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# MULTIFREQUENCY IONOSPHERE RECORDING AND ITS SIGNIFICANCE[1]

By Theodore R. Gilliland

ABSTRACT

Results obtained in hourly measurements of critical frequencies of the layers of the ionosphere are presented for the period of a year between May 1933 and April 1934. The critical frequencies were obtained by an automatic recorder which covers the frequency band 2,500 to 4,400 kc/s at a uniform rate of 200 kc/s per minute. Critical frequencies in this band are for the E and $F_1$ layers in the daytime and for the F layer at night. Graphs are presented which represent hourly averages of critical frequencies for each layer for each month. The points from which the averages are obtained are also plotted to show the scatter. The critical frequencies for the E and $F_1$ layers follow in phase with the sun both diurnally and seasonally. During the day "fine structure" is often in evidence, indicating other strata between the usual E and $F_1$ layers. The results obtained for the F layer during the winter night are of particular interest. After dropping to a minimum near midnight the critical frequency increases to a maximum at about 4 a.m., then drops to a second minimum before sunrise. This increase during the night represents more than a 100 percent increase of maximum electron density.

The results for the period September 11 to 30, 1933, are compared with those for the same period of 1934, showing a considerably greater ionization density for the latter period. The minimum point of the average curve for 1934 is about 180 kc/s higher than that for 1933. Whether or not this increase is connected with the new sun-spot cycle is not yet certain.

Some of the results have been studied in connection with a practical communication problem, which was concerned with skipping of signals in short-distance transmission along one of the airways. The results are used to determine the limiting frequency for any distance up to a few hundred miles.

Information of the type presented here should prove useful in the study of the properties of the upper atmosphere, as well as in the interpretation of communication problems.

CONTENTS



## I. INTRODUCTION

The purpose of this paper is to present some of the results obtained with an automatic recorder which gives the relation between the radio frequency of the pulse signals used and the virtual height reached by them in that portion of the upper atmosphere now called the ionosphere. With records of this type it is possible to interpret some of the characteristics of radio waves which travel by way of the ionosphere.

[1] Presented in part at Washington meeting of URSI, Apr. 27, 1934.

The equipment, which has been described previously,[2] employs the pulse method of Breit and Tuve with modifications which permit automatic recording. The system consists of a transmitter, receiving set, and galvanometer oscillograph with photographic attachment. The transmitter is made to send out short pulses, which arrive at the receiving set via the ionosphere as well as directly from the transmitter. By passing the output of the receiving set through the oscillograph a photographic record is made which gives a measure of the virtual height reached by the pulses. The frequency of the transmitting and receiving sets which are placed in the same room is shifted continuously from 2,500 to 4,400 kc/s at the uniform rate of 200 kilocycles per second per minute, thus requiring 9½ minutes for each record. During most of the time records are made once each hour although at times they are made each half hour. This work is being carried on at the National Bureau of Standards field station near Beltsville, Md., (lat. 39°2′ N.; long. 76°51.5′ W.).

During the daytime the band of frequencies used (2,500 to 4,400 kc/s) indicates the presence of at least three strata. For the lower range of frequencies the waves are returned from the E layer with a virtual height of about 110 to 120 km. As the frequency is increased the waves pass through the E layer and are returned from the $F_1$ layer with a virtual height usually between 180 and 240 km. As the frequency is increased still further the waves penetrate the $F_1$ layer and are returned from the $F_2$ layer with a virtual height of 280 km or more. In the late afternoon the $F_1$ and $F_2$ layers appear to merge so that at night only one well-defined layer is in evidence in the F region with a virtual height of 240 km and higher. As the ion density decreases in the evening, frequencies above 2,500 kc/s are no longer returned from the E layer. Later at night the highest frequencies in this band finally penetrate the F layer and are no longer returned at normal incidence (i. e., for transmission straight up and straight down). Occasionally the ion density becomes so low that even 2,500 kc/s is not returned. The lowest frequency which just passes through a layer at normal incidence is called the critical frequency of the layer. The discussion that follows deals mainly with the measurements of the critical frequencies of the E and the $F_1$ layers in the daytime and of the F layer at night. Besides the more or less regular refraction phenomena discussed above there are sporadic reflections from the E region which appear at almost any time but most often during the summer. Also reflections from the F region for frequencies above the usual critical values appear at times. That this sporadic phenomenon is reflection rather than refraction is indicated by the character of the pattern obtained. The usual F-layer refraction with critical frequencies for both ordinary and extraordinary rays is often "visible" through an E layer which can support several multiple reflections. The character of these sporadic reflections is shown in some of the records that follow.

The data discussed here were obtained over a period of a year between May 1933 and April 1934, inclusive. Also some of the data obtained during September 1934, are compared with those of September 1933.

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[2] Theodore R. Gilliland. BS J. Research **11**, 561 (1933) RP608; also Proc. Inst. Radio Engrs. **22**, 236 (1934).

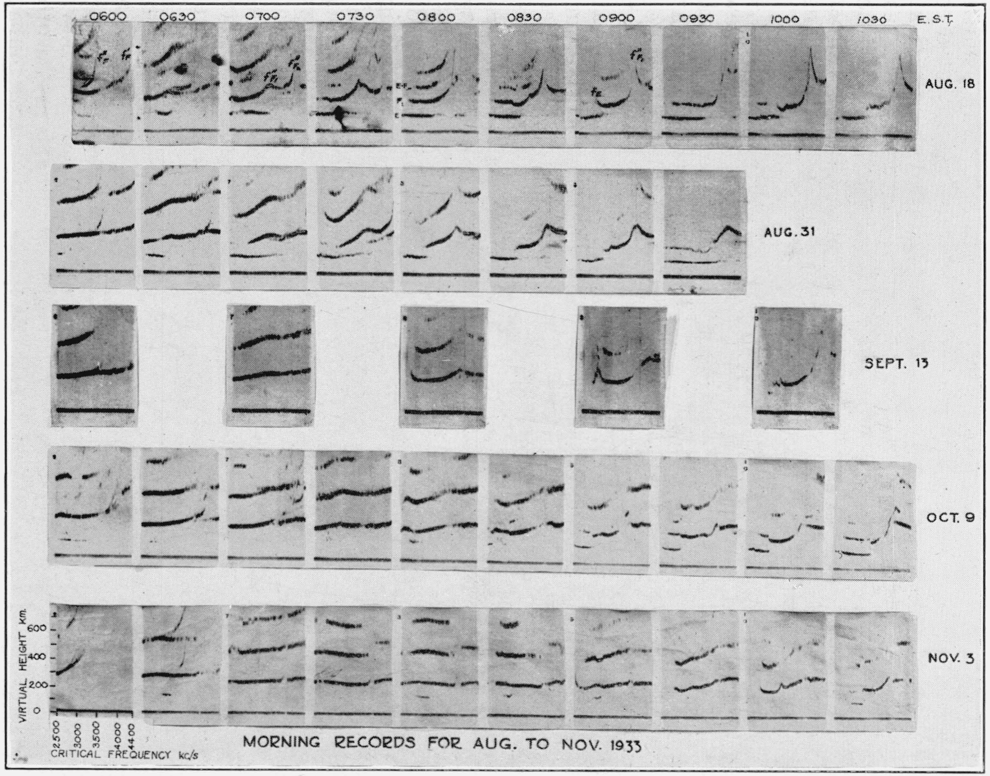


FIGURE 1.—*Records taken during the morning at half-hour intervals showing the changes in character of the patterns from August to November 1933.*

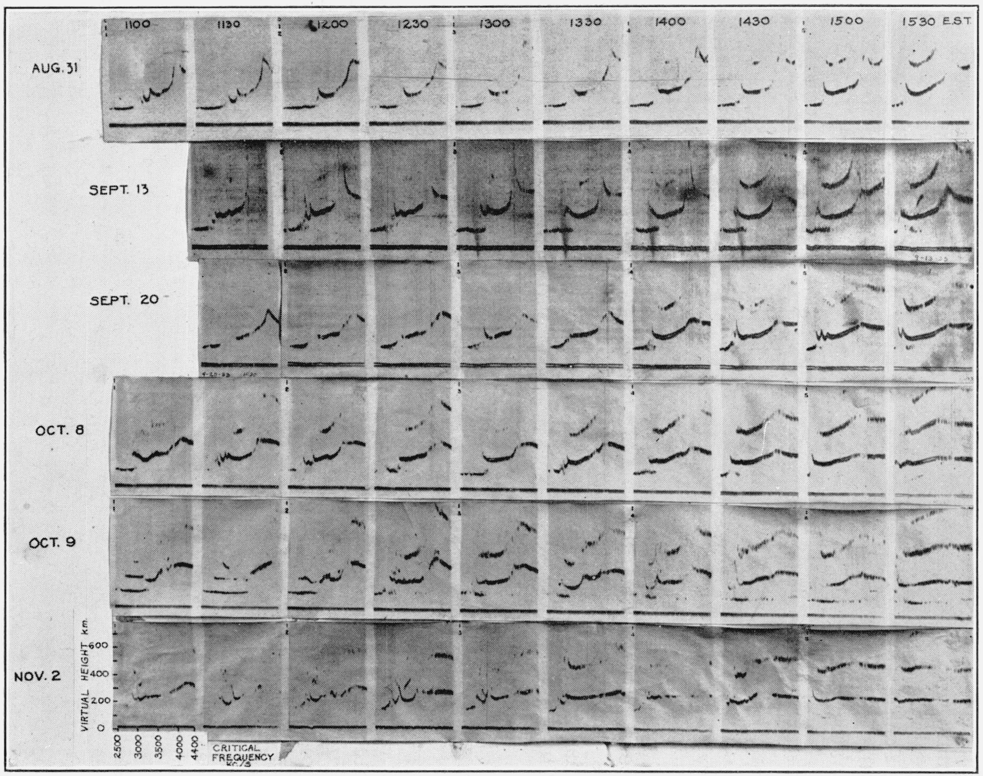


FIGURE 2.—*Records showing changes in the character of the patterns from August to November 1933 between 1100 and 1530, eastern standard time.*

## II. DAYTIME E AND $F_1$ LAYER RESULTS

The type of record obtained during the daytime is shown in figures 1 and 2. In figure 1 records taken during the morning at half-hour intervals show the changes with season from August to November 1933. Each small section of record gives the virtual height for the band from 2,500 to 4,400 kc/s. The interpretation of patterns of this type has been given previously [3, 4] and will not be discussed in detail here. The record at 0600 EST for August 18 shows the ordinary and extraordinary rays returned from the F region with the critical frequencies $f''_F$ and $f'_F$.[5] The critical frequency for each ray occurs at the point where the trace approaches the vertical. By 0700 the ordinary ray critical frequency is above 4,000 kc/s and formation of the $F_1$ layer is beginning to appear. The pattern at 0800 shows $F_1$ refraction with one multiple, as well as both E and E-F [6] reflections. E-F reflections are those which penetrate the E layer, then make two round trips between the top of the E and the bottom of the F layers before finally coming down through the E layer to earth. This type of reflection is quite common and can be differentiated from the others because its trace has the same shape as that of the F-layer trace below it, while its separation from the F trace is about the same as the separation between the E and F traces. This indicates that the reflecting E layer is fairly thin at times, perhaps less than 10 km in thickness when E-F reflections appear.

The pattern at 0900 shows both the E and $F_1$ critical frequencies. The $F_1$ critical frequency becomes more pronounced later in the morning. This critical frequency is for the ordinary ray. The extraordinary ray can be seen at times, but its critical frequency is usually above the limits of the present recording system.

The F-layer stratification is seen to become less pronounced and the decrease in both the E and $F_1$ critical frequencies can be seen as winter approaches. The records of figures 2 show the changes from August to November 1933, between 1100 and 1530. At 1100 on August 31 there is a triple critical effect between the usual E and $F_1$ layers. "Fine structure" of this type which has been noted by other observers is quite common and indicates other strata between the usual layers. Multiple critical frequencies occur at times of rapid increase in ionization, especially at sunrise. This is to be expected because the rate of change of frequency is not great enough to keep up with the rapid increase in ionization. It is not likely, however, that this is the cause of the fine structure shown above. At 1130 there are only two critical frequencies between E and $F_1$, and at 1200 and after there is only one. Fine structure is in evidence on many of the other records of figure 2. It should be pointed out that many of the patterns recorded are very complex and that it is often

[3] Theodore R. Gilliland. BS J. Research 11, 561 (1933) RP608; also Proc. Inst. Radio Engrs. **22**, 236 (1934).

[4] For a discussion of the theory see Kirby, Berkner, and Stuart, BS J. Research **12**, 15 (1934) RP632; also Proc. Inst. Radio Engrs. **22** (February 1934).

[5] The following nomenclature for critical frequencies is used:
$f_E$ for E-layer critical frequency.
$f''_{F_1}$ for $F_1$-layer critical frequency. Ordinary ray.
$f'_{F_1}$ for $F_1$-layer critical frequency. Extraordinary ray.
$f''_F$ for F-layer critical frequency. Ordinary ray.
$f'_F$ for F-layer critical frequency. Extraordinary ray.
Attention has just been called to nomenclature adopted at the London meeting of the URSI in September 1934. The URSI nomenclature will be used in future publications.

[6] Called M reflections by Ratcliffe and White in England.

difficult and sometimes impossible to interpret the results. With three or more layers, some of them giving double refraction, and with reflections directly from, as well as back and forth between layers, added to multiple reflections and refractions, it can be understood that some of the patterns will be quite complex.

The results of the year's measurements of E-layer critical frequencies are shown in the graphs of figures 3, 4, and 5. The time scale is divided into half-hour intervals and the frequency scale is divided into intervals of 50 kc/s. The points falling within a given interval are plotted within the rectangle corresponding to that interval. When there is only one critical frequency it is shown as a dot. When the critical frequencies are multiple (i. e., when fine structure exists) as shown in figure 2, the lowest one is plotted as a dot and the second one as a cross. The values higher than the second are not indicated.

The curves represent hourly averages of the lowest critical frequencies. The points representing measurements on the half hour are not included in the average curves because they are relatively few in number compared to the hourly measurements. The averages for the second critical frequency are not shown. The curves for May, June, and July are dotted because the measurements were relatively few in number during these months and the average value shown may not represent an accurate average for the month. It is likely that the maximum of the average curves for May and June should be higher. Most of the curves show some irregularity, which can be understood, considering the wide scatter of the points. Some of the scatter may be caused by the fact that one of the critical frequencies of a multiple group may disappear between records and it is usually impossible to tell which one is missing. As a result, the lowest one of the group which appears in the average curve may actually represent the critical frequency for a higher stratum. The maximum of the average critical-frequency curve for each month is shown in table 1. In each case the maximum comes very near to noon.

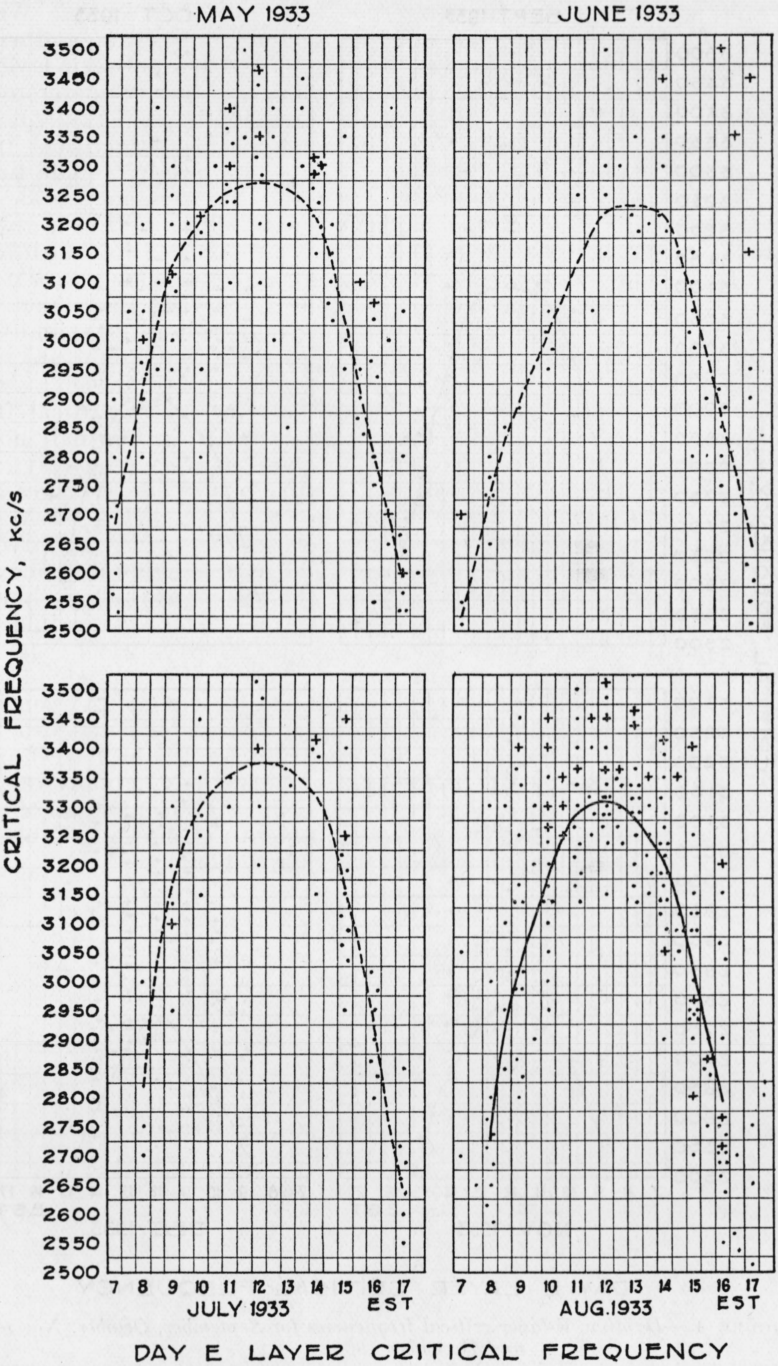


FIGURE 3.—*Daytime* E-*layer critical frequencies for May, June, July, and August 1933.*

Curves represent hourly averages of lowest critical frequencies.

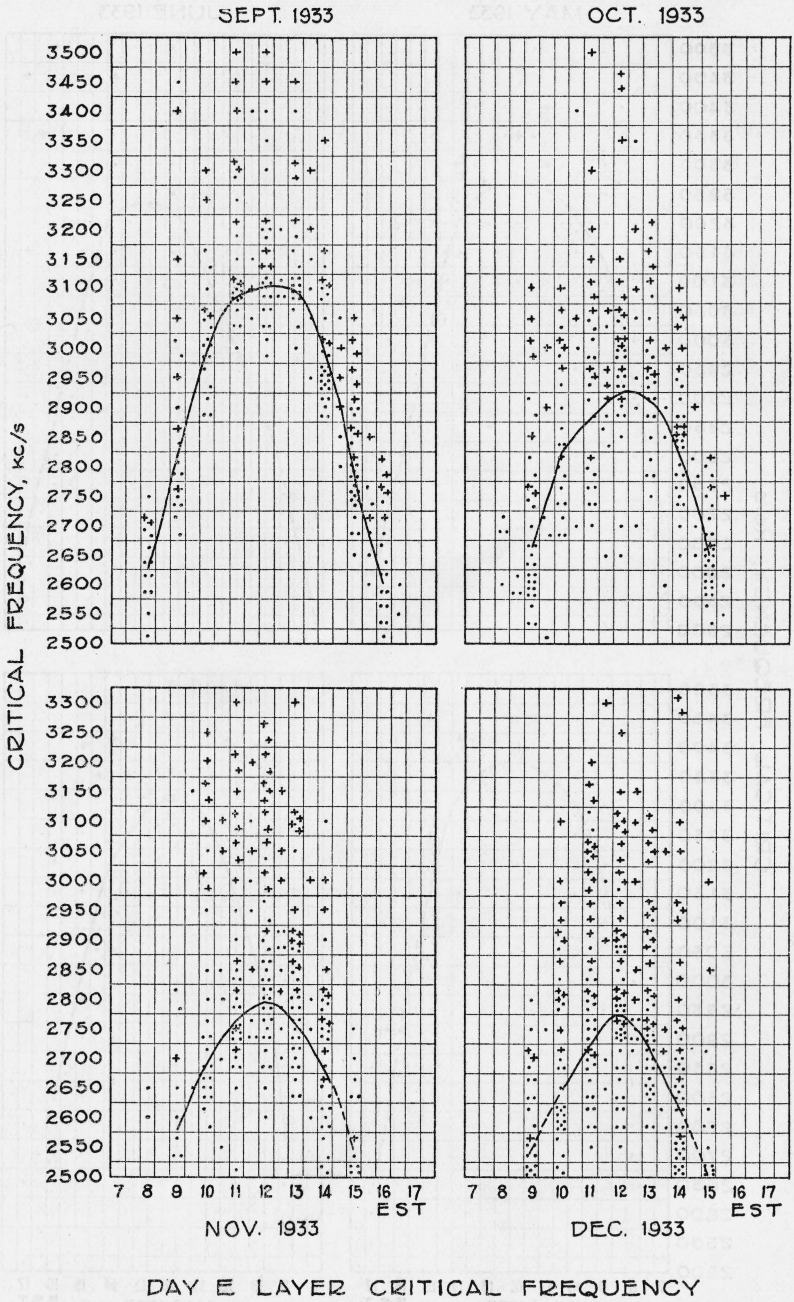


FIGURE 4.—*Daytime E-layer critical frequencies for September, October, November, and December 1933.*

Curves represent hourly averages of lowest critical frequencies.

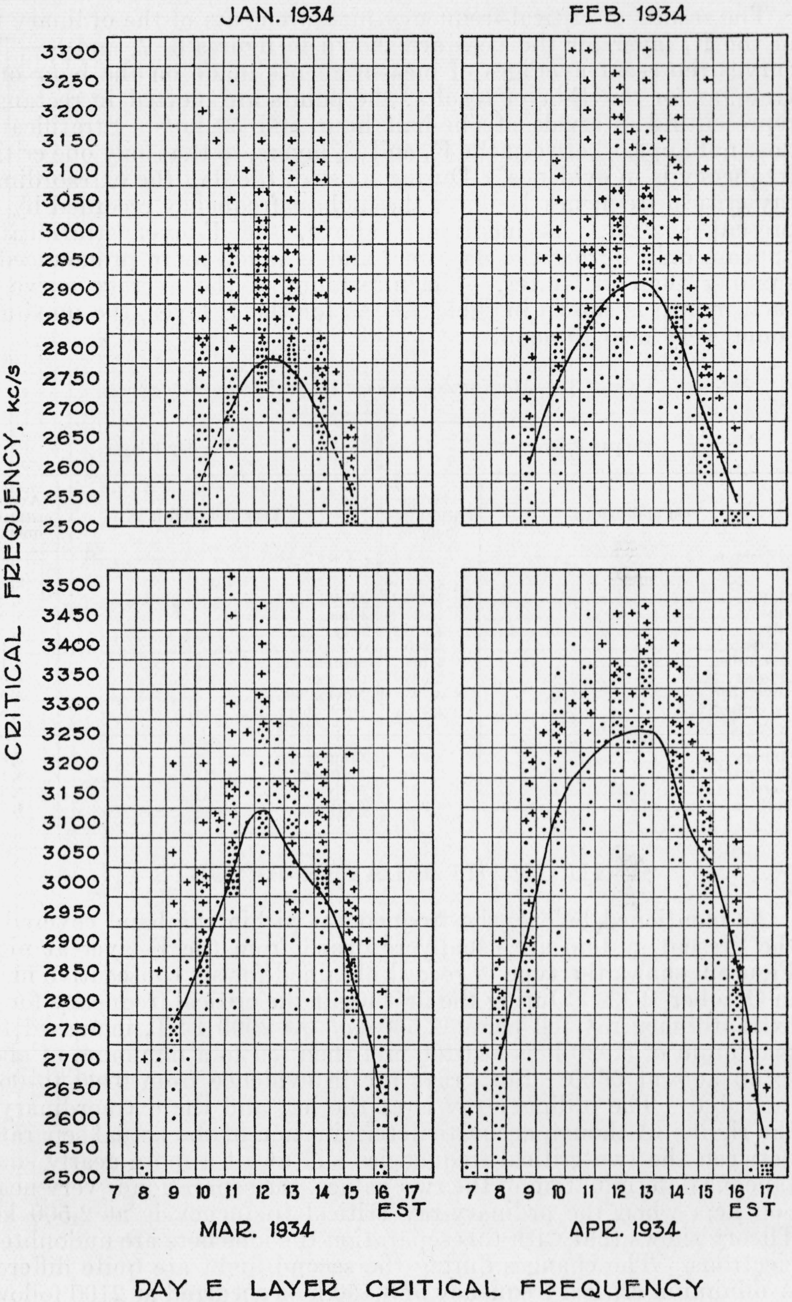


FIGURE 5.—*Daytime E-layer critical frequencies for January, February, March, and April 1934.*

Curves represent hourly averages of lowest critical frequencies.

The results of critical-frequency measurements of the ordinary ray in the $F_1$ layer for the year are shown in figures 6, 7, and 8. The curves represent averages of measurements made on the hour only. Here, as for the E-layer results, the points are plotted in rectangles representing intervals of one-half hour and 50 kc/s. Stratification does not appear between the $F_1$ and $F_2$ layers, so that only one critical frequency is in evidence. During most of the day the extraordinary ray critical frequency is above the highest frequency recorded by the present system. As mentioned above, the F-layer stratification appears only during the daytime, and is much more pronounced in summer than in winter. The maximum of the average curve for each month is shown in table 1. As for the E layer, the maximum comes very near to noon.

TABLE 1.—*Maxima of average critical frequency curves*

| For day E layer | | For day F layer | |
|---|---|---|---|
| Year and month | Average critical frequencies | Year and month | Average critical frequencies |
| 1933 | kc/s | 1933 | kc/s |
| May | 3, 270(?) | May | 4, 205(?) |
| June | 3, 230(?) | June | 4, 205(?) |
| July | 3, 375(?) | July | 4, 205(?) |
| August | 3, 310 | August | 4, 160 |
| September | 3, 105 | September | 4, 175 |
| October | 2, 925 | October | 4, 050 |
| November | 2, 795 | November | 3, 980 |
| December | 2, 775 | December | 3, 870 |
| 1934 | | 1934 | |
| January | 2, 780 | January | 3, 850 |
| February | 2, 910 | February | 4, 115 |
| March | 3, 120 | March | 4, 215 |
| April | 3, 255 | April | 4, 275 |

## III. NIGHT F LAYER RESULTS

As mentioned before, the frequencies within the band covered by the present system are usually returned from the F layer at night. Figure 9 shows the type of record obtained for six consecutive nights in October 1933. During the first night the critical frequency for the extraordinary ray fell below 2,500 kc/s at 2000 EST, increased to a maximum of 3,920 kc/s at 0400 and then fell to a minimum of about 3,750 kc/s at 0600. Both rays are in evidence from 0200 to 0600, inclusive. The ordinary ray is at the left and the extraordinary at the right. Although accurate determination of the actual separation between the two critical frequencies will await a more nearly simultaneous determination of the two values, the separation is very nearly 800 kc/s when the ordinary-ray critical frequency is at 2,500 kc/s. Theory shows that with this separation the ions here are undoubtedly electrons. The changes during the second night are quite different. A minimum critical frequency of 3,450 kc/s occurred at 2100 followed by a maximum of 4,100 kc/s at 0000 and another minimum below 2,500 kc/s at 0500. The critical frequency increased also during the other four nights, but it did not fall below 2,500 kc/s unless possibly during the third night when F refractions were obscured by strong sporadic E reflections at 2300 and 0000.

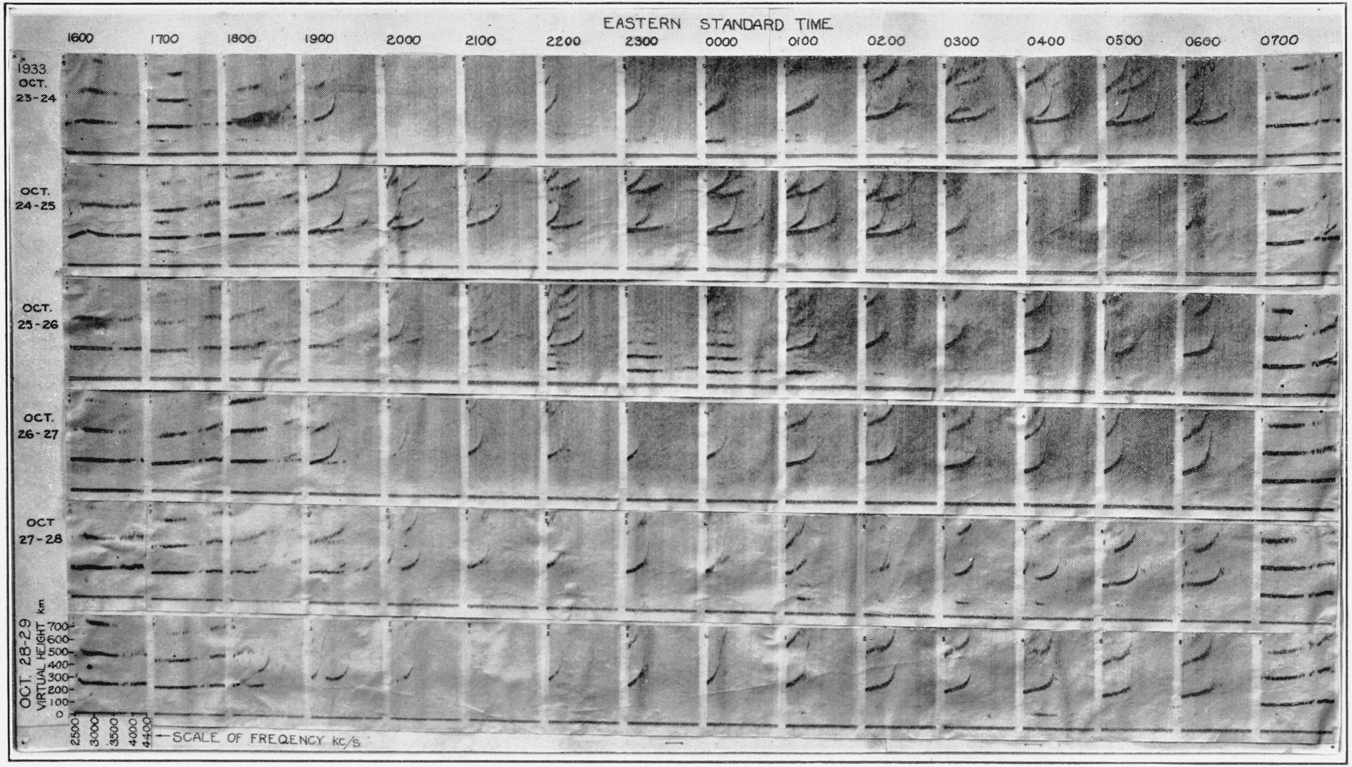


FIGURE 9.—*Records obtained for six consecutive nights in October 1933.*

Note E-layer reflections at 2300 and 0000 eastern standard time during third night.

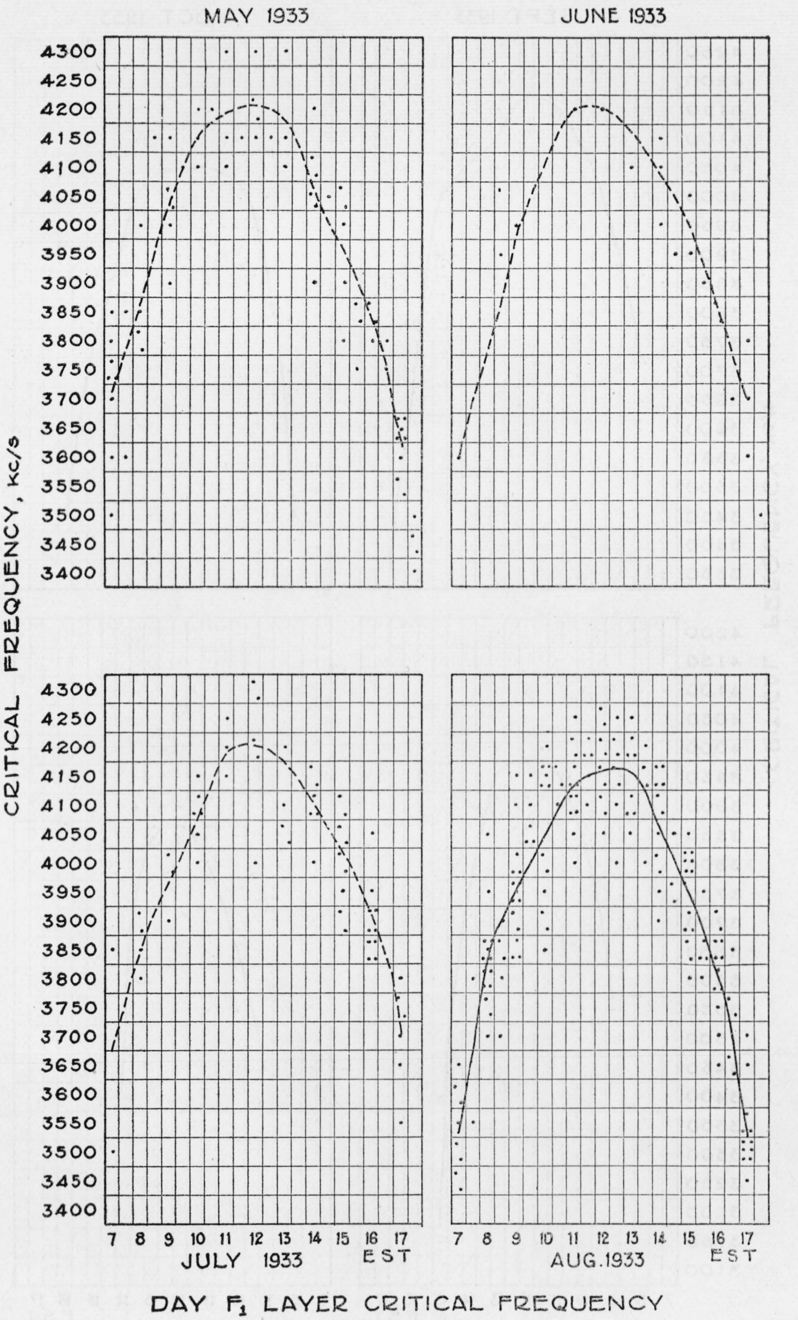


FIGURE 6.—F$_1$-*layer critical frequencies for May, June, July, and August 1933.*

Curves represent hourly averages.

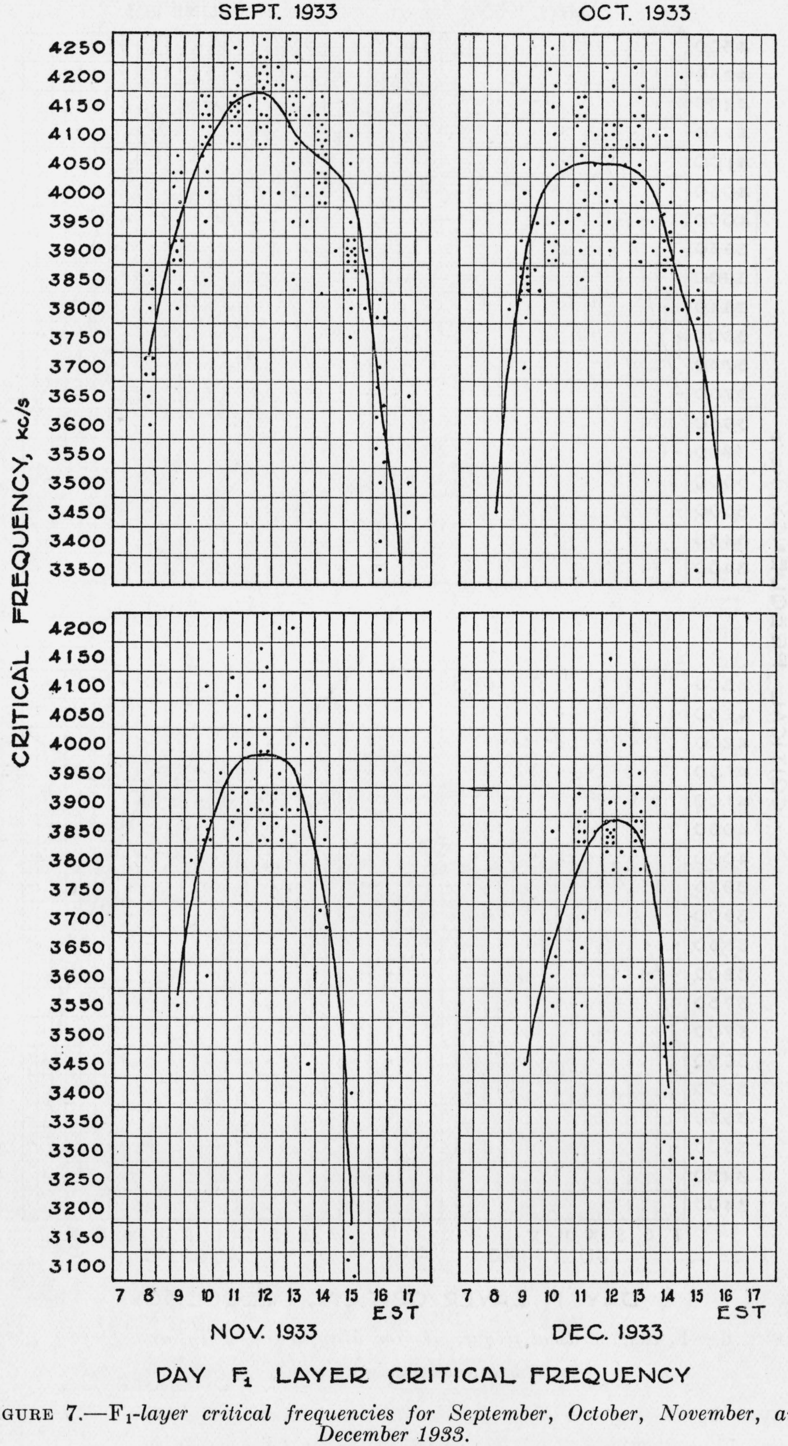


FIGURE 7.—$F_1$*-layer critical frequencies for September, October, November, and December 1933.*

Curves represent hourly averages.

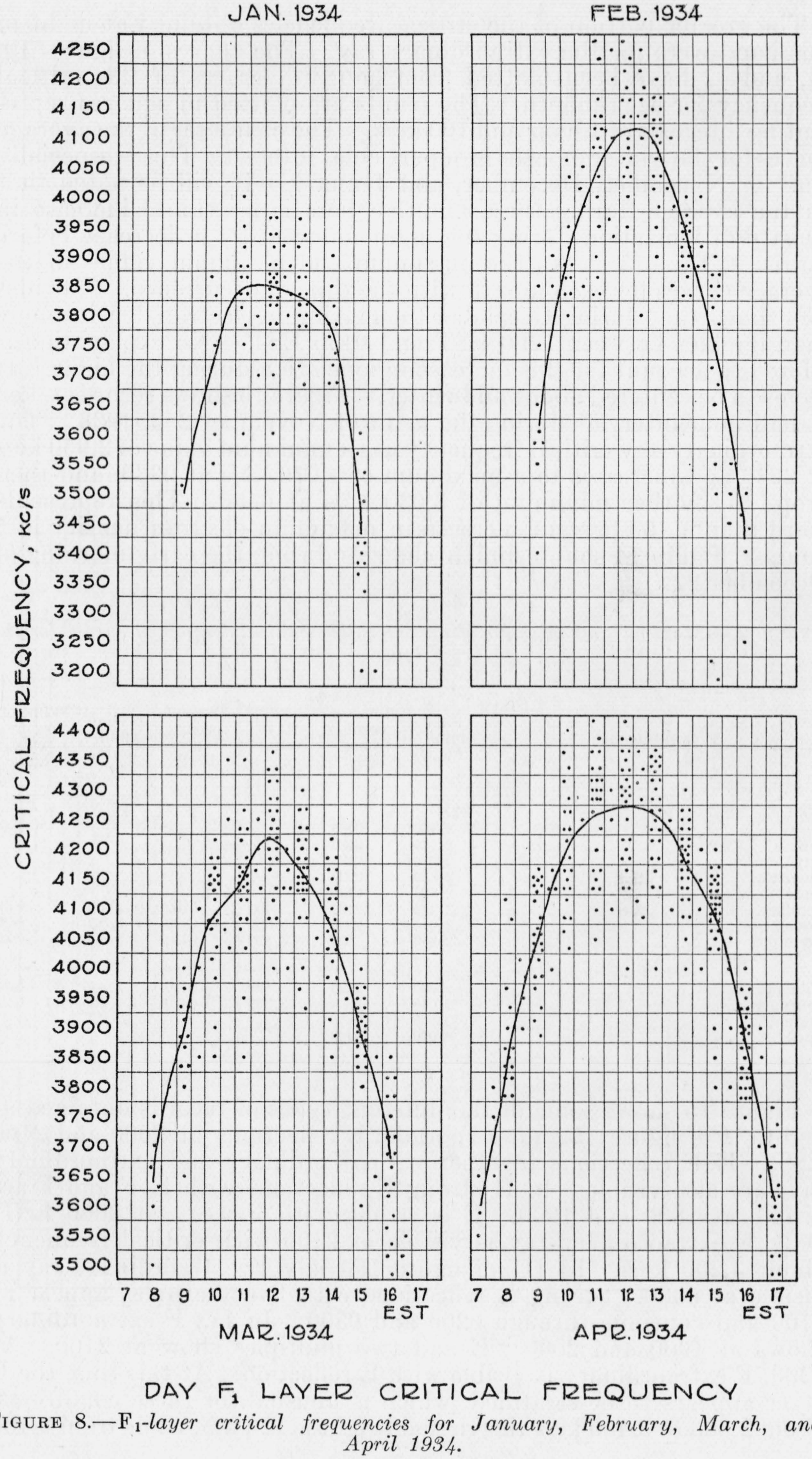


FIGURE 8.—$F_1$-*layer critical frequencies for January, February, March, and April 1934.*

Curves represent hourly averages.

The greater portion of the critical frequencies obtained at night in this band were for the extraordinary ray. The curves of figures 10, 11, and 12 have been plotted from hourly averages of this critical frequency for each month. The points are plotted in squares representing intervals of 1 hour and 100 kc/s. The character of the average curves for the winter months is of particular interest. This is especially true for November, December, and January. It will be noted that on the average during these months there is a definite increase in density of ionization during the night followed by a decrease before sunrise. Table 2 shows the maximum and minimum values of the average curves for each month with the time of occurrence. Calculation shows that during December the maximum electron density more than doubles between 2200 EST and 0430 EST. No explanation is offered to account for this increase in ionization during the night. It seems to be centered about midwinter. Figure 13 shows records taken at half-hour intervals during the night of November 2–3, 1933. The extraordinary-ray critical frequency has a minimum value of 2,950 kc/s at 2230 and increases to a maximum of 4,070 kc/s at 0330, and then drops to another minimum of 3,030 kc/s at 0530. This represents more than a 100-percent increase in maximum electron density in 5 hours. Figure 14 shows similar changes during the early morning of December 22.

TABLE 2.—*Maxima and minima of average night critical frequency curves for the F layer*

| Year and month | First minimum, | Time of occurrence EST | Maximum | Time of occurrence EST | Second minimum, | Time of occurrence EST |
|---|---|---|---|---|---|---|
| 1933 | kc/s | | kc/s | | kc/s | |
| May | 3,160? | 0400 | | | | |
| June | 2,735? | 0400 | | | | |
| July | 2,750? | 0400 | | | | |
| August | 2,850 | 0200 | | | | |
| September | 2,825 | 0430 | | | | |
| October | 3,330 | 2300 | 3,400 | 0100 | 3,150 | 0430 |
| November | 3,045 | 2300 | 3,830 | 0320 | 3,370 | 0600 |
| December | 2,800 | 2200 | 3,820 | 0430 | 3,430 | 0600 |
| 1934 | | | | | | |
| January | 2,800 | 2320 | 3,820 | 0400 | 3,440 | 0600 |
| February | 3,045 | 0000 | 3,335 | 0320 | 3,155 | 0510 |
| March | 3,265 | 0410 | | | | |
| April | 3,010 | 0400 | | | | |

Figure 15 shows some of the different types of records obtained at night. I of figure 15 shows sporadic E reflections at 2000 and 2100 EST. E–F reflections together with F ordinary and extraordinary rays are also visible. In II strong E reflections with E–F and F are visible at 1800 and 1900. E is strong with F weak at 2000 EST. Only F extraordinary ray is visible at 2100 with critical frequency about 3,200 kc/s. In III of figure 15, only F extraordinary ray is visible at 0000. Strong E reflections with five multiples appear at 0100 and continue through 0200 and 0300. In IV, F extraordinary shows at 1900 and 2000. E and two multiples show at 2100. At 2200, F extraordinary is visible with E reflection. At this time the E layer appears to be stratified, which is unusual for these conditions. From 2,500 to 3,400 kc/s the virtual height is 120 km, while from 3,400

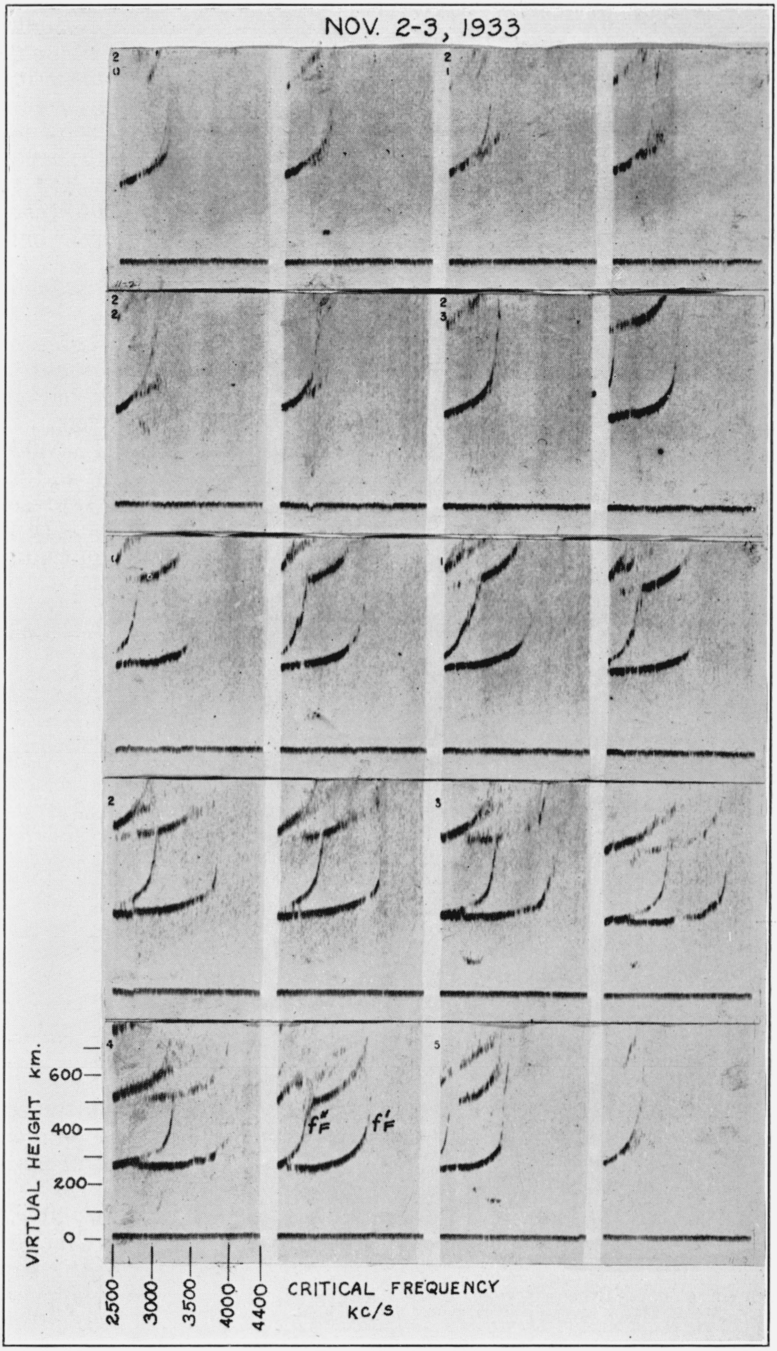


FIGURE 13.—*Records of November 2–3, 1933, showing increase of* F-*layer critical frequency during the night.*

Between 2230 and 0330 the critical frequency for the extraordinary ray increases from 2,950 to 4,070 kc/s, representing more than a 100 percent increase in maximum electron density. $f''_F$ represents ordinary ray critical frequency. $f'_F$ represents extraordinary ray critical frequency.

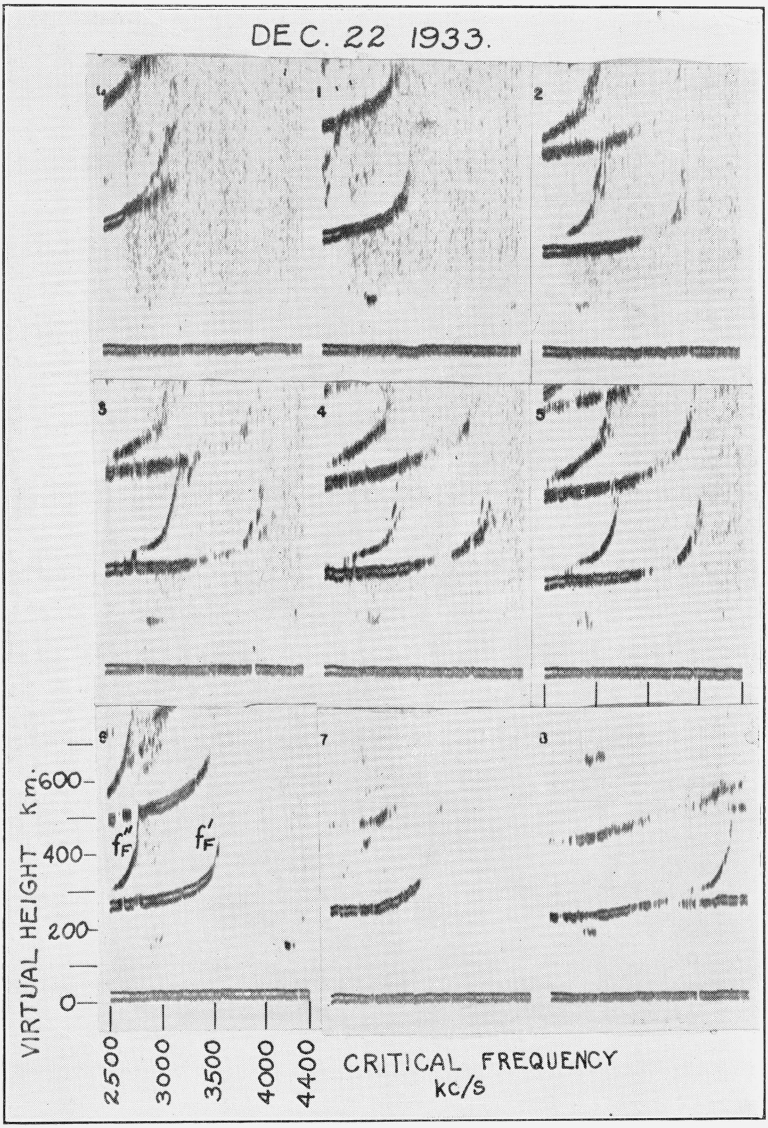


FIGURE 14.—*Records showing increase of* F-*layer critical frequency during the night, December 22, 1933.*

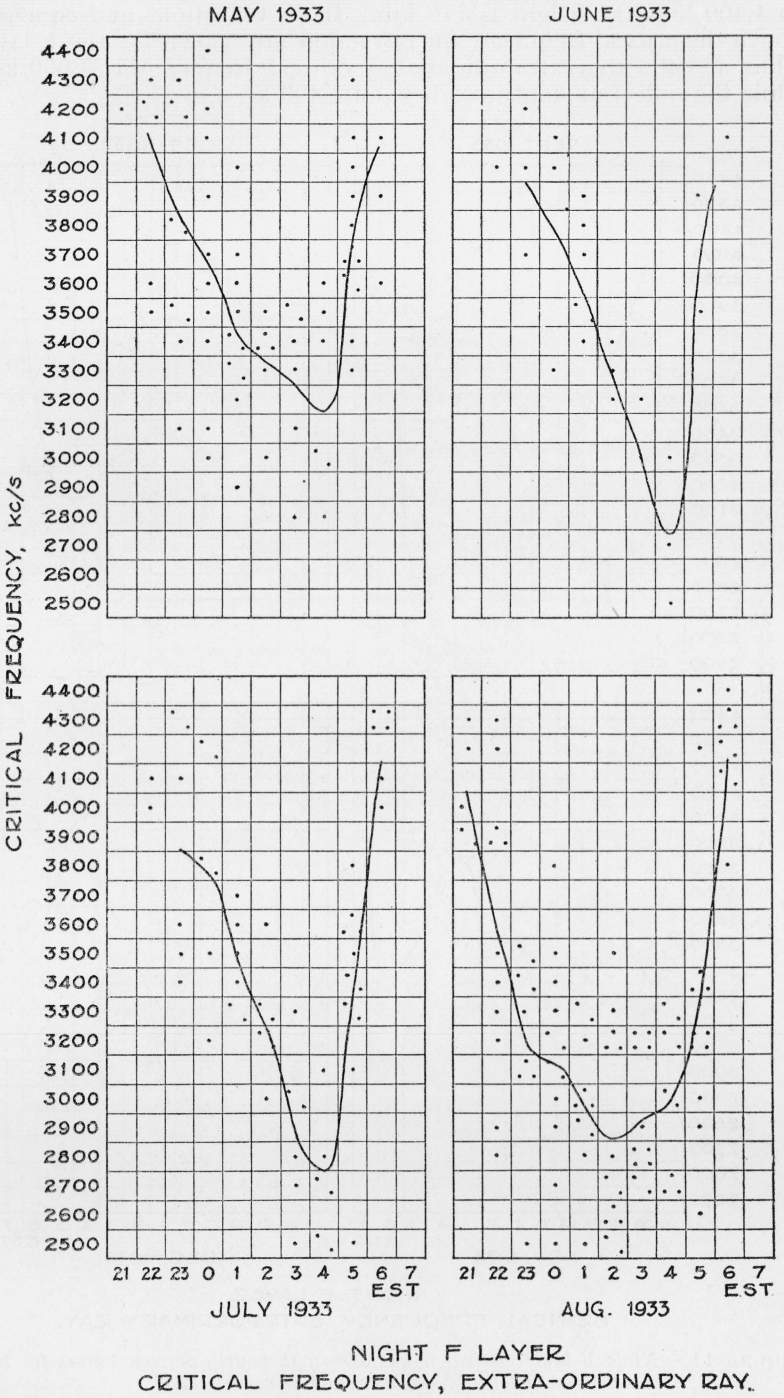


FIGURE 10.—*Night F-layer critical frequencies with hourly average curves for May, June, July, and August 1933.*

to 4,400 kc/s the height is 170 km. In V, reflections at frequencies above the critical frequency for refraction are shown for the F layer. Thus at 0400 the extraordinary-ray critical frequency is 3,950 kc/s, while the reflection continues beyond 4,400 kc/s.

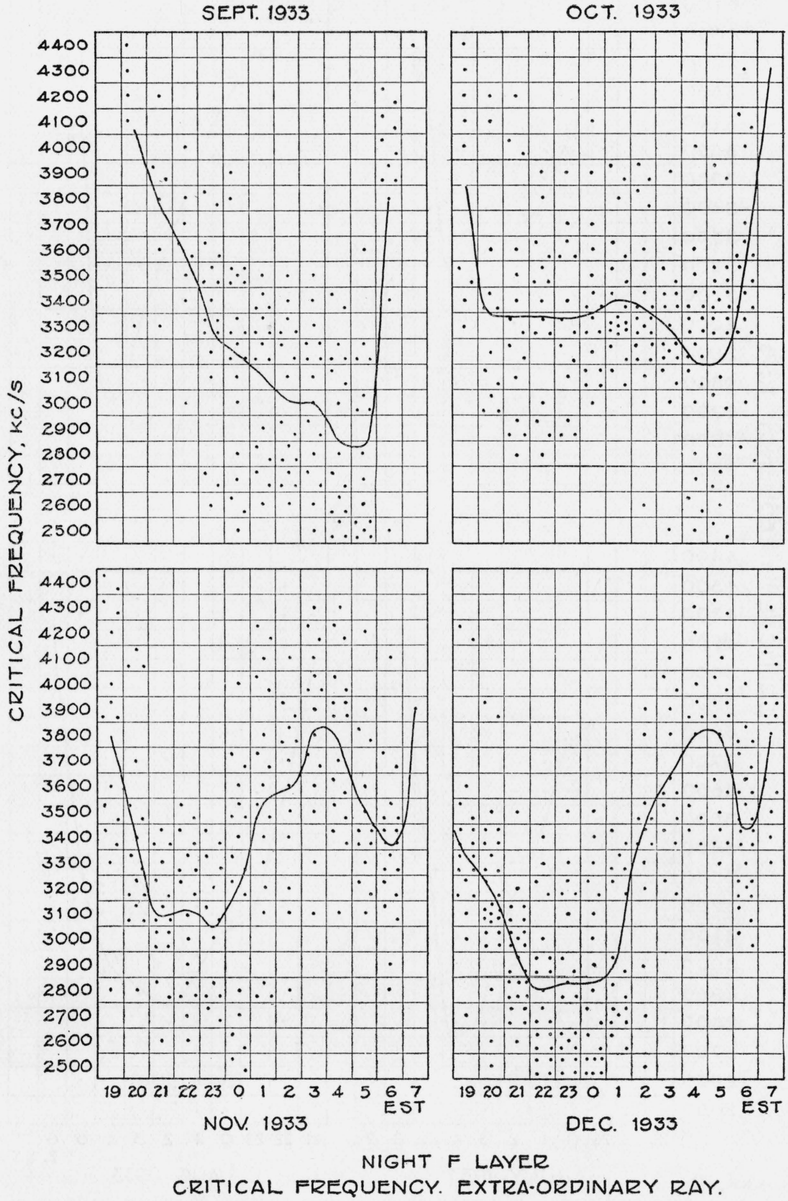


FIGURE 11.—*Night F-layer critical frequencies with hourly average curves for September, October, November, and December 1933.*

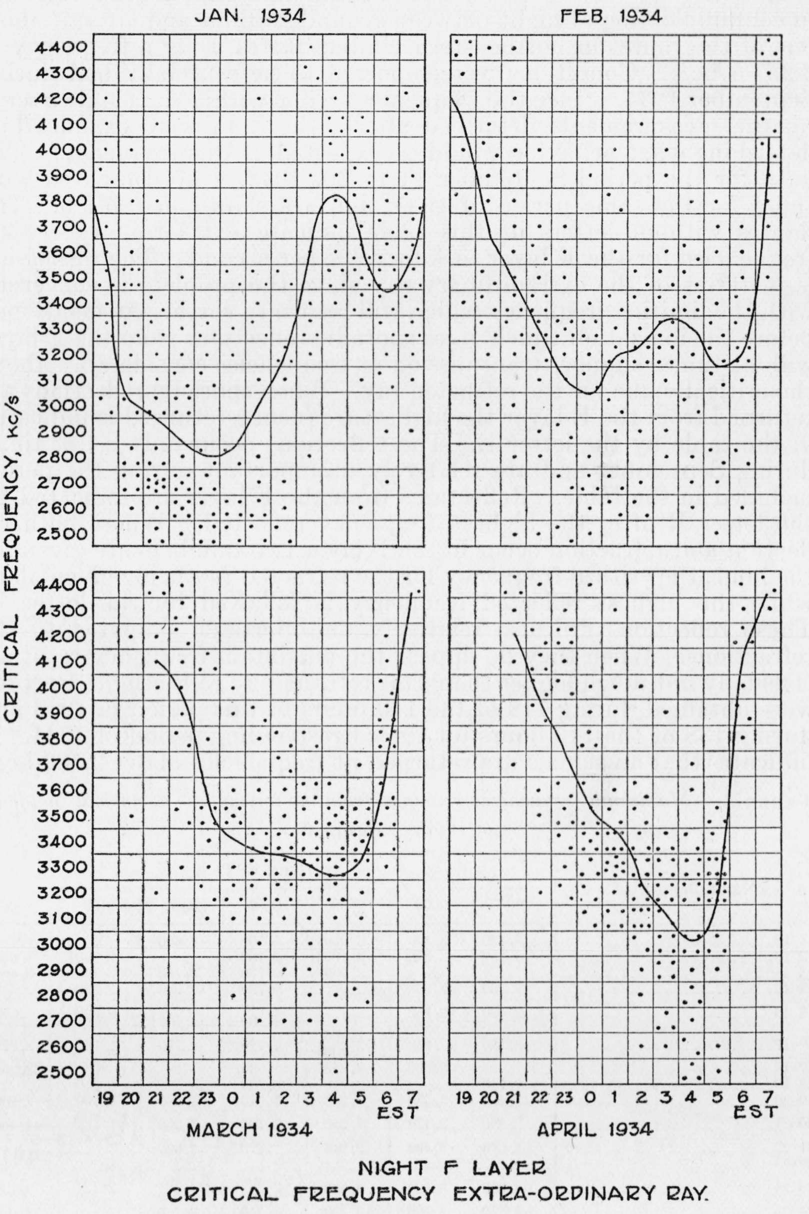


FIGURE 12.—*Night F-layer critical frequencies with hourly average curves for January, February, March, and April 1934.*

## IV. APPLICATION OF RESULTS TO A PRACTICAL COMMUNICATION PROBLEM

Recently one of the air-transport companies experienced difficulty in communicating at night between ground stations and aircraft along one of the routes in northeastern United States using a frequency of 3,257.5 kc/s. Conditions were reported to be especially bad during September 1934. Since the frequency used is within the band covered by the measurements described above, the data were examined to determine what behavior would be expected at this frequency. The data for the period September 11 to 30, 1933, were compared with those for the same period of 1934, and are shown in table 3. The figures without letters in this table indicate extraordinary critical frequencies for the F layer in kilocycles per second. The discussion is in terms of the extraordinary ray since the problem is concerned with the limiting frequency which will return to earth. As mentioned before the ionization which gives sporadic reflections from the E layer will, at times, support transmission at frequencies considerably above the critical value for the refracted ray. When sporadic reflections are returned from the E layer the highest frequency returned is indicated in the table by the letter E. The reflections occur only a few times during September and are relatively unimportant during the period included in the table. Reflections from the F layer are indicated by the letter R after the highest frequency reflected. Where both reflection and refraction occur in the F layer two numbers are given for the hour, the critical frequency for the refracted ray being given alone while the highest reflected frequency is followed by the letter R. These reflections are also relatively unimportant compared to the refractions. When they do appear the maximum frequency returned is usually not much higher than that returned by refraction. Records were obtained during 118 of the 140 hours of this period in 1933 and during 138 of the 140 hours for the corresponding period of 1934. X indicates that no signals are returned at frequencies above 2,500 kc/s.

TABLE 3.—*Maximum frequencies returned from the ionosphere at normal incidence*

Sept. 11 to 30, inclusive, 1933

| Night, September | Hour, EST | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 |
| 11–12 | 3, 220 | 3, 150 | 3, 200R | 3, 100R | 2, 600 | X | X |
| 12–13 | 3, 250 | 3, 250 | 3, 100R | 3, 100R | ---------- | 2, 900R | 3, 000R |
| 13–14 | ---------- | X | 2, 700 | 2, 770 | 3, 150 | 3, 150 | 2, 600 |
| 14–15 | 2, 700 | 2, 550 | ---------- | 2, 700 | 2, 680 | 2, 550 | 2, 530 |
| 15–16 | 2, 600 | 2, 550 | ---------- | 2, 710<br>3, 100R | 2, 700<br>3, 100R | 2, 620 | X |
| 16–17 | 3, 250 | 3, 230 | 2, 800<br>3, 200R | 2, 770 | 2, 770 | 2, 700 | 2, 720 |
| 17–18 | ---------- | 3, 500 | 3, 340 | 2, 930 | X | X | E3, 900 |
| 18–19 | 2, 730 | ---------- | 2, 710 | 2, 740 | ---------- | 2, 610 | ---------- |
| 19–20 | 3, 450 | 3, 230 | 3, 230 | 3, 210 | 2, 980 | 2, 700 | 2, 800 |
| 20–21 | 3, 330 | 3, 170 | 3, 250 | 3, 130 | 3, 290 | E2, 900<br>2, 770 | E4, 400 |
| 21–22 | 3, 270 | 3, 100 | 2, 910 | 2, 770 | 2, 900 | ---------- | ---------- |
| 22–23 | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| 23–24 | 3, 350 | 3, 500 | 3, 460 | E3, 400<br>3, 200 | E4, 400<br>3, 170 | E3, 400<br>3, 350 | 3, 220 |
| 24–25 | 3, 630 | 3, 500 | 3, 430 | 3, 310 | 3, 150 | 3, 180 | 3, 010 |
| 25–26 | ---------- | 3, 530 | 3, 220 | 2, 570 | E4, 000 | E4, 400 | E3, 300<br>3, 180 |
| 26–27 | ---------- | 2, 870 | 2, 570 | 2, 730 | ---------- | 2, 970 | 3, 200 |
| 27–28 | 3, 770 | 3, 510<br>2, 750R | 3, 400<br>3, 800R | 3, 310 | 3, 230 | 3, 150 | ---------- |
| 28–29 | 3, 200 | 3, 280 | 3, 180 | 3, 250 | 3, 140 | 3, 090 | 3, 000 |
| 29–30 | 3, 080 | 2, 950 | 2, 790 | 2, 910 | 2, 910 | 3, 050 | 2, 970 |
| 30–Oct. 1 | 3, 470 | 3, 100 | 3, 150 | 3, 200 | 3, 200 | 3, 270 | ---------- |
| Average | 3, 220 | 3, 135 | 3, 080 | 2, 955 | 2, 950 | 2, 875 | 2, 840 |

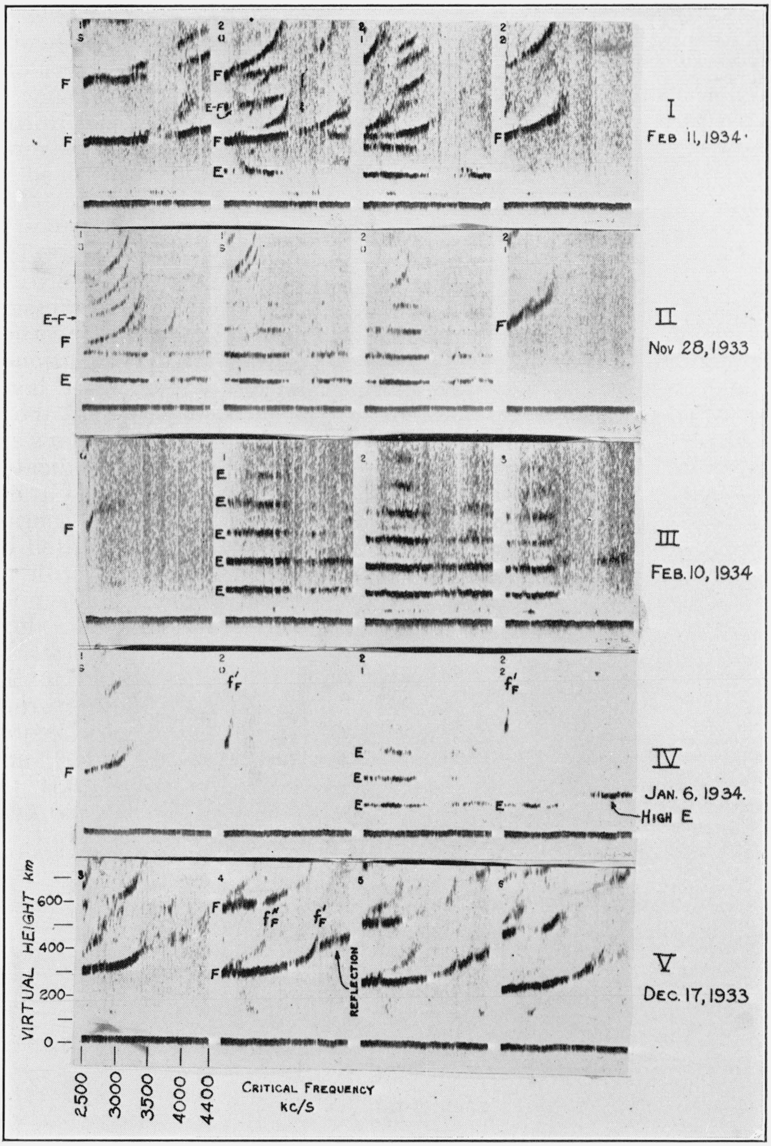


FIGURE 15.—*Different types of records obtained at night.*

I shows sporadic E reflections at 2000 and 2100 eastern standard time. E–F reflections together with F ordinary and extraordinary rays are also visible. II shows strong E reflections with E–F and F at 1800 and 1900. E is strong with F weak at 2000. Only F extraordinary ray is visible at 2100 with critical frequency about 3,200 kc/s. III shows F extraordinary ray at 0000. Strong E reflections with five multiples appear at 0100 and continue through 0200 and 0300. IV shows F extraordinary ray at 1900 and 2000. E and two multiples show at 2100. At 2200 F extraordinary ray is visible with E reflections. At this time E layer appears to be stratified, which is unusual for these conditions. From 2,500 to 3,400 kc/s the virtual height is 120 km, while from 3,400 to 4,400 the height is 170 km. V shows reflections at frequencies above the critical frequency for refraction for the F layer. Thus at 0400 the extraordinary ray critical frequency is 3,950 kc/s while the reflection continues beyond 4,400 kc/s.

TABLE 3.—*Maximum frequencies returned from the ionosphere at normal incidence*—Continued

Sept. 11 to 30, inclusive, 1934

| Night, September | Hour, EST | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 |
| 11–12 | -------- | 3, 900 | 3, 350 | 2, 950 | 2, 770 | 2, 700 | 2, 760 |
| 12–13 | 4, 200 | 4, 100 | 3, 900 | 3, 670 | 3, 170 | -------- | 3, 000 |
| 13–14 | 4, 250 | 3, 950 | 3, 750 | 3, 500<br>3, 900R | 3, 550<br>3, 800R | 3, 400<br>3, 800R | 3, 350<br>3, 800R |
| 14–15 | 4, 500 | 4, 000 | 3, 550 | 3, 400 | 3, 330 | 3, 180 | 3, 200<br>3, 800R |
| 15–16 | 4, 060 | 3, 820 | 3, 600 | 3, 510 | 3, 280 | E3, 500<br>3, 260 | 3, 060 |
| 16–17 | 4, 180 | 4, 050 | 3, 670 | 3, 370 | 3, 000 | 2, 550 | X |
| 17–18 | 3, 650 | 3, 700R | 3, 680R | 3, 450R | 3, 500R | 3, 600R | 3, 900R |
| 18–19 | 3, 630 | 3, 530 | 3, 650 | 3, 720 | 3, 570 | 3, 600 | 3, 350 |
| 19–20 | 4, 000 | 3, 900 | 3, 600 | 3, 330 | 2, 850 | 2, 750 | 3, 100 |
| 20–21 | 3, 800 | 3, 500 | 3, 200 | 3, 200 | 3, 000 | 3, 020 | 2, 940 |
| 21–22 | 4, 500 | 4, 270 | 3, 650 | 3, 240 | 2, 900 | 2, 760 | E2, 650<br>2, 770 |
| 22–23 | 3, 300 | 3, 050 | 2, 770 | 2, 760 | 2, 720 | 2, 730 | E weak<br>2, 800 |
| 23–24 | 3, 750 | 3, 600 | 3, 650 | 3, 330 | 2, 950<br>3, 400R | X | 3, 150 |
| 24–25 | 4, 300 | 4, 070 | 3, 870 | 3, 350 | 3, 300 | 2, 700 | 2, 500<br>3, 100R |
| 25–26 | E3, 500 | E3, 200 | 2, 800<br>3, 400R | 2, 870<br>3, 500R | 3, 300 | E3, 400<br>2, 950 | 3, 250 |
| 26–27 | 3, 650 | 3, 500 | 3, 650 | 3, 830 | 3, 530 | 3, 400 | 3, 320 |
| 27–28 | 3, 150 | 3, 130 | 3, 160 | 3, 130 | 3, 180 | 3, 110 | E3, 700 |
| 28–29 | 3, 500 | 3, 380 | 3, 280 | 3, 250 | 3, 300 | 3, 400 | 3, 450 |
| 29–30 | 3, 600 | 3, 730 | 3, 650 | 3, 600 | 3, 470 | 3, 580 | 3, 530 |
| 30–Oct. 1 | 3, 130 | 3, 000 | 3, 120 | E3, 000<br>3, 160 | E2, 950<br>3, 160 | 3, 150 | 3, 200 |
| Average | 3, 840 | 3, 690 | 3, 470 | 3, 320 | 3, 175 | 3, 040 | 3, 060 |

The curves of figure 16 are plotted from the hourly averages of the F-layer extraordinary ray critical frequency and may be used together with the lower curve of figure 17 to determine, on the average, the highest frequency which would be expected to be useful for transmission for any short distance between transmitting and receiving stations.

For example, the average critical frequency at 4:00 a. m. during the period September 11 to 30, 1934, is 3,040 kc/s. Then from the lower curve of figure 17 the factor for 100 miles, say, is found to be 1.06 and for 200 miles is 1.21. Then on the average during this period no sky-wave frequencies above $1.06\times3,040$, or 3,225 kc/s, would be received at distances nearer than 100 miles from the transmitter, and no frequencies above $1.21\times3,040$, or 3,680 kc/s, would be received at 200 miles or nearer. The variability from night to night is quite large so that individual values of critical frequency are often much different from the average value. Table 3 shows that the critical frequencies from which the average value was taken for 4:00 a. m. range from 2,700 to 3,600 kc/s. The curves of figure 17 may be used together with table 3 to determine the limiting frequency for any distance at any hour of this period. The upper curve should be used if E reflections occur. The factors given by the curves of figure 17 are simply secants of the angle of incidence at the layer.

It will be noted that the curve for September 1933, shown in figure 16, is somewhat different from that shown in figure 11. This is due to the fact that the curve of figure 11 represents the whole month while the other curve represents only the last 20 days of the month.

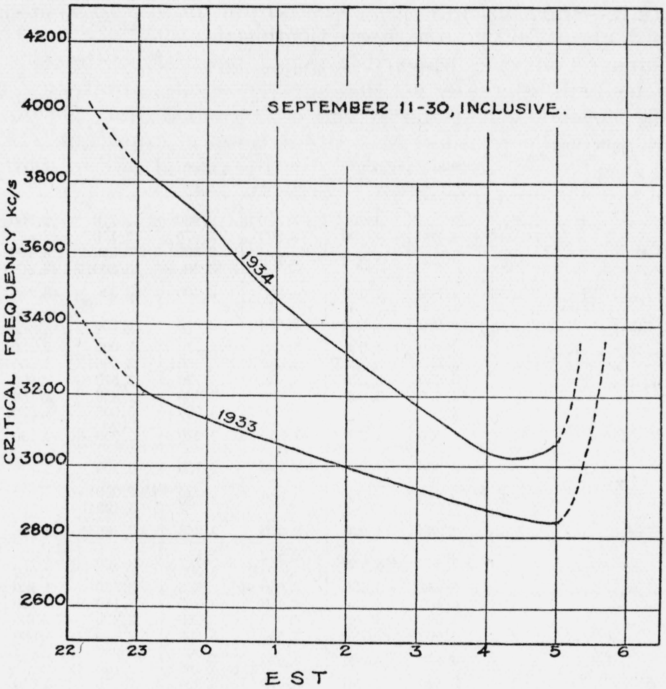


FIGURE 16.—*Hourly averages of night F-layer extraordinary ray critical frequencies for periods September 11 to 30, 1933, and for September 11 to 30, 1934.*

Note that minimum for 1934 is about 180 kc/s higher than for 1933.

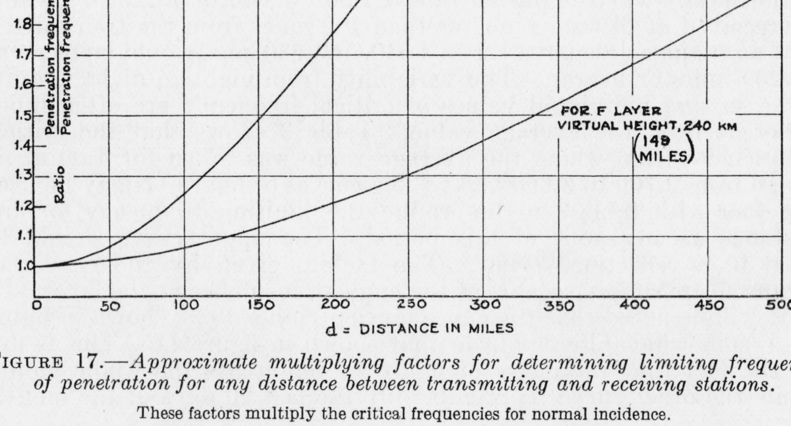


FIGURE 17.—*Approximate multiplying factors for determining limiting frequency of penetration for any distance between transmitting and receiving stations.*

These factors multiply the critical frequencies for normal incidence.

It is interesting to note that the minimum of the average curve for 1934 is about 180 kc/s higher than that for 1933. Since the trend of the sunspot curve is upward it might be inferred that the critical frequencies will increase as the sunspot cycle progresses upward, but since these observations extend over such a short period of time it is not advisable to make any predictions at this time. The provisional sunspot numbers total 57 for this period of September 1933, and 106 for the same period of 1934.

Table 4 is prepared from table 3 and shows the percentages of the time that the critical frequency for the extraordinary ray falls below 2,500, 2,750, 3,000, and 3,250 kc/s during the periods September 11 to 30, 1933 and 1934. The percentages of the time that 2,750, 3,000, and 3,250 kc/s were above the limiting frequency for a distance of 100 miles and, similarly, when 3,000 and 3,250 kc/s were above the limiting frequency for 200 miles, are also given in table 4.

TABLE 4.—*Percentages of the time during the periods Sept. 11 to 30, 1933 and 1934, for which limiting frequencies fell below specified values*

[Data cover hours 2300 to 0500; 11:00 p. m.-5:00 a. m. EST]

| *f*=frequency specified | Critical frequency falls below *f* | | *f* exceeds limiting frequency— | | | |
|---|---|---|---|---|---|---|
| | | | For 100 miles | | For 200 miles | |
| | 1933 | 1934 | 1933 | 1934 | 1933 | 1934 |
| kc/s | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 2,500 | 5.1 | 1.45 | | | | |
| 2,750 | 25.4 | 5.8 | 10.2 | 2.9 | | |
| 3,000 | 44.0 | 17.4 | 30.5 | 12.3 | 5.1 | 1.45 |
| 3,250 | 74.5 | 39.2 | 46.5 | 22.4 | 15.3 | 2.9 |

It is likely that the satisfactory ground-wave range at this frequency is only 30 or 35 miles so that transmission is mainly by sky wave. The results of this study show that at times night transmissions over short distances at a frequency of 3,257.5 kc/s pass through the ionosphere and are lost from the earth. The results also indicate that a lower frequency such as 2,750 kc/s passes through the ionosphere at a given angle a much smaller percentage of the time. It would be necessary to go below 2,500 kc/s to obtain practically complete freedom from skipping. The other F-layer critical frequency graphs indicate that transmissions at a frequency of 3,257.5 kc/s will often pass through the ionosphere during any season. These graphs (fig. 10, 11, and 12) together with the lower curve of figure 17, may be used to determine, on the average, the limiting frequency for any time of the year for any distance.

In allocating frequencies for a given type of service a consideration of data of the type shown here should prove useful. World-wide information will be necessary for an intelligent allocation of frequencies to be used in different geographical locations and for different types of service.

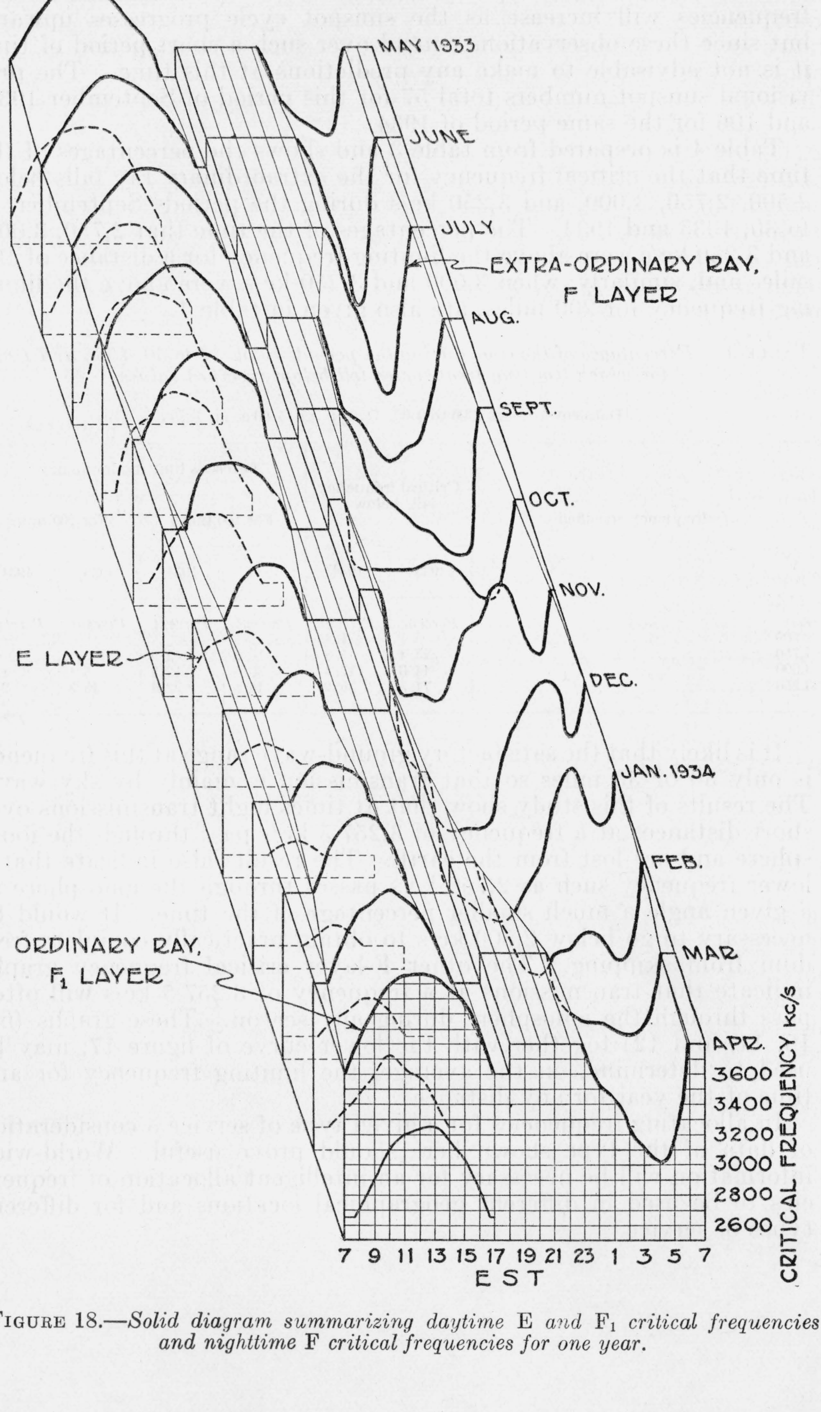


FIGURE 18.—*Solid diagram summarizing daytime* E *and* $F_1$ *critical frequencies and nighttime* F *critical frequencies for one year.*

## V. CONCLUSIONS

An attempt is made to picture the results of the year's critical frequency measurements in the solid diagram of figure 18. The hourly averages of the day $F_1$ critical frequencies above 3,600 kc/s are shown in the solid curves at the left. The dotted curves below these represent averages of the day E critical frequencies above 2,650 kc/s. The solid curves at the right represent averages of night F critical frequencies below 3,800 kc/s. It is evident that the band used (2,500 to 4,400 kc/s) gives an important and interesting part of the total cross section. The day E and $F_1$-layer critical frequencies are seen to follow in phase with the sun both diurnally and seasonally. During the winter night the F-layer critical frequency drops until an hour or two before midnight, then increases until about 0400, after which it decreases again before sunrise. The maximum density of ionization frequently more than doubles after the first minimum.

A detailed analysis of the data has not yet been made with relation to magnetic storms. There have been no severe magnetic storms coincident with the hourly observations during the last one and one-half years. Professor Appleton has reported that during magnetic storms in the northern Norway polar region reflections from the ionosphere were absent at all frequencies. No such pronounced effect has been observed in this latitude during the past one and one-half years. It is expected that the severity of magnetic storms will increase with the advance of the sunspot cycle during the next four or five years so that the relation between magnetic storms and changes in the ionosphere will be more easily recognized.

The probable effect of solar disturbances likewise will be demonstrated only by the accumulation of data over a longer period of time. Although the average night F-layer critical frequency curve for September 1934 is considerably higher than that for September 1933, no predictions are made at this time that this indicates a definite trend upward in the future. Data accumulated during the next four or five years should show how much sunspots do affect critical frequencies.

Information of the type shown here should prove useful in the study of the properties of the upper atmosphere as well as in the study of radio transmission.

Although the results obtained give a considerable part of the whole cross section it is desirable to extend the present system so that all of the critical frequencies will be obtained for the 24 hours. When more complete information of this type is available for different parts of the world and when the results are compared with actual transmission data a more complete understanding of sky-wave transmission should follow.

WASHINGTON, December 27, 1934.