A STUDY OF THE AUDIO-FREQUENCY RADIO PHENOMENON KNOWN AS "DAWN CHORUS"

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Summary

The main characteristics of dawn chorus, as observed at Wellington, New Zealand, between July 1955 and October 1956, are presented. These are : no general correlation with whistlers ; a strong correlation with simultaneous local magnetic variations ; a pronounced diurnal variation in activity, with the peak occurring near 0400 hr local time ; and possibly a weak seasonal variation in activity.

The correlation of observations of dawn chorus at Wellington with those at other places is discussed. It is concluded that dawn chorus signals are propagated along lines of force of the Earth's magnetic field, and that the signals are probably initiated by the entry of charged solar particles into the outer ionosphere at times of magnetic disturbance.

I. Introduction

Within the past few years considerable interest has been aroused in a variety of natural phenomena which occur at audio frequencies (0·5–30 kc/s), following on the publication by Storey (1953) of a theory to account for the production of whistling atmospherics, or whistlers, at these frequencies. This interest has arisen from the realization that the study of whistlers at various latitudes could result in the determination of electron density at heights well above the level of maximum ionization of the presently highest known (F_2) ionospheric layer. Recently the prospect of also obtaining information on the strength of the Earth's magnetic field at such great heights has been enhanced by the discovery of a high-latitude form of whistler, the "nose whistler", by Helliwell *et al.* (1956).

In addition to the whistler, another audio-frequency phenomenon, called "dawn chorus", is commonly observed in middle latitudes. Whereas a typical whistler consists of a whistling tone whose pitch steadily falls, dawn chorus consists of many rising tones, and has been likened by Storey to the sound of a distant rookery. A typical tone has a frequency range from about 2 to 4 kc/s. A study of dawn chorus at Cambridge, England, led Storey to conclude that its intensity varied greatly throughout the day, reaching a peak around 6 a.m., and that its occurrence correlated strongly with magnetic activity.

This paper describes the main characteristics of dawn chorus as observed since July 1955 at Wellington, New Zealand, which is about 10° nearer the geomagnetic equator than Cambridge. A second site at which regular observations are made in New Zealand is near Dunedin, 600 km from Wellington. These

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stations lie almost on the same geomagnetic meridian. The geomagnetic latitude of Wellington is 45 °S., and that of Dunedin 50 °S.

Evidence is presented which suggests that dawn chorus signals are propagated along the lines of force of the Earth's magnetic field, and that the signals are initiated by extraterrestrial particles impinging upon the Earth's atmosphere, probably at great heights above the Earth's surface. If this hypothesis is correct, then the systematic study of dawn chorus could yield additional information on the structure of the Earth's outer atmosphere.

II. Experimental Details

One of the difficulties encountered in making observations of audio-frequency phenomena is that the signals are often weak in comparison with the background hum and other noise in the vicinity of electric-power transmission lines. The incident power flux for the strongest dawn chorus signals is of the order of 10^{-14} Wm^{-2} $(c/s)^{-1}$. The field station at Moores Valley, near Wellington, where the present series of observations were made, is situated at the end of a 230-V service main in a rural district. The loop aerial used for reception of the signals is 80 yd from the hut housing the recording and timing equipment, and is orientated for minimum hum pick-up. After passing through an amplifier of about 80 dB gain and of bandpass between 1 and 7 kc/s, the received signals are recorded on magnetic tape, on a schedule of 4 minutes' recording every 3 hr, on two days per week, commencing at 0235, 0535, . . ., 2335 U.T. These schedules coincide with those at Dunedin and at stations in North America.

The equipment at Dunedin is similar to that at Wellington, and is operated and maintained by New Zealand Broadcasting Service personnel. The tapes are analysed along with the Wellington tapes at the Dominion Physical Laboratory, Lower Hutt. Except where otherwise specified, the results in this paper apply to Wellington data only.

In the course of this paper, two different criteria of dawn chorus activity are used :

(*a*) the occurrence of dawn chorus, expressed as a percentage (or fraction) of the total number of schedules considered ;

(*b*) for data obtained since April 1956, a subjective measure of the strength of dawn chorus signals, using a 0–5 scale (0=nil ; 5=very loud).

For each specific comparison of dawn chorus activity with another phenomenon, the criterion quoted is that which illustrates the conclusion more clearly (usually due to more adequate statistical sampling). In each case, the use of the alternative criterion would not have produced an inconsistent result.

III. Lack of Correlation with Whistler Activity

Figure 1 shows two histograms of whistler activity, based on those schedules in which dawn chorus was present (102) and on those schedules in which it was absent (106). Because of the near equality of these totals, normalizing would have altered the histograms to an insignificant extent. Evidently the presence or absence of dawn chorus does not affect the probability of occurrence of whistlers. If dawn chorus were associated with whistler activity, then more whistlers would be heard when dawn chorus was present than when it was absent; alternatively, if the two phenomena were mutually exclusive in some degree, then less whistlers would be heard when dawn chorus was present than when it was absent. Figure 1, however, clearly shows that the average number of whistlers per schedule is virtually independent of the presence of dawn chorus. The general shape of the histograms is also the same in both cases.

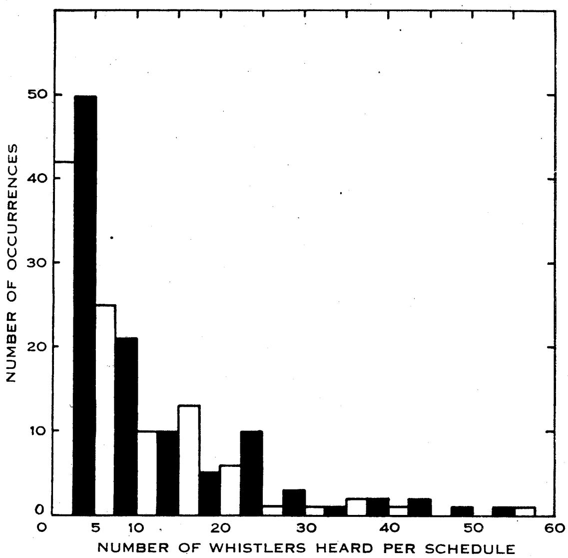

Fig. 1.—Histograms of whistler activity, showing absence of correlation with dawn chorus. Unshaded: dawn chorus present; shaded: dawn chorus absent.

The data used in Figure 1 are those for the 1435 U.T. schedules, when both dawn chorus and whistlers are frequently heard. Similar comparisons made for other schedules lead to the same conclusions.

This general independence of dawn chorus and whistlers does not preclude the possibility that on a limited number of occasions there could be a causal relationship between the two phenomena. For example, it is possible that a very strong dawn chorus signal might give rise to a whistler of apparently abnormal dispersion.

IV. Correlation with Magnetic Activity

(a) *Correlation in Space*

Initially a correlation was sought between the occurrence of dawn chorus and the world-wide magnetic activity index k_p, in the following manner. For the 4-min recording schedule commencing at 0235, 0535, . . . U.T. the value of k_p for the interval 00–03, 03–06, . . . U.T. respectively, on the same day, was taken to be representative of the magnetic conditions existing at the precise time of the recording. Thus, statistically, a comparison was made between magnetic conditions at 0130 U.T. and the reception of dawn chorus at 0237 U.T. This time difference of 1 hr 7 min assumes significance when the question of simultaneity of occurrence of the two phenomena is discussed in Section IV (*b*).

For the schedules corresponding to each value of k_p in turn (0, 1, . . .) the proportion of recordings containing dawn chorus signals, however faint, was determined (Fig. 2 (*a*)). (Because of the comparative rarity of values of k_p greater than 5 during the period under investigation, all such occasions were

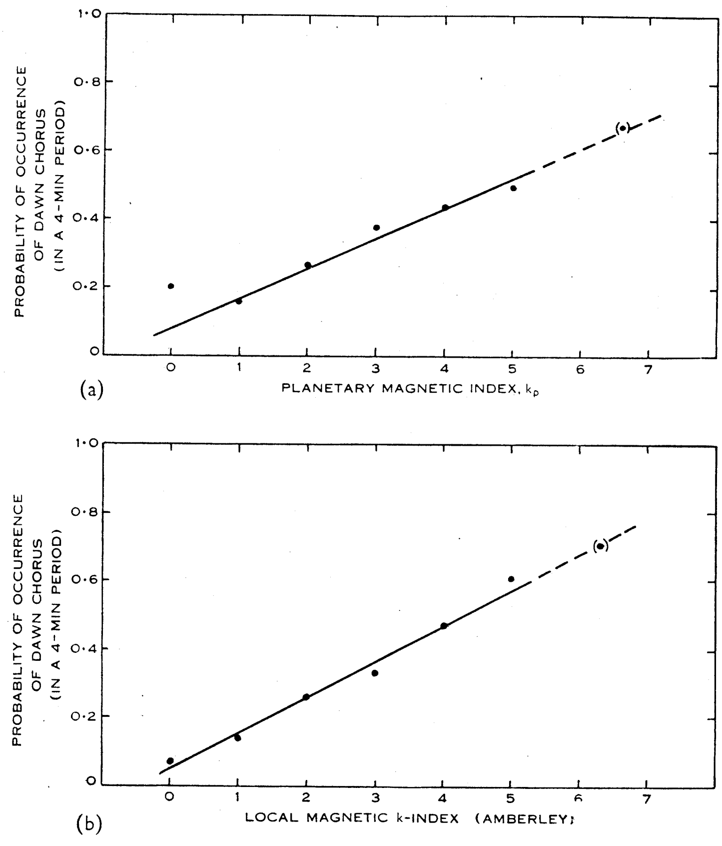

Fig. 2.—Relationship between the presence of dawn chorus and the magnetic activity: (*a*) using planetary magnetic indices; (*b*) using local magnetic indices.

considered together, and are represented by the bracketed point, where the abscissa corresponds to the average value of k_p.) A near-linear relationship between the two quantities is indicated, except for $k_p=0$. A similar analysis was carried out, using the local magnetic k-indices from Amberley, 300 km distant. The resulting graph is shown in Figure 2 (*b*); there is now no significant departure from a linear relationship for $k=0$. From this it is inferred that the occurrence of dawn chorus depends more closely on local magnetic disturbances than on global ones. On this argument alone, it would not therefore be expected that dawn chorus would always be heard simultaneously throughout the whole world, but that, at least to some extent, it is a localized phenomenon. Further evidence on this point is offered in Section VI.

(b) *Correlation in Time*

A lag correlogram of dawn chorus signal strengths with Amberley magnetic k-indices shows that the correlation is a maximum near zero time delay, and falls off fairly rapidly on either side. As an example, the lag correlogram for the 1435 U.T. schedules is shown in Figure 3. Correlation with the Amberley

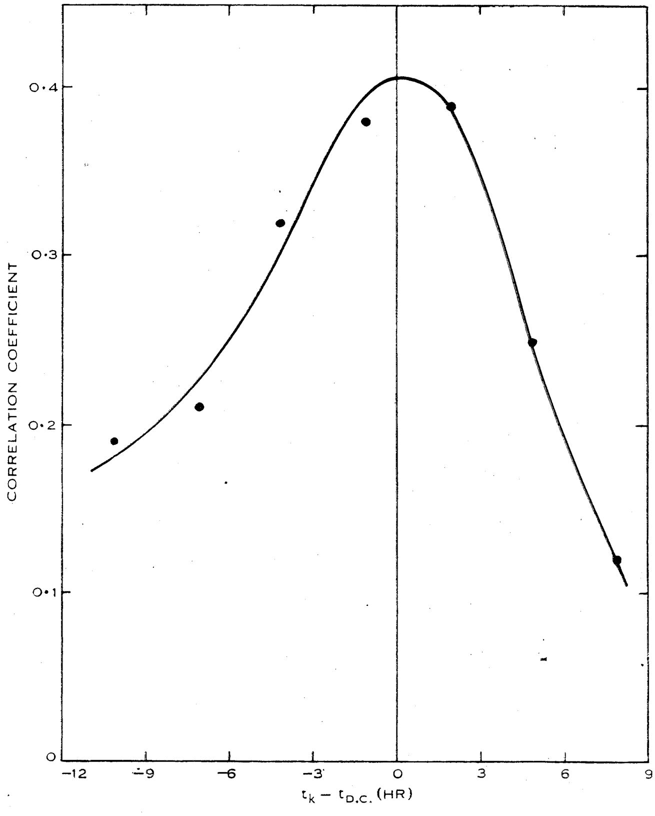

Fig. 3.—Correlogram between the strength of dawn chorus and magnetic activity at earlier and later times.

k-index at 1330 U.T. is plotted as for a lag interval of minus 1 hr 7 min, as discussed in Section IV (a). The other points indicate the correlation with magnetic indices 3, 6, or 9 hr earlier or later. It is seen that there is no significant lag between local magnetic disturbances and the strength of dawn chorus. There remains the possibility that a close examination of the original magnetograms at the actual dawn chorus recording times may result in the correlation of certain characteristics of dawn chorus with specific types of magnetic variations.

V. Temporal Variations in Activity

(a) *Diurnal Variation*

The average signal strength of dawn chorus during April–October 1956 varies markedly throughout the day as is shown in Figure 4. During this period the time of ground sunrise varied between 0514 and 0744 N.Z.S.T., whilst ground sunset occurred at times between 1658 and 1855 N.Z.S.T. A period of minimum dawn chorus activity exists for several hours after sunset, whilst maximum activity occurs well before sunrise, namely, around 0400 hr local time.

When considered month by month the observations show that the time of peak activity at Wellington does not change significantly throughout the year. It is related to local time rather than to local sunrise. Hence it appears that ionospheric absorption of the signals in the sunlit regions is not sufficient to affect the time of maximum dawn chorus activity at Wellington.

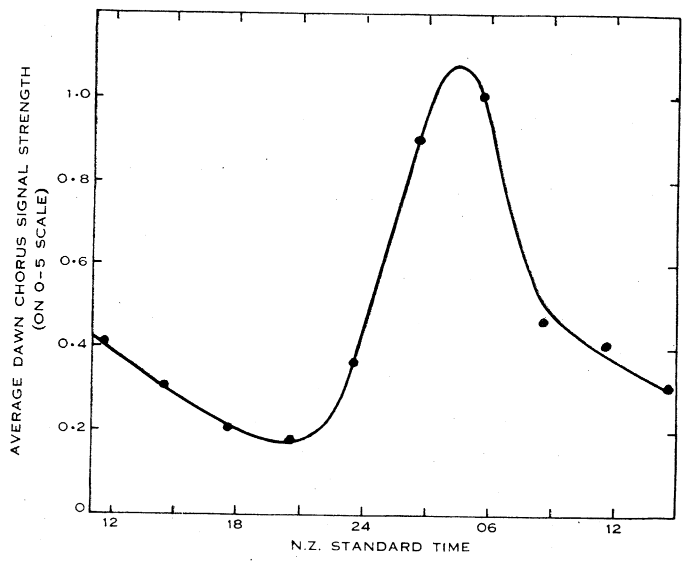

Fig. 4.—Diurnal variation in dawn chorus activity at Wellington.

At Cambridge the maximum activity occurs about 0600 hr local time. Thus it appears that the time of peak activity depends upon latitude. This is discussed more fully in Section VIII.

(b) *Seasonal Variation*

During the period August 1955–October 1956 the monthly percentages of schedules (irrespective of time of day) during which dawn chorus was heard have varied rather irregularly according to the full line in Figure 5. Some of these variations can be attributed to changes in the level of magnetic activity from month to month. Using Figure 2 (*b*), an estimate was made of the variation of the percentage occurrence of dawn chorus to be expected from *k*-index changes alone ; this is shown as the broken line in Figure 5. It will be seen that there is a rather weak tendency for dawn chorus to be more prevalent around the December solstice (local summer) than around the June solstice (local winter). Further data are obviously required before a firm conclusion can be reached.

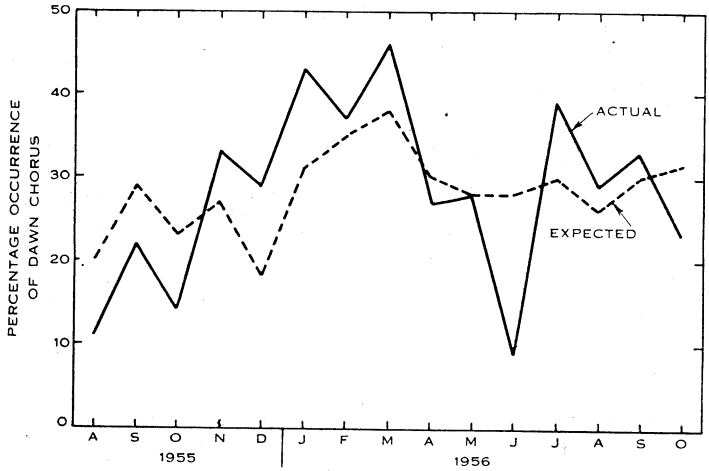

Fig. 5.—Month-by-month variation in occurrence of dawn chorus at Wellington (full line), with that expected from changes in magnetic activity only (broken line).

VI. Correlation of General Activity at Various Stations

Tabulated results of observations at three North American whistler stations have been kindly made available to the author by Dr. M. G. Morgan of Dartmouth College. The locations and geomagnetic latitudes of the stations are : Hanover, N.H. (55 °N.), Washington, D.C. (50 °N.), and Unalaska (50 °N.). The data from these and the New Zealand stations for the period April–June 1956 were examined, to determine the degree of association of general dawn chorus activity at each pair of stations in turn. This was carried out by preparing a contingency table of the actual results, and comparing this table with the equivalent random table, i.e. that which would be expected if there were no association whatever between the results at the two stations. Three such sets of tables, for typical neighbouring, distant (but non-conjugate), and conjugate stations are given in Table 1. (Stations are defined as conjugate if the same, or closely adjacent, lines of force of the Earth's magnetic field pass through these stations, on the currently accepted dipole model.)

By comparing the actual and " random " number of simultaneous occurrences of dawn chorus (the " Yes-Yes " figures), it can be seen that there is a significant association between occurrences at neighbouring and conjugate stations. On the other hand, the association between distant non-conjugate stations is weak, and disappears if the cases of simultaneous occurrence at all stations (during great magnetic disturbances) are eliminated from the data. A statistical (χ-squared) test on the complete tables supports these inferences drawn from an inspection of the Yes-Yes figures alone.

A comparison of dawn chorus data at Wellington and Dunedin with the corresponding whistler data for the same period is given in Table 2. To facilitate comparison, relative figures are also given, based on 100 simultaneous occurrences. The table shows that the degree of simultaneity is of the same order for both phenomena. Thus it would appear that the same dawn chorus signals are heard throughout a region on the Earth's surface of a size comparable with that in which the same whistlers are heard.

TABLE 1

CONTINGENCY TABLES FOR ESTIMATING THE CORRELATION OF DAWN CHORUS ACTIVITY AT PAIRS OF STATIONS

No = number of schedules during which dawn chorus was absent
Yes = number of schedules during which dawn chorus was present

(*a*) *Wellington* (*WE*) *and Dunedin* (*DU*); *neighbouring stations, 600 km apart*

Actual

		WE	
		No	Yes
DU	No	70	16
	Yes	6	22

Random

		WE	
		No	Yes
DU	No	57	29
	Yes	19	9

(*b*) *Unalaska* (*UN*) *and Hanover* (*HA*); *distant non-conjugate stations, 6500 km apart*

Actual

		UN	
		No	Yes
HA	No	74	6
	Yes	46	10

Random

		UN	
		No	Yes
HA	No	71	9
	Yes	49	7

(*c*) *Unalaska and Wellington*; *conjugate stations*

Actual

		UN	
		No	Yes
WE	No	90	3
	Yes	32	13

Random

		UN	
		No	Yes
WE	No	82	11
	Yes	40	5

VII. Correlation of Particular Events

(a) *Bursts of Dawn Chorus*

Since the occurrence of dawn chorus is related closely to *local* magnetic activity, it is of interest to determine over what region or regions of the world the same dawn chorus signal can be heard. Difficulties arise immediately, as normally the individual rising tones are separated by only a few seconds; furthermore, the tones are usually weak, being not much stronger than the background hum and atmospheric noise level. Considerable fluctuation of signal strength from one tone to the next could also reduce the confidence with which the same signal could be identified at two distant stations.

Table 2

COMPARISON OF DAWN CHORUS AND WHISTLER DATA AT WELLINGTON AND DUNEDIN

Number of Occasions heard at:	Dawn Chorus		Whistlers	
	Actual Number	Relative Number	Actual Number	Relative Number
Wellington	68	212	419	265
Dunedin	39	122	239	151
Both stations	32	100	158	100

However, occasionally during a display of normal dawn chorus, a "burst" of activity occurs. The burst consists of a sudden increase in the rate of occurrence of individual tones. During a typical burst, the rate might abruptly change from one rising tone every few seconds to several such tones per second. Often the tones overlap, the high-frequency components of one tone arriving at the same time as the low-frequency components of the next tone. The duration of the burst is of the order of several seconds; thus the specification of the time of commencement and the duration of a burst facilitates its identification at another station, and the difficulties encountered in identifying individual rising tones largely disappear.

(b) *Coincident Bursts at Wellington and Dunedin*

Allcock and Martin (1956) have reported the simultaneous reception of bursts at Wellington and Dunedin, 600 km apart, during an exceptionally clear display of dawn chorus. From an examination of spectrograms of some of these bursts, they concluded that the bursts occurred simultaneously at the two stations to within 0·01 sec, on the average. The general character of the first rising tone in each burst was found to be the same at both stations, but there were small differences in detail which were thought to be real, and could have been due to slight differences in the characteristics of the propagation paths between the source and the separated receivers.

(c) *Coincident Bursts at Conjugate Stations*

The station at Unalaska, Aleutian Islands, is very nearly magnetically conjugate to Wellington. Because of the magnetic linkage, simultaneous reception of dawn chorus would be expected if dawn chorus signals are propagated along the lines of force, as are whistlers (Morgan and Allcock 1956).

Information on six bursts observed at Unalaska on September 5, 1955 has been kindly supplied by Dr. H. W. Curtis of Dartmouth College, New Hampshire, U.S.A. The starting times of these bursts were given to the nearest second, and the bursts were said to be of about 3 sec duration. Bursts were also heard at Wellington during the same schedule, the starting times being identical with those at Unalaska to within 1 sec, on the average. The average duration of the Wellington bursts was 4 sec. Thus it seems very likely that the same bursts can be heard at conjugate points.

VIII. Nature and Location of Source of Dawn Chorus

At this stage the above experimental results can conveniently be summarized as follows :

(*a*) Using Wellington data only :

- (i) no significant association with whistlers ;
- (ii) strong association with simultaneous local magnetic variations ;
- (iii) pronounced diurnal variation in activity, with an early-morning peak which is invariant throughout the year ;
- (iv) possibly a weak seasonal effect.

(*b*) Using data from several stations :

- (i) significant association between neighbouring stations, and also between magnetically conjugate stations ;
- (ii) no significant association between distant non-conjugate stations, except for instances of world-wide occurrence of dawn chorus ;
- (iii) some degree of simultaneity as for whistlers at neighbouring stations ;
- (iv) coincident bursts identified at neighbouring stations ;
- (v) coincident bursts probable at conjugate stations.

A consistent interpretation of these results is that both the propagation path and the magneto-ionic mode of propagation are the same for both dawn chorus and whistlers. Thus it is considered very probable that dawn chorus consists of electromagnetic radiation which is propagated in the extraordinary mode along the lines of force of the Earth's magnetic field. If this is the case, then the rising tones of dawn chorus cannot be caused by the dispersive properties of the medium, as it is known from the study of whistlers that the higher frequencies travel faster than the lower frequencies within the frequency range under consideration. There remains the alternative that the source itself produces a rising tone.

No audible precursors of dawn chorus signals have yet been identified, in spite of a careful search. Hence it is unlikely that the source of dawn chorus is located in the lower atmosphere. A measurement of the time differences between occurrences of bursts at conjugate stations, to an accuracy of $\pm 0 \cdot 1$ sec, should fix the position of the source to an accuracy of about ± 2000 km along the propagation path, i.e. to the nearest 10° geomagnetic latitude.

In Section V (*a*) it was suggested that the time of maximum dawn chorus activity may vary with latitude. An investigation of this possibility was carried out by deriving the diurnal variation curves for the stations already referred to, and also for College, Alaska, and Cambridge, England, from data kindly supplied by the Geophysical Institute, University of Alaska, and Dr. L. R. O. Storey respectively. A marked variation of the time of maximum activity with geomagnetic latitude was found (Fig. 6). It is seen that only in middle latitudes is dawn chorus predominantly a dawn phenomenon.

We shall now make the hypothesis that dawn chorus signals are generated in the vicinity of the geomagnetic equatorial plane. It is then appropriate to replot the data of Figure 6 as a polar graph of local geomagnetic time (angular

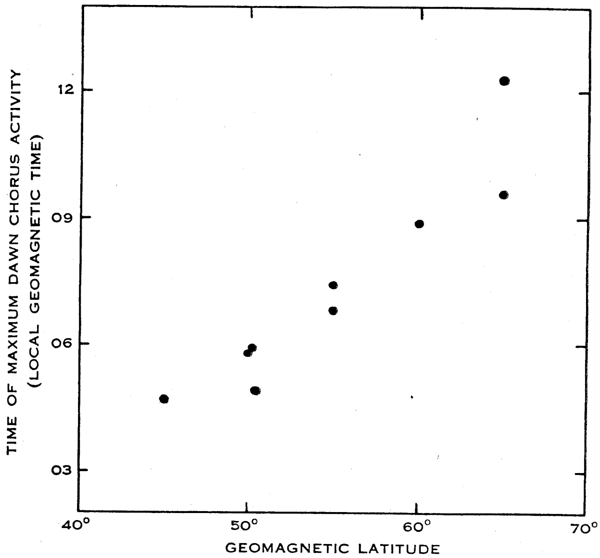

Fig. 6.—Latitude variation in time of diurnal maximum of dawn chorus activity.

coordinate) against the height above the equator of the magnetic line of force passing through the observing station (radial coordinate). This is done in Figure 7 ; the curve fitting the data is characteristic of the locus of a positively charged incoming particle travelling in the equatorial plane, and being deflected by the Earth's magnetic field. Thus the experimental evidence is not inconsistent with the hypothesis that dawn chorus signals are initiated by the arrival over the geomagnetic equator of positively charged particles of solar origin. As a speculation, it is suggested that a cloud of such particles excites ions already present in the outer ionosphere. These ions would then re-emit the excess energy acquired as electromagnetic radiation at a natural resonance frequency which increases as the incoming cloud penetrates to lower heights.

For electrons, two such resonance frequencies immediately suggest themselves, namely, the gyrofrequency and the plasma frequency. Both of these are likely to be much greater than the lowest frequency in the dawn chorus spectrum (about 2 kc/s). The minimum electron gyrofrequency along the magnetic flux line through Wellington would be about 110 kc/s, whilst from measurements of whistler dispersion characteristics it can be deduced that the electron plasma frequency must be at least some tens of kilocycles per second.

Dungey (1955) has put forward the view that hydrogen ions (protons) are more numerous than ions of any other element in the outer atmosphere. However, the proton gyrofrequency will be too low, with a maximum value of about 400 c/s at ground level.

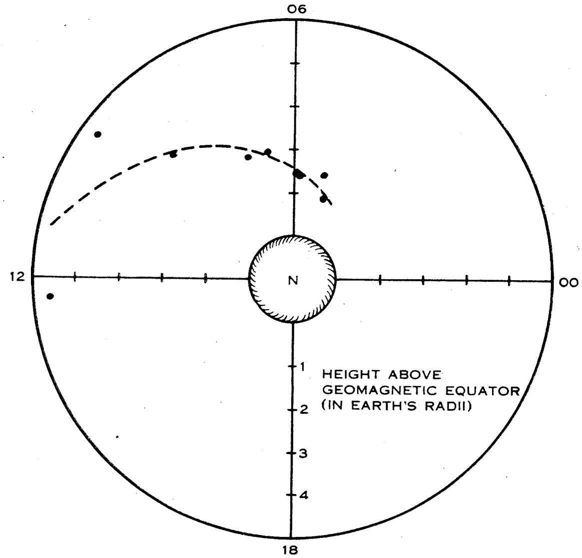

Fig. 7.—The same data as Figure 6, replotted to show that the latitude variation could be due to incoming positively charged particles.

According to Emeleus (1951), if the electron temperature is sufficiently high, plasma ion oscillations of protons are possible at a frequency f given by

$$f^2 = ne^2/\pi m,$$

where n=ion density (cm^{-3}),
e=ionic charge (e.s.u.),
m=ionic mass (g).

Now, since the space charge density is small in the outer ionosphere (Dungey 1955), the proton density would be of the same order as the electron density. Thus a proton plasma oscillation of frequency of the order of a few kilocycles per second may be possible.

A test of this speculation is that the lowest frequency in the dawn chorus spectrum should increase as the point of reception moves towards the equator.

IX. Conclusion

From a study of the characteristics of dawn chorus at Wellington and at other stations, especially its relationship to magnetic activity, it seems very probable that dawn chorus signals are generated in the outer ionosphere and are propagated along lines of force of the Earth's magnetic field in the extraordinary magneto-ionic mode.

The experimental evidence supports the hypothesis that the signals are a consequence of the entry into the outer ionosphere of clouds of positively charged particles. Because of the correlation of dawn chorus with magnetic activity, and the pronounced diurnal effect invariant with season, such clouds would presumably be of solar origin.

X. Acknowledgments

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XI. References

Allcock, G. McK., and Martin, L. H. (1956).—*Nature* **178**: 937.

Dungey, J. W. (1955).—"The Physics of the Ionosphere." p. 229. (Phys. Soc.: London.)

Emeleus, K. G. (1951).—"The Conduction of Electricity through Gases." p. 88. (Methuen: London.)

Helliwell, R. A., Crary, J. H., Pope, J. H., and Smith, R. L. (1956).—*J. Geophys. Res.* **61**: 139.

Morgan, M. G., and Allcock, G. McK. (1956).—*Nature* **177**: 30.

Storey, L. R. O. (1953).—*Phil. Trans.* A **246**: 113.