MOVEMENT OF SPORADIC *E* IONIZATION

By J. A. Harvey*

[*Manuscript received July 18, 1955*]

Summary

The horizontal movement of patches of day-time sporadic *E* ionization has been observed by using a system of spaced pulse transmitters and a central recorder. The directions of movement are mainly towards the north and west, with speeds mainly between 40 and 80 m/sec. These velocities differ in direction from the *F* region disturbances recorded at the same time and have only about half the speed.

I. Introduction

During the last few years, evidence for movement of patches of sporadic *E* ionization (hereafter called E_s patches) has come from several sources. Ferrell (1948) and Gerson (1950) demonstrated the movement of large patches of E_s by using the observations of amateur radio operators. Bramley (1953) tracked small patches by using direction finders and Findlay (1953) observed the movement of small patches by using a phase path method.

Gerson calculated that the E_s patch movements had speeds of about 50–60 m/sec in various directions. Bramley, from only a small number of instances, found speeds of between 40 and 60 m/sec in various different directions, while Findlay's calculations, for speeds only, gave results of the same order.

Using a system of spaced pulse transmitters and a common receiver, records of virtual height against time ($h't$) have been made during the day-time at Sydney for the purpose of studying types of horizontal movements occurring in the ionosphere. Some results of these experiments, for the *F* region, have been described by Munro (1950). For periods of minutes to hours, *E* region echoes from heights of about 110–120 km frequently appear on these records. The times of occurrence of such echoes, as observed for the three transmissions, differ by some minutes.

Except in about 5 per cent. of the cases considered in this paper, the echoes show a constant height for each E_s patch. The exceptions show an apparent fall in height after the first appearance of the echo and a corresponding rise as the echo disappears. During these changes in height, which take about 10–15 min, the echoes are weak. Assuming that these E_s patches have a lenticular shape, the apparent change in height shown by the echo would plausibly indicate reflection from the edge of an approaching (or receding) E_s patch; the rate of change of height would give a measure of the horizontal speed of the patch. However, due to difficulties of measurement only very approximate speeds can be obtained in this way; these range between 50 and 100 m/sec.

* Radio Research Board, C.S.I.R.O., Electrical Engineering Department, University of Sydney.

More accurate velocities of movement of the E_s patches can be determined from the time differences of appearance (and disappearance) of the echoes from the three transmitters. Velocities so obtained for the period from November 1950 to October 1952 are discussed in this paper.

Also present on the records are E region echoes which appear simultaneously from all three transmitters. They show virtual heights of about 100 km and last only a few seconds. These are almost certainly due to transient ionization produced by meteors ; they will not be considered further in this paper.

II. Observing System

Figure 1 shows the relative positions of the three pulse transmitters, the recorder, and the corresponding reflection points, assuming a plane and horizontal ionosphere. Transmitter $T1$ and the recorder are located at the University of Sydney, $T2$ at Camden, and $T3$ at Blaxland. The transmitters operate on a

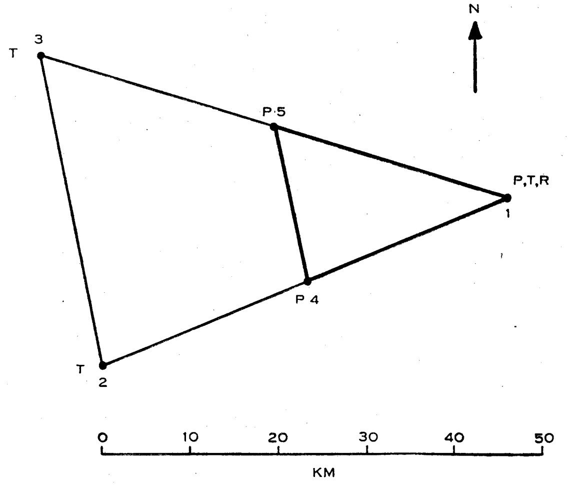

Fig. 1. — Plan of observing system. R, recorder ; T, transmitter ; P, projection of reflection point. Points 1, 4, and 5 form the observing triangle.

frequency of 5·8 Mc/s with a pulse duration of 30 μsec, a pulse repetition frequency of 50/sec, and a peak power output of 1 kW. Horizontal half-wave aerials are used and the effective power radiated vertically is approximately the same for all three. They irradiate the sky directly above them uniformly within a cone whose aperture is 130° in the vertical plane perpendicular to the aerial and 90° in the vertical plane containing the aerial. The remote transmitters are slave-triggered by the ground pulse from the master transmitter situated at point 1. Triggering delays of about 400 and 1000 μsec are introduced so that the echoes due to the three transmitters are suitably spaced on the record. For timing purposes, and to permit identification of the echoes due to each transmitter, $T1$ is interrupted every minute for a few seconds ; $T2$ every minute (but not synchronously with $T1$) ; and $T3$ every half minute.

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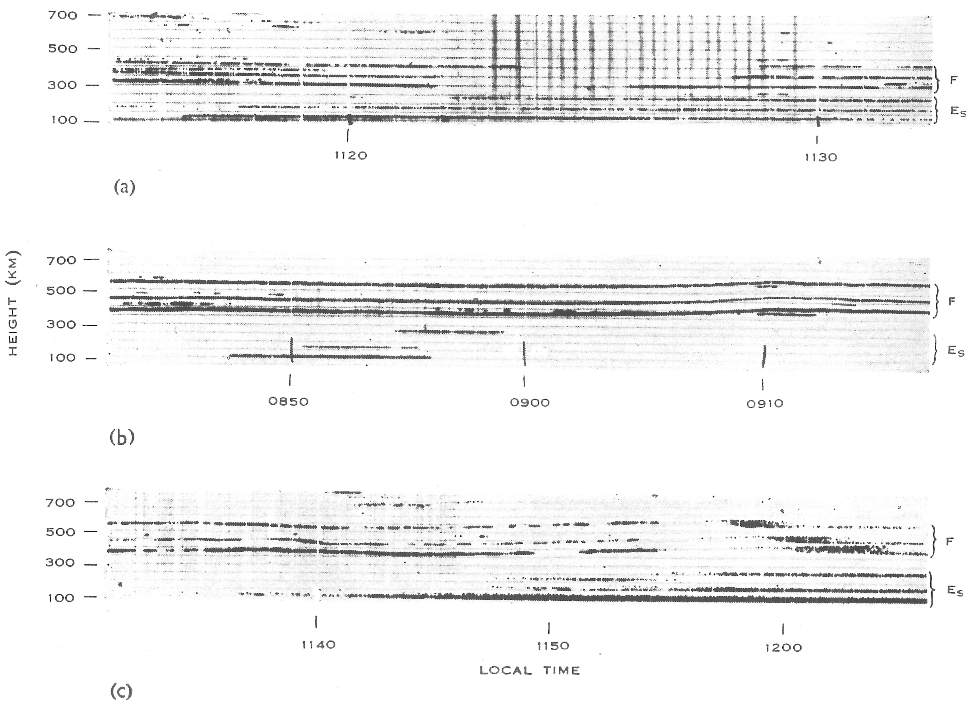

Examples of echoes from E_s patches. From bottom to top of each example the order of the echoes from the three transmitters is $T1$, $T2$, and $T3$. The height scale applies only to $T1$, the pulses from the other transmitters being delayed so as to separate their echoes on the record. (*a*) August 20, 1951 : a set of clear E_s echoes. The F echoes are cut off for a few minutes. (*b*) December 25, 1951 : a set of clear echoes from a small patch. (*c*) December 31, 1951 : a set of slightly diffuse E_s echoes. These show a slight fall in height particularly for the echo from $T1$.

A typical F disturbance has occurred near the right-hand end of the F traces.

For reception a half-wave aerial is used, oriented approximately at right angles to the mean direction of the remote transmitters so as to equalize their signals. The echoes, together with height calibration marks, are displayed on a cathode-ray tube intensity modulated. The display is photographed on 35-mm film moving slowly at right angles to the time base, so producing an $h't$ record of the three sets of echoes.

III. Characteristics of the E_s Patches

The echoes from the E_s patches appear on the records either as clear traces or as diffuse traces. The E_s echoes producing clear traces show a spread of 10 km equivalent height, this being the sharpest trace obtainable with the recording equipment used. They appear and disappear, sometimes very rapidly, with no change in height. The F echoes are frequently cut off, sometimes very rapidly and in a number of cases for nearly the full duration of the E_s echoes. Fading is slow, with periods ranging from a few seconds to one or two minutes. In Plate 1, (*a*) and (*b*) illustrate two examples with these properties. Diffuse E_s echoes, which always appear and disappear gradually, are spread over as much as 50 km equivalent height. The F echoes are often blanketed when this occurs, the onset of blanketing being gradual. Fading is always fast, with periods of less than a second, different parts of the spread echo fading at different rates. Some diffuse echoes show a fall in height during the first 15 min after appearance and a similar rise before disappearing. This change in height is usually about 20–30 km but may be as much as 50 km ; the echoes are weak at such times. In Plate 1, (*c*) shows a slightly diffuse echo with a small change in height taking place during the 8 min following its first appearance.

These properties are consistent with the assumption that E_s patches are sheets (or clouds) of moving ionized particles. The occurrence of clear traces showing no height changes suggests that the E_s patches sometimes have surfaces that are flat and smooth enough to give only specular reflections. The diffuse traces suggest that at other times the surfaces are sufficiently rough to give scattered, rather than specular, reflections. The initial fall in height, together with the accompanying small amplitude of some of the diffuse echoes, also suggests that these patches have sufficient thickness to give weak edge scattering when as far as 120 km horizontally from the recorder. (The low amplitude of these echoes is not due to the aerial radiation patterns—see Section II.)

The heights of the E_s patches lie mainly between 110 and 120 km with limits of 100–140 km ; $h'f$ records show that they lie just above the normal E layer, which is usually at a height of 100–110 km.

IV. Analysis of Records

In order to calculate the velocities of the E_s patches from the differences in time of appearance (or disappearance) of the echoes, it is necessary to assume a definite shape for the E_s patch. The simplest assumption is to assume that the E_s patch has leading and trailing edges which are straight and parallel, that it is moving with constant velocity, and that it is fixed in size. This enables the use of a simple graphical method for calculating the velocities of movement.

The validity of this assumption was tested by comparing, for each E_s patch, the velocities calculated in three different ways, namely, from the times of appearance of the three echoes, from the times of their disappearance, and from the times of occurrence of the mid points of the three echo traces. If this assumption is valid, these three velocities should be identical.

Figure 2 is a diagrammatic representation of a typical record of the echoes from a small patch of E_s similar to the example shown in Plate 1 (*b*). Lines 1, 2, and 3 represent the echoes of pulses from the three transmitters reflected from the E_s patch, while the *t*'s are the various times of occurrence indicated

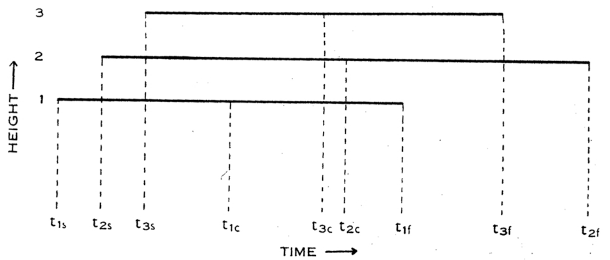

Fig. 2.—This diagram represents the echoes from an E_s patch, similar to the examples in Plate 1 and shows the various times referred to in the text.

by the suffixes *s* for the start, *f* for the end, and *c* for the mid point of each echo trace. The starting time differences are then defined as:

$$T_{2s}=t_{2s}-t_{1s}, \qquad T_{3s}=t_{3s}-t_{1s},$$

and similarly the ending time differences. The centre time differences are then determined from the relation:

$$T_{2c}=(T_{2s}+T_{2f})/2, \qquad T_{3c}=(T_{3s}+T_{3f})/2.$$

From these time differences, the corresponding velocities of movement can be calculated. As the patches are assumed horizontal and the reflection specular, negligible error is incurred by assuming that the reflection points are directly above the half-way points between the remote transmitters and the recorder. Also, as the angle of incidence of the rays from the remote transmitters is about 15°, the possible error due to obliquity is also negligible.

The time of the start and the finish of each echo trace was noted. For all patches where the start and finish times for all three echo traces could be read to an accuracy of 1 min or better, the time differences were calculated. Many of the patches whose echoes showed diffuseness, including all those which showed change of height, and also some which showed no diffuseness, were thus rejected. The corresponding directions and speeds were then determined from the time differences for the remaining patches.

It was found that the directions and speeds, as calculated from the beginning, centre, and ending of the echo traces from an E_s patch, were usually different. The directions differed by anything from 0° to 180° while the ratio of the speeds varied between 1 and 12 or occasionally more. Figure 3 shows a histogram of the distribution of the direction differences for the period from November 1951 to February 1952. For approximately 60 per cent. of the patches, it shows that the start and finish directions differ by 60° or less but for the remainder the direction differences are fairly evenly distributed up to 180°. It appears then that the simple assumptions about shape and movement made above do not always apply. Possible causes of the differences are that the E_s patches have curved edges, are moving with variable speed, and changing in size and shape. However, it is not possible to determine which of these causes is responsible or to make any estimate of the shape of the patches from observations taken at only three points.

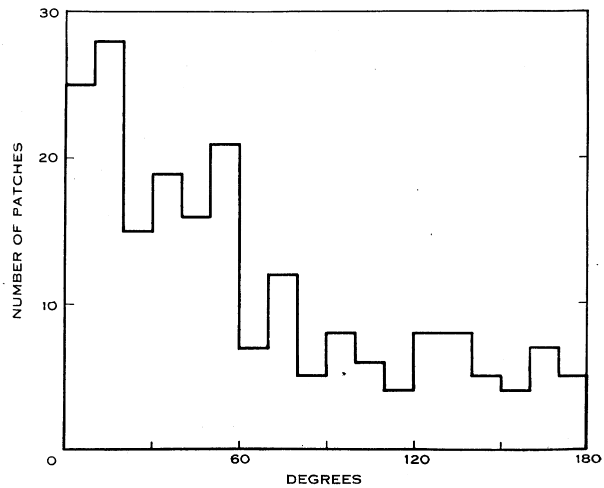

Fig. 3.—Distribution of the difference between the beginning and ending directions of each E_s patch, from November 1951 to February 1952.

It seemed more reasonable to take the velocities of the centres of the patches rather than those of the edges. This reduced errors due to possible differences in output from the three transmitters and any residual effects of obliquity, all other equipment effects being common to the three signals. The advantage of this method was emphasized by a numerical study of the velocities deduced for various regular-shaped patches crossing the observing network, which revealed that the centre velocity was consistently more reliable than the velocities of the edges. In particular, for triangular and circular patches moving at constant velocity, the centre velocities are correct, and, for constant rate of change of size as well, almost correct even though the beginning and ending velocities may be widely different, particularly in the direction component.

In order to establish a criterion for selecting the velocities thus determined so that E_s patches with predominantly horizontal movement rather than change in size or shape would be used, the numerical calculations of velocities for the assumed regular-shaped patches and the observed velocities of the E_s patches were compared. From this it was decided to select those E_s patches whose beginning and ending velocities differed in direction by less than 80° and with speed ratios less than 5 to 1. This eliminated about 35 per cent. of the patches. Figure 4 shows the difference between using the beginning and ending velocities for all the patches, and the velocities of the centres of the selected patches for June 1952. It will be seen that the scatter of points is considerably reduced by using the selected velocities.

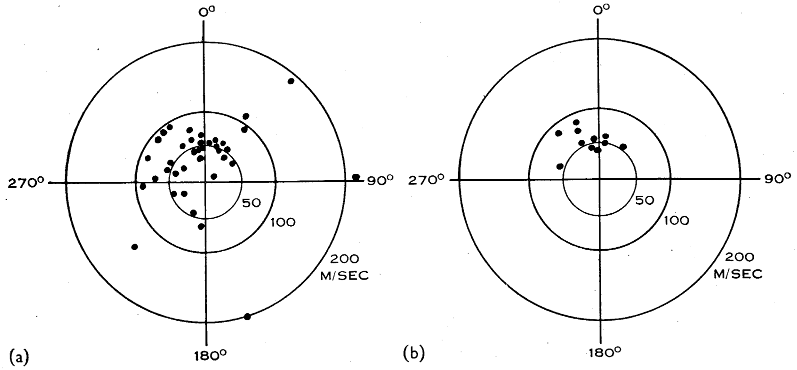

Fig. 4.—This diagram shows the reduction of scatter of points obtained by using the velocities of the centres of the selected E_s patches instead of the velocities of all the patches recorded in June 1952. (*a*) All E_s patches using beginning and ending velocities; (*b*) selected E_s patches using centre velocities.

V. Results

The recording period was from 0600 to 1800 hr daily, Eastern Australian time, and these records were examined for E_s times of appearance and disappearance for the period from November 1950 to October 1952. At 5·8 Mc/s during this period, the E_s was most prevalent during the summer months of November-February. A small subsidiary maximum occurred during the winter of 1951 (May-August) but not in 1952; during July and August there was much less E_s than during the same months of the previous year. E_s was almost completely absent in March and April of 1951, and in September and October of both years. The velocities of the E_s patches were then determined and selected as described in Section IV. About 65 per cent. of the patches whose velocities could be determined were accepted as suitable for investigation. They are discussed below, using centre velocities only.

Figure 5 shows the distribution of occurrence of the E_s patches during the day from November 1951 to February 1952. The E_s was most prevalent during the late morning. A similar distribution was found for the previous summer. For the winter, the E_s occurred mainly between 1200 and 1500 hr.

It was not possible to get much information on the size and shape of the patches using only three observing points. However, from a study of the differences in directions and speeds as determined from the beginning and ending of the echo traces, it seemed probable that the edges of the E_s patches were curved rather than straight, and that the patches usually changed in size or shape while crossing the observing points. In size they must have been at least as wide as the observing triangle, which is of the order of 25 km, otherwise

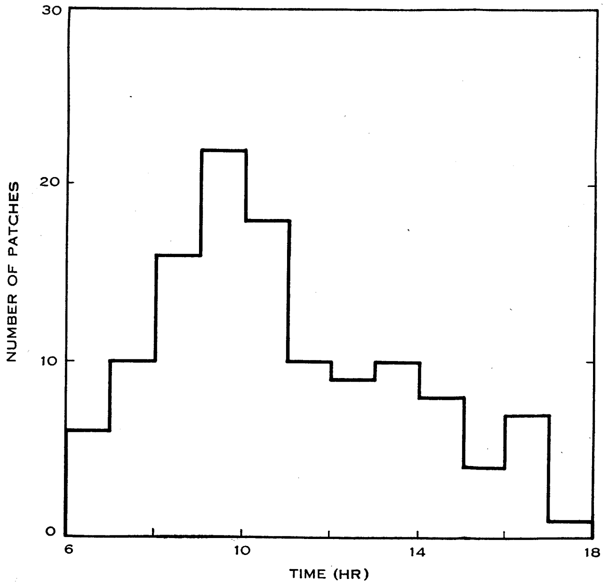

Fig. 5.—Distribution of the times of occurrence of the E_s patches, from November 1951 to February 1952.

specular reflections from all three transmitters would not occur. An approximate value for the length of a patch was obtained by taking the product of the speed

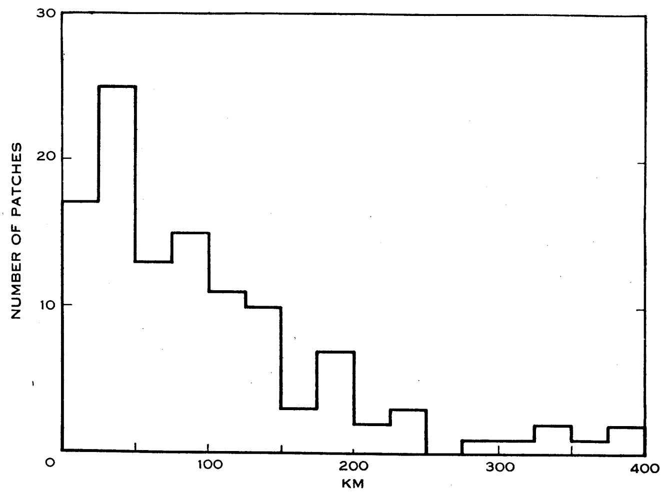

Fig. 6.—Distribution of the lengths of the E_s patches, from November 1951 to February 1952.

of its centre and the time taken for it to cross the recording point. Figure 6 shows the distribution of these lengths over the four summer months from November 1951 to February 1952.

This figure also shows that 13 per cent. of the patches have lengths less than 25 km. This means these patches are shorter than they are wide, the lengths of a few being as short as 6 km. Of those longer than 25 km, the length/width ratio is indeterminate, hence it is not possible to compare the relative proportions of short and long patches.

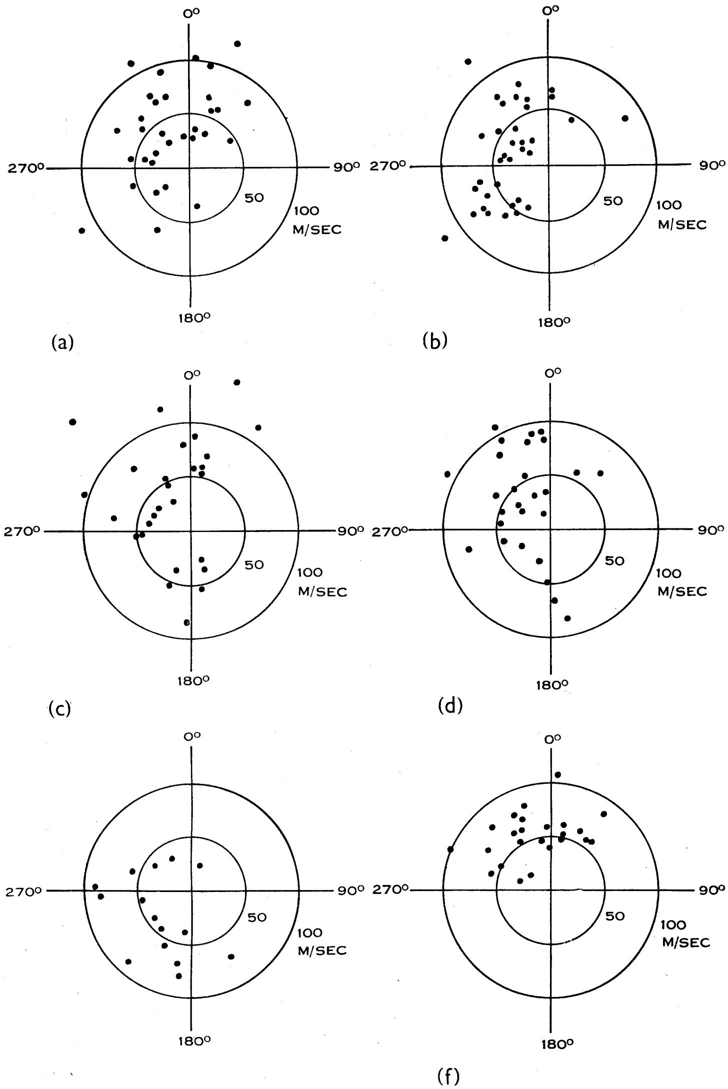

Fig. 7.—Velocities of the E_s patches. (*a*) November 1951; (*b*) December; (*c*) January 1952; (*d*) February; (*e*) March and April; (*f*) May-August.

(*a*) *Velocities*

Figures 7 (*a*)–7 (*d*) show polar plots of the velocities of the E_s patches for the four summer months from November 1951 to February 1952. The directions are the vector directions of movement measured in degrees east of north and the speeds are measured in m/sec. The directions lay mainly within the sector between 270 and 030°. In December, another group appeared around a mean direction of 240°; in January, there was a small group around 180°. The speeds lay mainly between 20 and 80 m/sec. There was no movement of patches in directions lying between 60 and 150°.

In winter, the directions of movement were similar to those in summer. Figure 7 (*f*) for May-August 1952 shows that the directions lay almost completely in the sector between 285 and 45°, the scatter being less than that for the summer. For the equinoctial months of March and April 1952, Figure 7 (*e*) shows that the directions were grouped around 225° but that the scatter was considerable.

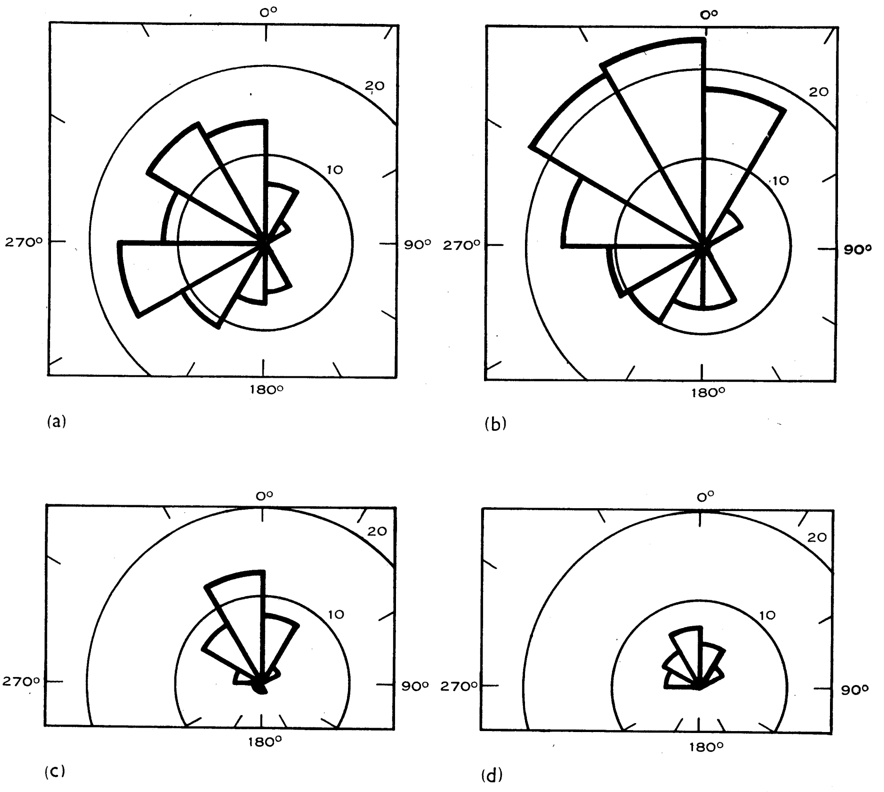

Fig. 8.—Distribution of directions of the E_s patches. (*a*) Summer 1950–51; (*b*) summer 1951–52; (*c*) winter 1951; (*d*) winter 1952. Circles: number of patches.

(*b*) *Comparison of 2 Years' Data*

For summer, Figures 8 (*a*) and 8 (*b*) are histograms of the distribution of directions for 1950–51 and 1951–52. During the summer of 1950–51, the directions were more westerly than during the summer of 1951–52. Figures 8 (*c*) and 8 (*d*) show the distributions for the winters of 1951 and 1952. Both distributions are very similar. In all seasons, summer, equinox, and winter, there was no movement of patches in directions lying between 60 and 150°.

Figures 9 (*a*)–9 (*d*) show histograms of the distribution of speeds for the above periods. The bulk of the speeds fell in the range from 20 to 80 m/sec. In 1951, there was a larger proportion of higher speeds than in 1952.

(*c*) *Seasonal and Diurnal Variations*

There are not enough data available to reveal any definite seasonal or diurnal changes. The only indication of seasonal change appears to be at the March-April equinox of 1952. Here there is a swing of directions of about 90°

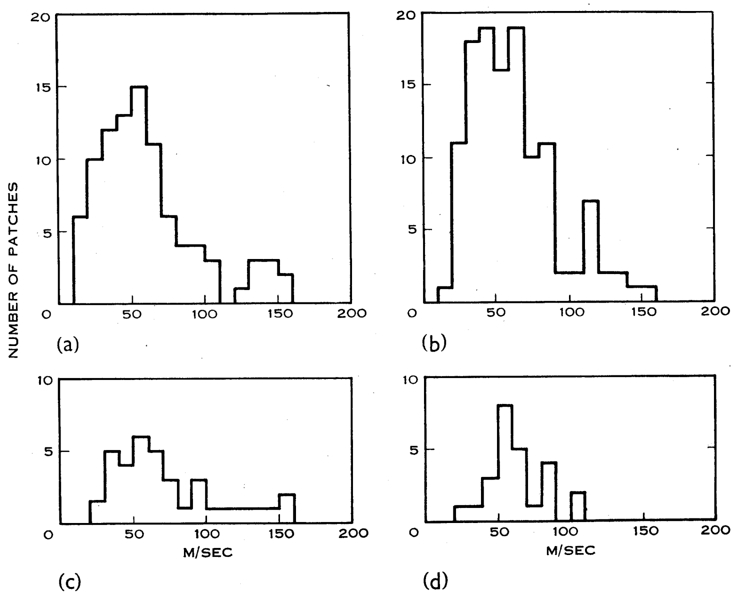

Fig. 9.—Distribution of speeds of the E_s patches. (*a*) Summer 1950–51 ; (*b*) summer 1951–52 ; (*c*) winter 1951 ; (*d*) winter 1952.

towards the south-west. For the same period of 1951 and the September-October equinox in both years, there was not enough E_s to give adequate statistics. As the E_s was recorded only in the day-time and occurred mainly over the limited period of 0800–1200 hr in summer, and 1200–1400 hr in winter, no diurnal variation could be found.

VI. Discussion of Results

The movements of E_s patches take place in the E region just above the normal E height which is usually about 100–105 km. The speeds of movement are similar to those found using different methods and in other places, such as the fading of echoes by Mitra (1949), Salzberg and Greenstone (1951), and Phillips (1952) ; observations of small E_s patches using a phase path method by Findlay (1953) ; direction-finding of remote transmitters by Bramley (1953) ; and observation of meteor trails by Manning, Villard, and Peterson (1950) and by Elford and Robertson (1953). Briggs and Spencer (1954) have discussed the various methods of measuring horizontal movements, particularly the fading method using closely spaced receivers. For the E region, they find a most probable speed of 80 m/sec; this is higher than our most frequent speed (60 m/sec) for the E_s patches.

Comparison in detail of the directions of movement of the E_s patches with those obtained by other methods is generally difficult owing to the limited amount of data for the E_s patches. The winds obtained by Elford and Robertson of Adelaide (which has a similar latitude to Sydney) for the months of November and December 1952, and between 0900 and 1200 hr, were mainly in the direction 90°. Briggs and Spencer quote similar directions for summer at Cambridge. This is almost directly opposite to the directions of the E_s patches, which are mainly between 270 and 360°. No patches were found moving in the directions between 60 and 150°. For winter, Briggs and Spencer quote directions which show a steady change through the day and which are 300, 330, and 030°, corresponding to 240, 210, and 150° for the southern hemisphere at 1200, 1300, and 1400 hr respectively. This compares approximately with our 340° for the E_s patches at the same time of day. There appears to be a westerly component of velocity in both cases; our north-south component is towards the north instead of the south.

In both seasons the directions of movement of the E_s patches are markedly different from those found by the echo-fading method, and by reflections from meteor trails. This suggests that there is a change of direction of movement with height as the E_s patches lie above the region (between 85 and 100 km) where meteor trails occur, and also above the region producing the fading of echoes. This latter cannot be higher than the E layer and may be lower.

Despite the differences in directions, the similarity of speeds suggests that there is a common cause for movements of E_s patches, fading patterns, and meteor trails. This cause could be winds. Martyn (1953) has discussed the drift of ionization due to winds in the presence of the Earth's magnetic field. At Sydney, the effect of the magnetic field on the motion of ionization is negligible up to a height of 120 km; hence the E_s patches move with the wind; above 120 km the effect of the magnetic field becomes more appreciable.

Clemmow, Johnson, and Weekes (1955) have discussed a steady state solution to the problem of the motion under the influence of a wind of a cylinder of ionization differing in density to the surrounding ionized medium and in the presence of a magnetic field. For the upper E region, a dense cylinder of ionization will move with a velocity different from that of the wind, but the difference is not large.

Both these effects seem insufficient to account for the wide differences between the directions of movement of the E_s patches, and of the fading patterns and the drift of meteor trails. Thus the cause of all the movements appears to be winds whose velocity changes with height.

VII. Comparison with F Region Disturbances

From the same records, the movements of F region disturbances as described by Munro (1950) are quite different. Table 1 shows the median values of direction and speed of both the E_s patches and the F disturbances for two summers and two winters.

The speeds of F disturbances are about twice those of the E_s patches. In summer the F directions are almost directly opposite to those of the E_s patches and lie mainly in the sector where there are no E_s directions. In winter the difference is only about 60°, the F directions having swung round about 90° to the north while the E_s directions have changed only a little.

TABLE 1
VELOCITIES OF E_s PATCHES AND F DISTURBANCES
Median values

Season	E_s Patches		F Disturbances	
	Direction (°E. of N.)	Speed (m/sec)	Direction (°E. of N.)	Speed (m/sec)
Summer 1950–51 ..	280	58	125	120
Summer 1951–52 ..	315	57	120	125
Winter 1951	340	60	030	142
Winter 1952	330	60	025	145

VIII. Conclusions

The results show that there is definite movement of ionization or ionizing sources in the E region. The similarity of the speeds to those obtained both by the fading method and by observations of meteor trails, indicates a common cause which is probably winds. There is some seasonal change of these winds.

IX. Acknowledgments

The author wishes to thank Dr. D. F. Martyn, F.R.S., Chief Scientific Officer, and Dr. G. H. Munro, both of the Radio Research Board, for their helpful discussions and advice. The facilities provided by the Department of Electrical Engineering of the University of Sydney are gratefully acknowledged.

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