THE EFFECT OF SUDDEN IONOSPHERIC DISTURBANCES (S.I.D.'S) ON 2·28 Mc/s PULSE REFLECTIONS FROM THE LOWER IONOSPHERE

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Summary

The effects of sudden ionospheric disturbances (S.I.D.'s) on the complicated structure of ionospheric echoes obtained with moderately high sensitivity at 2·28 Mc/s are described. The observations indicate that flares of classes 2 and 3 can produce high values of electron density near the base of the ionosphere. Mean electron density can exceed 1000/cm^3 over the height range 60–75 km, where the greatest relative increase in ionization occurs. Nevertheless, the greater part of the S.I.D. absorption of waves reflected from the E region or above still occurs above 85 km.

The times of maximum disturbance at the different ionospheric levels agree within the experimental limit of about 1 min. The times of subsequent recovery at levels up to 85 km also seem to be simultaneous. However, the recovery of the E echo lags behind that of the 85–90 km echo group, by about 4 min on the average for large S.I.D.'s. It is quite likely that the delay is not wholly due to different recombination rates at different ionospheric levels, but is partly caused by a change in the quality of the incoming solar radiation during the life of the flare.

I. INTRODUCTION

The characteristic anomalies in the lower ionosphere associated with solar flares, known as sudden ionospheric disturbances (S.I.D.'s), have been studied in a number of ways (see review of the different effects by Ellison 1950). These include the absorption of short and medium radio waves, the change in the reflection characteristics of long radio waves, and geomagnetic " crochets ". While it is accepted that all three are manifestations of some change in the ionosphere below the E-layer maximum, which is little affected itself, it is still far from clear just what the change is. A few years back a preliminary investigation of the D region using the weak scattered reflections from irregularities below the main level of reflection for 2 Mc/s pulses was made (Gardner and Pawsey 1953), but during the periods of observation no S.I.D.'s occurred. However, a more extensive series of observations of vertical-incidence pulse reflections at 2·28 Mc/s has been made during which time some 70 S.I.D.'s were noted. The results, described in this paper, provide some definite information on the heights and magnitude of S.I.D. effects in the lower ionosphere.

II. OBSERVATION PROCEDURE

The observations were made at the C.S.I.R.O. Radio Research Laboratory site at Camden.† Horizontal half-wave dipoles 60–70 ft above ground and about 400 ft apart were used for transmission and reception. The 2·28 Mc/s transmitter

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pulse length was ordinarily in the 30–40 μsec range. The power was about 10 kW, ten times higher than that used in the 1951–1952 observations, but the background noise, largely man-made, with an intensity approaching 10^6 °K equivalent temperature was more than 100 times the previous day-time noise level. The receiving bandwidth was around 50 kc/s. The receiver gain was switched cyclically to three positions with voltage gain ratios 1, 10, and 100 every 2 sec. When the intensity-modulated display was photographed on a slowly moving film the scans at the three gain settings merged and an approximately logarithmic intensity record was obtained. This record was supplemented by photographs of the class A display taken at 1-min intervals, each exposure lasting long enough to show a scan at each gain setting. Plate 1, Figures (*a*) and (*b*), shows the two records for a short S.I.D. on May 18, 1956. The 7·5 and 75 km range markers are provided by 50 and 500 μsec pips from a 100 kc/s crystal oscillator. In the amplitude photograph at 1129 the scan at low gain shows the *E* echo at 107 km just saturating, while echoes at shorter ranges 85 km and 95 km are small. At medium gain the three echoes saturate and at high gain saturating echoes fill the complete range interval from 85 to 130 km.

III. Observations

The observations were practically continuous (useful records for about three-quarters of the time) from February to December 1956. During this time 66 S.I.D.'s producing more than about 10 dB attenuation of the 1*E* echo were observed. This was a size that could be recognized easily and not confused with other absorption changes.

(*a*) *Association with Other S.I.D. Effects*

The radio records were compared with solar flare and S.I.D. data available from CRPL-F Part B publications, Kiepenheuer's daily maps of the Sun, and Ionospheric Prediction Service Series D publications, supplemented by local data. Of the 66 anomalies noted on the radio records :

49 were accompanied by short-wave fade-outs (S.W.F.'s) : of these 28 were " sudden start ", 3 " gradual ", and 18 " slow start " ;

22 were accompanied by sudden cosmic noise anomalies (S.C.N.A.'s) ;

20 were accompanied by effects on ionospheric *P′-f* records ;

4 were accompanied by sudden enhancements of atmospherics (S.E.A.'s) ;

31 were accompanied by flares of class 1 or above, of which 18 were class 1, 10 were class 2, and 3 were class 3.

The short-wave fade-outs (S.W.F.'s) are given both a widespread index ranging from 1 to 5, and an importance 1, 2, and 3 in CRPL-F. The median values of the indices for the 49 coincidences were 3 and 2 respectively. The corresponding flare size for the 31 coincidences was in the 1–2 range.

(*b*) *Effect of S.I.D.'s on the General Echo Pattern at 2·28 Mc/s*

The general pattern of the day-time echoes was similar to that shown in the previous paper and reproduced here as Figure 1. The echoes were in three main groups previously called the " 70 km ", " 90 km ", and *E*, and this grouping was found to be retained during S.I.D.'s. However, the " 70 km " echoes were often absent, and this can be accounted for by the noise background being higher than in the previous series. Figure 2 shows diagrammatically the variation in intensity of echoes at different heights during a moderately large S.I.D., associated with a class 2 flare. The E-echo amplitude drops by a factor of more than 10^3, to below the background noise. The echo reappears later as the ionosphere

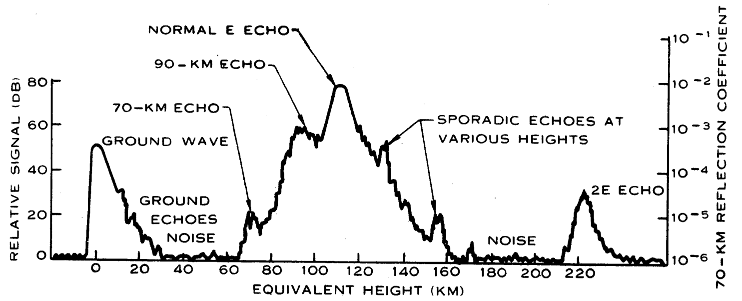


Fig. 1.—Sketch of typical midday echo pattern, reproduced from *J. Atmos. Terr. Phys.* **3**: 325 (1953).

returns to normal. The 85 km echo fades out and recovers in a similar way, although the recovery is a few minutes in advance of the E. The echo at 70–75 km behaves differently. Following an initial enhancement its amplitude is reduced to below noise, while the reverse occurs during the subsequent recovery. The lowest echoes around 65 km are enhanced with a maximum enhancement near the time of S.I.D. maximum.

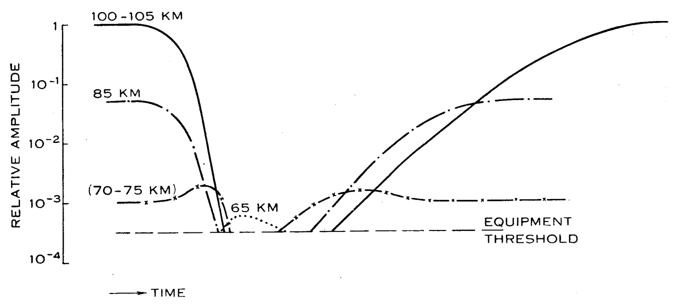
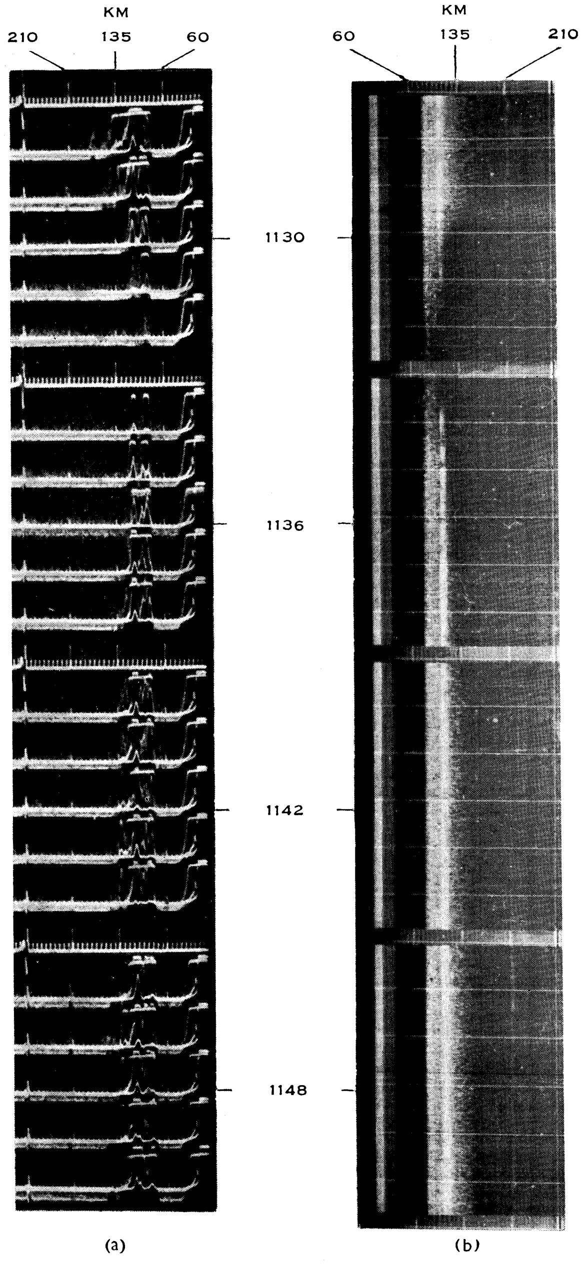


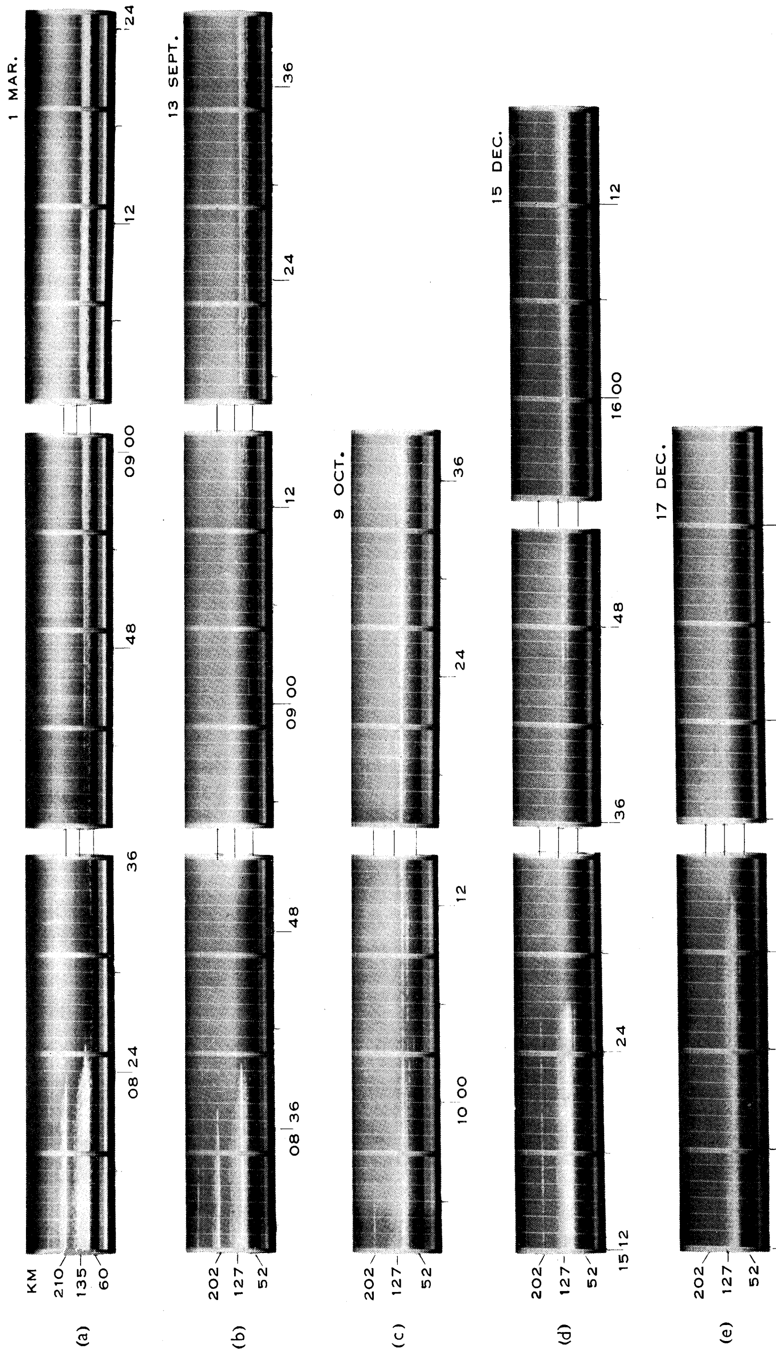
Fig. 2.—Diagram illustrating the variation in amplitude of echoes at different heights during a moderately large S.I.D.

Following the E echo in Figure 1 sporadic echoes are shown whose average intensity falls off rapidly with increasing range. These are thought to result from sideways scattering by irregularities below the E-region vertical-incidence reflection level. During an S.I.D. the intensity of these echoes decreases markedly, and variation in their maximum extent in range on the record provides a sensitive indication of the start and finish of the S.I.D. The variation in intensity of multiple E reflections is similar to, although greater than, that of the $1E$, as would be expected. Echoes between about 90 km and the E tended to disappear even in small S.I.D.'s.

SUDDEN IONOSPHERIC DISTURBANCES



Records for May 18, 1956 showing a short-lived S.I.D. (*a*) Amplitude record—A-scan photographs, with three different gains differing by ratios 1 : 10 : 100, taken at 1-min intervals. (*b*) Intensity record—scale is roughly logarithmic.



Intensity records for some typical S.I.D.'s during 1956. (*a*) March 1, (*b*) September 13, (*c*) October 9, (*d*) December 15, (*e*) December 17.

In about 10 per cent. of S.I.D.'s the normal E echo became spread, quite likely as the result of an increase in scattering by the " 90 km " region rather than an E-region change. In about the same percentage of cases the intensity of echoes in the 70–75 km range commenced some 2–5 min ahead of the first change in intensity of echoes from greater heights, as indicated by changes in the strength of $2E$ echoes or of echoes at the tail of the $1E$.

With S.I.D.'s smaller than the one illustrated in Figure 2 there is less progressive change in the strength of the different echoes before the S.I.D. starts to recover. Thus the dip in the intensity of the " 70 km " echo near S.I.D. maximum in Figure 2 may be absent. In addition, the features of individual S.I.D.'s differ in other respects, some of which are not due to changes of the incoming ionizing radiation. One difference is the result of the deep, irregular fading of the low-height echoes which tends to obscure changes in mean amplitude; another is the result of changes in the signal-to-noise ratio.

S.I.D.'s possessing some of the features discussed are shown in the intensity records of Plate 2. In (*a*) an echo at 67 km appears near the S.I.D. maximum, while the higher echo at 75 km varies in accordance with Figure 2; the echo at 90 km disappears and subsequently reappears ahead of the E. In (*b*) an echo at 68 km appears briefly during the S.I.D. (no echo at such a low height was received at any other time on the morning concerned); higher echoes disappear nearly simultaneously, but the 75 and 85 km ones reappear together ahead of the E. In (*a*) and (*b*) the S.I.D. absorption change is superimposed on the smooth diurnal increase in absorption which is quite rapid around 0900 hr; it is the latter change which is mainly responsible for the change in strength of the multiple reflections and also of the echoes at the tail of the $1E$ between the beginning and end of the records shown. In the small S.I.D. (Plate 2 (*c*)) the echo at 79 km shows the typical behaviour of the " 75 km " echo in Figure 2. In Plate 2 (*d*) there is an initial intensification of an echo at 76 km at least 2 min ahead of the S.I.D. absorption increase of the E echo. The recovery is unusual in that the E reappears ahead of the 90 km echo. In Plate 2 (*e*) there is again an initial intensification of an echo at 73 km, at least 4 min earlier than the S.I.D. absorption commencement; the 87 km echo reappears slightly ahead of the E.

The amplitude changes during a small S.I.D. can be seen in Plate 1 (*a*). At 1129, before the S.I.D. start, echoes are present to a little below 85 km. The E echo is large, with a mean amplitude of about 0·7 of saturation on the low gain, and between five and ten times the amplitude of the echo at 85 km. By 1130, however, the two echoes are practically equal, although both have been reduced. The E echo then disappears completely, implying a reduction approaching 1000/1, while the corresponding reduction for the 85 km echo which remains visible is about 30/1. The duration of this particular S.I.D. was very short, below a third of the average for its size.

(*c*) *Particular S.I.D. Effects*

(i) *Echo Heights during S.I.D.'s.*—In Figure 3 the distribution of heights of echoes up to 95 km, (*a*) whose intensities were increased during S.I.D.'s and (*b*) which were not, are compared. For echoes below 90 km, heights (*b*) were practically the same as those immediately before the S.I.D. The first thing to note in Figure 3 is that only the " 70 km " echoes are intensified. These are in two groups centred near 66–67 km and 73–74 km. This is the same grouping as ordinarily observed with a higher sensitivity equipment (see Fig. 7 (*d*) of

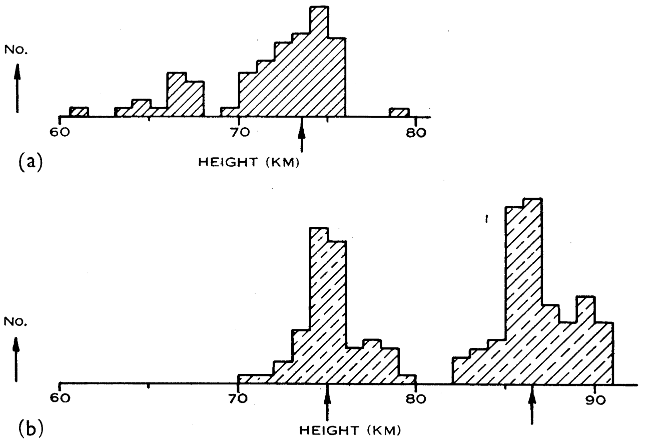


Fig. 3.—Histograms showing heights of echoes (*a*) whose intensity was increased during S.I.D.'s, (*b*) whose intensity was not increased—practically the same histogram as that of echoes immediately prior to the S.I.D. commencement.

Gardner and Pawsey (1953)). In Figure 3 there is a small difference of 1·5 km between the mean heights of the 70–75 km group of intensified and non-intensified echoes (the medians are 73·5 and 75 km respectively), although the most frequently occurring height, 75 km, is the same for both.

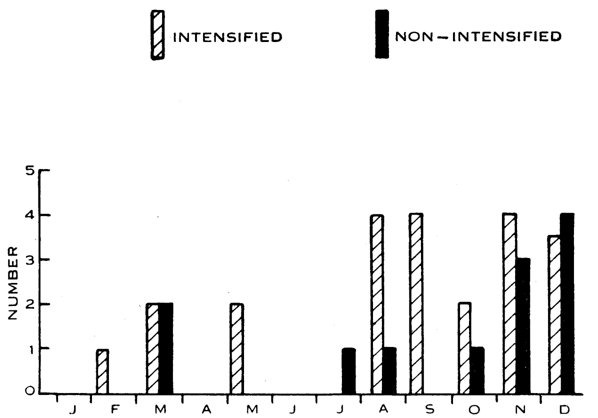


Fig. 4.—The frequency of occurrence of intensification and non-intensification of 70–75 km echoes during 1956.

Figure 3 shows a median height of 86·5 km for the " 90 km " echoes during S.I.D.'s, approximately the height of the lowest layer of the " 90 km " region under normal conditions.

(ii) *Changes in Echo Intensities during S.I.D.'s.*—It was found that the lowest group of echoes, those below 70 km, were intensified in seven cases. These echoes normally were not detectable, but in all cases when they were observable their intensity increased during an S.I.D. From our previous experience it is estimated that an increase in amplitude of at least 10/1 would normally be required for them to appear.

The 70–75 km echoes were intensified in 26 cases ; in 16 cases there was no change ; in the remaining 24 cases these echoes were below the sensitivity limit. The mean increase in amplitude was about 2/1. The subsequent reduction in

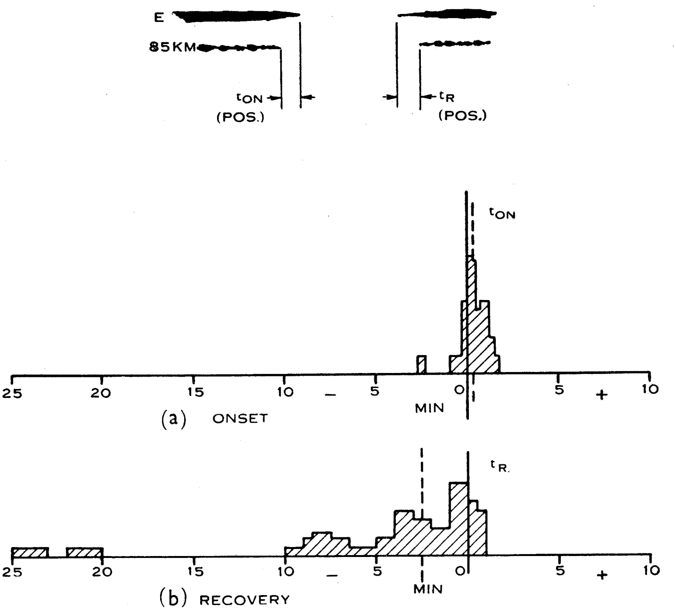


Fig. 5.—Distributions of the difference (*a*) of onset times t_{ON} and (*b*) of recovery times t_R of the " 90 km " and *E* echoes measured in accordance with the diagram at the top of the figure. The medians of the two histograms are shown by dashed lines.

amplitude at the S.I.D. maximum was as much as 8/1 below the pre-S.I.D. value. The relative frequency of occurrence of intensification and non-intensification appears to have a seasonal dependence as shown in Figure 4. It is more likely for the echo intensity to increase in winter than in summer.

Echoes above 80 km decreased in intensity during S.I.D.'s. In rare cases there might be a short-lived increase in the strength of an echo in this range. For the smaller S.I.D.'s where the 85–88 km and *E* echoes did not disappear it was observed that the proportional reduction of the *E* echo was considerably greater than that of the 85–88 km echo. In fact, when amplitude changes are expressed logarithmically, in nepers for example, the *E*-echo reductions were at least three times greater than those of the 85–88 km. With larger S.I.D.'s this was still the case during the portion of the S.I.D. when both echoes could be observed.

(iii) *Timing of Ionospheric Changes during S.I.D.'s*.—To the accuracy that variations in strength of fluctuating echoes could be timed, changes at different ionospheric heights were simultaneous in regard to times of start, maximum, and finish, apart from the recovery lag of the E echo behind the " 90 " of about 4 min and the intensification in some 10 per cent. of S.I.D.'s of the " 70 km " echo prior to the fade-out commencement.

The E-echo time lag can be demonstrated by noting time differences between corresponding points for the two echoes at the onset and at the recovery of the S.I.D. The most convenient are the times of disappearance and reappearance of the two echoes. This of course restricts attention to the larger S.I.D.'s, generally also those of longest duration. At the top of Figure 5 the two time differences measured are shown. The onset time t_{ON} is the time elapsing from the disappearance of the " 90 km " to the disappearance of the E ; t_R, the recovery time, is the time from the reappearance of the E to the reappearance of the " 90 km ". For a symmetrical disturbance and no real time lag t_{ON} and t_R should have the same sign and be equal. For a disturbance which decays, say, four times more slowly than it builds up, as does a typical S.I.D., t_R should equal $4t_{ON}$. Actually, Figure 5, which gives the distributions of t_{ON} and t_R, shows that the two times have different signs. t_{ON} is positive but t_R is negative (the " 90 km " both disappears and reappears ahead of the E). The median value of t_{ON} is $+0 \cdot 35$ min and that of t_R $-2 \cdot 5$ min. For a typical disturbance with a 1 : 4 onset : recovery ratio, the expected value of t_R for no lag is $4 \times 0 \cdot 35 = 1 \cdot 4$ min. The effective lag between the " 90 " and E echoes is therefore $1 \cdot 4 + 2 \cdot 5 \approx 4$ min.

IV. Discussion

(*a*) *Electron Density Changes*

It is obvious that changes in the pattern of ionospheric echoes during S.I.D.'s correspond to changes in the electron density-height distribution. There is, however, no direct method for deriving electron densities from echo intensities, and all that can be done is to see to what extent the observations fit the behaviour of simple models. The simplest explanation is to assume that changes in intensity are due solely to increases in absorption below the reflection levels, the correct explanation of the behaviour of echoes from above the region affected by the S.I.D., and therefore a good approximation for the E echo. Applied to the other echoes it gives a lower limit to the S.I.D. absorption increases. For the " 90 km " and E echoes the absorption values apply to the ordinary component alone, but with the " 70 km " echoes both components are involved. To produce the observed reduction of 8/1 in the amplitude of an echo near 75 km (Section III (*c*) (ii)), an increase in electron density of 1000/cm^3 over a height range of 15 km, say 60–75 km, is required,* an increase of some 10 times the pre-S.I.D. electron density.

* From the discussion of polarization behaviour by Gardner and Pawsey (1953), the reduction of 8/1 in amplitude implies almost complete absorption of the extraordinary component and at least $\frac{1}{2}$ neper increase for the ordinary. The electron densities follow from Figures 15 and 16 of their paper.

The absorption model does not explain the behaviour of echoes whose intensities increase during S.I.D.'s. An increase in reflectivity as well as an increase in underlying absorption must now take place. In the earlier investigation, when electron densities were measured it was found that average echo amplitudes were roughly proportional to electron densities when absorption effects were small. If such a proportionality continued to hold during an S.I.D., then the observed reflection coefficient R would be given by

$$R = \text{constant} \times N \exp(-\rho),$$

where N, the electron density, and ρ, the integrated absorption in nepers, are each a function of height. If R_0, N_0, and ρ_0 are the corresponding values prior to the S.I.D. commencement, then

$$R/R_0 = (N/N_0) \exp\{-(\rho - \rho_0)\}. \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

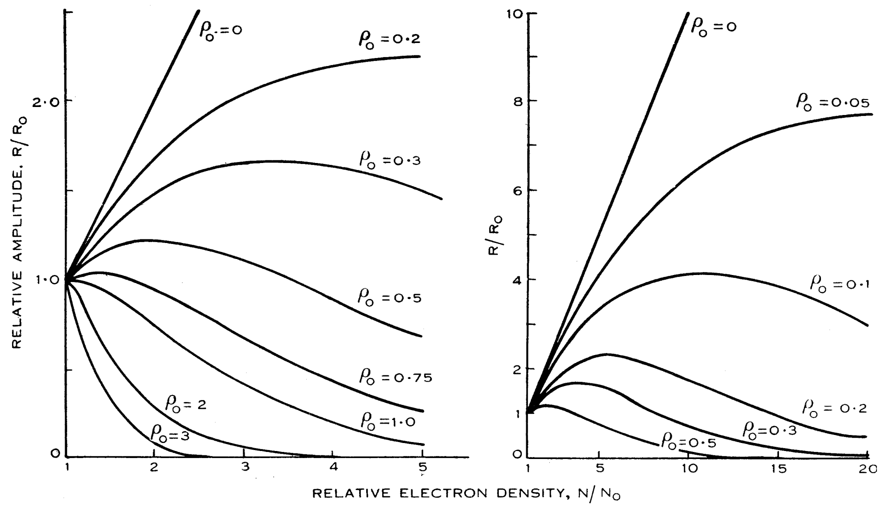


Fig. 6.—Variation of relative echo amplitude with increasing electron density, for different values of initial absorption ρ_0 in nepers. Two sets of curves with different scales are employed to cover the range of interest.

If the whole of the ionosphere below the reflection level for the echo concerned were affected in the same proportion, ρ would equal $(N/N_0)\rho_0$, and this is the basis for the next model. Substituting $\rho = (N/N_0)\rho_0$, equation (**1**) becomes

$$R/R_0 = (N/N_0) \exp[-(N/N_0 - 1)\rho_0]. \quad \ldots\ldots\ldots\ldots \quad (2)$$

In Figure 6, R/R_0 is plotted as a function of N/N_0 for different values of ρ_0. For $\rho_0 < 1$, R/R_0 reaches a maximum $(R/R_0)_{\text{max.}} = (1/\rho_0) \exp(\rho_0 - 1)$ at $N/N_0 = 1/\rho_0$, and returns to unity at $N = N_1$. For $\rho_0 > 1$, R/R_0 decreases continuously with increase in N/N_0. Figure 7 gives $(R/R_0)_{\text{max.}}$ and N_1/N_0 as functions of ρ_0.

It can be seen from Figure 6 that this model will explain echoes, the intensity of which during S.I.D.'s

(i) decreases, $\rho_0 > 1$;
(ii) increases then decreases, $\rho_0 < 1$, $N/N_0 > N_1/N_0$;
(iii) increases, $\rho_0 < 1$, $N/N_0 < N_1/N_0$.

For a 10/1 increase in the amplitude of echoes from 65 km, ρ_0 (65 km) would have to be below 0·05 and the electron density must increase by more than 10/1 (with $\rho_0=0\cdot05$ in Fig. 6, $(R/R_0)_{\text{max.}}=10$, $N/N_0=20$). The same proportional increase in electron density would explain the intensification and subsequent diminution of the echo at 72–75 km if the appropriate value of ρ_0 was in the range 0·3 to 0·4 for $\rho_0=0\cdot36$, $(R/R_0)_{\text{max.}}=1\cdot5$, $N_1/N_0=6$. An increase in electron density of some 6/1 would be required before the echo intensity fell below the pre-flare value. The observed maximum increase in amplitude of

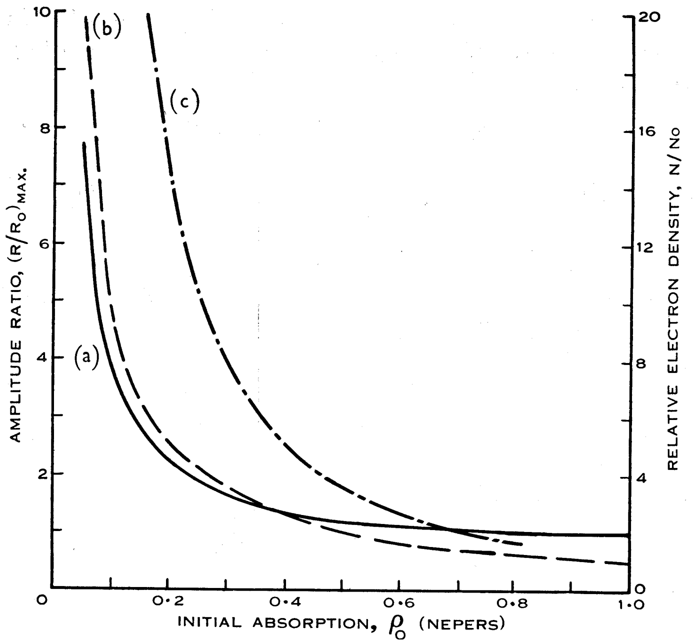


Fig. 7.—Variation of (*a*) $(R/R_0)_{\text{max.}}$, the maximum increase in echo amplitude expressed as a ratio of the pre-S.I.D. value; (*b*) $(N/N_0)_{\text{max.}}$, the value of N/N_0 at which this maximum occurs; and (*c*) the value, N_1/N_0, of N/N_0, at which R/R_0 returns to unity, each as a function of ρ_0, the initial absorption in nepers.

this 72–75 km echo was somewhat higher than the $(R/R_0)_{\text{max.}}$ value of 1·5.* Qualitatively, the behaviour of echoes at heights greater than 75 km is in accord with the model behaviour for $\rho_0>1$, but, as the general behaviour is similar for different values of ρ_0, it is not possible to make quantitative estimates of ρ_0.

When polarization effects are included, the values of ρ_0 required to explain echo intensity variations are approximately the mean of the values for the two components at the lowest heights around 65 km, gradually changing with increasing height to the value appropriate to the ordinary magneto-ionic component, which alone is important above 80 km. Corresponding to the

* If the reflectivity during an S.I.D. increased more rapidly than did the electron density, higher values of R/R_0 for a given value of ρ_0 would be obtained. This may have been the case with some of the S.I.D.'s.

previous values of ρ_0, 0·05 and 0·3–0·4, ρ_0 for the ordinary component will be less than 0·05 neper at 65 km, and around 0·2 neper at 72–75 km. These are in reasonable agreement with those derived in the previous observations (0·1 neper for 72 km echoes on May 6, 1952) when electron densities were around 20 and 200/cm^3 at the two heights. During S.I.D.'s these may increase by more than 10/1.

It was found that "70 km" echo intensities increased more frequently in winter than in summer (Section III (*c*) (ii) and Fig. 4). This fits the model behaviour, since ρ_0 will be smaller in winter than in summer.

In the model it has been assumed that N/N_0 is independent of height. This obviously cannot hold over the full range of echo heights. Some idea of the variation in electron density at heights above 75 km can be obtained from the E-echo variation. At the E-region maximum it is generally considered that the electron density is little affected. In the moderately large S.I.D.'s which we have been considering the overall absorption in nepers for waves completely traversing the D region might increase by a factor of 3.* As the centre of the absorbing region would be around 90 km, we obtain an N/N_0 variation of about 20/1 at 65 km, decreasing through 3/1 at 90 km to unity at 110 km. Notwithstanding the fact that the proportional increase is greatest around 70 km, it is concluded from the observations of the relative changes of the "90" and E echoes (Section III (*c*) (ii)) that, during an S.I.D., most absorption of the E echo still takes place between 85 km and the E-reflection level. In this region of the ionosphere the pre-S.I.D. electron densities are high and only small proportional increases are required to produce large increases in overall absorption.

The magnitude of the increases in electron density found for the 60–75 km range of heights, well over 1000 electrons/cm^3 in some cases, appears to be adequate to explain the variations in phase height of 16 kc/s waves at near-vertical incidence (Bracewell and Straker 1949). The reflection level, determined approximately by $N=100$, might fall some 10 km from 70 to 60 km and so produce a 360 degree phase change at 16 kc/s. Any fall in the reflection level could explain the worsening of long-distance propagation at frequencies below 8 kc/s causing a reduction in the strength of atmospherics at these frequencies (Gardner 1950), according to Budden's (1951) theory. The S.I.D. change in the electron density distribution with height might also explain the enhancement of atmospherics at frequencies between about 15 kc/s and 60 kc/s (Bureau 1937).

In a previous observation it was found that the ionospheric temperature, determined from the measurement of 2 Mc/s thermal radiation, increased by amounts of up to 40 °K during S.I.D.'s (Gardner 1954), but it was not obvious whether there was a real increase in electron temperature involved or whether the effect was due solely to a downward movement of the region of origin of the radiation to where the temperature was higher. From a consideration of the

* This would increase E-echo absorption from about 3 to 12 nepers (25 to 100 dB). With the non-deviative absorption formula the corresponding cosmic noise absorption at 20 Mc/s would be about 1 dB.

increases in electron density near the bottom of the ionosphere, together with the atmospheric temperature-height distribution, it appears that the latter effect alone is sufficient.

(b) *Timing of S.I.D. Effects*

It was demonstrated that there was a mean time lag between the recoveries of 85 and 105 km echoes of at least 3 min. No lag (unlikely to be more than 1 min) was detectable between events at 85 km and at lower heights. The latter suggests that variations at the bottom of the ionosphere follow closely the variations in ionizing radiation, as was suggested by Bracewell and Straker (1949), who estimated from a study of sudden phase anomalies (S.P.A.'s) at 16 kc/s that the equivalent time constant of the ionosphere effects at heights around 65–75 km did not exceed $2\frac{1}{2}$ min. Ellison (1953), however, found that changes in Hα line width during flares are some minutes ahead of the corresponding lower ionospheric effects, there being a mean lag of 7 min between the two maxima. If the ionospheric effects are in step, to within 1–2 min with the ionization radiation, the latter's intensity cannot be dependent on the Hα line width alone.

The lag of the E recovery behind the 85 km recovery is not necessarily the result of different recombination rates at different ionospheric levels, as would be the case if the quality of the enhanced ionizing radiation remained constant through a solar flare and only the intensity varied. Rocket observations of solar spectra (Chubb *et al.* 1957) suggest that two types of radiation are enhanced in S.I.D.'s, namely Lyman-α line radiation and short X-rays. If this is so it is quite possible that the relative amounts of the two will vary during the progress of the flare. Our observations would require that the radiation producing its effect at the greater average height should tend to last longer than that effective at the lower height. Otherwise the time lag must be of ionospheric origin. In any case it would be expected that large flares S.P.A.'s (sudden phase anomalies), controlled by changes near the base of the ionosphere, would recover some 3–5 min earlier on the average than S.C.N.A.'s (sudden cosmic noise anomalies), controlled by the changes of total absorption through the ionosphere. Such a comparison does not appear to have been made.

The enhancement of the 70–75 km echo a few minutes before the commencement of the absorption increase at greater heights observed in 10–15 per cent. of the S.I.D.'s (Section III (*c*) (iii)) is puzzling, although it could be explained by the two-component ionization theory.

V. Conclusions

The main conclusion from the interpretation of these observations is that very large increases in electron density take place in the lower ionosphere. The relative increases in electron density are greatest near the bottom of the ionosphere: in a typical large S.I.D. associated with a class 2 or 3 flare the enhancement of ionization might vary from 20/1 at 65–70 km, through 3/1 at 90 km to unity at 110 km, while the actual electron density increase could average more than 1000/cm^3 over the height range 60–75 km.

It was found that, for moderately large S.I.D.'s, the E-echo recovery lagged about 4 min on the average behind the recovery of lower echoes around 85 km. Events at 85 km and lower heights appeared to be simultaneous.

While these observations have yielded new information on the effect of solar flares on the ionosphere, they have suffered from a lack of sensitivity and means for determining electron densities directly. If these deficiencies could be made good, more precise information on individual S.I.D.'s could be obtained. An increase in sensitivity of at least 10/1 in power would be necessary to show the detailed changes of strength of the " 70 km " echoes, which are the ones of interest. Electron densities could be obtained using polarized aerials in the way described in the previous paper. Because of the large increases in electron density involved, it would be best to work at frequencies in the 3–4 Mc/s range where the differential absorption of the ordinary and extraordinary waves is not too great.

Note :

A letter describing the effects of S.I.D.'s on D-region echo intensity records made on a frequency of $1 \cdot 75$ Mc/s at Christchurch has recently been published by Gregory (1958). The results quoted appear to agree reasonably with ours, although differences in detail on account of differences in frequency and location are to be expected.

VI. References

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