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WWV Reception in the Arctic During Ionospheric Disturbances [1]

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Reception of WWV at four high-latitude stations is compared with ionospheric data during a period of severe ionospheric storminess. It was found that the reception quality of WWV closely follows the morphology of the disturbance. Reception at the lower frequencies was affected primarily by the PCA event and auroral-zone absorption, while at the higher frequencies reception depended upon the storm-time behavior of the F region. Also, reception was strongly affected for several hours during the storm by the appearance of a large sporadic-E cloud. Despite the fact that reception quality was assessed by aural monitoring, agreement between the reported WWV reception and that which would be expected from the ionospheric data is rather good. It is concluded that the behavior of radio reception can be explained on the basis of the space-time variations in ionospheric parameters.

1. Introduction

During the past few years it has been found that the ionospheric structure varies in a coherent but complex pattern throughout the lifetime of an ionospheric storm. When the study of WWV reception by Obayashi [1958] was made, the occurrence of PCA's had not yet been discovered. It is now known that prior to the onset of a geomagnetic storm intense absorption of HF radio waves usually occurs in polar regions. Also, there was not as clear a picture as there is now of the extent and movement of large regions of auroral-zone absorption and sporadic-E clouds associated with geomagnetic storms. In the present study, reception of WWV during a particularly severe ionospheric storm is analyzed, together with vertical-incidence radio soundings. The period covered will include the day previous so that reception during undisturbed conditions may be evaluated.

WWV data has been chosen for three reasons. First, the locations of the receiving stations (fig. 1) are in subauroral, auroral, and polar-cap regions. From these links it is possible to demonstrate how a given phase of an ionospheric storm affects HF circuits. Second, the data is recorded on a quality scale, so there is some measure of received signal strength. Third, since the analysis of WWV data includes a frequency range of 2.5 to 25 Mc/s, it is possible to show, on a given link, what frequencies are affected and in what time sequence.

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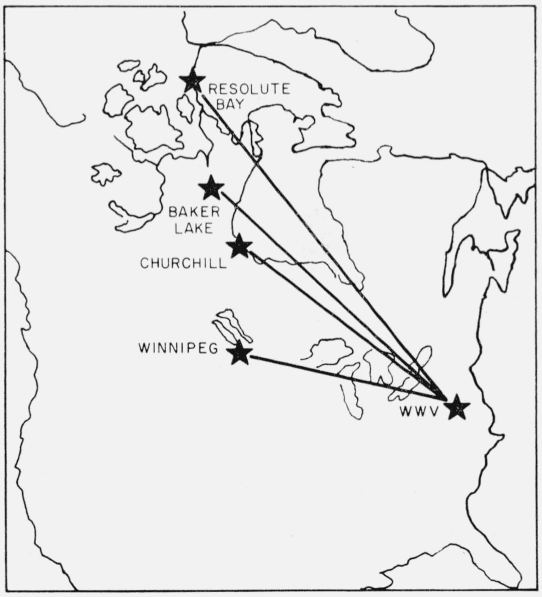

FIGURE 1. *Map of Canadian stations receiving WWV.*

2. Ionospheric Storm

To evaluate the effect of a severe but representative storm on WWV reception, the 11 through 15 September 1957 storm was studied. During this storm, typical patterns of anomalies in ionospheric structure were found [Hill, 1960]. The first was low-latitude absorption of radio waves associated with the occurrence of a class-three solar flare early on the 11th. After about a day, enhanced absorption was observed in polar regions. Such polar-cap disturbances usually begin within a few hours after a solar flare, but in this case the delay was longer. However, once the polar-cap absorption (PCA) began, the storm behaved in a rather typical way. During the PCA phase, geomagnetic activity was low and the F layer remained normal. On the 13th, enhanced absorption in the auroral zone, an extensive sporadic-E cloud, and a depression of the $F2$-layer critical frequency were found. By the time the f_0F_2 disturbance became fully developed, both the auroral-zone absorption and sporadic-E cloud had dissipated considerably. On the 14th and 15th, the $F2$-layer critical frequency gradually returned to normal.

3. Data and Method of Analysis

WWV data of several Canadian stations are recorded hourly on the basis of a quality index, which consists of whole numbers 0 to 9, representing no reception to excellent reception [Canadian Defence Research Board, 1957]. The quality index, S, is dependent upon signal strength, noise level, amount of fading, and personal bias. In spite of the number of factors affecting the index, hourly S indices provide a means to analyze quantitatively the reception of WWV during changing ionospheric conditions.

The structure of the ionosphere is represented by a spatial analysis of several ionospheric parameters. These are the $F2$-layer critical frequency, f_0F_2, the sporadic-E critical frequency, f_0Es, the regular E-layer critical frequency, f_0E, and the minimum recorded frequency, $f$min. Synoptic charts of these parameters have been constructed for the five-day period for every hour, so that the value of each parameter is available at the appropriate locations and times.

To show the effects of $F2$-layer disturbances, the reception quality at 20 Mc/s is used. At this frequency, reception is mainly affected by the value of f_0F_2. To make the comparison, reception quality at 20 Mc/s is plotted as a function of time along with f_0F_2. The other ionospheric parameters are also available for comparison, so the analysis may include occasions when absorption or sporadic-E affect 20 Mc/s reception.

To show the effects of absorption, the reception quality at 10 Mc/s is used. At this frequency, reception is usually good under normal conditions, yet it is quite sensitive to absorption. Therefore, the reception quality at 10 Mc/s is plotted along with values of $f$min for comparison. In the case of a one-hop mode, values of $f$min are measured from two points, i.e., where the signal passes through the D-region. For two hops, the measurements are taken from four points. Whether 10 Mc/s propagation is via a one or a two hop mode will usually depend upon the ion density of the E or Es layer.

Investigation of WWV reception quality at the other four frequencies has revealed that there are no additional factors governing the behavior of reception other than those affecting 10 and 20 Mc/s [Herman and Penndorf, 1961]. That is, reception on 2.5 Mc/s is mainly affected by absorption, as it is on 10 Mc/s, while reception on 15 and 25 Mc/s is mainly affected by f_0F_2, as it is on 20 Mc/s.

This method of analysis, described above, is illustrated in figure 2. As stated before, reception at 20 Mc/s and f_0F_2 are plotted together and appear on figure 2a. The stations Resolute Bay, Baker Lake, Churchill, Winnipeg, and Washington, represented by the letters RB, BL, CH, WI, and WA, respectively, are indicated on the ordinate according to their distance from Washington, so in a crude way the ordinate is representative of latitude. Each of the other four marks on the ordinate (between WA and WI) represents the midpoint of each path where f_0F_2 is measured. Both 20 Mc/s reception data and f_0F_2 are plotted on the same graph because the two sets of data do not overlap. The isopleths drawn on figure 2a connect points of equal reception quality (top) and points of equal f_0F_2 (bottom). In this manner the space-time patterns are easily visualized.

In figure 2b, $f$min is shown. It will be noticed that the analysis itself covers most of the region between Washington and Resolute Bay. The reason is that signals pass through D-region, not at the path midpoints, but at points about one-quarter and three-quarters of the distance between Washington and each of the receiving stations.

In figure 2c, values of reception quality at 10 Mc/s are shown. This graph is plotted in the same way as is the quality index at 20 Mc/s. On the bottom graph (fig. 2d), f_0Es is shown; values of f_0Es have been plotted in the same way as with $f$min.

4. Results

The graph of reception quality at 20 Mc/s in figure 2a shows distinct patterns. The main one is a period of good reception between about 13 and 03 UT (except at Resolute Bay). This is most apparent on the 11th and 12th when the F layer is undisturbed. The reception pattern on these days has been shown to be representative of normal conditions [Herman and Penndorf, 1961]. On the 13th and 14th, reception is severely reduced, but on the 15th it is near normal. This behavior is consistent with the values of f_0F_2. Good reception at Winnipeg, Churchill, and Baker Lake occurs when f_0F_2 is above 7 or 8 Mc/s. Therefore most of the 20 Mc/s reception during the five-day period occurs in five separate intervals between 13 and 03 UT. Reception is also present on the 13th between 03 and 09 UT. During these hours on other days, reception is usually absent. A strong sporadic-E layer (fig. 2d) is undoubtedly the cause of this anomalous reception. In addition, on the 13th, 20 Mc/s is received at the lower latitude stations between 11 and 19 UT, but with lower-than-normal quality. f_0F_2 appears to be too low to support these signals, suggesting that some sporadic-E is again present between Winnipeg and Washington. However, inspection of ionograms taken at Ottawa does not bear out this

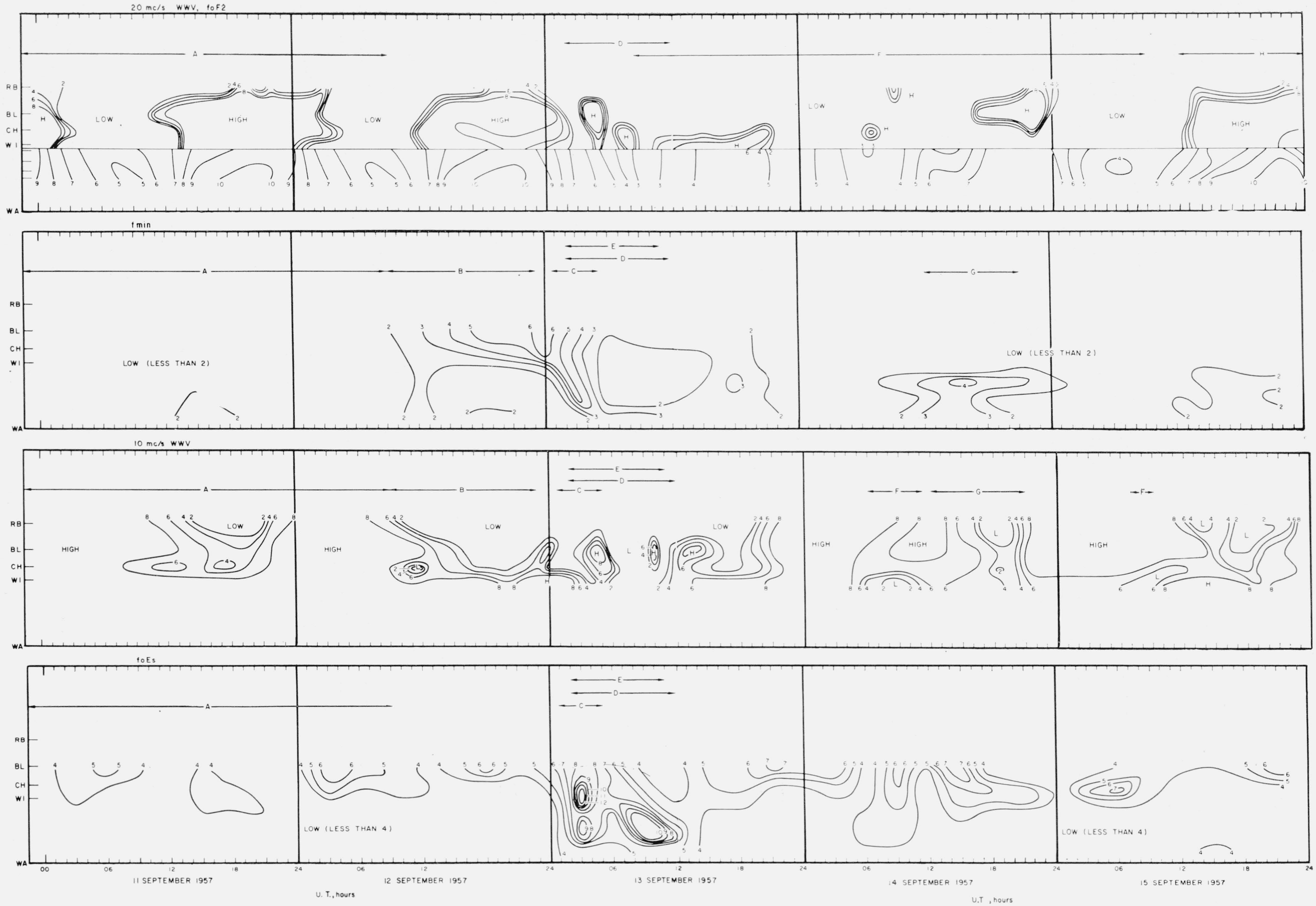

FIGURE 2. *Temporal and geographic variations of WWV reception quality and associated ionospheric parameters.*

In 2a are shown 20 Mc/s quality index and foF_2; in 2b, *f*min; in 2c, 10 Mc/s quality index; and in 2d, *foEs*. Variations in reception quality and in ionospheric parameters are separated according to the phase of the storm. Note that the letter designation of each phase also appears on the graphs for the relevant time intervals.

A. Undisturbed ionosphere
B. Development of polar-cap absorption
C. Dissipation of polar-cap absorption
D. Sporadic-*E* cloud
E. Auroral zone absorption
F. *F*2-layer disturbance
G. Reappearance of auroral zone absorption
H. *F*2-layer recovery

suggestion. Another possibility is that the regular E layer will support 20 Mc/s between the two stations provided that there is not much deviative absorption around the critical frequency (4Mc/s). Another interval of reception is on the 14th between 06 and 09 UT. This reception is much less significant than the first anomaly. It is probably due to sporadic-E, which extends southward to the vicinity of Washington.

On the graph of $f$min there are three main features. These are polar-cap absorption on the 12th, auroral zone absorption early on the 13th (which appears on the graph as a tongue extending southward), and a return of auroral zone absorption during daylight hours on the 14th.

On the graph of reception quality at 10 Mc/s (fig. 2c), the pattern should be considered first in terms of the quiet ionosphere, represented by the 11th, and then departures from quiet reception in terms of ionospheric disturbances. Accordingly, reception on the 12th is normal until 12 or 15 UT. After that the reception quality is markedly reduced, as would be expected, by the development of polar-cap absorption. Reception on the 13th is governed by auroral zone absorption and sporadic-E until about 12 UT. For the remainder of the day, reception is below normal but not strongly so. This reduction is probably due to the presence of enhanced daytime absorption. On the 14th, reception between about 06 and 12 UT is well below normal at Winnipeg. Also, during this interval the $F2$-layer critical frequency is very low. This value of f_0F_2 multiplied by the secant of the incidence angle is less than 10 Mc/s for Winnipeg, but greater than 10 Mc/s for the other stations. Thus, the F layer could not support 10 Mc/s transmissions to Winnipeg. Reception is weak even after 12 UT, but for another reason. Although f_0F_2 is increasing, good reception is prevented by the return of auroral zone absorption. On the 15th, reception is only slightly disturbed since the reception pattern is similar to that on the 11th.

From the bottom graph in figure 2 it is readily seen that there is a high percentage of sporadic-E near Churchill and Baker Lake. Sporadic-E extends well south of the auroral zone for only a short time. This occurs on the 13th between 00 and 12 UT during which time strong f_0E_s covers most of Canada and northern United States.

5. Conclusions

Comparison of WWV data with ionospheric parameters shows that the behavior of HF circuits during an ionospheric storm is closely linked with the storm's detailed development. This is the reason why not all circuit paths and frequencies are affected simultaneously. The major ionospheric factors governing the observed propagation anomalies are polar-cap absorption, auroral zone absorption, sporadic-E (auroral zone), and $F2$-layer depressions. Because each of these phenomena affects some geographic regions more than others, there are likewise differences in HF propagation depending upon where the circuit is located.

It is evident that the behavior of WWV reception in the Arctic during the ionospheric storm studied here can be adequately explained on the basis of the space-time variations of f_0F_2, f_0E_s, and $f$min. Because the September 11 to 15 storm development may not be typical of all storms, the pattern of radio reception will not necessarily be the same in all cases. However, the reception will be specified by the same ionospheric parameters regardless of the storm development. Thus, by knowing such space-time variations for other classes of storms, the communications engineer could provide improved communications reliability. This would be done by utilizing the ionospheric structure in the most favorable way through proper choice of frequencies and circuit routing.

6. References

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