Ionosonde 'fplots', A gift for the International Reference Ionosphere and for Space Weather today, from the 20th century

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1. Introduction

At the time of the International Geophysical Year in January 1957, about 200 of earth's ionosonde observatories were following the recommendations of the International Scientific Radio Union regarding the manual reduction ('scaling') of analog ionograms (Wright, et al., 1956). New with the IGY was a graphical daily 'fplot' of which several examples are shown in this document. Our present purpose is to re-awaken interest in this resource, and to suggest some steps by which it can be salvaged for modern use.

Approximately 300,000 daily fplots were generated by hand during the years 1957 through 1983; about 118 of the participating stations produced them for at least one solar cycle. A detailed listing is available (Conkright, et al. 1984).

The typical fplot is a sheet of special graph paper, 26.7 by 40.7 cm, ruled at 15 minute intervals between 0000 and 2400 local time along the abscissa. The ordinate axis is somewhat variable among observatory administrations, but generally includes the radio frequency range 1 – 20 MHz. The Maui Hawaii observatory, source of our examples, followed the US practice: a strictly logarithmic axis from 0.25 – 20.0 MHz. A small secondary graph, not to be discussed further here, displays the occurrence of 9 defined Sporadic E types.

2. Information content of fplots.

fplots display the time variation of distinctive frequency characteristics evident on most ionograms. Proceeding from low frequencies, the following quantities are usually recorded from each 15 minute ionogram:

fmin: a ruled line extending from the lowest sounding frequency up to a filled circle at the frequency of the first observed echo. *fmin* is useful when it is determined by D-region absorption. In Figure 1, *fmin* varies characteristically with solar zenith angle between 0600 and 1800 LT. In Figures 2, 3, 4 (the same station-day) a rather different variation is seen between 0800 and 1100 LT, probably the result of a solar flare (or perhaps two flares, in this case). At other times, *fmin* may be nearly constant at 1.5 MHz a result of MF broadcast interference.

foE: disconnected open circles representing the E-layer peak plasma frequency. The E-layer is dependably produced by solar radiation in daytime; other sources may also contribute to the E region (Titheridge, 2000).

fbEs: small, connected filled circles. When Sporadic E (Es) is present, it often "blankets" or obscures radio reflection from the overlying ionosphere, up to a frequency that is now generally accepted to represent the peak plasma frequency of the Es layer within the wide-angle (~100° full width) view of the ionosonde.

foF1: disconnected open circles; sometimes 'L' instead: When the F-region ionization production peak is distinct (e.g., usually in summer daytime) foF1 expresses the resulting peak plasma frequency. During summer sunrise and sunset periods, and throughout winter days, the peak is not distinct and only a dN/dh gradient inflection may be seen; its radio frequency is then plotted as 'L'.

foF2 and *fxF2*: symbols 'o' and 'x', denoting the F2 layer peak penetration frequencies of ordinary and extraordinary polarizations. They vary generally together, nominally separated according to $f_x^2 = f_o^2 - f_x \bullet f_H$ where f_H is the local electron gyrofrequency (about 1.0 MHz at Maui). Secondary propagation effects, together with meridional plasma gradients, cause small variations in $f_x - f_o$.

Spread F: vertical ruled lines, usually without symbols, within the *foF2*, *fxF2* pattern. The F-region is marginally unstable in its response to a number of causes, including gravity and variable winds, temperatures, and electric fields. In consequence, the region may become highly irregular, and over a wide spectrum of irregularity scales. Scales near the ionogram first Fresnel diameter (at group range R′ for the radio wavelength λ), $L_F = \sqrt{2\,l\,R'} \approx 10$ km, 'scatter' radio waves over wide angles, and with considerable variability of R′; the upshot is 'Spreading' of the penetration frequencies. The frequency range of this spreading, when it occurs, is represented directly on the fplot.

3. The IRI and Space Weather value of this Information.

We make no attempt to give a comprehensive account of the possible applications of fplot information, and instead wish to emphasize a few highlights.

Improved Time Resolution: The data on fplots are redundant with the widely available standard parameters (NGDC/NOAA, 1994), but fplots provide four times the temporal resolution of the hourly data of *fmin, foE, fbEs, foF1,* and *foF2* available in the IDD. The two fplots (e.g. Figures 1 and 2) show abundant examples of important fluctuations in each of these quantities, which would never be guessed from the hourly values. That they are genuine effects is evident from their serial correlations. Consider, for example:

The putative solar flare effects on fmin in Figure 2. Perhaps *foF2* and *fxF2* are similarly affected between 0800 and 0900 LT; in other examples, *foE* is also sometimes modulated by solar flares. Thus fplots contain quantitative information bearing on different portions of the flare emission spectrum, and on their temporal profiles.

fbEs variations in Figure 1, daytime. Mid-latitude Sporadic E layers are usually meteoric metallic ion concentrations, maintained by east/west shears in the neutral wind. Little is known of earth's meteoric material inventory, still less of its long-term variations. Little is known of wind variability near the 'turbopause'. fplots provide a unique multi-decade resource bearing directly on both topics.

AGWs, Figure 1, 1500 – 1900 LT. Atmospheric gravity waves frequently modulate the F-peak, and account for a major part of thermospheric variability. In this example, small oscillations of *foF2* and *fxF2* are seen, of about 2-hour period. Similar periods are seen, later, in *fbEs*. Such patterns are not uncommon on fplots, and are quite consistent with AGW influences on the ionosphere.

Global coverage: Recall that fplots are available from most of the ~200 IGY observatories, and for more than a solar cycle from at least half of them. We invite you to think through again, but globally, each of the three example fplot applications cited above: (1) Solar Flare radiation will be similar over all of the sunlit hemisphere, but its effects will reflect local differences of neutral composition and temperature. (2) Working out a global inventory of meteoric material is the only sense by which such an 'inventory' has value. As the inventory becomes better understood, the value of fbEs as a proxy for wind shears in the turbopause region is improved, and global coverage of *that* activity has important bearing on the boundary conditions for neutral composition of the thermosphere. (3) AGWs, by definition, propagate over large distances. The global AGW information in fplots incidentally contains important information for its own validation, whereupon important and unresolved questions of the sources and energetics of AGWs can be addressed.

Scintillations and Irregularity Diagnostics. The representation of Spread F on fplots, as described above, is much more than merely a resource for occurrence statistics. A study comparing Spread F with irregularity intensities measured by the OGO-6 satellite (Wright, et al., 1977) showed that the satellite *dN/N* was highly correlated with, and practically equal to, the frequency width of Spread F. The width was expressed as *df/f*, thus conforming to the length of the ruled lines for Spread F on the logarithmic frequency axes in Figures 1 and 2. In a later study, Wright and Argo (1996) present evidence that Spread F involves total reflection, thus implicating irregularities of the Fresnel scale defined above. This is also the scale range effective for the scintillation of satellite communication signals. Thus, fplots can provide a global and long-term database bearing directly on this signature aspect of Space Weather. But ***only if …***

4. fplots Can be Brought into the 21st Century.

The remainder of this document seeks to examine the problem of accessing fplots by modern information technology.

fplots can of course be obtained from data centers by photocopy in small quantities, and for 'case-study' purposes this is certainly to be encouraged. It appears that the only reason this has not happened more frequently, is simply a general lack of awareness, which perhaps this document can help to reverse. But global and long-term applications of fplots require two steps, and in the following order:

A. The ~300,000 paper original fplots must be scanned to machine-readable form, and then archived on more compact and exchangeable media such as CD-ROM or DVD.

B. An 'Optical Graph Interpretation' process akin to Optical Character Recognition (OCR) must be developed, to revert the graphic images to their numerical content.

Step (A) is valuable for the practical reasons stated, even if the development of step (B) is at present ill defined. Both (A) and (B) require the attention of their respective specialists, who would need little or no advice from us to make far more rapid progress than we can hope to do. This must be our final word at present regarding step (B). For step (A) we can do somewhat more to show, by Figures 2, 3, 4 below, the effect of available user options when a standard desktop scanner is used on photocopies of original fplots. The photocopying step (and photo-reduction) is necessary because of the oversize graph paper of the fplots. Industrial scanners (presumably) would not require this step.

The figure captions for Figures 2, 3, 4 summarize some user options of the HP ScanJet and HP Precision Scan Pro software used for these images, and their consequences for the resulting file size and image quality. Also shown are the number of resulting CD-ROMs (at 650MB each) for 300,000 fplots. An incomplete cost estimate based on $.05/fplot becomes $15,000 for the scanning plus $5/CD. The last pages are from the WebSite of one Service Bureau with (presumably) the competence to do this job. We show it without endorsement, and for general information only.

(end)

References

Conkright, R. M. Ertle, A. Feldstein, M. Hapgood, and N. Matuura, Combined catalog of ionosphere vertical soundings data. Report UAG 91, NOAA, Boulder Colorado 1984.

NGDC, NOAA, Ionospheric Digital Database, U.S. Dept. of Commerce, Boulder Colorado, 1994.

Titheridge, J. E. Modelling the peak of the ionospheric E-layer. J. Atmos. Solar-Terr. Phys. 62, 93-114, 2000.

Wright, J. W., R. W. Knecht and K. Davies, Ionospheric Vertical Soundings, Vol. III Part 1, Annals of the International Geophysical Year, W. J. G. Beynon and G. M. Brown, eds., Pergamon Press, London, 1956.

Wright, J. W., J. P. McClure and W. B. Hanson, Comparisons of ionogram and OGO 6 satellite observations of small–scale F–region inhomogeneities. *J. Geophys. Res. 82*, 548–554, 1977.

Wright, J.W. and P. E. Argo, On the radiophysics and geophysics of ionogram Spread F, *Radio Science,* 31, 349-366, 1996.

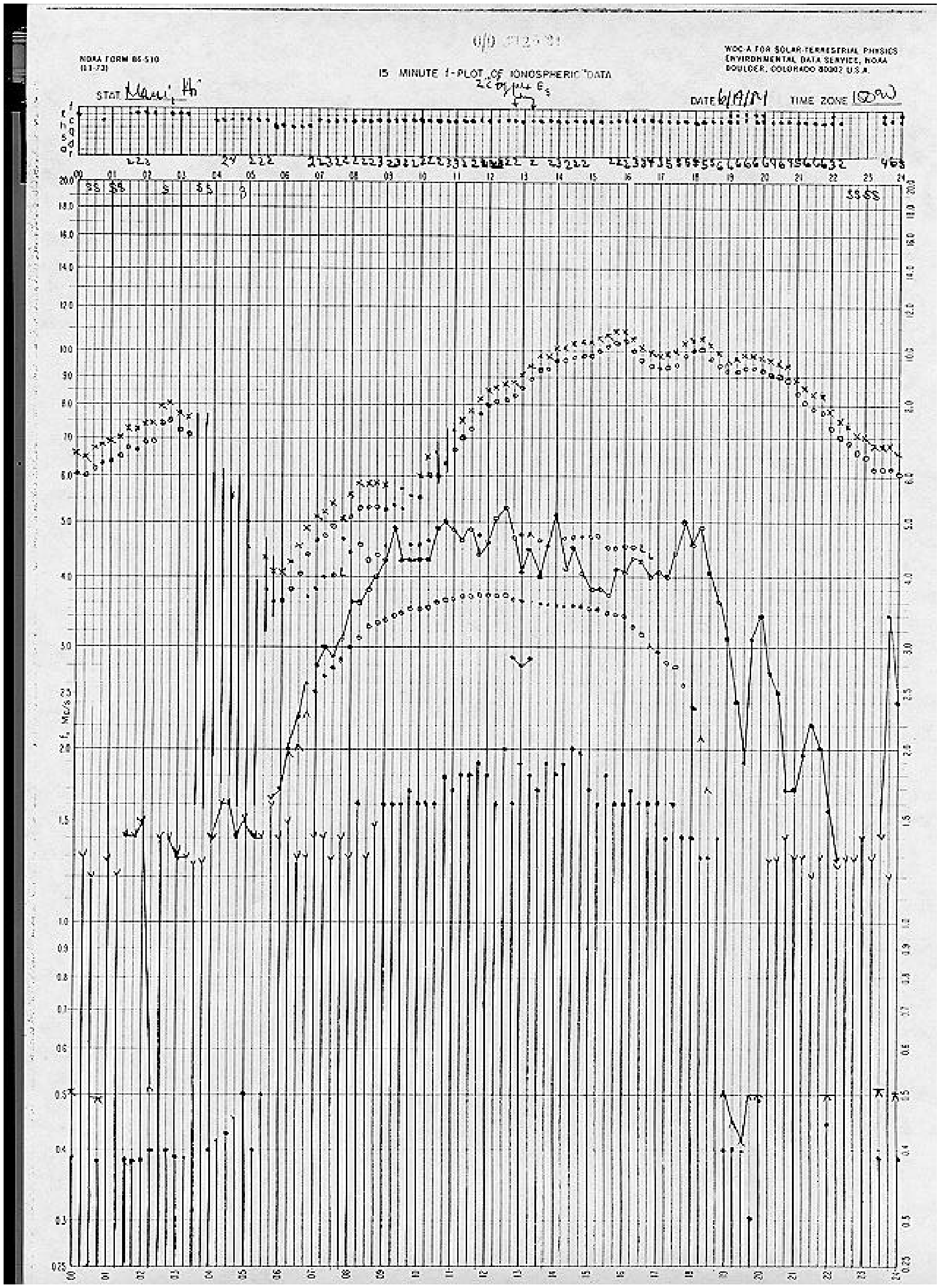

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Figure 1

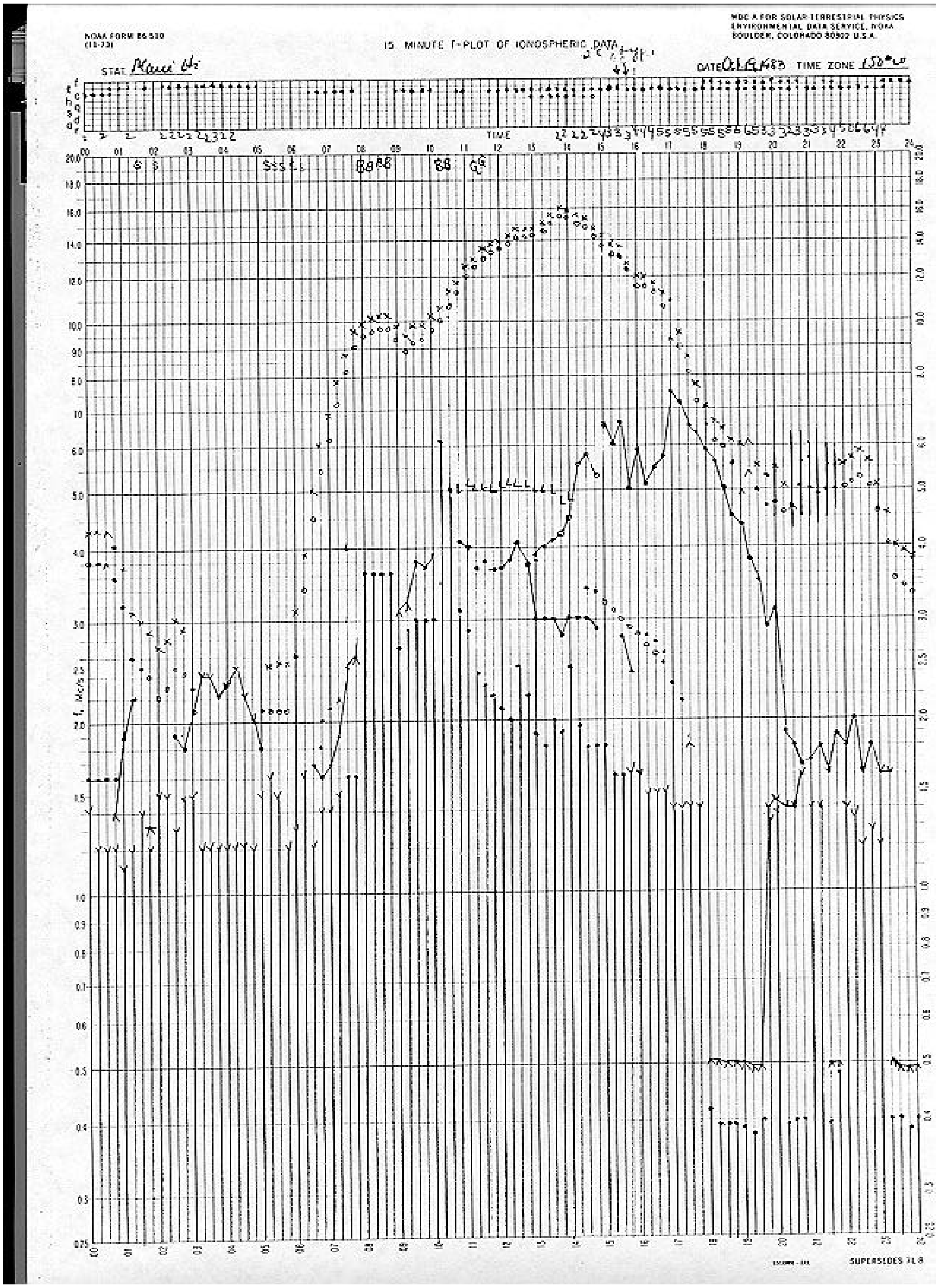

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Figure 2

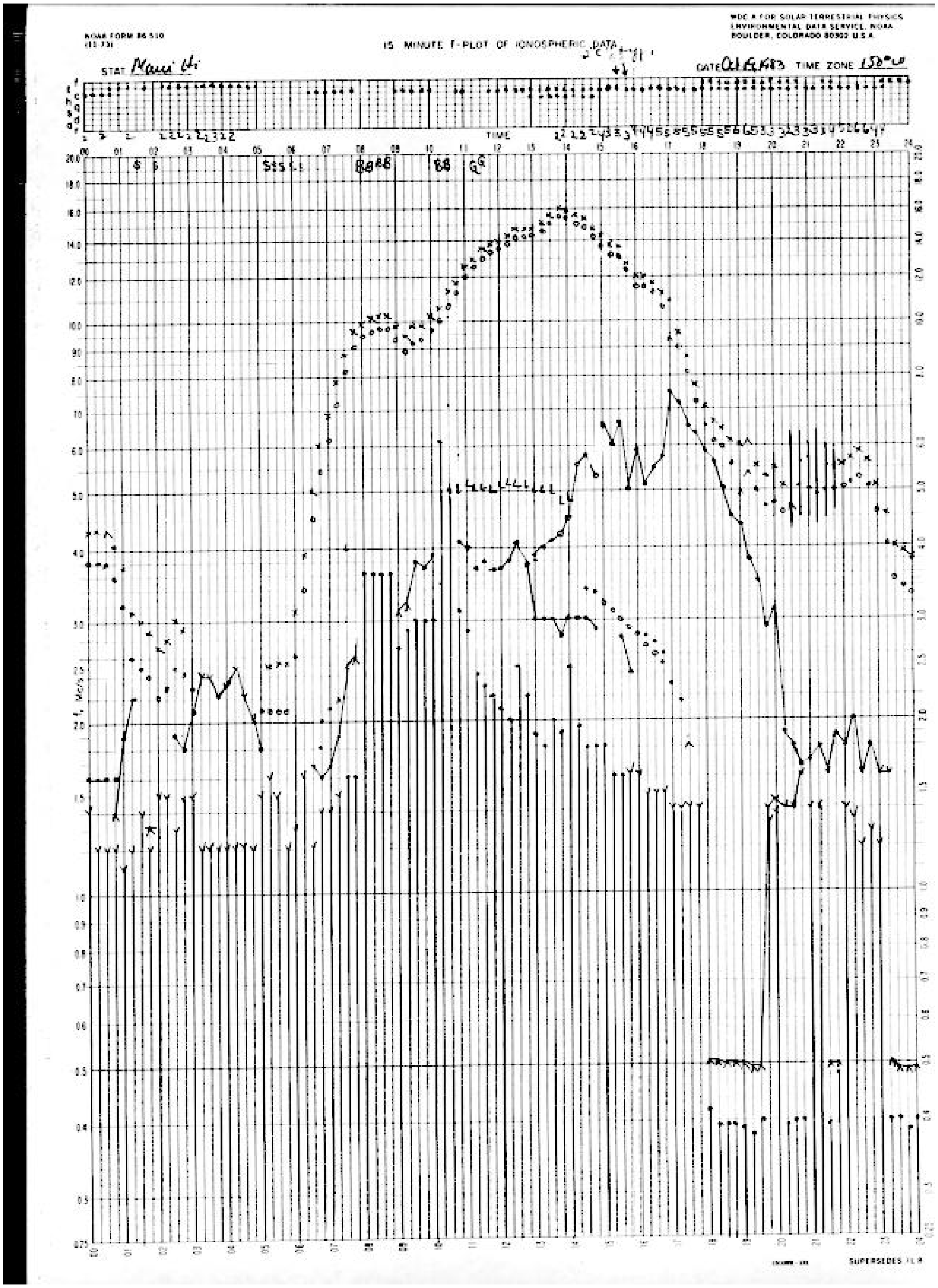

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Figure 3

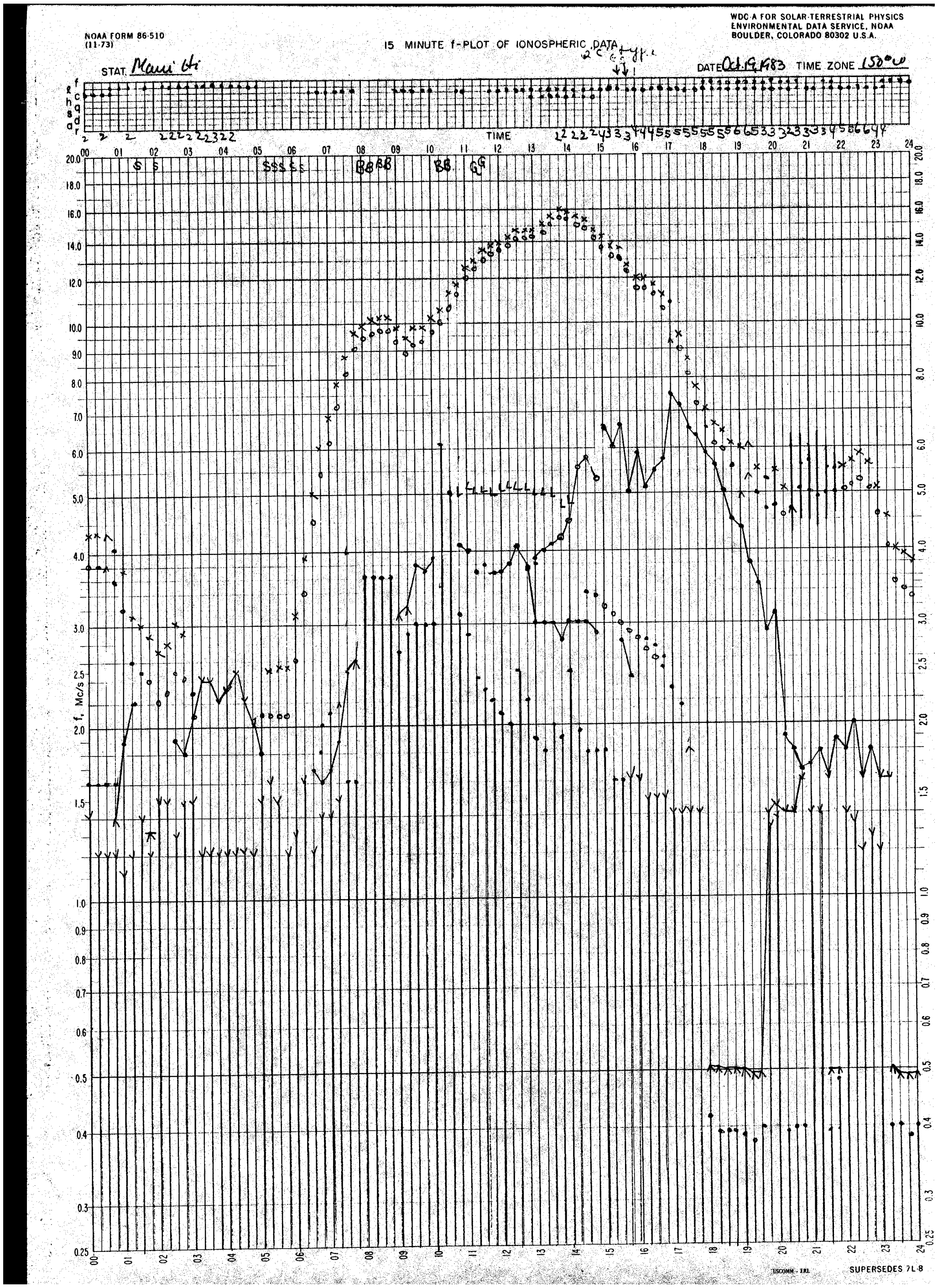

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Figure 4

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