

A STUDY OF "SPREAD- F " IONOSPHERIC ECHOES AT NIGHT AT BRISBANE

II. INTERPRETATION OF RANGE SPREADING

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Summary

A review is given of various hypotheses which might explain the behaviour of "range multiplets", in which satellite echoes accompany the F_2 echo at frequencies well below the critical penetration frequency. It is shown that these cannot arise from stratification of the layer. Some few may be due to reflection from the F layer of waves previously scattered upwards by an E_s irregularity. The great majority, however, appear to originate in reflections from irregularities in the F layer itself. This is confirmed by the directional observations, multiple-hop echo records, correlations between separated stations, and the usual shape of the range-time curves, as described in Part I.

Evidence is presented indicating irregularities with fronts up to several hundred kilometres long, with curvatures ranging up to 10^{-2} km^{-1} . The irregularities appear to take various forms, of which the simplest are (a) an inverted trough, around 100–200 km wide, (b) a gap, of roughly the same width, with reflecting surfaces which have, at some points, curvatures up to at least 10 km^{-1} , (c) a step, with height and breadth not exceeding some 10–20 km, again with edges which are strongly curved in parts. Each irregularity probably persists for a period of the order of 1–2 hr and is usually propagated through the F region with a nearly uniform velocity of the order of 200 km/hr. The balance of the evidence indicates that this is not related to any general drift of the region.

I. INTRODUCTION

The range multiplets described in the preceding paper (herein referred to as Part I) would appear, *a priori*, to admit of three possible interpretations:

- (1) A real stratification of the F layer leading to reflections at different heights.
- (2) Double reflections, one reflection (or scattering) at a non-horizontal ionization contour of the E_s layer, and one at F .
- (3) Reflections from non-horizontal ionization contours in the F layer, displaced laterally from the zenith point over the station, together with vertical reflection from horizontal contours directly overhead.

In this paper these three hypotheses are examined in the light of the results assembled in Part I and it is shown that, in the great majority of cases, hypothesis (3) appears the most plausible; this is in accord with the conclusions of other

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recent workers. Hypothesis (2) may operate in a very few cases. Using hypothesis (3) certain conclusions can be drawn concerning the horizontal irregularities in the ionization contours.

II. THE STRATIFICATION HYPOTHESIS

On this hypothesis, the satellite echoes are returned from layers above the normal F_2 ; the implication is that they come down vertically, or nearly so. The directional observations, which indicate that, for satellites of large range separation, the signals arrive at a considerable angle to the vertical, thus rule out this hypothesis for these satellites. For satellites close to the main trace the direction cannot be determined, but it seems improbable that the hypothesis is valid under any conditions for the following reason. Irrespective of the separation, the main trace on the swept-frequency ($P'f$) records has the same appearance whether satellites are present or not. This trace suggests a thick layer of nearly uniform consistency (for variations in maximum ion density would lead to spread in critical frequency, which is not characteristic of range multiplets). Hence it is difficult to see how any of the wave can penetrate through the layer. Considerable penetration would be necessary to enable an upper layer to give an echo of comparable intensity, as is observed. Moreover, considerable group retardation, increasing markedly with frequency, would occur in passing through the lower layer; one would thus expect the separation of the traces to increase as the frequency rises; this does not occur. There are thus essential discrepancies.

III. HYPOTHESES INVOLVING SPORADIC E

Eckersley (1937) has suggested that spread- F could be due to scatter from irregularities in the E_s layer, followed by regular (oblique) reflection at the F layer. The type of path postulated is shown in Figure 1 (a). Beckman, Menzel, and Vilbig (1941) have obtained results consistent with this hypothesis; but Dieminger (1951) concludes that it is untenable. On the other hand Meek

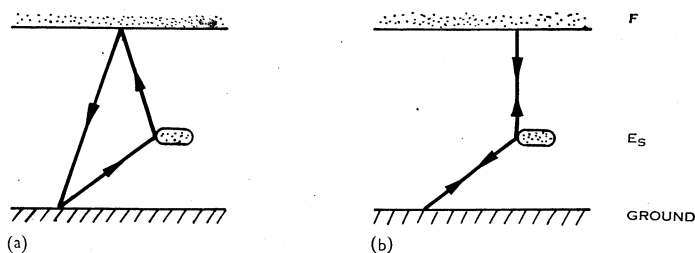


Fig. 1.—Possible F satellite ray paths via E_s clouds.

(1952) has obtained clear evidence of the occurrence of the phenomenon at high latitudes. Several of the general features of range multiplets, as set out in Part I, are hard to reconcile with this hypothesis, namely:

(a) The equality of critical frequencies of satellite and main trace. Since the F reflection in Figure 1 (a) is oblique, the critical frequency should be raised in the ratio $\sec \psi : 1$, where ψ is the angle of incidence on the F layer. From

the heights of E_s and F the dependence of ψ on R' can be found; the increase in critical frequency should be evident as soon as $R' - h'$ exceeds 50 km. There are, in fact, a few cases where the critical frequency of the satellite is markedly higher than for the main trace; these will be dealt with in Section VI.

(b) The almost universal agreement (shown in Table 1 of Part I) between the measured value of downcoming angle θ_M , and its value θ_C calculated from

$$\cos \theta_C = h'/R',$$

where R' is the actual, and h' the minimal range. In Figure 1 (a) the values of θ_1 and θ_2 would be considerably different from θ_C , and, although it is not unexpected that θ_M should be intermediate between θ_1 and θ_2 (since the path shown in Figure 1 (a) could be traversed in either direction), the agreement is too close for this explanation to be plausible. In a very few cases θ_M is in reasonable agreement with θ_1 or θ_2 .

(c) The systematic changes in the value of R' for the main trace near the junction with a satellite (Fig. 9 of Part I). Gipps (1954) suggested that for mixed multiplets these changes could be due to group retardation in E_s . The normality of the shape of the Pf curves, as contrasted to the distortion usually associated with group retardation by a lower layer, makes this explanation improbable and the absence of any pronounced difference between group path and phase path (where recorded) appears to rule it out.

(d) The high intensity frequently encountered in satellites, especially for range separation less than 40 km (cf. Fig. 14 of Part I), at times when the $(F + E_s)$ echo is absent or quite weak. If the satellite, like the $(F + E_s)$ echo, involves one reflection each from F and E_s , it should be roughly comparable in intensity.

(e) The absence of clear correlation between F satellites and the curved E_s traces referred to in Section III (k) of Part I. It is reasonable to suppose that, if there is sufficient forward scatter from E_s irregularities to give an overall reflection coefficient for the F satellite within an order of magnitude of that for the main trace, the back scatter will be not many orders lower.

Since there is some 30–40 dB of sensitivity in hand, a curved E_s trace should be recorded. Although occasionally there is very good correlation between F and curved E_s traces it is normally not much better than would be expected from pure chance. The mechanism for the inverse correlation (cf. Fig. 26 of Part I) between diurnal variation of three-hop E_s and that of occurrence of range multiplets is too obscure for it to provide evidence either way.

(f) The absence of correlation with geomagnetic disturbances. The currents responsible for these disturbances flow close to the E_s layer and might be expected to lead to ionospheric disturbances and hence to scatter clouds.

The hypothesis can only be valid for those cases where the critical frequency of the satellite is appropriately greater than that of the main trace. For short-lived satellites, of small separation, the change in critical frequency may be undetectable; hence such satellites may possibly have such an origin. If so, it would be expected that the diurnal variation of occurrence of short-lived satellites would be less marked than that of long-lived, for there is little consistent

diurnal variation of occurrence of E_s clouds (Thomas, unpublished data). The experimental data are not sufficiently extensive to test this point. Since the E_s scatter clouds may be quite small, this explanation would be consistent with the poorer correlation between short-lived than between long-lived satellites recorded at different stations.

With a few longer-duration satellites, records of the type shown in Plate 2, Figure 3, of Part I, have been obtained. The process shown in Figure 1 (a) should give a definite relationship between critical frequency rise and range. The experimental results are not in very good agreement, in the few cases which have been checked. Further, for oblique incidence, the $P'f$ curve for the satellite should have a characteristic "bent-back" configuration; this is not shown in the case under discussion and is rarely shown in other similar cases. Since the third hypothesis (F irregularity) can readily explain the critical-frequency differences, these discrepancies are serious.

Angle-of-arrival measurements and the shape of the traces also suggest that E_s scatter gives a few F satellites each year at Brisbane. The total evidence is, however, far from conclusive, and the main bulk of satellites are certainly not due to this process.

A variation of the hypothesis is indicated in Figure 1 (b). It would appear to be less probable than the first and no definite evidence has been established of its occurrence at Brisbane. In this case the critical frequency should be normal, but the zenith angle should be larger than $\sec^{-1}(R'/h')$ and a curved E_s trace should exactly parallel the F satellite.

IV. THE F -IRREGULARITY HYPOTHESIS

Gipps, Gipps, and Venton (1948) from the earlier observations at Brisbane concluded that the satellites arise from reflections from portion of the ionosphere at which the gradient of ionization is appreciably inclined to the vertical; these regions are displaced horizontally to an appropriate extent from the zenith but are at the normal height. Later work, in particular that of Bramley and Ross (1953), Bibl, Harnischmacher, and Rawer (1955), and Ratcliffe (1955), has shown that such non-vertical gradients are of common occurrence. This hypothesis is clearly consistent with the broad general conclusions of Part I, in particular:

(a) The general relation between the downcoming angle, θ , and R' , namely,

$$R' = h' \sec \theta.$$

This follows by simple geometry from the hypothesis.

(b) The quantity x defined by

$$x = \sqrt{(R'^2 - h'^2)},$$

varies roughly uniformly with time. This follows if one assumes, as seems reasonable, that the irregularity moves horizontally with a sensibly constant velocity.

(c) The existence of the common tangent in the plot using observations at three stations and the parallel motion of the tangent. If one extends the present hypothesis, by assuming that the irregularity is a ripple or front having considerable extent and constant configuration perpendicular to the direction

of motion, then the common tangent locates this front and the experimental behaviour follows automatically.

(d) The agreement between the measured azimuth and that deduced from the position of the common tangent. This also follows by simple geometry from the extended hypothesis.

(e) The appearance of double-hop satellites, the similarity of separation of the double-hop and single-hop traces, and the occasional appearance of a second satellite. This is readily understood from Figures 2 (a) and 2 (b) which show how the two satellites can be formed.

(f) The appearance of three-hop and higher-multiple hop satellites and their separations. The scheme for three-hop reflections is indicated in Figures 2 (c) and 2 (d); higher multiples follow corresponding patterns. The separations (in the few records measured) are fully consistent with this scheme.

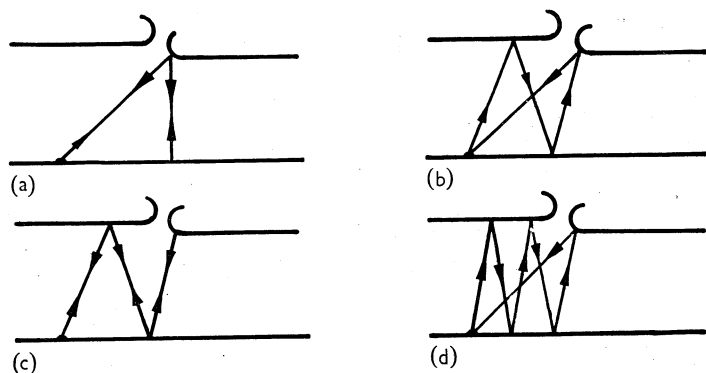


Fig. 2.—Possible paths for two-hop and three-hop *F* region satellites.

V. DETAILED CONFIGURATION OF THE IRREGULARITY

If the suggested hypothesis is the correct one, it should be possible, without passing the bounds of plausibility, not only to account for the idealized behaviour summarized in Part I, but also to explain departures from this behaviour. To do this, it is clearly necessary to make specific assumptions concerning the ionization contours.

(a) *Inverted Trough*

In his explanation of day-time *F* satellites, Munro (1953) postulated an inverted trough configuration. Following this idea, let us consider an ionospheric irregularity defined by

$$z = a + b(1 + \cos 2\pi x/\lambda), \text{ when } -\frac{1}{2}\lambda < x < +\frac{1}{2}\lambda,$$

$$z = a \text{ otherwise.}$$

Here z represents the height of a particular ionization density;

x represents horizontal distance along the direction of movement (i.e. perpendicular to the "front"), measured from the (moving) centre of the irregularity;

a , b , λ are arbitrary constants, a only being dependent upon the particular value of ionization density assumed. (In this respect the picture is simpler than that used by Munro.)

It is assumed also that z is independent of the third coordinate y (perpendicular to x , z). This is also implicit in the hypothesis of Toman (1955).

It is reasonable, on this assumption, to treat the problem by geometrical optics, regarding the particular ionization contour appropriate to the frequency in use, as a simple reflecting surface. On this basis and taking $a=230$ km, $b=20$ km, $\lambda=100$ km, and the speed as 450 km/hr, an $R't$ pattern of the form shown in Figure 3 is to be expected. By comparing it with Figure 8 of Part I, there is seen to be a considerable measure of agreement.

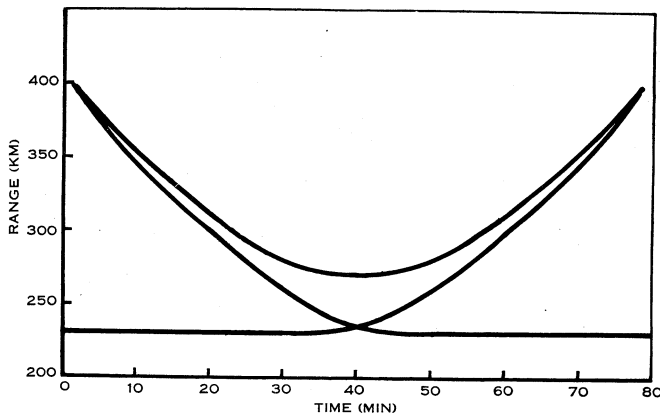


Fig. 3.—Expected $R't$ pattern for “inverted trough” disturbance travelling horizontally in F region.

The chief discrepancies are: (i) the rise of the lowest trace, to the point of intersection is larger experimentally than Figure 3 predicts; (ii) the pattern is unsymmetrical, the height being lower at the end than at the beginning; (iii) the upper member of the pattern is absent for much of the period. The first of these discrepancies can be adjusted by assuming a more abrupt rounding-off at the edges of the trough than has been specified. The second can similarly be adjusted by assuming an asymmetrical, instead of symmetrical, relationship between z and x , while the third is discussed in the next section.

(b) The Gap

The absence of the upper member of the pattern leads to the conclusion that part of the upper section of the trough is non-reflecting, possibly due to strong absorption immediately below the reflection level. Other records of mixed doublets exhibit this discrepancy even more markedly. (Figure 8 of Part I is a rare case, selected as showing the upper member clearly.) It is therefore appropriate to conceive the geometrical reflector as having a gap, in some cases with a few “islands” within the gap. The rounded-off edges of the gap supply the principal intersecting traces, and the islands supply the

vestiges of the top member, and perhaps the (poorly correlated) subsidiary satellites which frequently appear in a mixed multiplet. Figure 4 illustrates the pattern of satellites expected when there is a single island, at normal height, in a gap 200 km wide. (This is the order of magnitude found experimentally.)

Complex patterns bearing a resemblance to this are often observed. In such cases, the resolution is usually insufficient for the direction-of-arrival equipment to function.

It may be pointed out that the linear relationship between x and t suggests that the edges of the gap have a large curvature. The experimental points do not, however, fit such a relationship sufficiently closely to justify any firm conclusion. This matter is taken up again in Section VII.

In the production of a second satellite to the two-hop F trace by the mechanism pictured in Figure 2 (*b*), reflection from the (level) layer to one side of the irregularity is required. No reflection is possible from within the "gap"

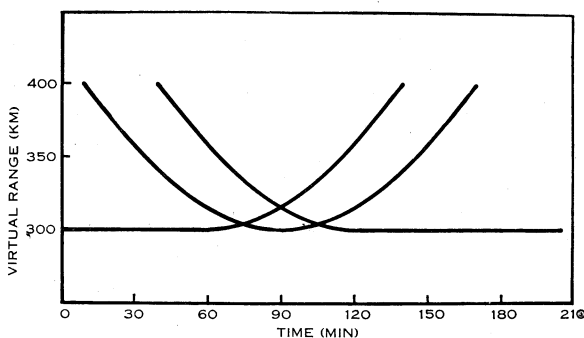


Fig. 4.—Expected $R't$ pattern for disturbance consisting of gap 200 km wide with central cylindrical cloud, travelling horizontally in F region.

postulated for a mixed multiplet and this satellite should therefore be absent for some time before and after the intersection of the two principal traces. In the one case suitable for detailed examination the satellite appeared first some time after intersection.

The geometrical picture can obviously only serve as a general guide. With curved ionization contours, some group-retardation effects are probable; these are presumably responsible for the discrepancies between phase- and group-path changes found to occur when there is rapid change.

(c) *The Step*

As with the inverted trough, it is reasonable to suppose that sometimes the relevant ionization contour is at different heights on the two sides of the gap, as suggested in Figure 5. In fact, if the gap arises from some sort of cellular wave (Martyn 1950) there would be a tendency to upward drift on one side and downward on the other. Under the conditions pictured in Figure 5, where the height difference is comparable with the gap width, the range doublet would clearly be markedly asymmetrical. The region immediately below the reflecting

contour is highly absorbing and would tend to prevent the appearance of the satellite even to the right of the point X . In many mixed doublets, the satellite on one side of the junction is, in fact, very short.

The existence of pure convergent and divergent multiplets can be fairly satisfactorily accounted for by postulating either such a narrow gap, or a "step"

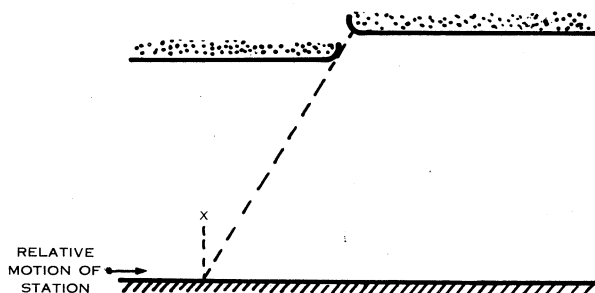


Fig. 5.—Narrow gap in F region—heights on two sides of gap unequal. No satellite visible if recording station is to left of X .

in the reflecting surface, as indicated in Figure 6 (a). This may be regarded as the limiting case of gap, when the width becomes negligibly small. Figure 6 (b) indicates the anticipated $R't$ record when the step is moving in the direction indicated with a speed of 200 km/hr; reversal of velocity changes the convergent into a divergent satellite. The theoretical curve indicates a short trace (shown

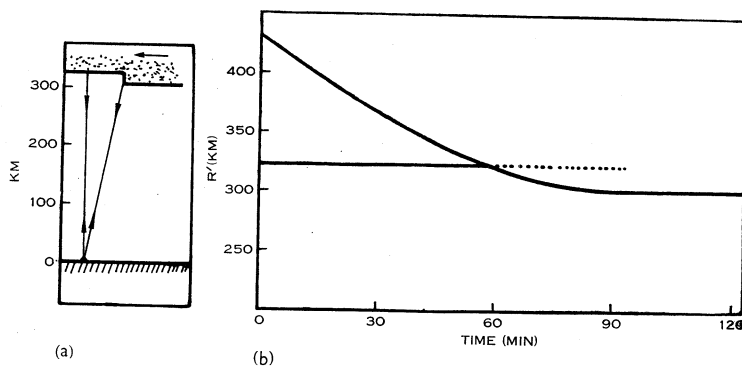


Fig. 6 (a).—Step F region disturbance.

Fig. 6 (b).—Expected $R't$ pattern for a disturbance in the form of a step 20 km high with speed 200 km/hr.

dotted) on the far side of the intersection. This is absent in the actual records; this could be due to confusion with the relatively broad lower trace, or to refraction associated with the strongly curved ionization contours below the reflection surface. It will be seen from the diagram that this picture also accounts for the records, noted in Part I, in which the single trace on one side of the junction is continuous with the satellite trace rather than the main trace

on the other side. It also explains the tendency for the "main" trace to rise at the junction with a divergent, and fall at the junction with a convergent satellite (Fig. 10 of Part I).

The satellites that appear at lenticels can probably be fitted into a scheme of this sort. Detailed checking is difficult because it is clear from the splitting of o - and x -rays and the wide discrepancy between group-path and phase-path changes that, in this case, successive ionization contours are by no means parallel or similar and that the simple geometrical picture is not valid.

(d) *Horizontal Extent and Horizontal Curvature of the Edges*

A rough estimate of the length of the gap or step can be formed from the falling-off of individual satellite correlation as between Brisbane-Toowoomba (95 km with 80–95 per cent. correlation) and Brisbane-Goondiwindi (300 km with 20–30 per cent. correlation). The orientation of the edge, in some of the cases giving correlation between Brisbane and Goondiwindi, was roughly along the line joining these stations; some steps, at least, must therefore have been more than 300 km long. Where the orientation was more nearly at right angles to this line, the correlation is more a measure of the permanence of the irregularity; this aspect will be discussed later. As it has not been possible to determine orientations in those cases where correlation was absent, the information is inconclusive, but it suggests that the average length of the edge is comparable with 300 km.

If the edges of the gap, or the step, as the case may be, are straight along their whole length, it is clear that, provided they move with uniform speed perpendicular to their length,

(i) the plot of x versus t will give a straight line; and

(ii) the slope of this line will be the same for all the observing stations.

Although certain satellites satisfy these requirements fairly closely, some (cf. Fig. 17 of Part I) show quite systematic departures. Such departures can be simply accounted for by postulating that the edge is curved (in a horizontal plane). If the edge retains its shape as it moves, this implies that any particular part of the edge will not, in general, move along its normal (cf. Fig. 7). Since the speed v' measured by dx/dt is the normal component of velocity, it follows that

$$v' = v \cos \alpha,$$

where v is the true velocity and α the angle it makes with the normal. As a curved edge moves, the reflecting point, for a particular station, will move along the edge and the value of α will change. Moreover, α will have different values for different stations.

Under these conditions the normals at two or more points on the edge may pass through a given station, so that one edge could provide several satellites, with different values of v' . It is, however, more likely that, when several satellites with different slopes coexist, they arise from a pattern of steps or gaps with different orientations and different (normal) velocities.

With these supplementary postulates, allowing steps, gaps, with and without intermediate clouds, and permitting the edges of steps, gaps, and clouds to be curved horizontally, sufficient arbitrary features are available to explain the tracks in all multiplets which have been recorded.

(e) *Implications of the Intensity Measurements*

Although, as discussed in Part I, the changes of intensity during the course of a satellite follow no regular pattern, the average behaviour is moderately well represented by a decrease at the rate of 0.4 dB/km, as indicated by the line marked *E* in Figure 8.

This is difficult to reconcile with the simple geometrical model, for the intensity of reflection from a cylindrical (convex) mirror of radius between 1 and 20 km, calculated on a geometrical basis, should decrease with increasing

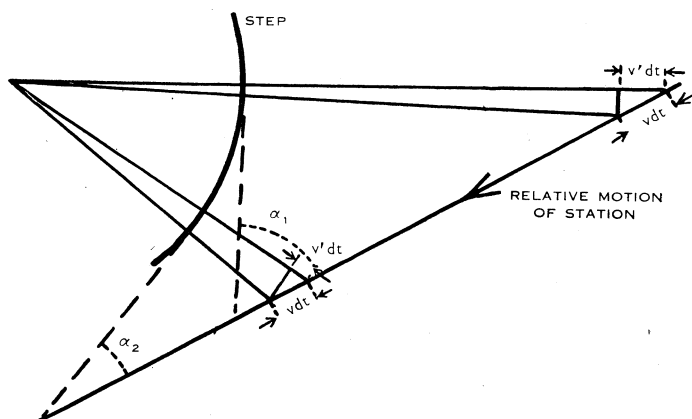


Fig. 7.—Dependence of dx/dt on orientation of tangent for step curved in horizontal plane.

distance roughly as shown in curve *A*. (In computing this curve it was assumed that the "aperture" of the mirror is small compared with the distances of source and image.) The experimental points shown in Figure 14 of Part I nearly all fall well below this curve.

In seeking an explanation of the discrepancy, calculations were made assuming the radius of curvature of the edge to be small compared with the wavelength (132 m). Diffraction theory is then necessary and as a first approximation Fresnel's theory for diffraction at the edge of an obstacle is applicable (regarding the ionosphere on one side of the edge as a semi-infinite reflector). Curve *B* was obtained thus; it gives a little better fit but falls too rapidly initially and too slowly later.

Since the ionosphere is known, from fading studies etc. to be far from smooth (cf. Briggs and Phillips 1950), it seems more reasonable to calculate intensities upon the same basis as is used by Briggs and Phillips in their analysis: the power scattered back from the portion of the ionosphere subtending a small solid angle $d\Omega$ at the source, at an angle θ with the vertical is assumed given by

$$dW \propto \cos^n \theta d\Omega,$$

and the contributions of the various elements are assumed additive arithmetically. For the ionosphere on one side only of the edge (assumed to have a radius of curvature small compared with the wavelength) the intensity variation has been calculated on this basis, taking $n=200$, which is typical for the F region. The result is indicated in curve C , of Figure 8.

The experimental points of Figure 14 of Part I nearly all fall between curves A and C , filling this area nearly uniformly. A plausible explanation of this result is that the curvature of the edge is not uniform, but changes considerably within one section, and from one section to another, along the length, so that there occur radii of curvature both large and small compared

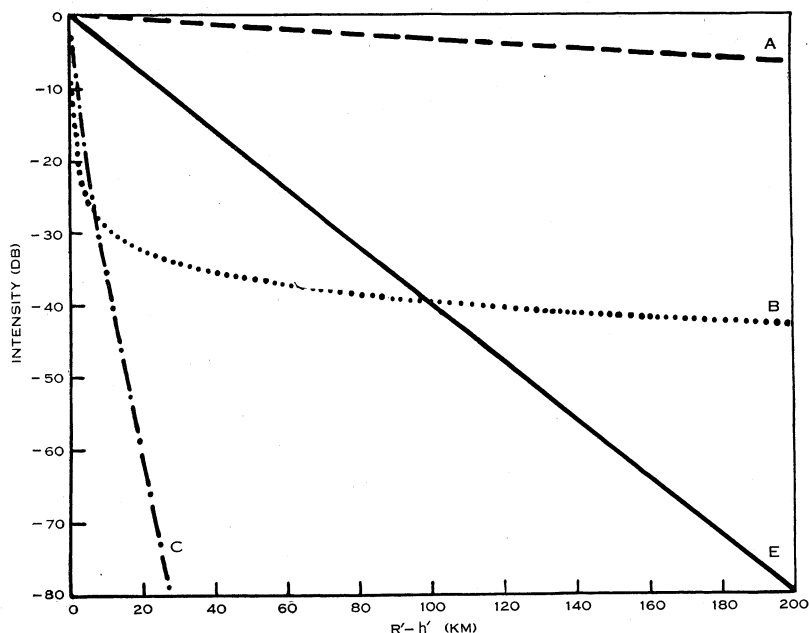


Fig. 8.—Intensity *v.* range-increment curves: E , empirical (from Fig. 14 of Part I); A , geometrical theory, cylinder of radius 20 km; B , Fresnel theory, sharp edge and optically flat surface; C , scattering theory, sharp edge, but rough surface.

with the wavelength. This is reasonable for an ionosphere possessing the amount of roughness indicated by typical fading records. The maxima and minima, shown in Figure 13 of Part I, could be due to movement of the reflecting point along the edge, between regions of different curvature; it could also possibly arise from interference of reflections at two or more points along the edge.

Another factor influencing the intensity is absorption in the deviative region below reflection level. This increases with increasing obliquity. However, the absence of appreciable group retardation and the relatively small absorption usually observed for vertical propagation make it unlikely that this phenomenon plays a major role in the intensity fall-off.

If the rate of decline of intensity with increasing range were 0.4 dB/km , then, since, on the average, an echo of intensity more than 50 dB below its maximum level would fail to record, the extreme range separation observed should be 125 km , corresponding to a horizontal separation of about 300 km . For a speed of 200 km/hr this would make the satellite last 90 min . Although, in view of the large spread of values of decline rate and speed, no firm conclusions can be drawn, the fact that 125 km range separation and 90 min duration are both rather larger than the experimental averages suggests that another factor may be operating, to limit the durations of the satellites. This could be the limited lifetime of the irregularity itself.

The rapid decline towards the end of certain divergent satellites (cf. Curve A in Fig. 13 of Part I) and the decline, instead of growth, of the intensity of certain convergent satellites as they approach the main trace, could also be explained in terms of degeneration of the irregularity.

Some further light on this question is thrown by a comparison of the times of commencement of convergent, and termination of divergent, satellites at different stations. If genesis and degeneration, respectively, of the irregularity determine these times, they should be the same at both stations, while if they are determined by the distance of the irregularity from the station, these times would correspond rather to equal range separations and hence would only be equal when the irregularity is parallel to the line of the stations. The experimental data quoted in Section III (g) of Part I are not wholly conclusive, but the many cases of simultaneity, or near-simultaneity, support the idea of a limited irregularity life. Other cases show equal range separations, with non-simultaneity, and others again correspond in neither respect. This last is not inconsistent with the operation of the two effects postulated, for it is likely that genesis and degeneration will often occur at different times along the length of the irregularity.

From the experimental distribution of satellite durations, in conjunction with the above considerations, it seems likely that the average lifetime of the irregularities is a little greater than the average satellite duration and thus lies between 1 and 2 hr .

VI. CRITICAL FREQUENCY DIFFERENCES

A small proportion of satellites are found to have critical frequencies different from those of the accompanying main trace. Higher and lower values have been observed about equally frequently. This is simply explained if we assume, as seems not unreasonable, that the ionosphere has a different maximum electron density on the two sides of the gap or step; or as between an intermediate cloud and the edges of the gap. While one would expect that the critical frequencies for a particular satellite would tend to remain constant, and are found in most cases to do so, a gradual change could readily be explained by movement of the reflection point along a curved edge or cloud.

VII. SIGNIFICANCE OF THE VELOCITY DETERMINATIONS

There is *a priori* no clue as to whether the phenomenon is due to a general drift of an ionosphere upon which "fixed" irregularities are engraved, or some

sort of wave motion, which may be quite independent of ionospheric movement. In favour of the former view, it may be pointed out that the strong tendency for disturbances to move westwards (rather than east) is consistent with the conclusion of Briggs and Spencer (1955) from results of other methods at night time, and the order of magnitude is similar. Martyn (1955) has pointed out that such a drift is well accounted for by the S field of daily magnetic variations.

If this view is adopted, the measured speed, in any particular case, may not represent the drift velocity, for the gap or step need not lie normal to the direction of drift. Where simultaneous satellites indicate different velocities, the gap must certainly be non-perpendicular to the drift; in fact, if the directions of movement for the two satellites are known, the drift velocity can be determined.

An endeavour has been made, adopting this hypothesis, to determine the distribution of drift speeds. (Insufficient data are available on directions to permit statistical analysis.) Assuming that the histogram of Figure 4 of Part I, after smoothing, represents the distribution $N'(v')$ of "apparent" speeds, and assuming that all inclinations between the edge and the direction of drift are equally probable, it can be shown that the distribution of true drift speeds $N(v)$ is given by

$$N'(v') = \int \frac{N(v) dv}{(v^2 - v'^2)^{\frac{1}{2}}}.$$

This equation is not in general capable of explicit solution but it happens that the histogram fits fairly well an expression of the form

$$N'(v') = A \exp(-v'^2/\sigma_1^2) - B \exp(-v'^2/\sigma_2^2),$$

and that in this case an explicit solution is possible. This, however, leads for small values of v to negative values of $N(v)$. Attempts to find a plausible curve of $N(v)$ which gave $N'(v')$ fitting reasonably closely to the histogram proved unsuccessful.

An explanation roughly fitting all the facts would be that the phenomenon arises from a wave motion, propagated with a velocity of the order of 200 km/hr. through a layer which may itself be drifting westwards at a comparable rate. The waves may be of the nature discussed by Martyn (1950). A satisfactory theory of the phenomenon must provide an explanation not only of the velocities but also of the diurnal variation of occurrence of doublets and its correlation with the rise and fall of equivalent height of the F_2 layer discussed in Part I.

VIII. CONCLUSIONS

The main conclusions from the above discussions are:

- (1) Most range multiplets at Brisbane are due to reflection at the rounded-off edges of gaps and steps in the contours at an approximately constant reflection level in the F_2 layer.
- (2) A few multiplets may be due to E_s scatter with return path via F_2 .
- (3) The F_2 irregularities responsible for multiplets move horizontally with fairly uniform velocity.

- (4) The motion thus determined is a wave motion rather than merely a general drift of the ionosphere.
- (5) The duration of an irregularity is of the order of 1-2 hr.

IX. ACKNOWLEDGMENTS

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