Geofísica Internacional (1993), Vol. 32, Num. 1, pp. 15-20

Ionospheric measurements conducted during the July 11, 1991 solar total eclipse at the ionospheric station "El Cerrillo", Mexico

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Received: 20 May, 1992; accepted: 8 February, 1993.

RESUMEN

Se presenta una descripción general de mediciones ionosféricas realizadas con un equipo de radiosondeo C4 desde la estación "El Cerrillo" en México durante el eclipse total de Sol del 11 de julio de 1991. Se obtuvieron un total de 52 ionogramas desde 20 minutos antes hasta 38 minutos después del eclipse. Los ionogramas cubren un rango de frecuencia entre 2.5 MHz y 20 MHz y están distribuídos en intervalos de 1 minuto de tiempo. Los resultados muestran una rápida caída de los valores f_oF_1 y f_oE_s antes de la totalidad y una clara recuperación después de ella. Las variaciones observadas son similares a aquellas inferidas de mediciones en la estación ionosférica Maui en Hawaii, la cual estuvo también localizada dentro de la zona del eclipse de Sol del 11 de julio de 1991.

PALABRAS CLAVE: Estación ionosférica en México, radiosondeo, ionogramas.

ABSTRACT

A general description of the ionospheric measurements conducted during the solar total eclipse of July 11, 1991 with a C4 ionospheric sounder at the El Cerrillo station in Mexico, is presented. A total of 52 ionograms were obtained from 20 minutes before to 38 minutes after totality. The ionograms cover the 2.5 MHz to the 20 MHz frequency range and are distributed evenly in 1 minute time intervals. They show a clear decrease of the f_oF_1 and the f_oE_s values prior to totality and an equally remarkable increase in the recovery phase. The observed variations are similar to those inferred from measurements carried out at the Maui, Hawaii, ionospheric station which was also located along the path of totality of the July 11, 1991 eclipse.

KEY WORDS: Ionospheric station in Mexico, ionosounder, ionograms.

INTRODUCTION

The ionospheric conditions present during the solar eclipse of July 11, 1991, were recorded with various instruments located both within and outside the totality path. Two ionospheric stations, one at Maui in Hawaii, and the other at El Cerrillo, Mexico, were located within the Lunar umbra, and at least three other stations (in San Diego, Ca, in Boulder Colo., and in La Havana, Cuba) were located in the penumbra region. Here we will describe the measurements conducted at the Mexican station which is located about 20 km north of the City of Toluca (Geomagnetic longitude $\Phi = 32°$W, Geomagnetic Latitude $\lambda = 29°$N, Geomagnetic dip angle $I = 48°$). At this site the eclipse occurred between 17 52:49 UT (first contact) and 20 47: 00 (fourth contact). Totality took place between 19 19:50 UT and 19 26:33 UT. The nearly seven minutes duration of the latter phase made this eclipse one of the longest of the 20th century.

Ionospheric measurements have been carried out regularly at the El Cerrillo station since 1959 with a C4 ionospheric sounder property of the Ministry of Communications of Mexico. The peak output power of the C4 sounder is 10 kW and its pulse repetition rate is 30 per second. A general description of its operation has been presented by Nuñez-Arellano (1962). The instrument did not operate in the late 80's but has now been fully rehabilitated and is in continuous monitoring duties (reports on daily and seasonal ionospheric variations inferred from El Cerrillo data have been presented by Pérez-de-Tejada, 1973).

MEASUREMENTS

The sequence of measurements was initiated at 19 01 UT, i.e. 19 minutes before the beginning of totality. A total of 52 usable ionograms were prepared up to 20 04 UT, i.e. 38 minutes after the end of totality. The measurements were taken in ~1 minute intervals throughout this period and were not interrupted during totality.A general summary of results is presented in Table 1. This includes the cut-off frequencies and virtual heights of the F1 and F2 regions. In order to better describe the gradual variation of the geometry of the h'(f) trace, a sequence of selected ionograms is reproduced in Figure 1 beginning with the first usable frame at 19 01 UT and ending with the last one at 20 04 UT. Each frame is representative of those obtained at neighbouring times in such a way that a gradual but distinct change of conditions can be appreciated among them. Most evident is the decrease of the f_oF_1 value during the event. This decrease is so severe that beginning at 19 15

Table 1

	UT	foF1 (Mhz)	h'F1(km)	foF2 (Mhz)	h'F2(km)
1	19 01	3.5	210	11.4	325
2	19 02	3.5	200	11.4	320
3	19 04	3.4	200	11.4	320
4	19 05	3.3	200	11.4	320
5	19 06	3.3	200	11.4	315
6	19 08	3.2	190	11.4	310
7	19 09	3.2	195	11.4	310
8	19 10	3.1	240	11.4	305
9	19 11	3.0	195	11.4	305
10	19 12	3.0	185	11.4	300
11	19 13	2.9	180	11.4	295
12	19 14	2.7	180	11.4	290
13	19 15	2.8	260	11.3	290
14	19 16			11.3	285
15	19 17			11.3	285
16	19 19			11.4	285
17	19 20			11.4	280
18	19 21			11.4	290
19	19 22			11.4	275
20	19 23			11.4	270
21	19 24			11.4	270
22	19 25			11.4	270
23	19 26			11.4	270
24	19 27	2.6	255	11.3	270
25	19 28	2.7	225	11.3	275
26	19 30	2.9	225	11.2	280
27	19 31	3.0	220	11.2	280
28	19 32	3.1	220	11.2	280
29	19 33	3.2	220	11.1	280
30	19 35	3.2	220	11.1	285
31	19 36	3.2	225	11.1	290
32	19 37	3.3	220	11.0	290
33	19 38	3,4	220	11.0	290
34	19 40	3.5	225	11.0	290
35	19 41	3.6	225	11.0	305
36	19 42	3.7	220	10.9	290
37	19 43	3.8	190	10.8	290
38	19 45	3.8	180	10.8	290
39	19 46	3.9	180	10.7	295
40	19 47	3.9	220	10.8	290
41	19 48	4.0	185	10.8	295
42	19 49	4.0	230	10.7	300
43	19 51	4.0	215	10.8	300
44	19 52	4.1	215	10.9	305
45	19 53	4.1	220	10.8	310
46	19 54	4.2	215	10.8	310
47	19 56	4.2	220	10.8	310
48	19 58	4.2		10.7	
49	19 59	4.3	230	10.6	315
50	20 01	4.3	225	10.7	315
51	20 03	4.4	230	10.7	315
52	20 04	4.4	230	10.6	315

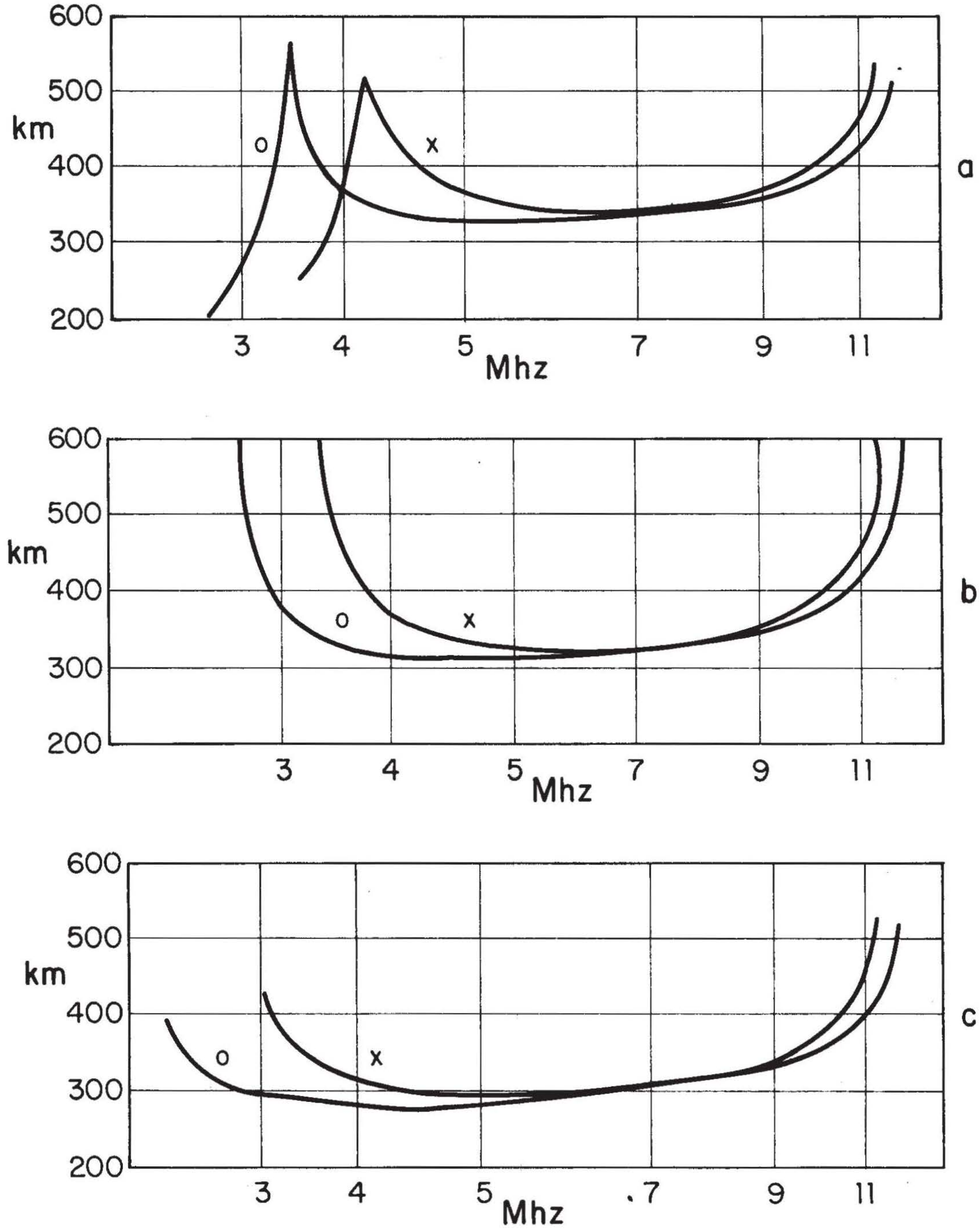

Fig. 1. Sequence of ionograms obtained with the C4 ionospheric sounder at El Cerrillo during the total solar eclipse of July 11, 1991. The frames are labeled as follows: (a) at 19 01 UT, (b) at 19 14 UT, (c) at 19 27 UT. In all frames the ordinary and extraordinary waves are marked by the labels "o" and "x" respectively.

UT (five minutes before totality) that value ocurred below the lowest effective operating frequency of the instrument (f_{min} ~ 2.5 MHz). The f_oF_1 value was recovered at 19 27 UT (nearly one minute after totality) and shows a gradual increase up to about 4 MHz. It is to be noted that this latter value of the cut-off frequency of the F1 region does not represent that of the normal ionospheric conditions at the site. This is due to the fact that the entire observation period ocurred within the time when the ionosphere was already perturbed by changes of the solar ionizing flux during the initial and ending phases of the eclipse.

Unlike the f_oF_1 value the cut-off frequency of the F2 region (f_oF_2 value) shows little change across the entire observation period. In all the ionograms we find 10.5 MHz $< f_oF2 <$ 11.5 MHz with a slight but consistent tendency to the lower values as the eclipse progressed. In this case the cut-off frequency occurs within the range of normal (unperturbed) conditions.

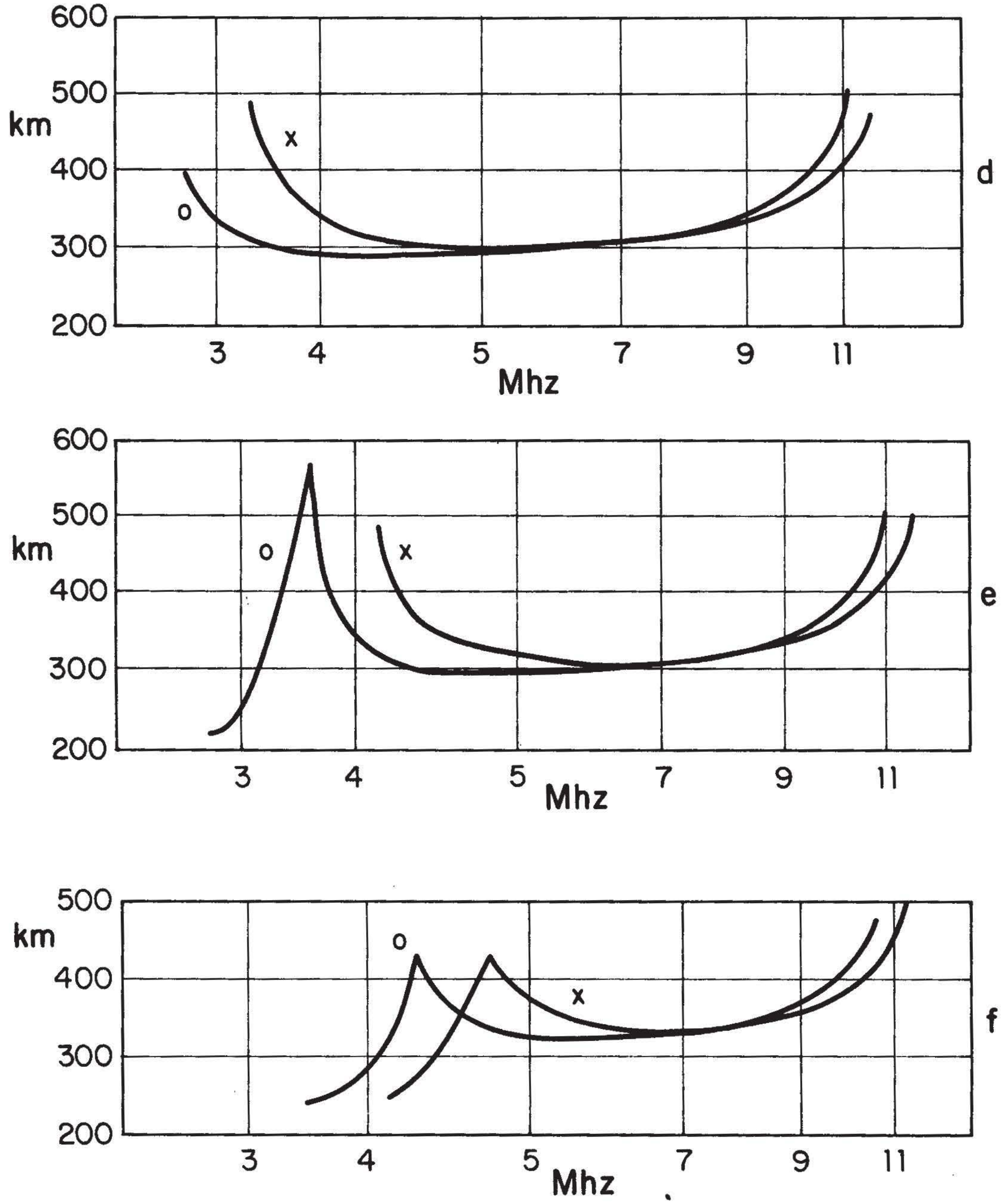

Fig. 2. Same as Figure 1 for the ionograms prepared at: (d) at 19 31 UT, (e) at 19 40 UT, and (f) at 20 04 UT.

Evidence of sporadic E layer is also present in some ionograms. The f_bE_s value (not included in Table 1) decreased during the event and, as was the case for the f_oF_1 value, occurs below the f_{min} frequency during totality. This limitation is even more stringent for the f_oE value which, in fact, is available only in a few of the last frames. The relatively high minimum operating frequency of the instrument prevented the identification of the E region throughout most of the observation period. An overall view of the variation of the f_oF_2, f_oF_1, f_bE_s, and f_{min} values from all 52 ionograms is presented in Figure 2. As noted earlier the interval shown corresponds to the time around totality and does not include the initial and ending phases of the eclipse. Thus, much larger f_oF_1 and f_bE_s values existed prior to, and after, the observation period.

Independent of the variation of the various cut-off frequencies the sequence of ionograms shown in Figures 1 and 2 illustrate consistent and well defined changes in the morphology of the recorded h'(f) traces. In particular, the section between f_oF_1 and f_oF_2 of the ordinary wave (marked "o" in all frames) experiences a gradual but uniform change from the beginning to the end of the observation period. In the first ionograms (represented by the frame labeled a) the trace exhibits a certain curvature and reaches a minimum virtual height of ~ 320 km. As the eclipse progressed the ionogram trace changes to a more flattened shape which, in addition, decreases to lower virtual heights. At 19 14 UT (before the beginning of totality) the bottom section of the h'(f) trace between the f_oF_1 and the f_oF_2 frequencies has dropped below 300 km and exhibits a certain deformation which becomes more noticeably in later frames. The deformation has the shape of a break or inflection point at ~4.6 MHz and may be related to irregularities in the position of the constant-height markers.

The virtual height of the trace decreases most noticieably before totality and remains nearly unchanged during this latter phase and shortly after the third contact. In particular, the minimum virtual heigth remains at the low ~ 280 km value between 19 14 UT (frame labeled b) and 19 31 UT (frame labeled d) and begins a gradual recovery to its initial position after the latter time. At 19 40 UT (frame labeled e) the minimum virtual heigth is comparable to that seen at 19 14 UT (frame labeled b) while at 20 04 UT UT (frame labeled f) that value has moved back to the one observed at 19 01 UT (frame labeled a).

A similar variation is also apparent for the extraordinary wave (labeled x) even though its geometry is somewhat different. The identification of distortions in the extraordinary wave is complicated by the superposition of both signals between the f_oF_1 and the f_oF_2 frequencies.

DISCUSSION

The fact that the path of totality of the July 11, 1991 eclipse passed over two ionospheric stations (at Maui, Hawaii, and at El Cerrrillo, Mexico) made it possible to prepare independent data sets under different illumination angles. Unlike the near midday conditions present at the El Cerrillo, the eclipse occurred shortly after sunrise at Maui and thus led to the perturbation of a local ionosphere under vastly different conditions. While the Maui data will be reported elsewhere (R. Conkright, personal communication, 1991) we note that the ionograms show variations similar to those reported here. Most notable is the fact that the behavior exhibited by the f_oF_1 value is remarkably close to that recorded at El Cerrillo and that a comparable decrease and recovery of that value is present around totality. This result may be a consequence of the fact that both the production and the loss of ionized material control locally the distribution of ionized material in the F1 region. This is not the case for the F2 region where the concentration of ionized material varies only slightly throughout the eclipse and thus the measured values depend strongly on the existing ionization. In the Maui data the f_oF_2 value remained near 6 MHz throughout the event (instead of the ~ 11 MHz measured at El Cerrillo) accordant to the different local solar angle at the time of the event in both stations (in the early morning hours the F2 region shows typically lower peak densities than at midday).

In addition to changes in the peak density of the ionospheric regions, the different geometry of the h'(f) trace observed at El Cerrillo throughout the eclipse may reflect structural changes in their distribution. For example, the flattening of the trace and the decrease in virtual height of the section between the f_oF_1 and the f_oF_2 frequencies near and during totality may be related to different vertical distributions within the F2 region. In particular, as the local source of ionization is diminished at the bottom of that region during the eclipse, a downward transport of material may occur thus resulting in a steeper vertical gradient at those altitudes and a certain flattening of the ionogram trace between the f_oF_1 and the f_oF_2 frequencies. On the other hand, the flat aspect of the trace may also result from the larger frequency difference between the F_oF_1 and the F_oF_2 values at that time (the decrease of the first frequency while the second remains nearly unchanged should contribute to produce a flattened trace).

A search was conducted among the 52 ionograms to identify the possible presence of the so-called $F_oF1.5$ critical frequency. That feature has been reported in the past as a ripple in the section of the ionogram trace between f_oF1 and F_oF2 during and shortly after the totality phase of some solar eclipses (Minnis, 1955; Ratcliffe, 1956). However, except for the above-mentioned distortion at the bottom of the trace seen in some of the ionograms of Figures 1 and 2 there is no evident indication of a feature that could be identified as the $f_oF1.5$ critical frequency. While we cannot entirely rule out the possibility that the observed distortion or some other feature present in the data may be associated with that phenomenon it is to be noted that most positive identifications have occurred from measurements in which the local geomagnetic dip angle is small ($I<20^o$) (see, Ratcliffe, 1956). This condition is not applicable to the el Cerrillo station where, as noted earlier, $I = 48^o$.

ACKNOWLEDGMENTS

Many individuals contributed to the success of the observations reported in this work. Foremost is S. Barnes Jr. whose competence and dedication proved vital to the rehabilitation of the C4 ionospheric sounder at EL Cerrillo. My appreciation is also extended to R. Conkright of the National Oceanic and Atmospheric Administration of the US, and to R. Galán, head of the Department of the Ministry of Communications of Mexico in Toluca for their encouragement and support. Thanks are also given to M. García Cisneros, F. Gómez-Rebollo and M. Corona, for technical support provided.

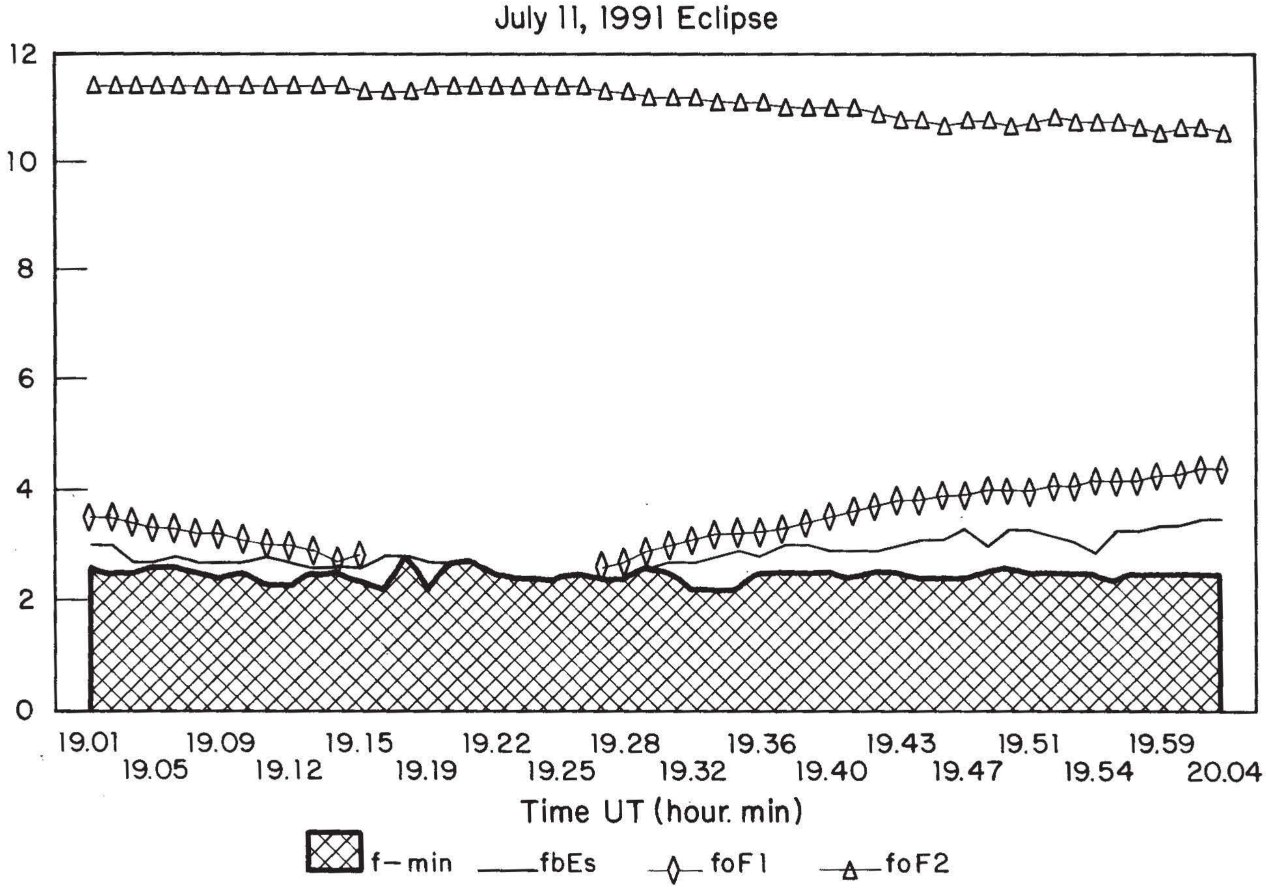

Fig. 3. Summary of critical frequencies f_{min}, f_bE_s, f_oF_1, and f_oF_2 measured from the 52 ionograms obtained throughout the observation period of the July 11, 1991 eclipse.

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