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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-2-5. The Detection and Study of Solar Cosmic Rays by Radio Thchniques*

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Three distinct radio techniques have thus far been extensively used in the study of polar-cap absorption events (PCA's). PCA's represent a major ionospheric phenomenon resulting from the existence of a low-energy tail of the rather steep spectra of solar cosmic rays ejected from time to time from active solar regions. The most important energy range is from about 30 to 300 Mev. PCA's are much more common than would be surmised if knowledge of them rested solely upon the occurrence of sharp increases in ground-level cosmic-ray intensity relative to normal background. The techniques, which to be of greatest use, must be employed in geomagnetic latitudes greater than 65° to 70°, are:

—study of f_{min} behavior from ionosonde observations,
—use of riometers, and
—study of field-strength variations of VHF waves scattered obliquely from the lower ionosphere.

Each technique supplies somewhat different information. The advantages and limitations of each are discussed.

Solar cosmic rays can be detected at high latitudes even in the absence of ground-level effects by means of measurements of radio wave absorption. The absorption results from ionization between heights of about 45 and about 75 km produced by the cosmic rays. Other types of particle ionization over the polar regions seem mainly to occur above 80 km and are especially important in the 85 to 105 km region.

The solar cosmic rays have been found to consist mainly of protons arriving essentially isotropically at least during times of moderate to great solar activity. Their energy spectrum is usually representable as a fairly steep power law, and the energy range of greatest significance for the ionospheric absorption is from about 30 to about 300 Mev. The ionospheric absorption associated with solar protons is usually termed polar cap absorption (PCA) since, unlike auroral zone absorption, it occurs with considerable uniformity over the entire polar cap, i.e. both at and inside the auroral zone. A decade of study of PCA's has shown them to occur with much greater frequency than ground-level solar cosmic-ray effects, though all of the latter occurrences, which were widespread geographically, were followed by polar cap absorption within a matter of an hour or so. The magnitude of the ionospheric absorption for a given flux of solar protons is markedly dependent upon the presence or absence of sunlight, being much greater during daylight.

Curves have been prepared showing the non-deviative absorption in decibels for the ordinary wave as a function of frequency, corresponding to a typical auroral absorption and a typical polar cap absorption by day. The curves labelled A and B respectively in Fig. 1 are normalized to give a plane-wave absorption of 5 decibels at 30 Mc/s for a wave passing once vertically through the ionosphere. The third curve of Fig. 1, labelled C, indicates typical night values of polar cap absorption. The curves are based on recent information and ideas about the abnormal ionization produced under these various circumstances. Because the absorbing region produced by solar cosmic rays is usually far below the E layer, in a height region where the electron collision number is high, the absorption at frequencies between about 2 and about 5 Mc/s is seen to be nearly independent of frequency and much less than might have been expected from

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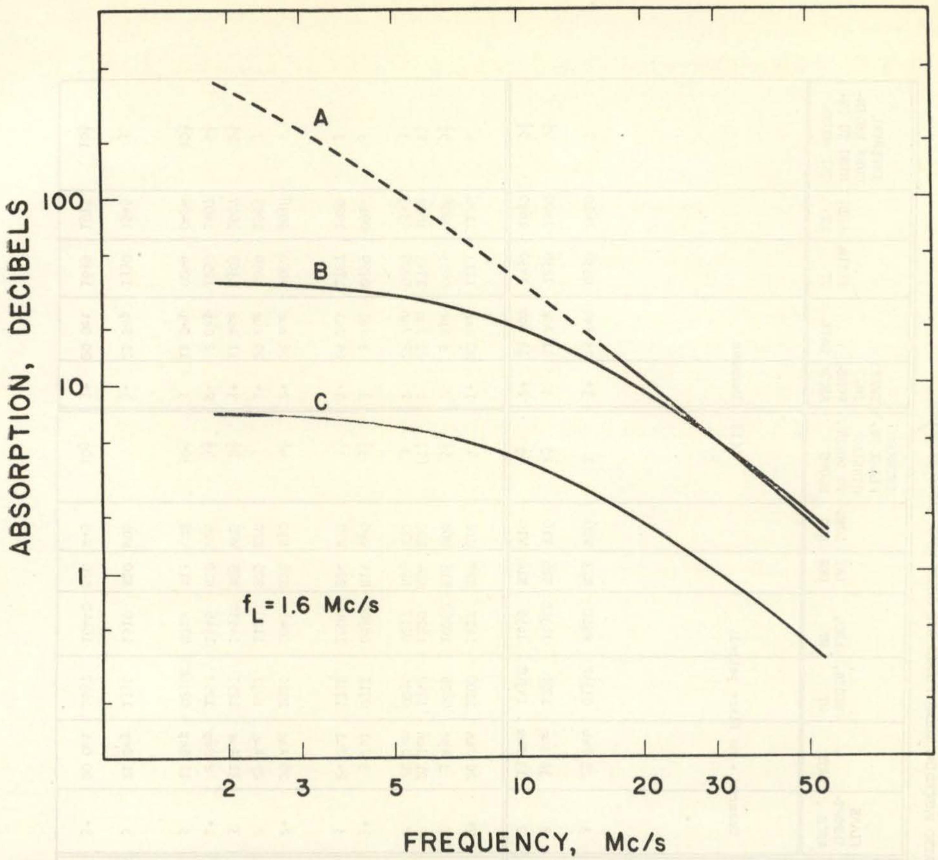

Fig. 1. Typical absorption versus frequency relations for A, auroral absorption, and B, C, polar cap absorption, day and night respectively, for the ordinary wave passing once vertically through the absorbing region.

the value at 30 Mc/s. On the other hand the auroral absorption, occurring in a region just below the *E* layer, rises more steeply with decreasing frequency. This is not accurately specified below about 16 Mc/s since total reflection often occurs at low frequencies.

These curves, though only crudely illustrative, are useful in the following discussion of the three principal radio techniques employed thus far in the study of solar cosmic rays (PCA events). A short Appendix gives the numerical data for which the curves were calculated.

Study of f_{min} Behavior

The study of ionosonde data for indications of PCA events is particularly valuable for extending the statistics of occurrence of PCA events backward in time into the period before other radio techniques for PCA detection had come into use. The increases in f_{min} for high-latitude ionosonde stations have been employed by Japanese and Canadian workers respectively to study specific PCA events and the statistics of PCA occurrence. The main difficulties associated with this technique are due to the small frequency dependence of the absorption in the frequency range where vertical incidence echoes are most commonly observed. Furthermore most modest PCA's, except possibly those of long delay, may not produce sufficient absorption to blackout the ionogram. A further difficulty arises when more than one PCA event takes place within a few days, and auroral absorption also occurs a day or so after the first event. Quite modest auroral absorption, insofar as observations at VHF are concerned, can cause complete ionosonde blackout. Comparison of simultaneous ionosonde records from several stations and other simultaneous geomagnetic data often proves useful in disentangling a PCA event.

Table 1 (a).

Table 1. CATALOG OF POLAR-CAP ABSORPTION EVENTS (1952 THROUGH 1960) FROM VHF IONOSPHERIC SCATTER OBSERVATIONS, WITH DETAILS OF POSSIBLY RELATED PRECEDING SOLAR FLARES AND SHORT-WAVE RADIO FADEOUTS

DATE	ONSET, UT	DURATION DAYS	CLASS	REMARKS	FLARE IMPORTANCE	DATE	BEGIN, UT	END, UT	LAT DEG	LONG DEG	INTERVAL FLARE BEGINNING TO ONSET, HOURS	SWRF IMPORTANCE	DATE	BEGIN, UT	END, UT	INTERVAL SWRF BEGINNING TO ONSET HOURS
1952				No PCA's detected.												
1953 19 May	1930	½	≤ S	Decimetric solar noise burst observed at Ottawa beginning 1916 UT.	Unknown - no flare patrol.						½(?)	Unknown				
1954				No PCA's detected.												
1955				No PCA's detected.												
1956 23 Feb	0430	4½	L	"Early effects" before 0400 UT, very large cosmic-ray increase.	3	23 Feb	0334E	0510	N23	W80	1	3+	23 Feb	0330	0610	1
31 Aug	1500	2½	S	Small cosmic-ray increase.	3	31 Aug	1228	1630D	N16	E16	2½	3	31 Aug	1239	1400	2½
13 Nov	2000	2	M		2	13 Nov	1430E	1555	N16	W10	5½	2+	13 Nov	1430	1630	5½
1957 20 Jan	1500	2½	S		2+	20 Jan	1100	1417	S27	W18	4	1+	20 Jan	1113	1126	4
3 Apr	1400	2½	S		3	3 Apr	0825	1026D	S15	W60	5½	2	3 Apr	0833	0908	5½
21 Jun 22 Jun	1300 0530	3½ 3	M	Possibly one event; onset time very uncertain; flare association very uncertain.	2 2	21 Jun 22 Jun	1742 0236	1820 0257	N14 N23	E02 E12	(?) 3	1 2	21 Jun 22 Jun	1743 0229	1802 0343	(?) 3
3 Jul	1030	2	M		3+	3 Jul	0712	0830D	N14	W40	3½	3	3 Jul	0729	0914	3
24 Jul	2030	½	VS	Doubtful late-afternoon effects of short duration; simultaneous onsets.	3	24 Jul	1712	1801D	S24	W27	3½	3-	24 Jul	1727	1920	3
29 Aug	0030	> ½	S		2+	28 Aug	2010	2048	S28	E30	4½	2+	28 Aug	2020	2038	4
29 Aug	1330	> 2	M	Superimposed on previous event.	2	29 Aug	1031	1110	S25	E20	3	1+	29 Aug	1039	1055	3
31 Aug	1530	2	M	Superimposed on previous event.	3	31 Aug	1257	1455D	N25	W02	2½	3+	31 Aug	1303	1607	2½
2 Sep	1730	1½	S		1+	2 Sep	1257	1346	N10	W26	4½	2-	2 Sep	1259	1407	4½
12 Sep	0900	1	VS	Doubtful effects; onset time very uncertain and of very long delay	3	11 Sep	0236E	0722	N13	W02	30½	3	11 Sep	0244	0424	30½
21 Sep	1630	2	M	Cutoff reduction effects beginning 1600 UT, 22 Sep.	3	21 Sep	1330	1510	N10	W06	3	3-	21 Sep	1330	1545	3
21 Oct	0300	2	M	Onset time very uncertain.	3+	20 Oct	1637	1644D	S26	W45	10½	3+	20 Oct	1639	1915	10½

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DATE	ON-SET, UT	DURA-TION DAYS	CLASS	REMARKS	FLARE IMPORT-ANCE	DATE	BEGIN, UT	END, UT	LAT DEG	LONG DEG	INTERVAL FLARE BE-GINNING TO ONSET, HOURS	SWRF IM-PORT-ANCE	DATE	BEGIN, UT	END, UT	INTERVAL SWRF BEGIN-NING TO ON-SET HOURS
1958																
10 Feb	0600	1	VS	Onset time very uncertain.	2+	9 Feb	2108	2302	S12	W14	9	1	9 Feb	2124	2144	$8\frac{1}{2}$
23 Mar	1830	$1\frac{1}{2}$	VS		3+	23 Mar	0947	1445	S14	E78	$8\frac{1}{2}$	3	23 Mar	0953	1309	$8\frac{1}{2}$
25 Mar	1300	$4\frac{1}{2}$	VL	Marked further increase in absorption at 1600 UT.	2 2	25 Mar 25 Mar	0529E 0557E	0555 0626	N17 S15	E25 E50	$7\frac{1}{2}$ 7	2 2	25 Mar 25 Mar	0525 0603	0600 0630	$7\frac{1}{2}$ 7
10 Apr	1000	$2\frac{1}{2}$	S	Uncertain flare association; no significant solar radio noise.	1+	10 Apr	0855E	1007	N18	W78	1	1	10 Apr	0841	0930	$1\frac{1}{2}$
7 Jul	0600	3	VL	Cutoff reduction effects beginning 1000 UT, 8 Jul.	3+	7 Jul	0020	0414	N25	W08	$5\frac{1}{2}$	3	7 Jul	0025	0230	$5\frac{1}{2}$
29 Jul	0500	1	VS		3	29 Jul	0259E	0408	S14	W44	2	3+	29 Jul	0240	0440	$2\frac{1}{2}$
16 Aug	0600	$2\frac{1}{2}$	M		3+	16 Aug	0433	0831	S14	W50	$1\frac{1}{2}$	3+	16 Aug	0432	0720	$1\frac{1}{2}$
22 Aug	1530	$3\frac{1}{2}$	L		3	22 Aug	1428	1717D	N18	W10	1	3+	22 Aug	1435	1727	1
26 Aug	0400	$2\frac{1}{2}$	L		3	26 Aug	0005	0124	N20	W54	4	3+	26 Aug	0010	0410	4
22 Sep	1400	3	M		2	22 Sep	1009	1035	N17	W65	4	1	22 Sep	1010	1025	4
1959																
11 May	0100	$5\frac{1}{2}$	VL	Cutoff reduction effects beginning 0400 UT, 12 May.	3+	10 May	2055	0200D	N18	E48	4	3+	10 May	2110	0630	4
10 Jul	0800	> 4	VL	Onset time uncertain, but marked further increase in absorption at 1200 UT; cutoff reduction effects beginning 1700 UT, 11 Jul.	3+	10 Jul	0206	0908D	N20	E66	6	3+	10 Jul	0200	0510	6
14 Jul	0800	> 3	VL	Superimposed on previous event; onset time determined from lower latitude paths; cutoff reduction effects beginning C700 UT, 15 Jul.	3+	14 Jul	0319	0901	N16	E06	$4\frac{1}{2}$	3+	14 Jul	0328	0628	$4\frac{1}{2}$
17 Jul	0300	5	L	Superimposed on previous event; onset time determined from lower latitude paths; very small cosmic-ray increase; cutoff reduction effects beginning 1800 UT, 17 Jul.	3	16 Jul	2115	0030	N15	W30	$5\frac{1}{2}$	3+	16 Jul	2118	0015	$5\frac{1}{2}$
2 Sep	0400	2	VS		2+	1 Sep	1924	2216	N12	E60	$8\frac{1}{2}$	2	1 Sep	1945	2058	8

Table 1 (b).

Table 1 (c).

Table 1. CATALOG OF POLAR-CAP ABSORPTION EVENTS (1952 THROUGH 1960) FROM VHF IONOSPHERIC SCATTER OBSERVATIONS, WITH DETAILS OF POSSIBLY RELATED PRECEDING SOLAR FLARES AND SHORT-WAVE RADIO FADEOUTS

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1960																
12 Jan	0700	1½	VS	Onset time uncertain.	3	11 Jan	2040	2355D	N23	E03	10½	2-	11 Jan	2100	2124	10
29 Mar	0800	1½	VS		2+	29 Mar	0705E	0952D	N11	E30	1	3+	29 Mar	0652	0853	1
30 Mar	2000	> 1½	VS	Masked by succeeding event; onset time very uncertain.	2	30 Mar	1455	1858	N12	E12	5	3	30 Mar	1520	1800	4½
1 Apr	0930	2	S		3	1 Apr	0845	1222	N12	W10	> ½	3	1 Apr	0850	0947	½
5 Apr	0800	1½	S		2+	5 Apr	0215E	0308	N12	W61	6	3+	5 Apr	0140	0417	6½
28 Apr	0200	1	VS		3	28 Apr	0130E	0145D	S05	E34	> ½	3+	28 Apr	0120	0300	½
29 Apr	0600	1½	M	Very rapid recovery during daylight on 30 Apr.	2+	29 Apr	0138	0710	N12	W20	4½	3	29 Apr	0205	0500	4
4 May	1030	<< ½	VS	Very short duration, about 2½ hrs; cosmic ray increase.	2	4 May	1000	1105	N14	W90	½	3	4 May	1015	1050	< ½
6 May	1800	2½	M	Onset time rather uncertain.	3	6 May	1404	2020	S10	E08	4	3	6 May	1427	1658	3½
13 May	0800	1	S	Some evidence for onset as early as 0400 UT.	3	13 May	0520	0733	N29	W67	2½	3+	13 May	0512	0853	3
3 Sep	0500	2½	S	Cosmic ray increase.	2+	3 Sep	0038	0154D	N18	E88	4½	3+	3 Sep	0045	0251	4
12 Nov	1400	2½	M	Large cosmic-ray increase; cutoff reduction effects beginning 0500 UT, 13 Nov.	3+	12 Nov	1320	1922	N26	W04	> ½	3+	12 Nov	1326	1600	½
15 Nov	0900	1½	S	Cosmic-ray increase; cutoff reduction effects beginning 1300 UT, 15 Nov.	3+	15 Nov	0207	0427	N26	W33	7	3+	15 Nov	0217	0630	6½
21 Nov	0200	1½	S	Small cosmic-ray increase.	2	20 Nov	2018	2024	N25	W90	5½	3-	20 Nov	2023	2145	5½

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Use of Riometers

Riometers measure total absorption through the ionosphere, and thus are influenced by auroral absorption. The irregular behavior of auroral absorption with time as compared with the fairly smooth behavior of polar cap absorption has proved useful in separating the effects. Riometers are capable of providing an accurate and quantitative measurement of the intensity of polar cap absorption by day, but are rather insensitive at night. Riometers have been mostly used at frequencies between about 27 and 50 Mc/s.

Use of Signal-Intensity Variations of VHF Waves Scattered Obliquely from the Lower Ionosphere

The principal advantage possessed by observation of oblique-incidence VHF scatter signal intensities is their complete immunity from effects of auroral absorption. This advantage, together with the availability of simultaneous and continuous records from a number of high-latitude paths, has made the observations especially valuable for defining onset times, durations, and approximate intensities of PCA events from late 1951 to the present time, thus providing what is believed to be the longest and most uniform set of PCA observations.

The intensity of the scattered signals, observed at frequencies mostly between 30 and 38 Mc/s, insofar as PCA observations are concerned, depends upon two considerations. From the transmission equation defining ionospheric scatter propagation it can be demonstrated that the received signal intensity, expressed in decibels, varies independently of frequency and directly as the logarithm of the ambient electron density at the levels where the scattering inhomogeneities exist. Thus if the electron density is increased, as during a PCA event, the signal intensity should increase. On the other hand if most of the abnormal ionization giving rise to the PCA event lies below the principal scattering levels then the signal intensity should exhibit a decrease owing to absorption which is proportional to the electron density and decreases rapidly as the frequency increases. During daylight when the increase in electron density associated with PCA events is very great, the absorption effect at the frequencies employed dominates the enhancement effect and the signal intensities show a strong net decrease. At night, on the other hand, when electron attachment occurs, the enhancement effect dominates the absorption, and the signal intensities are well above normal. Thus the onset times, and durations of PCA events can be ascertained with some precision independently of conditions of illumination, although the departures of signal intensity from normal do not directly measure the intensity of the absorption.

The discrimination against auroral absorption comes about because the principal scattering levels in high latitudes lie below the levels of the auroral absorption. By day the principal scattering stratum is believed to lie in the region of 65 to 75 km, whereas at night it lies near 85 km. Even at night the scattering takes place mostly below the region in which auroral absorption occurs.

An additional advantage possessed by the VHF scatter signal intensities lies in their immunity to interference from solar radio noise, which at times obscures the absorption effects when riometers are used by day.

In the next few years of low solar activity especially, useful information about solar cosmic rays can be obtained from a suitably distributed set of riometer stations in and near both polar caps, each station capable of observing at several frequencies simultaneously.

Appendix

The three typical curves shown in Fig. 1 are computed for approximating thick uniform absorbing layers as follows:

Curve	Lower and Upper Boundary Heights, km.		Electron Collision No., sec^{-1}	Corresponding Height, km.	Electron Density, cm^{-3}	Corresponding f_0, Mc/s
A Auroral	85	100	1.0×10^6	87	2.8×10^6	15.2
B PCA (day)	45	75	7.7×10^7	55	2.1×10^4	1.3
C PCA (night)	45	75	7.7×10^7	55	4.2×10^3	0.59

Discussion

Shapley, A.H.: It should be noted that PCA events which are classified as large by one technique may be small as seen by another, and vice-versa. There are many examples of this when one compares your "forwardscatter" list with the one compiled by Piggott and myself from southerh hemisphere f_{min} data. Isn't this because the techniques are effectively sensitive to increased ionizations at different levels, f_{min} relatively high and forward scatter relatively low?

Bailey, D. K: The answer to your question is "yes" as I described. In my list PCA's are classified according to the magnitude of the absorption observed at VHF at oblique incidence, and at levels below the scattering stratum.

Shapley, A.H.: The list of IGY PCA events by Piggott and myself from Antarctic f_{min} data was included in a paper given last month at the Pacific Science Congress. One looks forward to the possibility of intercomparing the various lists of events.

Piggott, W.R.: Mr. Chairman. If practical, it would be very helpful to us all to include Dr. Bailey's list of PCA events in the Proceedings of this Conference. Such lists are invaluable for further work.

Bailey, D. K.: If the conference proceedings can accomodate the extra material I should be happy to supply the list.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-2-6. Some Auroral Zone Disturbances at Times of Magnetic Micropulsation Storms

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Studies of magnetic field fluctuations coincident with auroral luminosity pulsations (J.G.R., Jan., 1961), with riometer absorption (J.G.R., Jan., 1961) and with electron bremsstrahlung (J.G.R., Oct., 1961) have been reported. There is strong evidence, therefore, that 5 to 30 sec period pulsations of the earth's magnetic field arise in the auroral zone at times of the precipitation of electrons into the ionosphere. It is the purpose of this paper to report some further investigations with this same point of view. The measurements to be described were taken near College, Alaska, between September, 1959, and September, 1960, using a two meter diameter loop antenna of 21,586 turns (J.G.R., Nov., 1959). A more complete report on this work will appear soon in the scientific literature.

First, we will discuss some studies in which standard magnetometer (magnetograms) and ionospheric sounder data (f-plots) were utilized. From the one year's records of 5 to 30 sec period micropulsation activity it was possible to select 31 occasions on which the field amplitudes increased rapidly on the record, clearly defining a "micropulsation storm" onset. Magnetograms and ionospheric f-plots were scaled during these times (Fig. 1). Most of the storms occurred near the midnight hours. The average behavior of the micropulsations shows a maximum in the first five minutes after the commencement and a decay at a rate of apx. 2.5 gamma per hour (Fig. 2). A measure of the percentage electron density increase over the monthly average value, evidenced by the f_{min} values, was obtained for the storm times and is shown in Fig. 3. Although only 15 min. data samples were available in this case a clear indication that the maximum occurs 30 to 60 min. following the micropulsation