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# Some Studies of Sporadic E-Layer Drifts [and Discussion]

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# Some studies of sporadic E-layer drifts

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## 1. Introduction

In the past two decades, measurements of E-region drifts, using the conventional closely spaced receiver method with pulse signals incident normally on the ionosphere, have been made by many workers. The great majority of such measurements have been carried out at frequencies in the 2 to 3 MHz range and refer to drift movements in the lower part of the normal E region. Measurements of sporadic E drifts by the fading method have almost always been limited to night-time hours, when the normal E layer is absent, and the results have generally been used to extend daytime normal E measurements over the full 24 h. The objectives of the present work, in which the fading method has again been used, were to obtain some simultaneous measurements of drift in the normal E and the sporadic E regions, to obtain some qualitative data on height gradient of sporadic E-layer drifts, and to compare the horizontal drifts of small- and large-scale sporadic E irregularities. (A survey of current experimental and theoretical work on sporadic E, and of outstanding problems, has recently been published by Whitehead (1970).)

The closely spaced receiver technique measures changes in a diffraction pattern at the ground and the interpretation of these changes in terms of 'ionospheric drift motion' is, of course, open to question. Certain basic ambiguities in the interpretation of experimental data obtained in the fading method cannot readily be resolved and are likely to remain until some direct comparisons can be made with actual movements at ionospheric levels of both the ionized and neutral constituents. In continuing the practice of referring to the processed data as 'ionospheric drifts' we recognize that the more appropriate term would be 'apparent ionospheric drifts', and that the 'drifts' refer only to possible motion of, or within the ionization.

## 2. Experimental techniques

In this work, simultaneous measurements of E and $E_s$ drifts have been obtained using the conventional closely spaced receiver method with pulse signals incident vertically on the ionosphere. Signals were received on loop aerials (2 m side) a polarimeter arrangement being employed to eliminate one of the magneto-ionic components. The receiving aerials were arranged in two arrays. In the first arrangement four aerials were located at the corners of a square of side 95 m (approximately one wavelength) and this group of four was used for most of the single frequency work. A second arrangement with groups of three aerials at the vertices of a right-angled triangle (sides 95, 95 and 134 m) was used when simultaneous observations on three frequencies were required.

For the $E_s$ drift studies the frequencies were selected so as to be larger than the prevailing normal E-layer critical frequency and were in the range 3.3 to 3.9 MHz. Occasionally, when conditions permitted, $E_s$ measurements were also made on much higher frequencies (5 to

7 MHz). Simultaneous studies of normal E-region drifts were also made and, for these, the frequency used was in the range 2.0 to 2.8 MHz.

The receiver signals were recorded photographically on film by means of a series of miniature galvanometer units built into a 35 mm camera. The mean time shifts on the film recordings were measured by means of an optical split mirror device which enabled any one trace to be displaced both laterally and longitudinally so as to superpose it on any other trace. Individual time shifts could be read to better than $\pm 0.5$ s and generally any drift measurement was based on the average of at least eight time-shifts.

The received signals were also recorded as audio signals on magnetic tape. For this system the echo amplitudes were converted to frequency changes using voltage-controlled oscillators, added together in a summing unit and recorded as an audio signal of varying pitch on magnetic tape. For computer processing, the magnetic tape was played back and pass band filters used to separate the original signals. The outputs of the filters controlled discriminators (which reproduced the amplitude variations of the original echoes), were fed to a digital voltmeter, were sampled twice a second, and the values punched on to paper tape. Data from the paper tape records were used for a full correlation analysis.

Not all of the records obtained experimentally were suitable for analysis since various factors made the analysis impossible or unreliable. In all about 40 % of the records taken were rejected for one reason or another.

Observations were made at Aberystwyth (52° N, 4° W) in the period September to November 1966 and April to November 1967. During the summer months continuous recordings were made from 07 h to 20 h G.M.T. on 4 days per week. In other months the observing period was inevitably reduced because of the decreasing occurrence of sporadic E.

In addition to these closely spaced receiver measurements, studies of large-scale $E_s$ drift motions have been made using television signals received from the continent of Europe. It is well known that during the summer daylight period long-distance propagation of v.h.f. signals via sporadic E ionization is of frequent occurrence. During 1968 and 1969 a study of such propagation over Europe was also made at Aberystwyth. Television signals in Band I (on 48.25 and 49.75 MHz) from some 33 stations distributed throughout Europe from Norway to Spain were monitored and recorded from all available transmitters in the range 1000 to 2500 km, these being the approximate lower and upper limits for single hop 50 MHz sporadic E propagation.

Records of television reception were made on 16 mm film using a suitably modified commercial television receiver, a camera being set to take single frames automatically every 15 s as long as a signal strong enough to provide a picture was being received. The equipment was operated daily during the summer months over the period 07 to 23 h G.M.T. In the analysis of the results, recordings of television reception were only included if the source of the signal had been positively identified. Such identification was effected from observations of test transmission cards and programme captions. The photographic recordings were supplemented by pen recordings of the received signal strength from several other European v.h.f. transmitters.

A careful analysis of reception times showed that the received signals were being received from large patches of sporadic E ionization which either drift bodily, or patches in which the electron density diminishes over one area and is enhanced at an adjacent location. Whatever the true explanation, the experimental results can be interpreted in terms of an apparent large scale movement of the reflection point in the $E_s$ ionization.

## 3. Experimental results

### (a) *Results from closely spaced receivers method*

#### (i) *Magnitudes and directions of drift*

Histograms showing the magnitude and direction of drift for simultaneous measurements of E and $E_s$ drifts during the daytime in the summer months of 1967 are shown in figure 1*a* and *b*. Both histograms peak in the velocity range 60 to 70 m $s^{-1}$, but the $E_s$ drift speeds show a rather larger variability than those for the normal E layer. For $E_s$ the drift direction is predominantly towards the west and southwest, but for the normal E region it is predominantly towards the east.

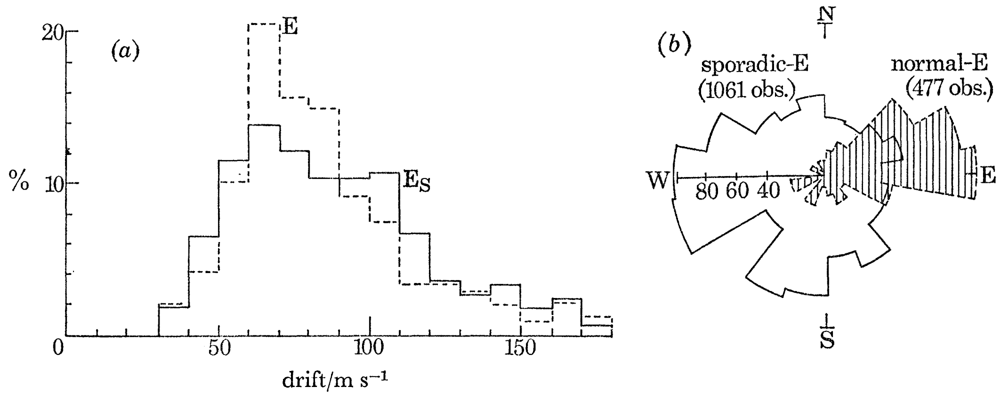


FIGURE 1. Simultaneous E and $E_s$ drift measurements. (*a*) Distribution of magnitudes. (*b*) Distribution of directions.

The average diurnal variations in $E_s$ and E-region drifts observed in different months are shown in figures 2 and 3. For both regions, and for all months with the exception of August 1967 there is fairly clear evidence for a semi-diurnal rotating component. There is also a suggestion that the amplitude of the rotating component is larger at the equinoxes. (A more extensive independent set of data on normal E-layer drifts obtained at Aberystwyth also shows that the amplitude of the rotating component is larger at the equinoxes than at the solstices, with the spring equinoxes value larger than that during the autumn.)

The results of a harmonic analysis of $E_s$ and E-layer drifts separating the semi-diurnal and prevailing components, for 6 individual months, are shown in figure 4. The seasonal variation in the amplitude of the normal E semi-diurnal component, the completely different directions of the prevailing component and the variability in the ellipses for the $E_s$ drifts are to be noted.

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#### (ii) *Height gradient of drift velocity*

The wind shear theory for the formation of sporadic E ionization suggests that large height gradients might be expected in $E_s$ drift speeds. During the present study some 272 measurements of $E_s$ drifts were made simultaneously on two frequencies and 79 measurements on three frequencies. The extremely large gradients of ionization normally found on the lower side of an $E_s$ layer are such that changes in the group reflexion height at different frequencies are too small to be measured. It is thus very difficult to obtain quantitative measurements of the height gradient of velocity but since we can be certain that, on average, higher frequencies will be reflected from greater altitudes, it is at least possible to obtain some qualitative indications about the height gradient of $E_s$ drifts.

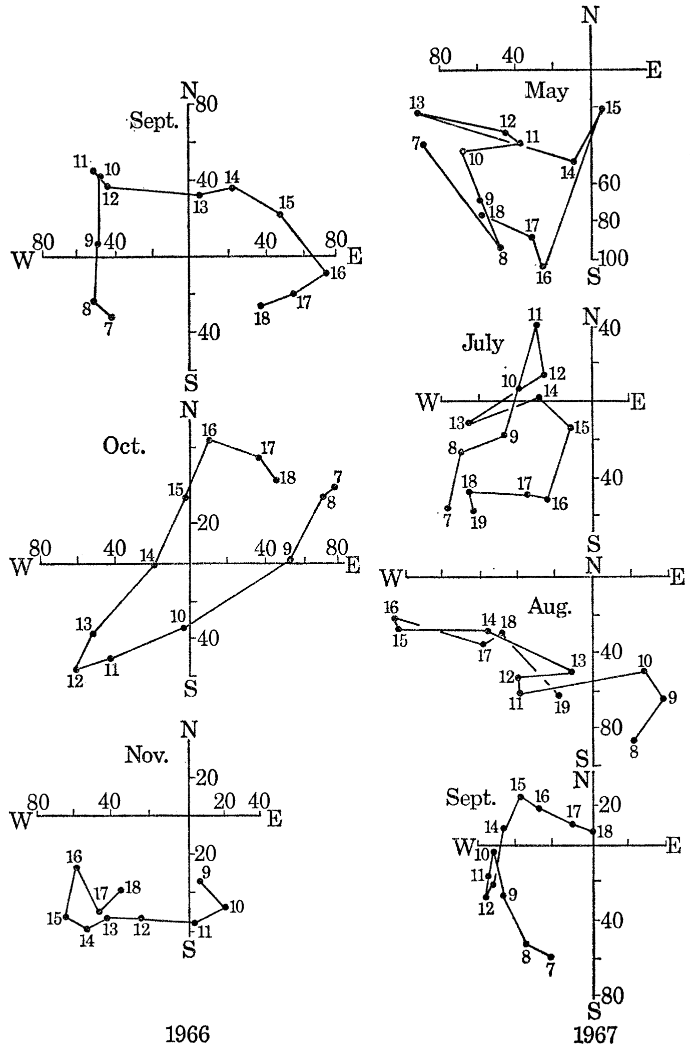



FIGURE 2. Monthly mean diurnal variations in $E_s$ drifts (in m $s^{-1}$).

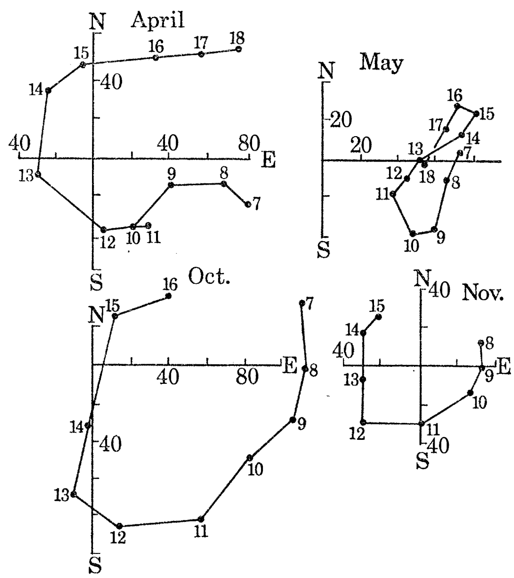



FIGURE 3. Monthly mean diurnal variations in normal E-region drifts.

The results of 79 measurements made simultaneously on 3.3, 3.5 and 3.7 MHz were classified into four categories depending on the form of the observed variation of drift with 'height'. (Actually the observed variation with frequency was used but, as stated, we assume that higher frequencies will penetrate further into the $E_s$ layer and consequently refer to a higher level.)

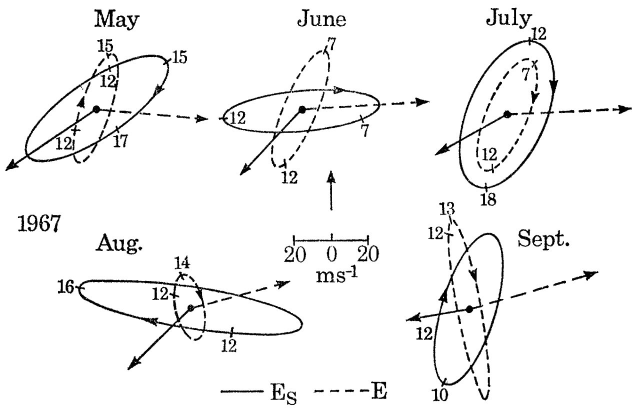
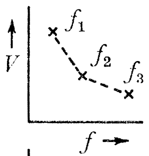
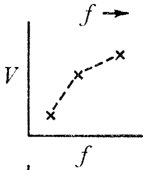
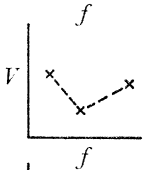
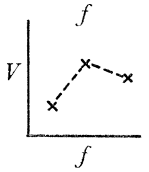



FIGURE 4. Semi-diurnal and prevailing components of $E_s$ and E-layer drifts.

TABLE 1

three frequency experiments

| type of gradient | N–S no. | N–S % | E–W no. | E–W % |
|---|---|---|---|---|
|  | 18 | 23 | 30 | 38 |
|  | 24 | 30 | 16 | 20 |
|  | 19 | 24 | 18 | 23 |
|  | 18 | 23 | 15 | 19 |
| | 79 | | 79 | |

two frequency experiments

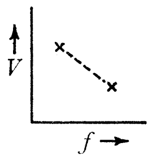
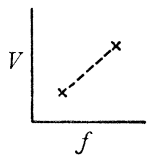
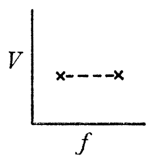
| type of gradient | N–S no. | N–S % | E–W no. | E–W % |
|---|---|---|---|---|
|  | 107 | 39 | 142 | 52 |
|  | 123 | 45 | 95 | 35 |
|  | 42 | 16 | 35 | 13 |
| | 272 | | 272 | |

Table 1 shows the results obtained for the NS and EW components in this group of 79 measurements. It will be seen that the highest fraction in any one category is the 38 % of the observations which show a continuous decrease of velocity with height (frequency) in the E–W component. The next most frequent category would appear to be those exhibiting a positive height gradient in the N–S component. In this group of results we are concerned with a negative height gradient which is sustained over three frequencies. If we consider the gradients deduced from measurements on two frequencies only it is found that a considerably higher percentage of the EW components show a negative height gradient of velocity. The results for 272 two-frequency measurements are also shown in table 1. In this case the results are classified into three groups, those showing a negative, positive, or zero height gradient. For the EW component it will now be seen that more than 50 % show a negative height gradient of drift speed, and for the NS component some 45 % show a positive height gradient of drift.

### (*b*) *Measurements of large scale* $E_s$ *drifts*

Measurements of large-scale $E_s$ drifts were made at Aberystwyth during the summer months of 1968 and 1969, using the technique described in §2 and a histogram of some 140 measurements of this large-scale movement is shown in figure 5. For comparison the histogram of $E_s$ drifts

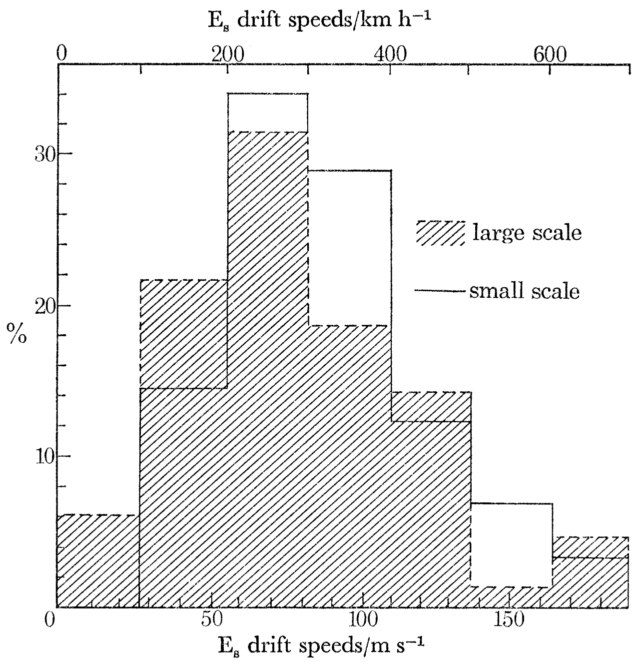



FIGURE 5. Histogram of large and small-scale $E_s$ drifts.

using closely spaced receivers is also included. It will be seen that the distribution of velocities is very similar and both sets of data show a most frequent velocity in the range 60 to 80 m s$^{-1}$. Figure 6 shows drift directions for these large-scale movements obtained in 1968 and 1969. The degree of agreement in the 2 years is quite remarkable with some 70 % of the results showing drifts within 45° of due west. Figure 7 shows drift directions from these large-scale experiments compared with directions obtained using the closely spaced receiver technique. (In figures 5 to 7 for comparison purposes, the small-scale drift results have been grouped into intervals of 100 km h$^{-1}$ and 30° sectors since these were the actual groupings of the drift data in large-scale irregularities.) It is clear from figure 7 that both the small- and large-scale irregularities show a predominant drift towards the west, although in the case of the small-scale irregularities there is much greater variability in direction.

This study of long-distance v.h.f. sporadic E reception can also be used to estimate the approximate size of these large scale $E_s$ 'clouds'. Some 100 such measurements were possible in the two summer periods of 1968 and 1969 and these indicate an average cloud size of about 310 km in the NS direction and about 245 km in the E–W direction, i.e. there would appear to be a significant degree of elongation in the NS direction.

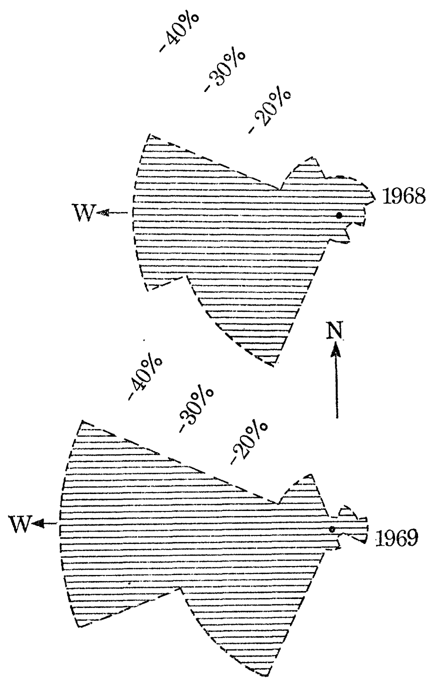



FIGURE 6. Large-scale $E_s$ drift directions 1968 and 1969.

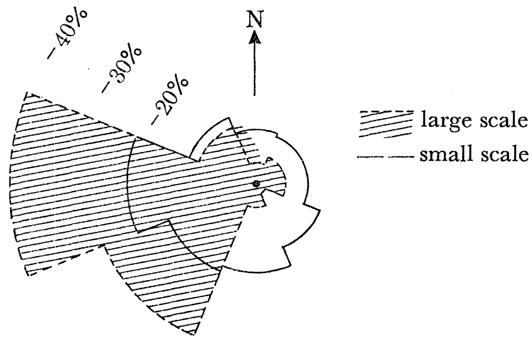



FIGURE 7. Large- and small-scale $E_s$ drift directions.

The main results of these experiments are:

(i) The magnitudes of drift velocities in $E_s$ and E are comparable, but the prevailing directions of drift are often quite different. $E_s$ drifts are also much more variable than those in E.

(ii) Both E and $E_s$ drifts show clear semi-diurnal tidal components with clockwise rotations. The E and $E_s$ drifts refer to average levels of 100 and 114 km respectively and over this height range the data indicate that the phase of the semi-diurnal component advances upwards at about 7° per km. The tidal components in $E_s$ are much more irregular and variable than in E.

(iii) The height gradient of drifts in $E_s$ shows that negative E–W shears occur most frequently but positive N–S shears form the next most frequent group.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(iv) The magnitude of shears in normal E-region drifts measured in this work averages about 2 m $s^{-1}$ $km^{-1}$ (0.002 $s^{-1}$). It is not possible from these experiments to give a quantitative estimate of the actual magnitude of the shears in $E_s$ drifts, but on any reasonable assumptions about the $E_s$ electron density/height profile it is clear that the shears in $E_s$ drifts are very considerably larger than those in the normal E layer.

(v) On average, $E_s$ drifts measured with closely spaced receivers, and which presumably refer to small-scale irregularities, move with the same speed and direction as those of very large-scale $E_s$ patches. These large-scale patches average some 250 to 300 km in size with some evidence for a 20% elongation in the N–S direction.

The various results listed above are not inconsistent with the conclusion that $E_s$ is subject to the same tidal influences as E, but the much greater variability in the measured amplitude and phase of the $E_s$ semi-diurnal drift vector suggests that there is some additional perturbing influence operating in the case of $E_s$ which could indeed be associated with the mechanism, or mechanisms, producing this sporadic concentration of ionization. The very large-drift shears, clearly present in $E_s$, are consistent with a wind shear production process and the high percentage of cases in which negative E–W shears are observed might be interpreted as support for one form of the wind-shear theory, but this would also involve an assumption that these $E_s$ drift data, which refer to the ionized component, also represent the ambient winds. Furthermore it has to be noted that the results also show a substantial number of examples of positive N–S shear in $E_s$ drifts.

### Reference (Beynon *et al.*)

Whitehead, J. D. 1970 Production and resolution of sporadic E. *Rev. geophys. & Space Phys.* **8**, 65–144.

### *Discussion*

C. O. Hines (*Department of Physics, University of Toronto, Canada*)

I should like to report briefly on some recent work of Dr G. Chimonas, to be published in the *Journal of geophysical research*, and then comment on the paper of Professor Beynon in the light of this work.

As you may know, conventional wind-shear theory of mid-latitude sporadic E layers (as developed by Whitehead, Storey, Axford, MacLeod and others) is concerned with the vertical transport of ionization from above and below, into a nearly horizontal layer, the transport being effected by certain shearing patterns of nearly horizontal neutral gas winds, acting in conjunction with the geomagnetic field. The winds that are thought to be dominant in this process are tidal winds, and their pattern of shears descends through the E region in the course of several hours as the tidal phases propagate. Metallic ions, originating in meteor trails, are most strongly affected because of their relatively long photochemical lifetimes.

Among the present difficulties faced by this theory are: (1) the tides are probably more regular than is the occurrence of sporadic E, and (2) the vertical compression into a horizontal layer is probably inadequate to account, by itself, for the intensities of ionization enhancement that are observed. Chimonas has developed a theory which, when added to the conventional theory, appears to overcome these difficulties. In my opinion, it points the way to further advance in this area.

The essential ingredient to be added is a spectrum of shorter-period gravity waves. The intensity of these waves is normally too low, and their periods too short, to provide for a substantial development of sporadic E on their own (although exceptions may occur on occasion). They may, nevertheless, act upon an incipient layer already established by the tidal shears, and, by compressing the ionization horizontally within that layer, they may build it up in regions of enhancement while diminishing it elsewhere. Their enhancing effect would still not be great, save for one feature: a certain portion of the wave spectrum, with a vertical trace speed matching that of the tide and so that of the incipient layer, may appear to be Doppler-shifted to zero frequency as seen by the ionization within the layer. Such waves, though perhaps weak in intrinsic intensity, nevertheless exert their influence for very long periods: they are capable of a resonant interaction, which will lead to strong horizontal bunching within the height range of the incipient layer. It is argued that this bunching is the final cause of the intense enhancements that show up clearly as sporadic E, and that the occurrence or absence of suitably resonant waves accounts for the sporadic nature of the phenomenon.

In application to Beynon's results, one would now be inclined to argue as follows. Sporadic E will occur only where the appropriate tidal winds and a suitable spectrum of gravity waves are to be found together, at appropriate (E region) altitudes. The westward propagation of the tides would tend to introduce a westward component of motion into the region so defined. Whether this might account for, or might be an influence upon, the westward bias in the motion of the observed sporadic E layers, I would hesitate to say without the opportunity for closer consideration of the data. If it did not account for the westward bias – and in any event, to account for the dispersion of the motions – one would look to a motion of the region in which suitable gravity waves occurred. This might be a motion generated by the group velocity of a wave packet, or a motion associated with the source of the resonant waves, or a deviation in the ray path (caused, for example, by the winds of planetary waves or of tides) from source to region of observation, or an apparent motion that resulted from a shift in the conditions for resonance as the tidal wind pattern changed.

On the other hand, motions of small-scale structure within the region of occurrence of sporadic E would be associated with the horizontal propagation of the phase structure of the resonant or nearly resonant waves. (Or, just possibly, with the actual wind velocities at the level of the layer, these velocities being revealed by background turbulence to which the fine structure of the radio fades is sometimes attributed.) This is in principle quite a different velocity from that of the region of resonant interaction as a whole. Whether it would be nearly the same as the latter or not, I cannot say off hand; but certainly there is, *a priori*, room for some difference between the two. While Beynon's observations do show the two distributions of velocities to be similar, there are certainly dissimilarities that do warrant attention. Individual cases might show even greater variations between the two velocities. Again, the very substantial dissimilarities between the small-scale 'drift' velocities for sporadic E and for normal E may find their explanation in the selection process, whereby sporadic E reveals the phase-structure motion of resonant waves, while normal E is revealing some averaged phase-structure motion of the full wave spectrum (or, just possibly, the actual wind velocities).

M. J. Rycroft (*Department of Physics, The University, Southampton*)

What is the range of wavelengths of the ripples discussed by Professor Hines?

C. O. Hines: Different wavelengths will be emphasized in different types of measurement. I take your question to refer to the horizontal wavelengths that I expect to contribute to E-region 'drift' observations, and the aswer to that is: 10 to 50 km, perhaps, with a maximum intensity possibly midway in that range. In the new theory of Chimonas, which requires resonant waves for sporadic E formation, there may be a selection process that favours some particular wavelength but I know of none; I would therefore anticipate much the same range of wavelengths in sporadic E.

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