PRELIMINARY RESULTS OF OBSERVATIONS OF ASPECT–SENSITIVE REFLECTIONS FROM IRREGULARITIES IN THE F REGION

By Evelyn M. Swenson*

[*Manuscript received July* 31, 1964]

Summary

Night-time radio reflections from irregularities in the F_2 region of the ionosphere have been studied at Brisbane (geomagnetic latitude $-35 \cdot 8°$), at a frequency of 16 Mc/s. The spatial limits and behaviour of the echoes were consistent with the hypothesis of specular reflections from field-aligned columns of ionization, with observational limitations imposed by echo surface configuration, aerial sensitivity, range attenuation, and absorption. The echoes, recorded with range-azimuth display, were of many shapes, but only a U-shape tended to recur. These U-echoes were preferentially observed under conditions of magnetic disturbance. Irregularity occurrence possibly increased with latitude from 45° to 55° geomagnetic latitude. No definite relationship was found between the echoes and v.l.f. noise, radio-star scintillations, spread-F, or auroras.

I. Introduction

For a period of 18 months from April 1960, observations were made at Brisbane (geographic coordinates 27°32′ S., 152°55′ E.; geomagnetic coordinates $-35 \cdot 8°$, $226 \cdot 9°$) of radio reflections from irregularities in the night-time F_2 region of the ionosphere. A 5 kW (peak pulse) backscatter sounder with a rotating aerial of 8° azimuth beamwidth (on transmit–receive operation) was used, at a frequency of 16 Mc/s (Thomas and McNicol 1960*a*, 1960*b*, 1962). Echoes were recorded which, from their general behaviour and the similarity of their characteristics to those of echoes studied at Stanford (geomagnetic latitude +43°), are thought to be due to specular or near-specular reflections from ionization irregularities in the F_2 region which are elongated in the direction of the geomagnetic field (Leadabrand 1955; Peterson *et al.* 1955).

The locus of points at which ray paths from a transmitter intersect the Earth's field at normal incidence is a surface, or family of surfaces, the nature of which has been computed by Dearden (1961, 1962*a*), taking account of moderate ionospheric refraction. Specular reflection from field-aligned irregularities can only occur from points in space lying on such "echo surfaces". The term "field-aligned echo" or FAE will be used to denote all echoes having the behaviour believed to be characteristic of specular reflections from field-aligned irregularities (FAI).

This paper discusses FAE recorded over a 6-week period between April and June 1960 (excluding those from the E region) and their possible relationships to other ionospheric and geophysical phenomena.

* Physics Department, University of Queensland, Brisbane.

II. FAE Identification and Classification

Three main types of echo were observed on the records:

(*a*) Ground backscatter echoes propagated via F-region reflections. Such echoes were generally extensive both in range and azimuth during day- and early night-time hours (often existing at all azimuths), and exhibited a well-defined low-latitude edge.

(*b*) Ground backscatter echoes propagated via sporadic E (E_s) region reflections. These echoes were usually patchy (with patch sizes of several hundreds of kilometres), often undergoing rapid changes of form within a few minutes. The echo edges were usually well defined and had slow fading rates, comparable with those of type (*a*) above.

(*c*) Echoes which could not be classified as either type (*a*) or (*b*). The majority of such echoes were classed as FAE, the general criteria for classification being:

(i) Spatial position, i.e. echoes in or near the region in space (centred on the direction of geomagnetic south) as defined by the appropriate echo surfaces (Dearden 1961, 1962*a*). Because of assumptions concerning the F-region electron density configuration, these surfaces are approximations only, and hence no exact correspondence was demanded between observed and expected echo positions.

(ii) Fading rate, this being usually in the range from 0·5 to 1 c/s (Dearden 1962*b*). This was much faster than the fading rates of F or E_s ground backscatter, and produced a characteristic diffuse or "fuzzy" appearance of the echo boundaries. On occasions, however, echoes whose behaviour otherwise was defined as that of FAE showed slow fading; such echoes were classed as FAE.

(iii) A number of echoes were observed (with range-azimuth recording) which had a clearly defined U-shape, and which are therefore known as U-echoes (Plate 1). This shape is predicted from echo surface considerations when an echoing region lies between two fixed heights. Other echoes were observed which, whilst having the other characteristics of FAE, were not U-shaped; these patch- or P-echoes were of a variety of shapes and forms. Plate 1 shows typical FAE configurations. Frequently the shape changed during the lifetime of any particular echo, so that the classification could alternate between P- and U-echo, often several times.

(iv) Echoes classed as FAE usually changed form only slowly, often maintaining their particular shape for periods of tens of minutes. They tended to appear by slowly increasing in signal level above noise, and to disappear in the reverse manner. In contrast, E_s ground backscatter echoes tended to fluctuate rapidly in form and intensity.

All criteria except fading rate had to be reasonably well satisfied for classification as FAE; U-echoes were always readily identifiable. On occasions, however, echoes resembling P-echoes could not be identified positively, due either to confusion on the records with E_s ground backscatter echoes near the same range and azimuth, or to some similarity between behaviour of the echo and E_s backscatter behaviour. Such doubtful echoes are not included here.

As well as dividing FAE into the two classes of U-echoes and P-echoes, a division was made into three types, according as the minimum (group) range of the FAE under consideration was:

(*a*) Less than the range of any $1F$ ground backscatter echoes existing at that time and azimuth. Such FAE are designated FAE_d. If no $1F$ backscatter was present, all existing FAE were classed as FAE_d.

(*b*) Greater than simultaneously existing $1F$ backscatter at that azimuth but less than any $2F$ backscatter at that azimuth. These FAE are known as FAE_{1F}.

(*c*) Greater than simultaneously existing $2F$ backscatter at that azimuth. No such FAE (known as FAE_{2F}) occurred during the period under discussion.

It is presumed that FAE_d arose by direct specular reflections from FAI, while the other two types involved as well intermediate reflections from the ionosphere and ground (Dearden 1962*b*). For the purpose of analysis, the type FAE_{1F} included a few cases of FAE which appeared at long ranges (greater than about 3000 km) at times of penetration of the $1F$ backscatter, and which are believed to be due to "trapped" propagation in a horizontal ionospheric gradient (Dearden 1962*b*).

The type FAE_d is considered to be equivalent to the "low-latitude auroral effect" observed at Stanford, whilst FAE_{1F} may be the same as some of the "long-range auroral-zone echoes" recorded there (Peterson and Leadabrand 1954; Leadabrand 1955; Peterson *et al.* 1955).

III. Boundaries of Areas Surveyed

The detection of a particular field-aligned irregularity, or group of FAI, is conditioned not only by its actual reflectivity but also by

(*a*) whether or not it intersects the echo surface within the F region,

(*b*) the antenna gain at the relevant elevation angle,

(*c*) the attenuation resulting from the spreading of the beam with greater distance, and

(*d*) loss of energy due to ionospheric absorption.

For a typical configuration of the echo surface, and assuming that the FAI extend from 250 km upwards without limit, the echo surface criterion limits the area reliably surveyed to a fan-shaped region, with radii 600 and 2500 km (group range) and azimuthal extent $\pm 60°$ from geomagnetic south.

The vertical polar diagram of the aerial array (J. G. Steele, personal communication) shows the maximum of the main lobe to be at 25° elevation, corresponding to a ground distance for direct F-region scattering of about 700 km. The overall sensitivity of the system (for FAE_d echoes) decreases by about 40 db between ground ranges 700 and 2000 km, neglecting ionospheric absorption, and it may be more reasonable to adopt 2000 km (rather than 2500 km) as the limit of reliable detection in the due south direction. As there is unlikely to be any marked dependence of probability of occurrence of FAI on geomagnetic longitude, it will be sufficient for studies of latitude effects if only a narrow zone of azimuths around due south is taken into account.

On some occasions, however, FAE_d echoes were detected at ranges considerably greater than 2000 km, probably due to the effect of "focusing" arising from a "trapped" propagation mode (Dearden 1962*b*). At times FAE_d could be observed up to about 3000 km, and still more remote FAI (over 4000 km) could sometimes be detected through the FAE_{1F} mechanism.

IV. Occurrence of FAE

(a) *Total Occurrence*

During the period April 24 to June 8, 1960, records were obtained during all or part of 38 nights, between 1600 and 0800 hr Eastern Australian Standard Time (E.A.S.T.; E.A.S.T. = U.T. + 10 hr). Records obtained outside these hours revealed no FAE.

$\mathrm{FAE_d}$ were detectable for some 30% of the total recording time. Allowance for obscuration by E_s and/or F ground backscatter, increased this figure to about 37%. FAE_{1F} were detected for 13% of the time that F ground backscatter was present (which was some 20% of the recording time). Either or both FAE types were recorded on 25 of the 38 nights. Approximately equal proportions of the $\mathrm{FAE_d}$ were classed as U- and P-echoes; of the FAE_{1F}, however, 92% were classed as P-echoes.

(b) *Latitude Variation of Occurrence*

The variation of FAE occurrence with latitude along the geomagnetic meridian was expressed in terms of the total duration of FAE at any given latitude, relative to the total observing time for hours during which echoes were detected. No correction was made for the occurrence of E_s or F-region ground backscatter which could prevent observation of $\mathrm{FAE_d}$; the presence of E_s backscatter affected the geomagnetic latitude interval 39° to 48°, and that of F backscatter, 48° to 62° latitude. These two phenomena obscured $\mathrm{FAE_d}$ to roughly the same total duration over all latitudes.

The values used in the derivation of the latitude variation were those of minimum echo (group) range and echo extent in range (measured at the azimuth at which the minimum range occurred). These values did not invariably lie on the geomagnetic meridian, but results showed that for 95% of all $\mathrm{FAE_d}$, the minimum range was at azimuths within ±15° of south. For deviations from south of this order, the expected decrease in probability of echo reception was negligible.

The latitude variation for $\mathrm{FAE_d}$ (U- and P-echoes separately) is shown in Figure 1(*a*), and that of FAE_{1F} (U- and P-echoes together) in Figure 1(*b*).

(c) *Diurnal Variation of Occurrence*

The diurnal variation of occurrence of $\mathrm{FAE_d}$ and FAE_{1F} is shown in Figure 2, expressed as a percentage of the total observing time within each of 1-hr periods. Since the observation of FAE_{1F} was controlled by the presence of $1F$ ground backscatter, the FAE_{1F} occurrence was confined to early evening or post-dawn hours. The diurnal variation of U- and P-$\mathrm{FAE_d}$ is shown in Figure 3.

The diurnal variation of $\mathrm{FAE_d}$ was essentially the same at all latitudes along the geomagnetic meridian. It was found, however, that at lower latitudes P-echoes tended to occur near midnight, whereas at these latitudes U-echoes tended to occur well before midnight. No systematic temporal behaviour was observed at higher latitudes.

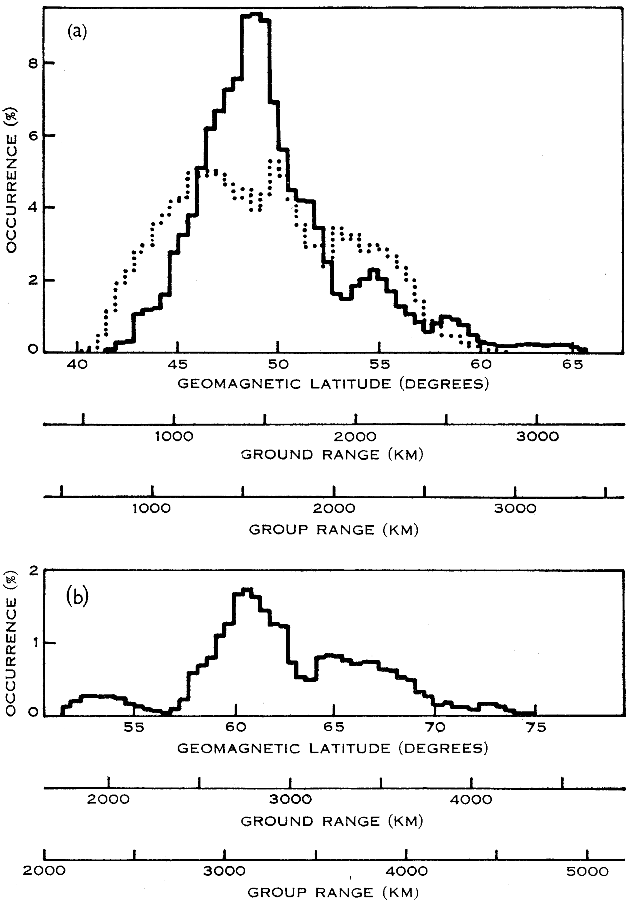

Fig. 1(*a*).—Percentage occurrence of FAE_d as a function of geomagnetic latitude, ground range, and group range. P-echoes, solid line; U-echoes, dotted line. An average correction was applied to reduce group range to ground range and latitude.

Fig. 1(*b*).—Percentage occurrence of all FAE_{1F} as a function of geomagnetic latitude, ground range, and group range. The reduction from group range to ground range and latitude was approximate only. In both parts of Figure 1, occurrence is relative to total observing time during which echoes were detected. Note the different vertical scales in each part.

(*d*) *Variation of Occurrence with Ionospheric Parameters*

In Figure 2 is shown also the diurnal variation of median f_0F_2 and $h'F$ at Canberra (geographic coordinates 35°18′ S., 149°12′ E.) for the 38 nights under consideration. It is seen that hours of high $h'F$ and low f_0F_2 are hours of high occurrence of FAE_d.

V. Shape and Morphology of FAE

(a) *Shape*

U-shaped echoes, when plotted in geographic (map) coordinates, reduce to an elongated east–west band, usually curved concave towards the transmitter (due

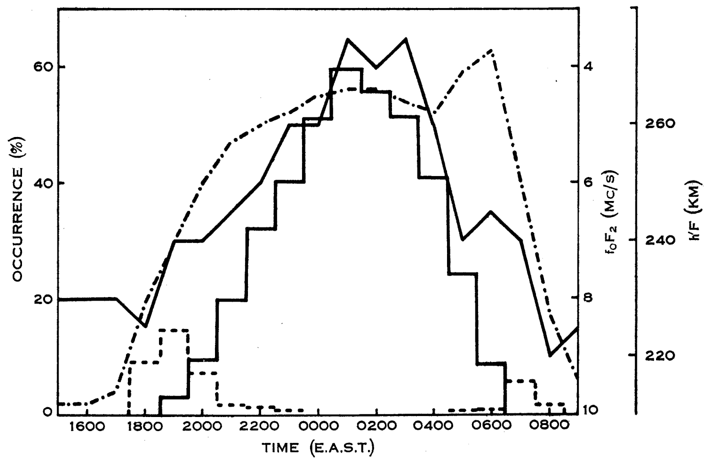

Fig. 2.—Percentage occurrence of FAE as a function of hour of night (histogram). FAE_d, solid line; FAE_{1F}, dashed line. Also shown is the variation with time of median f_0F_2 (chain line), plotted inversely, and median $h'F$ (solid line), both measured at Canberra.

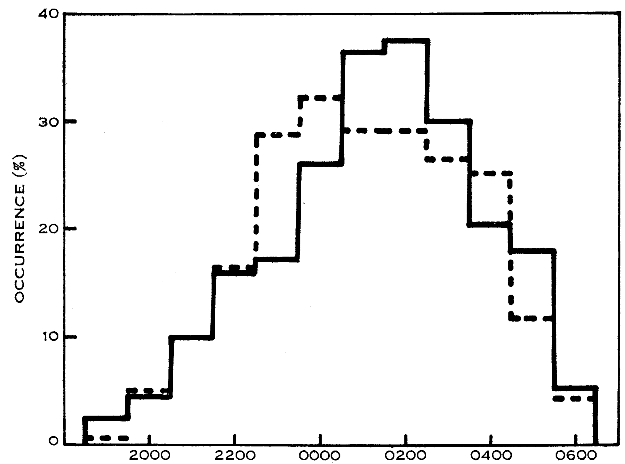

Fig. 3.—Variation of percentage occurrence of each class of FAE_d separately, with hour of night. P-echoes, solid line; U-echoes, dashed line.

mainly to distortion by aerial smoothing (Dearden 1962*b*)). Dearden (loc. cit.) has further shown that such U-echoes tend to show alignment with the lines of intersection of surfaces of constant geomagnetic adiabatic invariants *I* and *B* (Jensen, Murray, and Welch 1960). On the other hand, P-echoes, when plotted in geographic coordinates, show neither a recurrent shape nor significant association with the adiabatic invariant intersections.

(b) *Durations*

FAE_d had durations up to 9 hr, though the most frequent durations were less than 2 hr (average 3 hr). No U-echo persisted in that form throughout its entire lifetime; persistence of form did, however, occur for several P-echoes. The durations of FAE_{1F} were in general less than 30 min (average 25 min).

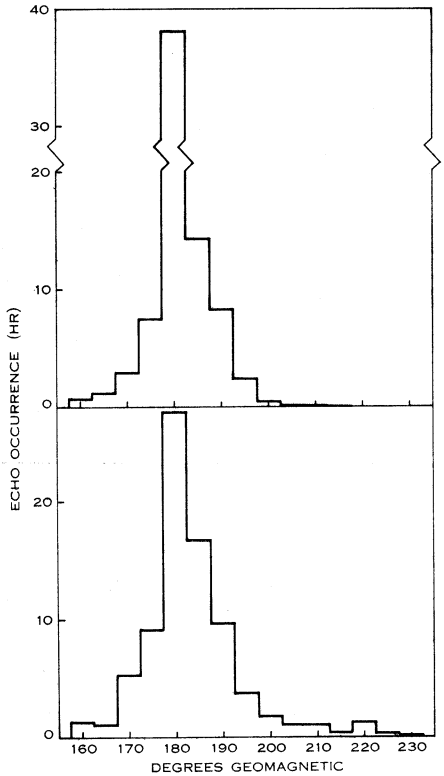

Fig. 4.—Distribution of occurrence of central azimuth values of FAE_d. U-echoes, upper; P-echoes, lower.

(c) *Central Azimuth*

The term "central azimuth" will be used to denote the geomagnetic azimuth for which the (group) range of the FAE is minimal. Provided that, at any particular time, FAI are distributed uniformly in geomagnetic longitude, a central azimuth of 180° would be expected for specular reflections from these irregularities.

Figure 4 indicates the departures of the experimental results for FAE_d from this prediction. The greater departures of the values for P-echoes than for U-echoes are possibly due to non-uniform distribution in longitude, and the greater departures of FAE_{1F} echoes are probably due to lateral deviation at the first F reflection. The histogram for FAE_{1F} (not reproduced) showed only a weak maximum at 180°.

In the case of FAE_d P-echoes (in particular), a predominance of westerly deviations was noted later in the night, and (at all times) for the lower latitudes.

(*d*) *Azimuthal Limits and Extents*

It was pointed out in Section III that the limits of the area of the ionosphere under surveillance are defined by attenuation and aerial sensitivity factors as well as by echo surface considerations. It might be expected, however, that the former

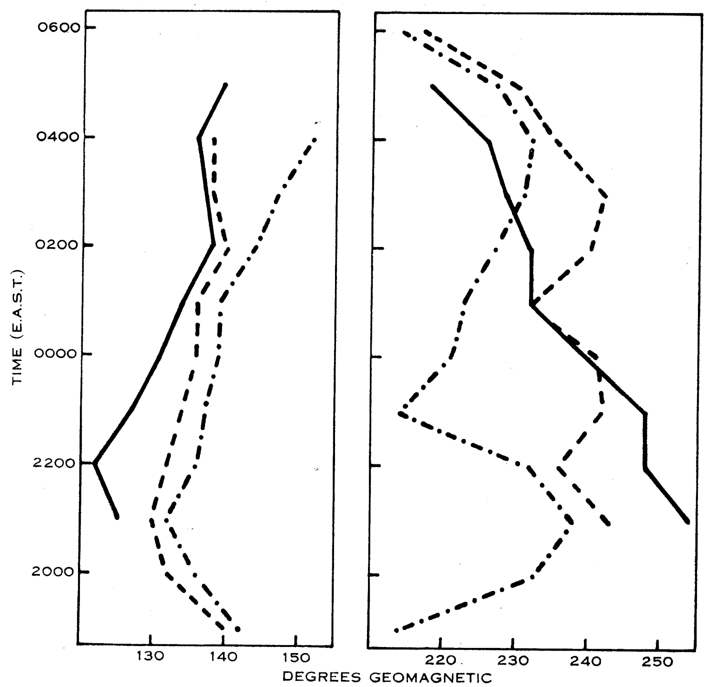

Fig. 5.—Variation of maximum azimuth limits of all FAE_d with hour of night. Predicted variation, solid line; 5% occurrence level, dashed line; 10% occurrence level, chain line.

factors would not vary markedly with time, whereas Dearden (1962*b*) has shown that the azimuthal extent of the echo surface, being a function of the electron density configuration, should show a systematic diurnal variation.

In Figure 5 are plotted the 5% and 10% occurrence contours for the extreme azimuths observed, irrespective of range, for all FAE_d, as functions of the hour of night. Dearden (personal communication) has computed, for 18 nights within the period in question, the limits of the echo surface for each hour, using ionosonde data. His averaged results are also shown in the diagram. The agreement between the theoretical and the 5% and 10% curves is poor in the west, but the observed and theoretical curves in the east are probably about as close as one might reasonably expect, having regard to the many assumptions and approximations involved.

Because the position of the extreme azimuths of the echo surfaces at any given range varies markedly with electron density configuration, it was difficult to compare the predicted and observed azimuth limits, taking account of range. The observed limits, however, were not inconsistent with the theoretical limits at any latitude, considering the assumptions involved.

(*e*) *Movements of the Inner Boundary of the Reflecting Regions*

Systematic changes were often noted in the (effective) range of the inner edge of an FAE, suggesting corresponding movement of the inner edge of the reflecting region. Whilst changes in central azimuth also occurred, these were not such as to allow definite interpretation as lateral movements of the boundary, and were accordingly neglected.

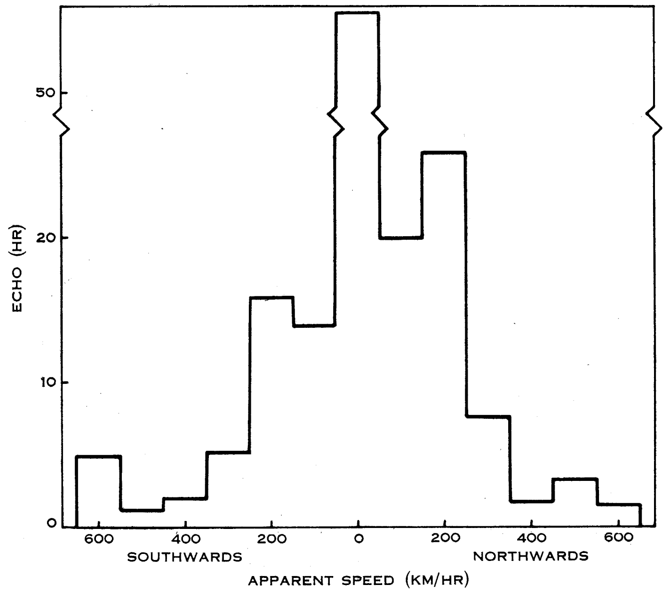

Fig. 6.—Distribution of apparent speeds of movement of all FAE_d, in 100 km/hr intervals.

Radial movements were indicated for about two-thirds of the total time during which P-FAE_d were recorded, and were about equally divided between northerly and southerly directions. In the first half of the night, however, northerly movements predominated, and after about 0030 hr, southerly. This tendency to change direction about 0030 hr was shown also by U-FAE_d, but in this case there was a general preponderance of northerly movement. The boundary of both U- and P-FAE_d at times remained stationary for more than 60 min.

The distribution of speeds of movement is indicated in Figure 6. (The highest speed intervals of the histogram include all speeds greater than 550 km/hr = 153 m/s.) It may be noted that the speeds generally were of the same order as ionospheric drifts determined by other means. Transient speeds, up to about 3000 km/hr, were occasionally observed, generally during times of echo disappearance, when the apparent echo range tended to increase very rapidly, possibly due to changes in ionospheric conditions that allow detection only of more distant regions of FAI.

(*f*) *Range-spread*

The term "range-spread" describes the difference in (group) range between the proximal and distal boundaries of the recorded echo (less 50 km to allow for pulse width and receiver bandwidth) measured along the line of azimuth at which the minimum range of the echo occurred. To a first approximation, this is equal to the north–south width in plan of the reflecting region.

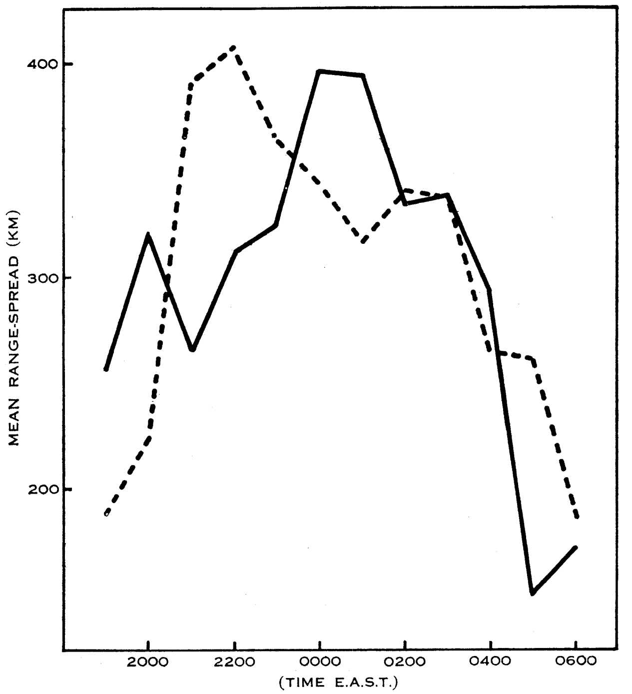

Fig. 7.—Variation of mean range-spread of FAE_d with hour of night. P-echoes, solid line; U-echoes, dashed line.

The mean value of range-spread for both P- and U-FAE_d was 325 ± 25 km; the modal value was in the interval 150–200 km, and the greatest range-spread observed was between 950 and 1000 km. FAE_{1F} had range-spreads up to 650 km, with a broad peak of occurrence between 250 and 400 km. These results are consistent with those of Leadabrand (1955), allowing for the longer pulse length used at Stanford.

The diurnal variation of mean range-spread of P- and U-FAE_d is shown in Figure 7. Figure 8 shows that the mean range-spread of both classes of FAE_d decreased markedly and reasonably systematically with increased latitude of the echo inner edge. No allowance was made, however, for any interaction between temporal and spatial variations.

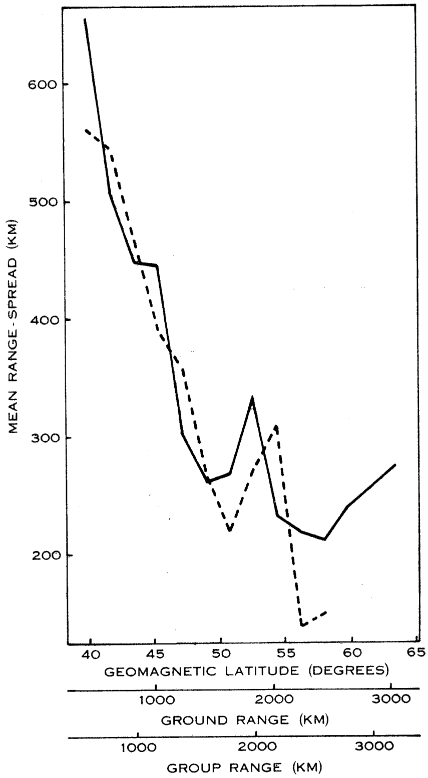

Fig. 8.—Variation of mean range-spread of FAE_d as a function of geomagnetic latitude, ground range, and group range. P-echoes, solid line; U-echoes, dashed line.

VI. Comparison with Other Methods of Detecting FAI

(*a*) *Radio-star Scintillations*

Since there is evidence that radio-star scintillations are produced by *F*-region irregularities elongated along geomagnetic lines of force (Spencer 1955; Jones 1960), it is possible that these irregularities are identical with those giving rise to FAE. An endeavour was made to check this point by comparing radio-star scintillations observed at Fleurs (geographic coordinates 33°52′ S., 150°46′ E.) at 85·5 Mc/s with FAE_d ascribed to FAI lying in the portion of the *F* region traversed by the line-of-sight between radio telescope and star. Although the radio stars (IAU 13S6A and IAU 16S6A) had transit times around midnight, there were, in fact, only six occasions during the period covered here, on which reliable comparisons could be made. On all six occasions the time of onset of scintillations was within 30 min of the first observation of suitable FAE; in two cases the onset was within 5 min. On numerous occasions scintillations appeared without corresponding FAE being present. This could have been due to the irregularities existing only above the height of intersection with the echo surface. Further, scintillations are probably a more sensitive indicator of irregularities than FAE.

Thus the comparison, on the whole, gave inconclusive results.

(*b*) *Spread*-F

Various theories have associated both types of spread-*F* (Bowman 1960) with field-aligned irregularities (e.g. Renau 1960; Pitteway and Cohen 1961). An attempt was made to compare the occurrence of spread-*F* at Canberra with the occurrence of $\mathrm{FAE_d}$ corresponding to a region within 100 km of Canberra. Again the information was meagre; for four of the five occasions when a suitable FAE was present, there was extremely good agreement between time of passage of the FAE into the appropriate region and the onset of, or increase in the amount of, spread-*F*. Results on the fifth occasion were indefinite. It may be noted that Goodwin and Thomas (1963) found an association between range-spreading of constant-height E_s and the occurrence of FAE from E_s clouds.

VII. Visual and Radar Auroras

The backscatter sounder presumably detects a proportion of what are referred to as "radar auroras", usually detected by radar of somewhat higher frequency. An attempt was made to compare the occurrence of visual auroras and FAE, but during the period of these observations no significant association was found between $\mathrm{FAE_d}$ and auroras observed from Australia. It is possible that some $\mathrm{FAE_d}$ echoes were associated with such auroras but, owing to lack of positional information, this could not be tested reliably. The observations of visual auroras from Antarctic stations were compared with FAE_{1F} records, but again with indefinite results, since no nights, at the two most suitable Antarctic stations, were unambiguously without auroras.

VIII. Relations to Other Geophysical Phenomena

(*a*) *Magnetic Disturbance*

Some comparisons were made between occurrence of $\mathrm{FAE_d}$ and magnetic disturbance, using

(i) *K* indices from Toolangi (geographic coordinates 37°32′ S., 145°28′ E.),
(ii) an empirical daily (rather than 3-hourly) index, derived from K_p indices,
(iii) general nature of magnetograms at Toolangi, and
(iv) micropulsations recorded at Camden (geographic coordinates 34°04′ S., 150°38′ E.).

There was a slight tendency for $\mathrm{FAE_d}$ to be absent on (magnetically) very quiet nights. U-$\mathrm{FAE_d}$ tended to be more prevalent when the *K* index was high, and under these conditions there was a greater tendency for northerly movement of the inner boundaries of both U- and P-$\mathrm{FAE_d}$. Similar but less pronounced correlations were obtained using the daily index. The mean range-spread of $\mathrm{FAE_d}$ appeared to decrease for *K* greater than 3.

Judging from the few (seven) occasions suitable for comparison of FAE_d with micropulsations, the correlation was close to zero.

(*b*) *Very Low Frequency Noise Bursts*

V.L.F. noise bursts, thought to arise in the exosphere (Ellis 1959), as recorded at Hobart (geographic coordinates 42°52′ S., 147°20′ E.) and Camden, were compared with FAE_d occurrence. For six of the eight occasions on which noise bursts suitable for comparison occurred, no FAE_d occurred; on the other two, pre-existing FAE_d were enhanced in intensity, the onsets and cessations of the enhancements agreeing very closely with the durations of the bursts. No firm conclusion can be drawn from these meagre results.

IX. Discussion

All the echoes observed at Brisbane lay within regions in space consistent with specular reflections from field-aligned irregularities, and experiments conducted at Stanford indicated that such is the case (Peterson *et al.* 1955). It may be noted also that Carpenter and Colin (1963) have reported a relationship between the existence of (field-aligned) whistler ducts and FAE (which they call "northscatter").

The marked decrease of mean range-spread with increasing latitude would be expected if echo surface cut-off were the controlling factor, and this decrease would be accentuated by the decreasing antenna gain, and by increasing range attenuation and absorption. These effects combine, therefore, to obscure any real variation in mean range-spread. The above effects were not eliminated when considering the diurnal variation of mean range-spread, and the relationship of range-spread to latitude and time was clearly complex.

Comparison of the observed latitude distribution (Fig. 1(*a*)) with meridian plane sections of various echo surfaces (Fig. 9, after Dearden 1962*b*) shows that the lowest latitude at which FAE_d were detected and that predicted agreed almost exactly. A possible reason for the disagreement at the high latitudes was discussed in Section III.

The following points may be noted from the latitude distribution of FAE_d (Fig. 1(*a*)).

(*a*) Comparison of the observed distribution with the variation of system sensitivity with range suggests that the probability of FAE_d occurrence was not uniform over the whole field of view. Preliminary attempts to eliminate the variations due to echo surface and other effects have proved unsatisfactory, but indicated that the probability of FAE_d occurrence may have increased with increasing latitude from 45° to 55° geomagnetic latitude.

(*b*) Comparison with the echo surfaces (Fig. 9) suggests that FAE_d occurred preferentially at heights greater than 400 km (Dearden 1962*b*).

(*c*) It is known that the field-aligned irregularities responsible for radio-star and satellite scintillations tend to occur at lower heights at times of high magnetic activity (Chivers 1963). Reference to Figure 9 shows that lower heights of the echo surfaces occur at lower latitudes. Thus the higher relative occurrence of U-FAE$_d$ at latitudes lower than about 45° (i.e. about 1200 km group range) may be associated with the preference for such echoes to occur at times of magnetic disturbance, when the irregularities are at lower heights.

The aerial system of the present equipment permitted considerably better spatial resolution of the echoes than equipment used elsewhere in previous studies at comparable frequencies (Leadabrand 1955). Thus the classification of the echoes into various shapes apparently has not been possible previously. Whilst U- and P-echoes are considered to be two aspects of the same phenomena, it is not possible

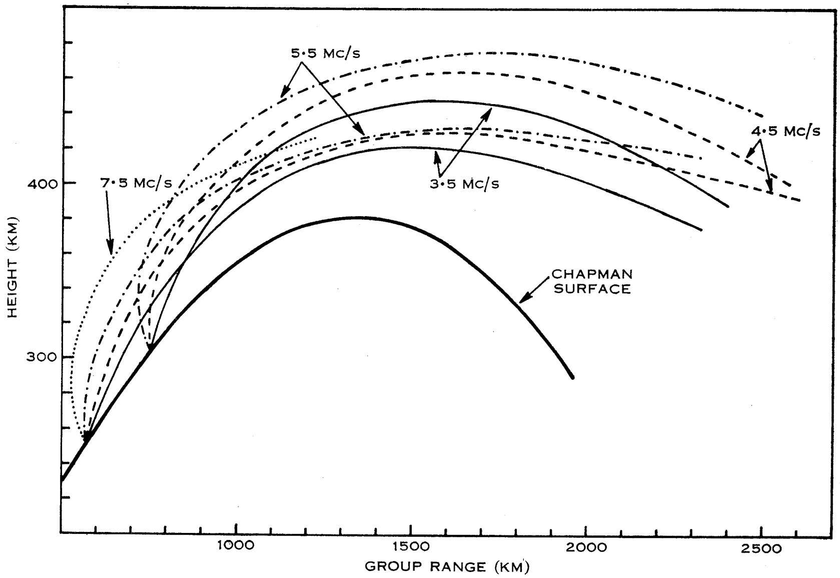

Fig. 9.—Meridian plane sections of various echo surfaces, for a parabolic layer of semi-thickness 100 km, and critical frequencies and base heights as marked. The no-refraction (Chapman) surface is included for comparison. (After Dearden (1962*b*).)

at present to give definite reasons for their behaviour being dissimilar in some respects. It is perhaps possible that P-echoes could be associated with discrete regions of particle dumping, restricted in space; U-echoes, appearing as east–west bands and occurring more frequently at times of magnetic disturbance, perhaps resulted from regions of dumping more extended in east–west extent.

The suggestion of lower heights of irregularities producing U-echoes, too, could have some bearing on the observed shapes. U-echoes could arise perhaps from FAI which exist continuously through the ionosphere to low heights, whilst P-echoes perhaps could arise from FAI whose lower limits are close to the height of the echo surface and which only intersect the surface in restricted regions, which may be of any shape. Present knowledge is inadequate, however, to explain how FAI are produced and maintained in existence.

X. Acknowledgments

This work was sponsored by the Electronics Research Directorate, Air Research and Development Command, United States Air Force, under Contract No. AF 64(500)-9. Financial assistance was also provided by the Radio Research Board of CSIRO. The author gratefully acknowledges tenure of a Commonwealth Post-Graduate Award.

Ancillary information was provided by various other persons and organisations, to whom sincere thanks are expressed, especially to: Mr. O. B. Slee, Division of Radiophysics, CSIRO, Sydney, for radio-star scintillation records; Upper Atmosphere Section, CSIRO, Camden, N.S.W., for data on geomagnetic micropulsations and v.l.f. noise bursts; Ionospheric Prediction Service, Sydney, for $p'f$ records from Canberra, A.C.T.; Bureau of Mineral Resources, Melbourne, for magnetometer records from Toolangi, Vic.; Antarctic Division, Department of External Affairs, Melbourne, for data on observations of visual auroras.

Thanks are also due to Dr. J. A. Thomas, Dr. J. D. Whitehead, Dr. J. Crouchley, and Mr. E. W. Dearden for much useful advice and discussion, and to Professor H. C. Webster for his unfailing interest and helpful advice.

XI. References

Bowman, G. G. (1960).—*Planet. Space Sci.* **2**: 133.

Carpenter, G. B., and Colin, L. (1963).—*J. Geophys. Res.* **68**: 5649.

Chivers, H. J. A. (1963).—"Proceedings of the International Conference on the Ionosphere, 1962." p. 258. (Institute of Physics and The Physical Society: London.)

Dearden, E. W. (1961).—Scientific Report No. 3, AFCRL-62-303. Radio Research Section, University of Queensland.

Dearden, E. W. (1962*a*).—*J. Atmos. Terr. Phys.* **24**: 375.

Dearden, E. W. (1962*b*).—Scientific Report No. 13, AFCRL-62-350. Radio Research Section, University of Queensland.

Ellis, G. R. A. (1959).—*Planet. Space Sci.* **1**: 253.

Goodwin, G. L., and Thomas, J. A. (1963).—*J. Atmos. Terr. Phys.* **25**: 707.

Jensen, D. C., Murray, R. W., and Welch, J. A. (1960).—"Tables of Adiabatic Invariants for the Geomagnetic Field 1955·0, Parts I and II." AFSWC TN 60–19, Air Force Special Weapons Center, United States Air Force.

Jones, I. L. (1960).—*J. Atmos. Terr. Phys.* **19**: 26.

Leadabrand, R. L. (1955).—Tech. Report 98, Radio Propagation Laboratory, Stanford University.

Peterson, A. M., and Leadabrand, R. L. (1954).—*J. Geophys. Res.* **59**: 306.

Peterson, A. M., Villard, O. G., Jr., Leadabrand, R. L., and Gallagher, P. B. (1955).—*J. Geophys. Res.* **60**: 497.

Pitteway, M. L. V., and Cohen, R. (1961).—*J. Geophys. Res.* **66**: 3141.

Renau, J. (1960).—*J. Geophys. Res.* **65**: 2269.

Spencer, M. (1955).—*Proc. Phys. Soc. Lond.* **B68**: 493.

Thomas, J. A., and McNicol, R. W. E. (1960*a*).—*Nature* **187**: 398.

Thomas, J. A., and McNicol, R. W. E. (1960*b*).—Scientific Report No. 1, AFCRL-TN-60-1119. Radio Research Section, University of Queensland.

Thomas, J. A., and McNicol, R. W. E. (1962).—Scientific Report No. 5, AFCRL-62-305. Radio Research Section, University of Queensland.

ASPECT-SENSITIVE REFLECTIONS

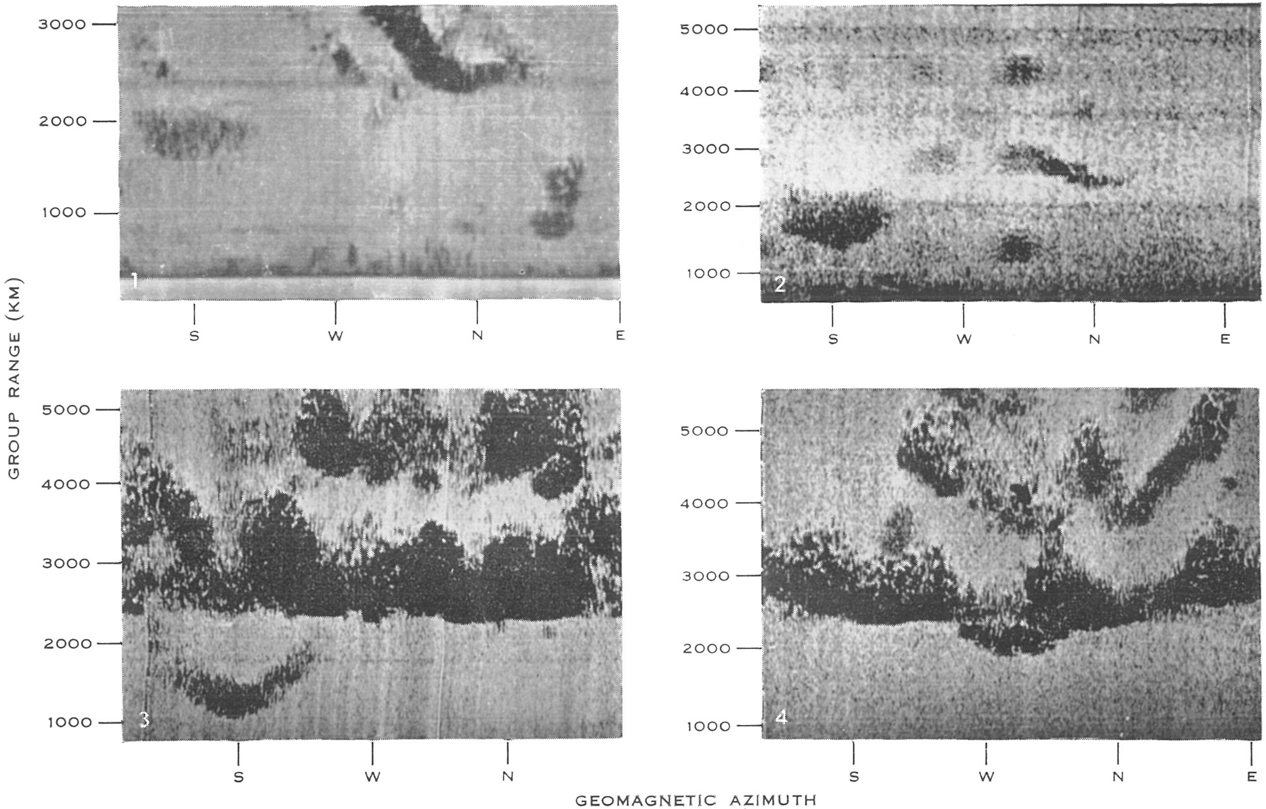

Fig. 1.—Record at 2220 hr E.A.S.T., May 2, 1960, showing a typical P-FAE$_d$ at 1600 km centred on 180°, in addition to normal F-region ground backscatter (at 2300 km and greater, between 240° and 60°), and a small E_s patch at 700 km, 60°.

Fig. 2.—Record at 0050 hr E.A.S.T., May 13, 1960, showing a typical P-FAE$_d$ at 1300 km, centred on 180°, and the remains of F-region ground backscatter at 2300 km (300°–30°). E_s patches at very short ranges; spurious echoes (interference) at 1000, 2500, and 4000 km.

Fig. 3.—Record at 2100 hr E.A.S.T., May 25, 1960, showing a typical U-FAE$_d$ at 1000 km, centred on 180°, in addition to normal 1F and 2F ground backscatter echoes.

Fig. 4.—Record at 2100 hr E.A.S.T., May 29, 1960, showing a typical P-FAE$_{1F}$ at 3300 km, at about 200°–230°, behind 1F ground backscatter at 2250 km. 2F backscatter also present.