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AN INVESTIGATION OF MAGNETIC PULSATIONS AT CANADIAN MAGNETIC OBSERVATORIES

BY

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Erratum

Page 276, line 23, *following* "the theoretical value of the slope" *insert* "is".

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ABSTRACT

More than 1,000 pulsations, with approximately constant periods and ranges exceeding 3 gammas, have been studied using Meanook and Agincourt standard run magnetograms for the years 1951 to 1954. This investigation confirms the existence of two separate classes of pulsations, differing in form, time of diurnal occurrence, and mean period. Some additional characteristics reported earlier from Scandinavia are confirmed, but it is now thought that the narrow band Rolf micropulsations are not infrequent $\sim$ 1200 kms. south of the auroral zone in Canada. Very few regular pulsations were observed on magnetograms from stations north of the auroral zone.

Although magnetohydrodynamic waves in the upper parts of the ionosphere provide a possible periodic explanation, the different times of occurrence of the classes in Scandinavia and Canada, and even across Canada, the relationship of the primary sources of pulsations to magnetic disturbance measured by K-indices, and the southern geomagnetic extension in Canada of observable pulsations remain unexplained. Screening effects in the lower ionosphere are considered and provide one explanation of the observed amplitude-period trend.

INTRODUCTION

Quasi-periodic magnetic field disturbances have been commonly reported since continuous photographic recordings of field components were first made a century ago. Fluctuations occur with periods ranging from a few minutes to a fraction of a second, and with amplitudes from several gammas (one gamma = 10^{-5} oersted) to the lowest detectable limit of the equipment used (nowadays $\sim 10^{-2}$ gammas at 1 c.p.s.). The fluctuations consist of components with widely variable period (wide frequency band disturbance) and, more infrequently, components with a quasi-periodic nature (narrow band disturbance). These latter have been discussed previously by a number of authors notably Birkeland (1901), Rolf (1931), Harang (1936) and Sucksdorff (1939) using the records from European observatories. The nomenclature used is not very precisely defined, but in general regular pulsations are classed as micropulsations when the amplitude of the perturbation does not exceed about 3 gammas, and as giant pulsations or Rolf micropulsations when the amplitude exceeds 3 gammas. The lack of a systematic method of classification and nomenclature makes the character of the reported data very unsatisfactory, and to some extent, confused. Table I is an attempt to summarize the known facts about pulsations in as clear a way as possible. When more than one value for any parameter has been reported, the range of such values is indicated in Table I. It is clear that giant and micropulsations appear to have some quite different properties, in particular their geographical extent being different. From observational evidence, therefore, it is not apparent that they have a common explanation. In Table I two classes of giant pulsations are noted, in the manner first suggested by Sucksdorff (1939). Class A consists of pulsations with an amplitude envelope showing more or less regular modulation, whereas a Class B pulsation has an amplitude remaining approximately constant during much of the time of the pulsation. The two types are thought to exhibit some different properties. The outstanding giant pulsations with a regular shuttle-shaped envelope all naturally appear in Class A.

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TABLE I

SUMMARY OF PREVIOUSLY PUBLISHED CHARACTERISTICS OF MAGNETIC PULSATIONS

	Micropulsations	Giant Pulsations or Rolf Micropulsations
Duration		20 to 240 mins.
Mean Duration		78-89 mins.
Period	20 to 300 secs.	20 to 300 secs.
Mean period		1.3-2.0 mins.
Range	$<$ 3 gammas	$<$ 30 gammas, $>$ 3 gammas
Classes		A: modulated amplitude B: essentially constant amplitude
Number		A: 10 per year
Diurnal Frequency		A: max. at 3 L.T. } in Scandinavia B: max. at 10 L.T. }
Seasonal Distribution	Fairly uniform	Confused—perhaps maximum in equinoxes
Geographical Extent	Perhaps simultaneous over entire earth.	Over limited areas near auroral zone with linear source dimensions $\sim$1000 km.
Field Components		$\Delta Z < \Delta H$ or ΔD, $\Delta Z \sim \frac{1}{2}(\Delta H^2 + \Delta D^2)^{\frac{1}{2}}$
Phase of Components		Not in phase
Solar cycle variation	None	No. at solar min. = twice no. at solar max.: possible different behaviour of classes A, B.

Since all previous descriptions of the transient properties of giant pulsations refer to the European auroral regions, it seemed important to examine the phenomena in Canadian auroral regions. No detailed examination appears to have been made, although Madill and Cook (1956) have examined Meanook magnetograms for the occurrence of a number of short-period phenomena, and Whitham and Loomer (1957) have discussed some of the characteristics of pulsational activity well inside the auroral zone. In particular both the geographical extent of such activity in Canada and the diurnal frequency of occurrence at longitudes nearly 180° away from Scandinavia, were unknown. Of great interest also is the relationship of pulsational activity to magnetic disturbance generally.

It is now thought that magnetohydrodynamic waves are a possible source of giant pulsations, and Lehnert (1956) has shown that the observed periods do correspond to possible modes of oscillation. He suggests that damping is sufficiently small to allow standing waves to exist, and discusses in particular an approximation, in which two modes of oscillation, a longitudinal mode and a transverse (Alfvén) mode, can occur. A standing wave across the auroral zone with induced currents directed along the zone corresponds to the longitudinal mode, whereas a standing wave between ionosphere surfaces corresponds to the transverse case. No detailed discussion of the boundary conditions or the agency exciting an ionosphere resonant frequency appears possible, but Lehnert does suggest that giant pulsations may be limited to the auroral zone because enhancement of electron density caused by auroral discharge can remove the damping, and that the correlation of pulsations with magnetic storminess may be caused partly by an enhancement in conductivity, and partly by an increase in the number and strength of sources which may generate pulsations. Earlier Harang (1939) reported that radio echoes showed pulsations in an ionized region at a height of 650-800 km. with the same period as that of

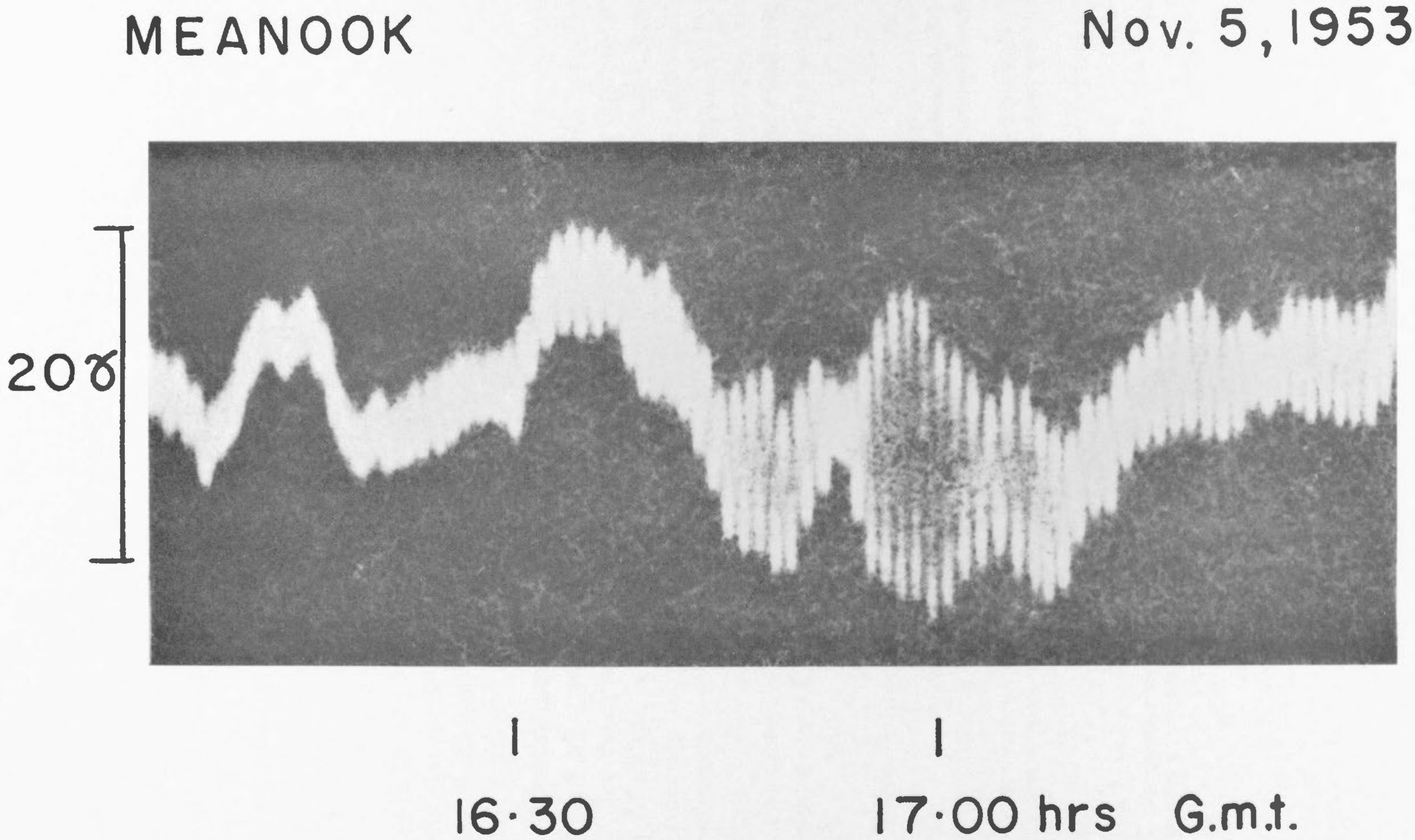

FIGURE 1. Regular pulsation at Meanook in D trace, Nov. 5th, 1953.

a giant pulsation which occurred at the same time. This possibly represents the detection by radio means of a magnetohydrodynamic wave.

The more widespread micropulsations were at first regarded as evidence for the closed periodic orbits calculated by Stormer. The usual objections to Stormer's theory can, of course, be made. Now it seems possible that magnetohydrodynamic phenomena may exist at very great distances from the earth, and the wave-lengths can become very large in interplanetary space.

* Note added in proof.

PROCEDURE

This investigation is limited because no quick run records are available. However, medium to high quality standard-run magnetograms are available. These have paper speeds from 15 to 20 mm. per hour and sensitivities from 2 to 10 gammas per mm. in different field components, depending on the variometers in use. Using these it is possible to investigate many of the properties of the two classes of giant pulsations discussed in Table I. It is of course impossible to measure phase differences between components, or the bandwidth directly, but information on such parameters as the mean period, intensity and duration and the diurnal, and annual frequency of occurrence can be obtained. It is estimated that, in practice, using a hand magnifying glass and good quality magnetograms, any disturbance with a period spread less than 0.3 times the midband period is counted as a regular pulsation. Rather arbitrarily, pulsations of fairly regular period with a maximum range in any field component greater than 3 gammas were examined.

Meanook (geomagnetic latitude, = 61.8°N) observatory records for the years 1951-54, when sufficiently good quality magnetograms for this purpose were available, were first read. Following Meanook, Agincourt (geomagnetic latitude, = 55.0°N) magnetograms for the same time interval were studied, and finally the available magnetograms from Baker Lake (geomagnetic latitude, = 73.7°N) and Resolute (geomagnetic latitude, = 83.0°N) were examined. The geomagnetic latitude of Meanook corresponds most closely to that of the auroral zone station Sodankyla in Finland, whereas Agincourt is generally south of the latitudes for which Rolf pulsations have been reported. The geographical locations of the other Canadian observatories with respect to Meanook are Agincourt ~2700 km. E.S.E., Baker ~1400 km. N.E. and Resolute ~2300 km. N.N.E. The path between Meanook and Baker Lake or Resolute crosses the auroral zone, whereas the path from Meanook to Agincourt lies entirely south of the zone.

Figure 1 is an illustration of a giant pulsation at Meanook obtained by enlarging a portion of the original magnetogram ×5. In an attempt to correlate regular pulsations with magnetic disturbance the A and B classes of pulsations were classified A_d, B_d and A_q, B_q respectively depending upon whether the pulsations appeared during disturbed or quiet magnetic conditions. The assessment of magnetic conditions was, like the magnetic character figure C, entirely subjective. Thus in Figure 1 the pulsation is classified A_q. It is clear that the classification into sub-classes is often an ambiguous process, but

* *Since the completion of the work, Committee No. 10 on "Rapid Variations and Telluric Currents" of the International Association of Geomagnetism and Aeronomy, I.U.G.G. has recommended a new system of classification of pulsations. Under this classification, the events described in this paper would in general be listed as pt, and many of them, particularly in the sub-group A, would be listed as pt A. The selection of the outstanding shuttle-shaped regular pulsations described later becomes in the terminology now accepted, the selection of pg.*

was nevertheless believed to be worthwhile. It is convenient to use the term regular pulsations in discussing the results, and reserve the term giant pulsations for very regular shuttle-shaped oscillations only, which are discussed later.

THE RESULTS FROM MEANOOK AND AGINCOURT OBSERVATORIES

In the years 1951-54, 489 regular pulsations were observed at Meanook and 521 at Agincourt. Table II shows the distribution in classes in each of the four years. Allowing for uncertainties introduced (more particularly at Meanook) by the varying definition of the magnetograms, it seems likely—

TABLE II

THE DISTRIBUTION IN CLASSES OF REGULAR PULSATIONS AT MEANOOK AND AGINCOURT DURING 1951-1954

Year	Observatory	A_q	A_d	B_q	B_d	A	B	Total
1951	Meanook..........	5	2	17	5	7	22	29
1952	Meanook..........	5	9	71	16	14	87	101
1953	Meanook..........	14	21	143	16	35	159	194
1954	Meanook..........	26	20	103	16	46	119	165
All	Meanook..........	50	52	334	53	102	387	489
1951	Agincourt..........	11	2	69	12	13	81	94
1952	Agincourt..........	18	1	94	18	19	112	131
1953	Agincourt..........	9	2	82	35	11	117	128
1954	Agincourt..........	22	0	98	48	22	146	168
All	Agincourt..........	60	5	343	113	65	456	521

(1) that the number of pulsations of this type observable at Agincourt ~1200 km. south of the centre of the auroral zone is much the same as the number observed at Meanook ~500 km. south of the centre,

(2) that the number of both the A and B classes increases with decreasing solar activity (1954 was a year of minimum solar activity): the more uniform Agincourt magnetograms suggest about a two to one increase in number from sunspot maximum to sunspot minimum,

(3) that at Meanook about half the A class pulsations occur at magnetically quiet times, whereas about 80 per cent of the B class pulsations occur at quiet times. A similar result for the B class pulsations holds for Agincourt, but an even higher percentage of the A class pulsations appears at quiet times. This suggests that there is no very simple relationship of the two classes to disturbance generally: this must presumably mean that the identification of the B class in particular, is often only possible when the magnetogram records are temporarily quiet.

Figure 2 shows the diurnal frequency distribution for classes A and B, and for the A_q, B_q sub-classes. The ordinate is the number of pulsations occurring in two-hourly intervals of the Greenwich day for the four years. A pulsation is counted in any hourly interval in which it occurs for at least 20 minutes. The times of local noon and midnight are also indicated on the Figure 2 and the typical diurnal variation of the K-index of disturbance is shown. For comparison the results of Sucksdorff (1939) for Sodankyla are shown. It is obvious that the times of maximum of the A and B classes do not agree on a universal time basis or on a local time or local geomagnetic time basis. In particular the nighttime phenomena of Scandinavia become daytime phenomena in Canada and

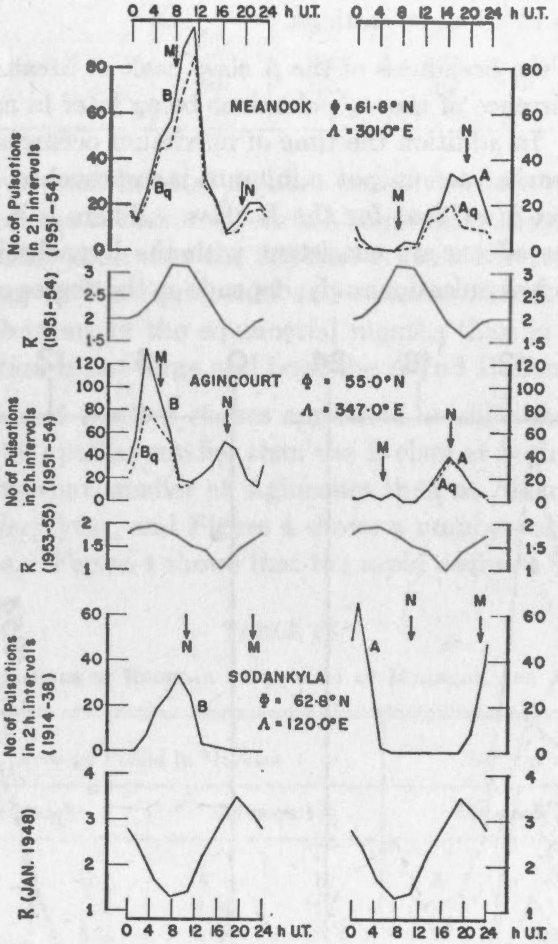

FIGURE 2. The diurnal frequency of occurrence of the A, A_q, B, and B_q classes of regular pulsations and the diurnal variation of the mean K-index at Meanook, Agincourt and Sodankyla.

vice versa. Even across Canada, between Agincourt and Meanook, the only approximate agreement in times is that the broad A class maximum occurs near local noon or local geomagnetic noon at both locations whereas the sharper B class maxima occur at distinctly different times. It is important to consider Agincourt since without these results it would have appeared that there was agreement between Meanook and Sodankyla on local time, but with a reversal of classes. It is of interest to note that the results presented in Figure 2, contrasting the Canadian and Scandinavian data, do not support the idea that the primary sources of pulsational activity approach the earth in a geometrically fixed way, with respect to the sun, and enter the ionosphere along the earth's magnetic field lines.

In Canada the maximum of the B class occurs near the magnetically most disturbed time of the day on the average (slightly after it at Meanook and before it at Agincourt) whereas the broad A class maximum occurs near the magnetically quietest time of day, as indicated in the K-index curves. This variation is the opposite from that found in Scandinavia, and suggests that it is not true that regular pulsations occur shortly after the most disturbed times of day. However, a broad maximum in numbers is related to the minimum K values at all three stations.

It was found that the broadness of the A class peak at Meanook is produced by the time of maximum occurrence of the A_d pulsations being later in each year than the time for the A_q pulsations. In addition the time of maximum occurrence of the total A class becomes increasingly earlier as sunspot minimum is approached. This is illustrated in Figure 3; no such effect is evident for the B class. There is a much smaller effect at Agincourt. Both these effects are consistent with the hypothesis that the diurnal frequency maximum of A class pulsations only, depends on the degree of magnetic disturbance.

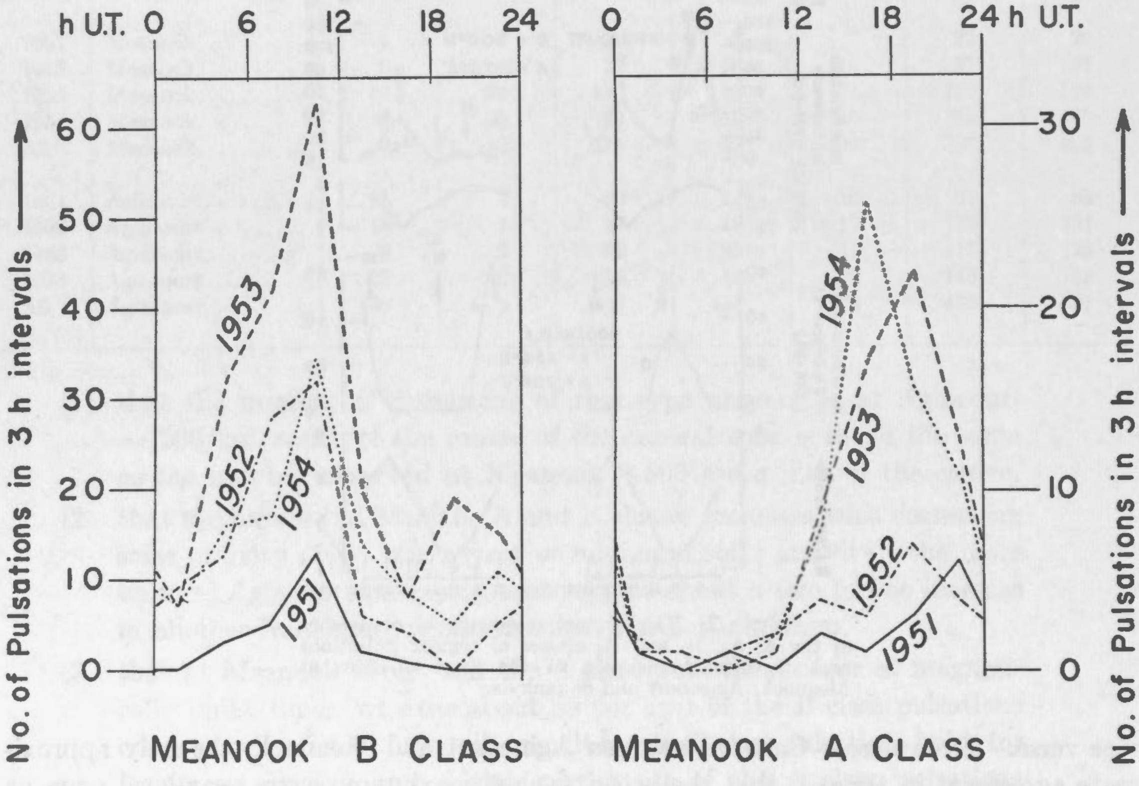

FIGURE 3. The diurnal frequency of occurrence of the A and B classes of regular pulsations at Meanook during the years 1951, 1952, 1953, and 1954.

The seasonal changes in the diurnal frequency of occurrence were investigated; generally the same results were obtained in all seasons for the more numerous B class pulsations. In all the years, it was found at Meanook that the sharpest maximum was obtained at the summer months and the broadest in the equinoxes.

The total number of pulsations of the two classes occurring in the different seasons is shown in Table III. Inconsistent results are obtained at the two locations. At

TABLE III

THE SEASONAL DISTRIBUTION OF REGULAR PULSATIONS AT MEANOOK AND AGINCOURT DURING 1951-54

	Meanook			Agincourt		
	A	B	Total	A	B	Total
Winter	41	122	163	22	149	171
Equinox	32	130	162	27	172	197
Summer	29	135	164	16	135	151

Meanook a seasonal variation in total number cannot be detected, that of the A class being opposite to that of the B class. There is a suggestion which is confirmed by examining the individual yearly data that the daytime A class is relatively more frequent in the winter months than in the equinoctial and summer months. At Agincourt there appear to be more pulsations in the equinoctial months than in the winter or summer months, but the variation is not large and both the A and B classes change together.

The average periods of the two classes appear to be different, the A class having a mean (and most probable) period smaller than the B class at both locations. The differences appear to be somewhat smaller at Agincourt than at Meanook. Table IV shows this trend is present every year, and Figure 4 shows a number-versus-period distribution curve for both locations. Figure 4 shows that the rapid decrease in number of pulsations

TABLE IV

THE AVERAGE PERIODS AND RANGES OF REGULAR PULSATIONS AT MEANOOK AND AGINCOURT DURING 1951-1954

	Average Period in Minutes				Average range $\triangle F$ in Gammas			
	Meanook		Agincourt		Meanook		Agincourt	
Year	A	B	A	B	A	B	A	B
1951	1.2	1.9	1.4	1.7	17	12	10	10
1952	1.3	1.9	1.4	1.8	12	15	9	9
1953	1.4	1.9	1.3	1.6	12	13	10	9
1954	1.1	1.5	1.2	1.5	13	15	10	9
All	1.3	1.8	1.3	1.6	13	14	10	9

with very short periods is real and is not an effect produced by the lower limit of resolution using standard-run magnetograms. The different average periods of the two classes produce a real diurnal variation in mean period which can be discerned on scatter diagrams for both observatories. Whilst the difference in mean period between the two classes seems real, it is not thought that the variations from year to year shown in Table IV, in the mean period of both classes, are significant. Figure 4 also suggests that the variation in period of regular pulsations is somewhat greater at Meanook than at Agincourt.

The maximum range of each pulsation was measured in three orthogonal field components. The average amplitude in each hour of the day is remarkably constant, but there is a small diurnal variation in amplitude because the B class of pulsations apparently have a mean amplitude somewhat larger than the A class at Meanook, and vice versa at Agincourt. Table IV shows that these mean differences are not very consistent from year to year at either station and it is not thought that there is any real difference. Amplitude distribution plots again show that there is a rapid decrease in the number of pulsations before the lower limit of measurement (3 gammas) is reached. The most probable range at both stations is between 5 and 10 gammas. Table IV refers to the total perturbing vector, $\triangle F$, but essentially the same results are obtained if the larger horizontal component of perturbation is used. The largest pulsations are of the B class type and usually occur near the diurnal frequency maximum.

The seasonal variation of duration, period and amplitude was investigated in each year, and Table V summarizes the results for the four years. At Meanook there is no

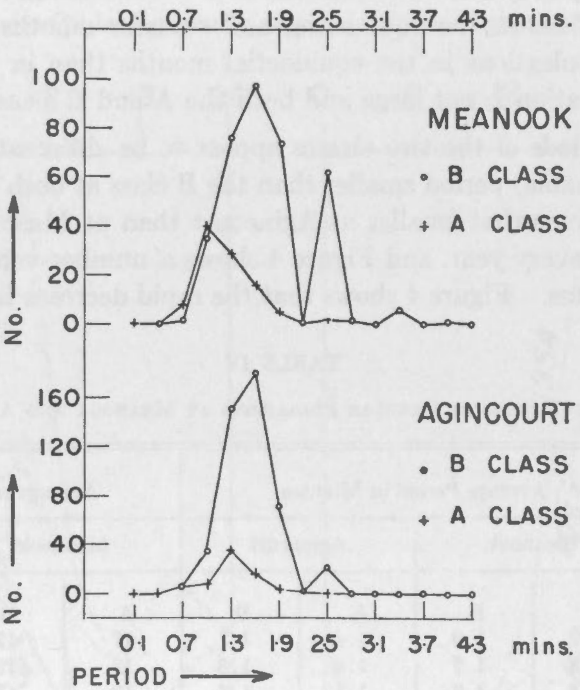

FIGURE 4. The number-period distribution curves for the A and B classes of regular pulsations at Meanook and Agincourt for the years 1951-54.

systematic difference in the mean period and duration from season to season and so the average in Table V for all years is very constant in each season. Much the same result is found for amplitudes: the vertical component, $\triangle Z$, is between three to four times smaller than the total horizontal component, $\sqrt{(\triangle D)^2 + (\triangle H)^2}$, and at Meanook the average component along the meridian is always greater than that perpendicular to the meridian. In computing $\triangle F$ however, we neglect the effects of induction inside the earth. The penetration depth of electromagnetic waves with a period $\sim 10^2$ seconds is ~ 100 km., and so it seems unlikely that local crustal conditions at different continental observatories would produce seriously different local corrections in $\triangle Z$ and in $\triangle H$, $\triangle D$ by the different effects of induction inside the earth. Consequently since $\triangle Z^2 << (\triangle H)^2 + (\triangle D)^2$ it

TABLE V

THE SEASONAL VARIATION IN PERIOD, DURATION AND RANGE OF REGULAR PULSATIONS AT MEANOOK AND AGINCOURT DURING 1951-54

Season	Observatory	T mins.	Duration mins.	ΔD	ΔH	ΔZ	ΔF	$\{(\Delta D)^2 + (\Delta H)^2\}^{\frac{1}{2}}/\Delta Z$
							gammas	
Winter......	Meanook...	1.7	51	7	10	4	13	3.3
Equinox.....	Meanook...	1.7	51	8	12	4	15	3.8
Summer.....	Meanook...	1.7	55	7	9	3	12	3.7
Winter......	Agincourt..	1.7	56	5	7	3	9	3.3
Equinox.....	Agincourt..	1.5	50	5	7	3	9	3.3
Summer.....	Agincourt..	1.5	40	6	7	2	9	3.9

seems likely that conclusions based on comparing ΔF cannot be seriously in error. It is clear that the effects of the highly conducting oceans may be serious on stations less than ~100 km. away.

At Meanook the mean amplitude of the disturbed and quiet sub-classes was determined for both the A and B types. It was found that

$$\frac{\Delta F\ (A_d)}{\Delta F\ (A_q)} = 1.0(5) \text{ and } \frac{\Delta F\ (B_d)}{\Delta F\ (B_q)} = 1.3(9).$$

This suggests that the strength of the B class sources increases with disturbance whereas no such effect is apparent for the A class.

At Agincourt a seasonal examination of the data for each season in each year shows that in general there are no outstanding seasonal variations in amplitude, duration and period, except that larger periods are apparently always found in the winter months, when the durations are also somewhat longer. Much the same ratio between the horizontal and vertical perturbations is found at Agincourt, and once again the mean perturbation is greater in the meridian.

The maximum range of any of the pulsations measured at Meanook was 33 gammas in ΔD, 47 gammas in ΔH and 19 gammas in ΔZ. At Agincourt the maximum pulsational range was only about half that at Meanook, 24 gammas in ΔD, 23 gammas in ΔH and 15 gammas in ΔZ.

THE OUTSTANDING GIANT PULSATIONS

For comparison with the infrequent shuttle-shaped giant pulsations, described in Scandinavia, the class A pulsations were re-examined and a selection made of those with a definite shuttle form; 47 were selected at Meanook and 24 at Agincourt. Approximately one half of them occurred at disturbed times at both locations. As found before, the diurnal variation of frequency of occurrence is somewhat later for the disturbed class than for the quiet class at both stations (20-21 hrs. U.T. for A_d, 15-17 hrs. U.T. for A_q at Meanook and 18-19 hrs. U.T. for A_d, 16-17 hrs. for A_q at Agincourt). The seasonal variation of the outstanding giant pulsations is the same as that of the A class discussed above. Since approximately half of the previously considered A class pulsations have been selected as outstanding pulsations at both locations, it is clear that the other statistical properties of the outstanding giant pulsations are also identical with the properties of the A class discussed above.

This suggests that the selection of precise shuttle-shaped forms has no intrinsic importance.

SIMULTANEOUS PULSATIONS AT MEANOOK AND AGINCOURT

A comparison of all the regular pulsations showed 22 coincident (i.e. within one or two minutes) pulsations with approximately the same period at both stations. This means that about 4 per cent of the pulsations have a linear extent of about 2700 kms. outside the auroral zone. During the months May, August, and October, 1954, 36 regular pulsations had been noted at Agincourt. On examination of the Meanook magnetograms at the same time, activity was observed on 29 occasions, often in the form of irregular perturbations on bay activity. Of the 43 listed for these trial months at Meanook, 33 could be traced on the Agincourt recordings during the same time intervals, but the perturbations were much reduced in amplitude, and irregular in form and often in period, and were therefore not noted as belonging to class A or B in the original magnetogram search.

Of 10 outstanding A_q giant pulsations found at Agincourt, 7 could be found at Meanook during the same universal time interval, but the pulsations appearing at Meanook occurred usually at disturbed times and occasionally with small amplitudes and could not have been counted as A_q pulsations at Meanook. Of the 24 outstanding A_q at Meanook, 13 were observed at Agincourt during the same time interval, but with ranges considerably less than 3 gammas. So far as can be determined, the periods were not always the same at the two locations.

REGULAR PULSATIONS AT BAKER LAKE AND RESOLUTE OBSERVATORIES

Baker Lake ($\Phi = 73.7°$N) is situated about as far north of the centre of the auroral zone, as Meanook is to the south, and disturbance characteristics there have been described by Whitham and Loomer (1957) as transitional between the auroral zone and the geomagnetic polar cap. Resolute ($\Phi = 83.0°$N) is situated well inside the polar cap. Previously no giant pulsations had been reported for such high latitude stations.

At Resolute, no definite regular pulsations of the types considered were found. The Baker Lake magnetograms were examined for regular pulsations occurring simultaneously with Meanook. Only 10 cases were found, and of these only 4 could possibly be identified as B class pulsations, the remainder being quite irregular. In one of these 10 cases, a pulsation also occurred at Agincourt during the same time interval. In most cases the periods of the pulsations observed at Baker Lake were too short to be measured using standard-run magnetograms: it seems therefore certain that shorter periods occur at Baker Lake than at Meanook for the 1 per cent of pulsations appearing at the same time. The high level of disturbance at Baker Lake and the uneven quality of the magnetograms may help explain the small number of regular pulsations which were found, but in any case regular pulsations are very infrequent inside the auroral zone.

SUMMARY OF RESULTS

It is considered that the above analysis supports the division, first suggested by Sucksdorff (1939), of regular pulsations in two classes, distinguishable by different form of amplitude envelope, and showing some distinctly different properties. Outstanding among these are the different daily variation of occurrence, and the different mean periods. As discussed above the results obtained from magnetic observatories in Canada considered with the published results from one Scandinavian station show that the pulsations discussed here are neither world wide phenomena occurring at the same universal time, nor local time (or local geomagnetic time) effects. A more complex explanation seems required, in which the occurrence of major sources at any location may prove to be a function of the latitude of the station as well as its longitude. At both stations, in each day there appear to be two preferred resonant frequencies occurring at different times of the day. So far as we can determine these two preferred frequencies are identical at both stations.

The two classes do however possess many common features which are subject to wide statistical fluctuations. Notable among these are the solar cycle dependence, very little systematic departure in mean range, no very marked or persistent seasonal variation in number, and the fact that the total horizontal field perturbation is always several times larger than the vertical field perturbation. In addition the average field perturbation in the plane of the meridian exceeds that at right angles to the meridian.

The regular pulsations described herein are not infrequent phenomena and of the order of 100 per year can be observed in Canada south of the auroral zone. It is considered that the infrequent Rolf or giant pulsations are best regarded as belonging to a sub-class of class A with a particularly well developed shuttle-shaped envelope and large amplitude.

South of the auroral zone, about 4 per cent of the pulsations measured at one location are visible as regular pulsations at the other location 2700 km. away. However, in a trial sample, about 80 per cent of the pulsations noted at one site do appear at the other location, but in a form not measurable as a regular pulsation. Furthermore the periods are not necessarily the same. Hence we must conclude that the extent of the waves is generally considerably less than 2000 to 3000 kms., and that in this distance the resonant frequency and its sharpness can change appreciably and that the strength of the exciting sources considerably decreases. The very few regular pulsations observed inside the auroral zone suggests that a standing wave system across the zone is not a very likely explanation. A standing wave across the zone was suggested by Lehnert's (1956) longitudinal mode. Essentially the non-occurrence at very high latitudes of giant pulsations confirms the findings of the 2nd Polar Year, 1932-33.

A comparison with the properties suggested in Table I shows that, whereas the durations, periods, amplitudes, geographical extent and solar cycle dependence listed there are largely confirmed in Canadian auroral regions, the relationships to daytime and nighttime occurrence are not confirmed and pulsations of this sort can be found down to geomagnetic latitude $\Phi = 55.0°N$ in Canada, even at a time of sunspot minimum.

DISCUSSION OF RESULTS

An attempt is made in this section to relate the observed characteristics to magnetohydrodynamic waves and their possible location, and to discuss the possible effects of ionosphere screening and the relationship of pulsations to magnetic disturbance.

Lehnert (1956) has shown that the periods and amplitudes of pulsations are reasonable for magnetohydrodynamic waves. Following his analysis, it can be shown that free oscillations may occur if the period $T \geq T_c$, where the critical period

$$T_c = \frac{\pi}{\mu\sigma V^2}$$

where μ is the permeability,

σ is the effective conductivity,

and V^2 is the square of the phase velocity of magnetohydrodynamic waves.

It can be shown that free oscillations appear most probable in the transverse mode in the F_2 layer, where $T_c \sim 40$ seconds only. When $T \sim 100$ secs., the wave-length is $\sim 2 \times 10^3$ kms. Since the long durations found indicate a standing wave phenomenon, the relationship between amplitude and period is not clear, but it seems possible that with decreasing period, the effects of wave damping might be to reduce the amplitude as e^{-z/z_0} where z_0 is the damping distance, and z_0 can be shown to be equal to

$$\frac{\mu\sigma V^3 T^2}{2\pi^2}$$

A scatter diagram of log $\triangle F$ against T^{-2} shows that for both the A and B class pulsations at Meanook, log F decreases with increasing T^{-2} and the best slope is $\sim 10^3$ secs^2. However the individual points for each pulsation are widely scattered. In the F_2 layer the theoretical value of the slope $\sim 3 \times 10^3$ secs^2. and this slope rapidly increases in lower ionospheric regions. This suggests that both classes of pulsations originate high in the ionosphere, and eliminates the possibility of explanations requiring the longitudinal mode in lower ionospheric regions.

It also is unlikely that magnetohydrodynamic waves in interplanetary space can provide a plausible explanation because, although T_c for such waves becomes very small, the wave-lengths become very large and as discussed earlier the observational evidence for widespread pulsations of the same period is very weak. However it does seem as if such waves might account for the geographically widespread micropulsations, not discussed here, and whose geographical spread is still in doubt.

Although the damping of a free magnetohydrodynamic oscillation is mentioned above, and used to suggest a high altitude for any standing wave system, there is another explanation of the observed amplitude-period trend. This could be produced by the screening effects of lower ionosphere levels. The influence of such screening may be written as $A(\omega) = A_0(\omega)e^{-\int_0^L (2\pi\mu\sigma\omega)^{\frac{1}{2}} dl}$ where $A(\omega)$ is the amplitude at the ground at angular frequency ω and $A_0(\omega)$ is the amplitude at the ground which would be obtained in the absence of shielding. Now $\int_0^L \sigma^{\frac{1}{2}} dl \approx L(\bar{\sigma})^{\frac{1}{2}}$ within a few per cent. Assuming the cross-conductivity to be the effective conductivity and using the ionospheric data listed by

Lehnert (1956), we find most of the shielding is caused by the upper ionospheric layers and the expression becomes $A(T) = A_0(T)e^{-25T^{-\frac{1}{2}}}$, and at $T \sim 100$ secs., the attenuation seems very large, some 92 per cent.

If we assume the primary sources have equal strength on the average, and if shielding were so important, it seems likely that the mean B class amplitude would appreciably exceed the mean A class amplitude at Meanook and Agincourt because of the difference in mean periods, and partly because the A class in Canada is a daytime phenomena whilst the B class is a nighttime class. Table IV indicates that no such very clear difference in amplitudes is found, and in any case $2\pi\,(\mu\,\bar{\sigma})^{\frac{1}{2}}\,L$ must be less than ~ 5.

Scatter diagrams of log $\triangle F$ against $T^{-\frac{1}{2}}$ were drawn and the inconclusive results obtained for all classes are illustrated in Figure 5, which shows the scatter diagram for the class of outstanding giant pulsations at Meanook. The best slope in Figure 5 indicates $2\,\pi\,(\mu\,\bar{\sigma})^{\frac{1}{2}}\,L \sim 9$ secs.$^{\frac{1}{2}}$. In view of the order of magnitude uncertainties in the conductivity this agreement might be considered quite satisfactory. Because a sharp decrease is found in the number of pulsations with very small amplitude before the 3-gamma level is reached, it appears unlikely that different amounts of ionospheric shielding can produce the apparent solar cycle variation.

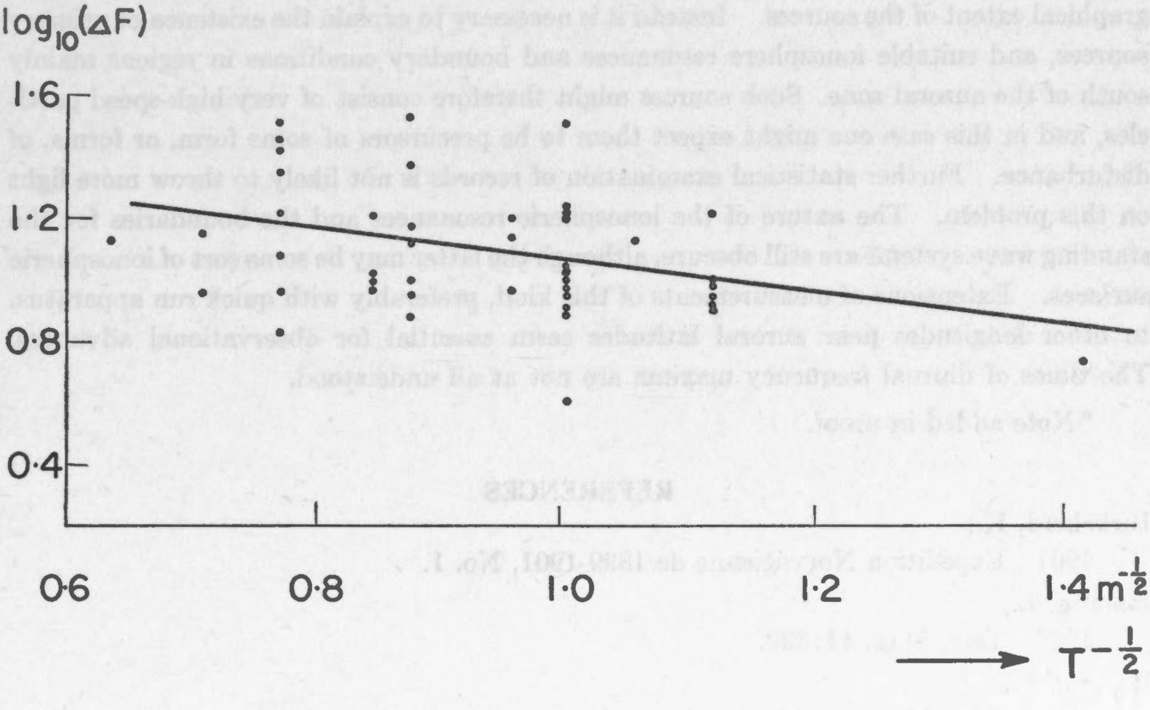

FIGURE 5. The scatter diagram relating log $(\triangle F)$ and $T^{-\frac{1}{2}}$ for the class of outstanding giant pulsations at Meanook.

Despite the attempts made to consider both classes at disturbed and quiet times it is difficult to associate either class in any certain way with disturbance. In particular the Agincourt results do not support the idea that the maximum frequency of occurrence of B class pulsations follows the maximum disturbance by a few hours, and between Scandinavia and Canada there is a reversal of the association of disturbed times and quiet times with the two classes of pulsations. Furthermore there appears to be an inverse relationship between solar activity and the number of sources. Hence the correlation with disturbance is indirect, and enhancement of conductivity by auroral discharges does not seem to be the major condition for a measurable pulsation to exist. Therefore the strength and number of primary sources seems of more importance. However, at Meanook, it was found that at times of disturbance there is appreciable enhancement of the amplitude of the B class pulsations, whereas no such enhancement occurs for the A class. It appears therefore that the strength of the sources may increase with disturbance at the usually disturbed time of day, but not at the usually quiet time of day. Because of this it is not possible to look for increasing screening effects of an enhanced conductivity. It has also been demonstrated that the diurnal frequency maximum of class A pulsations depends on the degree of magnetic disturbance.

In summary, magnetohydrodynamic waves in the upper parts of the ionosphere only can best explain regular oscillations. Oscillations in lower ionospheric layers, possible only when the conductivity is enhanced by auroral discharge, cannot explain the geographical extent of the sources. Instead it is necessary to explain the existence of primary sources, and suitable ionosphere resonances and boundary conditions in regions mainly south of the auroral zone. Such sources might therefore consist of very high-speed particles, and in this case one might expect them to be precursors of some form, or forms, of disturbance. Further statistical examination of records is not likely to throw more light on this problem. The nature of the ionospheric resonances and the boundaries for the standing wave systems are still obscure, although the latter may be some sort of ionospheric surfaces. Extensions of measurements of this kind, preferably with quick run apparatus, to other longitudes near auroral latitudes seem essential for observational advances. The times of diurnal frequency maxima are not at all understood.

* Note added in proof.

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* *Recently J. A. Jacobs and T. Obayishi (Contract AF 19(604)-2147, Scientific Report No. 5) have considered transverse magnetohydrodynamic oscillations of the lines of force of the earth's magnetic field as an explanation of those pulsations in this frequency range of comparatively widespread geographical extent. As shown above, our studies indicate that such widespread effects in the amplitude range considered, are comparatively infrequent, indicating that transverse oscillations over a limited region only are most common. Observations at conjugate points (which are being made during the I.G.Y.) should clarify which oscillations correspond to ionospheric surfaces in one region as boundaries, and which correspond to ionospheric surfaces in opposite hemispheres as boundaries.*

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