SPORADIC E AT BRISBANE

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Summary

Further data are presented in support of McNicol and Gipps's classification of two types of sporadic E at Brisbane (lat. 27·5 °S.), namely, sequential type (E_{ss}) and constant-height type (E_{sc}).

Information is given on the occurrence, critical and blanketing frequencies, reflection coefficients, range spreading, vertical movements, and lateral extent of E_s patches.

No correlation is found with sunspot cycle, meteor occurrence, or thunderstorm activity. Scattering from a turbulent medium is not responsible for E_{sc} at Brisbane. Tidal movement is regarded as the most likely cause of both types of E_s.

A method of obtaining information about D region absorption is briefly discussed.

I. Introduction

The sporadic E (E_s) region has been studied in some detail at Brisbane and a previous paper by McNicol and Gipps (1951) has given the broad outlines of its characteristics. This work has been continued and a more detailed examination of the $P'f$ records, now available for a period of 11 years, has led to some modification and enlargement of the conclusions previously drawn.

McNicol and Gipps have shown that a detailed examination of the $P'f$ records often allows a classification of the E_s layers represented on the records into two distinct types, which vary in respect to the phenomena associated with their appearance, and with respect to their blanketing properties. These two types were given the names " sequential " E_s (E_{ss} or E_{2s}) and " constant-height " type E_s (E_{sc}). Typical examples of these two types of E_s are shown in Plate 1 and Figure 1. Sequential E_s is characterized by its regular decrease in range and increase in critical and blanketing frequencies. Figure 2 gives the average variation of critical and blanketing frequencies with group height for this type of layer for December and January of the years 1950–53. An important secondary characteristic of E_{ss} is the fact that its blanketing frequency is always high—by the time the layer reaches the 120 km level the blanketing frequency is nearly always greater than 4 Mc/s. It is only during the last stages in the life of an E_{ss} region which has persisted for some hours that the strong blanketing by the region may cease.

The constant-height type of E_s layer gives a $P'f$ trace which is often patchy in nature and which appears in its final position, usually without any changes of height. It causes very weak blanketing which very rarely extends beyond 3·5 Mc/s. E_{sc} may occur simultaneously with E_{ss}, and may be above or (more frequently) below this region.

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It is found that above about 120 km one can determine with certainty, by examination of a succession of records, which type of E_s is present; the

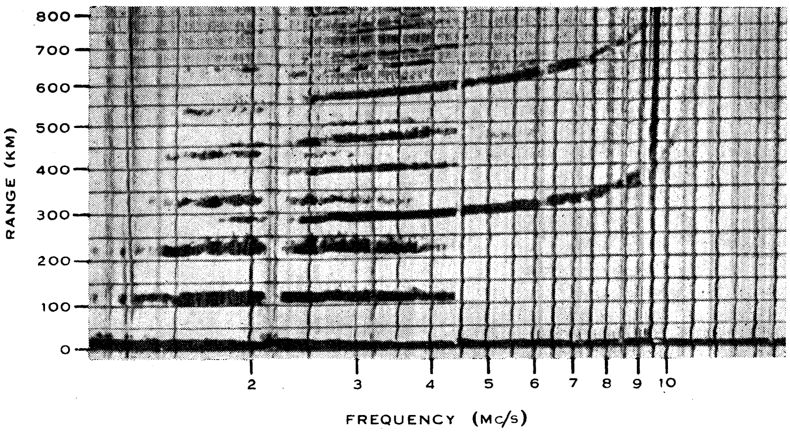

Fig. 1.—A typical $P'f$ record of E_s.

majority of such records are, in fact, due to sequential E_s in its early stages. At lower levels the classification becomes increasingly difficult and often impos-

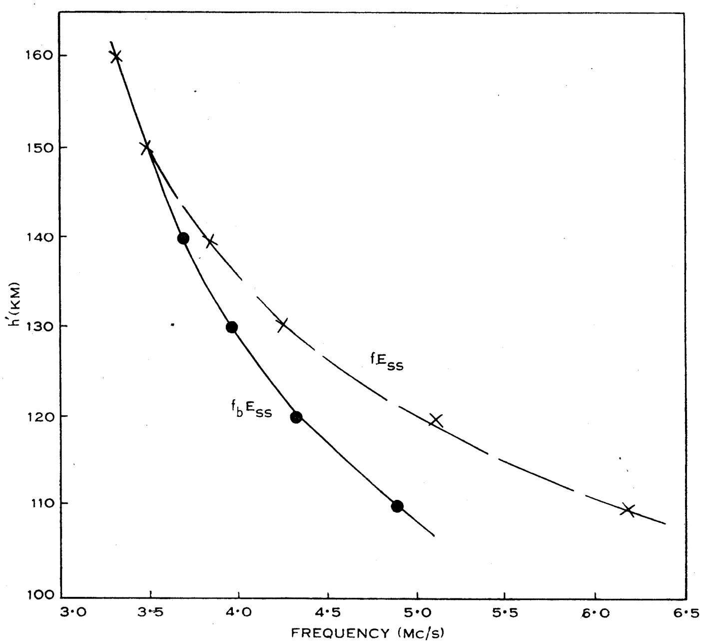

Fig. 2.—Variation of fE_s and f_bE_s with height for sequential E_s.

sible. Most of the E_s recorded at Brisbane is at or below the 120 km level, and the majority of the work described below refers to E_s occurring at or below the 120 km level. Specific mention is made when this is not the case.

II. Equipment Used

The automatic $P'f$ equipment in use and the scaling procedures adopted have been fully described by McNicol and Gipps (1951). In the period June

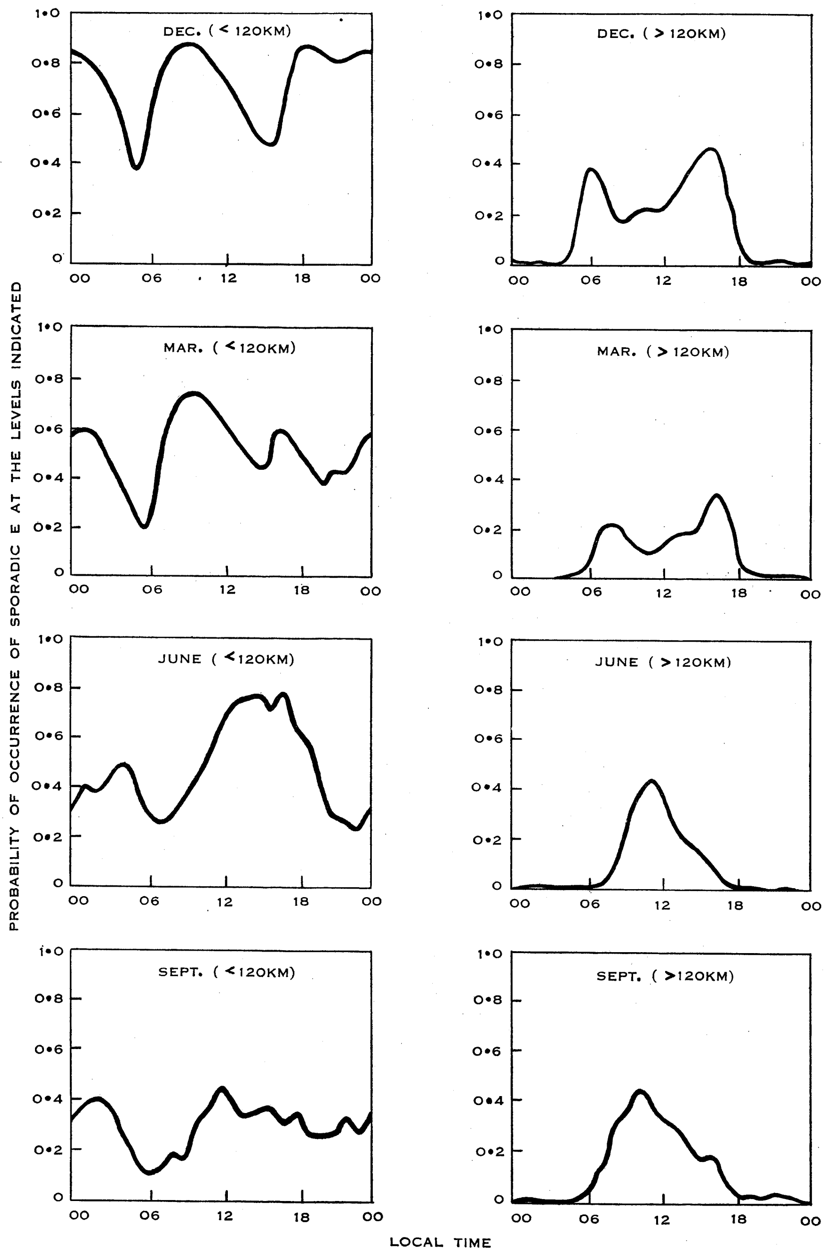

Fig. 3.—Seasonal-diurnal probability of occurrence of E_s echoes.

1943 to July 1947, the equipment operated over the range 2·2–13 Mc/s ; from July 1947 onwards, the range was increased to cover 1–16 Mc/s. The earlier equipment radiated about 200 W in a 100 μsec pulse and the later equipment about 500 W in a 70 μsec pulse. Due to variations in radiated power, receiver sensitivity, radio interference, and tuning, the overall sensitivity of the recorder

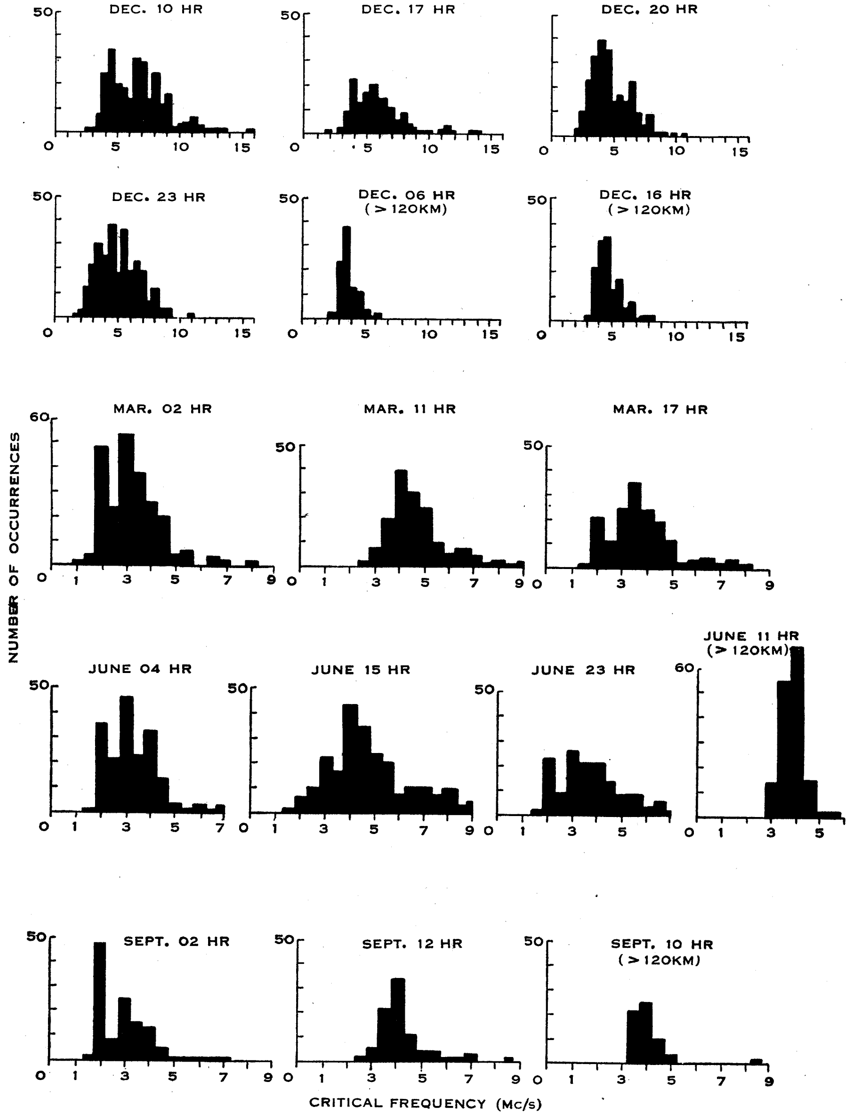

Fig. 4.—Frequency distributions for fE_s.

is by no means constant throughout the band of frequencies covered. A rough estimate shows that an effective reflection coefficient of about 0·003 is necessary before an echo will be recorded by the later equipment ; a slightly higher value was necessary for the older equipment.

Some use has also been made of recordings of echoes occurring at fixed frequencies of 2·28, 3·84, and 5·80 Mc/s ($P't$ recordings); these equipments operate at a higher transmitter power output of 1 kW and will record echoes from a region with effective reflection coefficient down to 0·001. The confinement to a single frequency makes possible a number of subsidiary experiments such as the measurement of the direction of arrival of the downcoming waves (Thomas and McNicol 1955), phase-path measurements, and the measurement of the relative intensity of echoes by the swept-gain technique* (McNicol, Webster, and Bowman 1956).

III. Occurrence of E_s and E_2

The probability of occurrence of E_s above and below the 120 km level is shown for four representative months of the year in Figure 3. These figures are derived from $P'f$ records and are therefore subject to the limited frequency coverage of the equipment.

Histograms are shown in Figure 4 of the distribution of critical frequencies of the E_s region for various seasons and hours. The fact that the distributions of Figure 4 fall off markedly at a frequency above the lowest frequency recorded

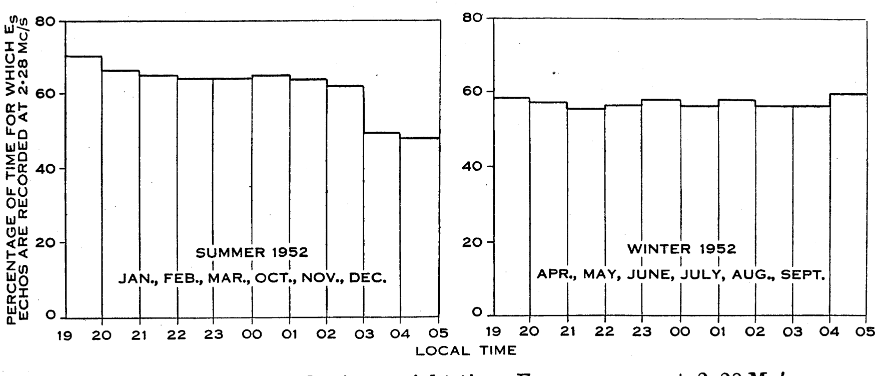

Fig. 5.—Summer and winter night-time E_s occurrence at 2·28 Mc/s.

(1 Mc/s) suggests that a distinction should be made between the type of E_s recorded between 1 and 16 Mc/s at Brisbane and the type recorded at much lower frequencies elsewhere in the world (Brown and Watts 1950; Watts and Brown 1951; Helliwell 1952; Lindquist 1953). If this is valid, the occurrence figures are not seriously affected by the limited frequency coverage of the recorder.

Night-time $P't$ records taken at 2·28 Mc/s with somewhat higher transmitter power and receiver sensitivity (about 10 dB overall improvement on $P'f$ equipment) show E_s echoes for about 60 per cent. of the night. The diurnal distribution of occurrence is fairly uniform throughout most of the night but decreases in the last few hours before dawn in the summer months (Fig. 5). The overall occurrence in summer is greater than that in winter.

* The receiver gain is uniformly reduced by 80 dB in a period of 2 min, the process being repetitive. The stronger the echo, the longer it lasts in any 2 min period.

Since sequential type E_s originates in stratification between the E_1 and F_1 regions, the frequency of occurrence of such E_2 echoes is of some importance in any discussion of the nature of E_{ss}. The seasonal-diurnal occurrence of E_2 echoes is shown in Figure 6.

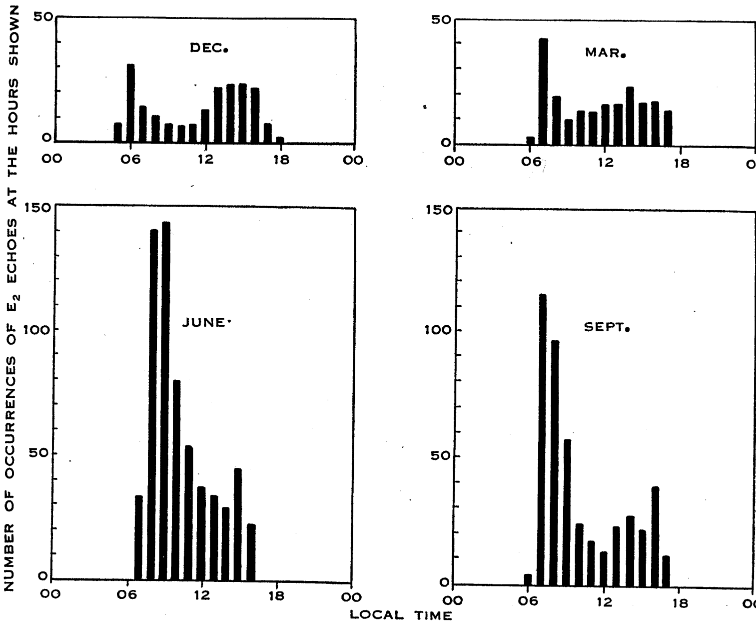

Fig. 6.—Seasonal-diurnal occurrence of E_2 echoes.

IV. Critical and Blanketing Frequencies

While it is generally possible to calculate the mean value of fE_s for any particular hour or season, this is often impossible for f_bE_s, due to the facts that (*a*) the blanketing frequency may be less than the lower limit of recording, and (*b*) the value of f_bE_s may be doubtful owing to overlap of normal E and E_s echoes, or because f_xF_2 may be less than the blanketing frequency (giving rise to complete blanketing). To overcome this difficulty, use is made of the fact that for a normal distribution of values, the mean value of f_bE_s or fE_s increases with the number of occasions on which f_bE_s or fE_s exceeds an arbitrary frequency near the median value. That the distribution of f_bE_s and fE_s is, in fact, an approximately normal one is shown in Figures 7 and 4 respectively. The arbitrary comparison frequencies chosen are 4 and 5 Mc/s respectively; these values are the most suitable for seasonal comparison. For convenience in comparison of the behaviour of critical and blanketing frequencies, the same procedure is used for both quantities.

McNicol and Gipps (1951) plotted histograms on this basis for the various months of the year and found a summer maximum of both critical and blanketing frequencies and a small winter sub-maximum of critical frequency alone. Rather more information may be obtained from seasonal-diurnal plots, and these are

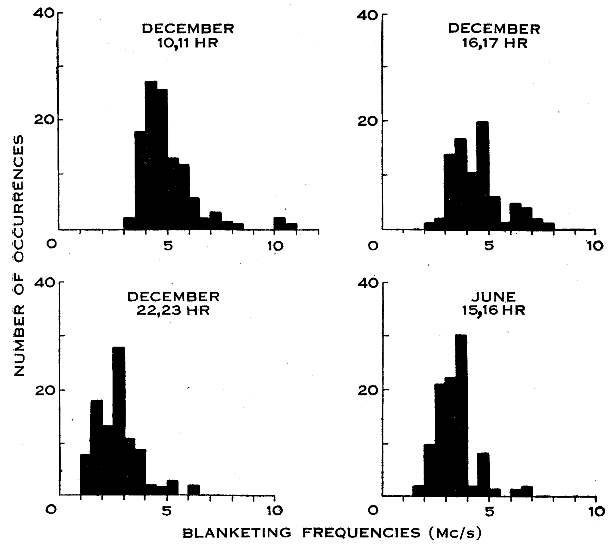

Fig. 7.—Frequency distributions for f_bE_s.

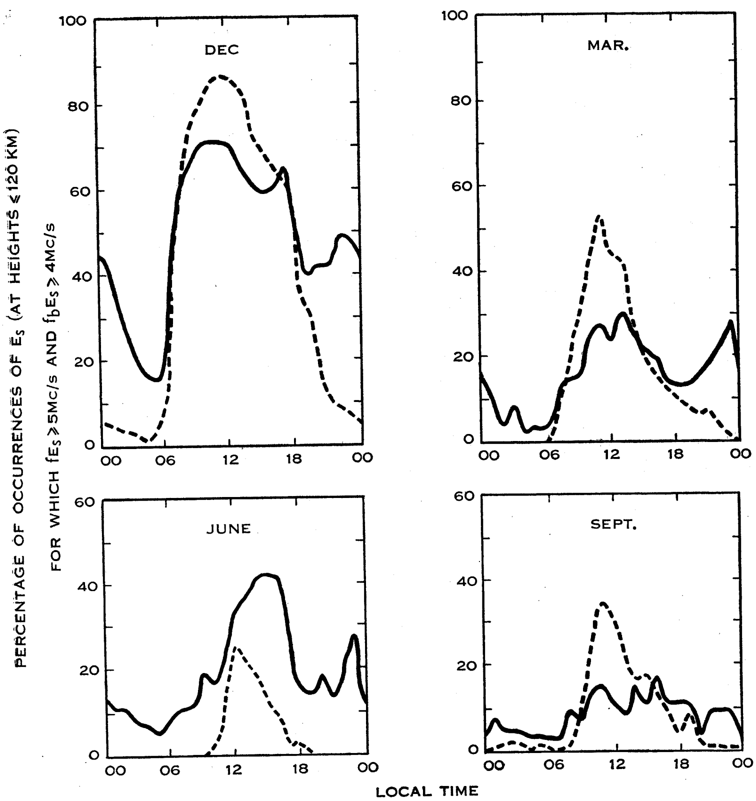

Fig. 8.—Seasonal-diurnal percentage occurrence of $fE_s \geqslant 5$ Mc/s and $f_bE_s \geqslant 4$ Mc/s.

shown for four representative months (averaged over 10 years) in Figure 8. Examination of Figure 8 brings out several points :

(a) In all seasons there is a dawn minimum of critical and blanketing frequencies ;

(b) In December there are three peaks in critical frequency, the first two at about 1000 hr and 1700 hr being accompanied by peaks in blanketing frequency, but the last at 2230 hr occurring at a time of low blanketing frequency ;

(c) In March there are only two predominant peaks in critical frequency at about 1200 hr and 2300 hr of which only the first is accompanied by strong blanketing ;

(d) In June there are two peaks of critical frequency at about 1500 hr, and 2300 hr while the blanketing frequency reaches a maximum at 1200 hr ;

(e) In September the critical frequency does not vary much through the day but the blanketing frequency reaches a maximum at 1000 hr.

The range of frequencies for which echoes are received from both the E_s and higher regions is given by $fE_s - f_bE_s$. Some indication of the increase in this quantity as sequential E_s moves downwards has been given in Figure 2.

TABLE 1

PARTIAL TRANSMISSION RANGES

Time	Predominant E_s	$fE_s - f_bE_s$ (Mc/s)
December 0700 hr (>120 km) ..	E_{ss}	0·25
December 1100 hr	E_{ss}	1·0
December 2200 hr	E_{sc}	2·7
March 1000 hr	E_{ss}	0·8
March 2300 hr	E_{sc}	1·9
June 1500 hr	E_{sc}	1·6

Average values for various times are given in Table 1. Sequential E_s has an obviously smaller range of partial transmission and reflection than E_{sc}. Rawer (1949), Briggs (1951*b*), and Chatterjee (1953) have made more detailed measurements of this range of partial transmission and reflection. Measurements made at Brisbane by introducing known changes of sensitivity in the *P′f* recorder (Thomas, Svenson, and Brown 1956) have shown that, within the limits of normal scaling measurements (0·1 Mc/s), $fE_s - f_bE_s$ is independent of recorder sensitivity over a range of 30 dB ; such fluctuations as do occur with change in sensitivity are no greater than those commonly occurring on fixed sensitivity.

The recorder sensitivity measurements also showed that at Brisbane, if E_s is of sufficient strength to record at all, its critical frequency is independent of equipment sensitivity for *both* E_{ss} and E_{sc}.

V. Multiple-hop Critical Frequency

In summer it is sometimes observed that the critical frequency of the trace representing two hops between ground and E_s is somewhat higher than that of the trace representing a single hop between ground and E_s (Plate 2, Fig. 1). If we denote these frequencies by f_mE_s and fE_s, then Figure 9 shows the diurnal variation of the occurrences of $f_mE_s > fE_s$ in December. There is a negligible number of occurrences of this phenomenon in winter.

Dieminger (1951) has discussed such records and states that the slight height rise associated with the higher critical frequency of the second echo is consistent with the hypothesis of ground scatter and oblique incidence propagation via the E_s region. Detailed measurements of records such as that shown in Plate 2, Figure 1, indicate, however, that the increases in range are much smaller than is necessary to fit Dieminger's theory. It is certainly true that the second

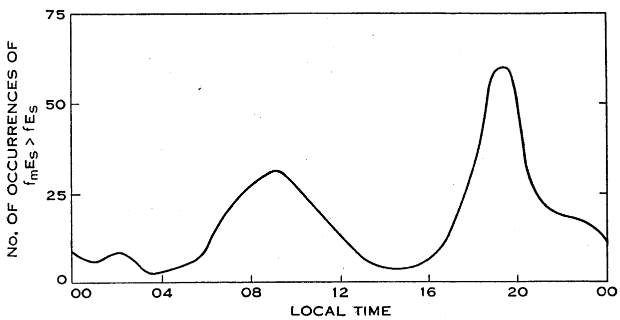

Fig. 9.—December variation of occurrence of $f_mE_s > fE_s$.

echo generally shows evidence of range spreading, but it is believed that this is more the result of the ionosphere behaving as a diffuse reflector giving a totally different type of illumination for the second hop, rather than ground scatter. Dieminger found it necessary to use very high powers to consistently observe ground scatter; at Brisbane, $2F_2$ scattered echoes such as he describes are never observed, and it is unlikely that such scattered echoes should be observed on day-time $2E_s$ echoes, and yet not on night-time $2F_2$ echoes.

Whatever explanation is finally advanced, it would seem that sequential E_s in its later stages (i.e. having dropped to its basic level and commenced to decay) is particularly favourable for the occurrence of such a phenomenon. It is believed (see Section XI (*a*)) that the sequential region at this stage consists of thin disk-like clouds which cannot be observed at any high degree of obliquity.

Records are often obtained with traces corresponding to a ray path from ground to F region to top of E_s region to F region and back to ground. These are the so-called M echoes. A typical summer and winter distribution of the occurrence of M echoes is given in Figure 10 for December and June, 1945. A comparison of these diagrams with Figure 3 shows an obvious correlation between the presence of E_s and the occurrence of M echoes, namely, M echoes are liable to be observed whenever E_s is observed below 120 km.

Sometimes records are made in which an M echo is observed reflecting at higher frequencies than the E_s layer itself; indeed, the E_s trace may be entirely absent from the record. Thus the " top " of an E_s region may, on occasion, be a much better reflector of radio waves than the lower boundary of the region.

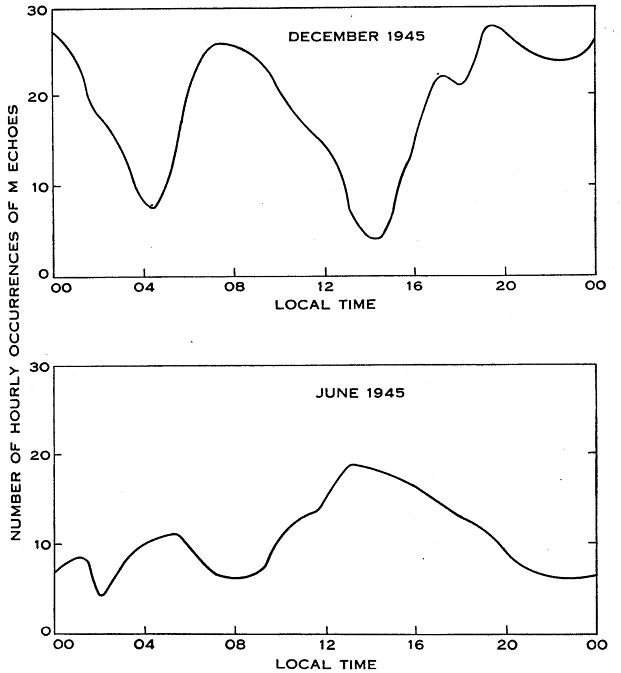

Fig. 10.—Summer and winter M-echo occurrence.

VI. Virtual Height of E_s Echoes

Using the published values of $h'E_s$ taken from $P'f$ records over 10 years, the diurnal variation of $h'E_s$ has been found and is shown in Figure 11. There is a large semi-diurnal variation in summer, autumn, and winter, but the spring equinox shows only a very ragged small diurnal variation. The phase of the height oscillation in June leads that in December by about 7 hr. The mean level of the E_s reflection shows a considerable seasonal fluctuation, being 5 km lower in winter than in summer.

A frequency plot of the occurrence of night-time E_s echoes at various heights (measured at 2·28 Mc/s to the nearest km by the method outlined by Thomas and Svenson (1955)) is shown in Figure 12 for the combined months of December 1952 and January 1953. The density of shading increases with increasing frequency of occurrences of recorded height values. The intermingling of the two types of E_s is quite obvious: a constant-height type layer at about 110 km is superimposed on the last stages of an afternoon sequential type layer, becoming prominent at about 2100 hr.

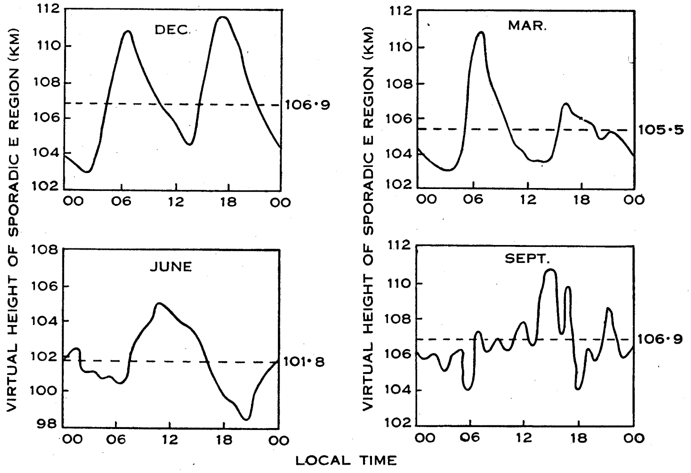

Fig. 11.—Seasonal-diurnal variations of $h'E_s$.

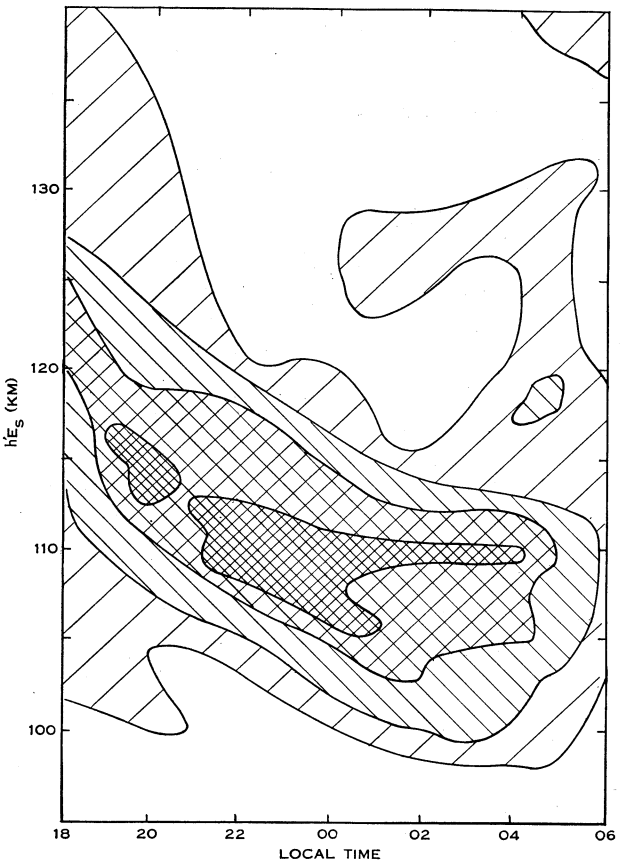

Fig. 12.—Mass plot of $h'E_s$ (measured at 2·28 Mc/s) for summer 1952–53.

VII. Range Spreading

On many records the E_s trace shows the phenomenon of " range spreading ", that is, the returned echo is elongated to a much greater extent than can be accounted for by the limited bandwidth of the receiver (Plate 2, Fig. 2). As a rough guide to the extent of this phenomenon successive indices (starting from 1) have been allotted to traces which appear to be twice, three times, four times,

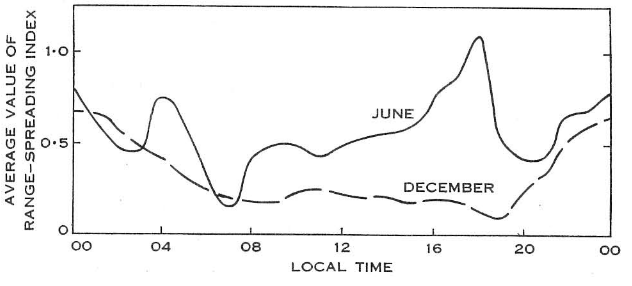

Fig. 13.—Summer and winter variation of range-spreading index.

etc. the normal trace width. Occasional traces with index 6 (i.e. ~140 km wide) have been observed. Figure 13 shows the mean value of this range-spreading index for the months of December and June. There is no evidence of solar cycle variation of this phenomenon. The marked peak and sudden drop after 1800 hr in June is evident in each year of the analysis. Range spreading

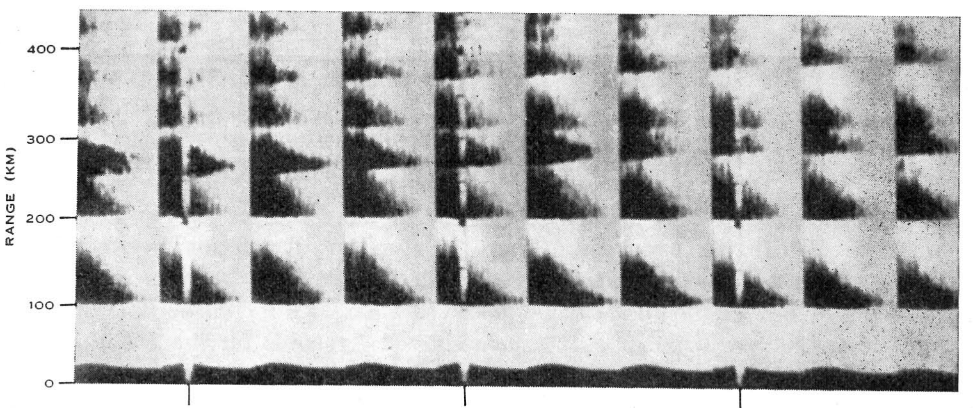

Fig. 14.—A typical swept-gain record at 2·28 Mc/s, showing $1E_s$, $2E_s$, $1F$, $3E_s$, $1F+1E_s$, and $4E_s$ echoes.

occurs most frequently at times when f_bE_s is small, that is, when E_{sc} occurs, and this indicates that the E_{sc} region is very irregular in nature.

Range spreading observed at 2·28 Mc/s has been further examined by means of the swept-gain technique. A typical record is shown in Figure 14. Webster (personal communication) has shown that, provided there is no specular component to the echo, a measurement of the slope of the swept-gain patches gives a direct measure of the index n in the $\cos^n \theta$ polar diagram of Briggs and Phillips (1950). The results are more conveniently expressed in terms of the half-amplitude angle, θ_0, of the polar diagram of scattered radiation received. A histogram of the computed values of θ_0 for one typical night is given in Figure 15.

Direction-finding measurements at 2·28 Mc/s can occasionally be made on an isolated part of a range-spread echo. Such echoes are invariably found to be non-zenithal. Ample evidence is found of the horizontal movement of patches of ionization, and these movements are to be the subject of another paper from this laboratory. Such movements can sometimes be detected on $P'f$ records.

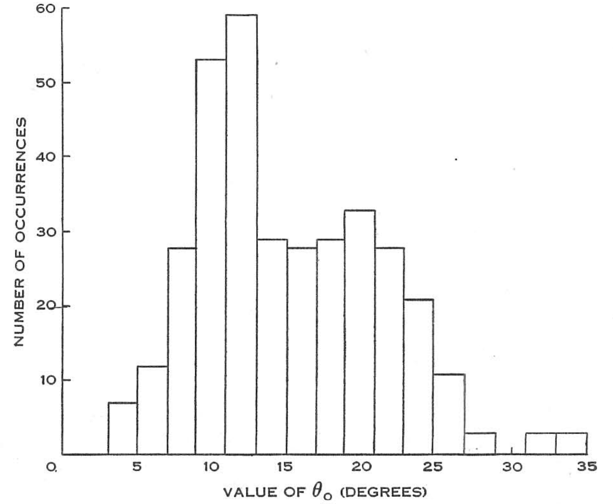

Fig. 15.—Values of θ_0 as determined from swept-gain records for the night November 16–17, 1954.

Measurements taken at 3·84 Mc/s and 5·8 Mc/s often show patches of sequential E_s drifting overhead; there is a major distinction between such drifting clouds and those commonly seen at 2·28 Mc/s, which are nearly all due to patches of E_{sc}. E_{sc} clouds can be observed when still a considerable distance from the station and appear as "saucer-shaped" records on the $P't$ film; E_{ss} clouds, on the other hand, show very little, if any, change of range as the cloud passes over. Phase-path measurements show that such E_{ss} clouds can only be seen when almost directly overhead.

VIII. Lateral Extent of E_s Patches

McNicol and Gipps (1951) have found that sequential E_s shows uniformity over wide areas. Sequences are recorded at the same times at recorders placed roughly on the same longitude, namely, Townsville (lat. 19·2 °S.), Brisbane (lat. 27·5 °S.), and Canberra (lat. 35·3 °S.). It was found, however, that the more southerly the station the less clear cut the sequence, the later the start, and the greater the tendency for decay to intervene before the sequence is complete.

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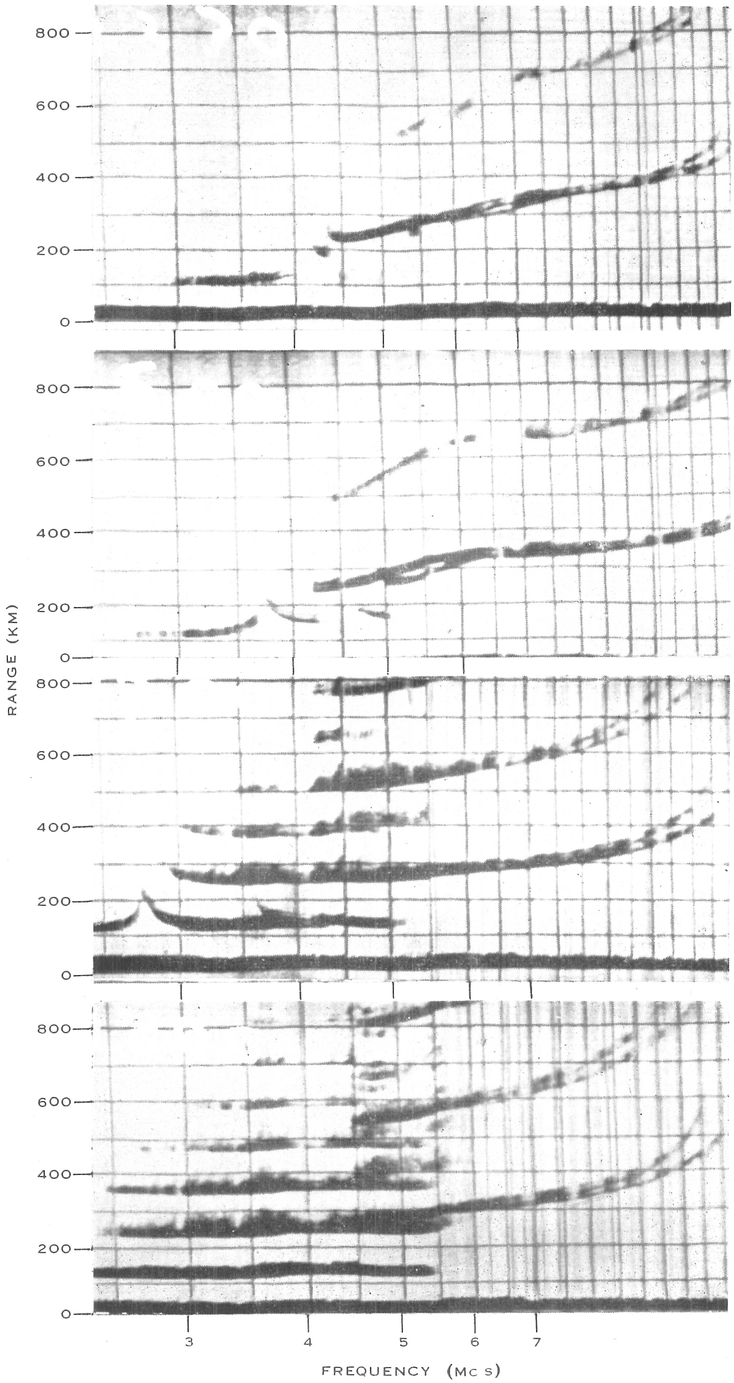

A series of $P'f$ records showing the formation sequence of E_{ss}.

Oblique incidence propagation of 73 Mc/s transmission from Melbourne to Brisbane, a distance of 1350 km, has often been reported* in summer. These reports have always occurred on days when fE_s at Brisbane was rather higher than normal, and hence when the E_s further south was also likely to be capable of reflecting high frequencies.

Constant-height type E_s, however, very often shows only limited correlation on fixed frequency records taken at stations separated by only 100 km. The average diurnal occurrence of E_{sc} is the same at each station but the spatial correlation is small. Records of slightly oblique reflections between pairs of these stations still show only limited correlation. Observations of isolated " clouds " which produce blanketing of the F region, indicate cloud sizes of the order of 10 km.

IX. Reflection Coefficients and Solar Cycle Control

On many occasions the reflection coefficient of the E_s layer is such that more than one reflection may be observed. On some occasions up to 20 reflections† have been recorded using a fixed frequency recorder operating on 2·28 Mc/s, and the occurrence of six or more reflections on the $P'f$ records is quite common. Diurnal variations of the average number of multiple echoes on $P'f$ records for

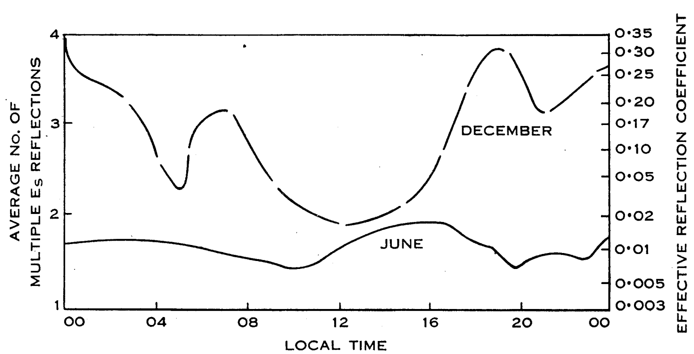

Fig. 16.—Multiple reflections and effective reflection coefficient for summer and winter.

summer and winter are shown in Figure 16. The day-time values of the effective reflection coefficient‡ is, of course, reduced by the presence of non-deviative absorption occurring below the E region level. But for this absorption, the number of multiples in December day-time would very probably be greater than in December night-time. This would indicate a higher reflection coefficient

* The author is indebted to the Radio Officer of the Queensland Ambulance Transport Brigade for these reports.

† Such a high number of multiple reflections is indicative of focusing effects as discussed by Baird (1954) and Schrag (1955).

‡ The effective reflection coefficient is found by comparing $P'f$ records with simultaneous swept-gain records at 2·28 Mc/s ; the effective reflection coefficient may be found directly from the latter.

for E_{ss} than for E_{sc}. One might expect some changes in reflection coefficient with changes in critical frequency. Such changes, if they exist, are not sufficient to materially affect the number of multiple reflections ; no kinks are observed in the curve for December corresponding to times of maximum critical frequency.

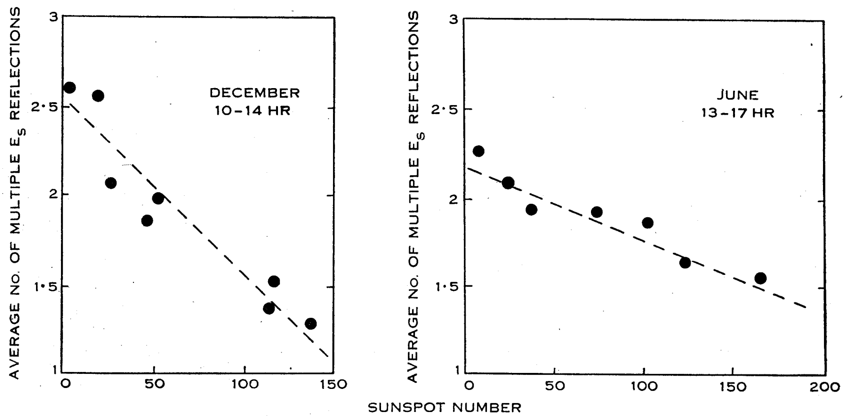

Fig. 17.—Sunspot cycle variation in E_s multiple reflections.

It thus appears likely that the reflection coefficient of E_{ss} is fairly constant throughout the daylight hours.

D region absorption is particularly evident in December. Figure 17 shows the variation in the average number of multiple reflections during the period

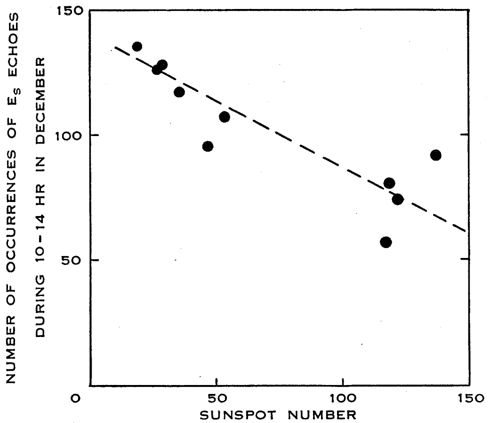

Fig. 18.—Sunspot cycle variation in E_s echoes recorded.

1000–1400 hr in December and 1300–1700 hr in June, as a function of sunspot number. Figure 18 shows the number of recordings of E_s echoes during 1000–1400 hr in December as a function of sunspot number. Both of these graphs indicate the strong dependence of the effective reflection coefficient on solar ionization. Since this is the *only* property associated with E_s reflections which shows any solar cycle dependence, it is a fair assumption that the majority of the solar cycle change in the effective reflection coefficient is due to a change in absorption occurring in the D region.

X. Correlation with Other Phenomena

(a) *Meteor Correlation*

The earlier paper by McNicol and Gipps (1951) pointed out that there is very little correlation between E_s at Brisbane and the occurrence of meteoric dust. Naismith (1954) has reported a " meteoric E " layer in England which is responsible for the majority of Slough records scaled previously as E_s. The diurnal distributions of the critical frequency and occurrence of this layer are entirely different from those for E_s at Brisbane. Occasional weak echoes are seen on the fixed frequency records below the normal E_s level. It is possible that these may correspond to such a meteoric E layer, only being observed when the reflection coefficient is sufficiently high.

(b) *Thunderstorm Correlation*

According to one theory of E_s formation, thunderstorms may provide a means of producing new ionization in the E region. Mitra and Kundu (1954) have reported an increase in E_s ionization coincident with the onset of squall-type storms in Bengal in the pre-monsoonal months. Reliable records of thunderstorm occurrences and paths are available in Brisbane, and a search through the records showed no E_s-thunderstorm correlation, even in the pre-monsoonal months of October and November.

XI. Conclusion

It has been found possible, on a statistical basis, to achieve a fairly detailed separation of the occurrence of the two types of E_s at and below 120 km. The chief instrument in this separation is the recorded value of the *blanketing frequency*.

(a) *Sequential* E_s

E_{ss} is predominant in summer, there being normally two sequences starting at about 0530 hr and 1300 hr. In both morning and afternoon the time of maximum intensity of E_{ss} ionization occurs about 4–5 hr after the breakaway from E_2, that is, about 4 hr after the ionization is at its maximum height.

Sequential E_s occurs with decreasing regularity and strength until September, after which there is a rapid rise to the peak in December.

Many workers have discussed the types of ionization distribution which could lead to the conditions holding in the early stages of sequential E_s (Best, Farmer, and Ratcliffe 1938 ; Appleton, Naismith, and Ingram 1939 ; Rawer 1939*a*, 1939*b*, 1940, 1949 ; Briggs 1951*a*, 1951*b* ; Whale 1951 ; Chatterjee 1953). Briggs (1951*b*) has shown that when the frequency overlap (or frequency range of partial penetration and partial reflection) is small, then the ionization is in the form of a thin layer of high ionization density, with absorption occurring near the critical frequency. The increase in the frequency overlap from zero at the beginning of a sequence, to 1 Mc/s or more in the later stages thus suggests a very substantial thinning down of the ionized region. Martyn (1953) has shown that a mass of excess ionization which moves in a region where Hall conductivity is appreciable will accrete ionization on one side at the expense of the other, the ionization building up into a thin shell on the leading edge of the moving mass. If the stratification and breakaway of ionization from around the 200 km level were due to solar tidal motion in the upper atmosphere, then E_{ss} formation could be satisfactorily explained on that basis.

The increased number of E_2 records obtained in winter and spring suggests that the tidal forces causing breakaway of ionization from the E_2 region are stronger in summer and autumn than in the other two seasons.

The facts that (i) the maximum in fE_s lags behind the maximum virtual height by 4–5 hr, and (ii) the lunar tidal analyses of Matsushita (1953) show a lag of fE_s on $h'E_s$ of about 2 hr, indicate some measure of support for the hypothesis of tidal drift of ionization, as the source of E_{ss}—accretion of ionization will not be well marked until the region has been moving downwards for an appreciable time. It is rather difficult, however, to account for the lack of increase in critical frequency with an upward drift, which exists, for example, between the morning and afternoon downward drifts in summer months.

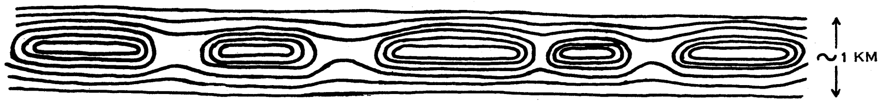

Fig. 19.—Suggested ionization contours in the latter stages of sequential E_s.

The coincidence of sequential movement at the three widely spaced stations along roughly the same latitude shows that the E_2 stratification and subsequent breakaway are indications of the widespread effect of some type of solar control. It is obviously not a direct solar control since there is often decay and re-formation of E_2 after midday in summer, followed by another sequence. The most plausible explanation of such double sequences lies in solar tidal drifts of ionization.

In the later stages of the sequence (below about 120 km) the range of partial transmission extends to more than 1 Mc/s and the $P'f$ record may take on the patchy appearance often associated with E_{sc}. It is probable that at this stage the " thin layer " is breaking up into discrete regions or " clouds " of ionization, remaining fairly thin, but with the gaps between the clouds still retaining a reasonably high electron density and hence capable of producing blanketing to quite high frequencies (Fig. 19). Such thin disk-like clouds would be capable of giving substantial reflection only when almost exactly overhead. In the final stages the overall ionization density decreases so that both fE_s and f_bE_s decrease together.

(b) *Constant-height Type* E_s

The " patchy " appearance often associated with E_{sc} traces is indicative of a considerable amount of frequency fading. Briggs (1951*a*) has found such frequency fading to be associated with a region capable of giving scattered reflections at a considerable angle to the vertical ; such reflections are not found for the sequential type of E_s.

There is ample evidence of non-zenithal reflections from E_s clouds and the nature of this type of E_s is not much in doubt. E_{sc} consists of ionization in which is imbedded patches or clouds of enhanced ionization. This background of ionization may, or may not, be observed.

The oblique reflections obtainable from E_{sc} ionization are responsible for the range spreading referred to in Section VII. The late afternoon winter peak in range spreading indicates that immediately before decay the region tends to become very patchy or rough and can thus reflect strongly from non-zenithal points.

Experiment has eliminated three theories for the origin of E_{sc} at Brisbane. Booker's (1950) scattering theory is untenable since fE_s is independent of recorder sensitivity. The negative correlation of E_s with meteor and thunderstorm occurrence eliminates these two as causes of E_{sc}.

The true cause of E_{sc} ionization is not known with any certainty. The most probable explanation lies again in tidal drifts due to solar forces. The seasonal shift in the times of maximum occurrence of high critical frequency (keeping 4–5 hr behind maximum $h'E_s$) cannot well be explained on any other hypothesis.

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