charges in the polar ionosphere. The charges are produced in the magnetosphere through a viscous-like interaction between the solar wind and the geomagnetic field, and conveyed to the ionosphere-dynamo-region through geomagnetic field lines. The S_q^p-system could be intensified by either an increase in the solar wind velocity or by an enhanced ionization produced in the dynamo region.

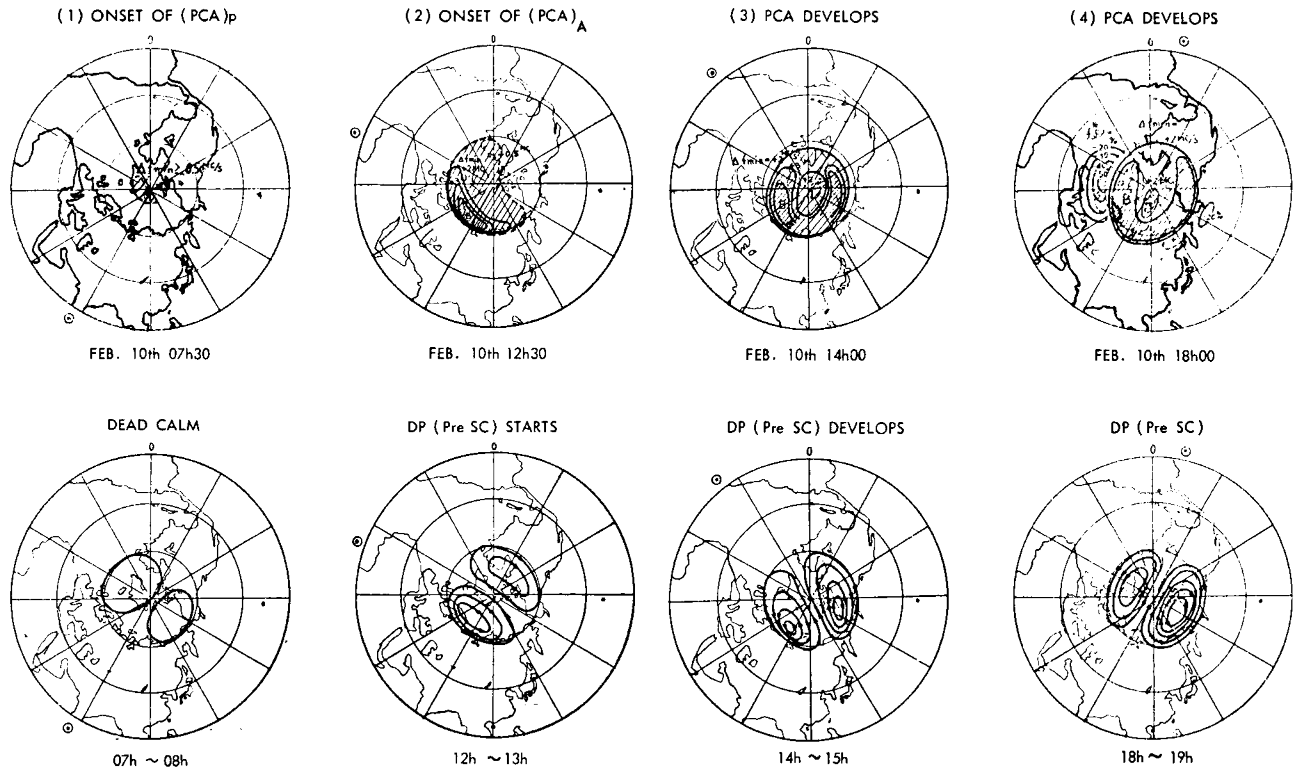

Figure 4—Four pairs of synoptic patterns of PCA (upper rank) and equivalent current systems of geomagnetic disturbance (lower rank) in the initial phase of February 10, 1958 events.

As shown in the preceeding sections, the DP(PreSC) is a S_q^p-augumentation which is possibly connected with sub-cosmic rays of solar origin. Protons with energies 0.1 - 1 Mev, when they come down in a standard atmosphere, precipitate in a height region of 110 - 90 km, and thus could be an origin of the S_q^p-augumentation. Thus the discussion in the present paper is directed to a possible ampleness of the low energy protons in a solar cosmic ray event producing a slow-onset type PCA.

The propagation of sub-cosmic rays through the interplanetary medium is a process of diffusion. The time delay of solar cosmic rays reaching maximum intensity at the earth is inversely proportional to their velocities. In a typical F-type event of July 7, 1966, for example, 100 Mev proton flux reached its maximum a few hours after a corresponding flare, while 1 Mev proton flux increased gradually and reached its maximum one and a half days after the flare (Heristchi et al., 1967; Armstrong et al., 1967. The PCA due to 1 Mev protons would have shown a time history similar to a slow onset type PCA. A speculation goes that a particle acceleration in some solar cosmic ray flares is very ineffective and produces only protons with lower energies. This gives a possible explanation for the S-type PCA.

It is well known that most of solar cosmic rays during solar active period are connected with a solar flare accompanied with radio outbursts of type IV (Hakura and Goh, 1959). A further statistics of PCA's and type IV outbursts have shown that the F-type PCA follows solar radio outbursts with predominating micro and decimeter parts, while the S-type PCA is related to radio outbursts with a rather weak micro part and a outstanding meter wave part (Hakura, 1961). Figure 5 shows a pair of typical type IV outbursts which produced F-type and S-type PCA events, respectively. Dynamic spectral features in both the outbursts are evidently different from each other. Solar cosmic rays responsible for the S-type PCA might be produced in a higher coronal region where meter wave radio wave is emitted. Solar magnetic field is too weak to keep protons trapped until they were accelerated to 10 Mev or higher.

Besides the diffusion process, propagation of solar cosmic rays is greatly influenced by the interplanetary magnetic field configuration. The spiral shaped interplanetary fields give a shorter path to solar cosmic rays propagating from the west side of the solar disk than to those from the east side. A linear relation exists between the delay-time of F-type PCA's and the heliographic longitudes of the PCA-producing flares (Obayashi and Hakura, 1960). A magnetized plasma cloud responsible for a geomagnetic storm, when supperposed with the stationary interplanetary field, also modulates the propagation of solar cosmic rays. Another speculation is that sub-cosmic rays could be trapped in the magnetized cloud, carried out into the interplanetary space, and then escape from it after the magnetic field is weakened by its expansion, causing a PCA event of slow onset type (Sinno, 1961). Figure 6 shows a relation between Δt_b and Δt_m in cases of slow-onset type events shown in Table 1. The linearity actually shows the importance of the ssc-producing cloud for the propagation of the sub-cosmic rays producing the PCA.

Energy spectrum of solar cosmic rays may change while they are trapped in the cloud for several hours. Thus, the ampleness of low energy protons may be expected.

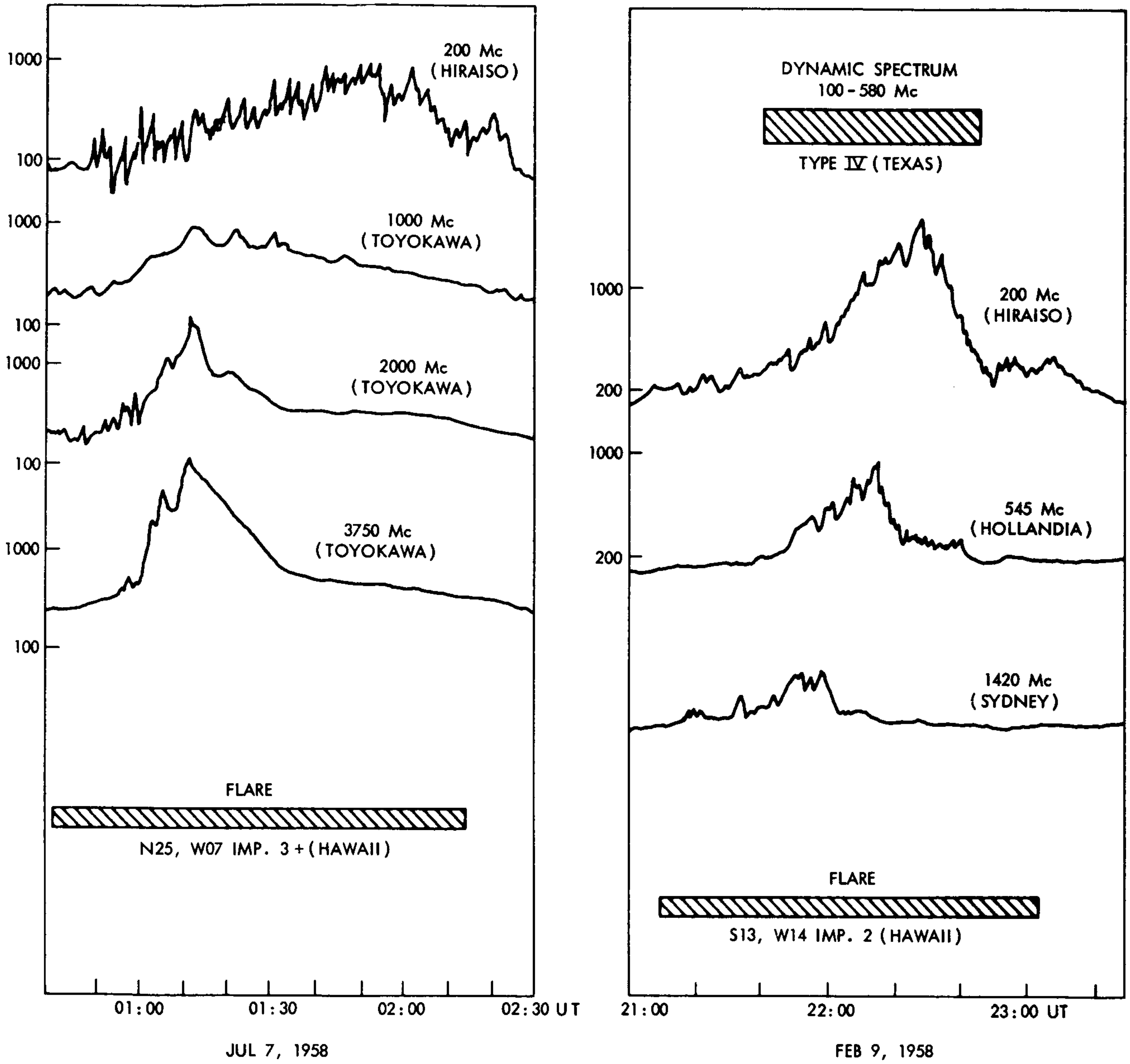

Figure 5—Dynamic spectra of solar radio outbursts and solar flares associated with
(a) Fast onset type PCA Δtb = 1 hour Δtm = 31 hours
(b) Slow onset type PCA Δtb = 10 hours Δtm = 28 hours

CONCLUSIONS

Development patterns of a slow onset type PCA, the February 10, 1958 event were reviewed in comparison with equivalent current systems of geomagnetic polar disturbance field, DP. A peculiar geomagnetic disturbance started simultaneously with a sudden development of the PCA, some 12 hours before the associated ssc. A remarkable feature of the geomagnetic disturbance is the absence of the ordinary Dst-part. A statistic of slow onset type PCA's assured the result. The disturbance is regarded as an intensified S_q^p field due to an enhanced ionization produced in the geomagnetic dynamo region. Low energy protons with energies 0.1 - 1 Mev in the solar cosmic rays may be the cause of the disturbance.

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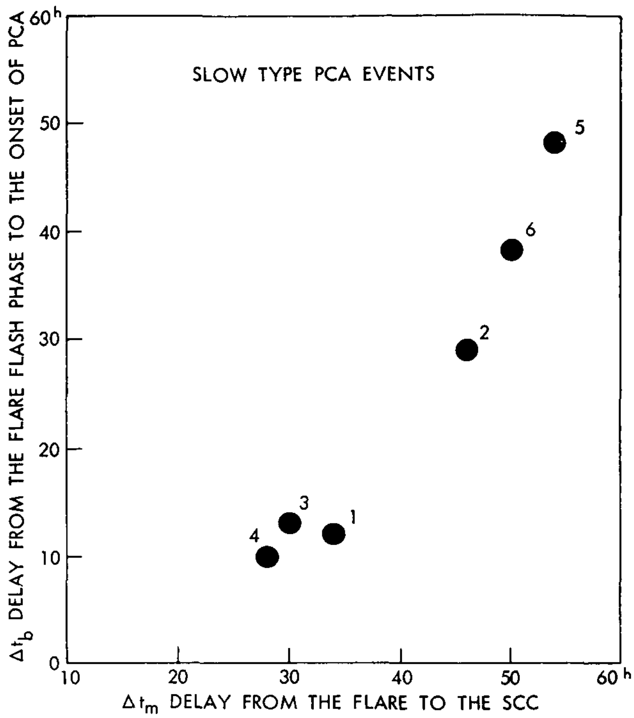

Figure 6—Relation between Δt_b and Δt_m, for six slow onset type PCA events.
Δtb: delay time of PCA from a corresponding flare.
Δtm: delay time of ssc from a corresponding flare.

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Δtb = 1 hour	Δ tb = 10 hours
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Δtb : delay time of PCA from a corresponding flare.

Δtm : delay time of ssc from a corresponding flare.