in sunlit polar cap compared with that in dark polar cap a general behaviour even in magnetically quiet periods or a special characteristic only in magnetically disturbed period?

Hines, C. O.: It is quite a general behaviour, although I could not say whether or not it might be subject to some variation from quiet to disturbed conditions. The behaviour is certainly less clear during disturbed conditions—it is, then, more clear during quiet conditions in contrast to the behaviour that might be implied in the question.

Pigott, W. R.: The variation of f_{min} with absorption, as measured on frequencies near 300 Mc/s is dependent on the variation of sensitivity and noise level with frequency. Thus, experimentally, as the measured absorption increases, f_{min} at first remains constant and then increases linearly with frequency at most stations. The agreement between f_{min} and absorption measured on high frequencies should therefore be expected to be linear. The knee in the curve accounts for many apparent differences between stations when the absorption is small.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-2-10. Observations of Unusual Low Frequency Propagation Made During Polar Cap Disturbance (PCD) Events*

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The Radio Physics Laboratory has undertaken a series of experiments for the purpose of studying the lower ionosphere at high latitudes by the propagation of long radio waves, in particular the effects caused by polar cap disturbance (PCD) events. Phase and amplitude recordings made during the series of intense solar eruptions of 10, 12, 15 and 20 November and 5 December, 1960, together with amplitude recordings made during previous PCD events, have established the following facts. When the PCD is weak, i.e. a weak event affecting propagation at high latitudes, or a strong event affecting propagation near the low latitude extent of the disturbance, the diurnal variation of field strength is opposite to that normally observed, and the diurnal variation of phase is less than normal. When the effect is intense the diurnal variations of both phase and amplitude disappear almost entirely. The phase measurements, in addition, suggest that the apparent reflection heights are 10–12 km less than a normal day, and the long waves are probably reflected from heights of about 50–55 km. The remarkable feature of a lack of any diurnal variation during an intense PCD suggests that the lower edge of the ionization produced is independent of normal ionospheric processes, such as attachment of free electrons to form negative ions during the night, and must be determined mainly by the characteristics of the bombarding particles, such as the steepness of the energy spectrum, and nocturnal ionization processes, such as collisional removal of electrons from negative ions.

The Transmission Paths

The experimental observations with which we are concerned are field strength, and in one case phase recordings of CW transmissions at frequencies about 80 kc/s propagated to distances about 2000 km. The various transmission paths monitored are shown in

* This paper was read by I. Paghis.

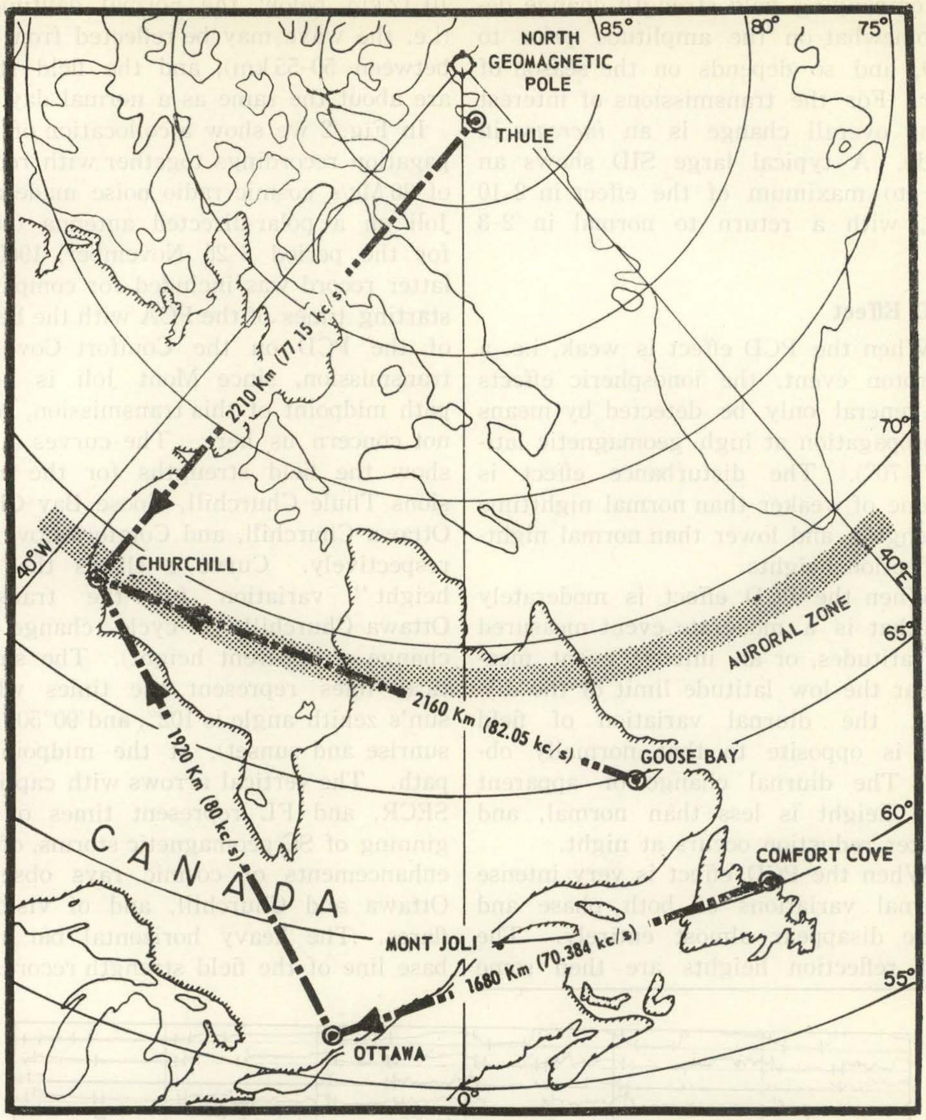

Fig. 1. Map showing the various L.F. propagation paths.

Fig. 1, from which it can be seen that we have recording for propagation paths south of, through, and to the north of the auroral zone, covering geomagnetic latitudes from 59.4°N to 78.5°N (at path midpoints).

The Observed Effects

A number of PCD events affecting LF propagation have been previously reported[1)-4)]. Until the events of November, 1960, no LF propagation transmissions above 60° geomagnetic latitude had been recorded during a PCD. The November events were nearly a perfect example demonstrating the different forms of the disturbance pattern on LF propagation under various intensities of PCD disturbances. A study of these observations, together with all past observations, has made possible an interpretation of the gross disturbance pattern, which is as follows:

The SID Effect

Since the PCD events are initiated by a large solar flare, class 3 or 3^+, the effects of the accompanying sudden ionospheric disturbance (SID) are large, and are as follows. The SID results in a *decrease* of the apparent "phase height" of reflection for LF waves.

The accompanying field strength change depends somewhat on the amplitude prior to the SID, and so depends on the season of the year. For the transmissions of interest here, the overall change is an *increase* in amplitude. A typical large SID shows an increase to maximum of the effect in 2–10 minutes, with a return to normal in 2–3 hours.

The PCD Effect

(i) When the PCD effect is weak, i.e. a weak proton event, the ionospheric effects can in general only be detected by means of LF propagation at high geomagnetic latitudes (>70°). The disturbance effect is mainly one of weaker than normal nighttime field strengths, and lower than normal nighttime reflection heights.

(ii) When the PCD effect is moderately intense, that is a moderate event measured at high latitudes, or an intense event measured near the low latitude limit of the disturbance, the diurnal variation of field strength is opposite to that normally observed. The diurnal change of apparent reflection height is less than normal, and the greater reduction occurs at night.

(iii) When the PCD effect is very intense the diurnal variations of both phase and amplitude disappear almost entirely. The apparent reflection heights are then some 10–12 km below the normal daytime value (i.e. the wave may be reflected from heights between 50–55 km), and the field strengths are about the same as a normal day.

In Fig. 2 we show a collocation of LF propagation recordings together with recordings of 30 Mc/s cosmic radio noise made at Mont Joli on a polar-directed antenna (curve f), for the period 8–25 November, 1960. This latter record was included for comparison of starting times of the PCA with the beginning of the PCD on the Comfort Cove-Ottawa transmission, since Mont Joli is near the path midpoint of this transmission, but need not concern us here. The curves a, b, c, d show the field strengths for the transmissions Thule-Churchill, Goose Bay-Churchill, Ottawa-Churchill, and Comfort Cove-Ottawa respectively. Curve e shows the "phase height" variation for the transmission Ottawa-Churchill (1 cycle change = 13 km change of apparent height). The short vertical lines represent the times when the sun's zenith angle is 102°, and 90°50′ (ground sunrise and sunset), at the midpoint of the path. The vertical arrows with captions SC, SECR, and FL represent times of the beginning of SC geomagnetic storms, of sudden enhancements of cosmic rays observed at Ottawa and Churchill, and of visible solar flares. The heavy horizontal bar near the base line of the field strength records means

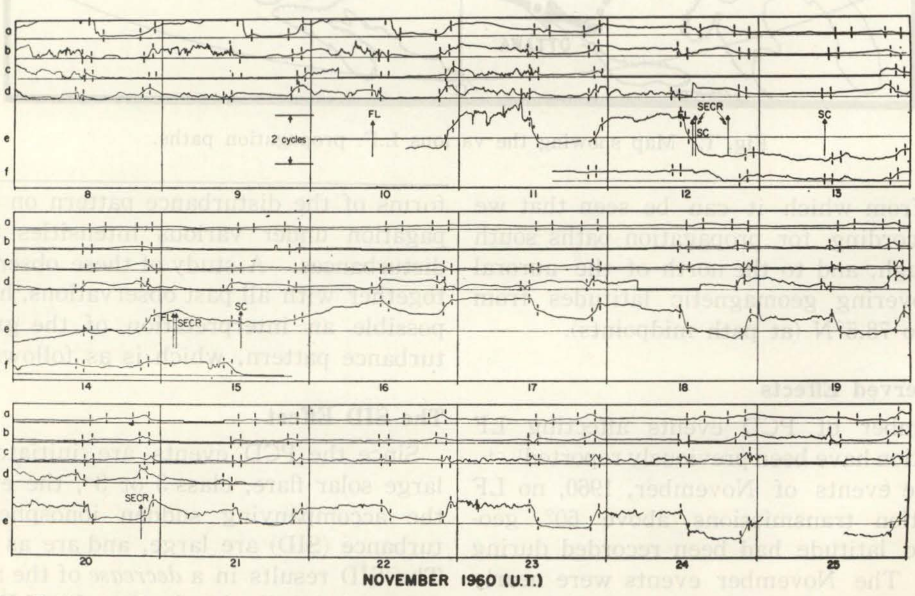

Fig. 2. Collocation of L.F. propagation data (see text for details) for month of November, 1960.

absence of records due to equipment failures.

These records show all the above described features.

Note:

(i) The SID effect on 12 November on the Comfort Cove-Ottawa transmission. It began at 1323, reached a maximum at 1332, and began to die away after this. The field strength would have returned to normal at about 1630 (in the usual way) if it were not for the PCD which began at 1354, and became apparent on this record at 1410.

(ii) The PCD on 12 November began coincident with the SECR. From 1400-1900 all LF field strengths were greater than normal, characteristic of an intense PCD. At 1900 a second SECR occurred, and after this the PCD became very intense since all transmissions show an absence of normal diurnal variations. The effects are more severe and longer in duration, the higher the geomagnetic latitude.

(iii) The decay of the PCD to moderate intensity occurred during the night of 14 November. Note that the variation of field strengths on 14 November is opposite to that normally observed for the Comfort Cove-Ottawa and Ottawa-Churchill transmissions, but the effect is still intense at higher latitudes (the Goose Bay-Churchill and Thule-Churchill records still show absence of a diurnal variation).

(iv) The PCD effect following the flare on 15 November was less intense than that on 12 November. Complete absence of diurnal variations were observed on the Ottawa-Churchill and higher latitude paths, but not on the Comfort Cove-Ottawa transmission, and the duration of the effects was shorter. This PCD event began at 0300 UT (i.e. during nighttime conditions for the paths concerned).

(v) The weak PCD effect following the SECR on 20 November was of still shorter duration, and affected the nighttime propagation only of the Comfort Cove-Ottawa and Ottawa-Churchil ltransmissions, but the effect was more severe at higher latitudes, since a diurnal variation on the Thule-Churchill transmission was completely absent on 21 November, whereas the PCD following the flare of 15 November had recovered to moderate intensity by 20 November.

(vi) A weak PCD effect is evident in the Thule-Churchill transmission during the nights of 10-11 and 11-12 November, presumably following the class 3 flare on 10 November. A similar weak PCD effect was observed following the class 3 flare of 5 December.

In Summary the PCD effects are as follows: the "phase height" is always less than normal, principally the nighttime height since the ionization produced during a PCD seems to be at heights below 75 km; the nighttime amplitude is always less than normal, but the daytime amplitude can be either the same or greater than normal depending on the magnitude of the disturbance.

Discussion

Low frequency (80 kc/s) radio wave propagation is quite different for short and medium range paths on the one hand, and long range paths on the other. Up to 1000 km, the reflecting layer, presumably the *D*-layer, is directly controlled by the ionizing radiations from the sun[5]. At 2000 km, the reflecting layer forms quickly at dawn, is exhaustively ionized shortly after sunrise, and disappears during evening twilight. Since this lower layer is independent of the zenith angle of the sun, it may be due to cosmic rays, as suggested by Nicolet and others[6)-8)]. If so, it should be named the *C*-layer to distinguish it from the *D*-layer.

The lack of diurnal variation during an intense PCD shows that this reflection level is now sufficiently low that the excess ionization produced is not markedly dependent on photodetachment, but is governed by the bombarding particle energy spectrum, and by the geomagnetic field, which determines the lowest energy particles to reach a given latitude.

PCD events very often happen in sequences, and the events of 10, 12, 15 and 20 November and 5 December were a remarkably long sequence. The active sunspot group responsible for the November PCD's appeared on the eastern limb of the sun on 6 November, crossed the central meridian on 12 November, and was last seen on the western limb on 18 November. The possible causative flare for the SECR on 20 November occurred from this same sunspot group (then behind the limb of the sun)[9),10)]. The flare of 5 December could quite reasonably have been from this same sunspot group, on its second time around. Activity died out after 5 December.

The PCD events of 10 November and 5 December do not seem to have been observed by other earth surface methods, although measurements made at Churchill[11)] of hydrogen emission from the night sky indicate the presence of considerably more hydrogen than normal on the nights of 10–11 and 11–12 November. LF recordings at very high latitudes seem to be the most sensitive method of detecting the presence of solar protons in the ionosphere by an earth surface experiment.

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I-2-11. The Electron Density Profile of the Lower Ionosphere During a Polar Cap Absorption Event*

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Polar cap absorption of radio waves is assumed to be caused by excess ionization produced by incoming solar protons. Taking a proton energy spectrum which appears to be fairly typical of these events, the resulting electron density profile is determined for both day and night conditions.

Assuming that the only species of negative ion in the lower ionosphere is O_2^-, the transition between day and night conditions is examined, and the electron density profile determined for solar zenith angles in the range from 90° to 102°. The vertical-incidence absorption of 30 Mc/s radio waves is evaluated as a function of solar zenith angle on the basis of this model. The theoretical prediction is compared with riometer measurements made during sunset conditions, and it is concluded that O_2^- is probably not the dominant negative ion in the lower ionosphere during twilight conditions.

Polar cap absorption of radio waves is now known to be caused by the ionization produced in the lower ionosphere by an influx of low-energy solar cosmic rays. The flux and spectrum of these particles have

* This paper was read by I. Paghis.