MOTION IN THE NIGHT-TIME E_s REGION AT BRISBANE

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Summary

An analysis is made of night-time motion in the E_s region, as determined from a study of radio echoes at 2·28 Mc/s. Night-time E_s usually consists of moving clouds of ionization of lateral extent $\sim$10 km ; these clouds may be either isolated or close-packed to form layers of ionization. There is evidence that the clouds are sometimes elongated in a direction different from their direction of travel.

Good correlation is found between velocities of E_s movement as determined by fading analysis (Mitra 1949) and direction-finding techniques. Speeds of movement are grouped about 70 m/sec, and the winds are predominantly towards the north.

I. General

It has been shown in previous papers (Thomas and Svenson 1955 ; Thomas 1956*a*) that the two types of E_s at Brisbane ("sequential" type (E_{ss}), and "constant-height" type (E_{sc})), show considerable vertical motion of a tidal nature. It is logical to expect large horizontal motions to accompany the vertical movements in the ionosphere. Measurements of horizontal drift velocities of "patches" of E_s ionization have been reported from many parts of the world. In Australia, Harvey (1955) has measured the drift velocities of large patches of (mainly) sequential E_s as it occurs near Sydney.

An examination of the $P'f$ records at Brisbane shows that there are frequently E_{sc} traces which, over a period of time, gradually decrease and/or increase their range. Examples are shown in Figures 1 and 2. These changes are quite distinct from the large decrease of range associated with E_{ss} formation. Since the changes of range are the same at all frequencies up to fE_s, measurements made at any one frequency will be characteristic of measurements at all other frequencies ; use is therefore made of the various fixed frequency records which have been made at Brisbane by the techniques described by Thomas and McNicol (1955) and by McNicol, Webster, and Bowman (1956).

The various types of records available are outlined below :

(*a*) Simple $P't$ type records covering the ranges 0–500, 90–150, 200–500, 300–1000, 0–2800, 0–4000 km.
(*b*) Pulse-operated A.G.C. records of the $P't$ type in the range 90–150 km.
(*c*) Swept-gain $P't$ records, giving a measure of the relative intensity of echoes, and operating over the range 0–500 km.
(*d*) Phase-path records over the range 0–500 km.
(*e*) Records giving the directions of arrival of echoes in the range 0–500 km.

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(*f*) Fading records from a three-point aerial system (after Mitra 1949) giving values of ionospheric wind velocities.

(*g*) Simultaneous $P't$ records (0–500 km) taken at stations about 100 km apart.

(*h*) Slightly oblique $P't$ records (0–500 km) between stations about 100 km apart.

A double advantage arises from the use of such records in conjunction with the $P'f$ records: the sensitivity and resolution of echoes is higher than with $P'f$ records and the records are continuous in time, thus simplifying the interpretation of the various phenomena.

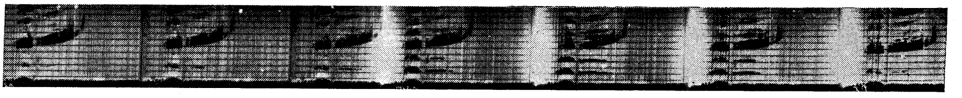

Fig. 1.—An E_s "cloud" on $P'f$ records, showing successive decrease and increase in ranges.

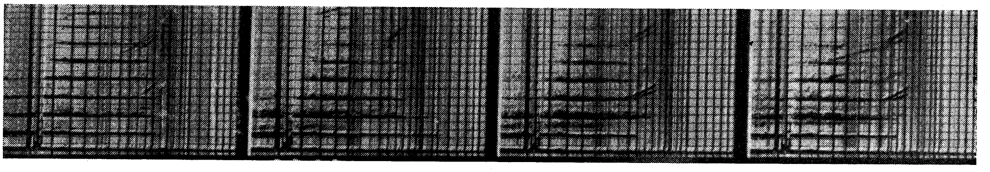

Fig. 2.—$P'f$ records showing the gradual separation of a subsidiary E_s trace from the lowermost trace which remains at constant range.

The greater part of the work described hereunder forms an analysis of night-time records obtained at 2·28 Mc/s at Brisbane. Some small use has been made also of $P't$ records taken at 3·84 and 5·80 Mc/s.

II. Nature of the Phenomena Investigated

At 2·28 Mc/s the majority of E_s records are due to E_{sc}, although in the early parts of summer night-time records both E_{sc} and E_{ss} may occur either simultaneously or individually. At such times special "double-layer" phenomena are sometimes observed and these are discussed in some detail by Thomas (1956*b*).

Several slightly different types of $P't$ records can occur, depending on whether a continuous background of E_{sc} is present or not. Tracings of the most common occurrences are shown in Figure 3. For convenience of classification these various types of record have been given the specific names mentioned in the caption to the figure. The distinction between a "layer" and a "cloud" is obviously only an artificial one; a saucer-shaped trace lasting less than an hour is regarded as being due to reflection from the edge of a small isolated moving cloud rather than from a large sheet or layer of ionization, and, for convenience, the traces are given the same names as the assumed causes. Detailed examination of the expanded E region $P't$ records (i.e. 80–160 km) shows that the "layer" type trace is quite often made up of a large number of

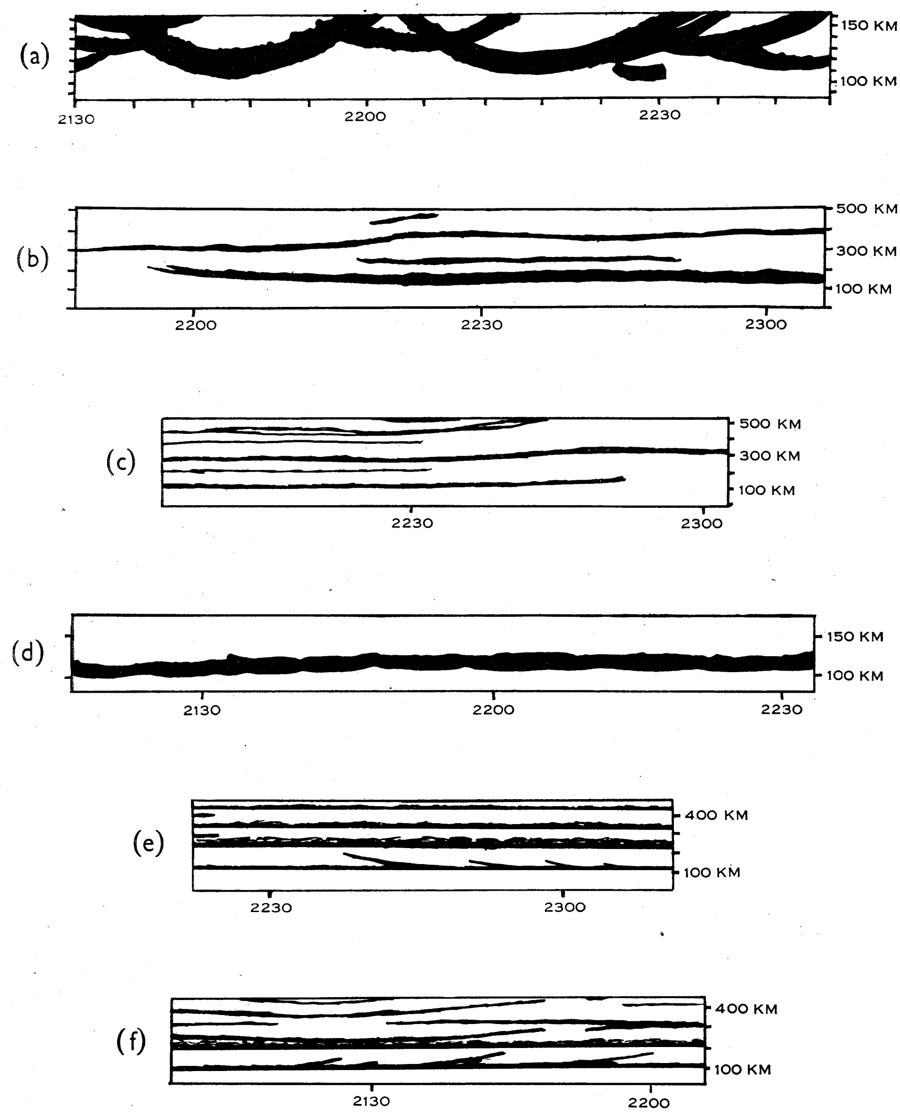

Fig. 3 (*a*).—Isolated E_s " clouds " recorded on expanded time-base $P't$ equipment. (Traces of this type are recorded as " clouds " when they do not exist for periods greater than one hour.)

Fig. 3 (*b*).—$P't$ record showing echoes from a " layer " of ionization moving " in " (or overhead). Such traces are recorded as " layer-in ", when the range remains sensibly constant after the initial decrease.

Fig. 3 (*c*).—$P't$ record showing echoes from a " layer " of ionization moving " out " (from overhead).

Fig. 3 (*d*).—Expanded $P't$ record showing the detailed structure of a " layer " of E_s ionization.

Fig. 3 (*e*).—$P't$ record showing traces converging to the main E_s trace. Such traces were recorded as " spurs in ".

Fig. 3 (*f*).—$P't$ record showing traces diverging from the main E_s trace. Such traces were recorded as " spurs out ".

overlapping " cloud " type traces (Fig. 3 (*d*)). Sometimes the more extreme ranges of these clouds are masked, but at other times traces may be seen entering and leaving the base trace giving rise to the " spurs " of Figures 3 (*e*) and 3 (*f*).

The critical frequency of such E_s spurs, which show as apparent stratified layers on $P'f$, may be slightly different from that of the base layer (either greater or less) but the difference is usually less than 2 Mc/s. This lends support to the view that the E_{sc} region consists of clouds which may or may not be close enough to give continuous echoes on $P't$; one would not expect all such clouds to have exactly the same ionization density.

The phenomenon of frequency spreading in F region echoes has been discussed by Singleton (1956) and he arrives at a similar conclusion as to the cause. In the E_s region, such frequency spreading can only be observed when it is accompanied by range stratification.

Very occasionally, traces are recorded in which no discernible evidence is shown of a range decrease at the beginning or a range increase at the end of the trace. The rate of fading of amplitude in such traces is always found to be very slow, indicating very little ionospheric movement; there is no preferential time for the appearance of such traces.

III. Nocturnal and Seasonal Distribution of the Phenomena

The nocturnal distributions of the times of occurrence (i.e. start and finish) of clouds, spurs, and layers have been separately and collectively plotted for each month of 1952. As would be expected from the argument of the previous section, there is no major disagreement between the three phenomena. Separate clouds are more easily identifiable in the base layer on some occasions than on others, so that more clouds are recorded than spurs; at other times the reverse is true. The nocturnal distributions for all the phenomena are usually similar in any one month.

The collective histograms show a tendency for more apparent E_s movement to occur in the summer months before midnight than after. It should be remembered that sequential E_s persists until around 2100 hr in summer; this may well be the reason for the enhanced recordings of apparent movement.

It has been found (Thomas 1956*a*) that the occurrence of night-time E_s echoes at 2·28 Mc/s is fairly constant throughout the year. The histograms show, however, that in October 1952 there was little apparent evidence of E_s motion—E_s was present for about 60 per cent. of the night but sloping traces were not observed as frequently as during the other months. No real explanation can be put forward for this fact, but it has been found (Section V) that during this particular month the " winds " in the E_s region at night tended to maintain a roughly constant amplitude with a smooth change in direction; this may possibly be a significant factor in explaining the paucity of sloping $P't$ traces.

IV. Methods of Measurement of Speeds and Velocities

Since there is very little correlation between $P't$ records taken at points 50 km apart, all calculations of speeds and directions of E_s movements have been made from data recorded at one station only, using the curved traces referred to in the previous sections.

In making most of these calculations one is forced to put forward some simple hypothesis regarding the E_s patch and its motion. The simplest hypothesis is to suppose that the E_s patch may be regarded as a point reflector moving with uniform horizontal velocity. The effect of changes in the nature of the patch will be shown in Section VI.

(*a*) *Speeds*

There are three basic methods for determining speeds from single-station records. Consider the diagrams of Figure 4. While these diagrams are not necessarily in a vertical plane through the transmitter, it is here assumed, following the above hypothesis, that v is purely horizontal.

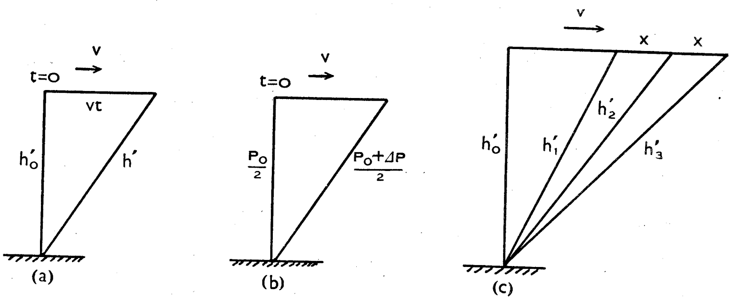

Fig. 4.—Diagrams illustrating three methods of calculating the horizontal speed of cloud movement.

(i) We have (Fig. 4 (*a*))

$$v^2=\frac{h'}{t}\cdot\frac{\mathrm{d}h'}{\mathrm{d}t}, \qquad \text{(1)}$$

or

$$v=\frac{h'}{\sqrt{(h'^2-h_0'^2)}}\cdot\frac{\mathrm{d}h'}{\mathrm{d}t}. \qquad \text{(2)}$$

Either of these expressions may be used to derive the speed of movement of the patch. The latter is to be slightly preferred, as the minimum range h_0' can often be determined more easily than the exact time at which minimum range is reached (i.e. the instant $t=0$).

(ii) Here (Fig. 4 (*b*)) we have (after Findlay 1953)

$$\Delta P=2v^2t^2/P_0.$$

A plot of ΔP as a function of t^2 thus gives a measure of v, if we assume that for night-time records very little error is incurred by substituting $P'_{\text{min.}}$ for P_0 in the above expression.

(iii) In this case (Fig. 4 (*c*))

$$x^2=\tfrac{1}{2}(h_3'^2+h_1'^2-2h_2'^2)$$

so that by measuring h' at definite intervals one may find v. This method is only suitable where very accurate measurements of h' are available (i.e. to better than 0·5 km)—large errors arise in the squaring and further manipulation if the readings are not very accurate.

(b) *Velocities*

The additional directional data necessary to determine the velocity of movement of E_s patches is provided by the automatic recording of the direction of arrival of the echoes. Knowing the azimuth and elevation of the reflecting point and its slant range, the point of reflection may be plotted at 3-min intervals on a horizontal polar diagram (at the E_s level) and the horizontal motion of the reflecting point easily calculated.

It will be shown in Section VI that for E_s clouds as observed at 2·28 Mc/s at Brisbane accurate velocity measurements can be obtained from the directional data even in the case of clouds which have elliptical sections in horizontal planes but which are assumed to be negligible in vertical thickness. The correct motion is still found even when the elliptical cloud is orientated to this direction of motion; it is only necessary to neglect (for this purpose) any readings giving the reflecting point less than 10 km from the zenithal point at the E_s level and to thereby isolate the decreasing and increasing range portions of a cloud. This sacrifice is not very great, as it usually only means the non-utilization of one or two D.F. readings.

It is not possible to obtain directional data on all E_s clouds as the signal strength from the oblique echoes is often quite low, and at 2·28 Mc/s E_s nearly always shows considerable amplitude and phase fading. These two facts often make an accurate measurement of the direction of an echo impossible. Nevertheless, some 60 clouds or spurs have been so examined from about 15 weeks' total running time spread throughout the year.

In addition to this method of finding the drift velocity of E_s patches, there is the method of fading analysis of three-point amplitude records developed by Mitra. This method gives the velocity of drift of the ionospheric diffracting screen, but some doubt often exists as to the position of the diffracting screen in the ionosphere. Special measurements taken at Brisbane to check this point by correlating the direction-finding velocities with the Mitra "winds", have shown that for the night-time E_s region the correlation is good. The results of this series of measurements are shown in Table 1. Such disagreement as exists can be quite easily explained if one remembers the simplifying assumptions of the Mitra technique, namely, that "the line of maximum amplitude" is normal to the drift direction and that the drift velocity is large compared with the velocity due to random changes. In the former case, if the normal to the line of maximum amplitude is inclined at an angle θ to the direction of the drift velocity, the resultant velocity will be too low in magnitude by a factor $\cos\theta$ and in error in direction by the value θ. In the latter case Yerg (1955) has shown that, if the velocity due to random changes is of the same order as the drift velocity, then the "method of similar fades" as used in Brisbane will give results much greater in magnitude than the true drift velocity (by up to several hundred per cent.), and approximately correct in direction. It is thus highly likely that there will be some errors in the values obtained from each E_s patch used in the above correlation tests.

In view of the correlation between these two methods of drift determination and the paucity of good direction-finding records, nearly all the velocity results are taken from the analysis of the fading patterns.

TABLE 1

CORRELATION BETWEEN VELOCITY MEASUREMENTS

Date	Time	Direction of Arrival Velocity		Mitra Velocity		Errors	
						Speeds (%)	Angle
		(m/sec)		(m/sec)			
5.iv.56	1912	75	315°	64	350°	—15	+35°
	1939	45	20°	31	61°	—30	+41°
	2003	73	210°	(200)	(158°)	+180	—52°
	2021	100	15°	60	31°	—40	+16°
	2100	90	310°	104	355°	+13	+45°
	2239	(75)	(345°)	86	327°	+15	—18°
	2355	110	274°	171	244°	+55	—30°
9.iv.56	2300	(60)	(98°)	56	9°	—7	—89°
10.iv.56	2230	50	304°	58	332°	+16	+26°
11.iv.56	2055	100	320°	100	336°	0	+16°
11.iv.56	2020	100	5°	100	(17°)	0	+12°
13.iv.56	0400	80	20°	67	325°	—16	—55°
16.iv.56	2030	105	300°	111	334°	+6	+34°
21.iv.56	0340	54	305°	60	319°	+10	+14°
				Average	.. ..	+13	+1·5°

V. RESULTS

(*a*) *Speeds and Cloud Sizes*

A histogram of speeds derived by the methods of Section IV is shown in Figure 5. Although there is a large spread in values, the most probable speed appears to lie in the vicinity of 4·5 km/min and the mean speed is about 5 km/min.

Speed measurements may be coupled with observations of blanketing by clouds (Fig. 6) to give an estimate of cloud size. The period of zero phase-path change may be correlated with cloud speeds in the same fashion. Thus, for example, the estimated speed of the cloud of Figure 6 is 3·9 km/min and blanketing occurs for 2·5 min ; this leads to a cloud about 10 km in extent in the direction of movement. The average cloud size as determined by 28 such measurements is 13 km. This value agrees well with the lack of correlation between records taken 50 km apart, as reported in the earlier paper.

(*b*) *Velocities*

Although fading records have been taken on the E region for both day and night-time, only the night-time results are included herein, as at the operating frequency of 2·28 Mc/s it is often impossible to determine whether the day-time reflection is from the E_s or the normal E region. All wind directions quoted are vector directions.

In Figure 7 are shown polar plots of the hourly changes in E_s drift velocity for the year July 1952 to June 1953. For nearly all months the winds have an easterly component in the early hours of the night followed by a swing to the

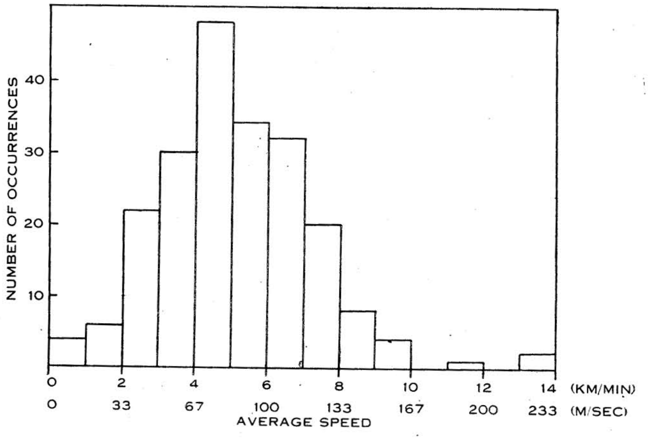

Fig. 5.—Distribution of E_s speeds.

west. Harmonic analysis* shows that this trend is due to the semi-diurnal component of the east-west variation ; for nearly all months this has a maximum amplitude in the easterly direction at about 18–20 hr.

Figure 8 shows the prevailing winds for night-time E_s for this same period. It is to be noted that the majority of these prevailing winds tend to be northerly with a bias towards the west.

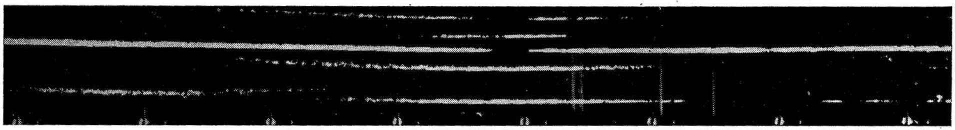

Fig. 6.—An example of F-blanketing caused by an E_s cloud. Measurements of the cloud speed and duration of blanketing give an estimated cloud size of 10 km.

The velocities as found from the directional data are plotted as a scatter diagram in Figure 9. As mentioned previously, these data represent readings taken over a long period and there has been no attempt to separate the small number of values into diurnal or seasonal components. One obvious and striking fact, however, is that there were very few velocities recorded with a southerly component ; there is a preponderance of velocities in the north-west sector. This diagram is thus in good agreement with the prevailing winds derived from fading analysis and shown in Figure 8.

* The harmonic analysis is carried out using data from the full 24 hr ; this work will be reported in a further paper.

VI. Cloud Shapes

Measurements of the vertical thickness of E_s layers may be made by comparing the measured height of M-echoes with the height calculated on the basis $2h'F - h'E_s$. Such measurements have been made at Brisbane from the $2 \cdot 28$ Mc/s

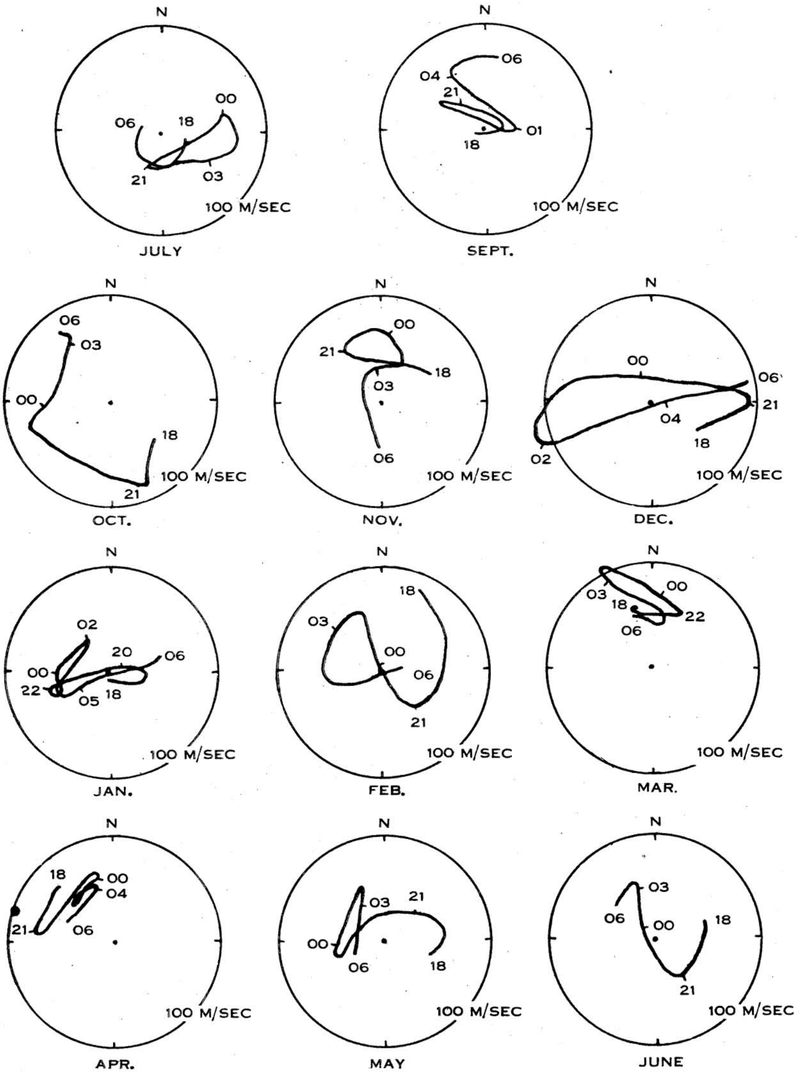

Fig. 7.—Diurnal variation of velocity of drift of night-time E_s for the year July 1952–June 1953.

$P't$ records using expanded range scales (Hosking, unpublished data). The results show that night-time E_s has a thickness which is probably not greater than 1 km.

The measurements of Section V (a) indicate that the probable horizontal extent of an E_s cloud is of the order of 10 km.

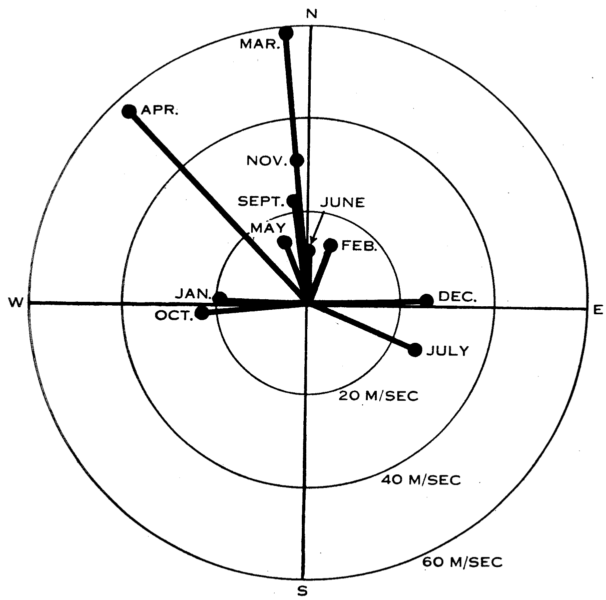

Fig. 8.—Prevailing wind components of night-time E_s drift velocities for the year July 1952–June 1953.

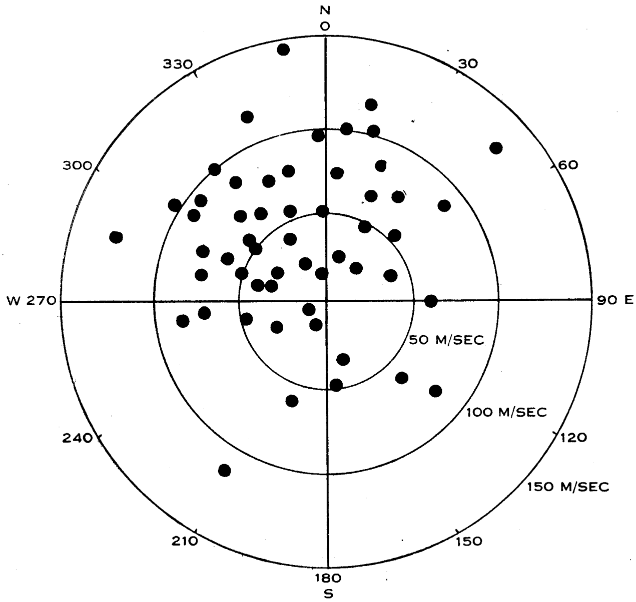

Fig. 9.—Scatter plot of E_s cloud velocities as determined from directional recordings.

It is necessary to examine what effect, if any, the shape of a cloud will have on the velocity calculated by the methods outlined above.

(*a*) If the cloud is spherical of diameter 1 km the velocity values will be essentially correct, since it would only be necessary to add $\frac{1}{2}$ km to all range values to have the motion of the " point " cloud of the original hypothesis.

(*b*) If the cloud is cylindrical (10 km diameter, 1 km high) then it is easy to calculate what the resultant effect will be on the range and directional data. If we choose a cloud speed of 5 km/min (83 m/s) and a variety

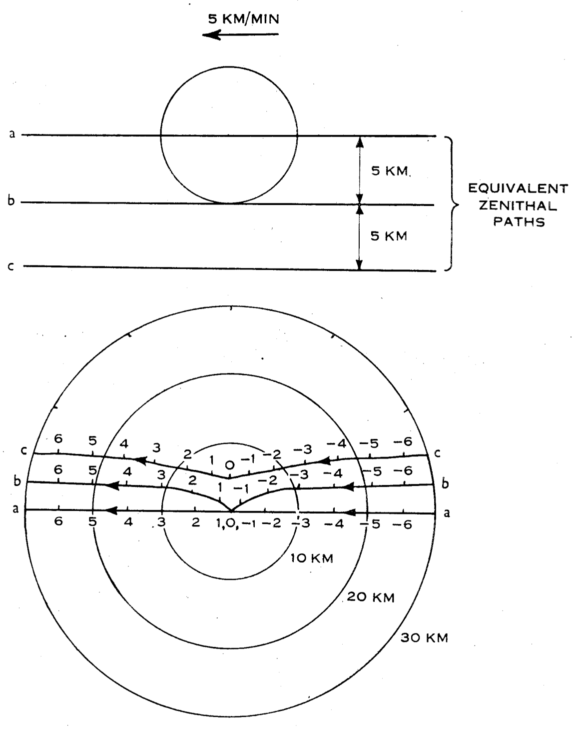

Fig. 10.—Reflection point paths for a circular disk cloud travelling at 5 km/min. The numbers on each path represent time in minutes ; the time $t=0$ is taken as the time of closest approach of the cloud centre to the zenith.

of paths varying from those passing vertically overhead to those at some degree of obliquity, the relevant data are shown plotted on the diagram of Figure 10. If the edges are rounded off to $0 \cdot 5$ km curvature, the diagram is not noticeably altered.

(*c*) If the cloud is elongated in one direction, then besides the variation in the ratio of diameters we have to consider also the possibility of movement of the cloud at an angle to the direction of elongation. To put this on a more concrete basis, we may once again choose a speed of

5 km/min and plot the positions of the reflection points for elliptical cylinders of varying magnitude, eccentricity, and orientation. The plot for one case in which the elliptical cylinder moves in a direction different from that of its major axis is shown in Figure 11.

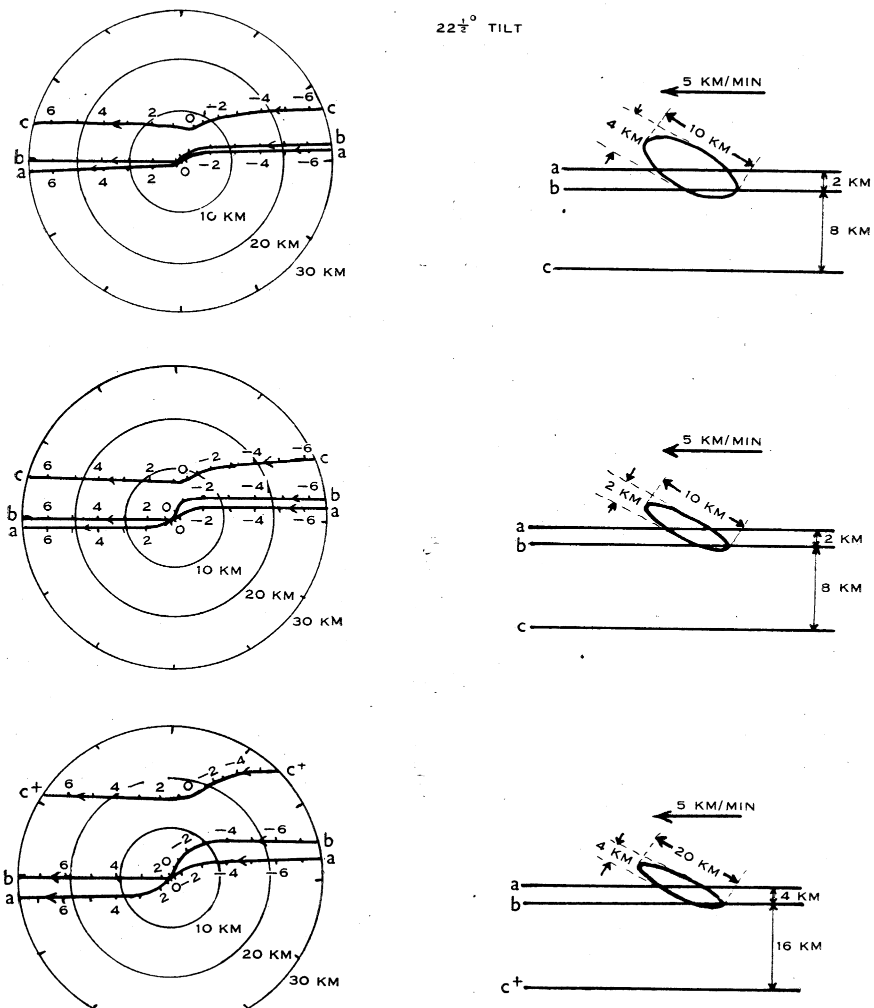

Fig. 11.—Plots of paths of reflecting points for reflection from the edge of elliptical cylinders for the configurations, paths, and speeds, shown on the right-hand side. *a*, *b*, and *c* represent different effective paths of the zenithal point past the cloud. Time is marked on the paths in minutes, zero time being taken as the time when the cloud centre is nearest the zenith.

From these diagrams it is clear that if we are to find the true drift velocity, we must deal separately with the decreasing and increasing range portions of the data, and avoid using the data which indicate that the reflecting point lies within a circle of radius $\sim$10 km about the zenithal point at the cloud level.

D

If these precautions are taken the residual errors are negligible. If accurate directional measurements could be made within the 10 km zone, information could be derived concerning the eccentricity of the cloud. Such measurements would be extremely difficult to achieve in practice, owing to the fact that the cloud echoes are weak and often subject to severe phase and amplitude fading which limits the accuracy with which the direction of arrival may be determined. Some information may, however, be obtained from a close examination of the expanded $P't$ records. If we suppose that the E_s cloud of Figure 11 (c*) is at a height of 100 km and calculate the slant range to the reflecting point on the cloud at various times, we obtain the hypothetical $P't$ curve of Figure 12. The striking point is the lack of symmetry of the " trace " about the point of minimum

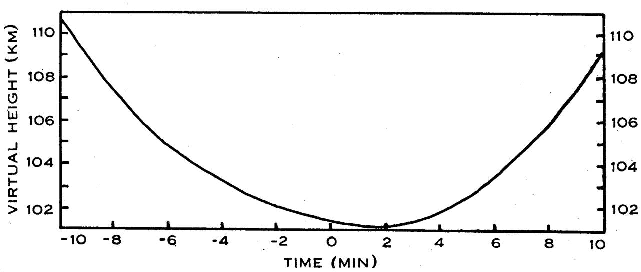

Fig. 12.—$h't$ plot of cloud (c*) of Figure 11.

range (which does not occur at our time $t=0$). A calculation of speed from this curve shows that nearly correct speeds are found only from the steeper side of the trace; speeds calculated using the other side of the trace are all too small ($\sim 3\cdot 5$ km/min).

Such asymmetric traces do occur in the $P't$ records, although the asymmetry is often very slight; in such cases the higher speed has been used for statistical purposes. Some of the cloud traces of Figure 3 clearly show asymmetry.

The conclusion is forced, then, that E_s clouds can and often do have considerable elongation, and that the elongation may be in a direction different from the direction of travel of the cloud. The elongation is subject to the overall restriction that the mean cloud size is $\sim$10 km.

VII. Conclusions

It has been demonstrated that E_{sc} consists of (generally) moving patches of ionization; the average speed of movement is about 80 m/sec, and the directions of drift have semi-diurnal swings from the north-east quadrant in the early evening to the north-west quadrant after about 22–2300 hr. Prevailing winds tend to be towards the north.

Layers of E_{sc} ionization are thought to be aggregates of roughly horizontal disk-like clouds, the disks not necessarily being circular, but at times showing considerable eccentricity in a direction differing from the direction of travel.

VIII. Acknowledgments

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