X-641-67-116
REVISED June 1967

NASA TM X-55720

THE POLAR CAP ABSORPTION ON JULY 7-10, 1966

BY

YUKIO HAKURA

MARCH 1967

NASA —— GODDARD SPACE FLIGHT CENTER ——
GREENBELT, MARYLAND

X-641-67-116
REVISED June 1967

THE POLAR CAP ABSORPTION ON JULY 7-10, 1966*

by

Yukio Hakura

March 1967

* A contributed paper to the Tenth Meeting of COSPAR, Working Group II Proton Flare Project, London, July 17-29, 1967, to be published in Annals of IQSY, a special issue of July 7, 1966 events.

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

PRECEDING PAGE BLANK NOT FILMED.

THE POLAR CAP ABSORPTION ON JULY 7-10, 1966

Yukio Hakura*
Goddard Space Flight Center

ABSTRACT

Time history of a PCA on July 7-10, 1966 was analyzed using 16 riometers in the northern polar region and concurrent satellite observations of solar cosmic radiations. The PCA was attributed to a solar flare of importance 3 observed at 00:25 U.T. on July 7, that was accompanied by a major radio outburst of type IV. Time variation in the SID effects was very similar to those in solar microwave impulsive bursts and hard X-rays observed by the satellite OGO-3. The first onset of PCA was noticed at 01:20 U.T. at Shepherd Bay, Canada which is located 10° from the northern pole, and the slight enhanced ionization of a few tenths of db covered the whole north pole region before 02:00 U.T. On the other hand, auroral zone stations observed the PCA after 02:00. The two-stepped onset of the PCA corresponds to the differential arrival of solar electrons and protons at the earth, detected by the satellite IMP-3. The flux of 40 kev electron bursts observed by the satellites Explorer 33 and IMP 3 can explain the first onset of a slight PCA near the geomagnetic pole. The PCA in the polar region marked a maximum of 2.5 db on 30 Mc/s at 13:00 on July 7, and then decayed gradually until it went down below 0.3 db after 23:45 on July 8. There was no discontinuous decrease in absorption in polar riometer as observed in the interplanetary proton intensity in association with an interplanetary shock wave, while the auroral zone stations observed a pronounced Sudden Commencement Absorption. The lowest latitude of the PCA during geomagnetically calm period was some 63° in the corrected geomagnetic latitude. After the onset of geomagnetic disturbances, the PCA was superposed by the AZA that appeared even in the lower auroral zone.

*Senior Research Associate, National Academy of Sciences, National Academy of Engineering, Radio Research Laboratories, Tokyo, Japan.

THE POLAR CAP ABSORPTION ON JULY 7-10, 1966

INTRODUCTION

The general morphology of PCA events has been studied extensively by means of riometers, world-wide ionograms, and other radio propagation techniques, using a number of events that were observed during the last sunspot cycle (Bailey, 1964; Obayashi, 1964, and papers cited there). The most detailed spatial patterns of PCA events were obtained during the IGY, 1957-58, when a comprehensive network of ionosphere soundings was in operation (Hakura and Nagai, 1964; Hakura, 1965). In recent years, artificial satellites have been instrumented appropriately and have detected in space the solar cosmic radiations responsible for the PCA. Comparisons between solar cosmic radiations and riometer absorptions have increased knowledge of spatial and time-variations in PCA events (Van Allen, Lin and Leinbach, 1964; Leinbach, Venkatesan, and Parthasarathy, 1965; Chivers and Burrows, 1966; Reid and Sauer, 1967).

The July 7-10, 1966 events are one of typical solar-terrestrial disturbances in the current solar cycle, where more sophisticated observations of the solar cosmic radiations are available. It is believed worthwhile to analyze the world-wide time history of the PCA and compare the results with the concurrent satellite observations. Special attention will be paid to the onset phase of the PCA in connection with the differential arrival of solar electrons and protons observed by the satellite, IMP-3(McDonald and Cline,1967; Lin and Anderson, 1967). Previous analysis of the present PCA event are also reviewed (Imhof, Musser, Oelermann, and Volz, 1966; Masley, 1966).

A SOLAR FLARE RESPONSIBLE FOR THE PCA ON JULY 7-10, 1966

The PCA on July 7, 1966 may be correlated with a solar H_α-flare of importance 3 observed at N35,W48 in McMath plage region 8362 at 00:25 U.T. The flare was accompanied by major radio outbursts of type IV which displayed a complex feature over wide frequency range. Figure 1 shows a dynamic spectrum of the outbursts in a frequency interval 200-9400 Mc/s, inferred from seven single-frequency-observations listed in Table 1. The increments of flux density from preburst levels (see Table 1) are graded into eight steps shown in the far right side of Figure 1.

The outbursts in the present frequency range are characterized by six main peaks that appeared with different peak-frequencies in the course of the solar disturbance. The first and the second outbursts were observed at 00:28

Table 1

Solar Radio Observatories, Frequencies, and Corrected Pre-burst Levels

Observatory	Frequency	Corrected Pre-burst Flux Level
Nagoya, Japan	9400 Mc/s	284
Nagoya, Japan	3750	120
Penticton, Canada	2700	93
Nagoya, Japan	2000	75
Nagoya, Japan	1000	57
Hiraiso, Japan	500	38
Hiraiso, Japan	200	12

and 00:30 U.T. with their peak intensities at frequencies greater than 9400 Mc/s. The most outstanding outburst covering wide frequency range down to 200 Mc/s, occurred around 00:38 with peak intensity at about 9400 Mc/s. The second and third outbursts are related to two maximums in the H_a-flare shown in the top of Figure 1, and classified as the impulsive microwave bursts. An impulsive microwave burst is ascribed to gyro-synchrotron radiation from energetic electrons created in the flash phase of a flare and gyrating in the sunspot magnetic field. A major part of high energy electrons stream into the middle chromosphere in which they lose their energy by hard (20-500 kev) X-rays (Winckler, 1963). Winckler (1967) observed a burst of X-rays (10-50 kev) at the time of the impulsive micro bursts on July 7. Cline and Hones (1967) using OGO-3 data showed that the impulsive bursts coincide accurately in their commencements and even in detailed features, with the hard X-ray burst ($\geq$75 kev and $\geq$450 kev).

Information of softer (1-10 kev) X-rays are not available (SRM satellite NRL, CRPL-FB,265) except after 01:44 U.T. The time variation in soft X-rays may be estimated from that in an ionospheric SID except a blunting effect due to the ionosphere sluggishness (Hakura, 1966). Figure 2 shows a SID effect on cosmic noise intensity observed at Penticton, Canada. Two-stepped drops at 00:28 and 00:35 correspond to onset times of the major impulsive bursts of microwave. The time variation in X-rays of 1-10 kev would be similar to that in harder X-rays observed by the satellite OGO-3 (Cline and Hones, 1967).

After the microwave impulsive bursts, followed the second phase of outbursts; the fourth, fifth and sixth peaks of radio emission are observed around 01:02, 01:24, and 01:57 respectively in lower micro and decimeter wave regions.

The type IV outbursts extend down to meter wave region, suggesting the production of 10 kev - 1 Mev electrons in the higher corona beyond the tight bound of sunspot magnetic field. It has been statistically established that the type IV outburst has a close correlation with the onset of a PCA event (Hakura, and Goh, 1959).

ONSET PHASE OF THE PCA EVENT

According to a private communication from G. C. Reid (December 1966), most of antarctic stations were in darkness during the July 7 event and the absorption was barely noticeable and cannot be measured with any accuracy. Thus, further discussion will be confined in the PCA event observed at northern hemisphere stations.

Information of enhanced ionizations used in the present study were obtained from 16 riometers, 6 additional vertical soundings, and 2 VLF propagation records located in the northern hemisphere. The station names, abbreviations, operating frequencies, and station locations in the geographic and corrected geomagnetic coordinates are shown in Table 2. The abbreviated station names and their locations (dots) are shown in the geographic coordinates in Figure 3, where iso-corrected latitude 40°, 50°, 60°, 70°, 80° are expressed by oval-shaped thick lines. All the riometers except at Penticton, Canada used antennas with a half power beamwidth of about 60° and operated on a frequency near 30 Mc/s. The absorption values (A db) were obtained by first obtaining a quiet day variation for each system. When no riometer data are available, absorptions on 30 Mc/s are estimated from f min values, using an empirical relation

$$A(\text{db}) = \frac{1}{2}\,\Delta f\ \text{min}\,(\text{Mc/s})\ ,$$

where Δf min is the deviation of f min from its monthly median.

Absorptions observed at 11 stations in the time interval 00:00 through 06:00 U.T. on July 7 are shown in the lower part of Figure 4. They are arranged in order of their corrected geomagnetic latitudes which are indicated in parenthesis. Following the immediate SID effect which was typically shown by Penticton data (hatched in the top), polar stations north of Shepherd Bay marked the onset of a PCA before 02:00 U.T. The first onset of PCA was observed at 01:20 U.T. at Shepherd Bay which was located 10° from the northern pole (Masley, 1966). However, auroral zone stations including Churchill, Canada (79.5°) and Kotzebue, Alaska (64.2°) observed PCA after 02:00 U.T. The lowest latitude

Table 2

Station Names, Abbreviations, Operating Frequencies, and Station Locations, Used for the Present Analysis

Station	Abr.	Freq.	Geographic		Corrected Geomagnetic	
			Latitude	Longitude	Latitude	Longitude
Thule, Greenland	TH	30 Mc/s	76.6 N	291.3 E	86.0	38.1
Resolute Bay, Canada	RE+	30 f min	74.7	265.1	84.3	306.0
Shepherd Bay, Canada	SH	30	68.8	266.6	79.5	321.3
Churchill, Canada	CC	30	58.8	265.8	70.3	325.9
Great Whale Rv., Canada	GW	30	55.3	282.2	68.2	354.1
Dixon Is., USSR	DX	32	73.5	80.4	67.9	154.7
Fort Yukon, Alaska	FY	30	66.6	214.7	67.1	260.7
Reykjavik, Iceland	RY	20,30,40	64.1	338.3	66.5	71.2
Tromsö, Norway	TR	27.6	69.4	19.0	66.0	105.2
College, Alaska	CO	30	64.9	212.2	64.9	260.3
Moosonee, Canada	MS	30(p)	≥51.5	279.3	≥64.6	348.5
Kiruna, Sweden	KR	27.6	67.8	20.5	64.3	104.9
Kotzebue, Alaska	KZ	30	66.7	197.5	64.2	247.8
Healy, Alaska	HY	30	63.8	211.0	63.7	260.2
Ottawa, Canada	OT+	30(p) f min	≥45.4	284.3	≥58.9	355.7
Penticton, Canada	PE	22	49.5	240.4		
Lycksele, Sweden	LY*	f min	64.6	18.8	61.2	101.4
Kenora, Canada	KE*	f min	49.9	262.6	61.1	323.5
St. John's, Canada	ST*	f min	47.6	307.3	58.3	29.8
Nurmijärvi, Finland	NU*	f min	60.5	24.6	56.6	103.5
Slough, England	SL }	NPM	51.5	359.4		
Maui, Hawaii	MU }	26.1 kc/s	20.8	203.5		
Payerne, Switz.	PY }	NPG	46.8	6.9		
Jim Creek, USA	JC }	18.6 kc/s	48.2	238.1		

station of appreciable PCA was Healy, Alaska (63.7°), where a PCA started at about 04:00 U.T.

Since the absorption recorded by a riometer during a PCA event varies by a factor of about 4 between day and night, a standardized absorption should be used for detailed discussions. However, an onset time could easily be determined except for Moosonee (64.6°) where it was difficult to fix an onset time because of slightness of a PCA (D. H. Jelly, private communication, February

1967). Latitude dependence of the definite onset of PCA is shown in the upper part of Figure 4. In spite of minority of observing points, the general sequence is quite similar to the pattern of PCA initial phase obtained on the analysis of world-wide f min records during the IGY 1957-58, that the initial phase of PCA consists of at least three characteristic stages; the first stage is observed as a slightly enhanced ionization near the geomagnetic pole; the second stage as a remarkable development of PCA in the polar cap above 65°; and the third stage as an extension of the enhanced ionization to lower latitude zones (Hakura, 1967). It has been suggested that the result is due to differential precipitation of solar electrons, protons, and α-particles.

Actually, the satellites IMP-3 and OGO-3 detected a differential invasion of solar electrons and protons during the initial phase of July event. According to McDonald-Cline (1967), the IMP-3 observed a 3 Mev electron burst that started at about 01:00 U.T. and lasted about 2 hours. The energy spectrum in the interval 3-10 Mev was expressed by a power law $(kE)^{-5}$. Concurrently with the Mev electrons, a burst of $\sim$40 kev electrons was observed by the satellites IMP-3 and Explorer 33 (Lin and Anderson, 1967). According to a private communication from Lin, R.P. (1967), the Explorer 33 observed the onset of the electron burst at about 01 h U.T. A flux value of $>$1500 electrons/cm^2.sec.ster was obtained before $\sim$02:00, and it became difficult to detect further time-variations in electrons because of considerable proton contributions to the Geiger counter that started at about 02:00 U.T. The empirical relationship between the precipitating flux (cm^{-2} sec^{-1} $ster^{-1}$) of E > 40 kev electrons and the magnitude of broad beam absorption at 30 Mc/s could be expressed as

$$A(db) = 3.3 \times 10^{-3} \sqrt{N(>40\ kev)}$$

when the precipitation is isotropic (Parthasarathy et al, 1966). Taking the 40 kev electron flux of $>$1500 cm^{-2} sec^{-1} $ster^{-1}$, an estimated absorption is

$$A(db) > 1.3 \times 10^{-1}$$

which is comparable with the absorption of a few tenths of db observed in the pole stations in the first phase of the PCA, at 01:20 - 02:00 U.T. on July 7.

On the other hand, the satellite IMP-3 observed the onset of $\sim$100 Mev protons after 02:00 U.T. (McDonald-Cline, 1967). Since the energy range of solar protons effective on PCA is 1-100 Mev, the proton invasion after 02:00 U.T. explains the second phase of the PCA observed over the whole polar cap.

It has been known that a trans-polar cap Very Low Frequency (VLF) propagation is a sensitive detector of PCA events (Bates and Albee, 1964). During the July event, VLF experiments along two transpolar circuits (dotted lines in Figure 3) were in operation by HRB-Singer Inc. (Imhof, Musserm Oelbermann, and Volz, 1966). Figure 5 shows the phase deviations (middle) and relative amplitude variations (bottom) of NPG (18.6 kc/s) and NPM (26.1 kc/s) received in Europe, along with Penticton riometer (top), in the time interval of

00:00 through 05:00 U.T. on July 7. Concurrently with the Penticton SID, Sudden Phase Anomalies (SPA's) were produced over both of the high-latitude VLF paths. At approximately 01:20 U.T., a second but slower phase advance began on both signals, showing an onset of a slight PCA event. At about 02:00 U.T. the signal strength (bottom) also began to decrease because of intensified PCA. The two-stepped onset pattern in the VLF-PCA seem to correspond to those in the riometer-PCA discussed above.

GENERAL VIEW OF ABSORPTION EVENT OBSERVED ON JULY 7-10, 1966

Figure 6 shows the time history of cosmic noise absorptions at Thule (86.0° in corrected geomagnetic latitude), Fort Yukon (67.1°), and Healy, Alaska (63.7°) on July 7 through 10, 1966. Figure 7 shows latitude profiles of 30 Mc/s absorptions, along with the time variation of geomagnetic activity expressed by planetary Kp indices. The absorption is graded into three ranges as shown in the right top of Figure 7.

Since Thule is located near the geomagnetic pole and since the event occurred in July when the ionosphere above Thule was continuously sunlit, the time history of Thule record shows a time variation of solar cosmic ray flux. Chiver and Burrows (1966) obtained an empirical relation

$$N(1.3 < E < 7 \text{ Mev}) = (2 \times 10^{3}) A^{2.0}$$

at the South Pole with a 30 Mc/s riometer during September 1963 events. The PCA at Thule marked a maximum of 2.5 db at 13:0[illegible] U.T. on July 7, showing that the maximum flux of 1.3-7 Mev protons was some [illegible] 10^4 cm^{-2} sec^{-1} $ster^{-1}$. The PCA then decayed gradually until it went down below 0.3 db after 23:45 U.T. on July 8. Van Allen and Ness (1967) observed a distinctive, discontinuous drop in the intensities of solar protons flux with energy around 0.5 Mev at 21:06 U.T. on July 8, in association with an interplanetary shock wave that corresponds to the terrestrial sudden commencement (SC) at 21:02.2 U.T. However, there was no discontinuity in the Thule riometer records around the time of the SC. The absorption at 21:00 was 0.7 db, and it took some 4 hours before it went down below its half value. The same situation was observed by the Resolute Bay f min which indicates the flux of solar protons in somewhat lower energy regions. The difference between interplanetary protons and those precipitating upon the polar cap should be examined in further details.

The absorption at Ft. Yukon (67.1°) showed a typical time variation which is usually seen at the lower edge of the polar cap (Leinbach, Venkatesan, and

P. rthasarathy, 1965). The ratio of absorption Fort Yukon/Thule decreased in the local afternoon on July 7, but increased after 00:00 U.T. on July 8 along with the enhanced geomagnetic activity. In the pre-geomagnetic disturbance period, Healy, Alaska (63.7°) was the lowest latitude station which marked the PCA effect.

At the time of sudden commencement, 21:02 U.T. on July 8, the auroral zone stations including Churchill (70.3°) and Healy (63.7°) observed a pronounced enhancement of absorption, called the SCA (Sudden Commencement Absorption). Intermittent but outstanding absorptions were observed throughout the geomagnetic active period, especially in the local nighttime of the observatories. The AZA's (Auroral Zone Absorption) are associated with polar geomagnetic disturbances and auroral displays.

Figure 8 shows the latitude profiles of cosmic noise absorptions at 6 selected stages in the course of the PCA and AZA events. The numbers (1) through (6) correspond to those shown in Figure 7. These profiles are preliminary and need some correction, since the absorption in the polar cap edge is subject to a diurnal change in the geomagnetic cutoff as well as to the sunlight effect (Chivers and Burrows, 1966). However, these figures give a general idea of time sequence of absorption profiles throughout the event. At 01:45 on July 7 (1), an absorption of a few tenths of db was observed in the pole region, while all riometers above 64.2° observed the PCA at 02:30 (2). At 08:00 on July 7 (3), the lowest latitude of PCA attained to 63.7°. The dotted and chain lines in the profiles (5) 03:00 on July 9 and (6) 09:00 show the Auroral Zone Absorptions in American and European regions respectively.

SUMMARY

16 riometers, 6 vertical soundings, and 2 VLF propagation records in the northern polar region were used to analyze the development pattern of a PCA on July 7-10, 1966. The results obtained are summarized in what follows:

1. The PCA is attributed to a solar flare of importance 3 observed at 00:25 U.T. on July 7, that was accompanied by a major radio outburst of type IV. Time variation in the SID effects on a Penticton riometer was very similar to those in solar microwave impulsive bursts and hard X-rays observed by the satellite OGO-3 (Cline and Hones, 1967).

2. The first onset of PCA was observed at 01:20 U.T. at Shepherd Bay, Canada which is located 10° from the northern pole, and the slight enhanced ionization of a few tenths of db covered the whole north pole region before 02:00 U.T. On the other hand, auroral zone stations observed the PCA after

02:00. The two-stepped onset of the PCA corresponds to the differential arrival of solar electrons and protons at the earth, observed by the satellite IMP-3 (McDonald-Cline, 1967). The flux of 40 kev electron bursts, 1500 electrons cm^{-2} sec^{-1} $ster^{-1}$, observed by the same satellite can explain the first onset of a slight PCA near the geomagnetic pole (Lin and Anderson, 1967).

3. The PCA in the pole region marked a maximum of 2.5 db at 13:00 on July 7, and then decayed gradually until it went down below 0.3 db after 23:45 on July 8. There was no SC-assocated discontinuous decrease in absorption as observed in the interplanetary protons (Van Allen and Ness, 1967), while the auroral zone stations including Churchill (70.3°) and Healy (63.7°) observed a pronounced SCA.

The lowest latitude of enhanced ionization in the pre-geomagnetic storm stage was some 63° in the corrected geomagnetic latitude. After the onset of geomagnetic disturbances, the PCA was superposed by the AZA that appeared even in the lower auroral zone.

ACKNOWLEDGMENTS

The author is most grateful to the following members who collaborated in this subject by providing their useful data and giving valuable comments:

A. E. Covington, National Research Council, Ottawa, Canada

V. M. Driatsky, Arctic and Antarctic Research Institute, Fontanka, Leningrad, USSR

T. Goh, the McMath-Hulbert Observatory, Univerity of Michigan, Pontiac, Michigan, USA.

O. Holt, the Auroral Observatory, Tromsö, Norway

B. Hultq[illegible], the Royal Swedish Academy of Science, Kiruna Geophysical Observatory, Kiruna, Sweden

D. H. Jelly, Defence Research Telecommunications Establishment, Defence Research Board, Shirley Bay, Ottawa, Canada

J. V. Lincoln, Data Services of ITSA, ESSA, Boulder, Colorado, USA

A. J. Masley, Space Science Department of the Missile and Space Systems Division, Douglas Aircraft Company, Inc., Santa Monica, California, USA

E. J. Oelbermann and G. W. Imhof, HRB-Singer Inc., State College, Pennsylvania, USA

R. Parthasarathy, Geophysical Institute, University of Alaska, College, Alaska, USA

G. C. Reid, Space Disturbance Laboratory, ITSA, ESSA, Boulder, Colorado, USA

R. Rogers, Dominion Radio Astrophysical Observatory, Penticton, B.C., Canada

K. Sinno, F. Yamashita, and Y. Takenoshita, Hiraiso Branch, the Radio Research Laboratories, Hiraiso, Japan

H. Tanaka, Toyokawa Observatory, Nagoya University, Toyokawa, Japan

K. Toman and R. J. Cormier, AFCRL (CRUR), Bedford, Massachusetts, USA
I.Zhulin,IZMIRAN,p/o Akademgorodok, Moscow, USSR

The present work was carried out while the author held a senior post-doctral resident associate of the NAS-NAE at the NASA-Goddard Space Flight Center, on leave of absence from the Radio Research Laboratories, Tokyo, Japan. He is grateful to Dr. W. N. Hess, GSFC, for his kind hospitality. His thanks are due to Drs. F. B. McDonald and T. Cline, GSFC, for their discussions and comments.

REFERENCES

Bailey, D. K., Polar-cap absorption, Planet. Space Sci., 12, 495-541, 1964.

Bates, H. F. and P. R. Albee, High latitude VLF propagation, Report of Geophys. Inst. University of Alaska, UAG-R154, 1964.

Chivers, H. J. A. and J. R. Burrows, Simultaneous satellite and ground-based observations of solar protons, Planet. Space Sci., 14, 131-142, 1966.

Cline, T. L. and E. W. Hones, High energy solar X-rays of July 7 1966 presented at OGO-I and III working group meeting, GSFC, March 2, 1967.

Hakura, Y. and T. Goh, Pre-SC polar cap ionispheric blackout and type IV solar radio outburst, J. Radio Res. Lab. Japan, 6, 635-650, 1959.

Hakura, Y. and M. Nagai, Synthetic study of severe solar terrestrial disturbances of February 9-12, 1958, J. Radio Res. Lab. Japan, 11, 197-249, 1964.

Hakura, Y., Initial phase of the PCA events and compositions of the solar cosmic radiations, J. Radio Res. Labs. Japan, 12, 231-273, 1965.

Hakura, Y., Time variations in the solar X-rays producing SID's, Rep. Ionos. Space Res., Japan, 20, 30-32, 1966.

Hakura, Y., Entry of solar cosmic rays into the polar cap atmosphere, J. Geophys. Res. March, 1967.

Imhof, G. W., J. M. Musser, E. J. Oelbermann, C. Volz, Coordinated high-latitude experiments for the simulation of nuclear-burst effects on VLF systems, HRB-Singer Inc., 356-R-3, 1966.

Jelly, D. H., Private communication, February 1967.

Leinbach, H., D. Venkatesan, and R. Parthasarathy, The influence of geomagnetic activity on polar cap absorption, Planet. Space Sci., 13, 1075-1095, 1965.

Obayashi, T., Interaction of solar plasma streams with the outer geomagnetic field, J. Geophys. Res., 69, 861-867, 1964.

Parthasarathy, R., F. T. Berkey, and D. Venkatesan, Auroral zone electron flux and its relation to broadbeam radiowave absorption, Planet. Space Sci., 14, 65-83, 1966.

Reid, G. C., Private communication, December 1966.

Masley, A. J., and A. D. Goedeke, 1966 solar cosmic ray activity, presented at the USNC/URSI Fall Meeting, Palo Alto, California, December 9, 1966.

Reid, G. C. and H. H. Sauer, The influence of the geomagnetic tail on low-energy cosmic-ray cutoffs, J. Geophys. Res., 72, 197-203, 1967.

Van Allen, J. A., W. C. Lin, and H. Leinbach, On the relation between absolute solar cosmic ray intensity and riometer absorption, J. Geophys. Res., 69, 4481-4491, 1964.

Van Allen, J. A. and N. F. Ness, Observed particle effects of an interplanetary shock wave on July 8, 1966, J. Geophys. Res., 72, 935-942, 1967.

Winckler, J. R., Energetic X-ray bursts from solar flares, AAS-NASA Symposium on the physics of solar flares, GSFC, NASA-50, 117-129, 1963.

Winckler, J. R., Solar flare energetics, presented at OGO-I and III working group meeting, GSFC, March 2, 1967.

Lin, R.P., and K.A.Anderson, Electrons 40 kev and protons 500 kev of solar origin, to be published in Solar Physics,1967.

McDonald,F.B., and T.L.Cline, Relativistic solar electron event of 7 July 1966, to be presented at Tenth Meeting of COSPAR, London, July,1967.

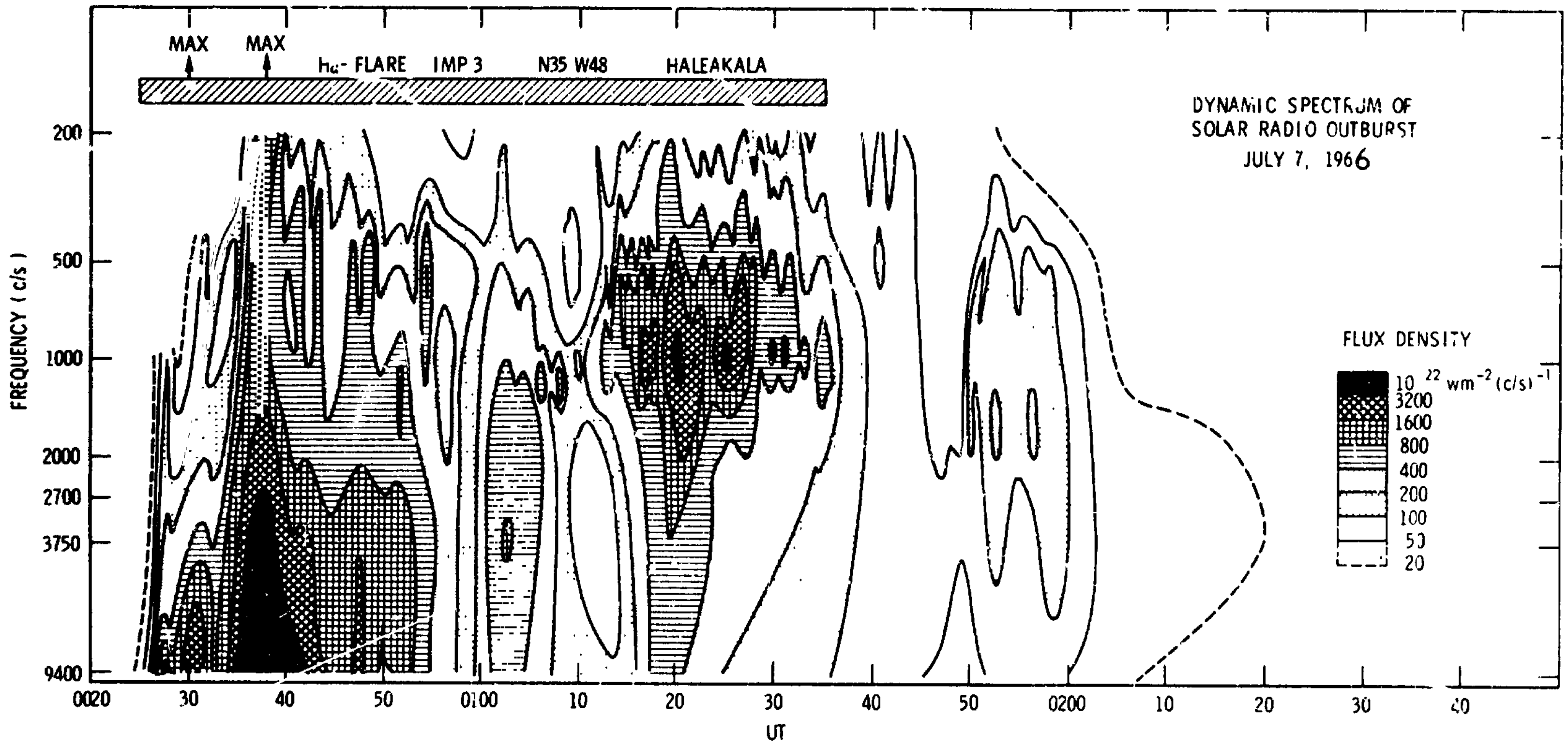

Figure 1. Dynamic Spectrum of Solar Radio Outbursts on July 7, 1966.

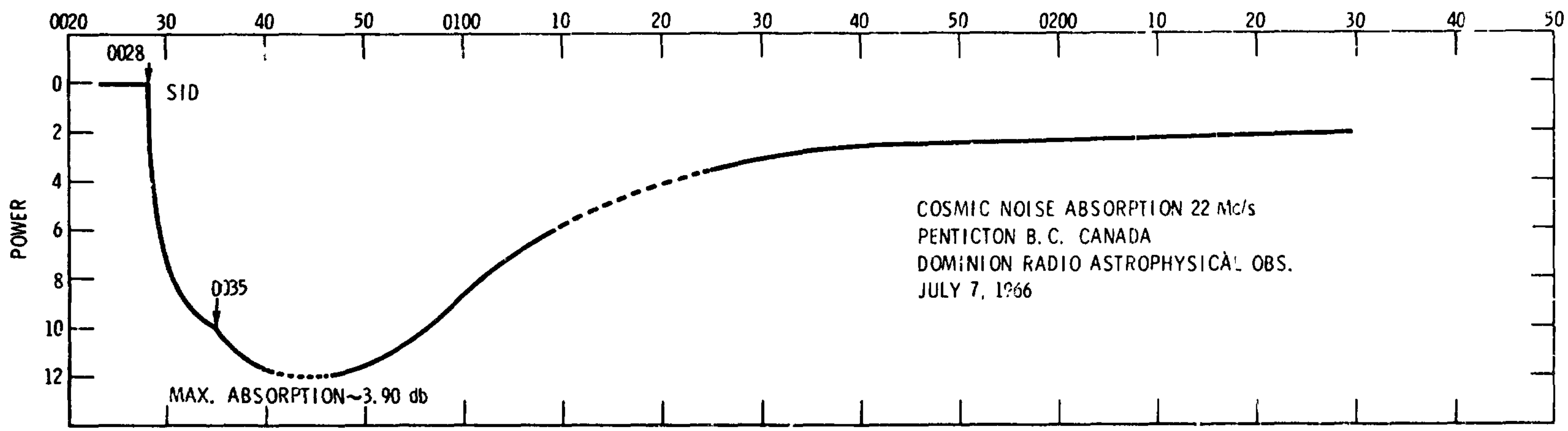

Figure 2. Sudden Cosmic Noise Absorption Observed at Penticton, Canada on July 7, 1966.

IONOSPHERE OBSERVATORIES IN THE NORTHERN HEMISPHERE

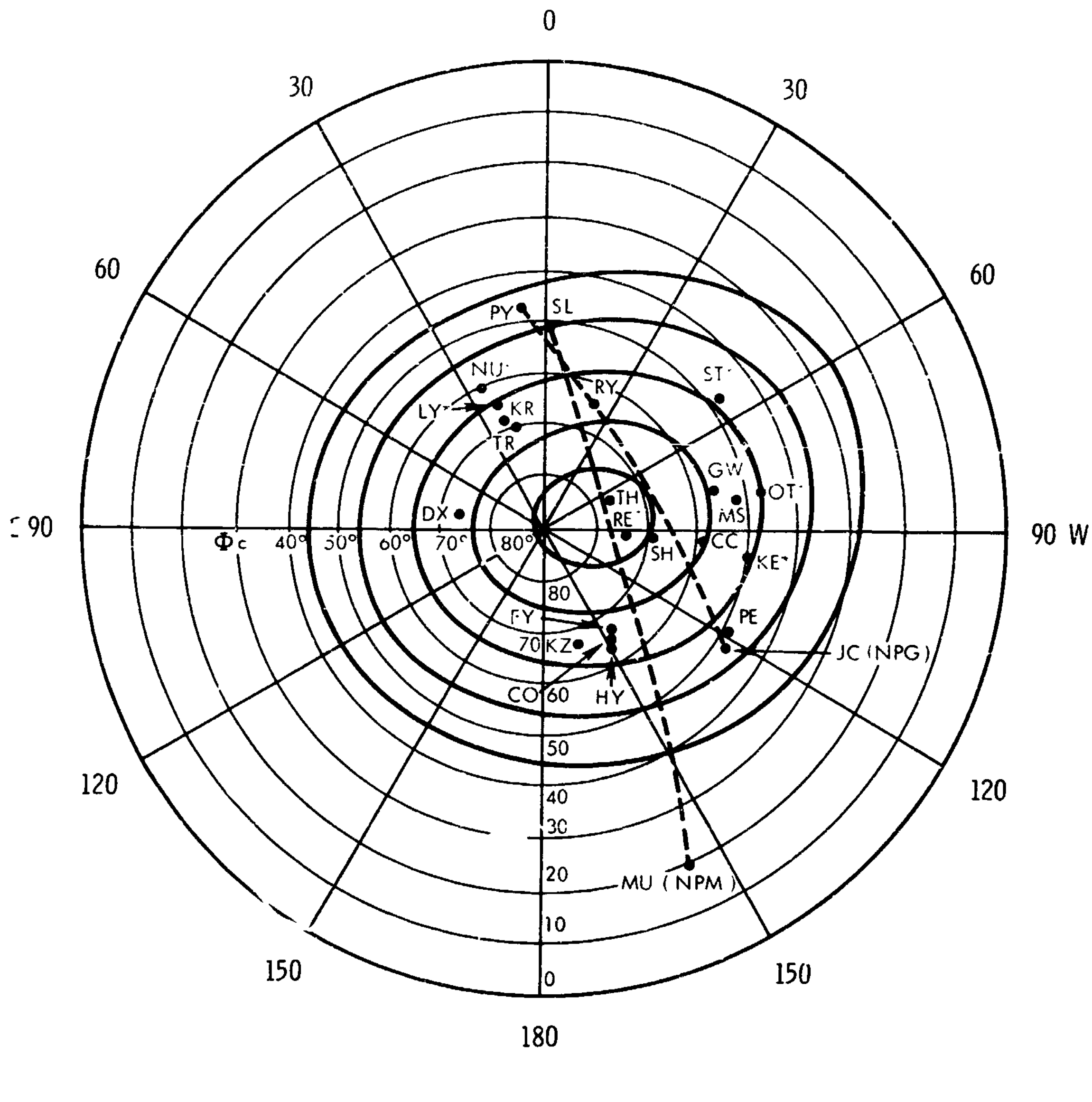

Figure 3. Locations of Ionosphere Observatories in the Northern Hemisphere in the Geographic Coordinates. Oval-shaped thick lines show the corrected geomagnetic latitude in a 10° step. The abbreviations are referred to Table 2, where marks * and + show the f min record used fully and partly, respectively.

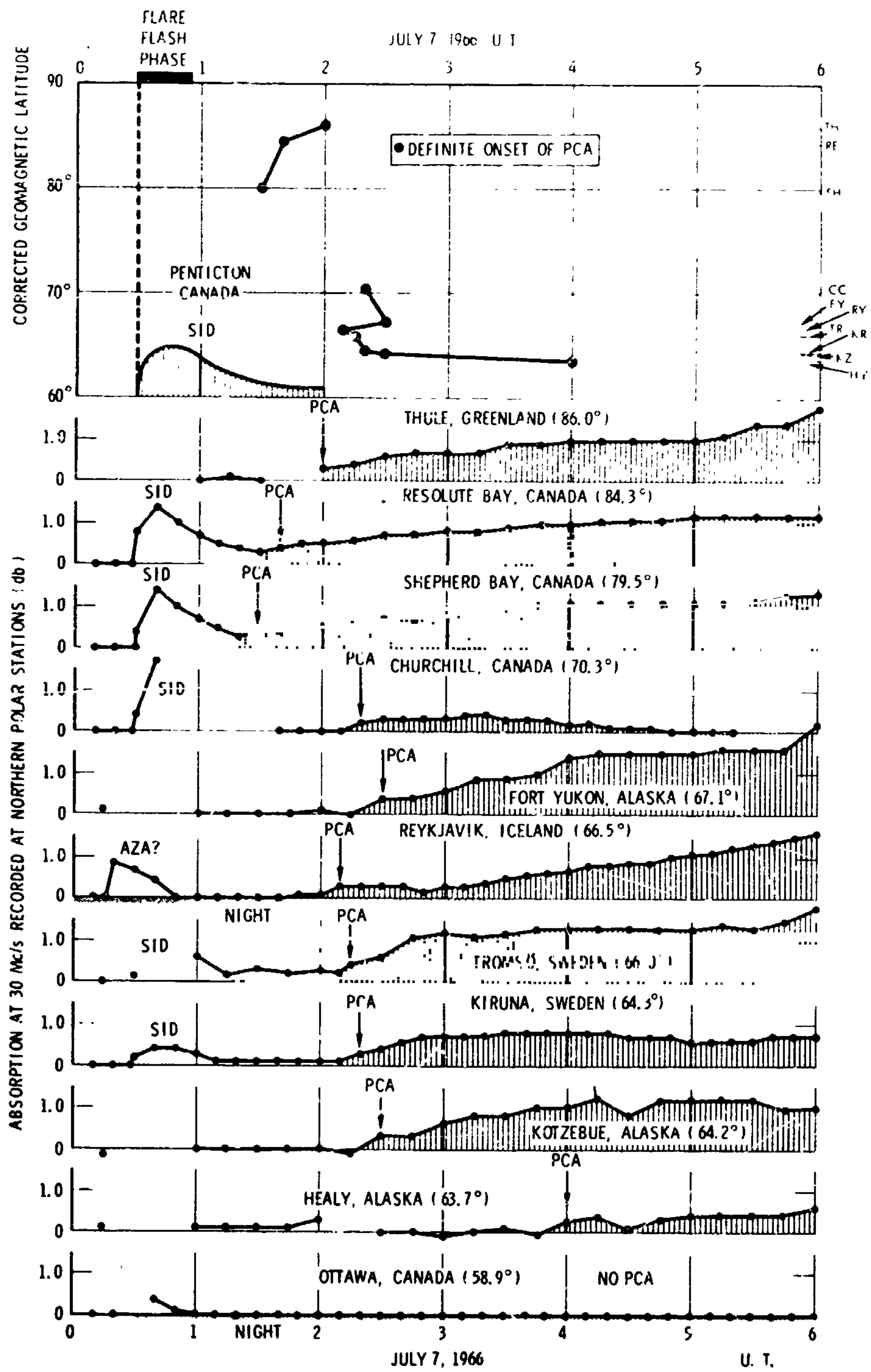

Figure 4. Initial Phase of PCA on July 7, 1966. Upper Figure: Latitude Dependence of Definite PCA Onset Time, and the SID Observed at Penticton (Hatched). Lower Figures: Variations in Absorption Observed at 11 Stations, Where Definite Onset Times are Indicated by Arrows.

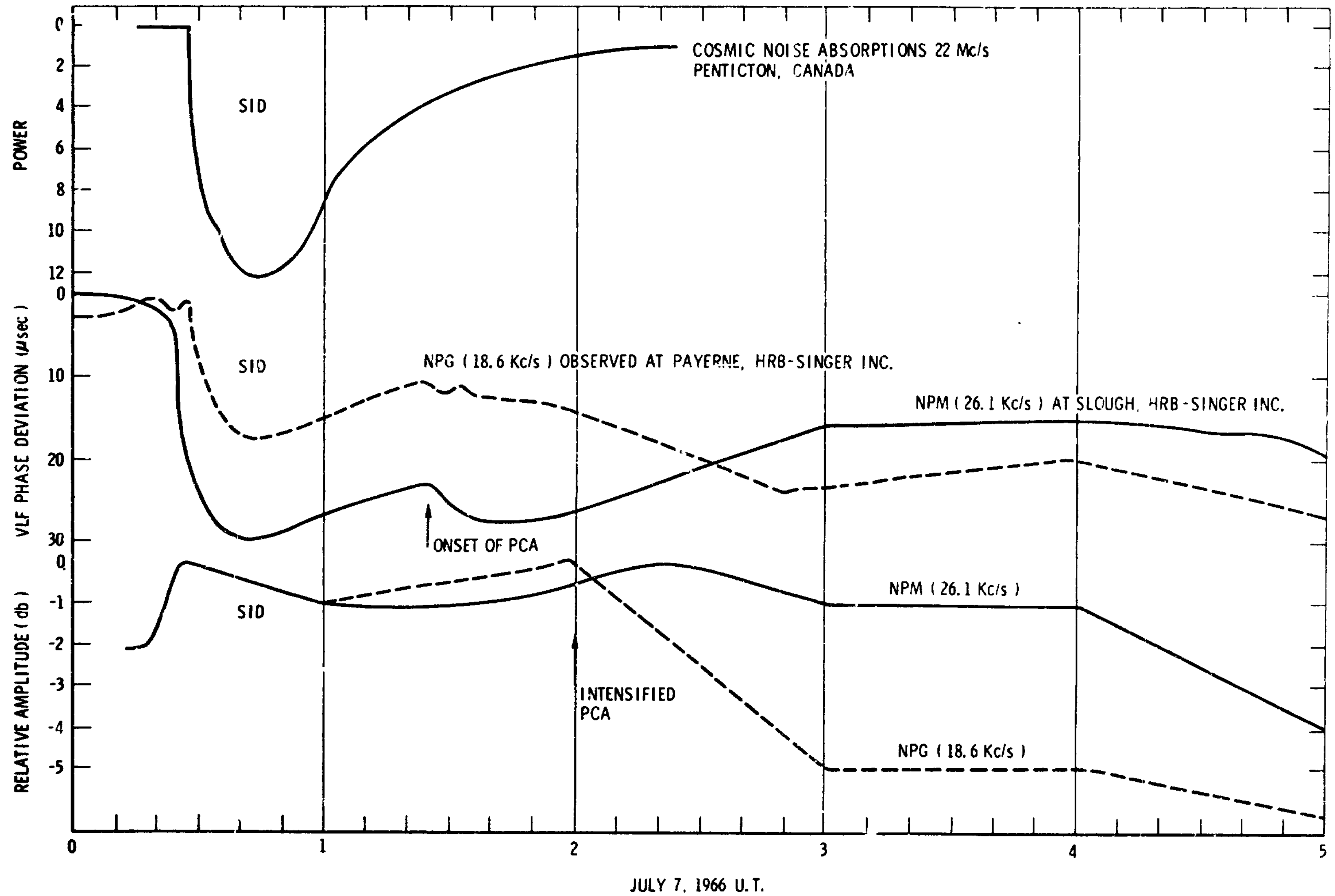

Figure 5. Initial Phase of July 7, 1966 Events Observed by Penticton Riometer (Top), VLF Phase Deviations (Middle) and Relative Amplitudes (Bottom) of NPM and NPG Signals to Europe. An SID and Two-Stepped Onset of PCA are Clearly Seen.

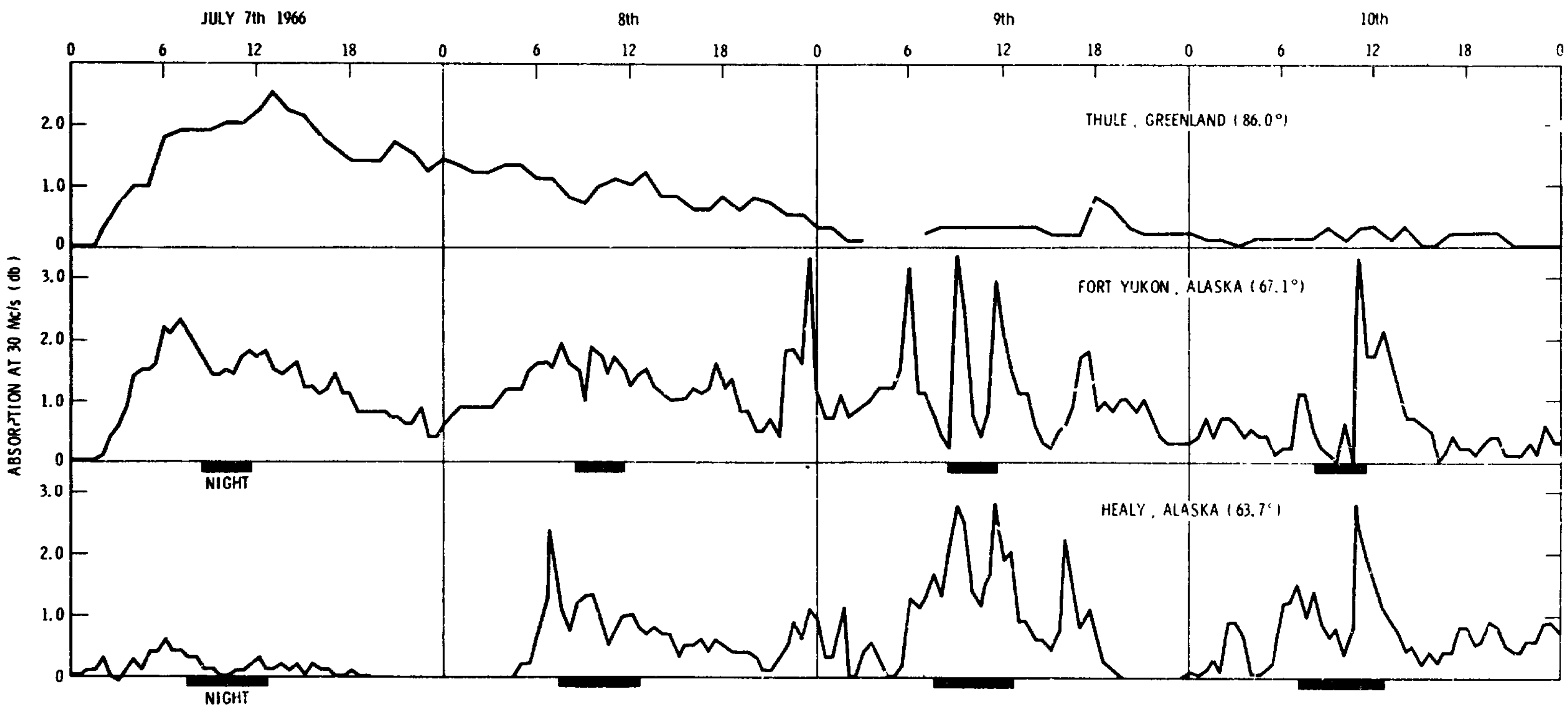

Figure 6. Polar Cap and Auroral Zone Absorptions of 27.6 Mc/s Cosmic Noise, July 7 - 10, 1966.

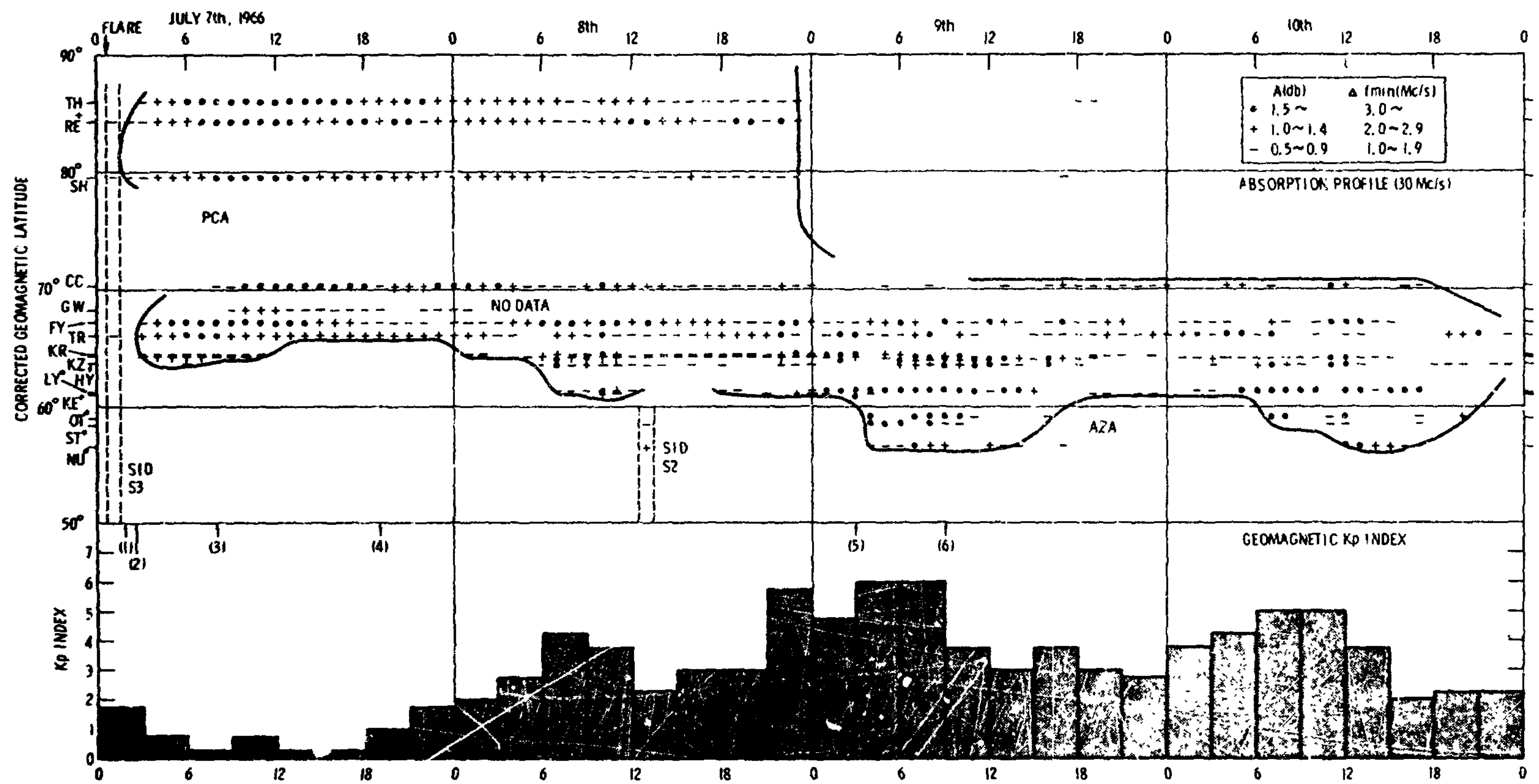

Figure 7. Development of SID, PCA and AZA Events on July 7 - 10, 1966 Expressed in the Corrected Geomagnetic Latitude Northern Hemisphere and Associated Geomagnetic Activity.

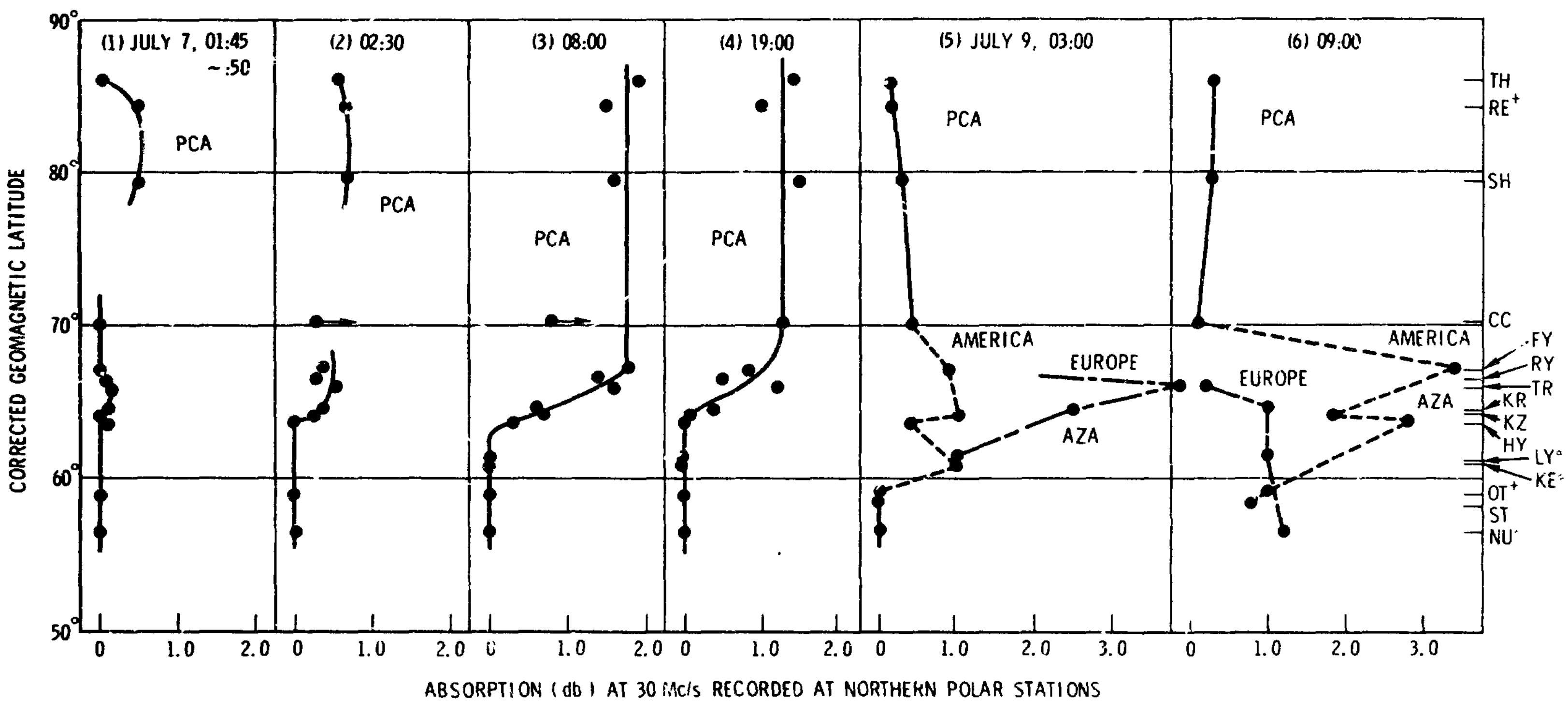

Figure 8. Latitudinal Profiles of Cosmic Noise Absorptions at 6 Stages During PCA and AZA Events on July 7 - 9, 1966.