SUNRISE AND ECLIPSE EFFECTS ON THE IONOSPHERE AT BRISBANE

By G. G. Bowman*

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Summary

A rotating spaced-loop direction-finding system, located at Brisbane, has been operated to investigate sunrise effects by using pulsed $3 \cdot 84$ Mc/s transmissions, (*a*) at normal incidence and (*b*) at oblique incidence. For oblique-incidence recording the transmitter was located at Armidale (bearing 202° and distant 355 km from Brisbane).

Evidence is presented which suggests the formation (at both E- and F_2-layer levels) of several frontal irregularities, spaced some tens of kilometres apart, extending in directions parallel to the sunrise line and travelling, relative to the Earth, with this line. These fronts pass overhead at Brisbane approximately half-way between the 90 km level and ground level sunrise times.

In the post-sunrise period, F_2-layer spreading on the two-hop trace appears, and the spreading width increases for about 2 hr, suggesting an F_2-layer ripple structure, with increasing ripple amplitude. The post-sunrise sporadic E occurrence suggests frontal irregularities, lying close to the sunrise line direction, soon after sunrise, but indicates a swing in direction as time progresses.

Rotating-loop normal-incidence transmissions were also used to investigate effects due to an eclipse of the Sun, at Brisbane, on April 8, 1959. Post-eclipse E- and F_2-layer frontal irregularities, oriented in directions close to the line representing the end of eclipse in the region of Brisbane, suggest a mechanism operating as the eclipse ends, which is similar to that operating at sunrise.

The possibility, that the ripple structure which produces night-time spread-F at Brisbane is generated at sunrise, is discussed.

I. Introduction

Sunrise effects have been investigated using a rotating spaced-loop direction-finding system located at Brisbane ($27 \cdot 5$ °S.; $152 \cdot 9$ °E.). This was capable of determining azimuths-of-arrival for signals received away from the vertical, and it recorded simultaneously, on separate displays, two pulsed $3 \cdot 84$ Mc/s transmissions. One transmitter was located at Armidale (bearing 202° and distant 355 km from Brisbane) and the other on the same site as the rotating-loop system. Detailed descriptions of this system and the nature of the records from it are contained in another paper (Bowman 1960*a*). Ionograms and fixed-frequency $h't$ records have also been used in this analysis.

II. E-Layer Sunrise Irregularities

(*a*) *Oblique-incidence Effects*

(i) *Introduction*.—During the period of rotating-loop recording in 1958, oblique-incidence records were taken during 12 sunrise periods in July. Within five of these periods, additional traces, of a character not found at other times of

* Physics Department, University of Queensland, Brisbane.

the day, were recorded. These traces occurred in a series, spaced from 50 to 100 km apart. Each trace decreased range at a considerable rate and moved towards a range representing the shortest distance from Armidale to Brisbane via the *E* layer. These traces were found to persist, sometimes for as long as 30 min. When the records were good enough, azimuths-of-arrival could be read for these signals. The distribution of these azimuths was centred roughly on east. This, and the rapid change of range, suggested an association with a sunrise irregularity moving with the speed of rotation of the Earth. Plate 1, Figure 1, shows the nature of the traces recorded.

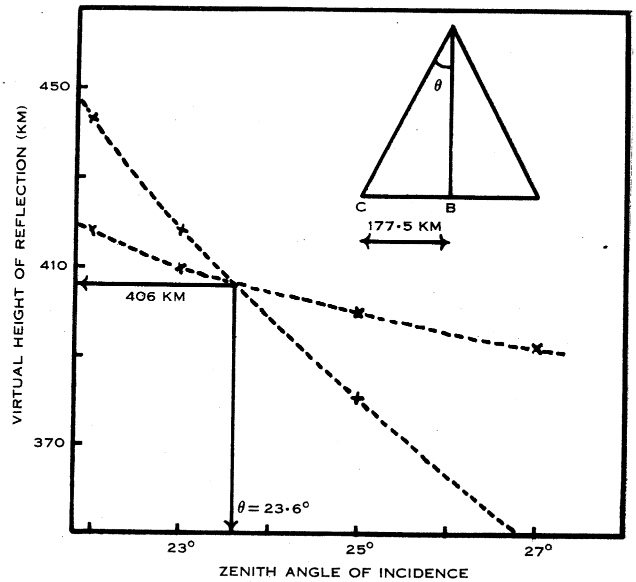


Fig. 1.—Diagram illustrating method for calculation of virtual height of reflection and angle-of-incidence for 3·84 Mc/s oblique-incidence transmissions at 0540 on July 31, 1958.

(ii) *Analysis of Sunrise Effect on July 31, 1958*.—The first step in this analysis was to establish the true ranges of the satellite echoes recorded. To do this, a calculation of the group path of the one-hop F_2-layer signal was necessary, as, because of the method of recording, this has to be used as a reference level. Use is made of the fact that the virtual height of reflection for the equivalent normal-incidence frequency ($f=f' \cos \theta$) is the same as that for the oblique-incidence frequency, f'. The oblique-incidence virtual height of reflection at 0540 has been calculated in the following manner. Table 1 shows, for various angles of incidence θ, (*a*) normal-incidence virtual heights read from the ionogram at the normal-incidence equivalent frequency ($f=f' \cos \theta$) and (*b*) oblique-incidence virtual heights of reflection from the expression, $177 \cdot 5 \cot \theta$ (177·5 km is half the distance between Brisbane and Armidale). Figure 1 shows how a plot of these variations will give (*a*) the angle-of-incidence and (*b*) the virtual height of reflection, at this time. The ionogram is for

Brisbane, and, strictly speaking, the virtual height found (406 km) represents the virtual height of reflection of $3 \cdot 84$ Mc/s transmissions from stations, one midway between Brisbane and Armidale and the other an equal distance on the far side of Brisbane (see Fig. 2 (*a*)). This virtual height gives a group path of 886 km.

TABLE 1

Normal-incidence Equiv. Freq. for Angle-of-Incidence θ (Mc/s)	Normal-incidence Virtual Height of Refln. (km)	Oblique-incidence Virtual Height of Refln. ($177 \cdot 5 \cot \theta$) (km)
$3 \cdot 84 \cos 22° = 3 \cdot 56$	418	443
$3 \cdot 84 \cos 23° = 3 \cdot 53$	410	418
$3 \cdot 84 \cos 25° = 3 \cdot 48$	400	381
$3 \cdot 84 \cos 27° = 3 \cdot 42$	392	348

Similar calculations have been made for other times within this period, and the oblique group paths plotted against time are shown in Figure 2 (*c*) (using the upper time scale). Since the rapid changes in the F_2 layer, around sunrise, travel round the Earth with a speed equal to that of the sunrise line, the

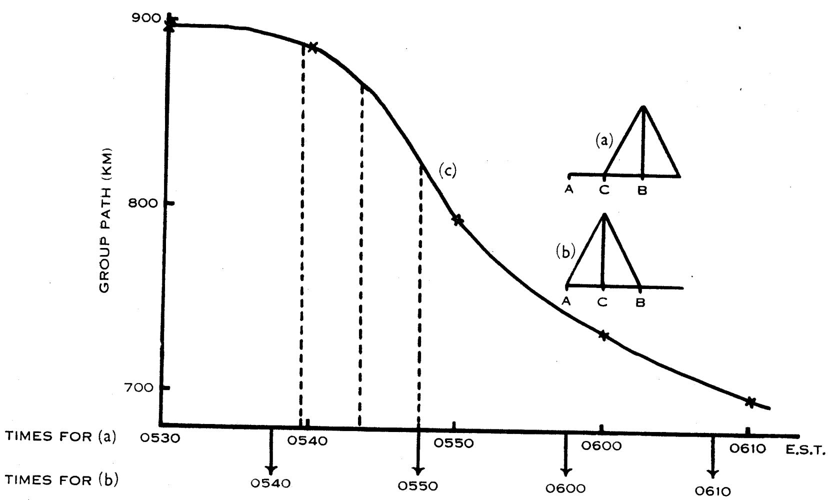


Fig. 2.—Calculated group-path variation of oblique-incidence $3 \cdot 84$ Mc/s transmissions between Armidale and Brisbane on July 31, 1958. *A*, Armidale ; *B*, Brisbane ; *C*, mid point between Armidale and Brisbane.

propagation parameters for the Armidale to Brisbane reflection point can be taken as the same as those which pertained $2\frac{1}{2}$ min earlier above Brisbane (5 min of time being the longitude difference between Armidale and Brisbane). Thus, in using Figure 2 (*c*) the lower time scale gives the correct group path for the one-hop F_2-layer signal (the *o*-ray has been used for all calculations).

Table 2 summarizes the observations made on " sunrise " traces of July 31, 1958.

Neglecting group retardation and assuming the reflection height to be 90 km, the data of Table 2 lead to locations, in plan, of the reflection points, shown in Figure 3. The choice of 90 km for the reflection height will be discussed later. In Figure 3, positions are plotted relative to a plane which has a constant orientation with respect to the Sun. Thus, the positions on it of Brisbane and Armidale move with the speed of the sunrise line at 90 km (1500 km/hr). With this arrangement, any ionospheric configuration moving with the sunrise line should appear stationary on the plot. No azimuth information is available for signals recorded at 0550, so loci of possible reflecting points are plotted in this case. The information shown on Figure 3 is consistent with reflection taking place from a series of fronts nearly parallel to the sunrise line and moving with it. The first front passes overhead at Brisbane at about 0601 Eastern Australian Standard Time (E.S.T.).

TABLE 2

Time	Group Path of F_2 Trace (km)	Additional Path of Sunrise Trace (km)	Sunrise Trace Group Path (km)	Sunrise Trace Azimuth
0542	887	275	1162	080°
0546	865	225	1090	085°
		125	990	085°
0550	823	410	1233	—
		350	1173	—
		275	1098	—
		200	1023	—

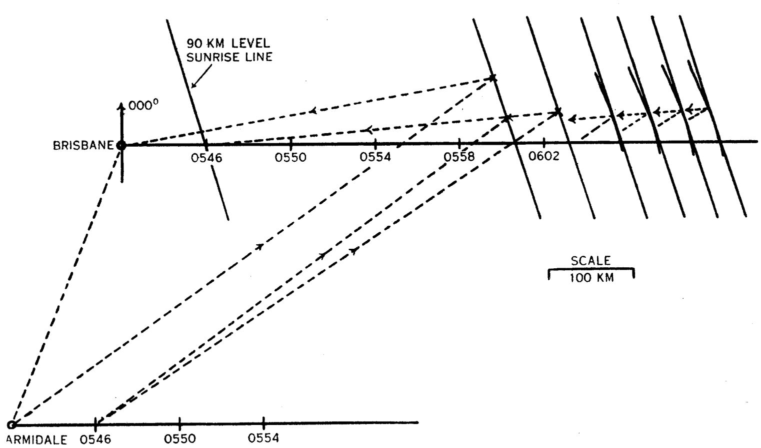


Fig. 3.—Plan position of reflecting surfaces at the 90 km level, around sunrise on July 31, 1958.

(iii) *Analysis of Sunrise Effects on July 13 and 15, 1958.*—A method of calculation similar to that explained in (ii) has been used for the sunrise traces on the oblique-incidence rotating-loop record for July 15, 1958. Figure 4 shows the group path plotted against time for these traces; also for the one-hop F_2-layer o-ray trace. Azimuth-of-arrival information is also indicated. The first

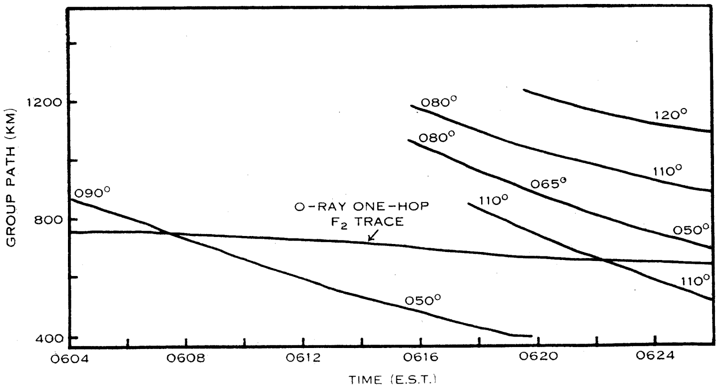


Fig. 4.—Illustration of traces from E-layer sunrise irregularities on July 15, 1958.

sunrise trace terminates at a group path corresponding to great circle reflection from the vicinity of the E layer. At this point it shows as a well-defined trace with no change of group path for about 1 min. This is, apparently, the smallest range possible for this sunrise trace, and its separation in range from the one-hop

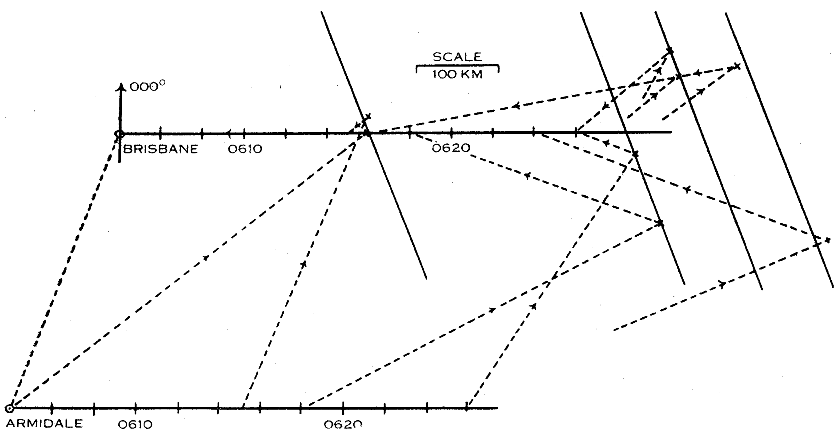


Fig. 5.—Plan position of reflecting surfaces at the 90 km level, around sunrise on July 15, 1958.

F_2-layer trace (o-ray) allows a determination of the height of reflection of the sunrise trace. This was found to be (88 ± 5) km. For the plan-position plots (e.g. Fig. 3) the value, 90 km, was assumed. The observed group paths were so large that a few kilometres error in height around this level would not affect the calculated positions of reflection very much.

Figure 5 is a plot (similar to that of Fig. 3) showing the calculated plan positions of reflecting points determined from the ranges and azimuths shown on Figure 4. In this case the first sunrise front passes overhead at Brisbane at 0616 E.S.T. Of the reflection paths shown in Figure 5, 50 per cent. are such as would be expected if specular reflection occurred from irregularities lying along the sunrise line.

Similar calculations for sunrise traces on July 13, 1958, indicate the initial frontal irregularity passing overhead at 0613 E.S.T., followed by two other reflecting surfaces spaced roughly 100 km apart.

TABLE 3

Day	Time Transit 1st Irregularity A (E.S.T.)	Ground Sunrise B (E.S.T.)	90 Km Sunrise C (E.S.T.)	B–A (min)	A–C (min)
13.vii.58	0613	0641	0552	28	21
15.vii.58	0616	0640	0551	24	25
31.vii.58	0601	0632	0546	31	15

Table 3 indicates the relationship of times, for the first sunrise irregularity transit, with the times for ground sunrise and 90 km level sunrise, on the three days analysed.

Although normal-incidence recordings were made at the same time as the oblique-incidence records discussed in this section, no traces were seen thereon which could be attributed to reflection from these frontal irregularities.

(*b*) *Post-sunrise Sporadic* E *Orientation*

On certain days in April and May 1959, the rotating-loop system was operated from 0500 to 0800 E.S.T., using the normal-incidence transmitter only. Sporadic E traces were sometimes observed, starting after 90 km sunrise and lasting for several minutes. They showed a definite azimuth-of-arrival. Plate 1, Figure 2, is an example. It has been shown by the writer (Bowman 1960*b*) that sporadic E patches are probably frontal in character. Therefore, these azimuth readings should give an indication of the orientation of the sporadic E fronts. Table 4 shows the days of recording, together with information on these sporadic E occurrences. These short-period sporadic E traces appear to be present on most days.

Baral (1955) has reported, from Calcutta, the occurrence of a " sunrise-time " E_s, appearing generally between E-layer and ground sunrise times. These traces occurred regularly (in more than 60 per cent. of the total observations).

Figure 6 shows a plot of the time separation between this sporadic E occurrence and the 90 km level sunrise time, against the angular separation between the normal to the sporadic E front and the perpendicular to the sunrise line. This reveals that sporadic E fronts occurring soon after the 90 km level sunrise are nearly parallel to the sunrise line. Although the information is meagre, the points on Figure 6 representing sporadic E occurring more than 1 hr after 90 km level sunrise suggest a swing of this orientation as time progresses. This indicates a swing of approximately 90° in $2\frac{1}{2}$ hr.

TABLE 4

Day	Sunrise 90 km Level	Sporadic E Occurrence	Azimuth-of-Arrival	Perpendicular to Sunrise Line	Sporadic E Duration (min)
1959					
April					
8 ..	0526	0538	080°	083°	6
9 ..	0527	—	—	—	—
10 ..	0528	—	—	—	—
11 ..	0528	0800	180°	082°	10
12 ..	0529	0546	100°	082°	3
13 ..	0530	0548	070°	081°	2
16 ..	0533	0600	080°	080°	5
17 ..	0534	—	—	—	—
18 ..	0534	0554	090°	080°	4
19 ..	0535	0642	120°	079°	7
20 ..	0536	0800	170°	079°	12
May					
21 ..	0554	0716	100°	070°	10
22 ..	0555	—	—	—	—
23 ..	0556	—	—	—	—
24 ..	0556	0656	090°	070°	3

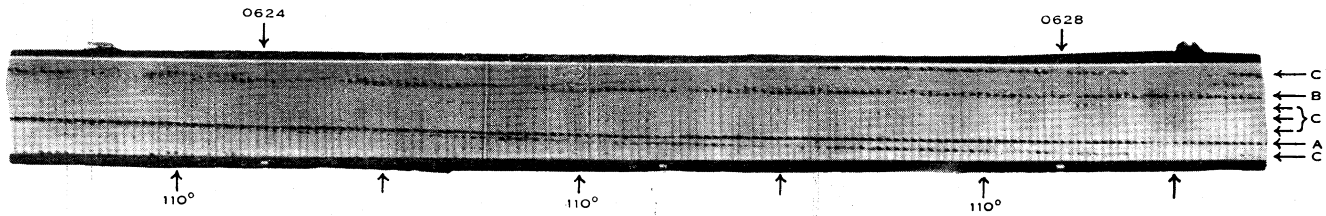
III. F_2-LAYER SUNRISE IRREGULARITIES

(a) *Pre-sunrise High Multiples*

A regular feature of Brisbane ionograms recorded just before sunrise is the presence of high-multiple traces (tenth hop or greater). Plate 2, Figure 2, shows such ionograms and Plate 2, Figure 1, an example on an $h't$ record (at $2 \cdot 28$ Mc/s). The probability that these traces are due to combinations of E-layer and F_2-layer reflections is ruled out, since the spacings between the several high-multiple traces are approximately equal to the one-hop F_2 virtual height. (This is shown most clearly in Figure 7 (*a*) which represents a tracing of part of Plate 2, Figure 1.) The duration of the high multiples which occur at this time is seldom greater than 30 min.

Plate 2, Figure 3, shows a recording of this phenomenon on a rotating-loop record indicating an azimuth-of-arrival of 090°. This is consistent with the irregularity causing the high multiples being frontal in nature and oriented nearly parallel to the sunrise line. The average azimuth-of-arrival for six readings taken in April 1959 was 088°, while the perpendicular to the sunrise line during this period was at approximately 080°. The average azimuth-of-arrival for four readings taken in July 1958 was 082°, and the perpendicular to the sunrise line was at 070°.

1



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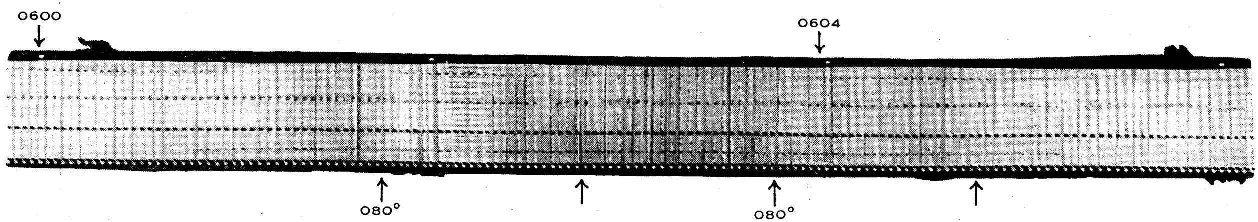
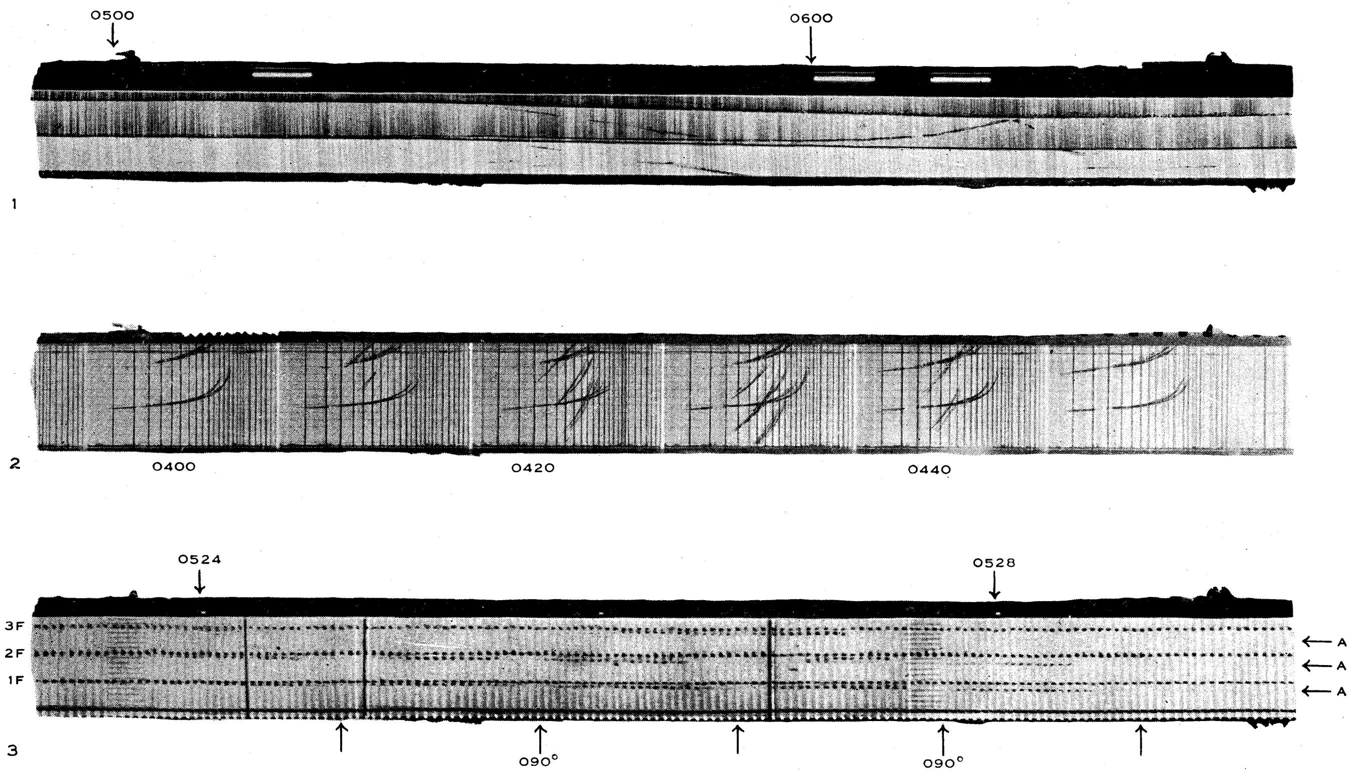


Fig. 1.—Example of oblique-incidence rotating-loop record at 0615 on July 17, 1958, illustrating traces received from sunrise irregularities in the E layer. A, one-hop F_2 trace; B, two-hop F_2 trace; C, traces from sunrise irregularities.

Fig. 2.—Example, on normal-incidence rotating-loop record, of post-sunrise sporadic E occurrence at 0600 on April 16, 1959.

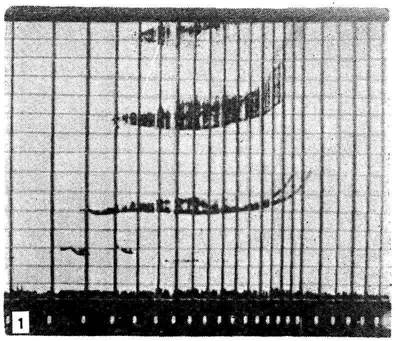


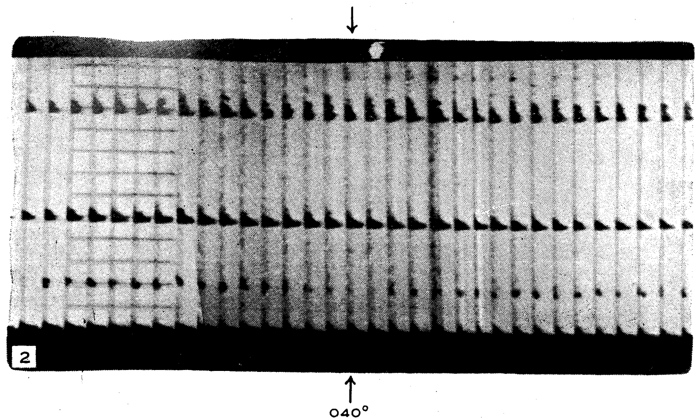
Examples of pre-sunrise high-multiple traces from F_2-layer irregularities.

Fig. 1.—2·28 Mc/s *h′t* record on July 27, 1958.

Fig. 2.—Ionograms on September 27, 1956.

Fig. 3.—Normal-incidence rotating-loop record on April 19, 1959, illustrating azimuth-of-arrival of pre-sunrise high-multiple traces. *A*, High-multiple traces.





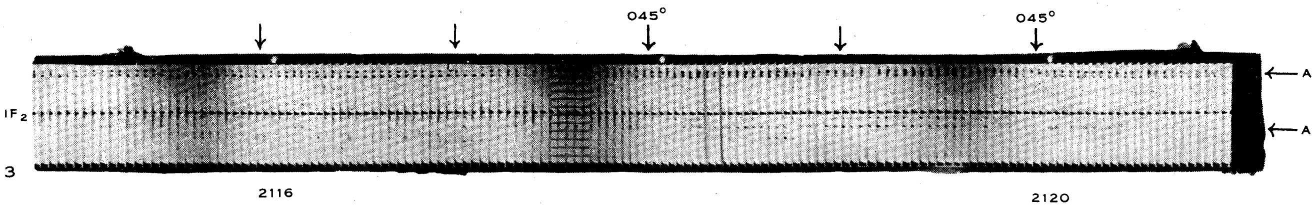


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Fig. 1.—Ionogram at 0720 on March 29, 1956, illustrating post-sunrise spread-F on two-hop F_2 trace.

Fig. 2.—Post-eclipse normal-incidence rotating-loop record at 1756 on April 8, 1959, indicating azimuths-of-arrival for sporadic E and spread-$2F$ traces.

Fig. 3.—Post-eclipse normal-incidence rotating-loop record on April 8, 1959, indicating azimuths-of-arrival, and nature of high-multiple traces. A, High-multiple traces.

A detailed study has been made of the occurrence of this phenomenon on Brisbane ionograms during 1956. Figure 8 indicates the diurnal variation of percentage occurrence, month by month. Also plotted (to the nearest 10 min) are the times for ground sunrise. The time of occurrence of the pre-sunrise peak in the distribution appears to move with the time of sunrise through the year. This pre-sunrise peak is evident from the results of Baird (1954). Figure 9 shows the aggregate of these distributions plotted relative to the time of ground

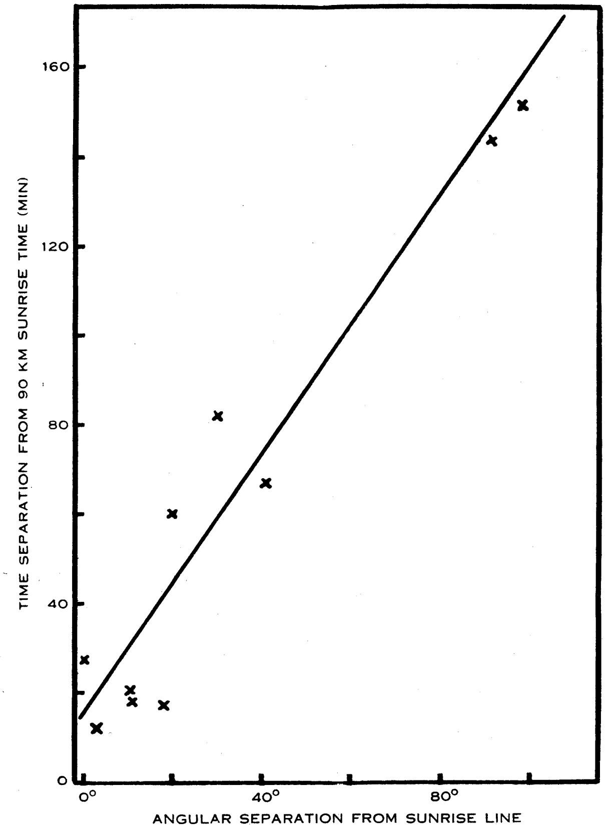

Fig. 6.—Graph of post-sunrise sporadic E occurrence. Time separation from 90 km level sunrise time is plotted against angular separation between the normal to the sporadic E front and the perpendicular to the sunrise line.

sunrise. This shows a peak in the distribution approximately 30 min after the 250 km level sunrise, and 50 min before ground sunrise. The average percentage occurrence of 37 per cent. for this peak indicates that, in 1956, this phenomenon occurred regularly. The seasonal variation of percentage occurrence of this phenomenon in 1956 is shown in Figure 10, when occurrence is considered in the period between the time of ground sunrise and an hour prior to this time.

Referring again to Figure 7 (a), since the pulse repetition frequency used was 50 c/s, the position of the ground pulse represents 2998 km virtual range when

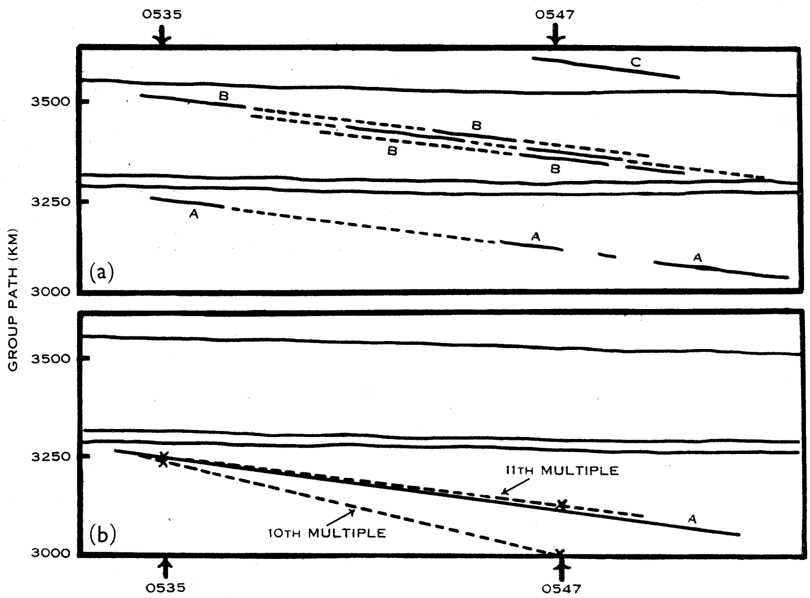

Fig. 7 (*a*).—Tracing of part of Plate 2, Figure 1, illustrating the nature of high-multiple traces in detail.

Fig. 7 (*b*).—Comparison between rate of change of group path for trace *A* from (*a*) and calculated changes for 10-hop and 11-hop transmissions.

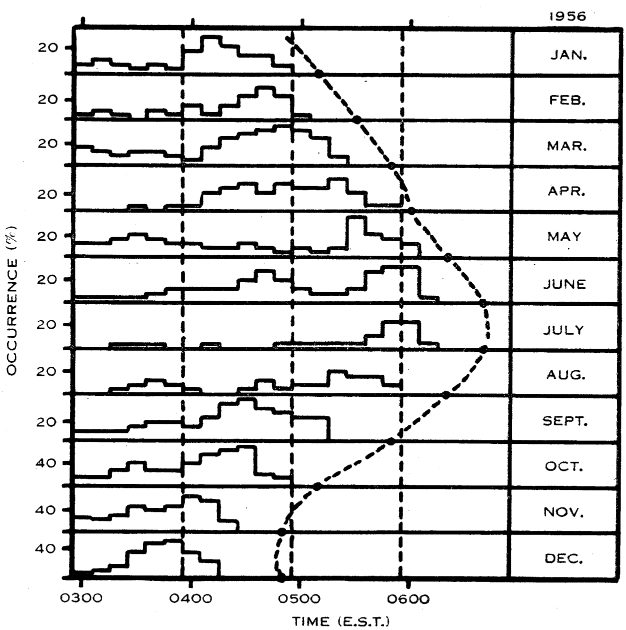

Fig. 8.—Percentage occurrence of high-multiple traces, around sunrise, for the 12 months of 1956. Times of ground sunrise (to the nearest 10 min) are indicated.

considering high-multiple traces. The traces marked A appear to correspond with the same irregularity, since they are in line, whereas the traces marked B suggest a sequence of irregularities, the reflection point jumping from one irregularity to the other as time progresses. This multiplicity of traces is a common feature of the phenomenon. It is also illustrated by Plate 2, Figures 2 and 3.

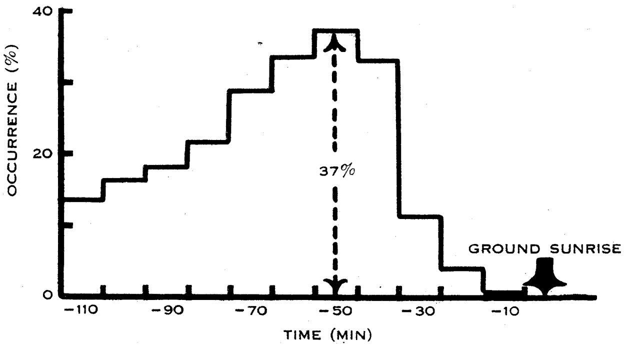

Fig. 9.—Percentage occurrence of high-multiple traces (from ionograms) for 1956 when plotted relative to ground sunrise.

It is possible, in some cases, to estimate which multiple hop the trace represents and the position of the sunrise F_2 irregularity relative to the station at the time of recording, by the following method. Using the information from ionograms, true heights of reflection for a fixed frequency are calculated

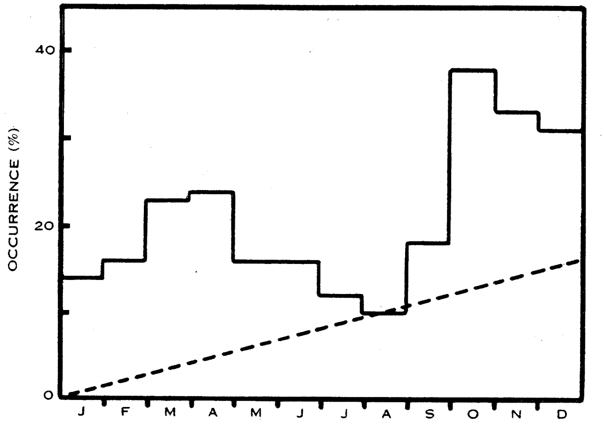

Fig. 10.—Seasonal distribution (for 1956) of percentage occurrence of high-multiple traces for the hour before ground sunrise.

(Schmerling 1958) at 10-min intervals. It is then assumed that the changes in height arose from the movement of a fixed ionospheric configuration over the Earth with the same velocity as that of the F_2 sunrise line ; and a true height versus distance diagram is constructed on this basis. The results for sunrise, July 27, 1958, are shown in Figures 11 (a) and 11 (b) and the group retardation for vertical reflections is shown in Figure 11 (*c*). The frequency used here was $2 \cdot 28$ Mc/s.

It is now possible to determine, by trial, the location of a scattering irregularity on the configuration such that the group path for the multiple-hop echo, at a selected time, would fit the observed results. This is not, however, a simple geometrical problem, since allowance must be made for group retardation at each reflection from the ionosphere. Since this retardation is relatively small (in terms of equivalent path), it is sufficiently accurate to assume it the same for oblique as for vertical reflection. A guess must be made as to the number of hops involved. In the example used (trace A at 0535 on July 27, 1958, Fig. 7 (*a*)), since the total group path for trace A is just less than 12 times the group path for one-hop F_2, it is clear that the number of reflections involved must be 11 or 10.

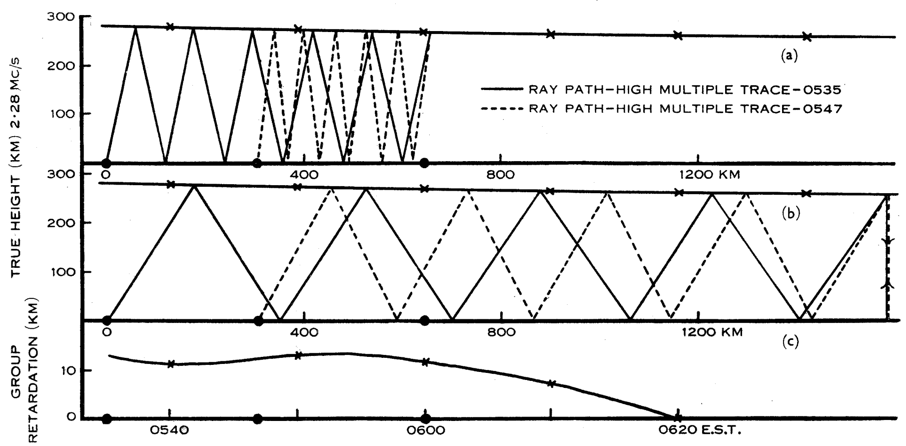

Fig. 11 (*a*).—Proposed ray paths for 11-hop F_2-layer transmissions for high-multiple traces observed at sunrise on July 27, 1958.

Fig. 11 (*b*).—Proposed ray paths for 10-hop F_2-layer transmissions for high-multiple traces observed at sunrise on July 27, 1958.

Fig. 11 (*c*).—Variation of group retardation for vertical-incidence $2 \cdot 28$ Mc/s transmissions at sunrise on July 27, 1958.

Solutions, based on these alternative assumptions, are shown in Figures 11 (*a*) and 11 (*b*), the positions of Brisbane, relative to the configuration, at the selected times, being shown by dots on the horizontal axis. Another time, several minutes later (0547), was then chosen, and the group paths calculated (on the same basis as before) to the position of the irregularity for 10- and 11-hop transmissions at 0535. Figure 7 (*b*) shows the rate of change of group path, calculated in this way, for the alternative transmissions. The rate of change of group path for 11-hop transmission is very close to that observed for trace A, and therefore Figure 11 (*a*) must indicate the approximate position of the principal F_2 irregularity. This appears to pass overhead at Brisbane at approximately 0600. This time is 34 min before ground sunrise.

(*b*) *Post-sunrise Two-hop Spread*-F

Another frequently recurring feature of ionograms at Brisbane is the presence of unresolved satellite traces related to the two-hop F_2 trace. This type of spreading commences a short time (within 30 min) after ground sunrise. Plate 3, Figure 1, illustrates an example of this. Calculations have been made of the average spreading widths (in range) of these spread-2F traces for March 1956, April 1956, and July 1958. These average spreading widths are shown, by Figure 12, to grow from a value slightly greater than the transmitter pulse width of 10 km to a width in the region of 40 km about 2 hr later. After this,

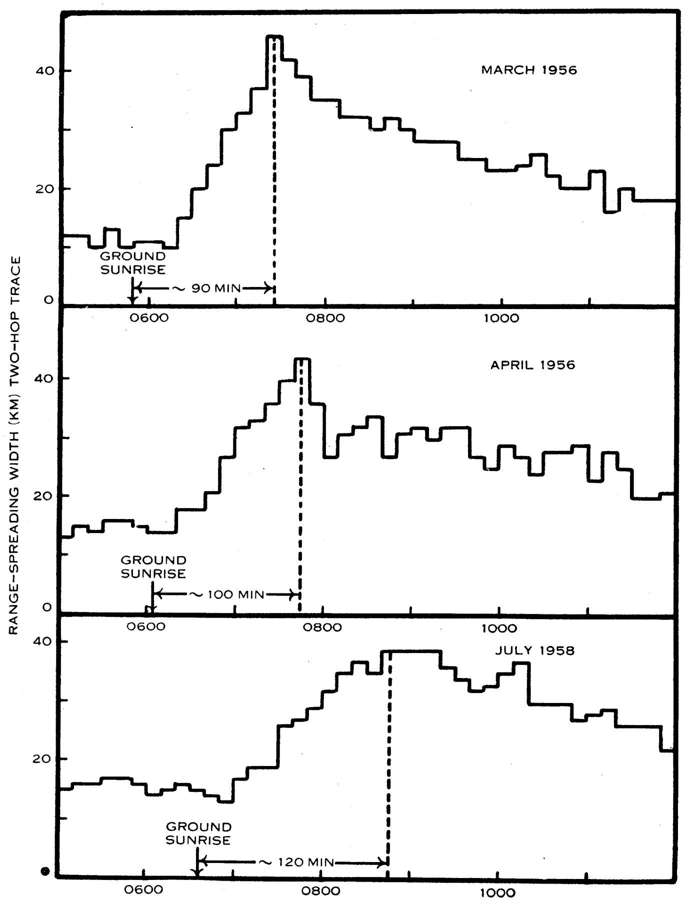

Fig. 12.—Variation of average range-spreading width of two-hop spread-F between 0500 and 1200 for March 1956, April 1956, and July 1958.

there is a gradual fall in average spreading width, at least until 1200 (no readings were taken after 1200). The times of commencement of this phenomenon and the times of maximum average spreading widths appear to be closely related to the time of ground sunrise (Fig. 12).

In view of the apparent orientation of the sunrise F_2 irregularities along directions close to the sunrise line (reported in Section III (a)), and also the sunrise line orientation of sporadic E and its subsequent swing in direction

(Fig. 6), the azimuths-of-arrival of these satellite echoes appear to be of interest. Attempts were made during April and May 1959 to measure the azimuths-of-arrival on the assumption that these ionospheric irregularities were of a nature similar to those causing spread-F at night (Bowman 1960*a*). However, the signal strength of these echoes was so low that they were not recorded by the rotating-loop system.

IV. Post-eclipse Ionospheric Effects

During and after the eclipse of the Sun at Brisbane on April 8, 1959, normal-incidence rotating-loop records were made. During the eclipse nothing of interest concerning the azimuth-of-arrival of signals was recorded.

However, from 1600, about half-an-hour after the end of the eclipse, two-hop F_2-layer spreading appeared, the spreading width gradually increasing until 1830 when it was 150 km, made up of some 10 or more satellite traces. A plot of the

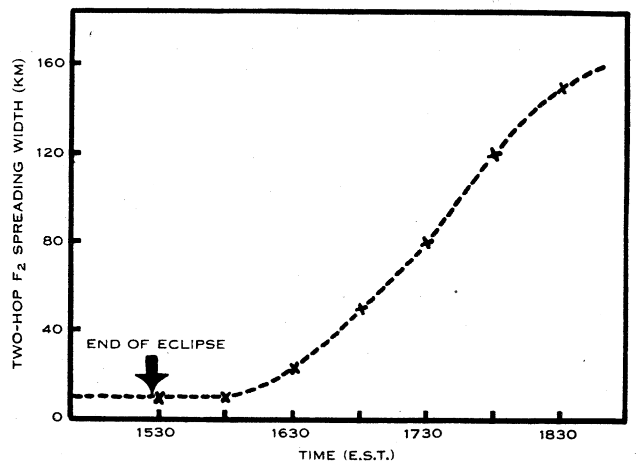

Fig. 13.—Variation of range-spreading width of two-hop spread-F at 3·84 Mc/s for 3 hr after the end of the eclipse at Brisbane on April 8, 1959.

variation of spreading width with time is shown in Figure 13. After 1830, the range of the main two-hop trace was so great that the extent of the spreading could not be determined because of the limited range of recording. It was still present at the end of the rotating-loop recording at 2122. The azimuth-of-arrival of these satellite signals did not vary by more than 20° in this period, ranging from 030° to 050°. Plate 3, Figure 2, illustrates the null at 1756. Figure 14 indicates that the spread-F fronts, in this case, are aligned roughly in the same direction as the line representing the end of the eclipse at Brisbane at 1527 E.S.T. Under normal conditions this orientation of the spread-F fronts is rare (Bowman 1960*a*).

No nulls were found in the sporadic E traces present from 1530 until 1550 and from 1616 until 1644, but the trace present from 1740 until 1820 (illustrated in Plate 3, Fig. 2) gave an azimuth-of-arrival of approximately 040°.

From 2012 until the end of recording at 2122, high-multiple traces were present on the rotating-loop record, indicating echo ranges between 3000 and 3600 km. These traces showed little change of range during this time, but they did show a change in appearance. They first appeared as clean traces, but by 2122 they showed a number of satellite traces. The azimuth-of-arrival of the high-multiple traces was consistent with that found for two-hop spread-F and sporadic E in this period (between 030° and 050°). Plate 3, Figure 3, illustrates the nature of high-multiple traces at 2120.

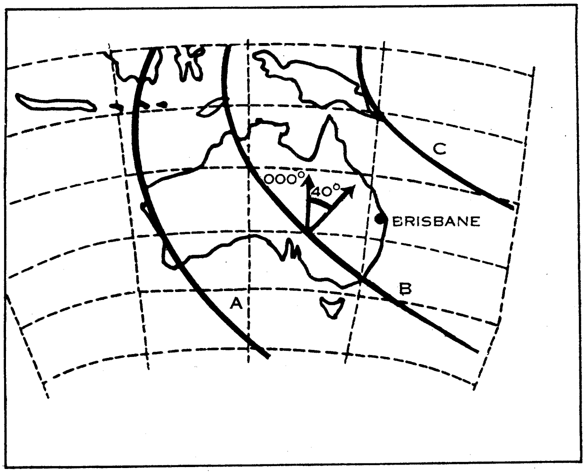

Fig. 14.—Illustration of times for the end of the Sun's eclipse over Australia on April 8, 1959. *A*, Eclipse ends 1400 E.S.T. ; *B*, eclipse ends 1500 E.S.T. ; *C*, eclipse ends 1600 E.S.T.

V. Discussion

The results of this present investigation suggest that, at a time approximately half-way between 90 km sunrise and ground sunrise, a series of frontal irregularities, having spacings of the order of tens of kilometres, are created at both the E- and F_2-layer levels. These have been detected in the E layer by oblique-incidence recording, and in the F_2 layer by high-multiple traces which appear on normal-incidence records about an hour before ground sunrise. These frontal irregularities (E and F_2 layer) are shown to be oriented close to directions parallel to the sunrise line and appear to move with it.

Evidence is presented to show that, after the occurrence of these irregularities (moving with the sunrise line) in the E and F_2 layers, irregularities of the same form appear to remain in both layers. Figure 12 shows that, if the F_2-layer irregularities be regarded as " ripples " in the ionization contours, the amplitude of these ripples probably increases after sunrise to a maximum from $1\frac{1}{2}$ to 2 hr later, since the spreading width appears likely to be a function of ripple amplitude. (The conditions for the occurrence of two-hop spreading, when one-hop spreading is absent, are discussed by Bowman (1960*a*).) Evidence for post-sunrise sporadic E irregularities, aligned close to the sunrise line, is obtained from the small patches of sporadic E recorded soon after the sunrise period (Fig. 6). Baral (1955) has reported isolated sporadic E occurrence, mainly during the sunrise period.

Bracewell *et al.* (1951) and Lauter and Schmelovsky (1958) have detected sunrise effects on very-low frequency transmissions, which may possibly be related to the results of this paper. Recording the signal strength of 16 kc/s oblique-incidence transmissions, Lauter and Schmelovsky (1958) found a sudden reduction (of the order of 20 dB) in signal strength at the time for 90 km level sunrise, at the mid point of the transmission path. A minimum of signal strength occurred between 90 km level sunrise and ground sunrise (for the mid point of the transmission path). This minimum was followed by a broad peak in signal strength (about ground sunrise), after which it assumed a normal day-time value.

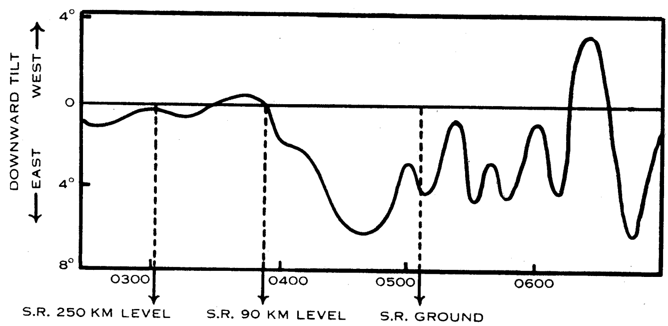

Fig. 15.—Variation of F_2 layer tilt around sunrise at Slough (after Bramley 1953).

It is interesting to note, that, in the case investigated, of pre-sunrise F_2-layer high multiples, the F_2-layer sunrise irregularity appears to pass overhead at approximately the same time (0600 on July 27, 1958) as the leading E-layer sunrise irregularity four days later (0601 on July 31, 1958). This suggests an effect generated at the E-layer level and transmitted to the F_2-layer by electrodynamic coupling.

Figure 15 reproduces a result due to Bramley (1953) showing the variation of the F_2-layer tilt around the sunrise period. Times for sunrise at 250 km, 90 km, and ground levels are indicated. Figure 15 reveals a tilt of the F_2 layer which increases with time and commences at the 90 km level sunrise rather than at the 250 km level sunrise. This may be important in view of the coupling suggested earlier. As pointed out previously, Figure 12 suggests ripples of increasing amplitude after sunrise. Therefore the marked oscillation of the F_2-layer angle of tilt after the initial sunrise effect (Fig. 15) appears to be consistent with the results shown in Figure 12.

Conditions in the ionosphere after the eclipse on April 8, 1959 are very similar to those found after sunrise. If the uncovering of the Sun after the eclipse be regarded as a virtual sunrise, the line along which the eclipse ends is analogous with the sunrise line. The gradual increase in two-hop F_2 spreading widths after the eclipse, and the continued orientation of E- and F_2-layer irregularities along directions close to the line representing the end of the eclipse, all point to a mechanism operating as the eclipse ceases that is comparable with that operating at sunrise.

The possibility arises that ripples, generated either at sunrise or sunset, are responsible for the one-hop spread-*F* observed at night at Brisbane. Effects, similar to those discussed here for sunrise, have not been detected at sunset, but there is some evidence to suggest that ripples, generated at sunrise, persist

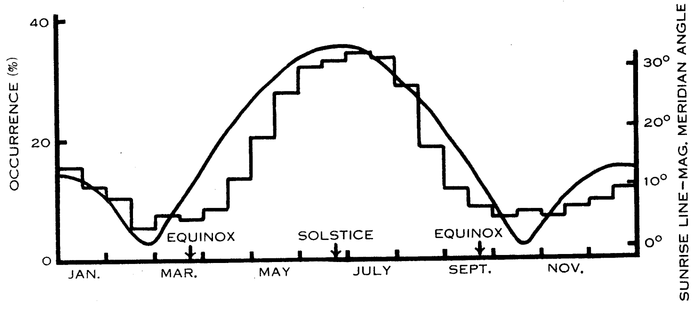

Fig. 16.—Diagram illustrating comparison between seasonal variation of spread-*F* at Brisbane (1944–1958 inclusive) and the angular separation between the sunrise line and the magnetic meridian.

throughout the day, and are responsible for the spread-*F* observed at night. The two-hop, post-sunrise spreading width, illustrated by Figure 12, should be a measure of the amplitude of the ripples. At 1200, it is obvious that a ripple structure is still present, particularly for July, a month of maximum spread-*F* occurrence. Another possible association between ground sunrise and night-time spread-*F* is shown in Figure 16. Here, the seasonal distribution of spread-*F*

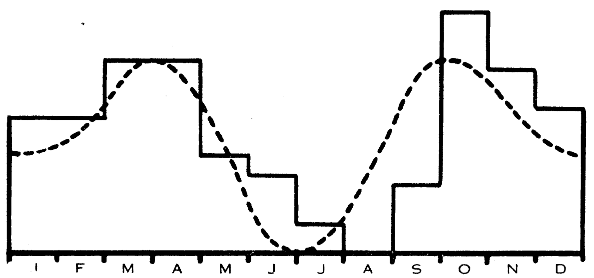

Fig. 17.—Seasonal distribution of sunrise high multiples for 1956, after an allowance is made for a possible sunspot-cycle variation.

(for the years 1944–1958 inclusive) is compared with the seasonal variation in the angular separation between the sunrise line and the magnetic meridian. The similarity is interesting, particularly as the spread-*F* minima are displaced somewhat from the equinoxes and occur roughly at times during the year when the sunrise line lies along the magnetic meridian.

Another apparent association between sunrise and night-time phenomena is revealed by considering the seasonal distribution of the sunrise high multiples.

During 1956 the sunspot activity rose sharply, and therefore the distribution shown in Figure 10 suggests a direct relationship with sunspot activity. If this association is assumed, a seasonal distribution, with some independence from sunspot activity, is obtained by subtracting from the percentage occurrence of each month, the background variation proposed on Figure 10. Figure 17 shows the distribution deduced in this way, revealing equinoctial maxima, a winter minimum, and a summer sub-minimum. This distribution is the inverse of that found for spread-*F* at Brisbane. One possible clue to this inverse relationship is the need for a small ripple amplitude to produce high multiples (Baird 1954) and much larger amplitudes for one-hop spread-*F*.

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