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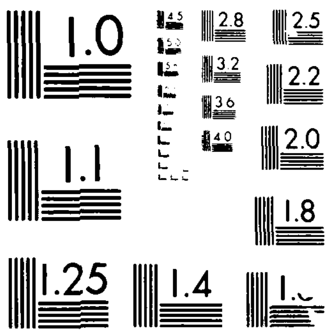

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The MUF (3000) as an Indicator for F-Region Variations

A. K. Paul

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Ionograms recorded at Brighton, Colorado during the last sunspot maximum are still being studied. Samples show that the high quality and high temporal resolution of the data may yield new information about the dynamics of the ionosphere, especially in the F-region. F-region parameters from these data show that this part of the ionosphere is highly variable, with short periods of the order of fractions of an hour.

This report explains why the maximum usable frequency (MUF) (3000) appears to be the most appropriate indicator for F-region variations.

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INTRODUCTION

During the last sunspot maximum in 1980 and 1981, ionograms were recorded at Brighton, Colorado with a new digital ionosonde developed by the Space Environmental Laboratory of National Oceanic and Atmospheric Administration (NOAA), cosponsored by the National Science Foundation. At the time the program was terminated in 1981, only a small percentage of the data recorded had been analyzed. The results of those samples indicated that the high quality and high temporal resolution of the data may yield new information about the dynamic of the ionosphere, especially in the F-region. This justified a more systematic and detailed study of all the data available. All the F-region parameters derived from the data show clearly that this part of the ionosphere is highly variable, with short periods of the order of fractions of an hour. These observations raise questions about the physical nature of the phenomena like cause, origin, propagation speed, and direction. They also provide some indirect information about the effects on high frequency (HF) propagation due to variable tilts of contours of constant electron densities. Mainly for application in the HF-propagation area, but also for correlations with other geophysical parameters, it is desirable to have a parameter that can give a first order estimate of the F-region variability. As will be discussed later, the maximum usable frequency (MUF)(3000) appears to be the most appropriate indicator for the F-region variability.

We will show that F-region oscillations are present all the time with variable intensity, that those variations are well represented by the MUF(3000), and that correct estimates of the rate of change of the MUF(3000) and therefore of the F-region variability require a sampling rate of at least 10 to 12 ionograms per hour, much faster than the standard rate of 4 ionograms per hour. Since very few ionogram sequences with a high sampling rate exist, we show plots of the MUF(3000) for all the rapid sequences taken during the lifetime of the program in the appendix A. For comparison we also show most of the 15-minute interval data in appendix B.

THE DATA

A short outline of some of the features of the ionosonde is appropriate for a better understanding of the quality and the information content of the data. A more complete technical description was given by Grubb (1979). Four receiving antennas located in the corners of a square with a diagonal distance of 100 m were an essential feature of the system. Echoes reflected from the ionosphere were recorded at two antennas simultaneously by a two-channel receiver capable of recording amplitude and phase of the signal. All data were digitized and then recorded on magnetic tape. A basic data set was obtained by sounding a pair of frequencies (differing by 8 kHz) and recording the echoes at all four antennas, which required the transmission of four consecutive pulses. The switching of antenna pairs and frequencies was performed in such a way that the variation of the phase with frequency could be separated from its variation with time. A typical switching sequence was

1.	pulse:	frequency f,	north-south antenna pair
2.	pulse:	frequency f,	east-west antenna pair
3.	pulse:	frequency f + 8kHz,	east-west antenna pair
4.	pulse:	frequency f + 8kHz,	north-south antenna pair

Usually the time interval between consecutive pulses was 20 msec. This configuration in space, frequency and time, and the high accuracy of the phase of 1 degree or better permits the evaluation of the following quantities (Paul et al., 1974):

- the angle of arrival of the echo from the variation of the phase with antenna location,
- the Doppler frequency or Doppler velocity from the change of the phase with time,
- improved estimate of the virtual height from the change of phase with frequency.

The ionosonde operates on a quasi-logarithmic frequency scale and depending on the frequency density selected, a high quality ionogram can be recorded in less than a minute.

During the period of time when the data in question were recorded, the digital ionosonde was in its final stage of development and extensive testing of hardware and software took place. For this reason, data were recorded in an irregular fashion. For example, very few data were recorded during the summer months of 1980. Also, during this time it became more and more evident that the standard sequence of recording ionograms in 15-minute intervals actually undersamples the more or less regular short-term variations of the ionosphere. Therefore, the majority of the rapid sequences of ionograms were taken toward the end of the program.

The standard automatic processing routine used for this study provides the following parameters for each ionogram:

foF2,	the critical (penetration) frequency of the F-layer for the ordinary component
fxF2,	the critical (penetration) frequency of the F-layer for the extraordinary component
hmoF2,	estimate of the height of the F-region maximum derived from the ordinary echo trace
hmxF2,	estimate of the height of the F-region maximum derived from the extraordinary echo trace
YmoF2,	estimate of the half thickness of the F2-layer derived from the ordinary echo trace
YmxF2,	estimate of the half thickness of the F2-layer derived from the extraordinary echo trace
MUF(3000),	(the maximum usable frequency over a 3000-km path), derived from the ordinary echo trace
fMUF,	the frequency of the tangential point of echo trace and MUF curve
hMUF,	the virtual height of the tangential point of echo trace and MUF curve
ZE,	the zenith angle averaged over the ordinary echoes at six frequencies in the vicinity of the tangential point
AZ,	the azimuth angle averaged over the ordinary echoes at six frequencies in the vicinity of the tangential point
ftFs,	the highest frequency where an F-region echo is observed

While all the F-region parameters listed above do reflect the changes in the F-region, most of them do not qualify as a good variability parameter for various reasons. For example, the height of maximum and even more, the half-thickness are both extremely sensitive to small deformations of the layer and temporal changes of those parameters cannot be easily interpreted as changes in height or electron density. This is also true for the quantities fMUF and hMUF. For these reasons the following discussion of a variability parameter will be limited to the parameters foF2 and MUF(3000).

Approximately 23,000 ionograms recorded at Brighton were processed to obtain for each one all the parameters listed above. The same type of digital ionosonde became operational in late 1980 at White Sands, NM. Unfortunately, most of the data recorded there are, for various reasons, not well suited for automatic computer processing. This is especially true for the overlapping period of time when both systems were operational and only very few data were available for comparison of the two sites. For these reasons no White Sands results will be reported here.

THE MUF(3000)

The maximum usable frequency over a 3000-km path can be derived from a vertical ionogram. The process is based on the relationship between the vertical and oblique frequency to be reflected at a given height for a given electron density distribution. If the electron density is a function of height only, it is sufficient to know the vertical ionogram to establish this relation (Smith, 1939). In the traditional analog process, the MUF(3000) is determined by overlaying a set of transmission curves on the ionogram. The virtual height-frequency relation of those curves was published by URSI (Union Radio Scientifique Internationale) in the form of a table (Piggott and Rawer, 1972). An empirical algebraic expression for those curves of the form

$$r = MUF/f = (a - b^*h')\sqrt{h'}$$

was derived by Paul (1984). Here h' is the virtual height,

$$a = 67.629 \text{ and } b = -0.0148$$

For a given ionogram h'(f) the MUF(3000) can then be determined in a least square fit using the above expression. The coordinates fMUF and hMUF of the tangential point between the echo trace and the MUF curve are also obtained in this process. We found that for most ionograms the frequency, fMUF is on the average approximately 11% less than the critical frequency, foF2. Assuming a parabolic model for the F-layer, this frequency ratio corresponds to a true height somewhat above the middle of the lower half of the layer, or about 45% of a half-thickness below the height of maximum. This relationship gives a strong argument for considering the variations of the MUF(3000) to be representative of temporal changes of the lower half of the F-layer. An alternative parameter representative of variations of the F-layer is its maximum electron density or critical frequency, foF2. In our experience, three factors favor the MUF(3000) over foF2. The critical frequency, foF2, is obtained by extrapolation based on some model assumption and is very sensitive to small changes in the shape of the actual layer. This means that apparent variations in foF2 are likely to be more influenced by changes of the slope of the profile in the range used for the extrapolation rather than by changes of the maximum electron density. Another factor in favor of the MUF(3000) is the observation that in the presence of weak spread-F the echo trace in the vicinity of foF2 is often poorly defined.

while an accurate determination of MUF(3000) in a lower frequency range is still possible. An example for this type of condition is shown in figure 1. In addition, the MUF(3000) is more sensitive to F-region variations than the critical frequency, foF2. This is clearly demonstrated in figure 2. Here the lowest part shows the almost regular oscillations of the virtual heights for a set of fixed frequencies in the range where the MUF(3000) is determined. The same kind of variations are clearly visible in the MUF(3000) in the middle section of the figure. Those effects can still be recognized in the variation of foF2 (top portion of the figure) but they are relatively small and more noisy than those of the MUF(3000).

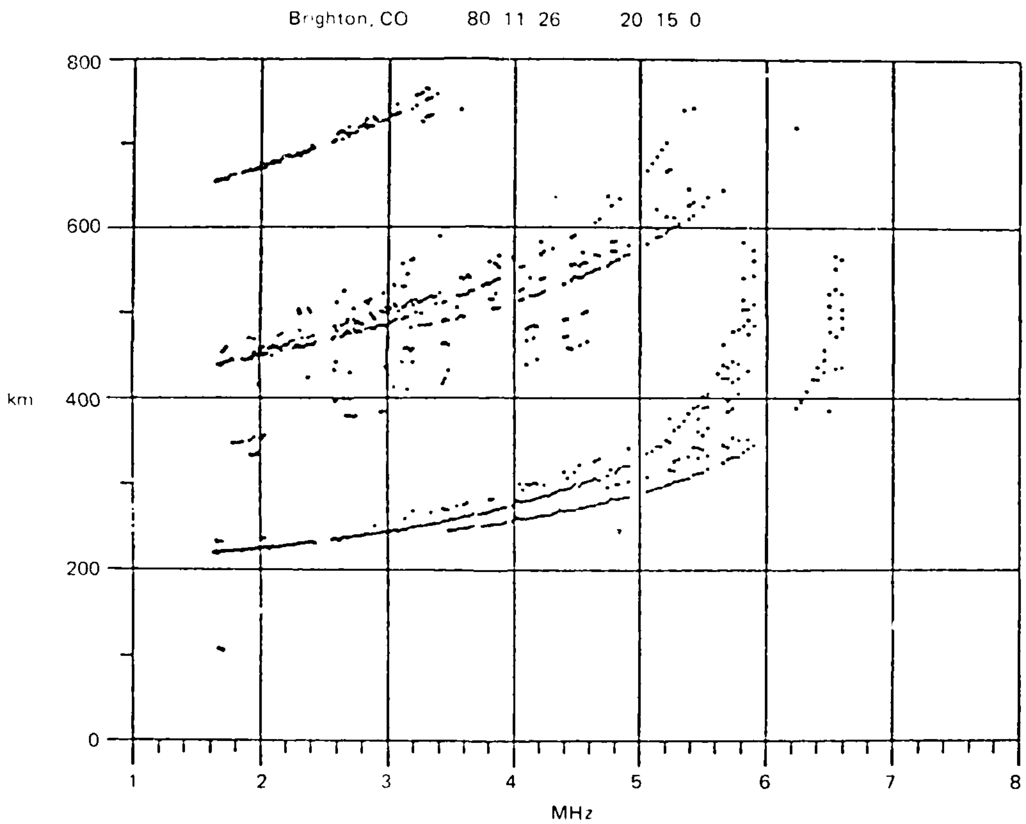


Figure 1. Nighttime ionogram showing weak spread-F condition.

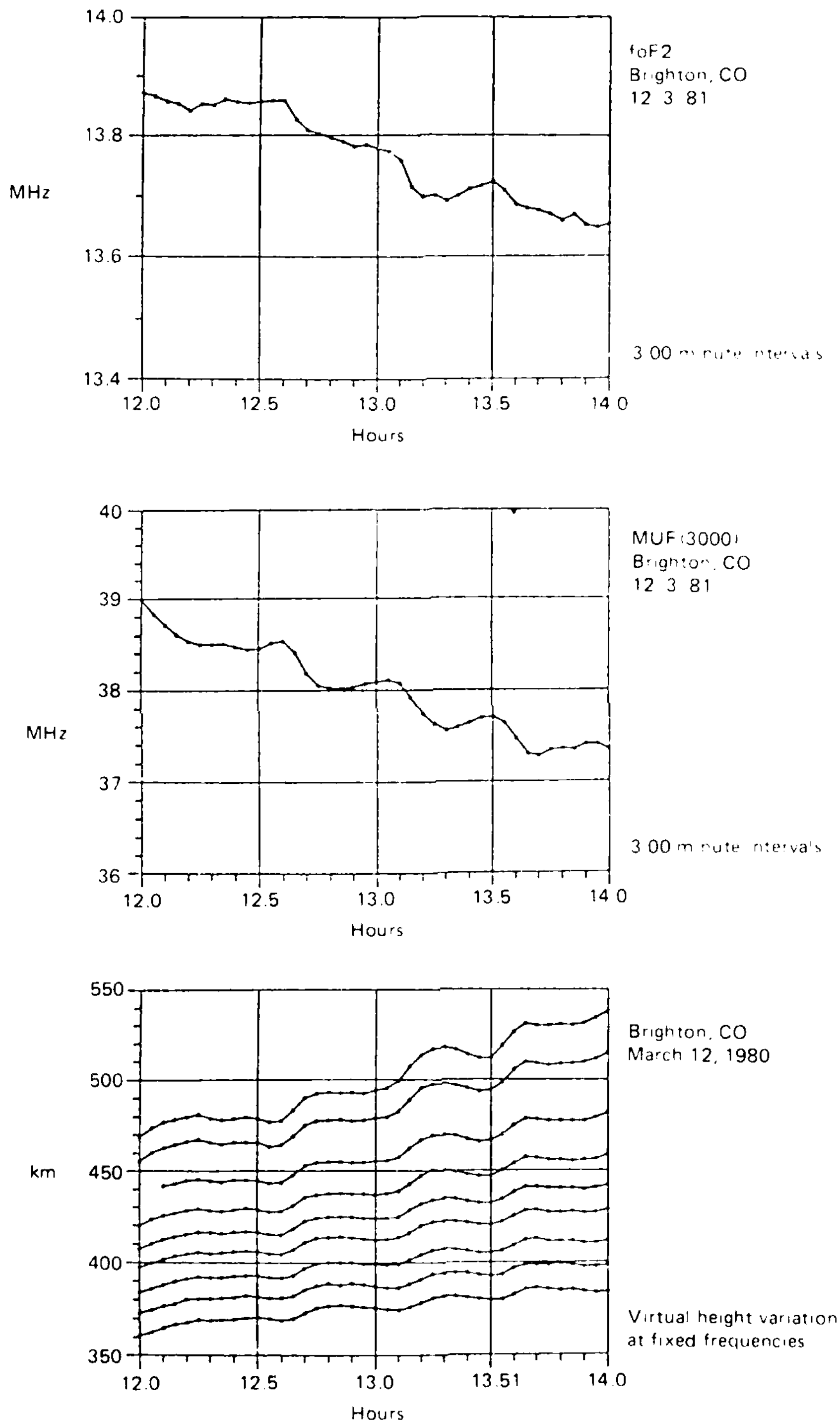


Figure 2. Comparison of foF2, MUF(3000), and virtual heights.

INTERPRETATION OF THE MUF(3000) VARIATIONS

Variations of the MUF(3000) can be caused by changes in height or electron density of the F-layer or a combination of both. In general, we will not attempt to distinguish between those effects, but we will study a few examples in greater detail. Figure 3 shows an example of MUF variations derived from ionograms recorded with different sampling rates, first for almost 3 hours at a rate of 30 ionograms per hour; later, only 4 ionograms per hour were recorded. A comparison of the two data sets gives a strong indication that the lower sampling rate definitely undersamples the true variation of the F-region. The oscillations in the morning have periods of approximately 20 minutes with amplitudes in the order of 1 MHz. While the length of the periods shown is quite common for all the data recorded and analyzed, the amplitudes are often much larger. This is shown in a different way in figure 4 where large changes over 6-minute intervals of the entire F2-layer echo trace become clearly visible. The MUF values for the sequence were 22.33, 21.35, and 22.09 MHz respectively; first, a decrease of 1 MHz and then, an increase of 0.7 MHz over the short interval of 6 minutes each.

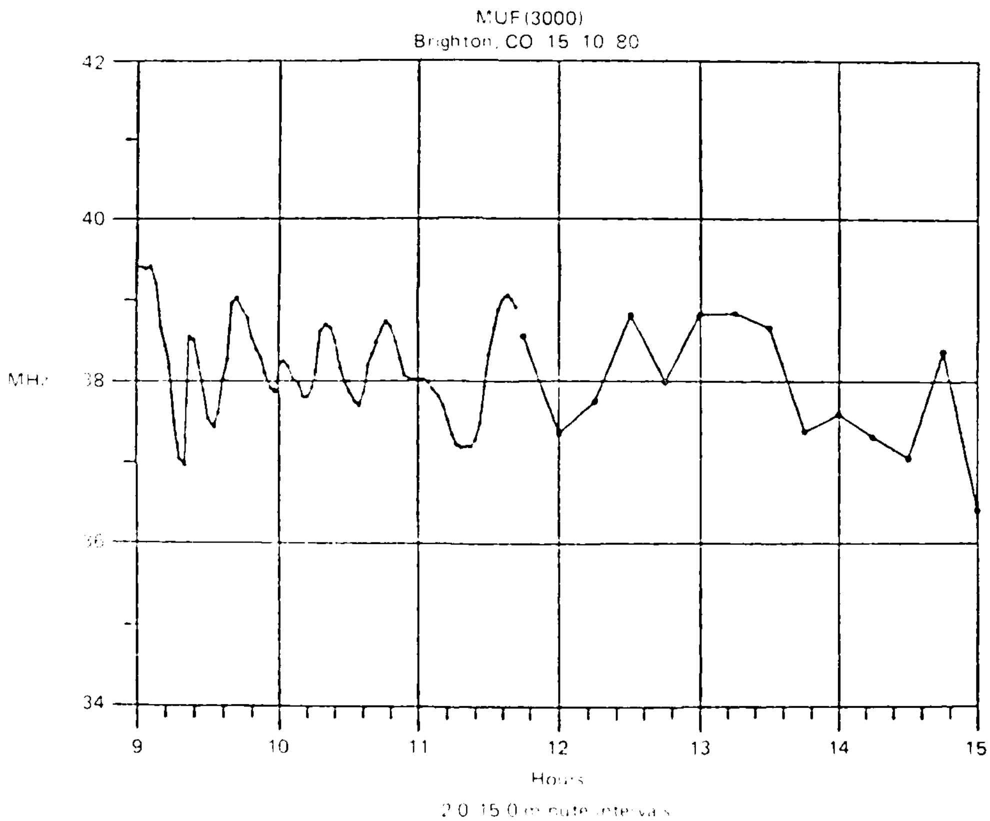


Figure 3. Comparison of different sampling rates.

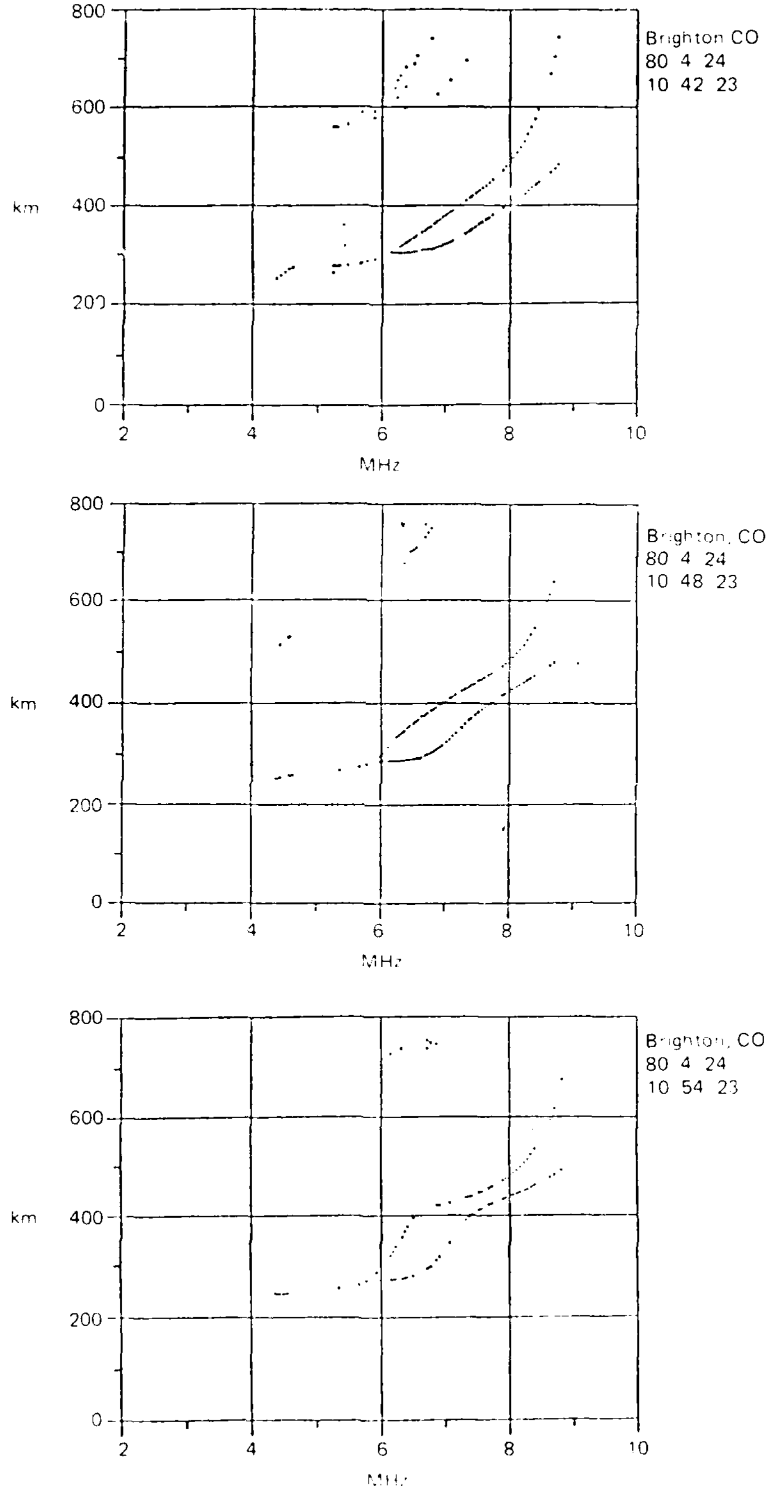


Figure 4. Sequence of rapid changes of echo traces

Figure 5 is another comparison between the temporal variations of the MUF(3000) (lower part) with the variations of the virtual heights for a set of four fixed frequencies (upper part). The pair of the lower frequencies is close to the fMUF at any given time and their corresponding virtual heights are close to the hMUF, while the other pair of frequencies is reflected close to the peak of the F-layer. This comparison shows that the MUF is indeed representative for the F-region variations as seen in the virtual heights over a relatively large frequency range. The relation between the two quantities shown is inverse, as expected, a decrease of the virtual height corresponds to an increase of the MUF and vice versa.

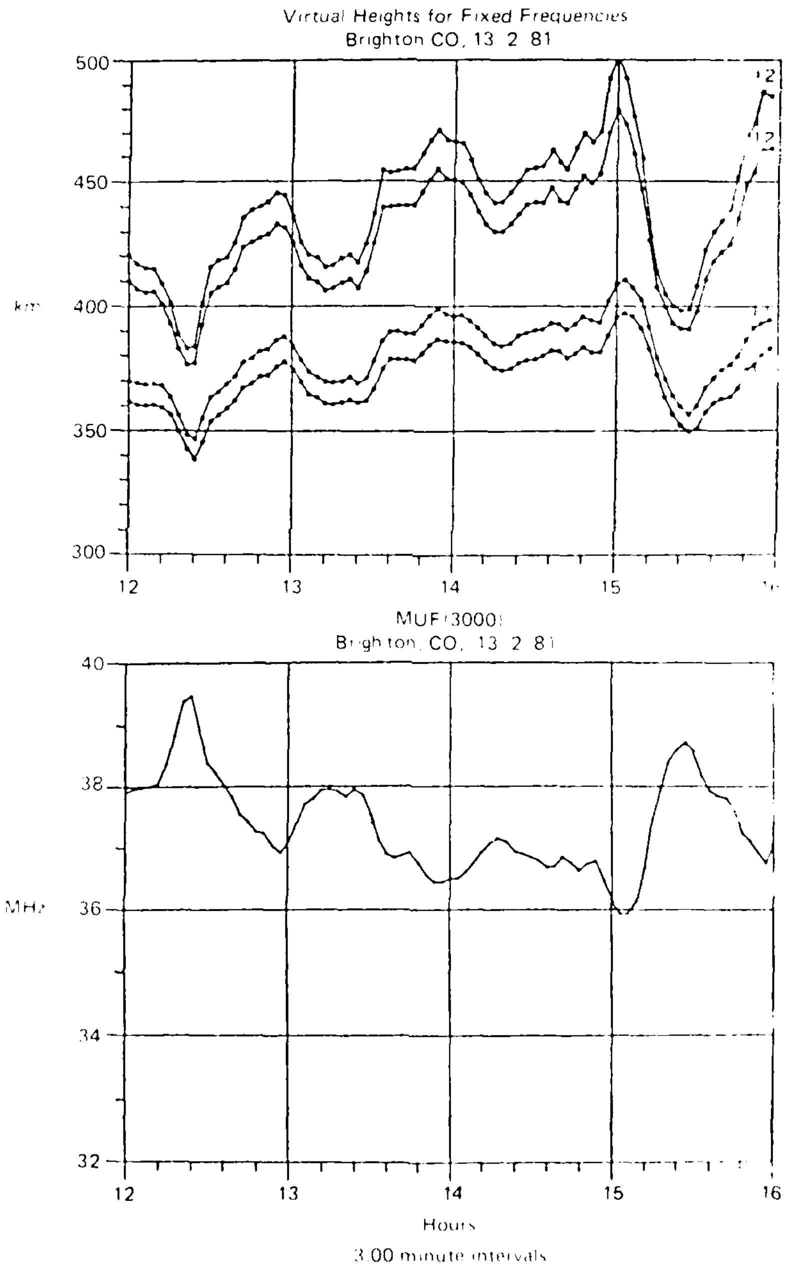


Figure 5. Comparison of virtual heights and MUF(3000)

A closer look at the upper curves in this figure reveal a time lag between the variations at the higher and lower frequencies. For example, the last minimum between 1500 and 1600 appears later at the lower frequencies than at the higher ones. The same is true for the preceding maximum. We also see that relatively short periods of approximately 12 minutes are present between 1430 and 1500 with larger amplitudes at higher frequencies than at lower frequencies. Those short periods are also clearly visible in the MUF curve.

The high accuracy of the MUF(3000) permits the estimate of its temporal derivatives by simply taking the divided differences of consecutive data. Two examples of this quantity are shown in figures 6 and 7. The top portion of figure 6 shows the MUF(3000) from noon to midnight for 12 March 1981, the temporal derivative of the MUF(3000) is plotted in the middle of the figure. The ionograms were taken in 3-minute intervals. The MUF curve shows a relatively smooth behavior with some oscillations of various durations superimposed. The variations become much more visible in the temporal derivative. We notice that many times the magnitude of the derivative can be comparable or even larger than the average rate of decrease during sunset. In order to demonstrate the aliasing effect, we eliminated from the original set all the data except those recorded at the full 15 minutes. The temporal derivative derived from those data is shown in the bottom portion of figure 6. The effect of undersampling is visible in different ways. For example, the half-hour oscillations between 1200 and 1400 are still present in the 15-minute data, but their amplitudes have only approximately half the value of the original data. Some rapid changes of the derivative take place between 2000 and 2100 as seen in the original data. This information, however, is lost completely in the 15-minute data. Figure 7 shows the continuation of this data set and includes sunrise. Again, very large magnitudes of temporal changes are clearly visible, some even larger after sunrise than during sunrise. A comparison of the time derivatives of the original data with the 15-minute data — e.g., between 0700 and 0900 — confirms the earlier finding that significant information can be lost by undersampling.

Angle of arrival measurements provide some evidence indicating that the temporal variations observed are not simply upward and downward movements of the ionosphere as a whole, but rather propagating weak deformations of the F-region, most likely acoustic gravity waves. If we assume a propagation velocity comparable to the speed of sound, we can translate the temporal variations into an estimate of the horizontal gradient of the MUF(3000). On the other hand, it turns out that for a given location at midlatitudes the relative velocity of the daylight boundary is also close to the sound velocity depending on the season of the year. Therefore, by comparing the temporal variations at a given time of the day with the temporal variations during sunrise or sunset we can reasonably assume that this ratio is also in first order valid for the corresponding horizontal gradients, where the ones for sunrise and sunset are relatively well known.

Tables 1a and 1b give some statistics for all the rapid sequence ionograms (10 or more ionograms per hour) that were recorded during the duration of the program. We computed lower quartile (LQ), median (MED), and upper quartile (UQ) of the absolute value of the time derivative of the MUF(3000) for three time intervals of the day: sunrise, daytime, and sunset. Nighttime values are not shown, since frequently spread-F condition caused relatively large uncertainties of the MUF(3000) values, and separation of uncertainties from actual variations would have been difficult and time consuming. For nights, when no spread-F was present, the data show that the variability at night can be as high as during the day. For a given day, the median values are usually largest for sunrise. There is a definite asymmetry between sunrise and sunset. We also see that median values for daytime are not much smaller than those for sunrise and that the daytime upper quartile is, on the average, close to the sunrise median. Similarly, the sunset upper quartiles are not much different from the daytime upper quartiles.

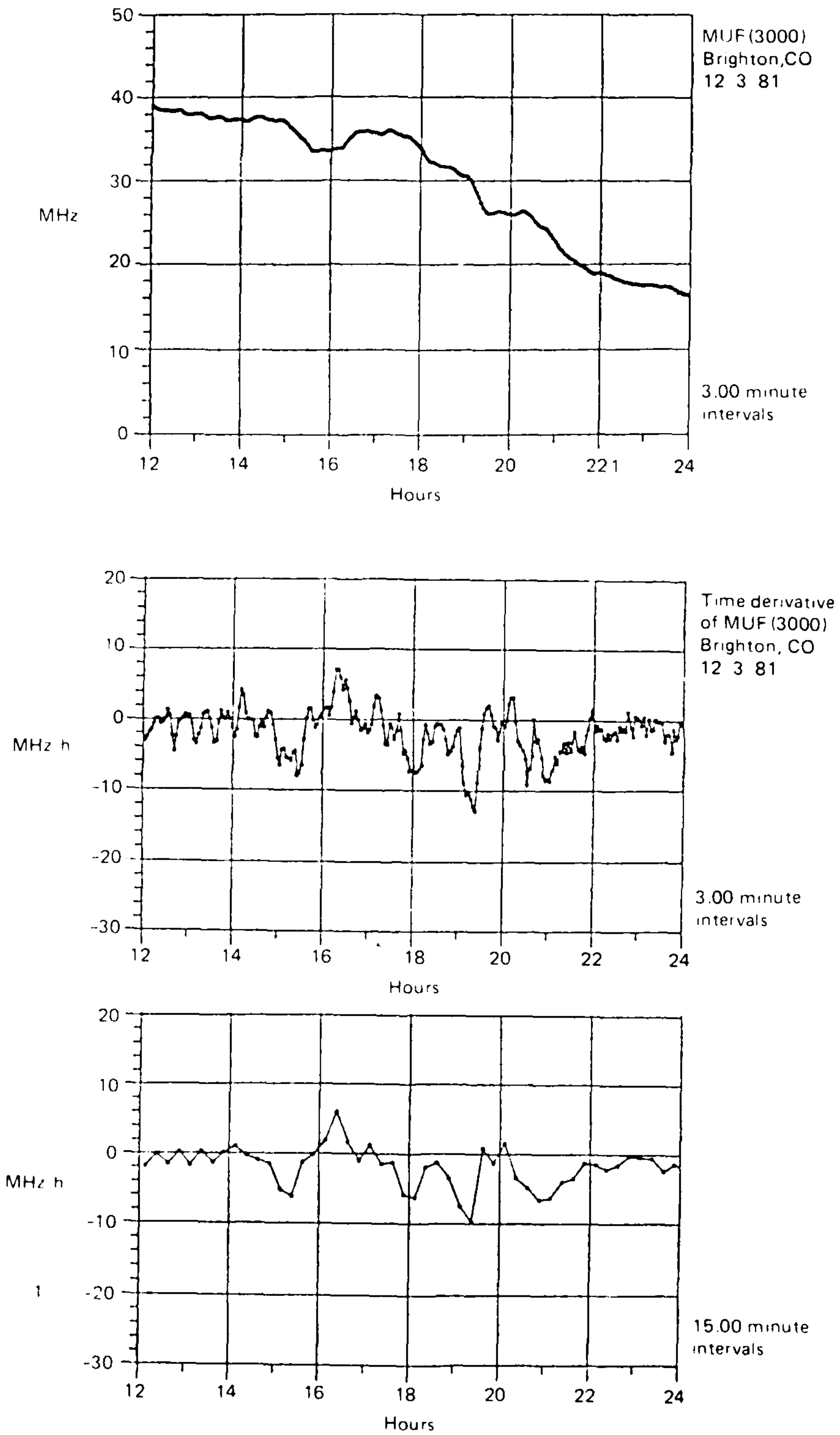


Figure 6. MUF(3000) and its temporal changes for 3- and 15-minute intervals for 12 March 1981.

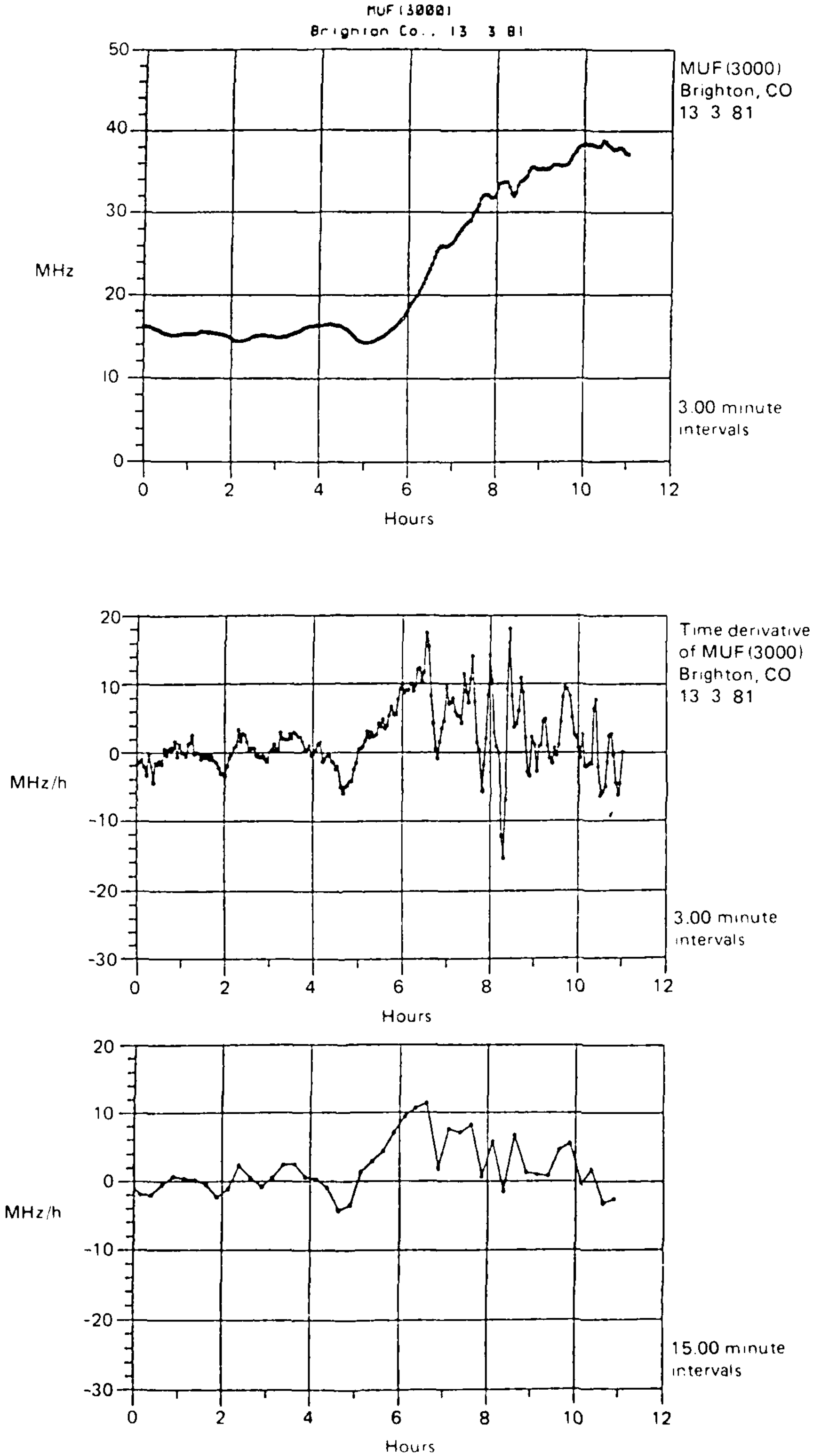


Figure 7. MUF(3000) and its temporal changes for 3- and 15-minute intervals for 13 March 1981.

Table 2, based on 15-minute data, has been added for comparison only and the data should be used with caution. As we have shown above, we have reason to believe that the relatively small daytime medians are the result of undersampling and do not necessarily reflect lower gravity wave activity. In addition, it should be mentioned that typically the sunrise period lasts for about 2 hours and with 15-minute sampling, only 9 data are available, which may not be a large enough sample for a good estimate of the statistics listed. Generally, the data in this table give the long-term trend (hours) of the MUF(3000) and are less influenced by the shorter variations.

Table 1a. Absolute values of temporal changes of the MUF(3000) in MHz/hour for all rapid sequence ionograms from 13 February 1980 through 3 January 1981.

Date			Sunrise			Daytime			Sunset			DT
Y	M	D	LQ	MED	UQ	LQ	MED	UQ	LQ	MED	UQ	Min.
80	2	13							1.97	3.55	6.20	6.00
80	2	14	2.75	7.85	9.03							6.00
80	3	14							2.43	4.03	6.49	5.00
80	3	15	12.40	14.10	15.91							5.00
80	3	15				0.84	2.08	3.42				5.00
80	3	15							1.31	3.34	6.07	5.00
80	3	16	9.04	13.23	15.49							5.00
80	3	16				0.87	1.66	3.01				5.00
80	3	16							1.57	3.69	5.95	5.00
80	4	23				0.53	1.36	2.32				6.00
80	4	23							1.88	3.64	5.46	6.00
80	4	26				1.37	2.56	3.99				2.00
80	10	15				2.13	4.22	7.04				2.00
80	11	21				2.17	5.87	8.94				3.00
80	12	3				2.97	10.62	21.98				3.00
80	12	9				5.71	9.29	13.09				3.00
80	12	10	10.02	13.90	20.25							4.00
80	12	16				2.66	5.43	9.71				3.00
80	12	16							3.15	6.58	11.71	3.00
80	12	17	4.12	7.47	17.94							3.00
80	12	17				2.81	5.99	8.85				3.00
80	12	17							4.17	6.76	12.60	3.00
80	12	18	7.73	13.37	16.17							3.00
80	12	18				2.06	4.92	6.98				3.00
80	12	18							5.02	7.56	12.65	3.00
80	12	29							3.13	5.45	11.41	6.00
80	12	30	4.44	6.24	11.52							6.00
80	12	30				2.78	5.19	11.72				6.00
80	12	30							4.14	6.19	11.97	6.00
80	12	31	6.26	9.80	11.48							6.00
80	12	31				1.76	5.04	7.83				6.00
80	12	31							3.46	7.65	11.13	6.00
81	1	1	6.53	10.62	12.57							6.00
81	1	1				2.03	4.05	6.83				6.00
81	1	1							2.65	6.15	9.11	6.00
81	1	2	5.93	11.76	16.40							6.00
81	1	2				3.66	6.83	13.19				6.00
81	1	2							3.02	4.10	9.94	6.00
81	1	3	5.74	10.87	13.45							6.00
81	1	3				4.46	8.88	13.77				6.00
81	1	3							2.62	5.29	9.81	6.00

Table 1b. Absolute values of temporal changes of the MUF(3000) in MHz/hour for all rapid sequence ionograms from 7 January 1981 through 16 September 1981.

Date			Sunrise			Daytime			Sunset			D[illegible]
Y	M	D	LQ	MED	UQ	LQ	MED	UQ	LQ	MED	UQ	M[illegible]
81	1	7	6.25	13.46	17.60							6.00
81	1	7				3.50	9.97	14.67				6.00
81	1	7							4.29	7.18	10.59	[illegible]
81	1	8	8.41	10.72	13.42							[illegible]
81	1	8				2.91	5.78	10.00				6.00
81	1	8							2.71	6.47	8.58	6.00
81	1	15				2.77	6.16	11.35				3.00
81	2	9							2.81	6.47	9.56	6.00
81	2	10	7.88	9.74	16.42							6.00
81	2	10				2.16	4.61	6.51				6.00
81	2	10							1.74	4.34	9.22	6.00
81	2	11	3.78	11.27	17.40							6.00
81	2	11				1.49	3.14	5.18				3.00
81	2	11							4.15	7.60	9.91	6.00
81	2	12	3.49	6.64	10.84							6.00
81	2	12				4.55	9.04	14.04				5.00
81	2	13				1.62	3.45	6.48				3.00
81	2	16				1.69	4.16	7.00				3.00
81	2	16							2.37	4.15	6.22	3.00
81	2	18				1.68	3.75	5.86				6.00
81	2	18							2.18	3.54	7.82	6.00
81	2	19	6.82	9.99	13.34							6.00
81	2	19				1.85	3.72	7.61				6.00
81	2	19							3.10	5.16	8.41	6.00
81	3	12				0.60	1.28	3.03				3.00
81	3	12							1.55	3.21	6.47	3.00
81	3	13	4.24	7.32	9.53							3.00
81	3	19				0.92	2.06	3.39				3.00
81	3	19							1.86	4.60	7.95	3.00
81	3	31							3.56	5.75	8.81	4.00
81	4	1	6.61	9.82	13.17							4.00
81	4	1				1.14	2.01	3.13				4.00
81	4	2	3.46	6.10	11.60							5.00
81	4	15				0.60	1.45	2.47				2.00
81	9	8							1.45	3.34	4.86	5.00
81	9	9	2.05	5.74	7.11							5.00
81	9	16	4.90	8.42	10.63							5.00

Table 2. Absolute values of temporal changes of the MUF(3000) in MHz/hour based on ionograms at 15-minute intervals from 8 August 1980 through 16 March 1981.

Date			Sunrise			Daytime			Sunset			DT
Y	M	D	LQ	MED	UQ	LQ	MED	UQ	LQ	MED	UQ	Min.
80	8	8				1.36	2.64	3.62				15.00
80	8	8							1.06	3.57	6.14	15.00
80	8	9	2.70	4.26	5.31							15.00
80	8	9				0.76	2.20	3.93				15.00
80	8	9							2.56	4.40	5.67	15.00
80	8	10	2.52	3.09	5.73							15.00
80	8	10				0.98	1.83	2.75				15.00
80	8	10							1.25	1.75	4.53	15.00
80	8	11	2.56	4.30	6.42							15.00
80	8	16				0.99	2.85	7.22				15.00
80	9	1							1.99	2.62	4.91	15.00
80	9	2	4.02	5.59	6.03							15.00
80	9	2				0.91	1.64	2.57				15.00
80	9	2							2.46	4.44	8.25	15.00
80	10	15							1.72	4.72	6.20	15.00
80	10	16	7.77	11.09	14.88							15.00
80	10	16				1.30	2.09	3.57				15.00
80	10	16							1.85	3.23	7.16	15.00
80	10	17	8.09	8.88	11.05							15.00
80	11	14							4.06	5.50	7.93	15.00
80	11	15	4.41	7.30	15.58							15.00
80	11	15				1.29	2.15	5.11				15.00
80	11	15							3.09	5.24	5.88	15.00
80	11	16	6.77	8.28	11.40							15.00
80	11	16				1.80	3.51	5.05				15.00
80	11	16							3.25	4.50	6.49	15.00
80	12	12							1.13	3.96	6.30	15.00
80	12	13	9.18	10.75	12.80							15.00
80	12	13				0.84	2.41	5.40				15.00
80	12	13							2.49	3.33	7.71	15.00
80	12	14	9.02	13.80	14.66							15.00
80	12	14				2.19	3.02	8.76				15.00
80	12	14							2.14	3.57	8.04	15.00
80	12	15	6.10	9.59	14.54							15.00
80	12	15				2.31	3.82	10.38				15.00
81	1	15							2.20	3.23	7.57	15.00
81	1	16	5.12	11.41	14.39							15.00
81	1	16				1.71	3.90	8.74				15.00
81	1	16							1.87	4.45	10.22	15.00
81	1	17	6.66	7.75	13.51							15.00
81	1	17				3.02	4.80	7.44				15.00
81	1	18	1.25	11.11	14.36							15.00
81	3	13							1.94	3.21	6.03	15.00
81	3	14	1.34	3.90	7.03							15.00
81	3	14				0.92	1.88	3.32				15.00
81	3	14							1.48	3.50	5.08	15.00
81	3	15	4.43	5.41	7.98							15.00
81	3	15				0.48	1.16	2.55				15.00
81	3	15							0.86	2.18	4.91	15.00
81	3	16	5.43	6.86	8.18							15.00

CONCLUSIONS

We consider three results of this study as highly significant:

(a) Oscillations of the F-layer are taking place more or less all the time with varying intensity and they are well represented by the temporal variation of the MUF(3000).

(b) Since the periods of those oscillations are relatively short, correct estimates of the temporal variations of the F-region parameters can only be obtained, if at least 10 to 12 ionograms per hour are recorded.

(c) Temporal variations and associated tilts, comparable with those during sunrise and sunset, can occur at any time of the day or night.

For further discussions we assume a propagation velocity of 300 m/s and a period of 20 minutes. This would then correspond to a wavelength of 360 km, if we can assume a periodic spatial structure. Consequently, spatial sampling should take place with grid distances of less than half a wavelength or less than 180 km if a true picture of the ionospheric structure is to be obtained. With the same velocity in a linear approximation a rate of change of the MUF(3000) of 10 MHz/hour would correspond to a change in a horizontal direction of approximately 1 MHz per 100 km. As mentioned earlier the quasi-periodic changes of the MUF(3000) are mainly caused by changes in the virtual heights and to a lesser degree, by changes in the electron density. The variations of the virtual heights correspond to changes of the true reflection height over an area with dimensions of the order of a fraction of a wavelength. By this relation, the temporal variations of the MUF(3000) are also indicators for tilts. In figure 2, the fourth curve from the bottom follows the virtual height very closely where the MUF is determined (hMUF). Comparing this curve with the MUF curve in the middle section of the figure, we find that an amplitude of the MUF(3000) oscillation of approximately 0.5 MHz corresponds to a variation of the virtual height with an amplitude of approximately 15 km. By a conservative estimate a virtual height interval of 15 km is equivalent to a true height interval of approximately 5 to 7 km. Such a change of the true height over a quarter of a wavelength would then represent an average tilt for a surface of constant electron density of 3 - 4 degrees. Angle off arrival measurements verify that the equivalent angles of deviation from vertical propagation are observed frequently.

While this type of consideration can give some first order estimates of some quantities defining the temporal and spatial structures, other very important parameters, such as the propagation velocity of an acoustic gravity wave in its magnitude and direction, cannot be obtained by single site vertical sounding. Knowledge of this velocity could have important applications ranging from locating the sources of gravity waves to directional updating of HF-propagation conditions. The Doppler velocity, which can be observed by an ionosonde, represents only the radial component of the temporal change of the phase path. It lags in time behind the group path velocity (Bennet and Dyson, 1986) and for these reasons, cannot be easily interpreted as a propagation velocity of gravity waves.

It has to be pointed out that the data set available for this study was insufficient to come to definite conclusions about the seasonal or even the solar activity or global dependence of the F-region variability. The data show, however, that the F-region was highly variable during the recording period and several parameters showed often shorter periods and larger amplitudes than previously anticipated. We further come to the conclusion, that no database exists to describe the short-term dynamics of the F-region and its corresponding medium scale structure on a larger scale in space and time. Answers to many remaining questions have to come from a continuous observational program with sufficient temporal (at least 10 ionograms per hour) and spatial (distances not more than ≈ 200 km) resolution.

COMMENTS ON APPENDICES A AND B

Appendices A and B contain plots of the MUF(3000) for most of the data available. Appendix A shows the data for the rapid sequences of ionograms (8 or more ionograms per hour). Appendix B shows the standard sequences (less than 8 ionograms per hour). Some of the data shown appear unreasonably large or small. In those cases, an accurate determination of the value was not possible due to spread-F condition or multiple reflections due to intense deformation of the layer. The continuity of the data derived from the rapid sequences of ionograms, in most cases, gives a clear indication if deviations from the mean trend represent real variations or poor data. This distinction is often not possible for the standard sequence data. The MUF(3000) values are set to zero, if for technical (e.g., incomplete ionogram) or natural reasons (blanketing sporadic E) a correct value could not be obtained.

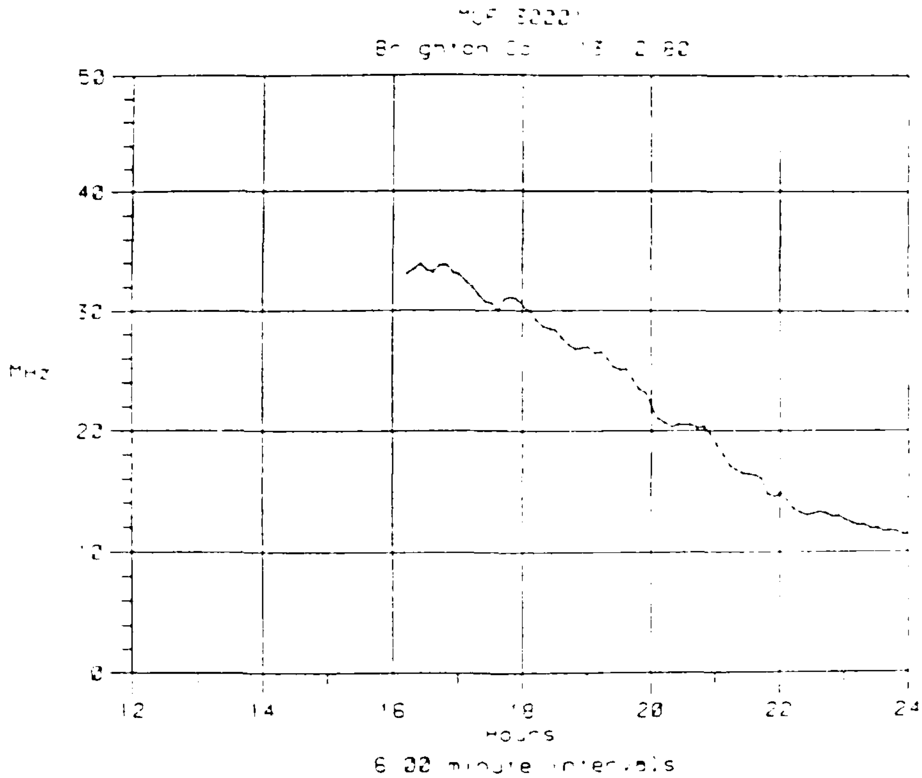
It has to be pointed out that each MUF value shown was derived from an individual ionogram and no smoothing or filtering was applied.

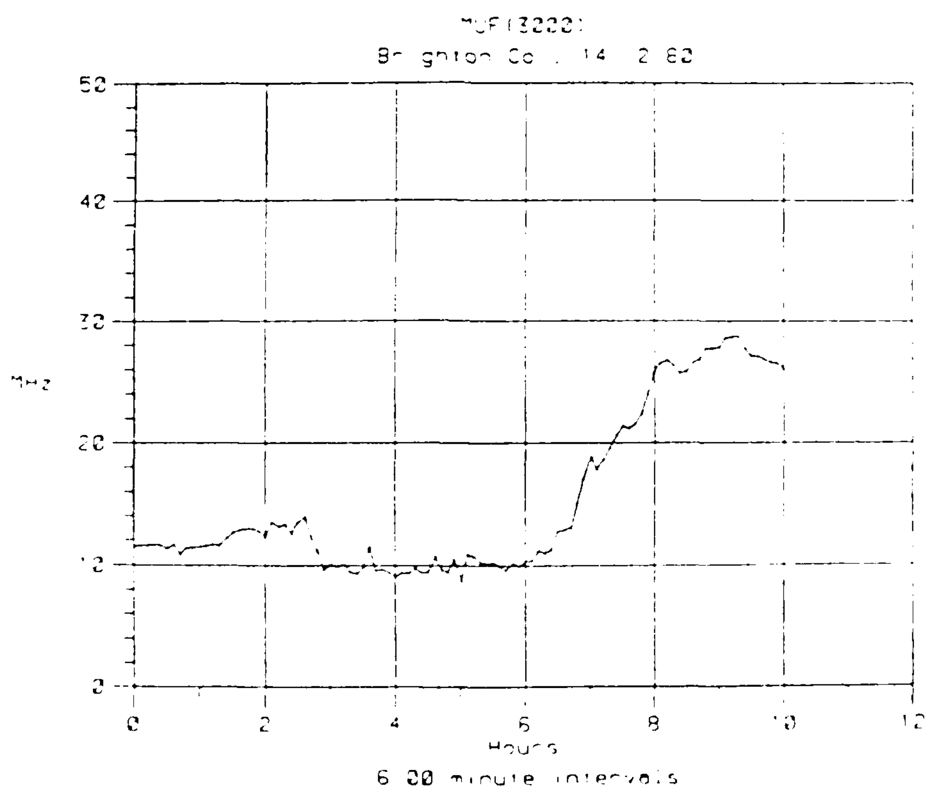
REFERENCES

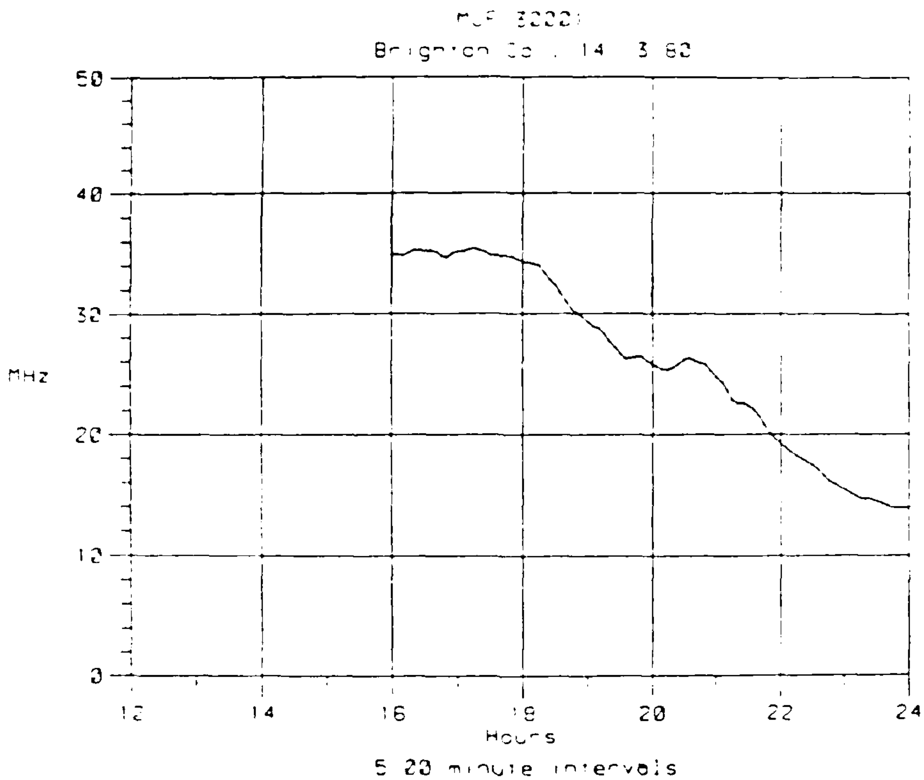
1. Bennet, J.A., and P.L. Dyson, 1986. "The Effect of Small Amplitude Wave Irregularities on Radio Wave Observations of the Ionosphere," *Radio Sci.*, vol. 21, pp. 375-387.
2. Grubb, R.N., 1979. "The NOAA SEL HF Radar System (Ionospheric Sounder)," *NOAA Technical Memorandum ERL SEL-55.*
3. Paul, A.K., J.W. Wright, L.S. Fedor, 1974. "The Interpretation of Ionospheric Drift Measurements — VI. Angle-of-Arrival and Group Path (Echolocation) Measurements from Digitized Ionospheric Soundings: The Group Path Vector," *J.A.T.P., vol.* 36, *pp.* 193-214.
4. Paul, A.K., 1984. "Computation of MUF(3000)F2," INAG Bulletin No. 45, p. 15.
5. Piggott, W. and K. Rawer, 1972. "URSI Handbook of Ionogram Interpretation and Reduction," *UAC Report, National Geophysical Data Center, p. 324.*
6. Smith N., 1939. "The Relation of Radio Skywave Transmission to Ionosphere Measurements," *Proc. IRE,* vol. 27, p. 332.

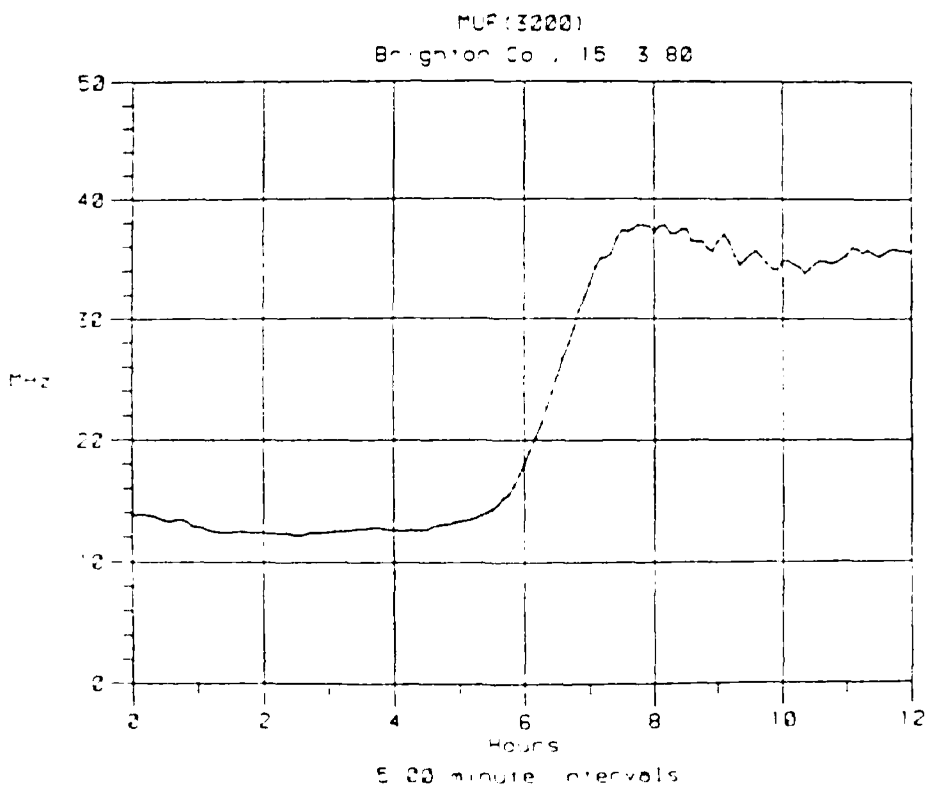
APPENDIX A

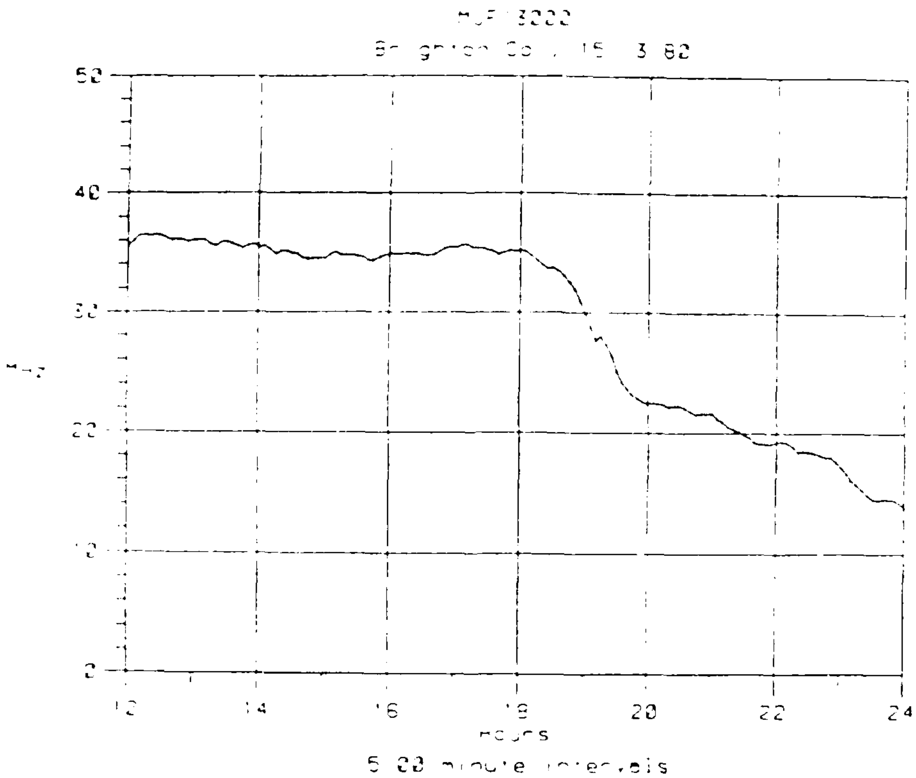
RAPID SEQUENCES OF IONOGRAMS


MUF(3000)
50
40
30
MHz
20
10
0
12
14
16
18
20
22
24
Hours
minute intervals

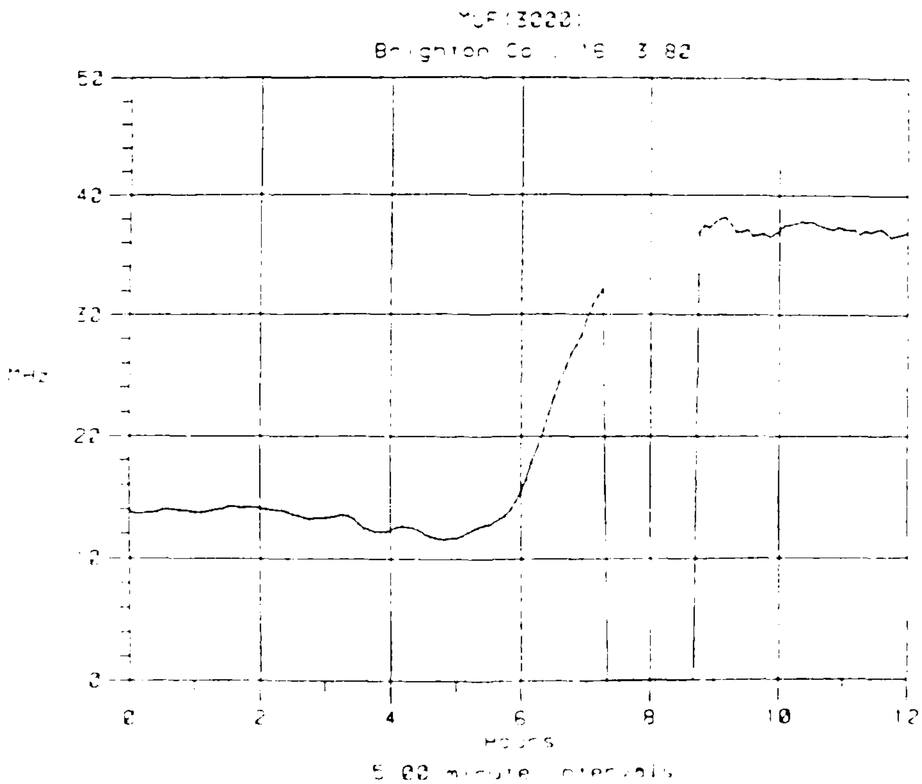

MUF(3000)
14 2 80
50
40
30
MHz
20
10
0
0
2
4
6
8
10
12
Hours
minute intervals


MUF(3200)
Brighton Co., 14 3 80
MHz
Hours
5 20 minute intervals


MUF(3200)
Brighton Co., 15 3 80
MHz
Hours
5 20 minute intervals

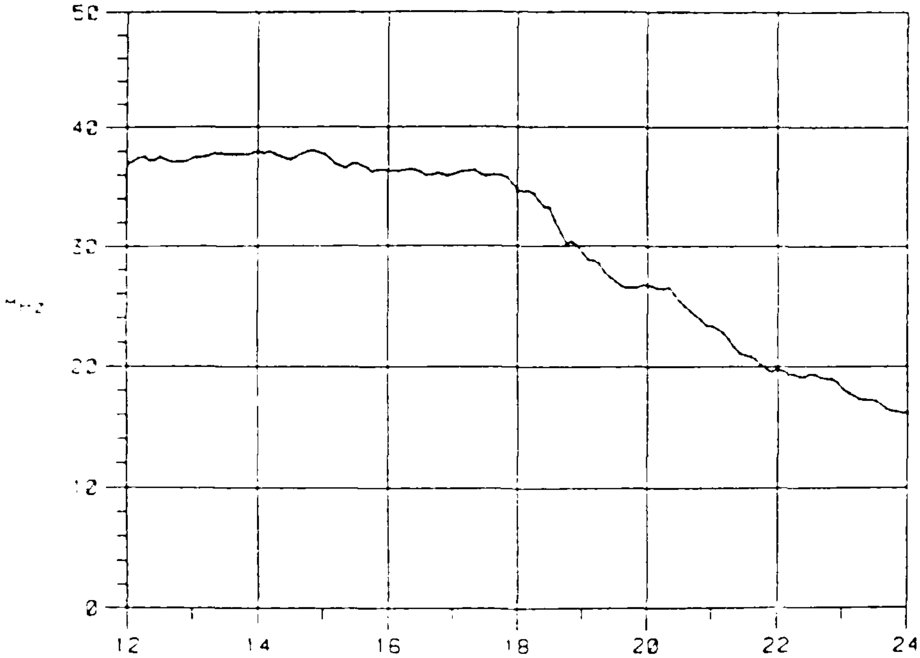


MUF(3000)
Brighton Co , 15 3 82
MHz
Hours
5 00 minute intervals



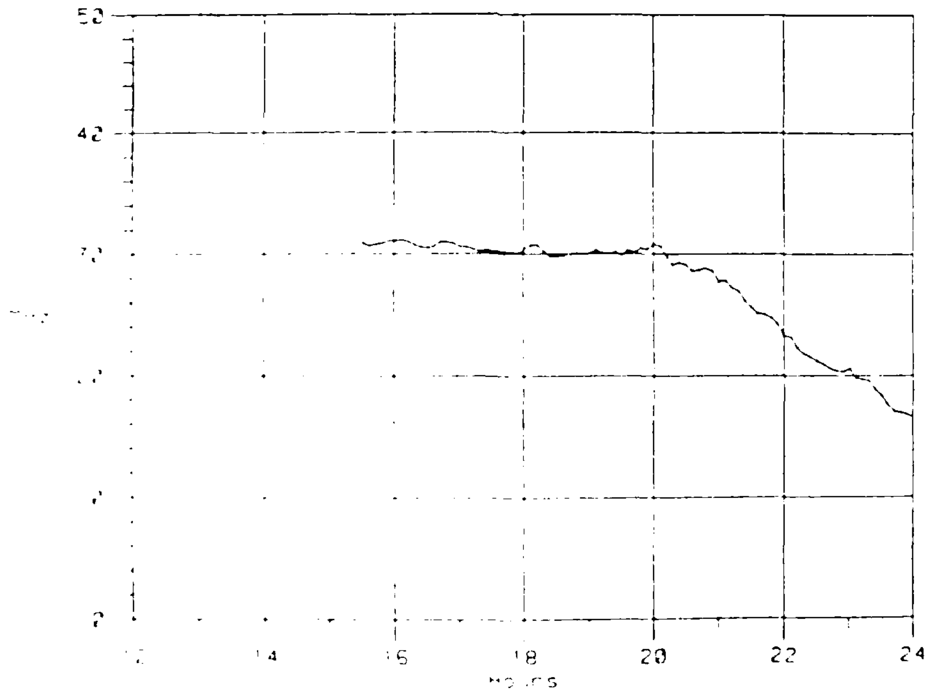
MUF(3000)
Brighton Co , 16 3 82
MHz
Hours
5 00 minute intervals

MUF(3000)
Brighton Co., 16 3 80

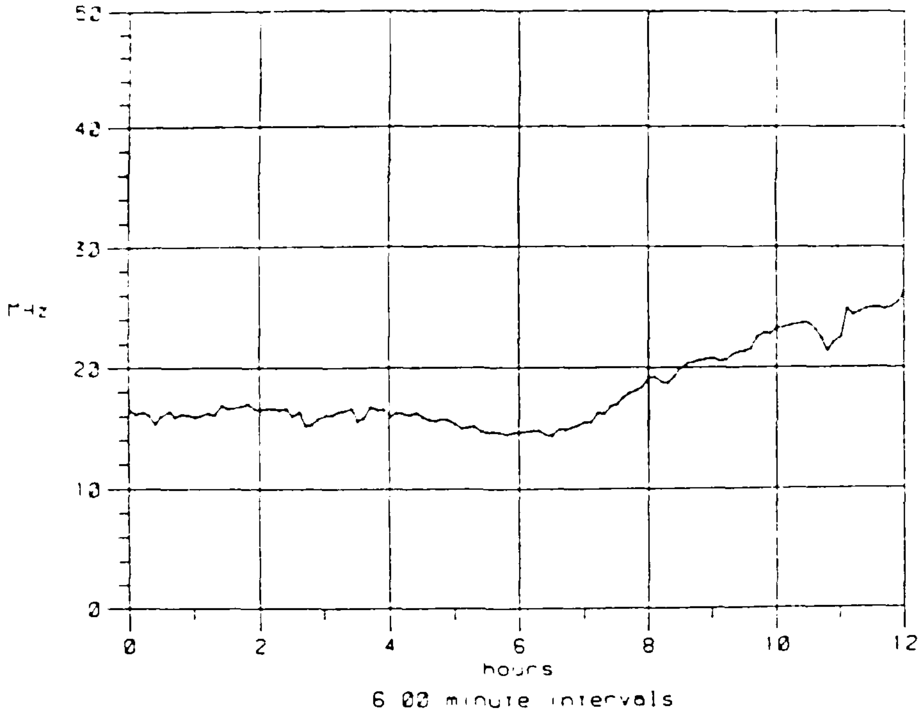


5 00 minute intervals

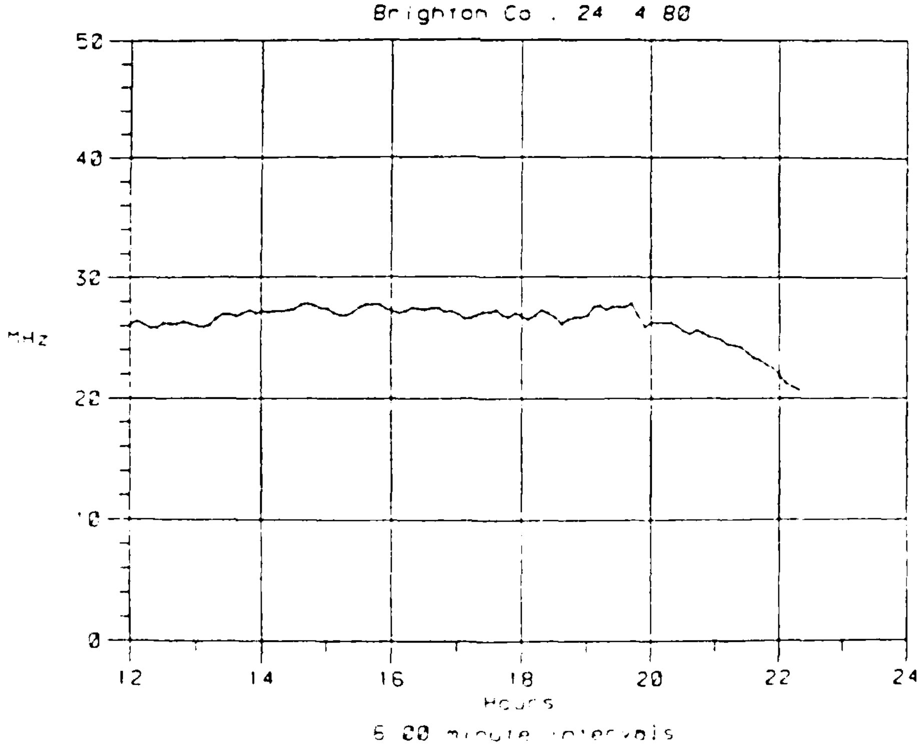
MUF(3000)
Brighton Co., 23 4 80

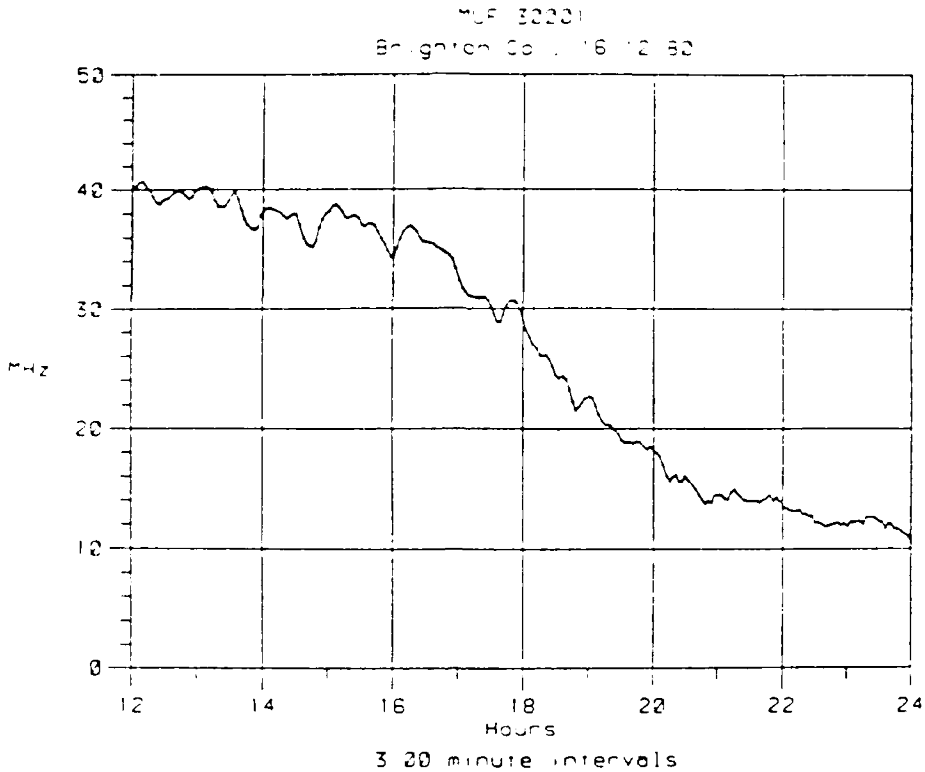


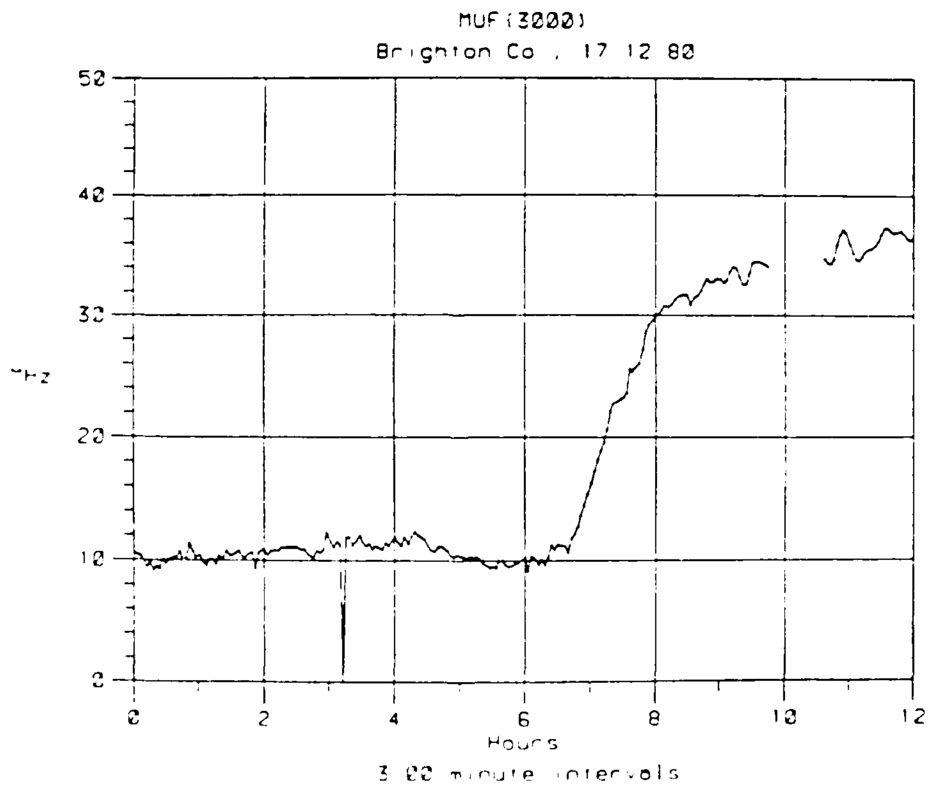
MUF (3220)
Brighton Co. 24 4 80

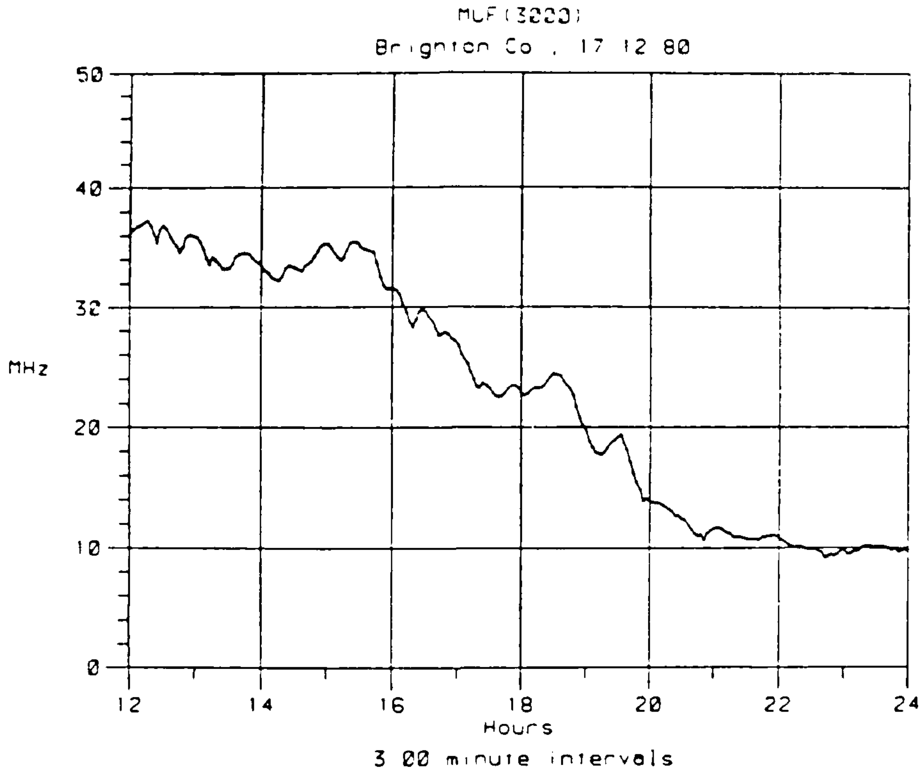


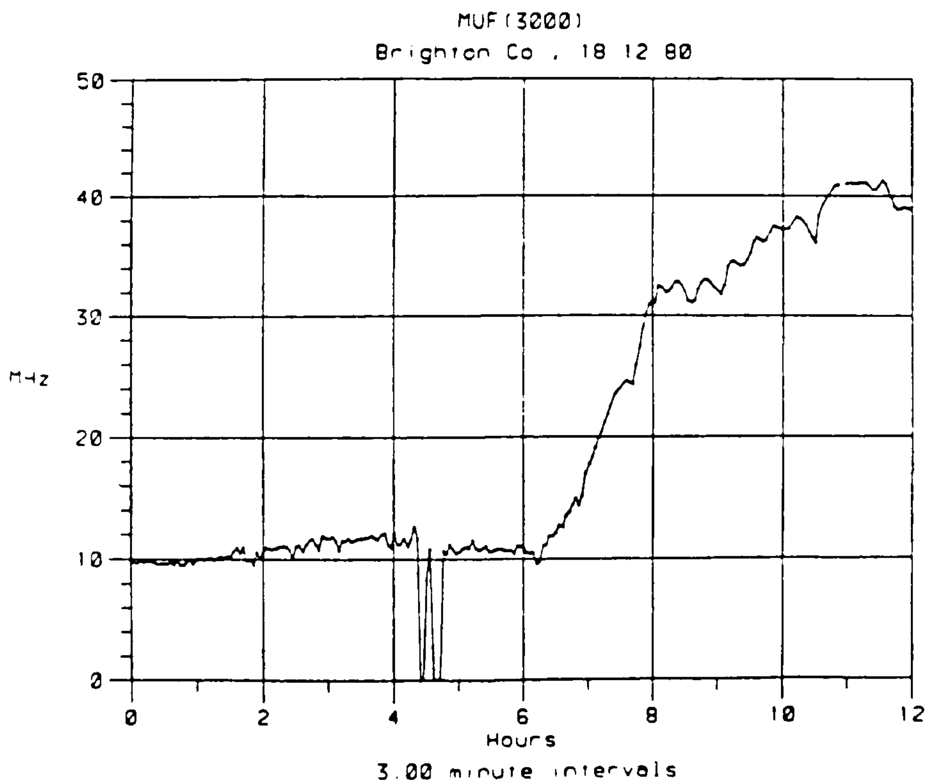
MUF(3220)
Brighton Co. 24 4 80

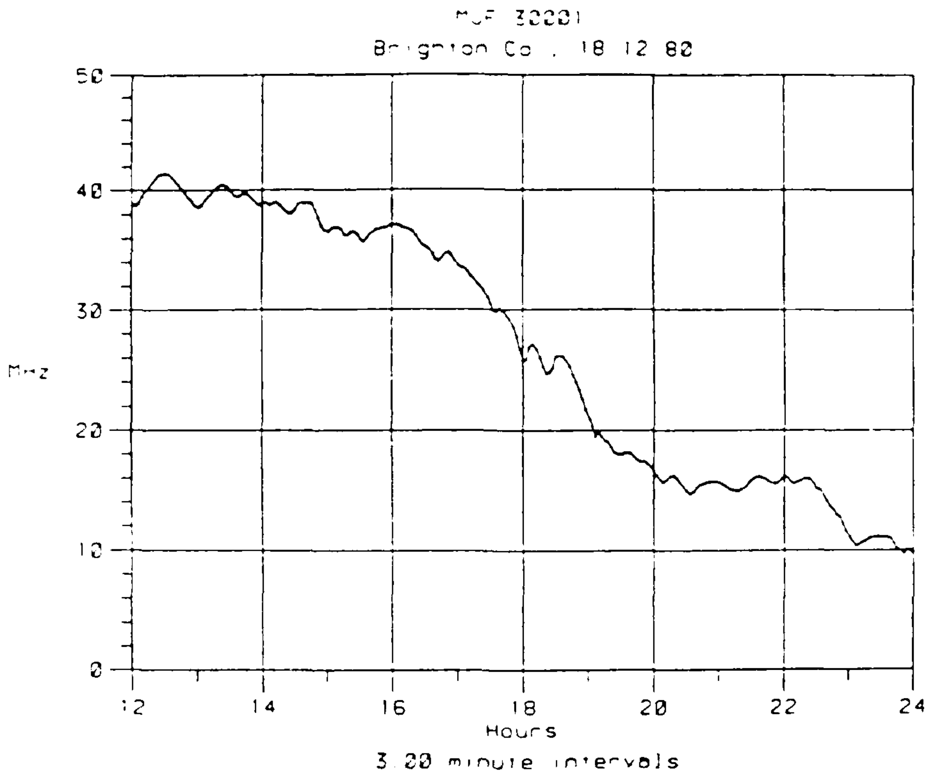



MUF (3000)
Brighton Co., 16 12 80
MHz
50
40
30
20
10
0
12
14
16
18
20
22
24
Hours
3 00 minute intervals

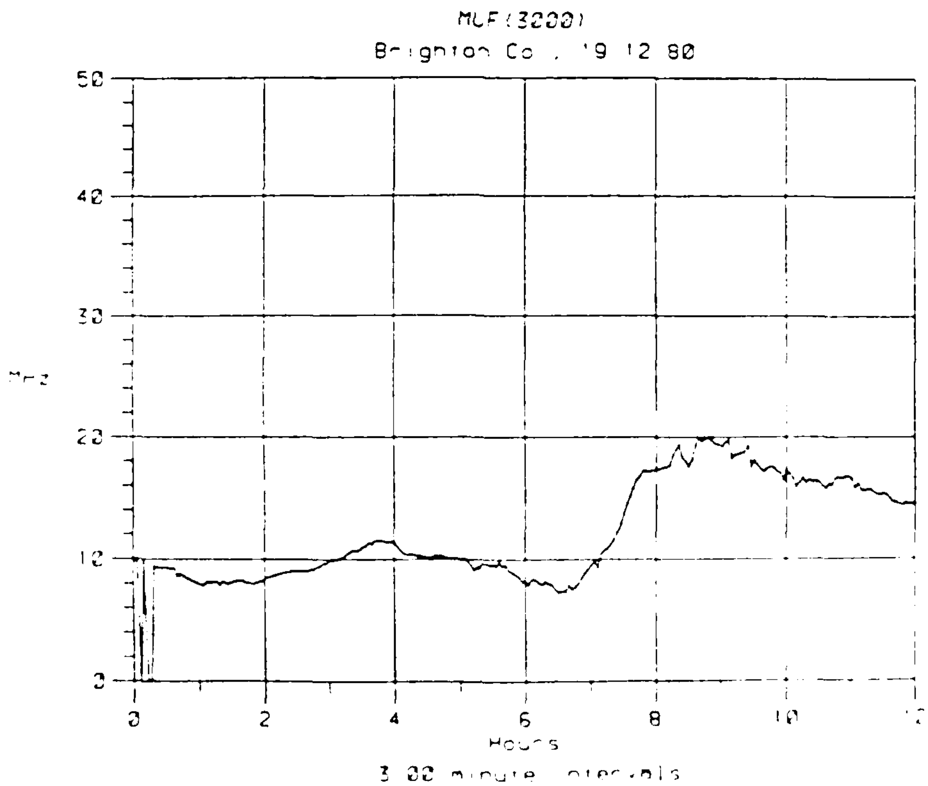

MUF(3000)
Brighton Co., 17 12 80
MHz
50
40
30
20
10
0
0
2
4
6
8
10
12
Hours
3 00 minute intervals


MUF(3000)
Brighton Co , 17 12 80
MHz
50
40
30
20
10
0
12
14
16
18
20
22
24
Hours
3 00 minute intervals

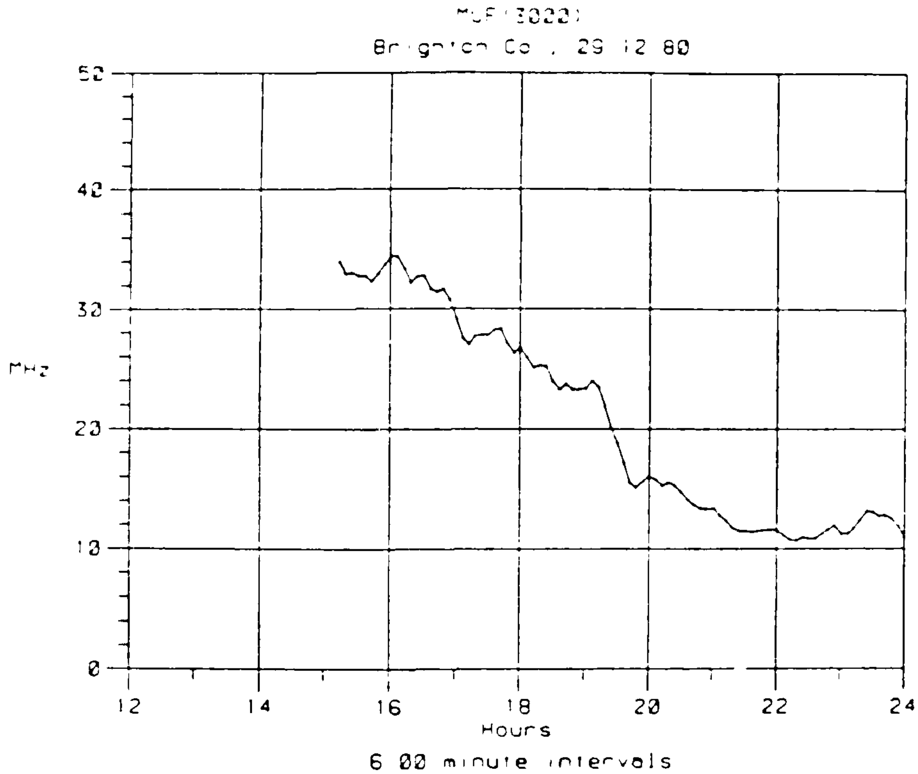

MUF(3000)
Brighton Co , 18 12 80
MHz
50
40
30
20
10
0
0
2
4
6
8
10
12
Hours
3.00 minute intervals

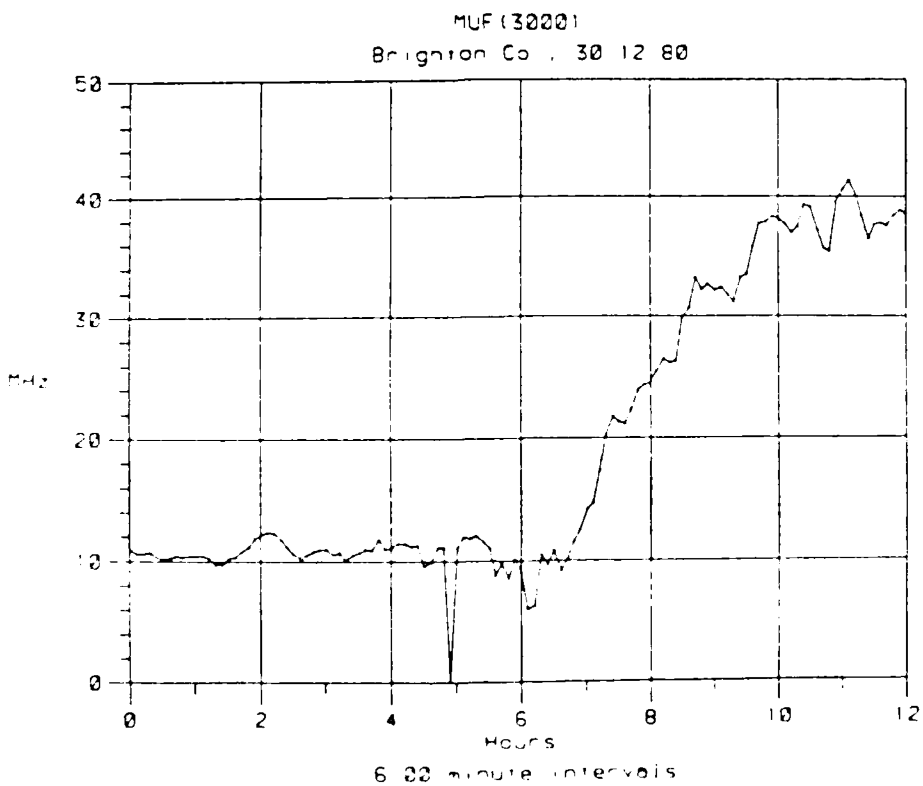


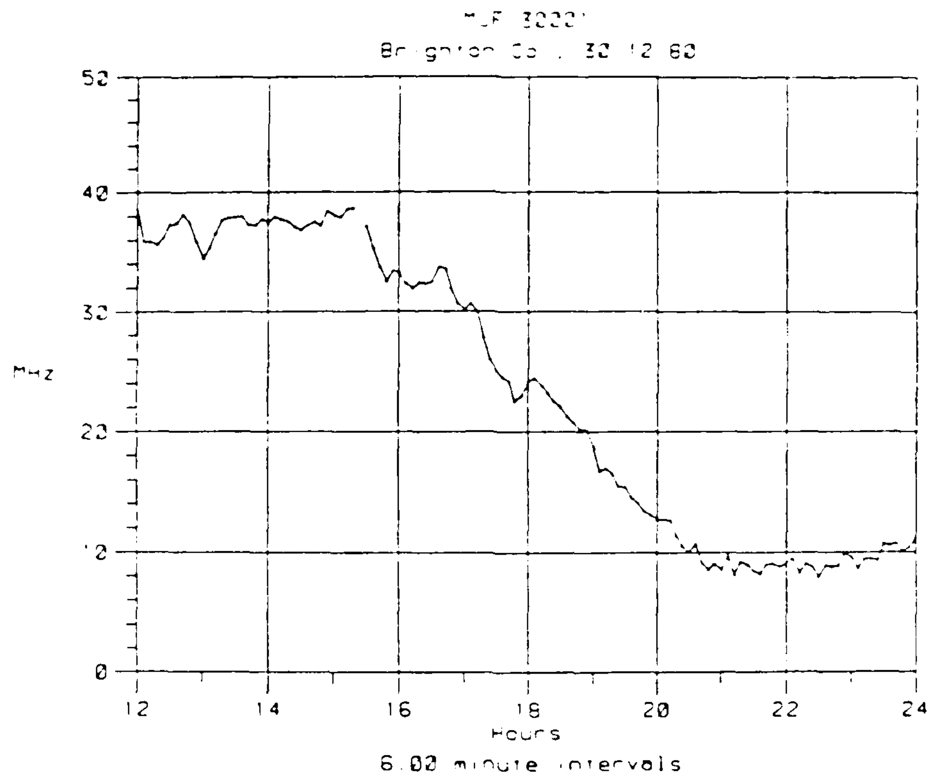
MUF (3000)
Brighton Co., 18 12 80
MHz
50
40
30
20
10
0
12
14
16
18
20
22
24
Hours
3 00 minute intervals

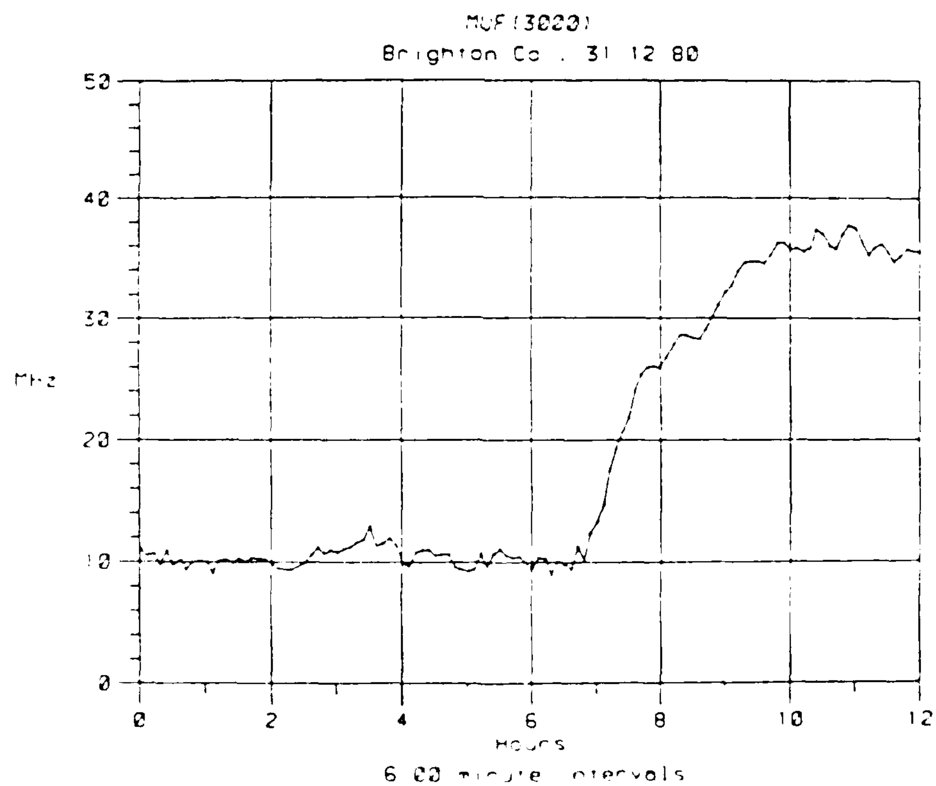


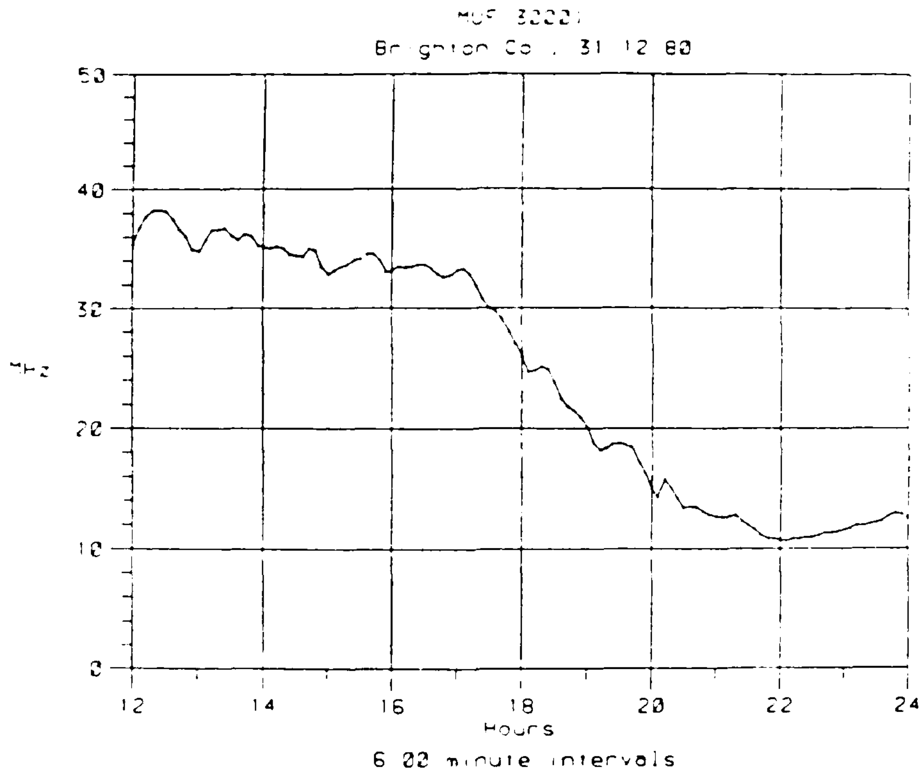
MUF(3000)
Brighton Co., 19 12 80
MHz
50
40
30
20
10
0
0
2
4
6
8
10
Hours

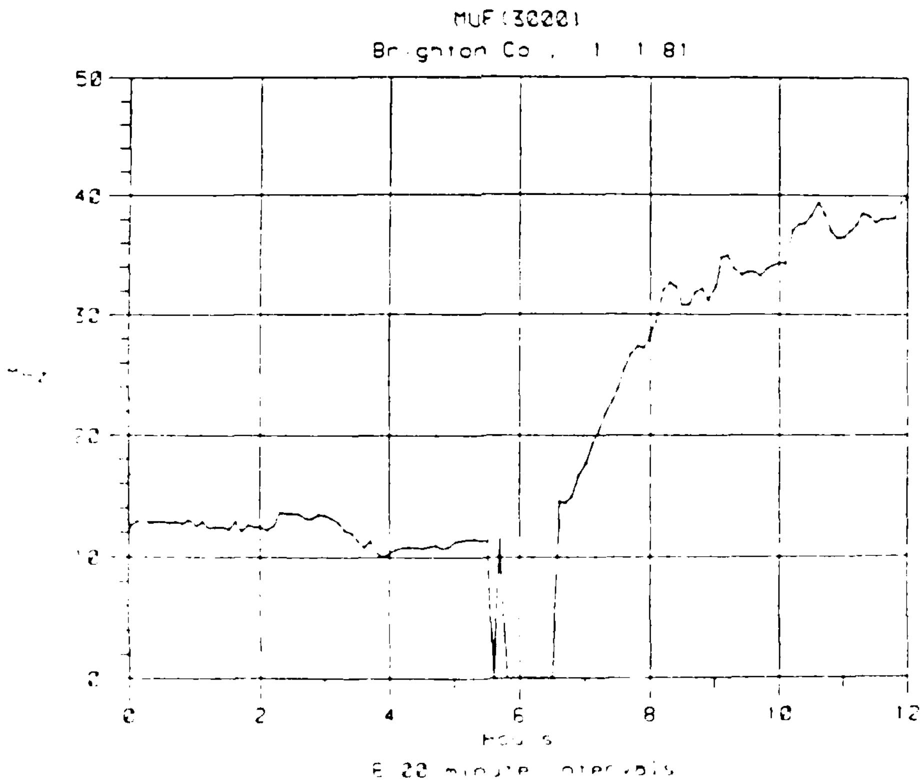

MUF(3000)
Brighton Co , 29 12 80
MHz
50
40
30
20
10
0
12
14
16
18
20
22
24
Hours
6 00 minute intervals


MUF(3000)
Brighton Co , 30 12 80
MHz
50
40
30
20
10
0
0
2
4
6
8
10
12
Hours
6 00 minute intervals

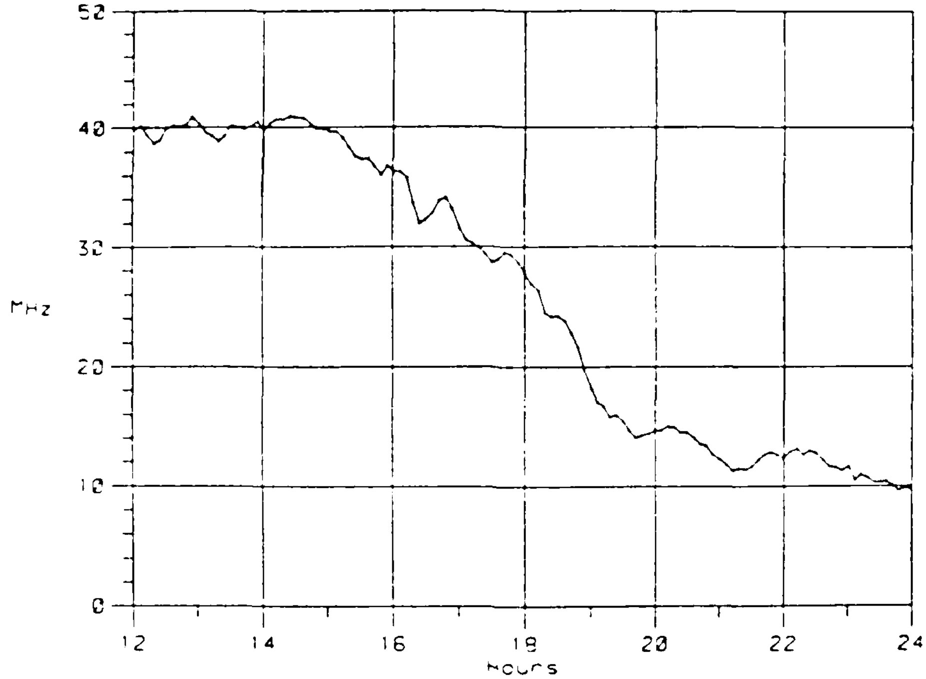

MUF(3000)
Brighton Co. 30 12 80
MHz
Hours
6.00 minute intervals


MUF(3000)
Brighton Co. 31 12 80
MHz
Hours
6.00 minute intervals


MUF 3000)
Brighton Co , 31 12 80
MHz
Hours
6 00 minute intervals

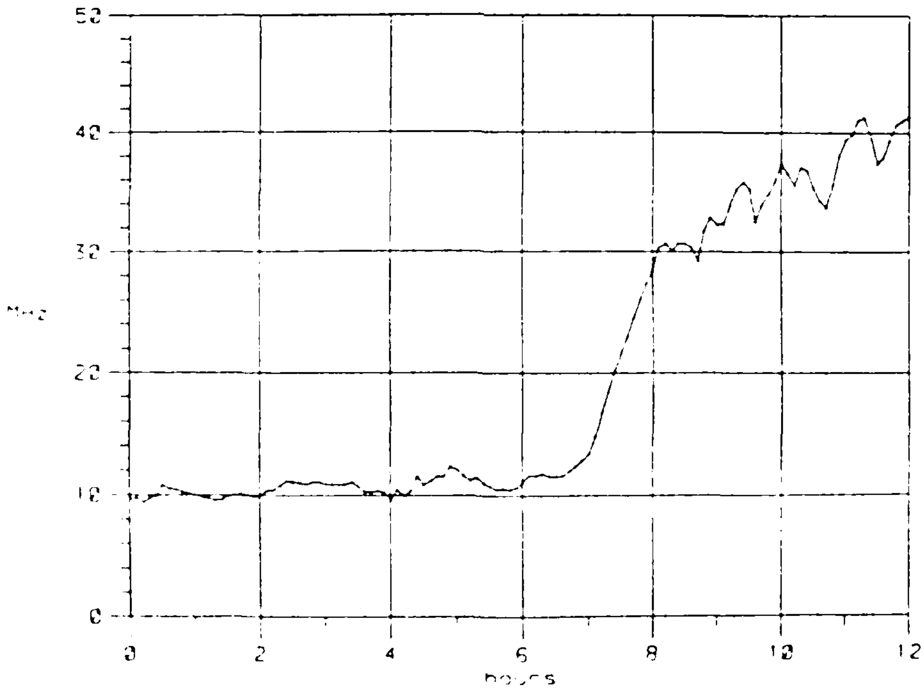

MUF(3000)
Brighton Co , 1 1 81

MUF(3222)
Brighton Co., 1 1 81

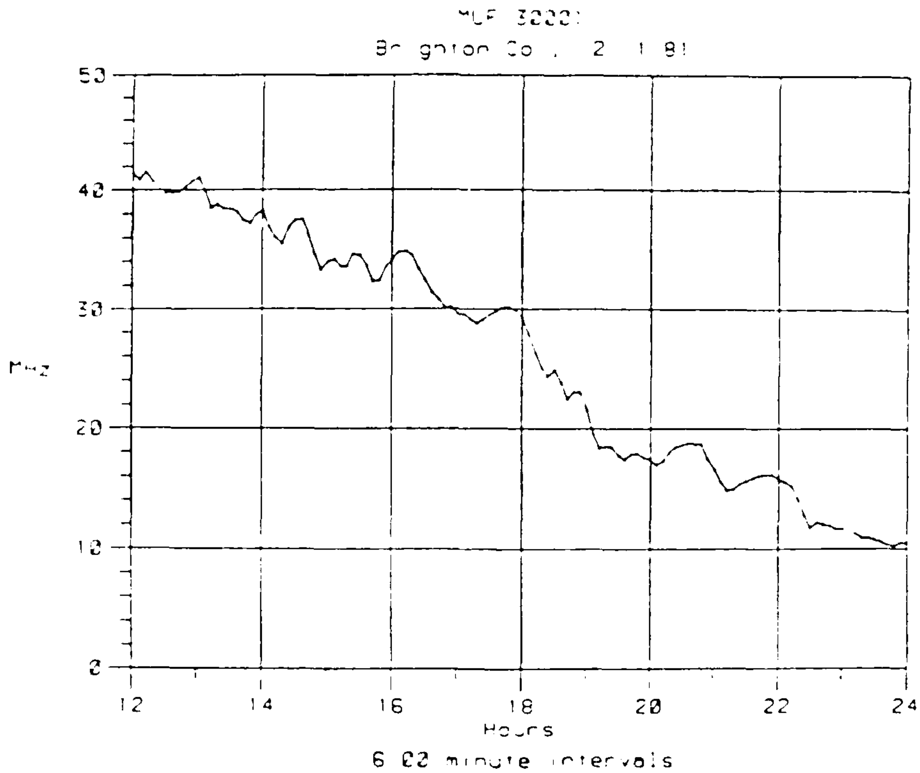


6 20 minute intervals

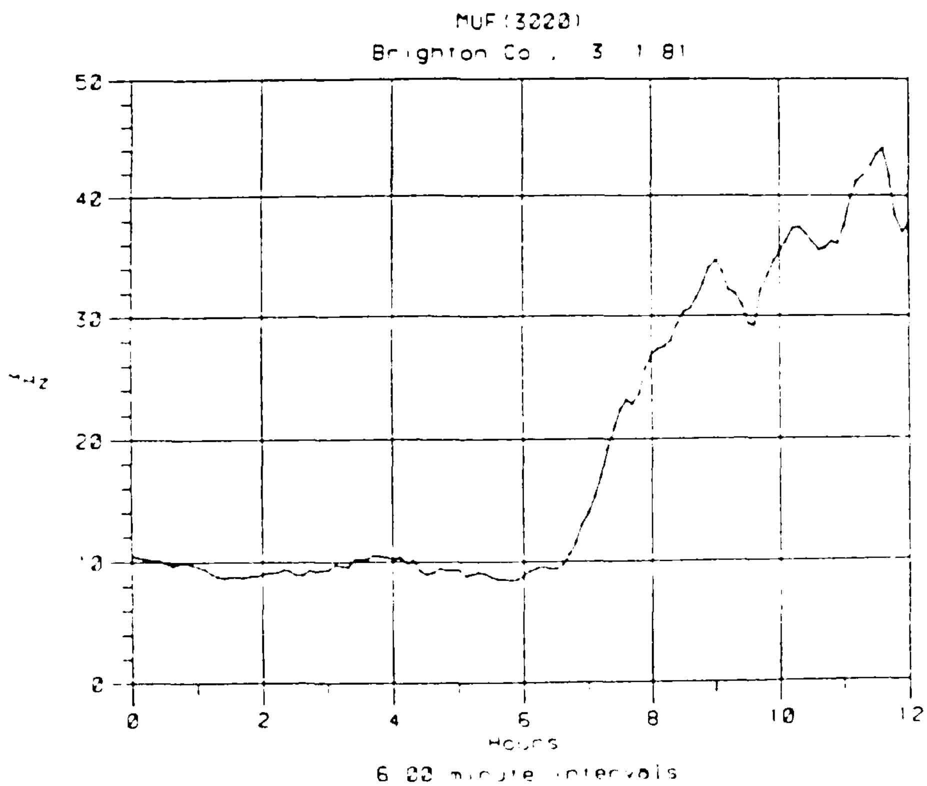
MUF(3000)
Brighton Co., 2 1 81



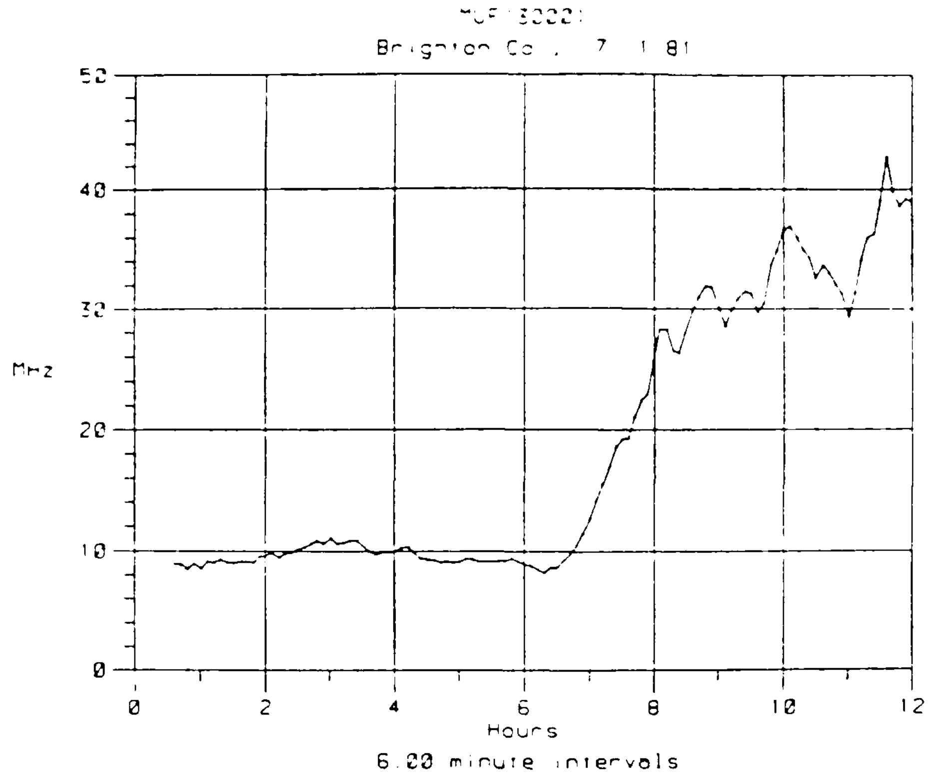
6 20 minute intervals

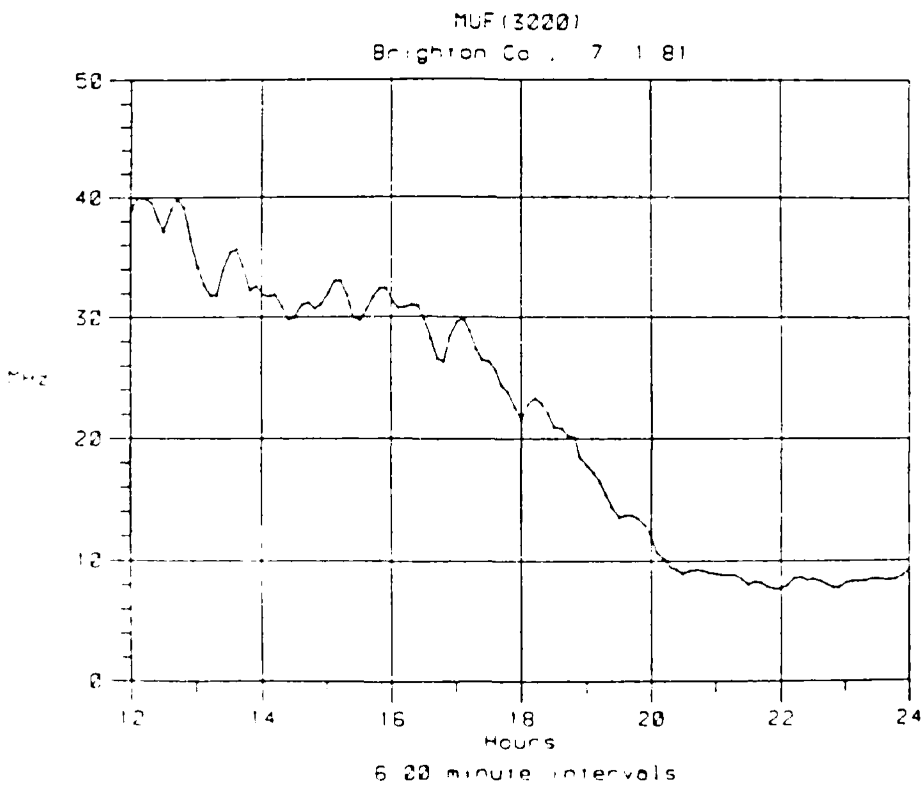


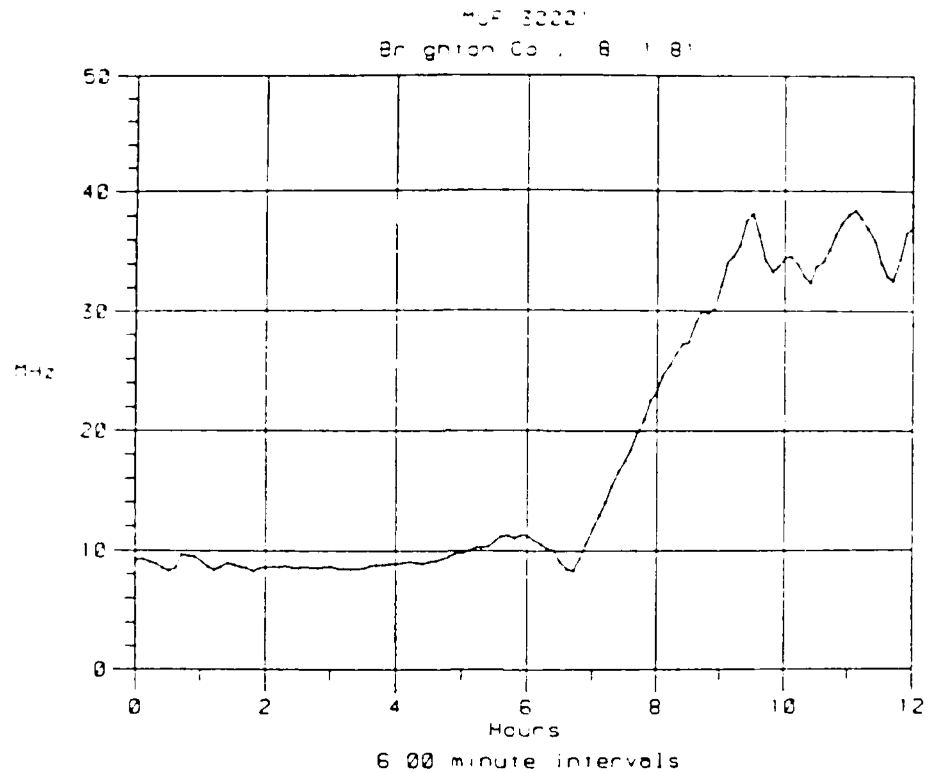
MUF(3000)
Brighton Co., 2 1 81
50
40
30
20
10
0
MHz
12
14
16
18
20
22
24
Hours
6.00 minute intervals

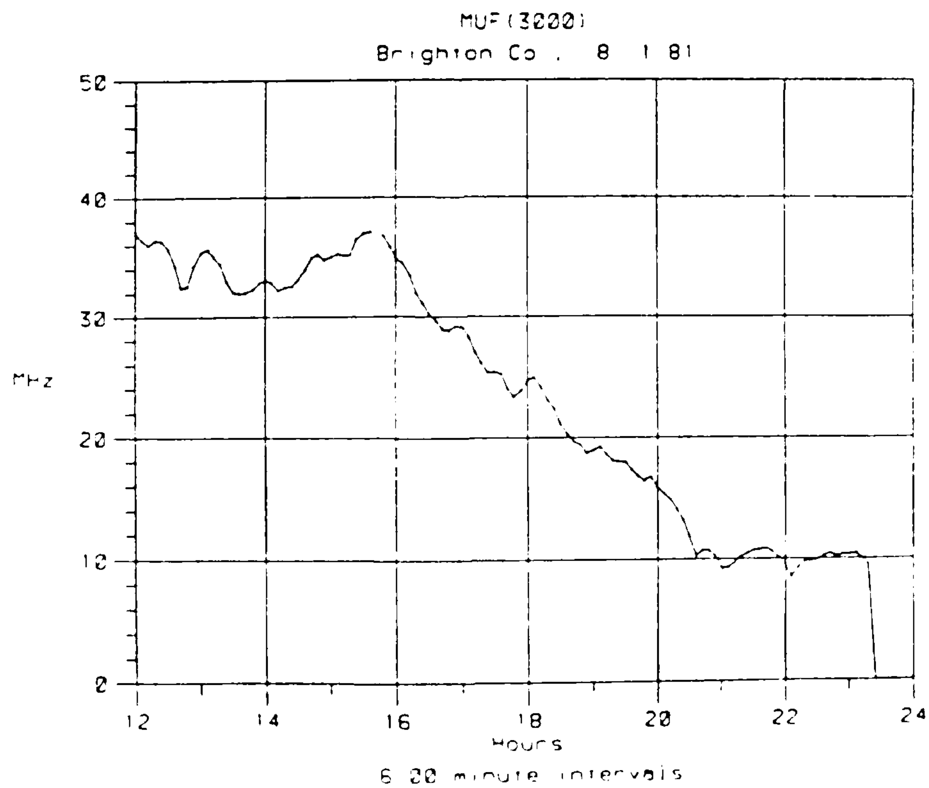


MUF(3000)
Brighton Co., 3 1 81
50
40
30
20
10
0
MHz
0
2
4
6
8
10
12
Hours
6.00 minute intervals

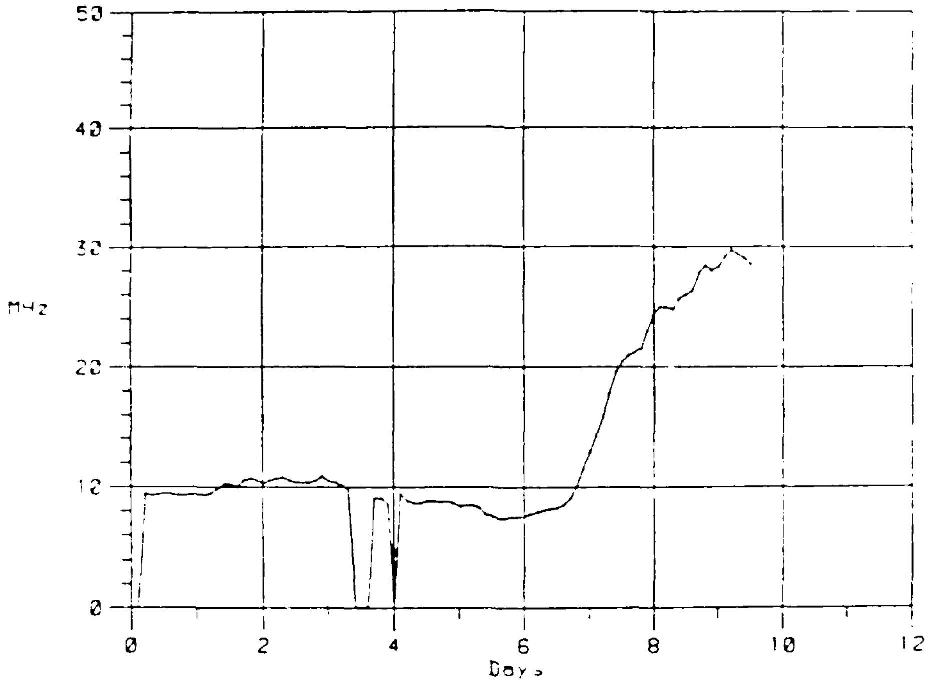

MUF(3000)
Brighton Co., 7 1 81
MHz
Hours
6.00 minute intervals


MUF(3000)
Brighton Co., 7 1 81
MHz
Hours
6.00 minute intervals


MUF(3000)
Brighton Co. 8 1 81
MHz
Hours
6 00 minute intervals

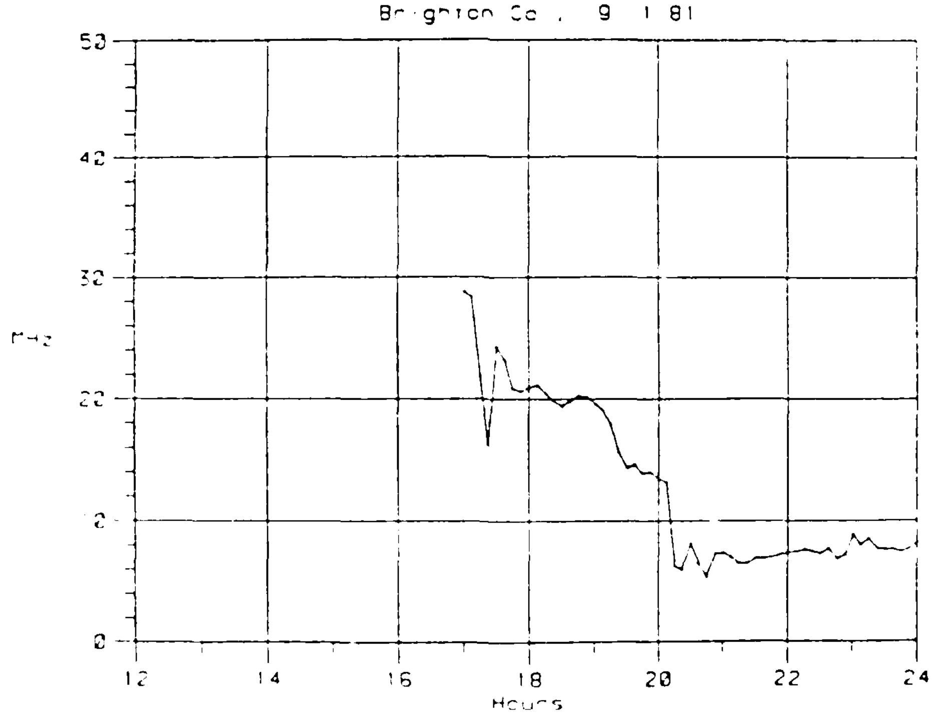

MUF(3000)
Brighton Co. 8 1 81
MHz
Hours
6 00 minute intervals

MUF(3000)
Brighton Co., 9 1 81

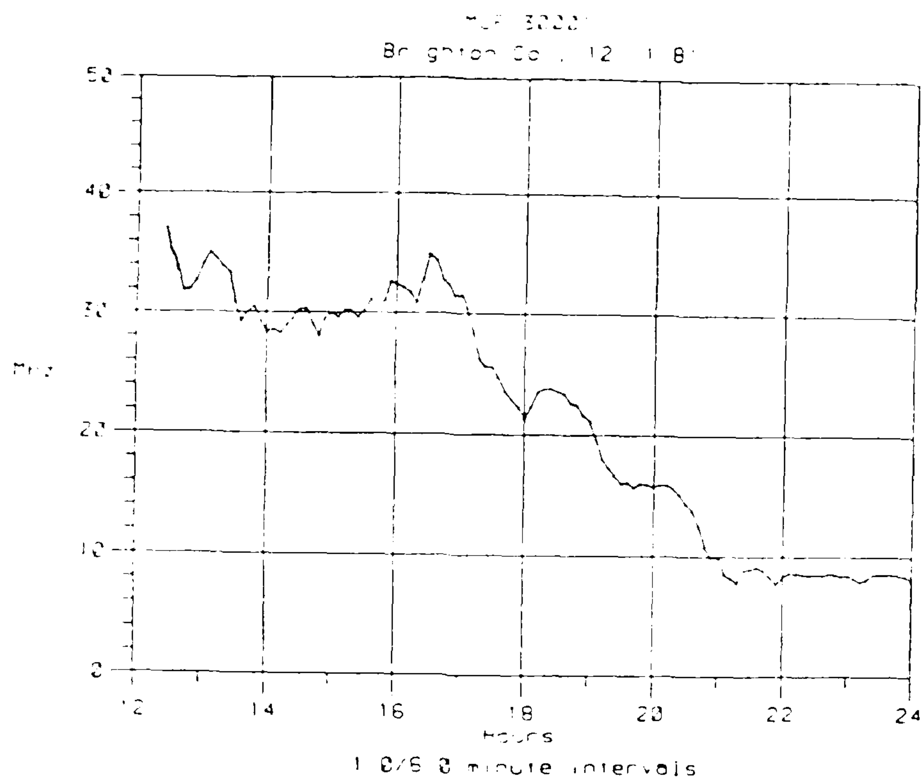


6 00 minute intervals

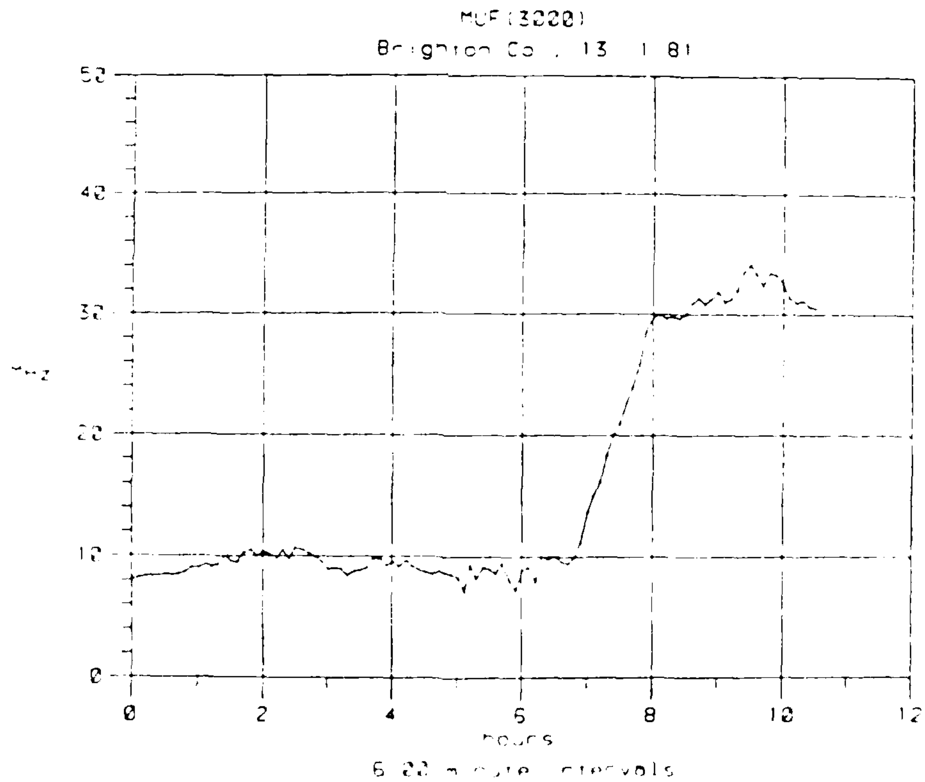
MUF(3000)
Brighton Co., 9 1 81



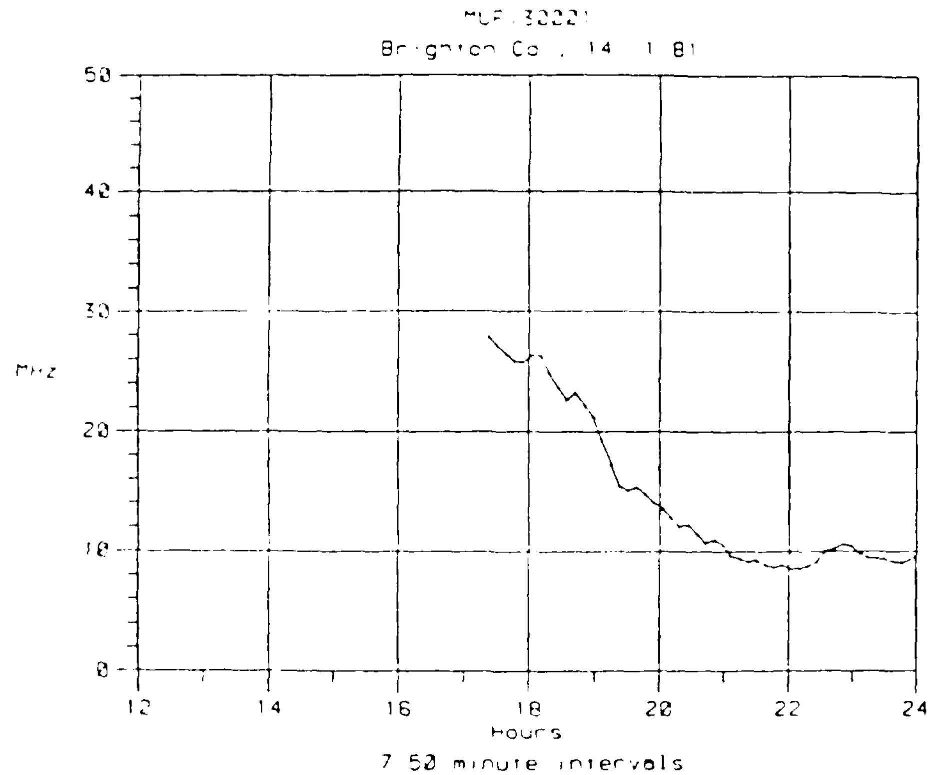
7 50 minute intervals

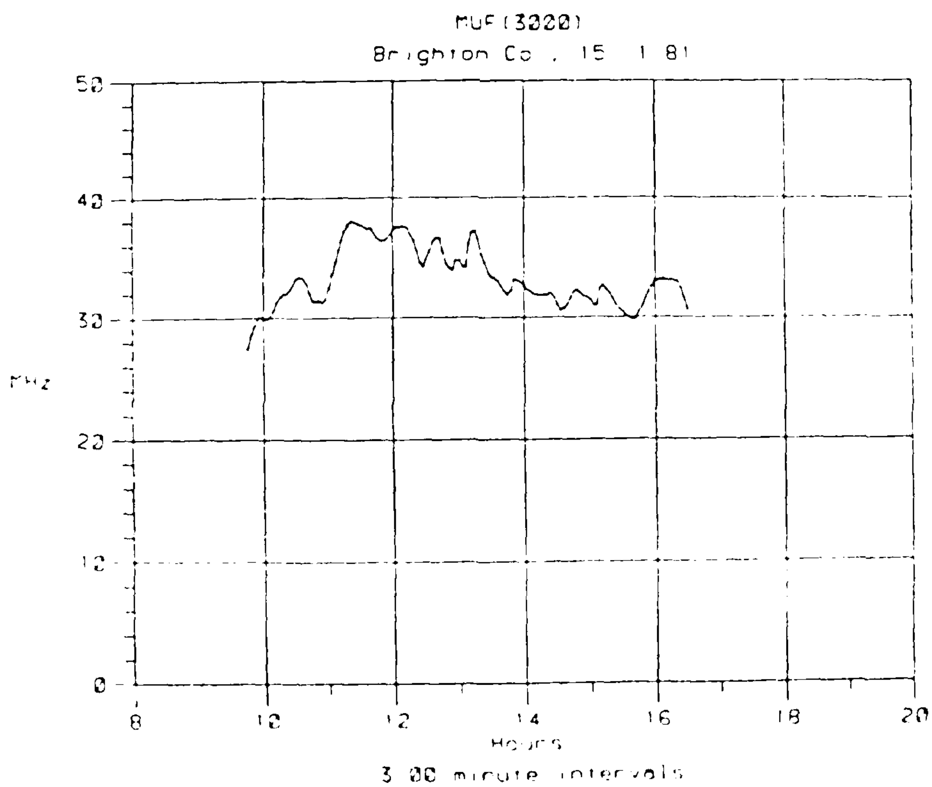


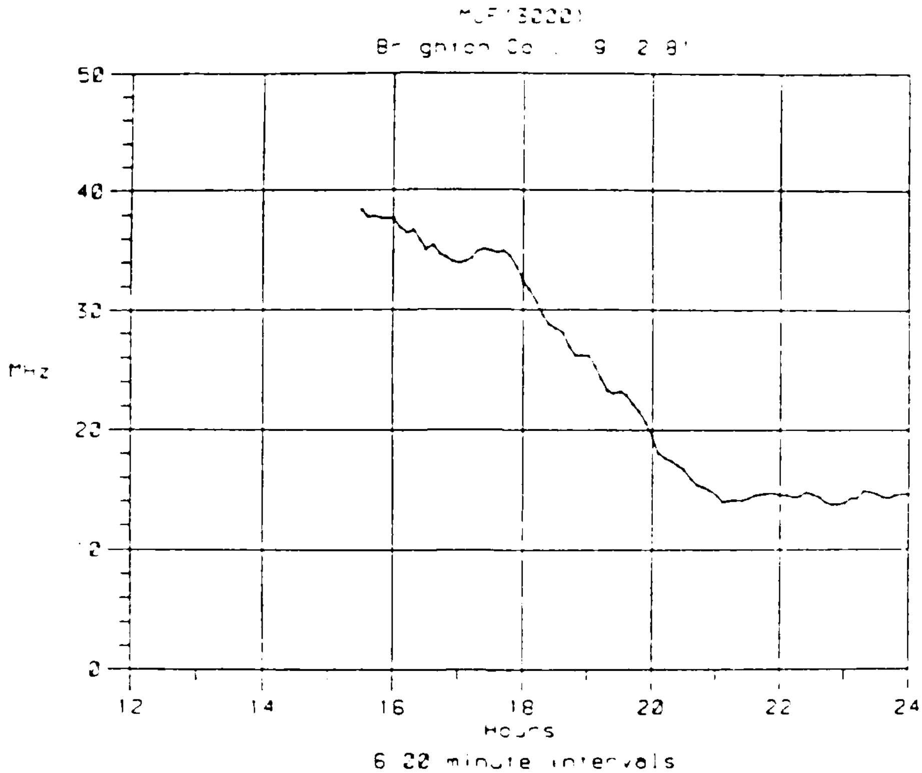
MUF(3000)
Brighton Co. 12 1 81
MHz
Hours
1 0/5 0 minute intervals

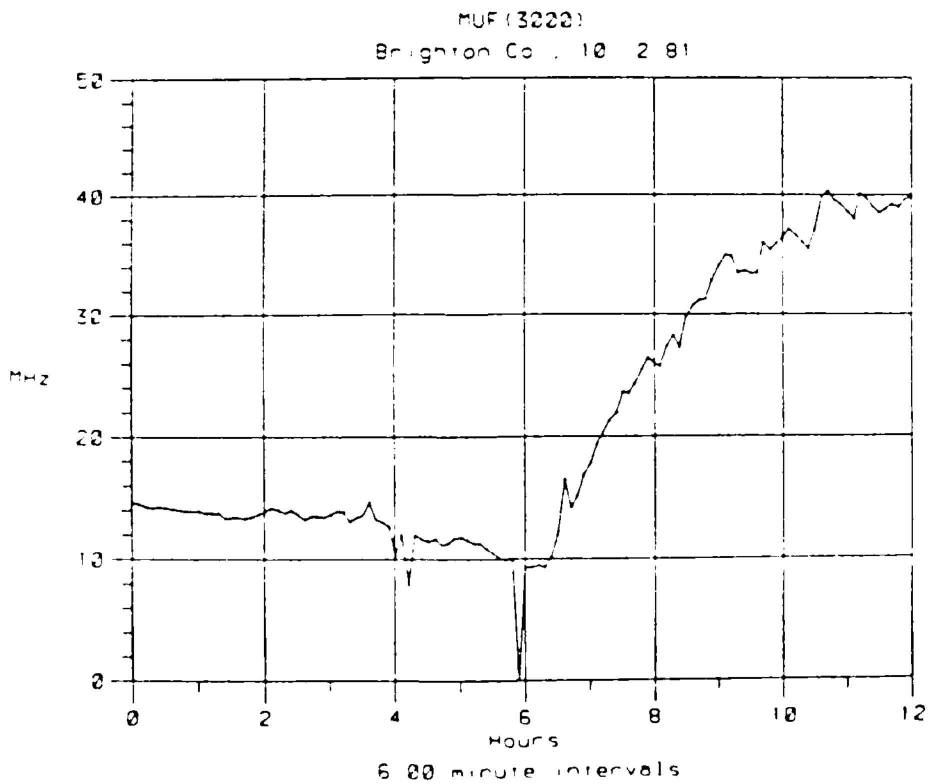


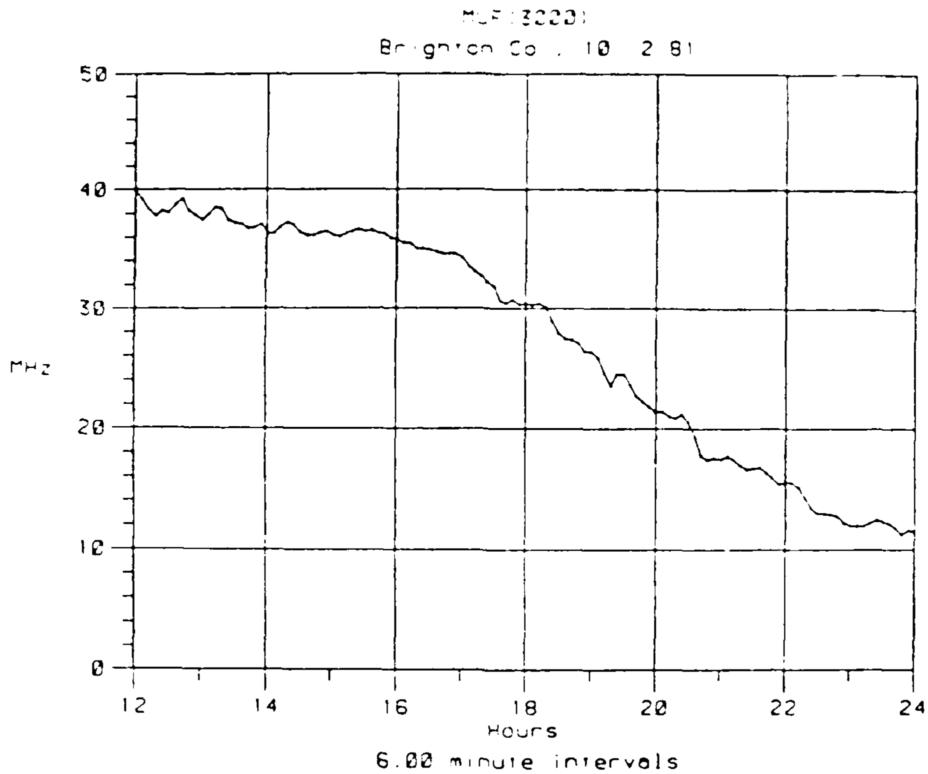
MUF(3000)
Brighton Co. 13 1 81
MHz
Hours
5 00 minute intervals

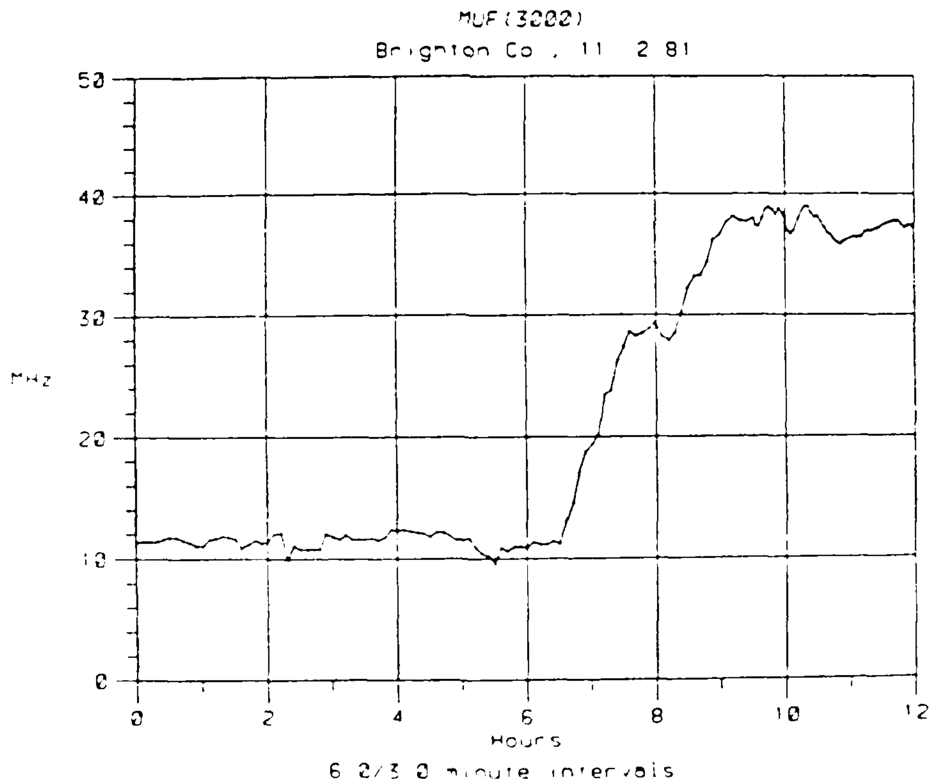

MUF(3000)
Brighton Co., 14 1 81
50
40
30
20
10
0
MHz
12
14
16
18
20
22
24
Hours
7.50 minute intervals

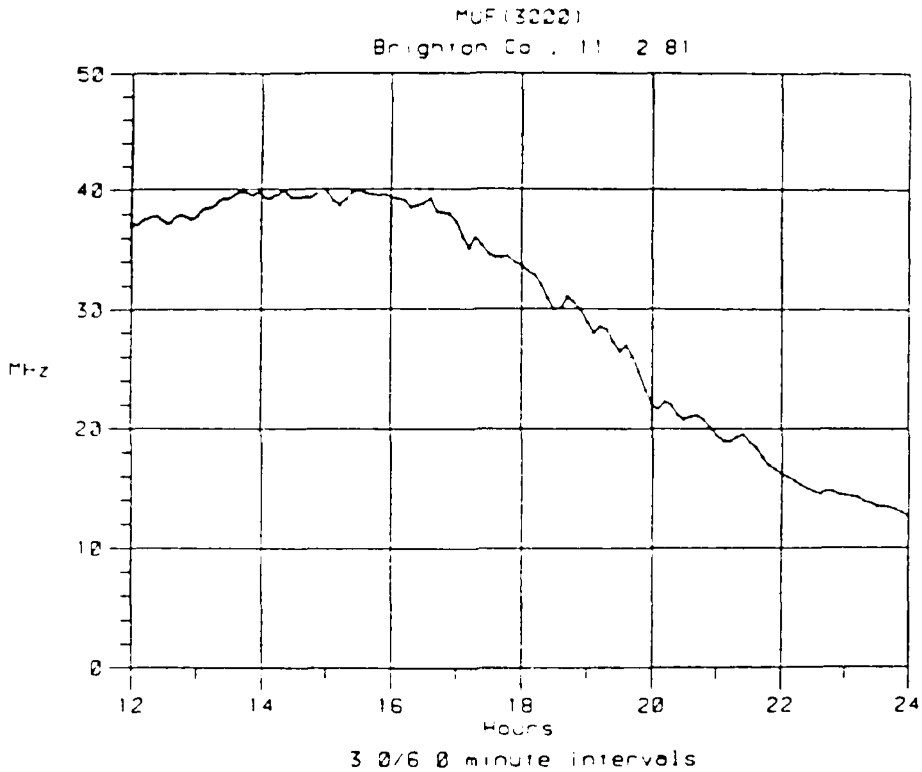

MUF(3000)
Brighton Co., 15 1 81
50
40
30
20
10
0
MHz
8
10
12
14
16
18
20
Hours
3.00 minute intervals

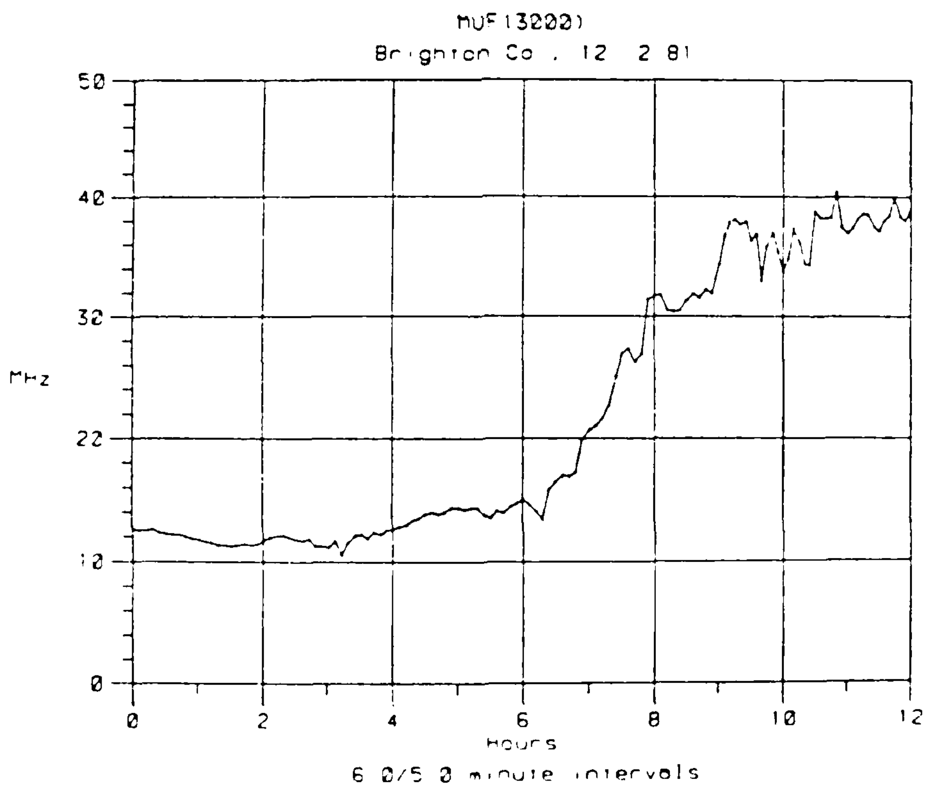

MUF(3000)
Brighton Co. 9 2 81
50
40
30
20
10
0
MHz
12
14
16
18
20
22
24
Hours
6 00 minute intervals

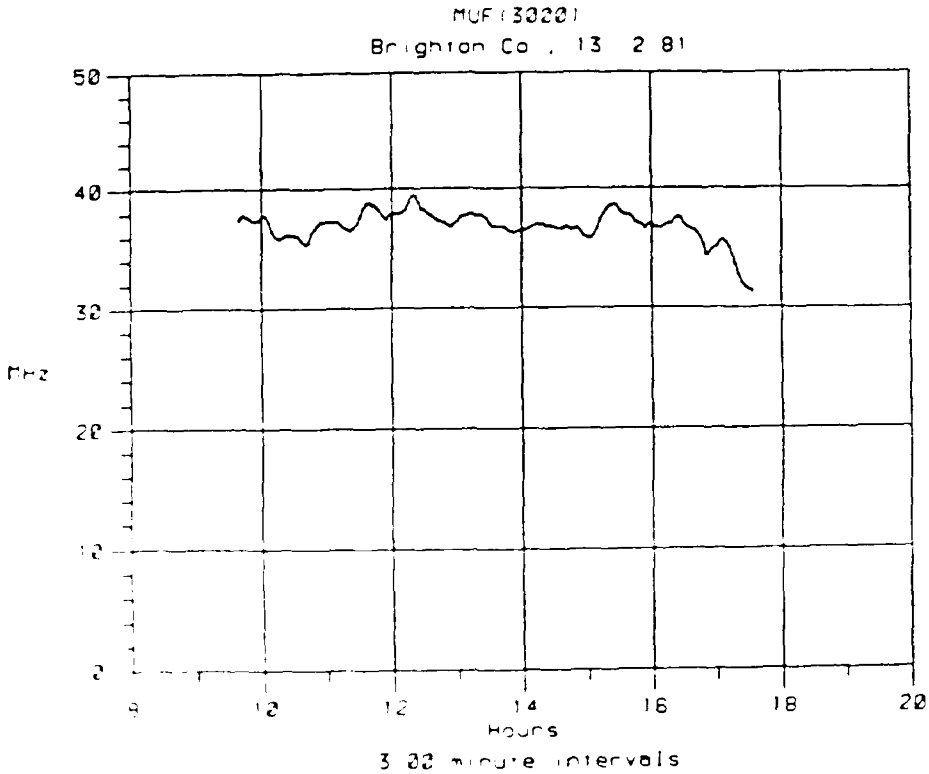

MUF(3000)
Brighton Co. 10 2 81
50
40
30
20
10
0
MHz
0
2
4
6
8
10
12
Hours
6 00 minute intervals

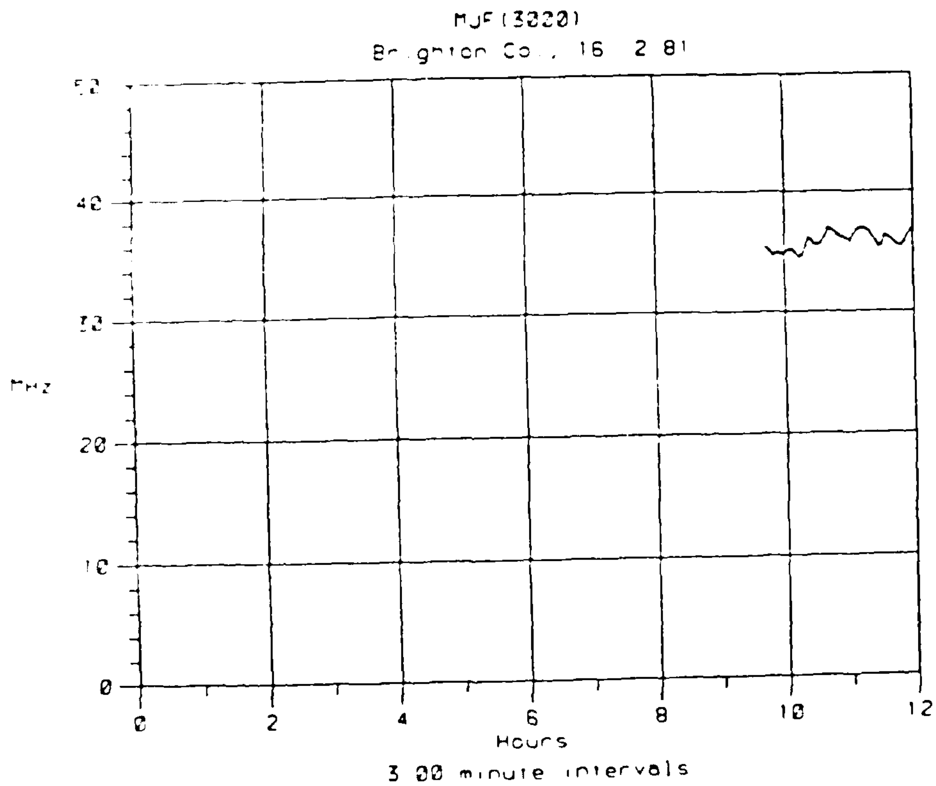

MUF(3000)
Brighton Co., 10 2 81
50
40
30
20
10
0
MHz
12
14
16
18
20
22
24
Hours
6.00 minute intervals

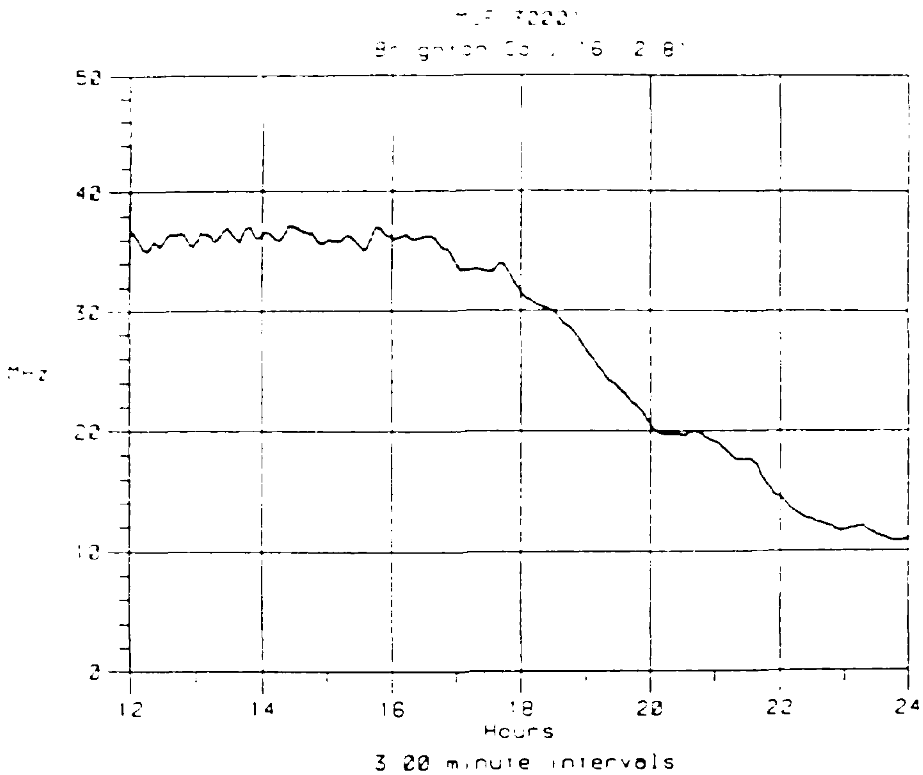

MUF(3000)
Brighton Co., 11 2 81
50
40
30
20
10
0
MHz
0
2
4
6
8
10
12
Hours
6 2/3 0 minute intervals


MUF(3200)
Brighton Co., 11 2 81
50
40
30
20
10
0
MHz
12
14
16
18
20
22
24
Hours
3 0/6 0 minute intervals

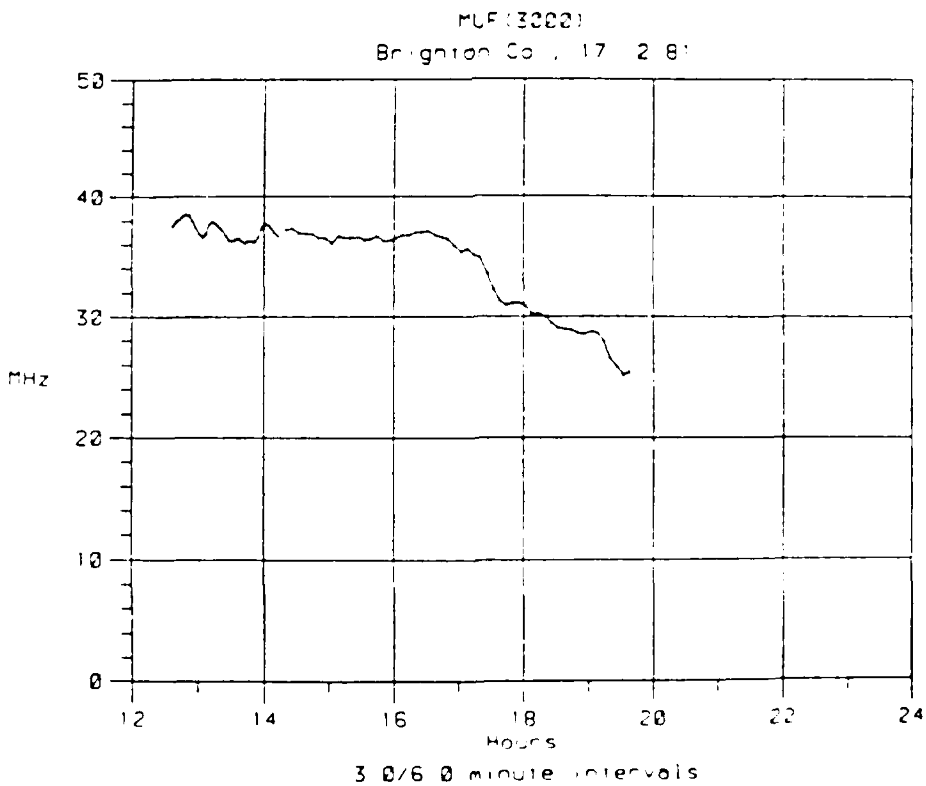

MUF(3200)
Brighton Co., 12 2 81
50
40
30
20
10
0
MHz
0
2
4
6
8
10
12
Hours
6 0/5 0 minute intervals


MUF(3020)
Brighton Co., 13 2 81
50
40
30
MHz
20
10
0
8
10
12
14
16
18
20
Hours
3 00 minute intervals

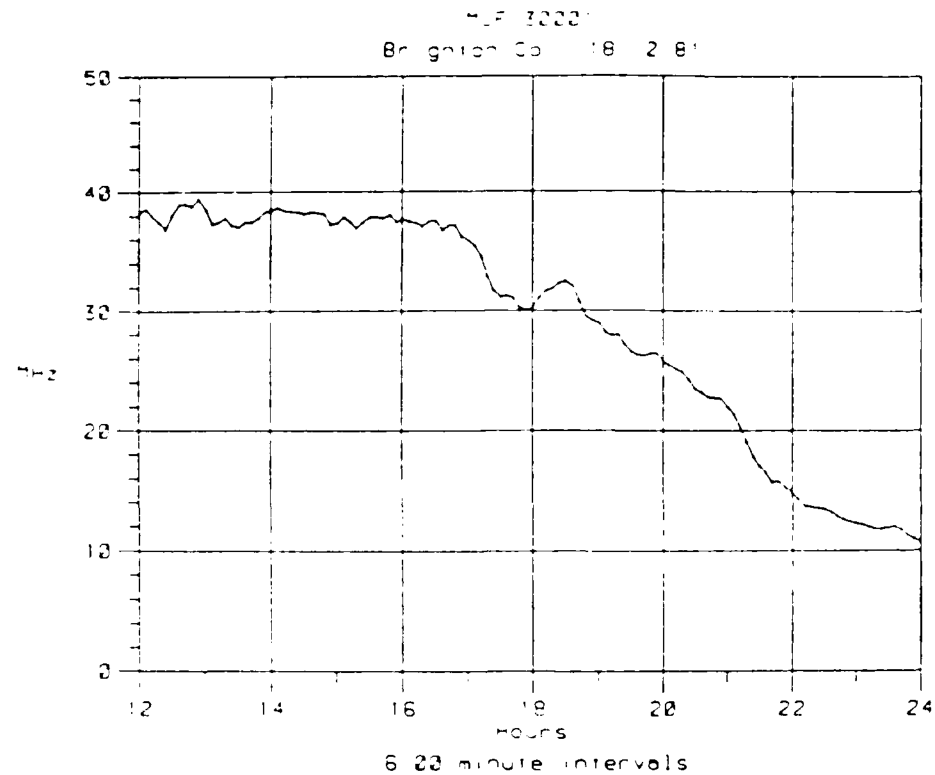

MUF(3020)
Brighton Co., 16 2 81
50
40
30
MHz
20
10
0
0
2
4
6
8
10
12
Hours
3 00 minute intervals

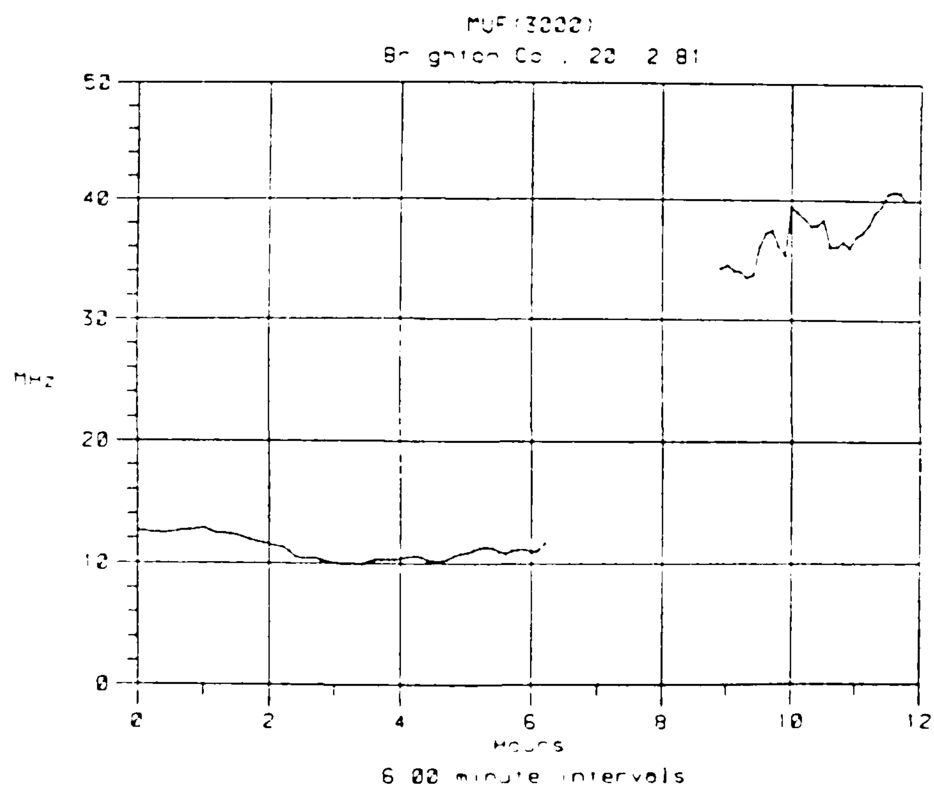


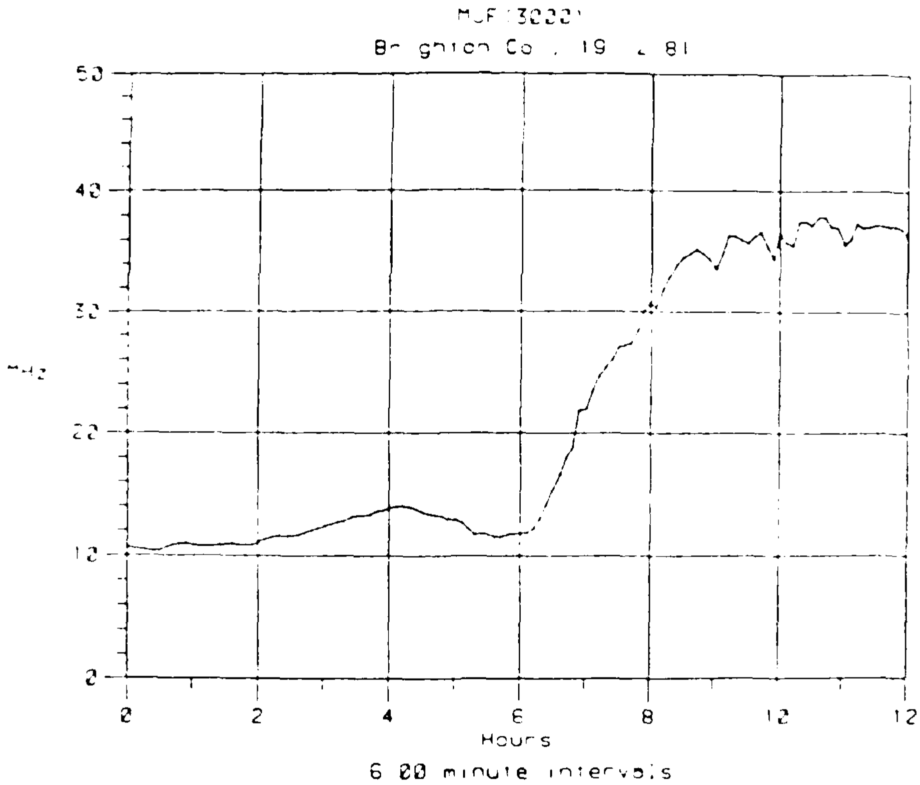
MUF (3000)
Brighton Co., 16 2 81
MHz
Hours
3 00 minute intervals

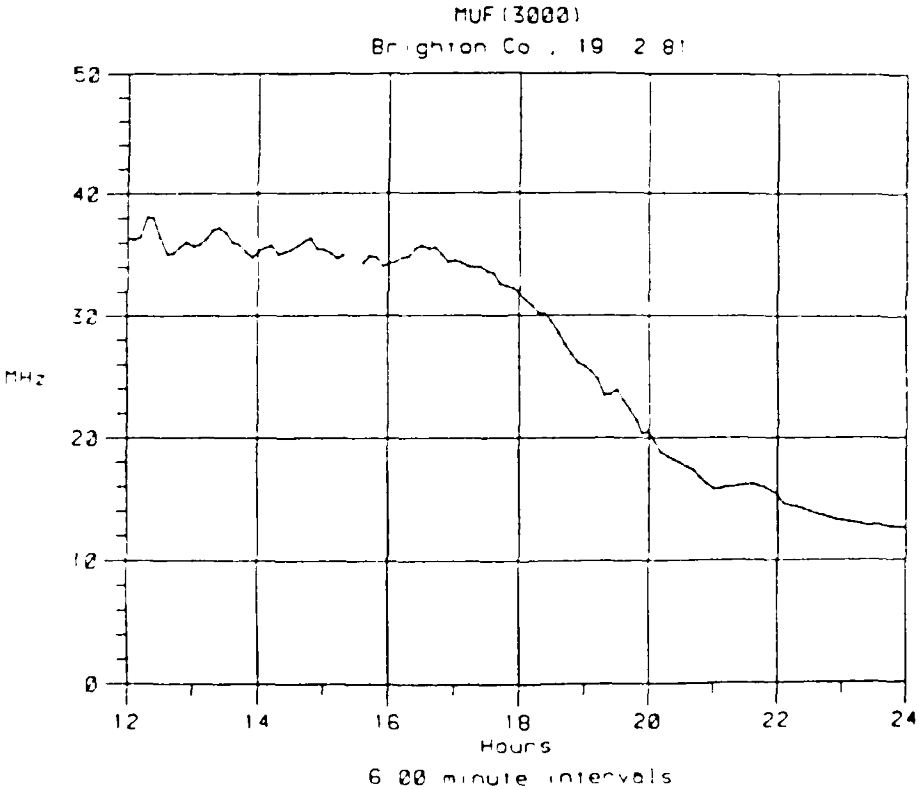


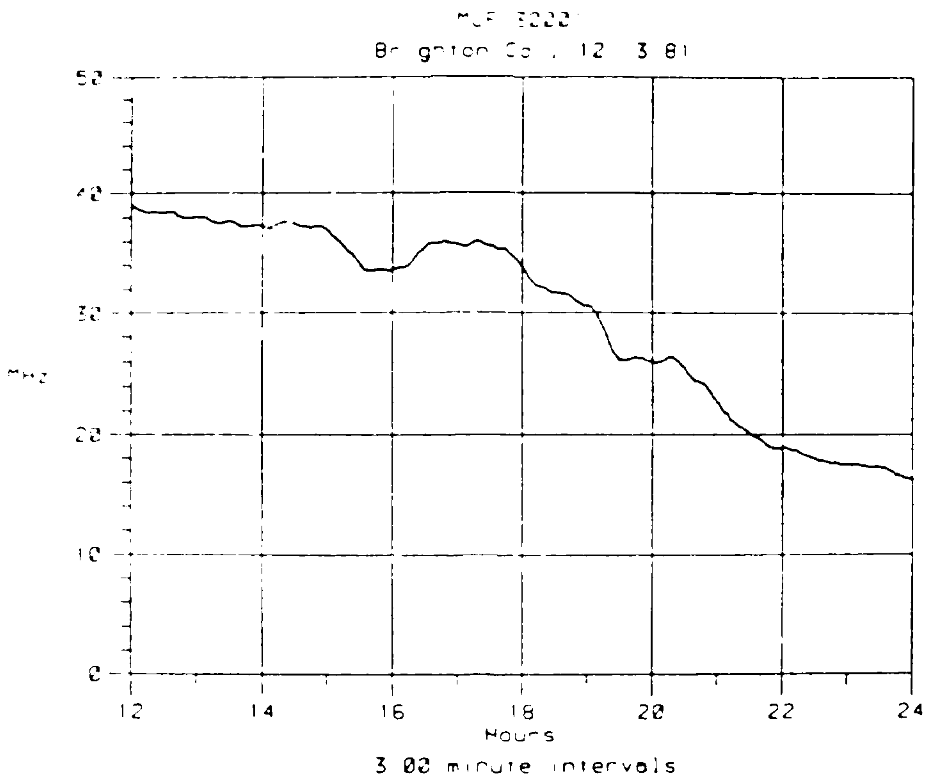
MUF(3000)
Brighton Co., 17 2 81
MHz
Hours
3 0/6 0 minute intervals

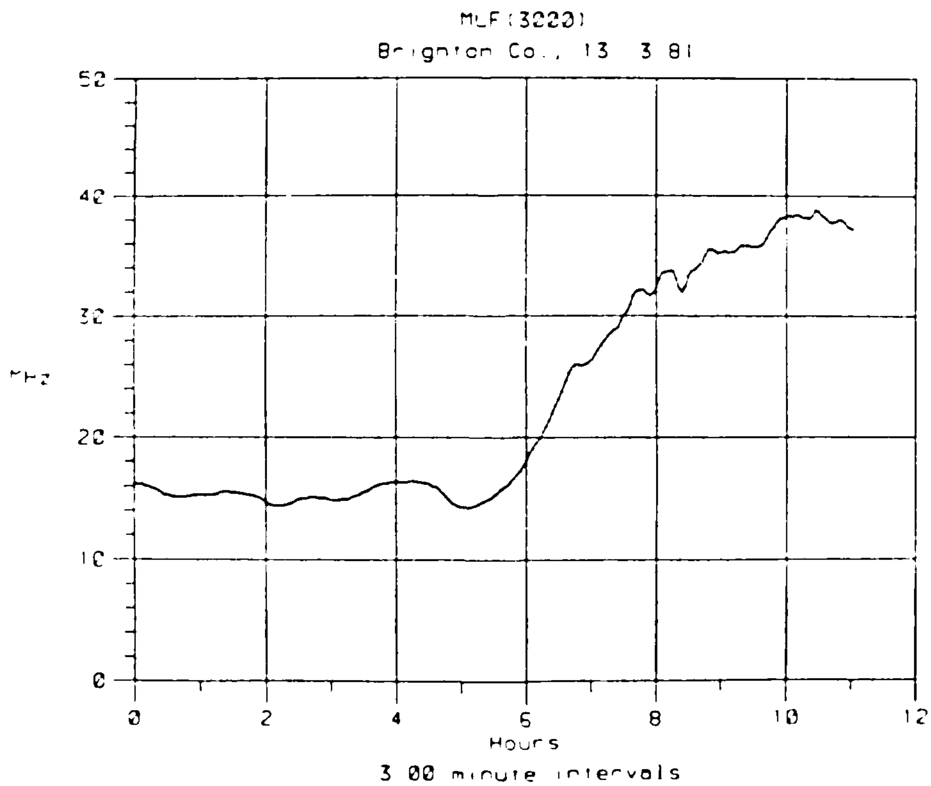

MUF(3000)
Brighton Co. 18 2 81
MHz
Hours
6 00 minute intervals

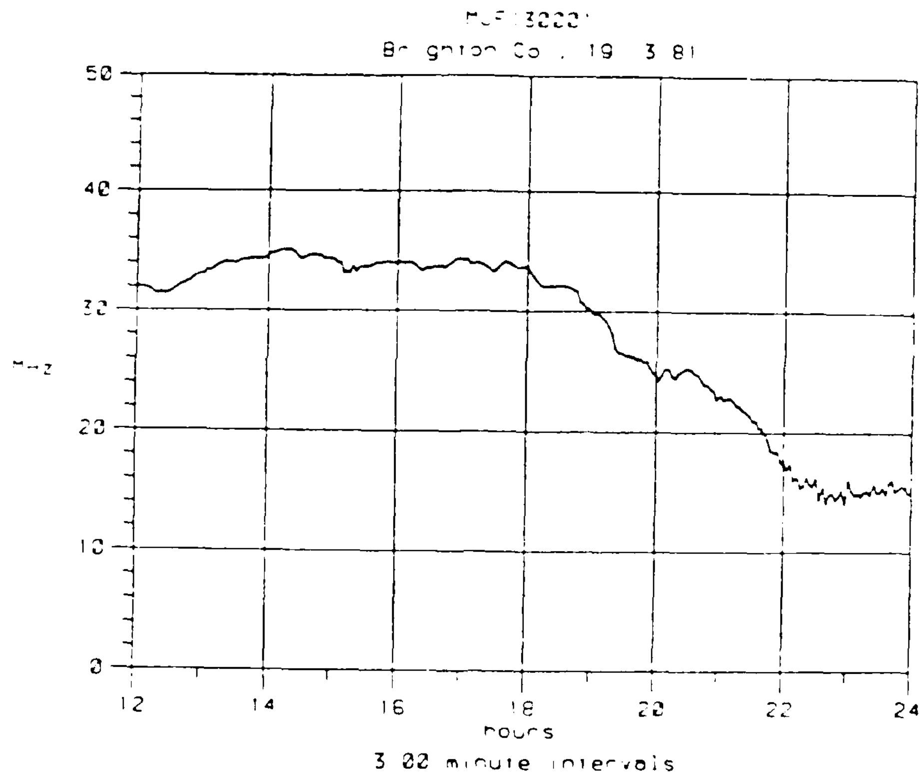

MUF(3000)
Brighton Co. 20 2 81
MHz
Hours
6 00 minute intervals

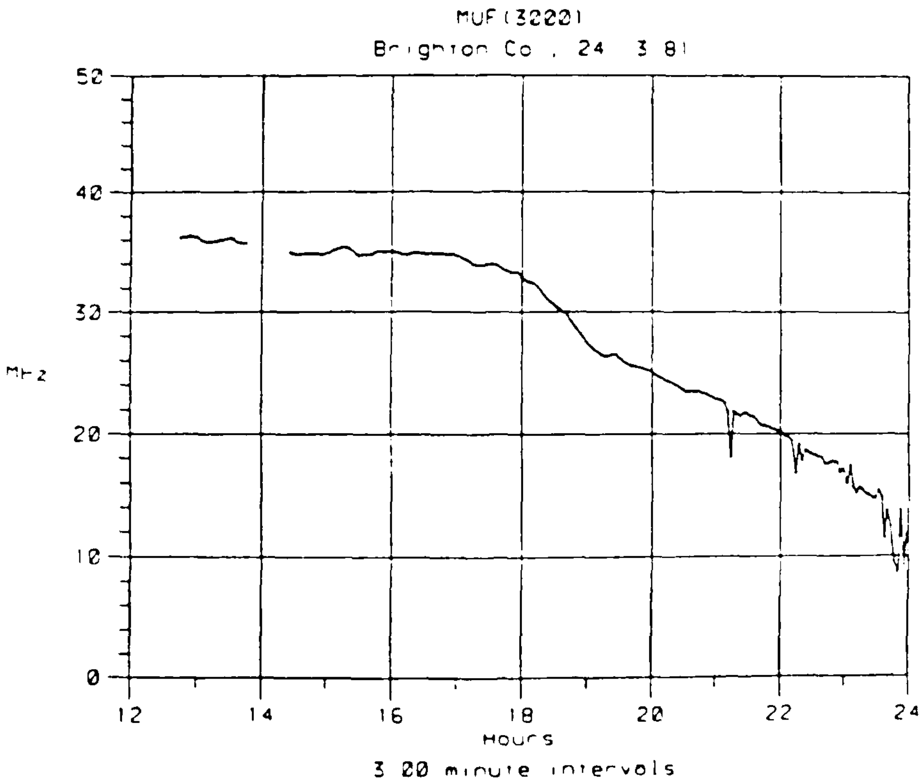

MUF(3000)
Brighton Co., 19 2 81
MHz
50
40
30
20
10
0
0
2
4
6
8
10
12
Hours
6 00 minute intervals


MUF(3000)
Brighton Co., 19 2 81
MHz
50
40
30
20
10
0
12
14
16
18
20
22
24
Hours
6 00 minute intervals

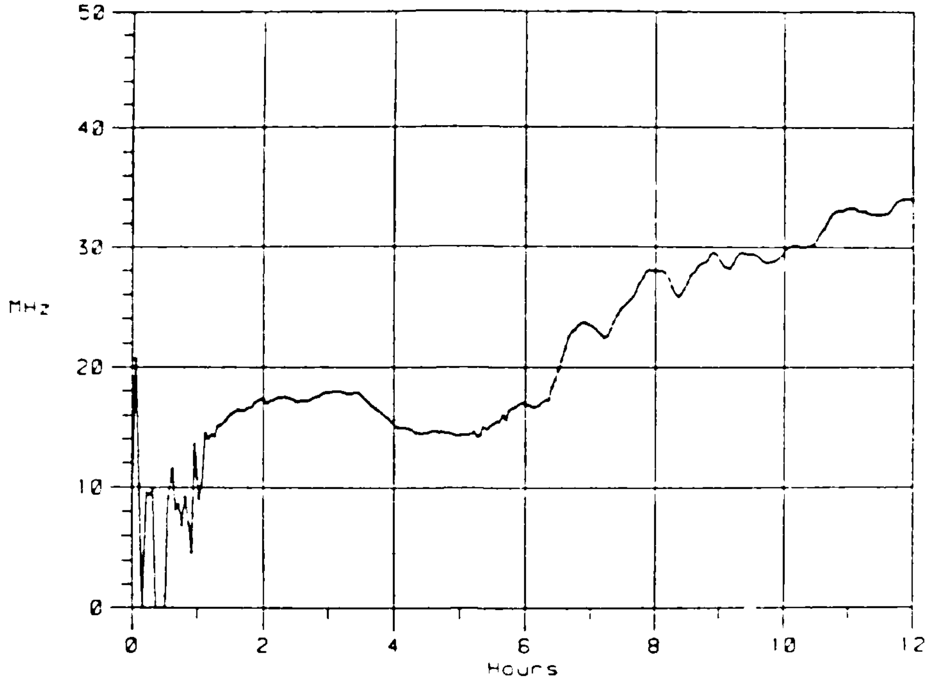

MUF (3220)
Brighton Co., 12 3 81
50
40
30
20
10
0
MHz
12
14
16
18
20
22
24
Hours
3 00 minute intervals


MUF (3220)
Brighton Co., 13 3 81
50
40
30
20
10
0
MHz
0
2
4
6
8
10
12
Hours
3 00 minute intervals


MUF(3200)
Brighton Co , 19 3 81
50
40
30
20
10
0
MHz
12
14
16
18
20
22
24
Hours
3 00 minute intervals

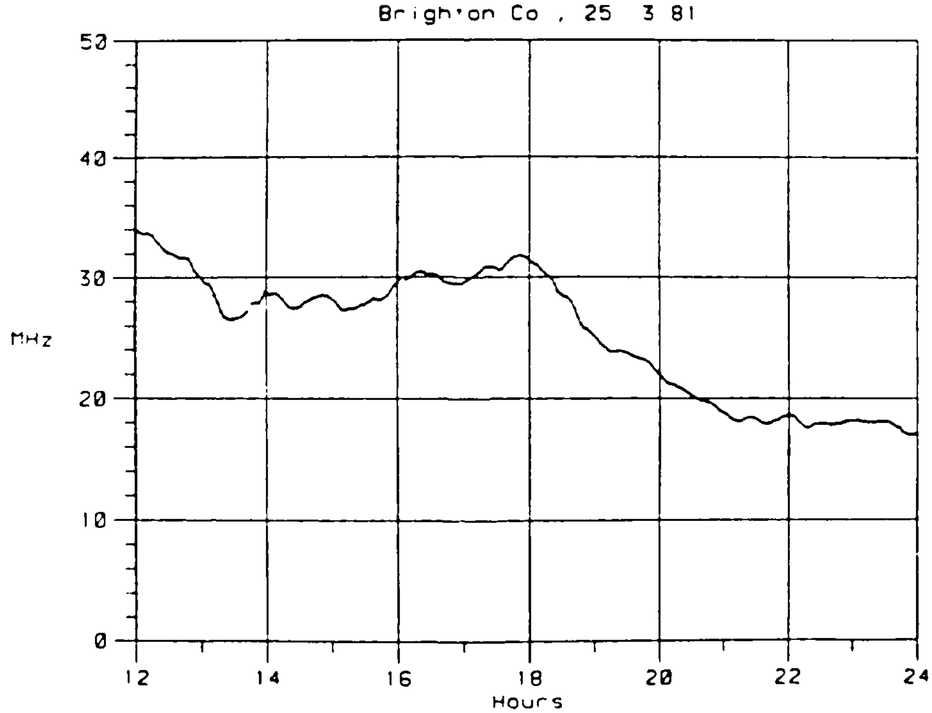

MUF(3200)
Brighton Co , 24 3 81
50
40
30
20
10
0
MHz
12
14
16
18
20
22
24
Hours
3 00 minute intervals

MUF (3000)
Brighton Co , 25 3 81

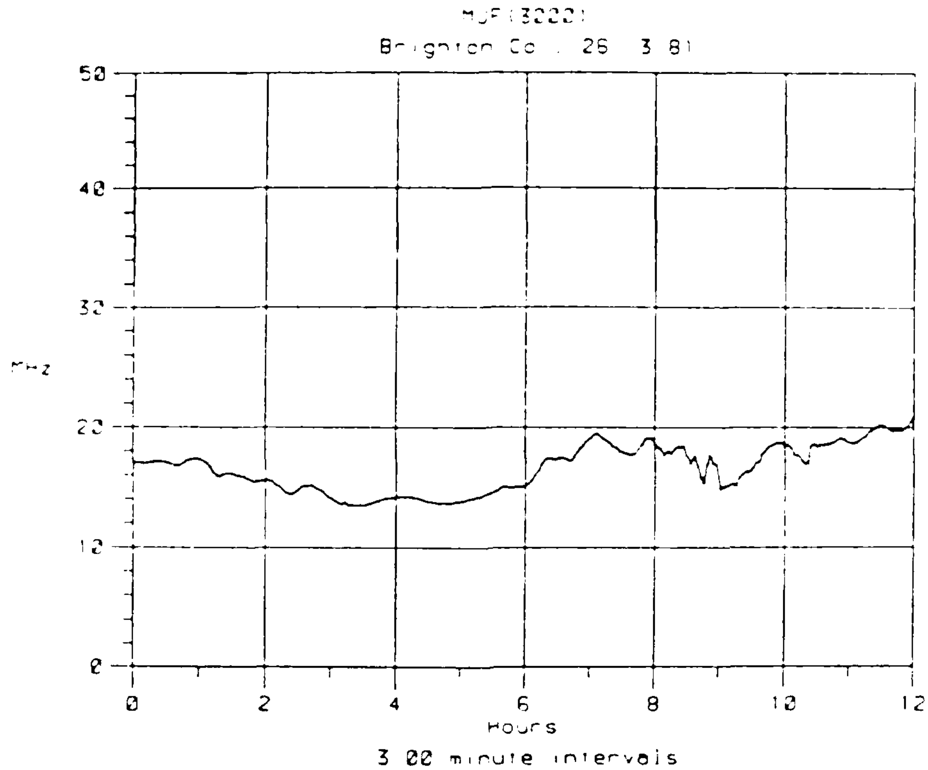


3.00 minute intervals

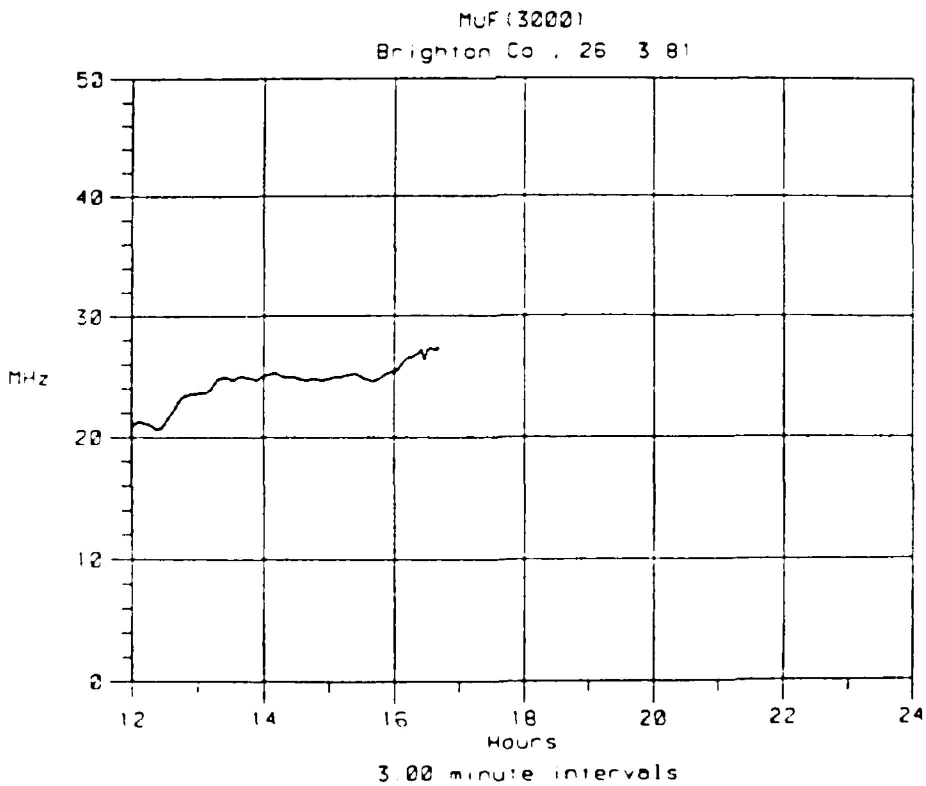
MUF (3000)
Brighton Co , 25 3 81



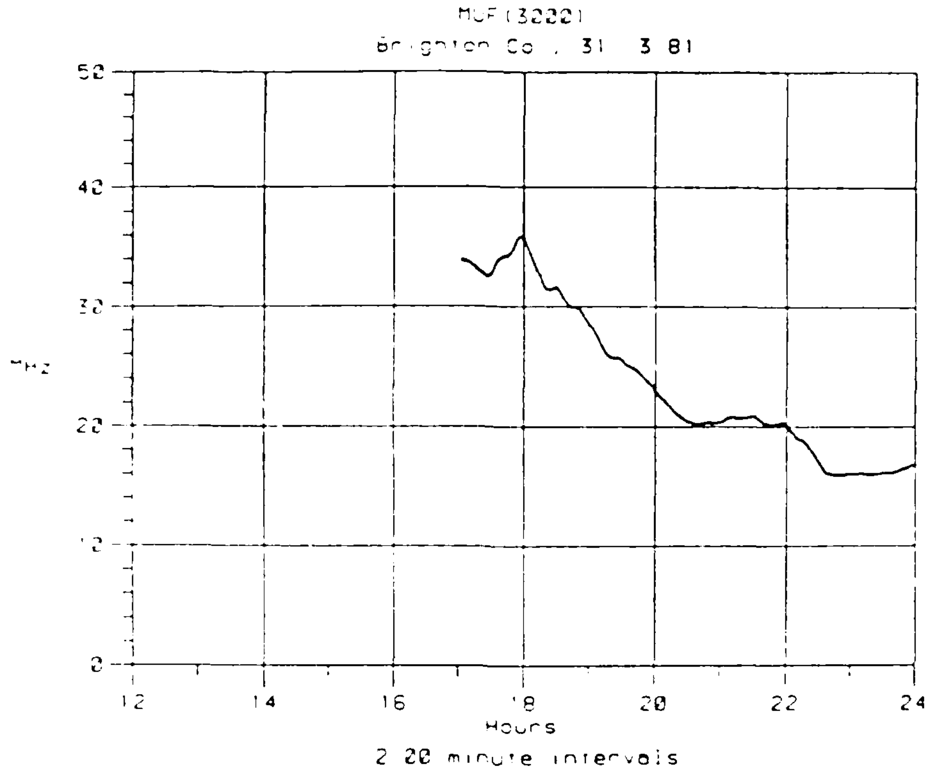
3.00 minute intervals



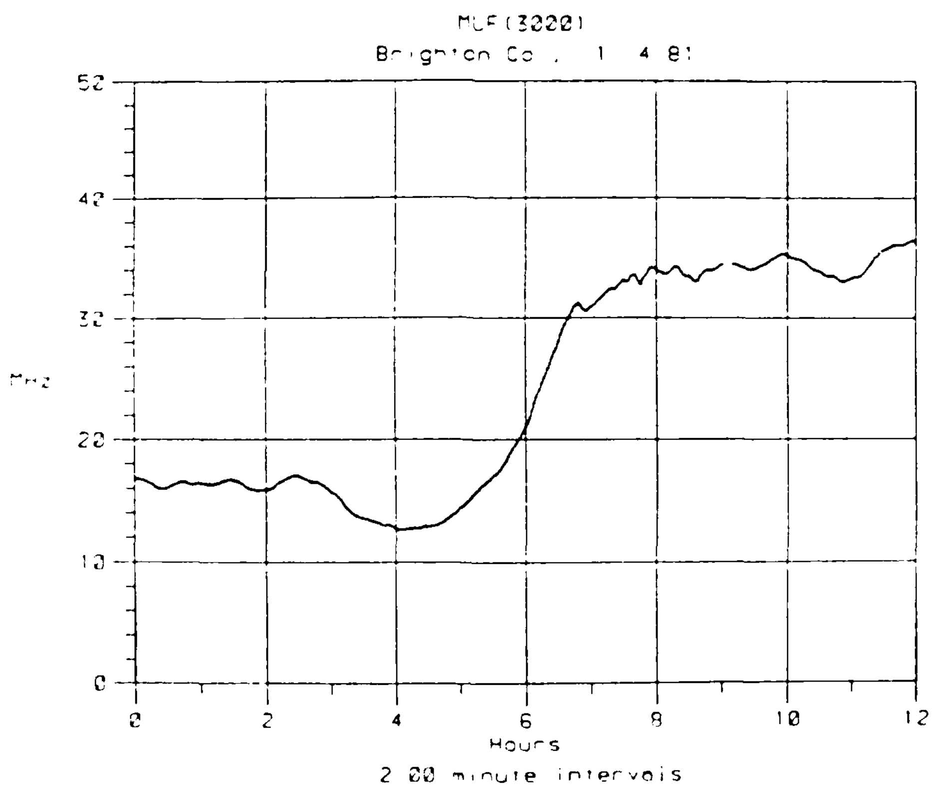
MuF(3000)
Brighton Co . 26 3 81
MHz
Hours
3 00 minute intervals



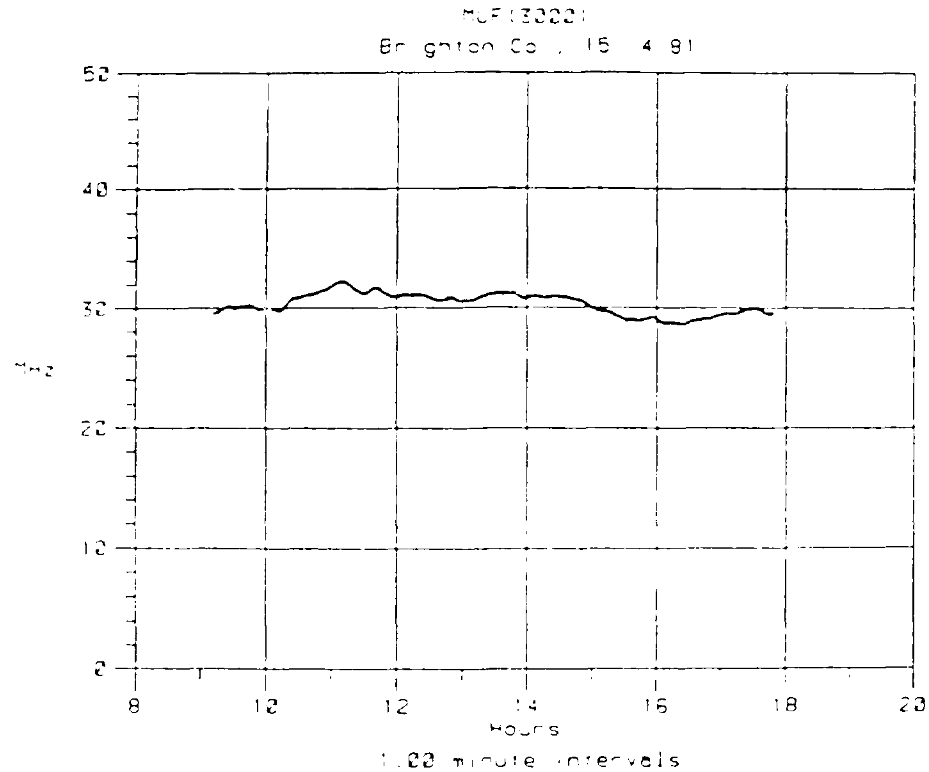
MuF(3000)
Brighton Co . 26 3 81
MHz
Hours
3 00 minute intervals

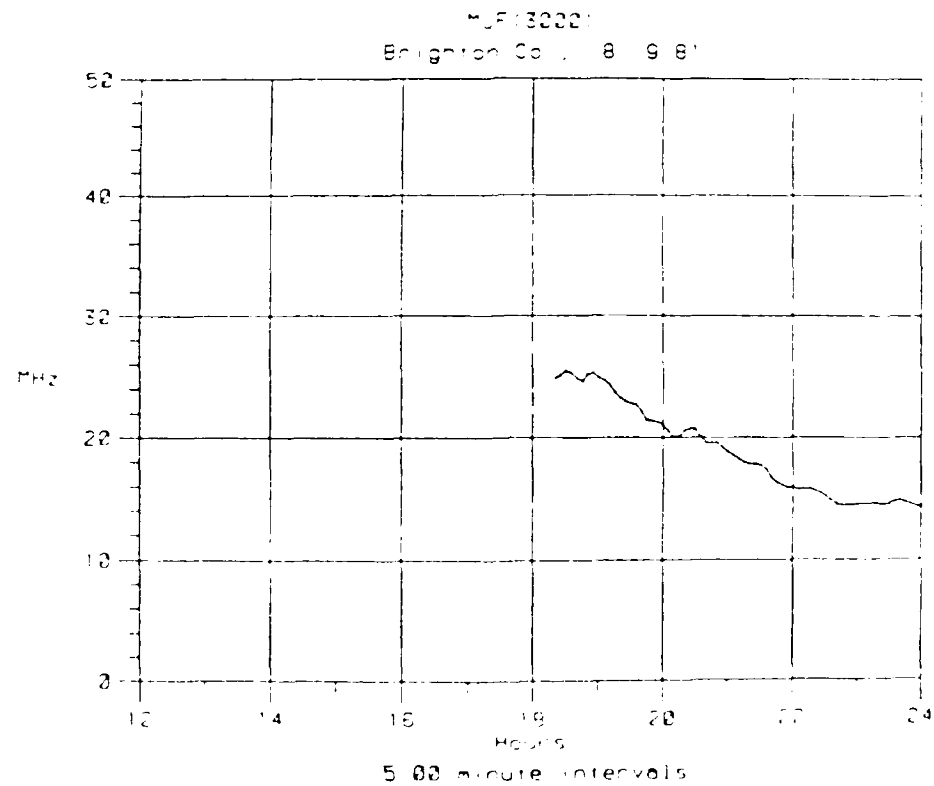


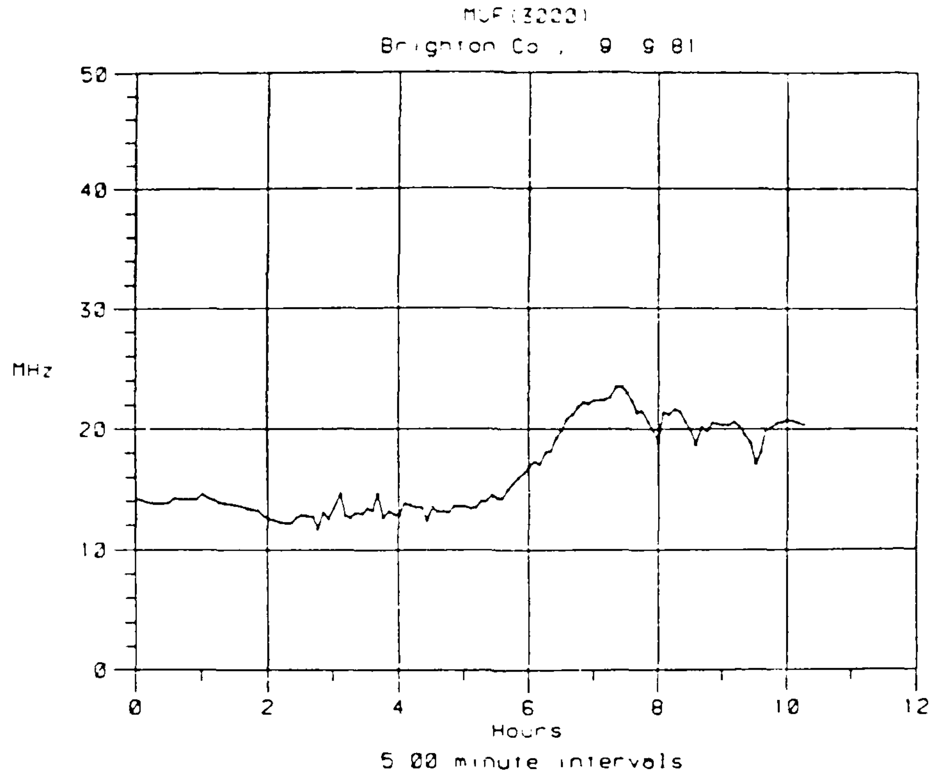
MUF(3000)
Brighton Co., 31 3 81
50
40
30
20
10
0
MHz
12
14
16
18
20
22
24
Hours
2 20 minute intervals

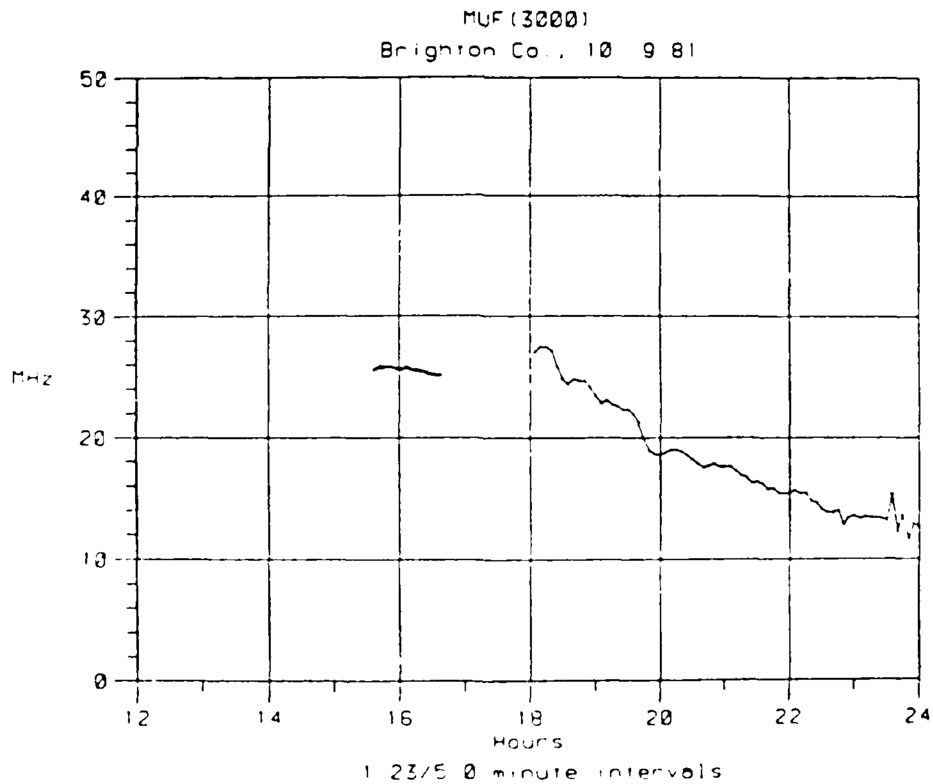


MUF(3000)
Brighton Co., 1 4 81
50
40
30
20
10
0
MHz
0
2
4
6
8
10
12
Hours
2 00 minute intervals

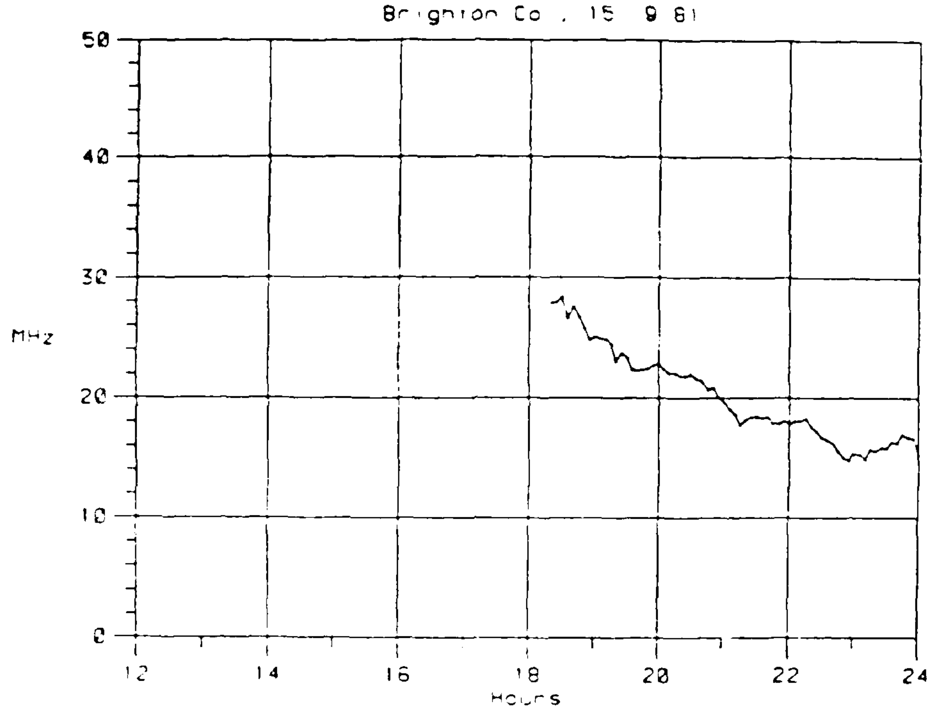

MUF(3000)
Brighton Co., 15 4 81
50
40
30
20
10
0
MHz
8
10
12
14
16
18
20
Hours
1.00 minute intervals


MUF(3000)
Brighton Co., 8 9 81
50
40
30
20
10
0
MHz
12
14
16
18
20
22
24
Hours
5.00 minute intervals


MUF(3000)
Brighton Co., 9 9 81
50
40
30
20
10
0
MHz
0
2
4
6
8
10
12
Hours
5 00 minute intervals

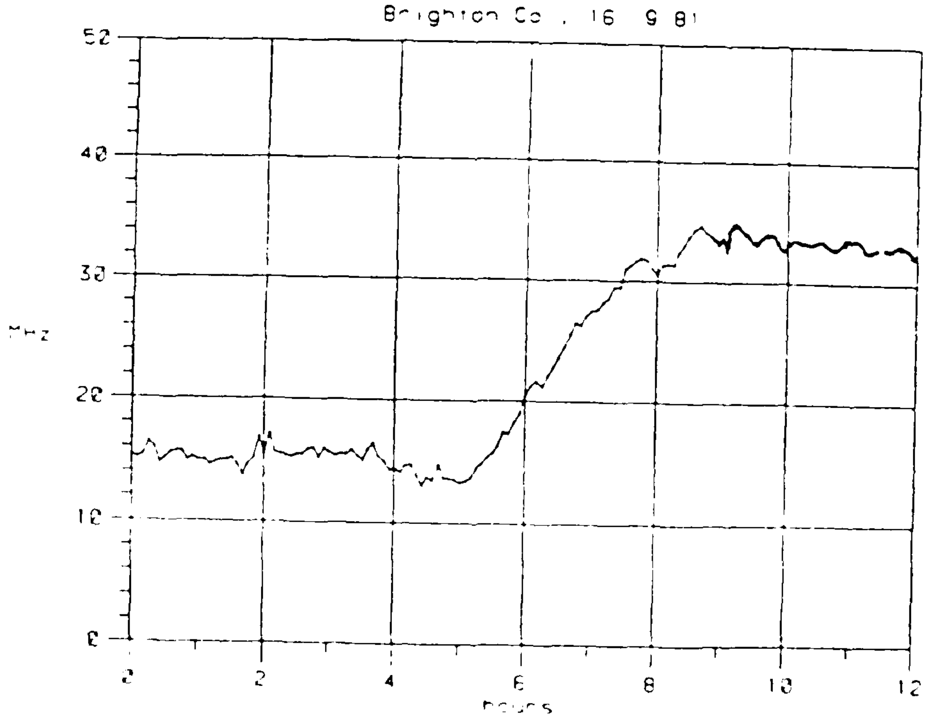

MUF(3000)
Brighton Co., 10 9 81
50
40
30
20
10
0
MHz
12
14
16
18
20
22
24
Hours
1 23/5 0 minute intervals

MUF(3222)
Brighton Co., 15 9 81



5 00 minute intervals

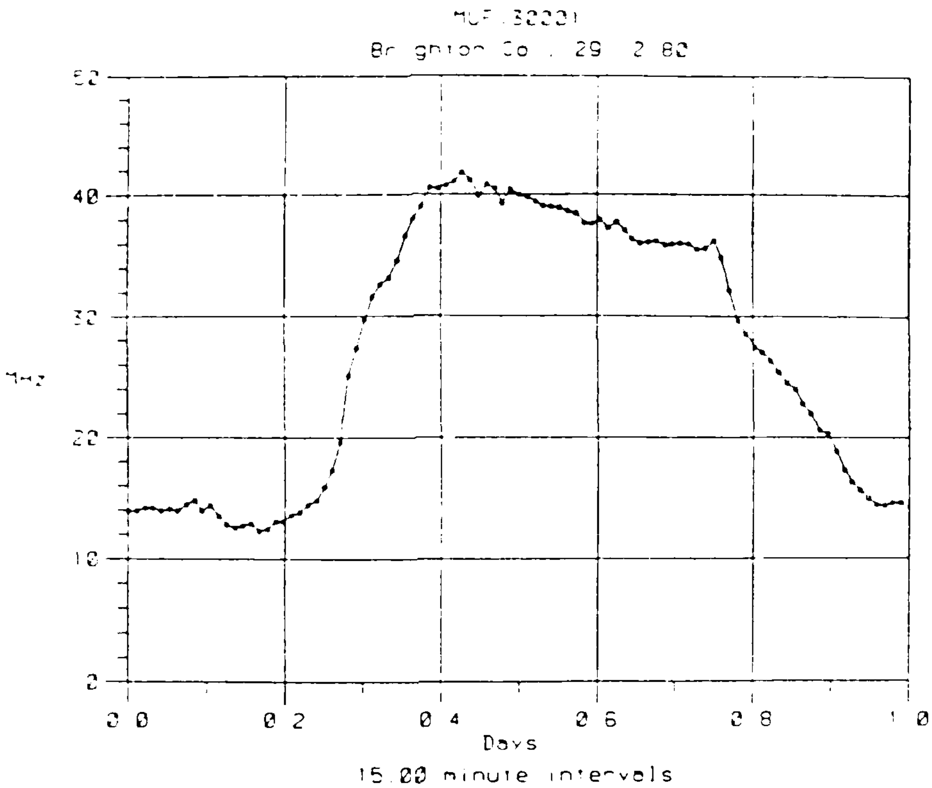
MUF(3222)
Brighton Co., 16 9 81



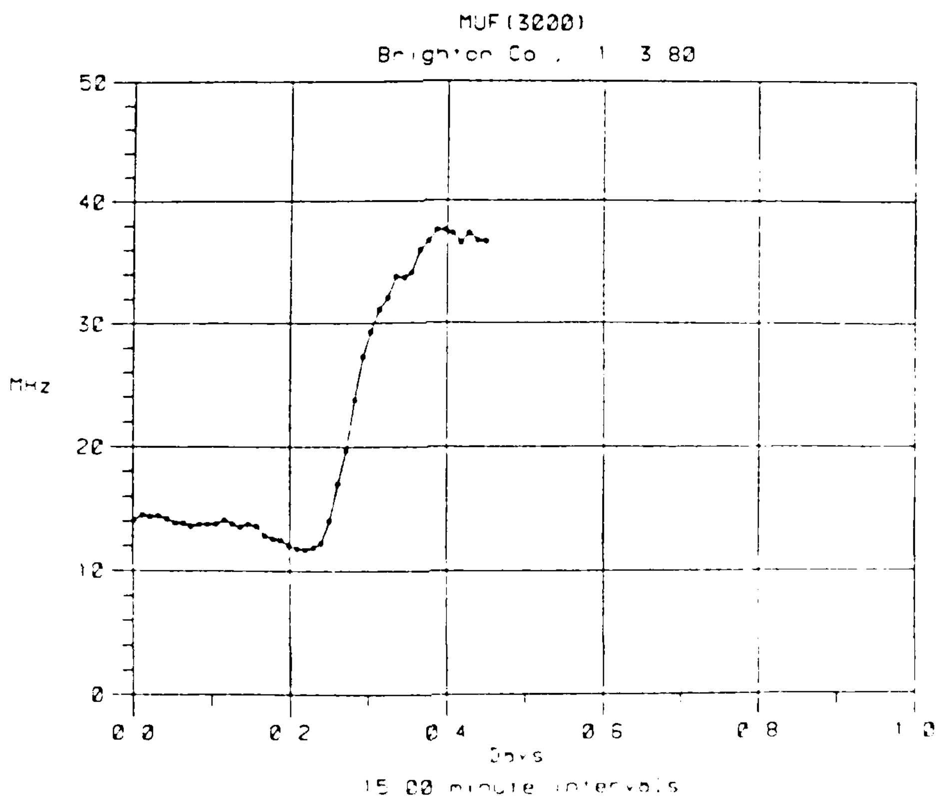
5 0/0 8 minute intervals

APPENDIX B

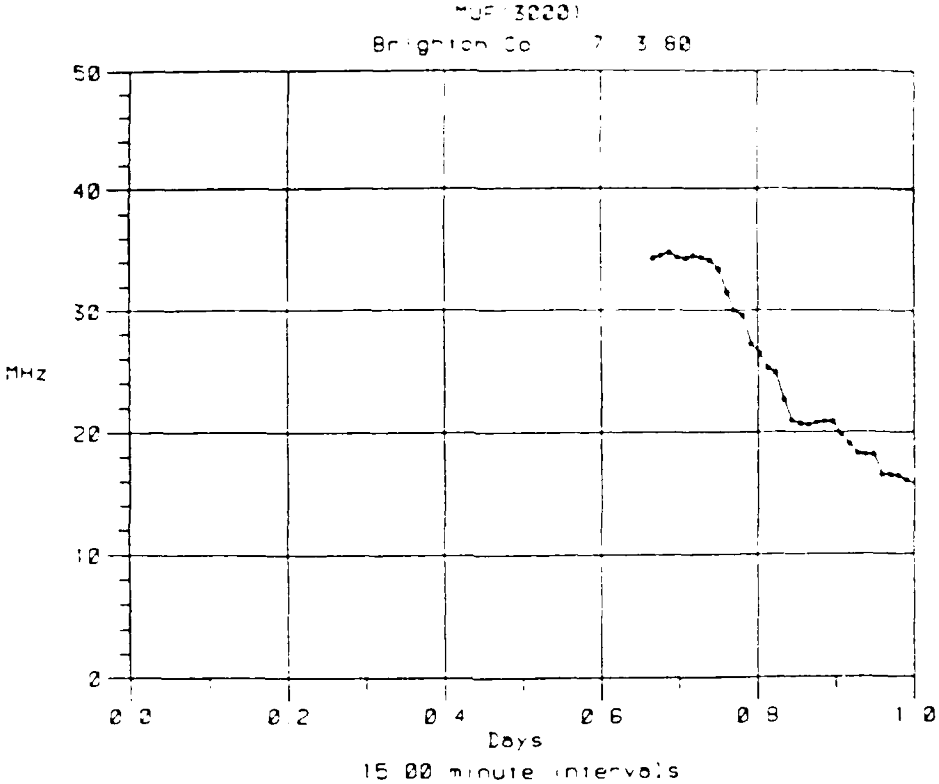
STANDARD SEQUENCES OF IONOGRAMS

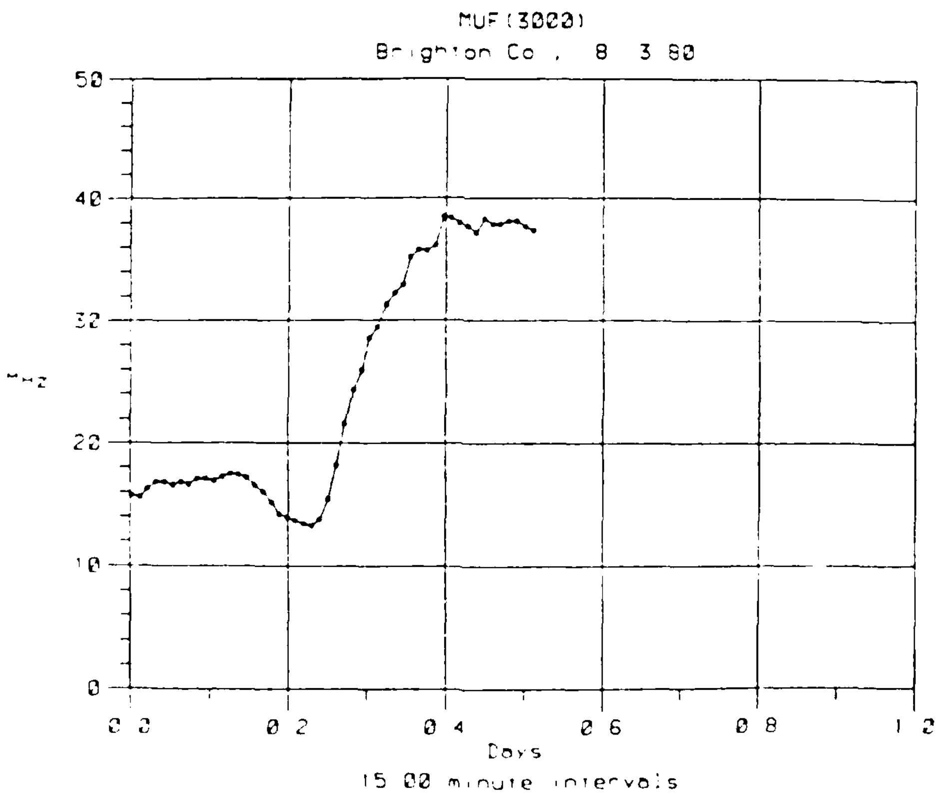


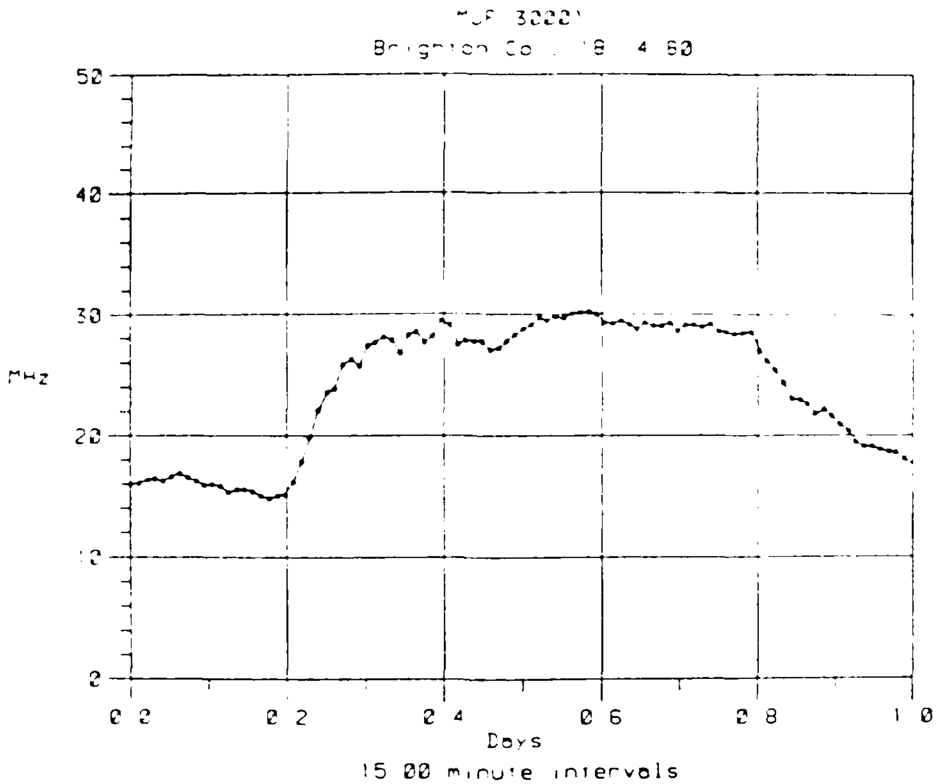
MUF(3000)
Brighton Co., 29 2 80
MHz
Days
15.00 minute intervals

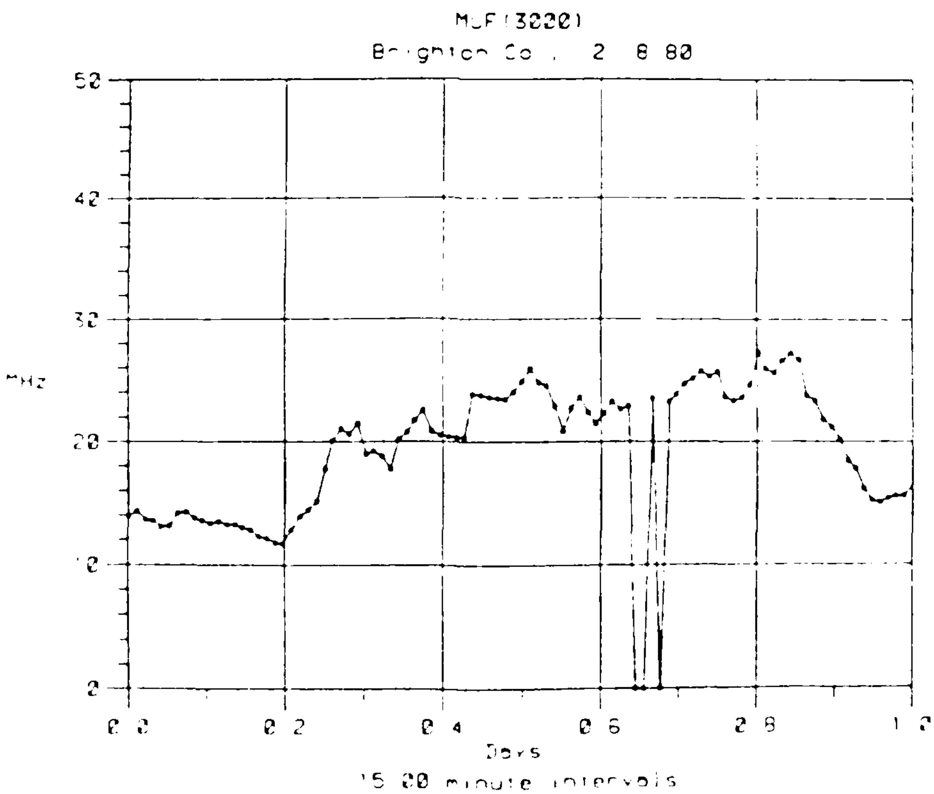


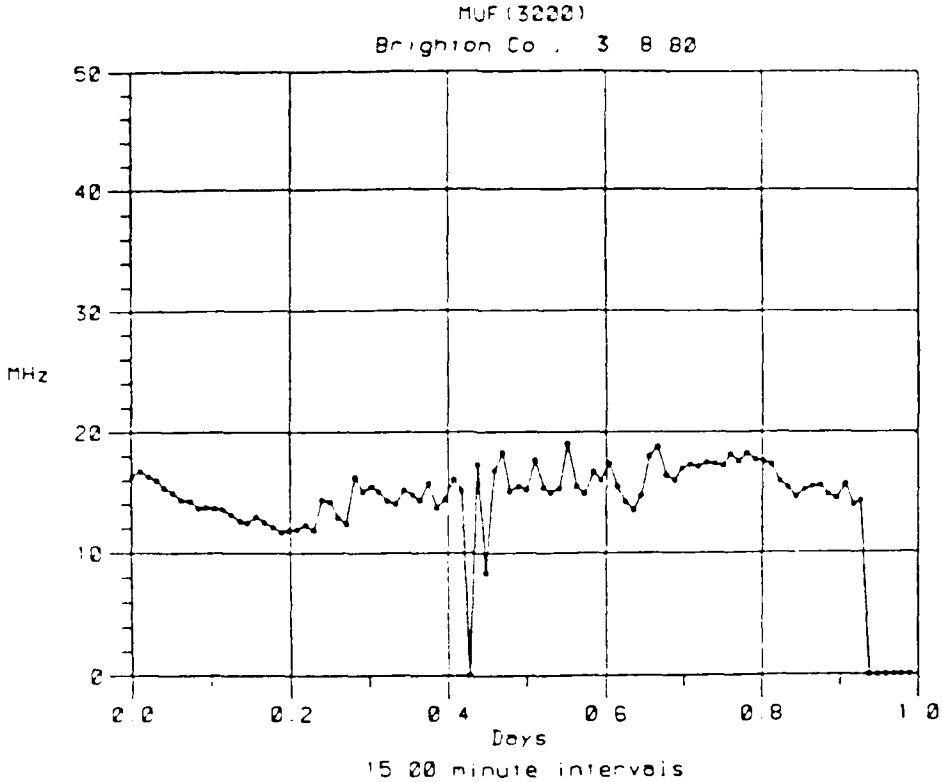
MUF(3000)
Brighton Co., 1 3 80
MHz
Days
15.00 minute intervals

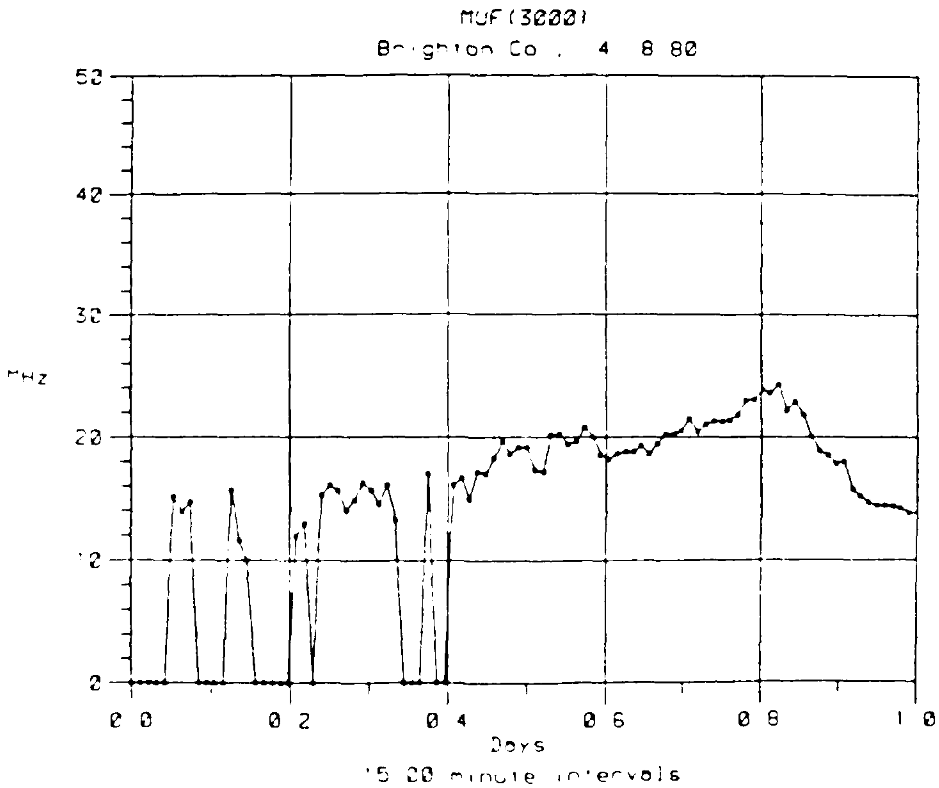

MUF(3000)
Brighton Co 7 3 80
50
40
30
20
10
2
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals

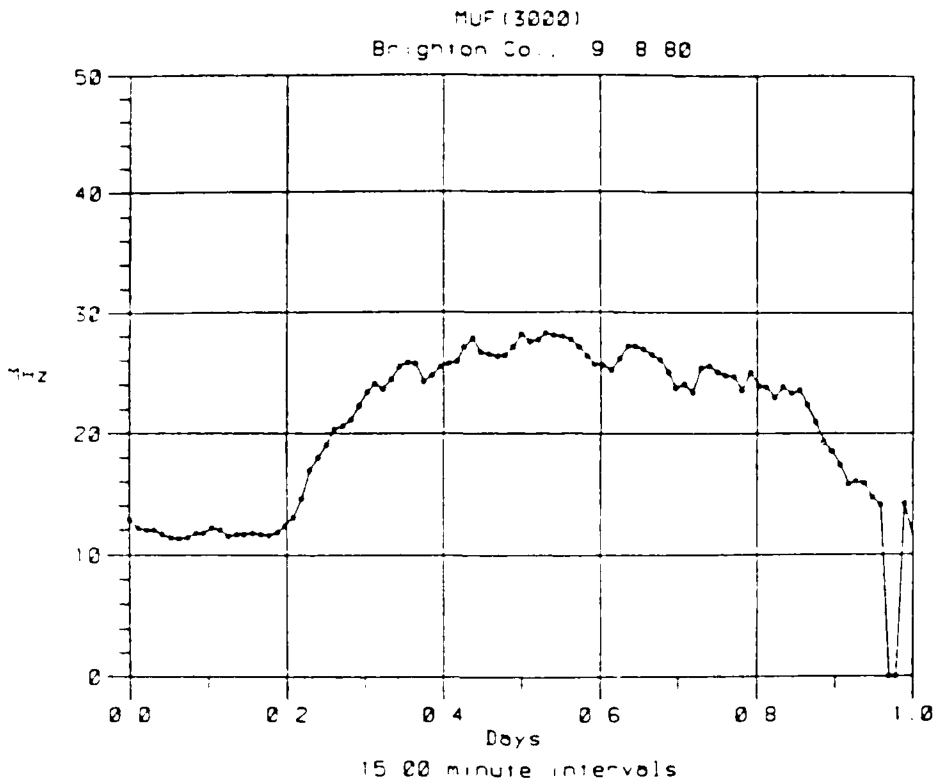

MUF(3000)
Brighton Co , 8 3 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals

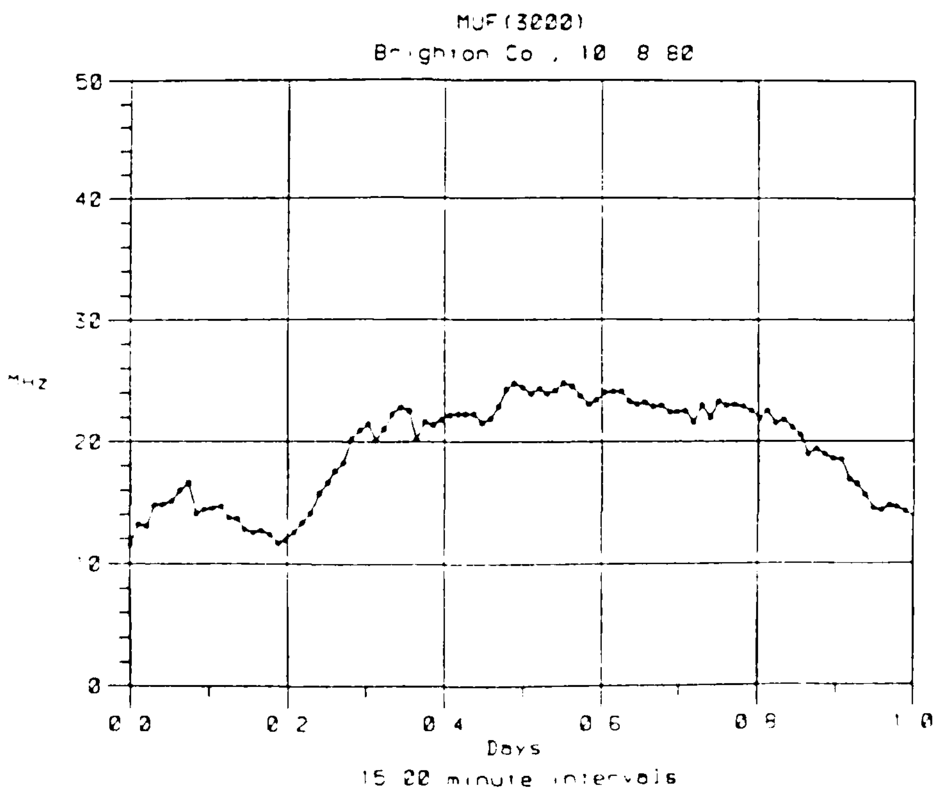

MUF (3020)
Brighton Co. 18 4 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals

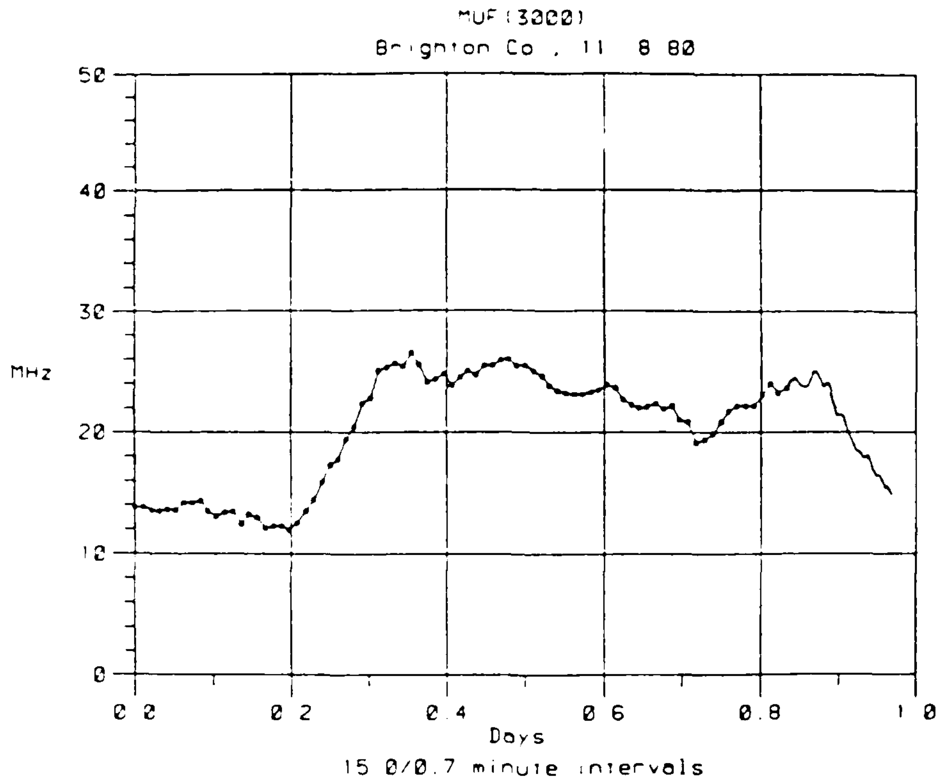

MUF(3020)
Brighton Co. 2 8 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals

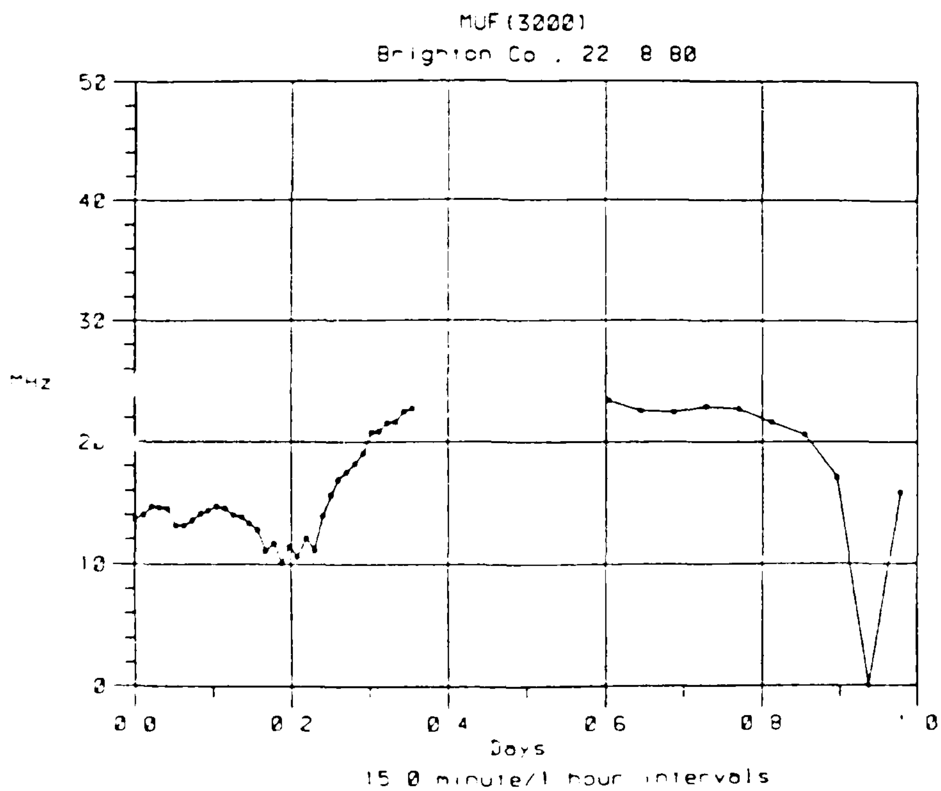

MUF(3200)
Brighton Co. 3 8 80
MHz
Days
15.00 minute intervals

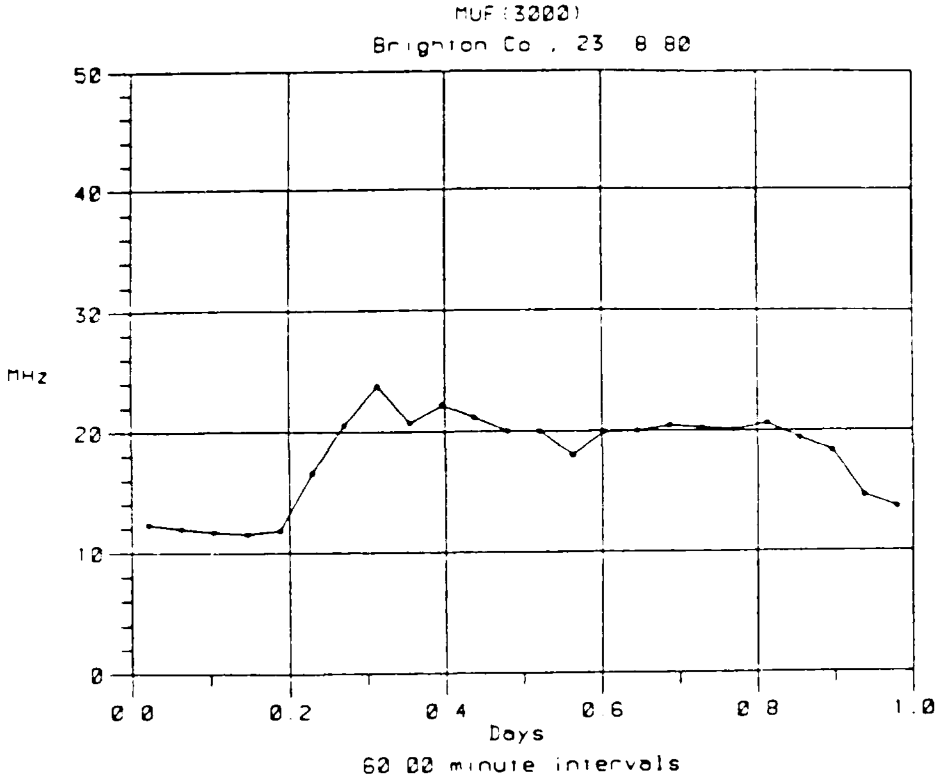

MUF(3000)
Brighton Co. 4 8 80
MHz
Days
15.00 minute intervals

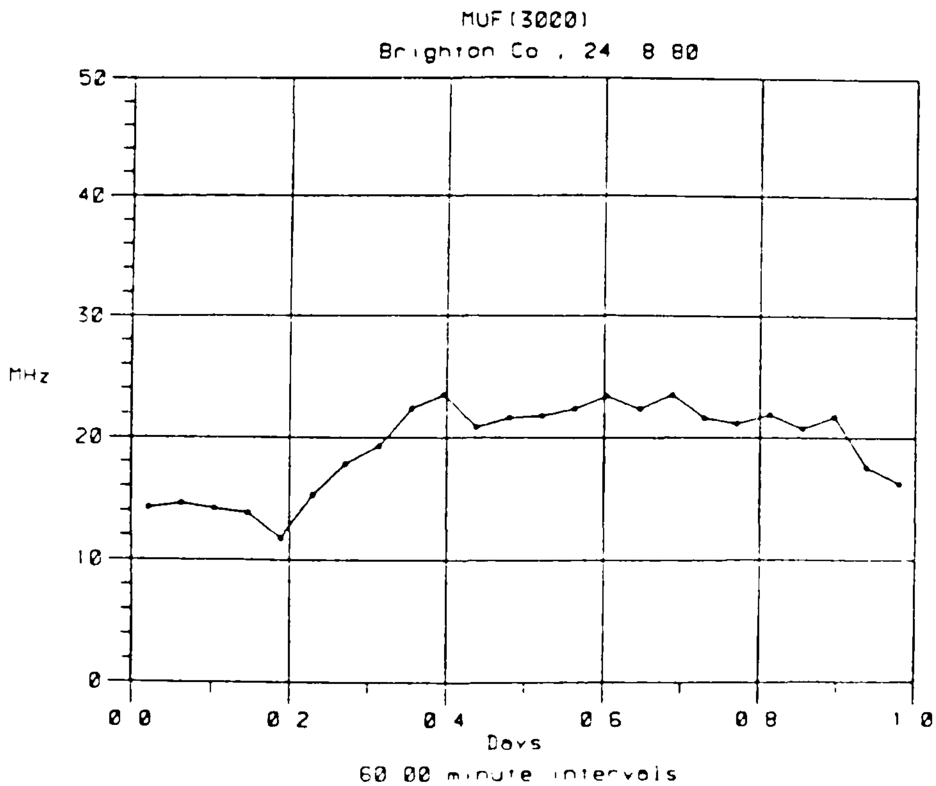

MUF(3000)
Brighton Co., 9 8 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals

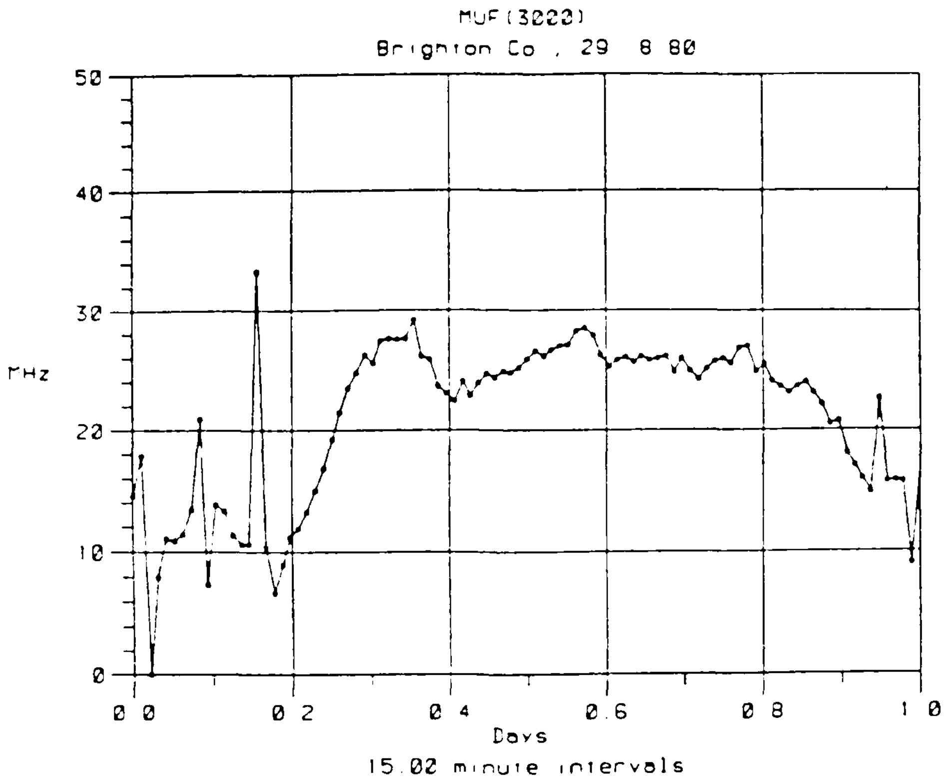

MUF(3000)
Brighton Co., 10 8 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals

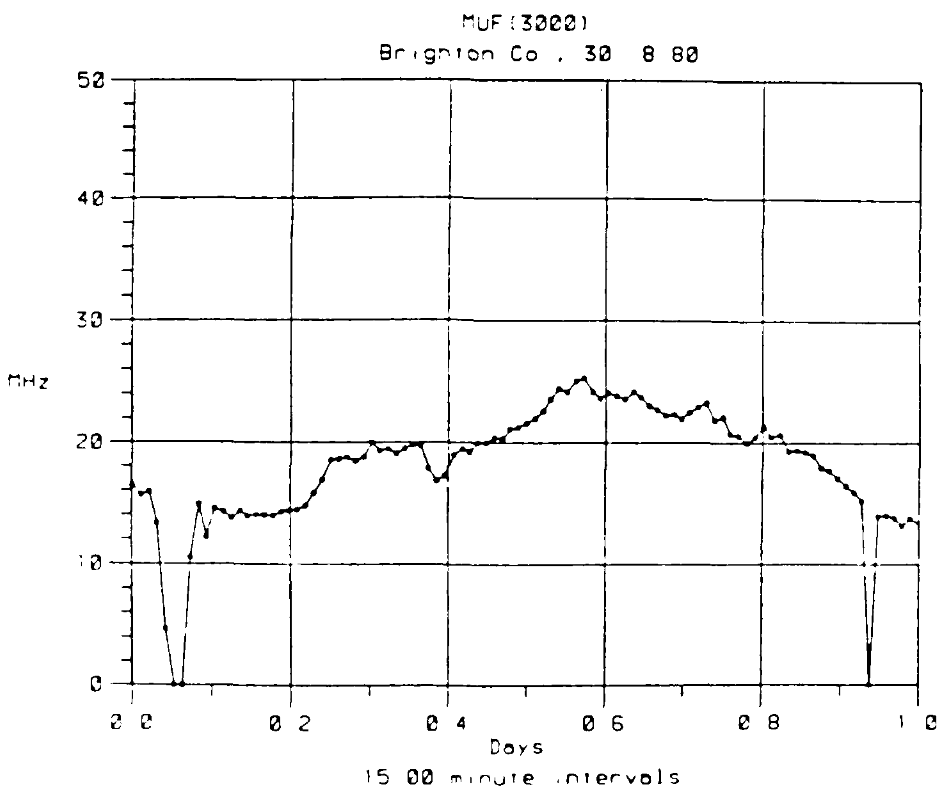

MUF(3000)
Brighton Co , 11 8 80
MHz
Days
15 0/0.7 minute intervals

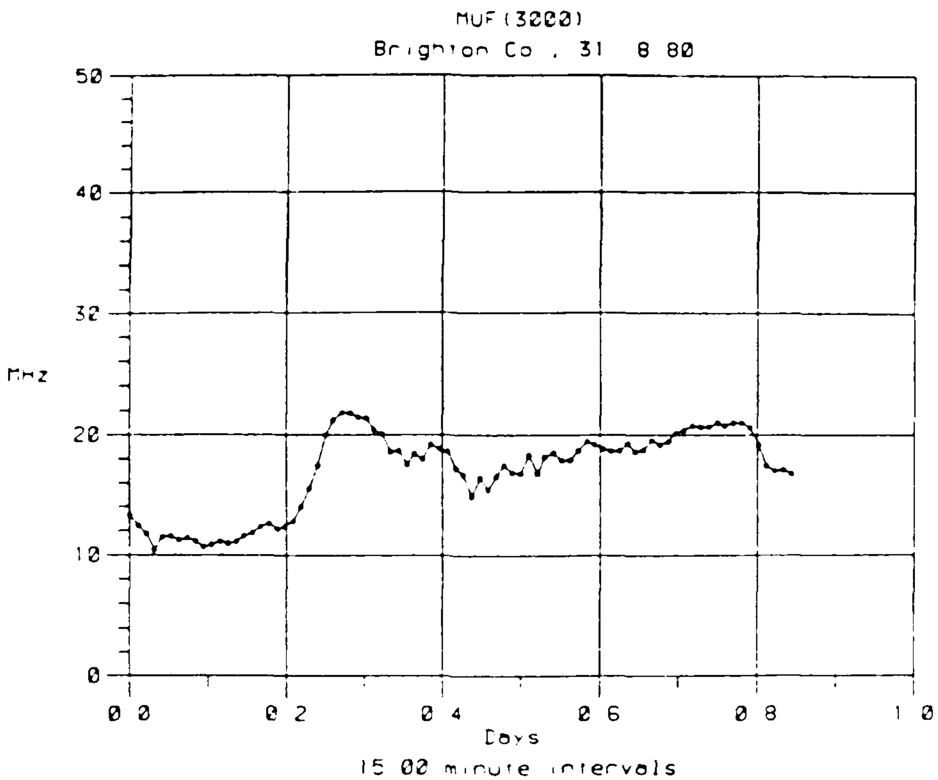

MUF(3000)
Brighton Co , 22 8 80
Days
15 0 minute/1 hour intervals

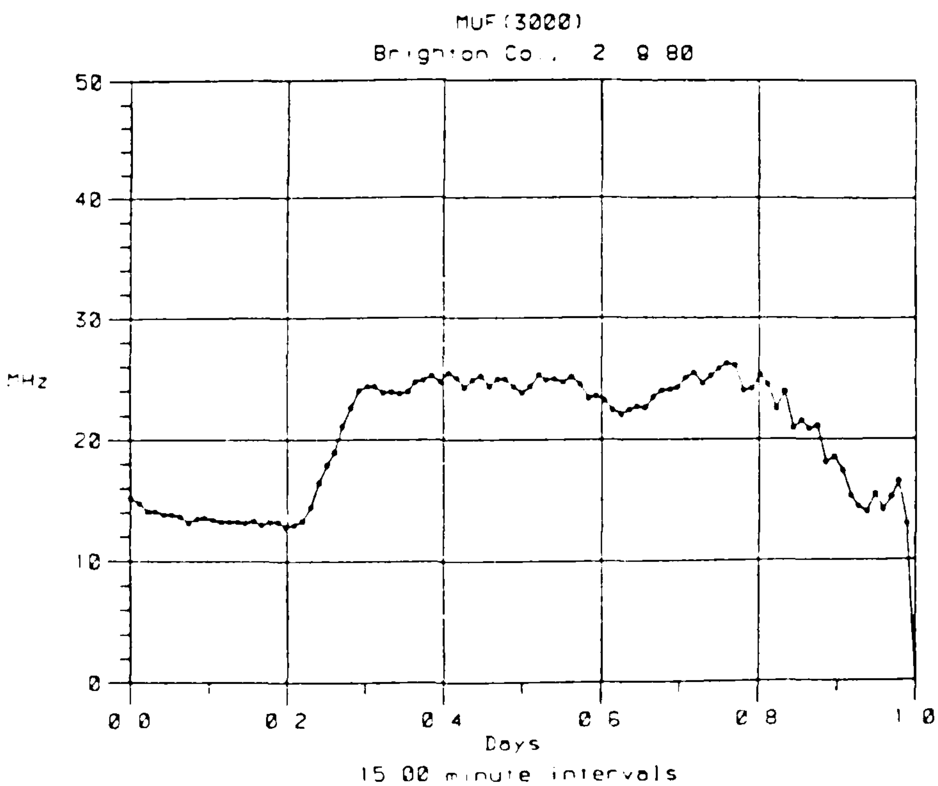

MUF(3000)
Brighton Co , 23 8 80
50
40
30
20
10
0
MHz
0 0
0 2
0 4
0 6
0 8
1 0
Days
60 00 minute intervals

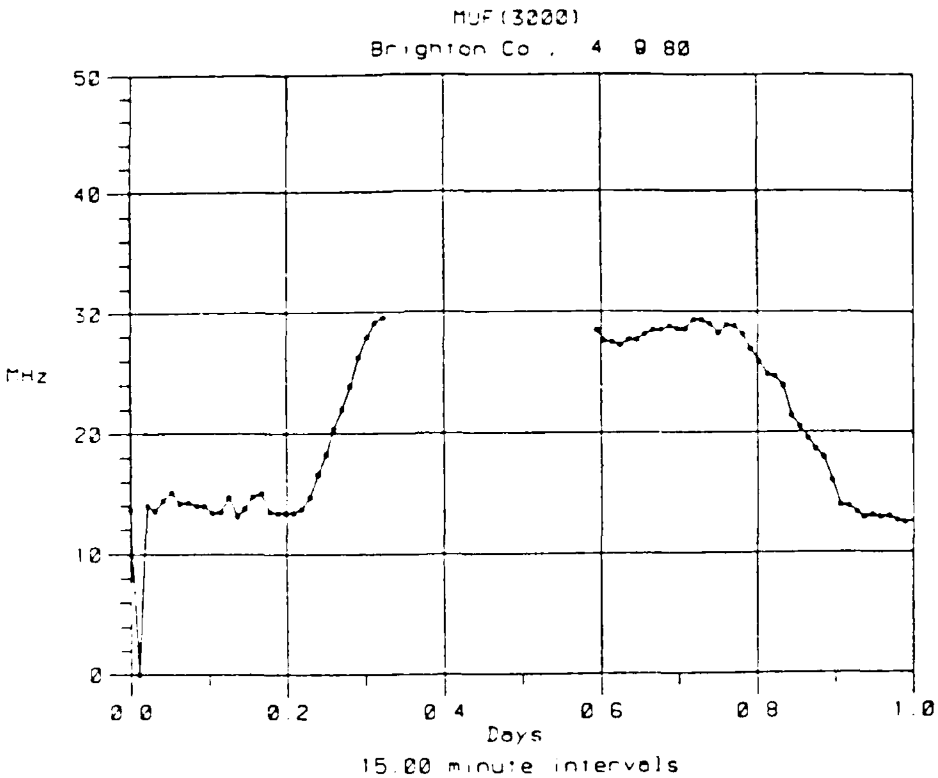

MUF(3000)
Brighton Co , 24 8 80
50
40
30
20
10
0
MHz
0 0
0 2
0 4
0 6
0 8
1 0
Days
60 00 minute intervals

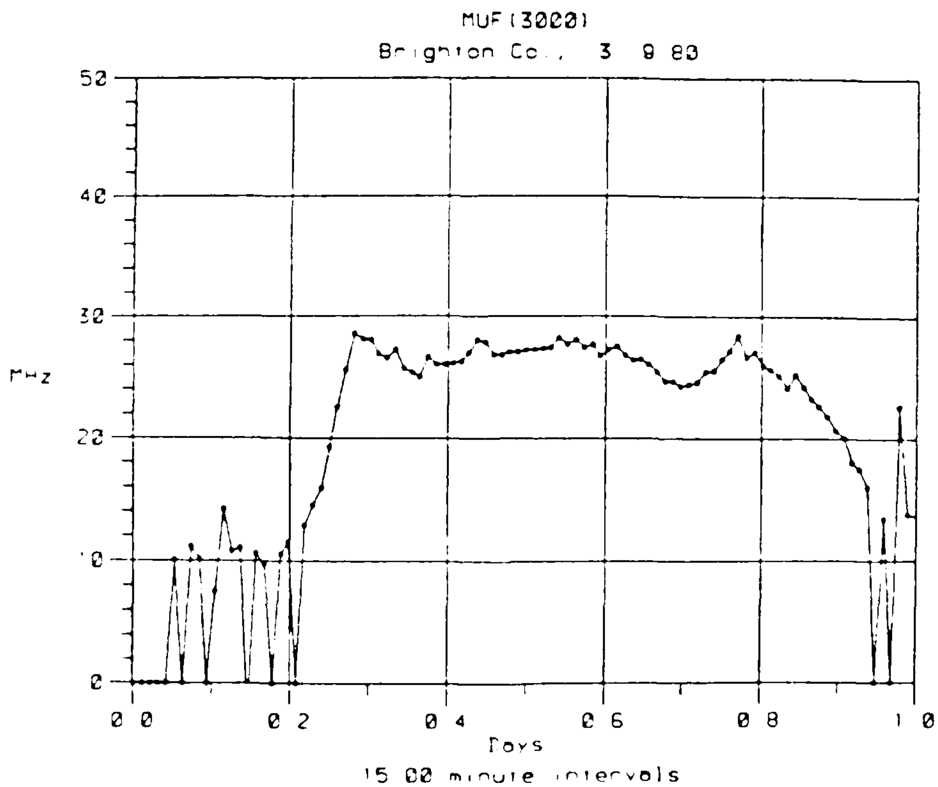

MUF(3000)
Brighton Co , 29 8 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.02 minute intervals

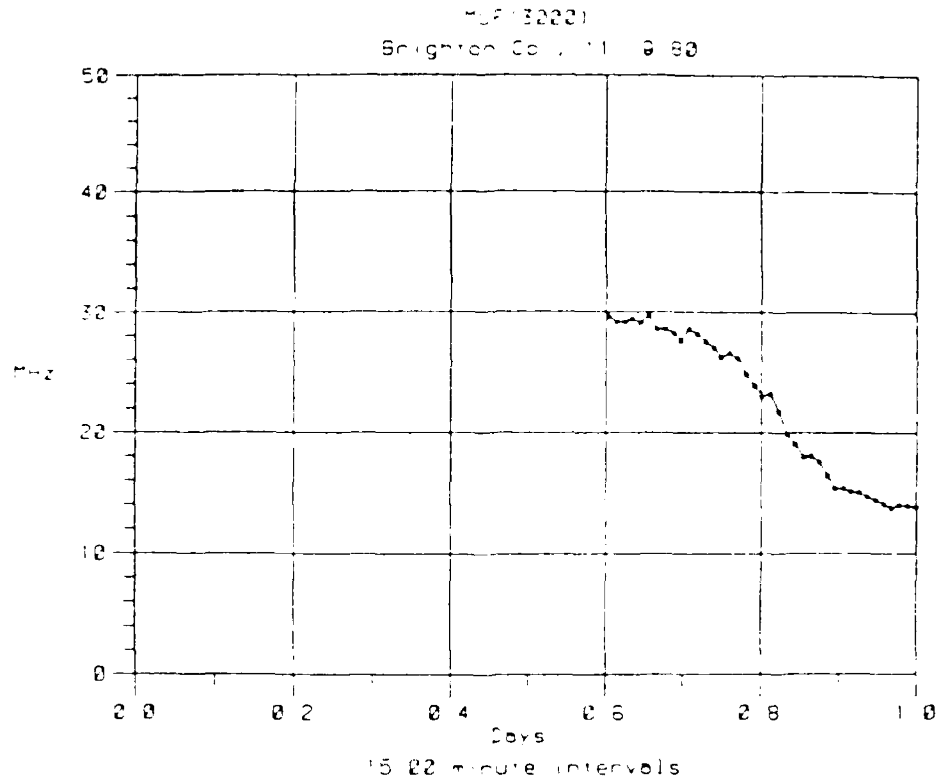

MUF(3000)
Brighton Co , 30 8 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals

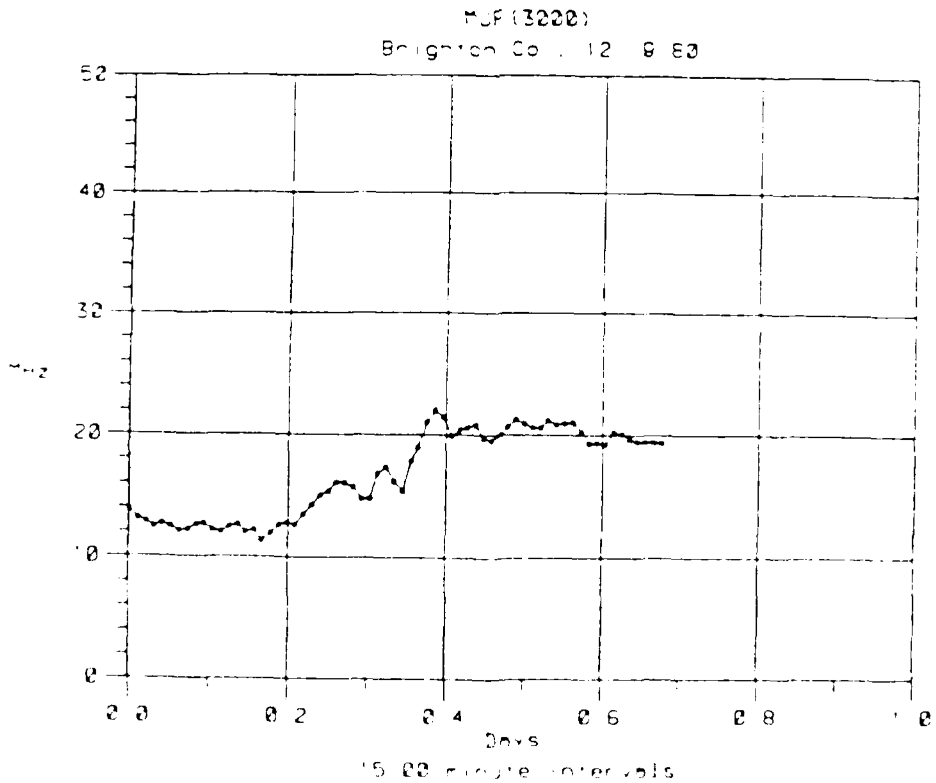

MUF(3000)
Brighton Co., 31 8 80
MHz
Days
15 00 minute intervals

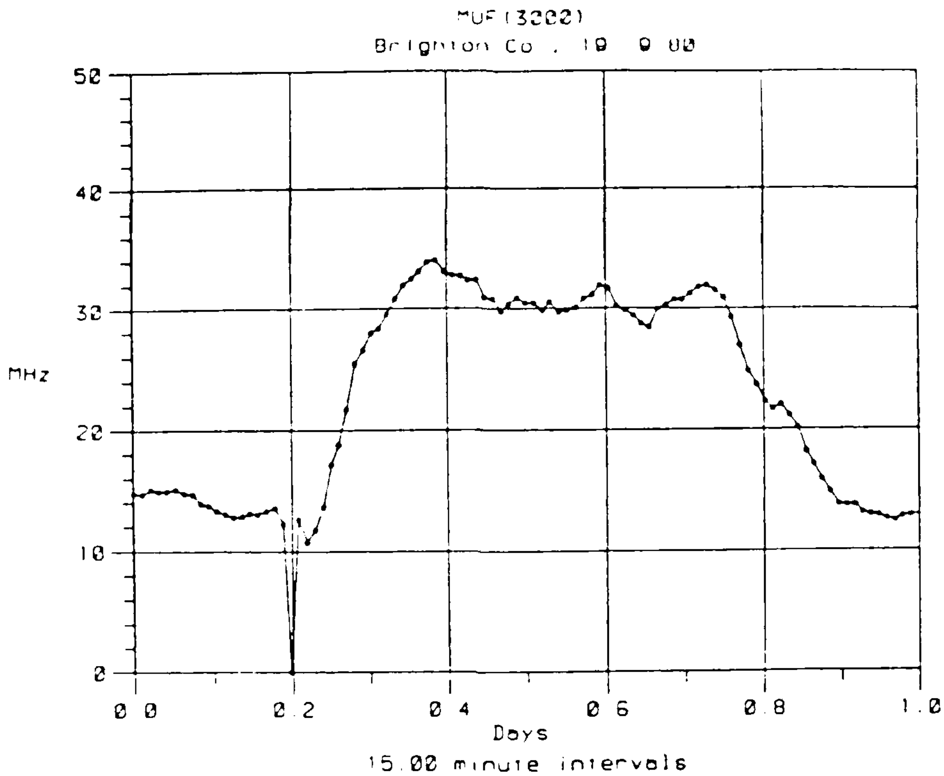

MUF(3000)
Brighton Co., 2 9 80
MHz
Days
15 00 minute intervals

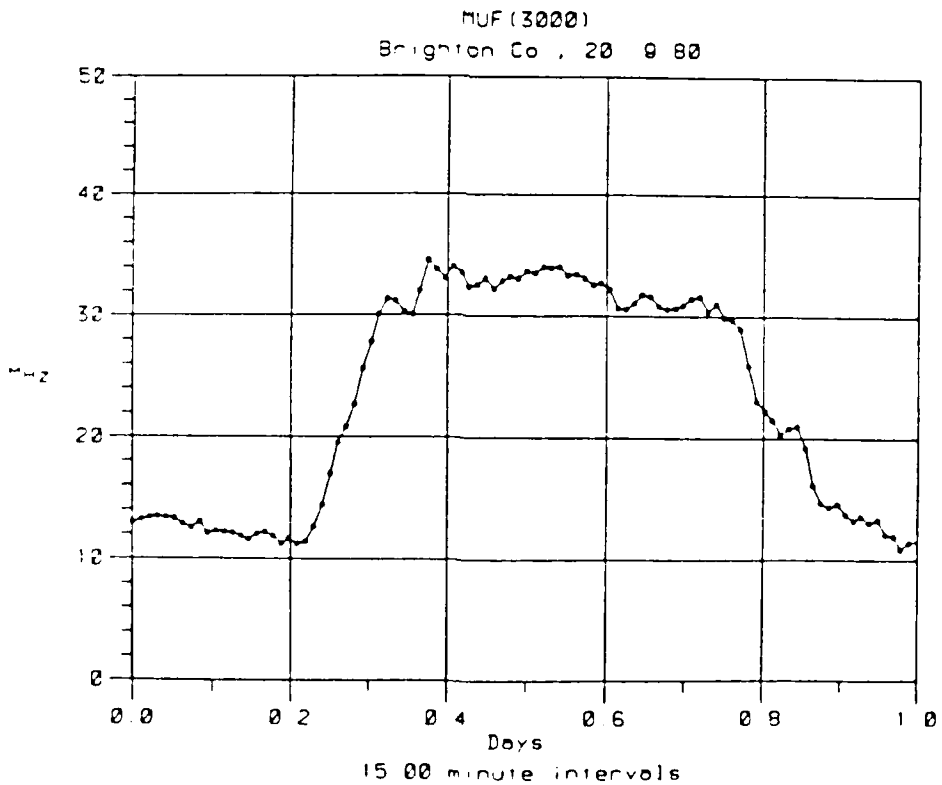

MUF(3000)
Brighton Co., 4 9 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals

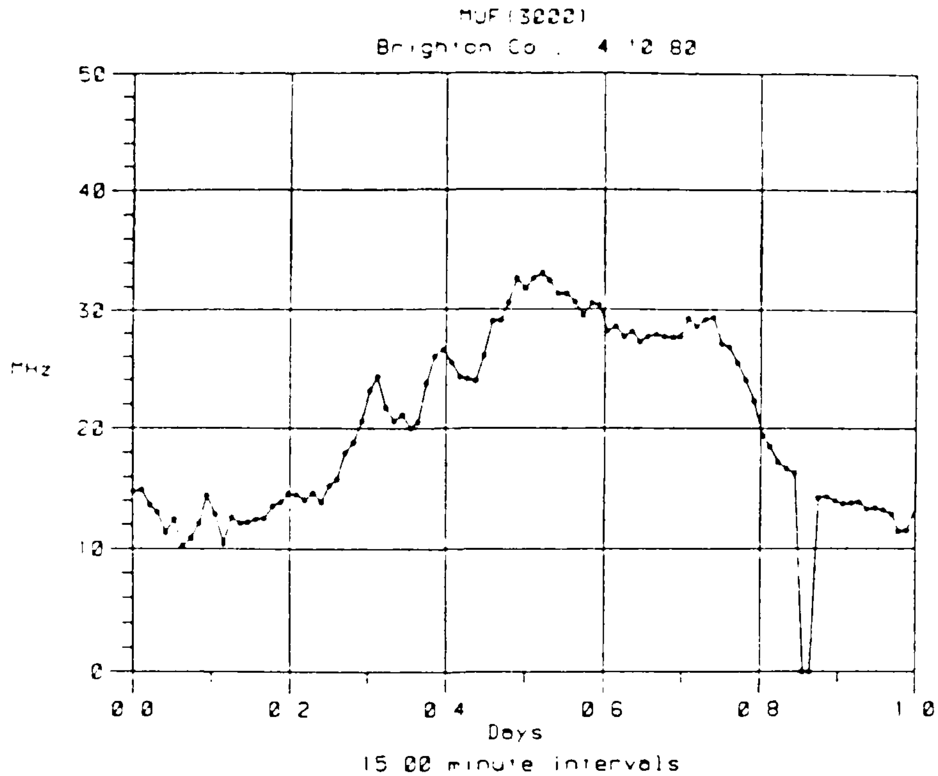

MUF(3000)
Brighton Co., 3 9 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co. 11 9 80
MHz
Days
15.00 minute intervals


MUF(3000)
Brighton Co. 12 9 80
MHz
Days
15.00 minute intervals


MUF(3000)
Brighton Co , 19 9 80
50
40
30
MHz
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co , 20 9 80
50
40
30
MHz
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 4 10 80
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30
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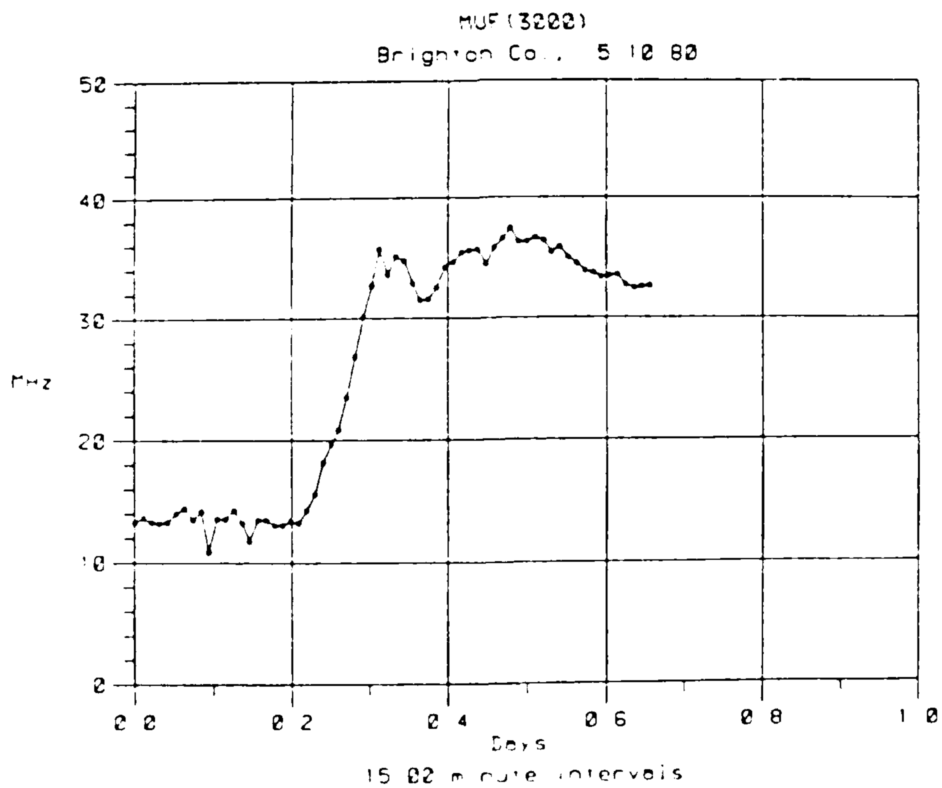
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 5 10 80
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MHz
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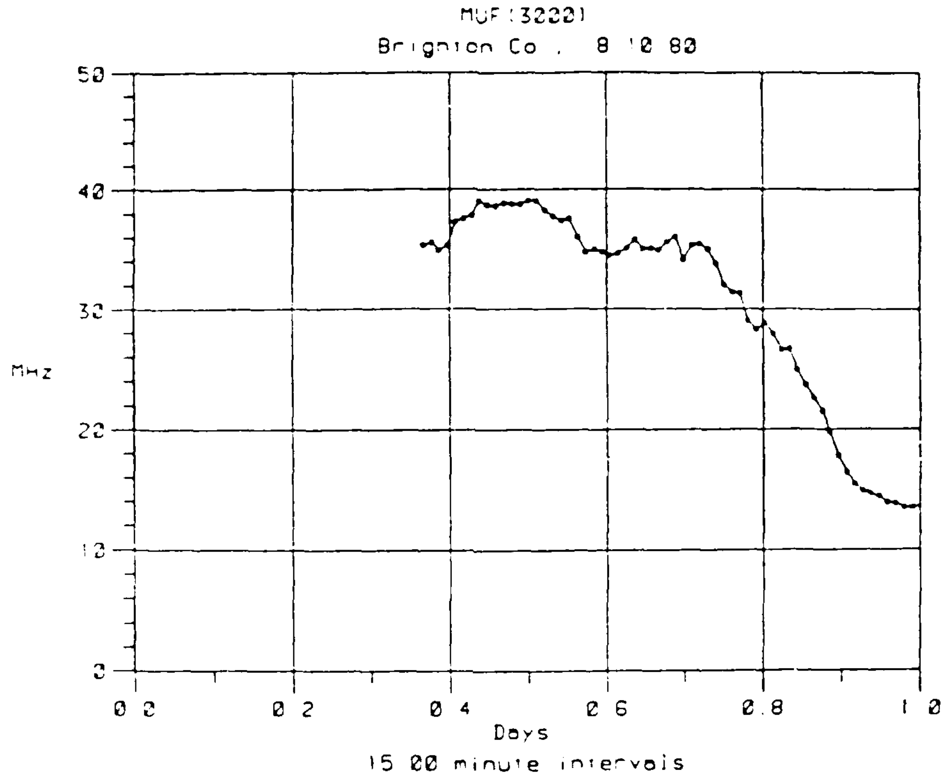
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 8 10 80
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MHz
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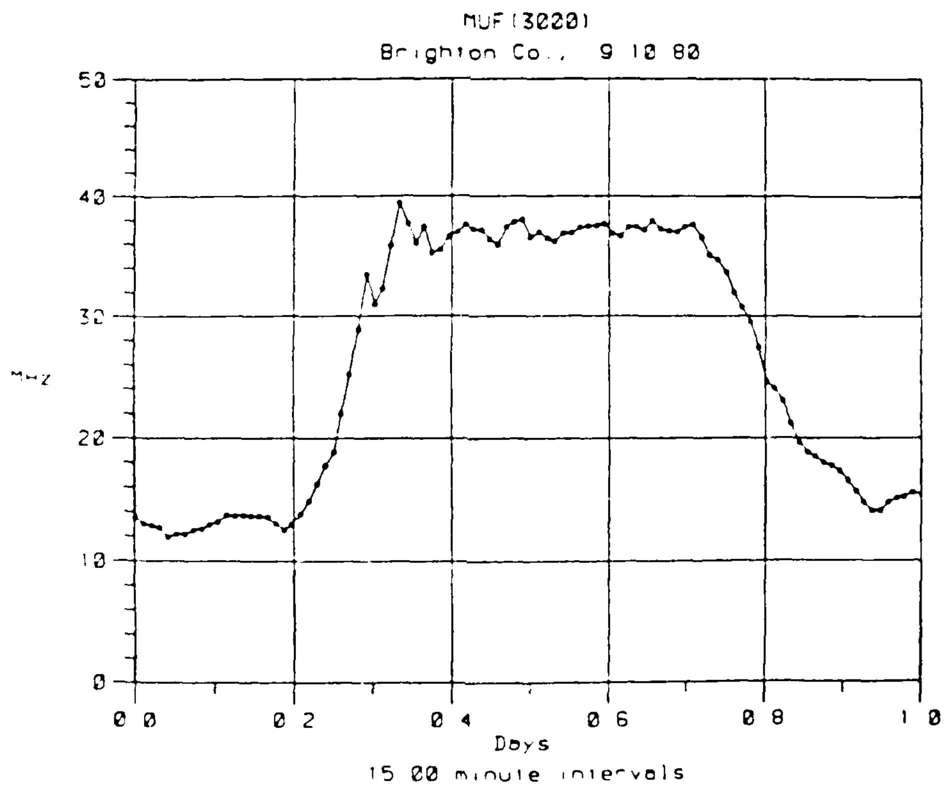
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 9 10 80
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30
20
10
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MHz
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0.4
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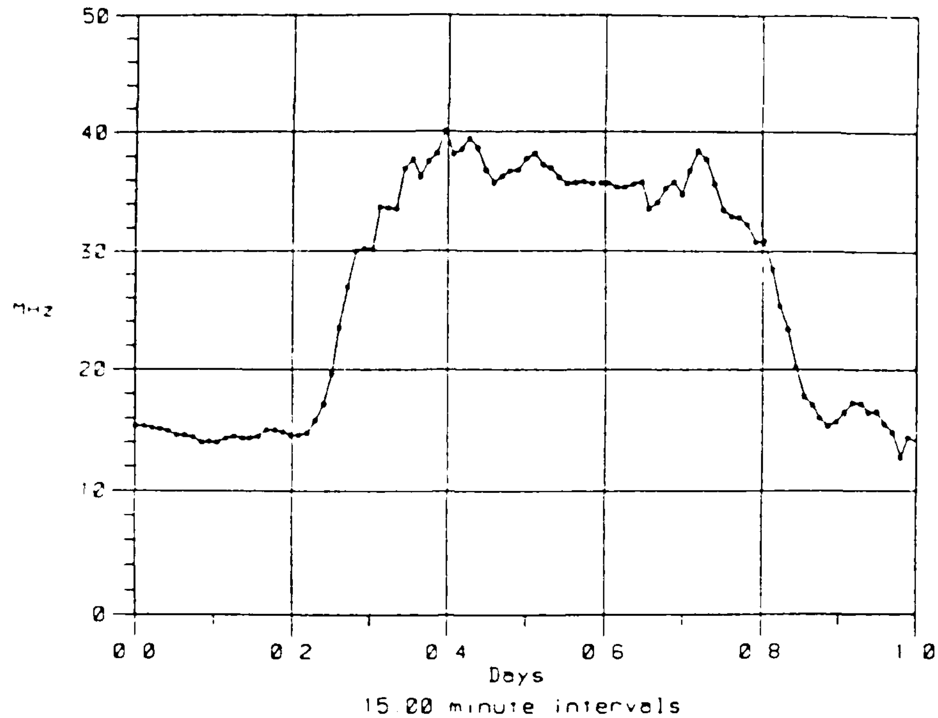
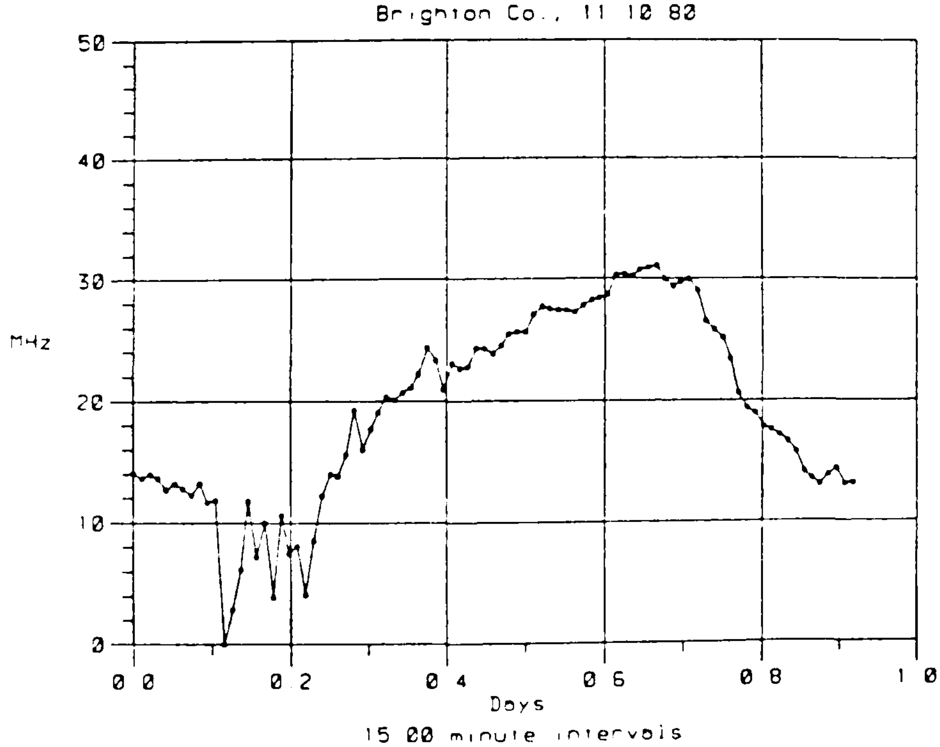
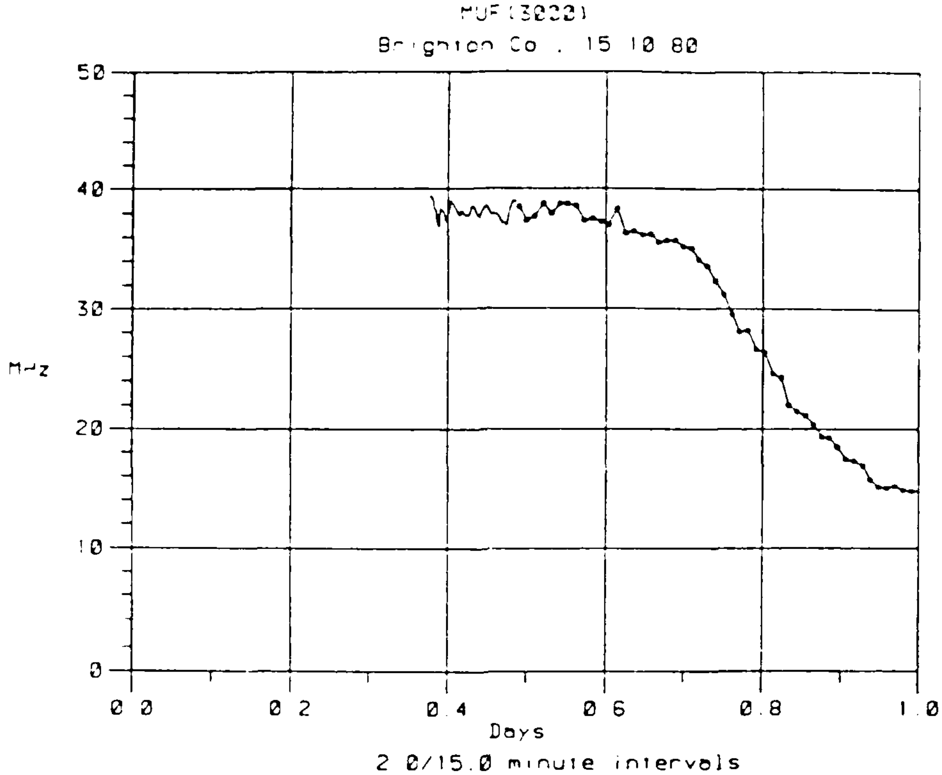
0.8
1.0
Days
15.00 minute intervals

MUF(3000)
Brighton Co., 10 10 80



MUF(3000)
Brighton Co., 11 10 80




MUF(3000)
Brighton Co , 15 10 80
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40
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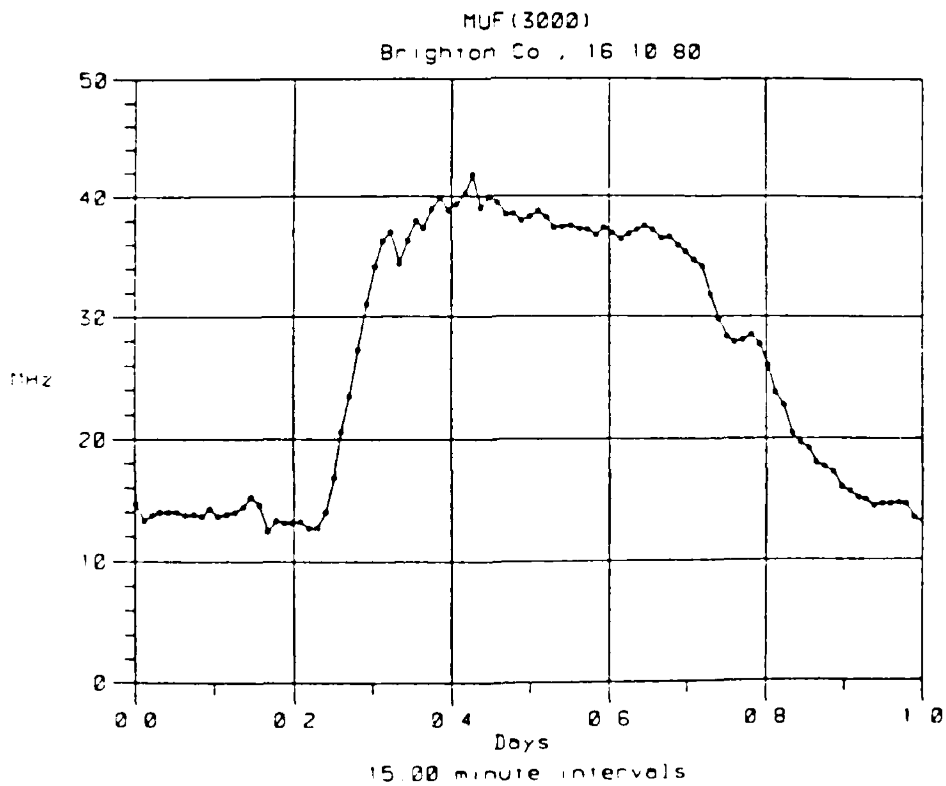
20
10
0
MHz
0 0
0 2
0 4
0 6
0 8
1 0
Days
2 0/15.0 minute intervals


MUF(3000)
Brighton Co , 16 10 80
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MHz
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0 4
0 6
0 8
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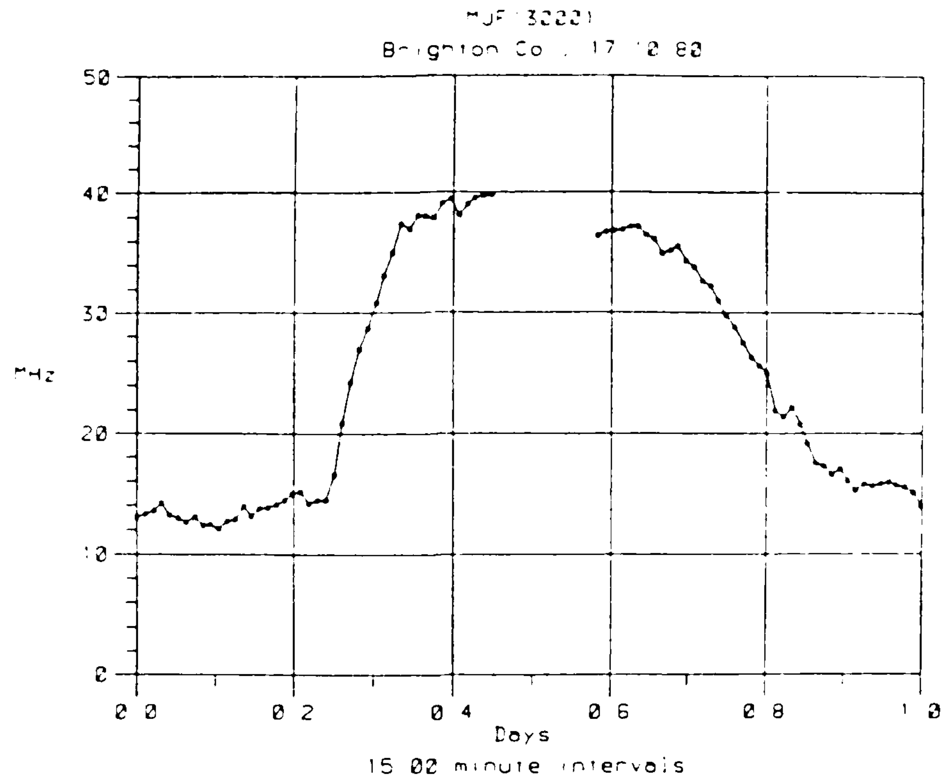
Days
15 00 minute intervals


MUF(3000)
Brighton Co., 17 10 80
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20
10
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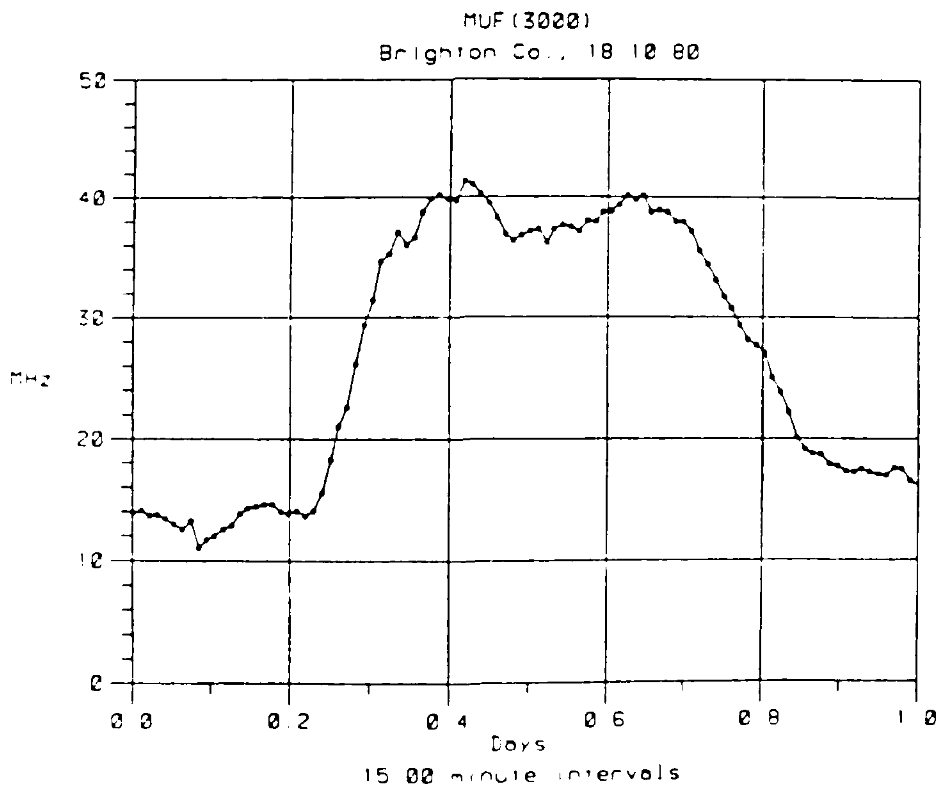
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 18 10 80
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20
10
0
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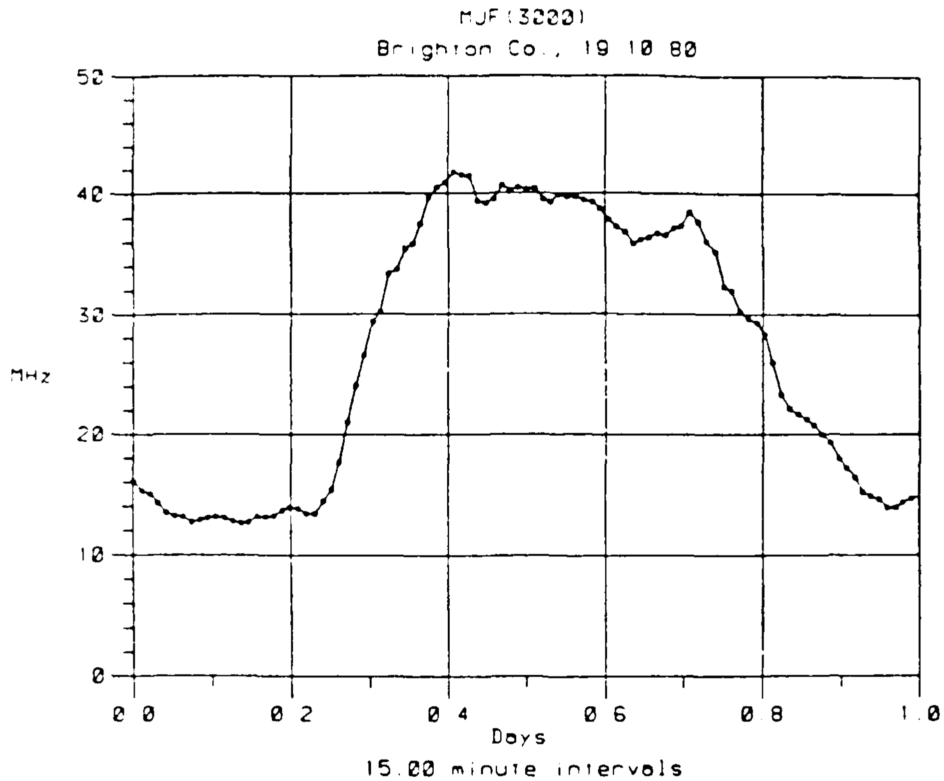
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 19 10 80
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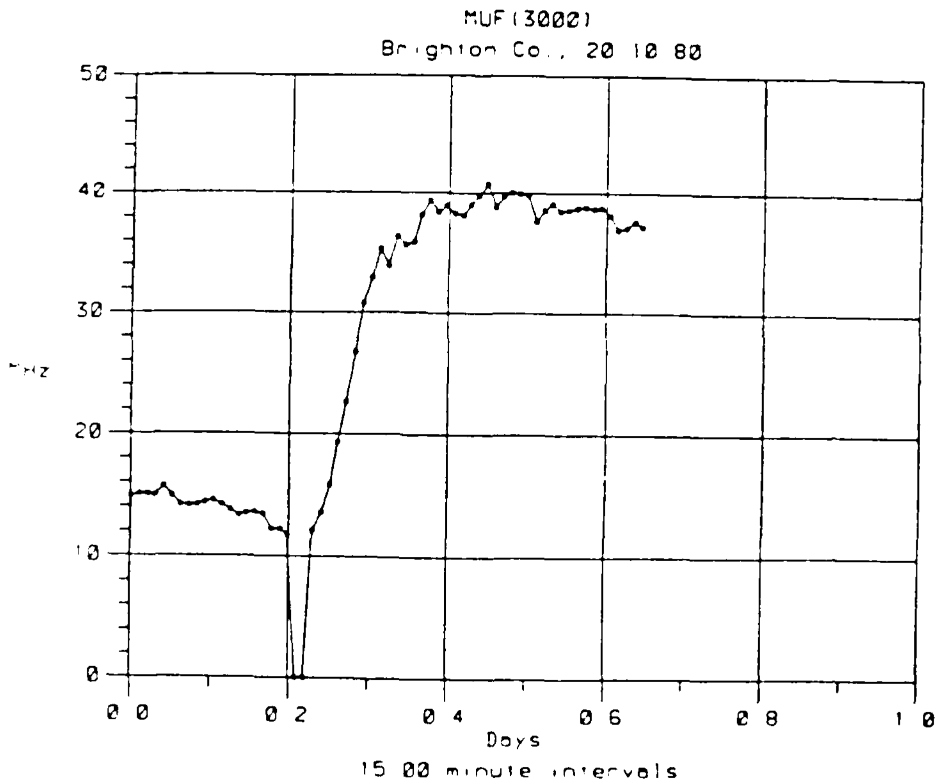
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 20 10 80
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10
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MHz
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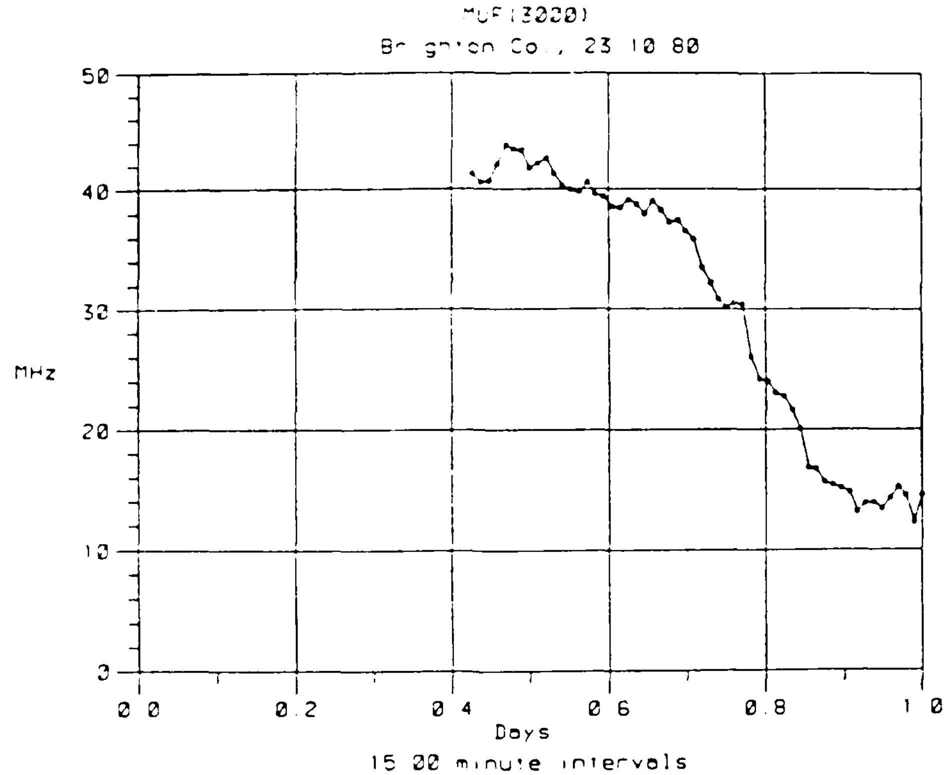
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 23 10 80
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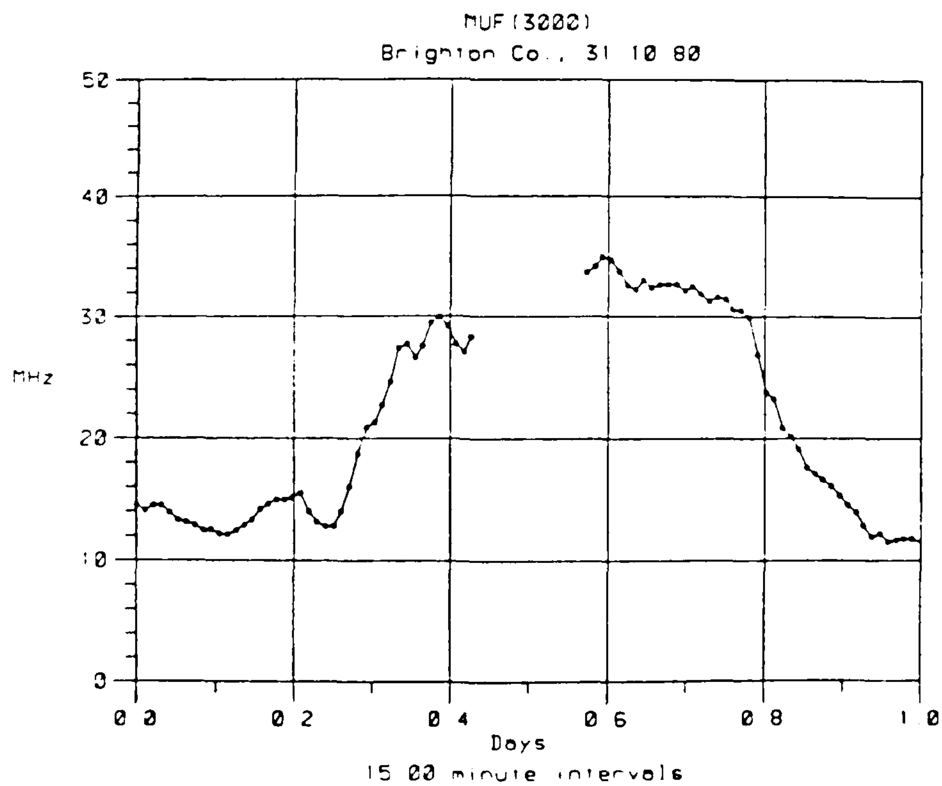
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 31 10 80
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20
10
0
MHz
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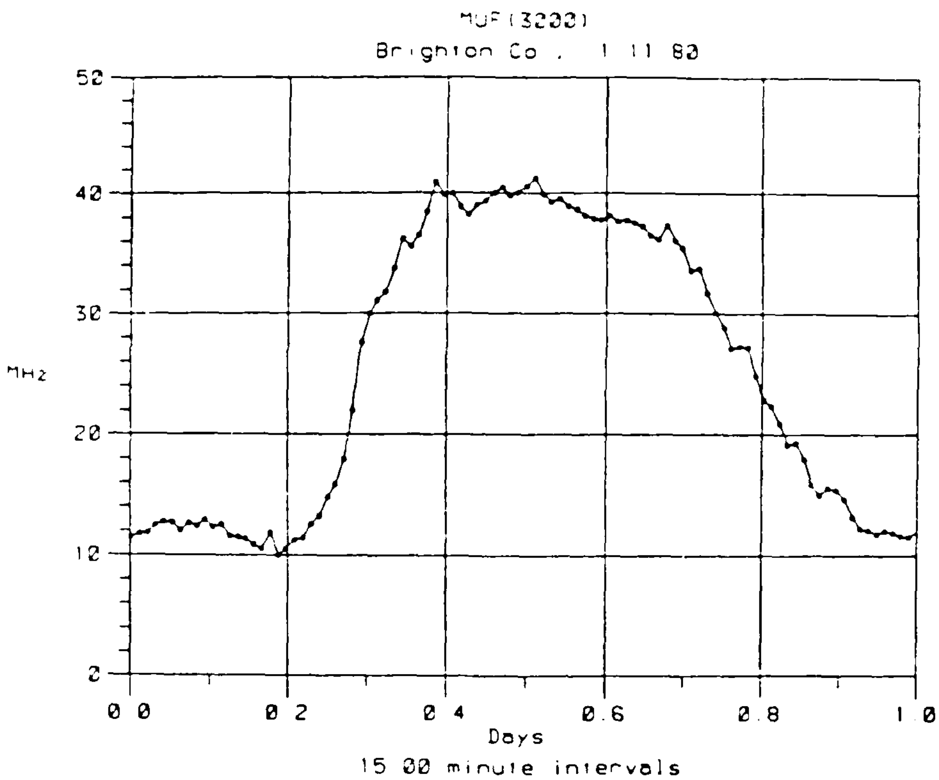
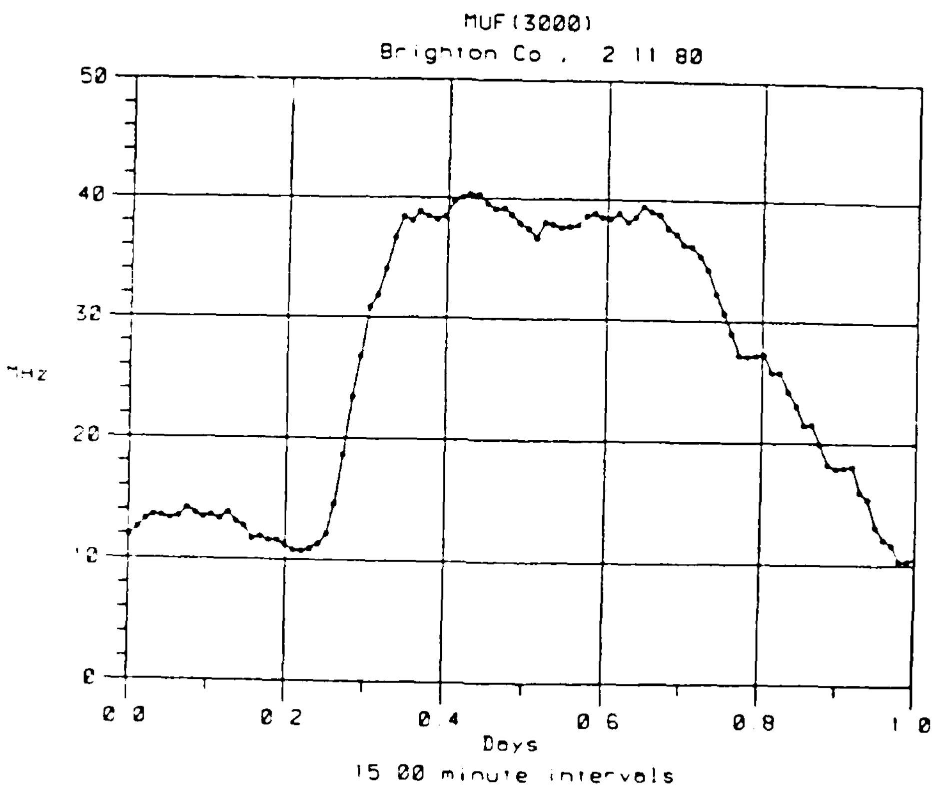
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co , 1 11 80
50
40
30
MHz
20
10
0
0 0
0 2
0 4
0 6
0 8
1 0
Days
15 00 minute intervals


MUF(3000)
Brighton Co , 2 11 80
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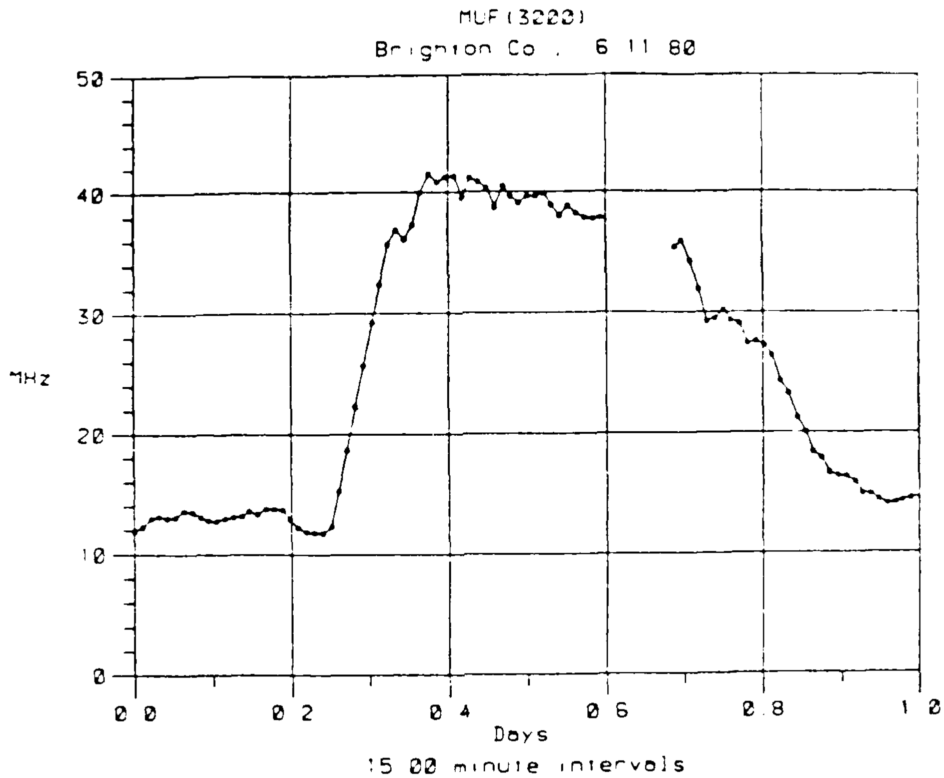
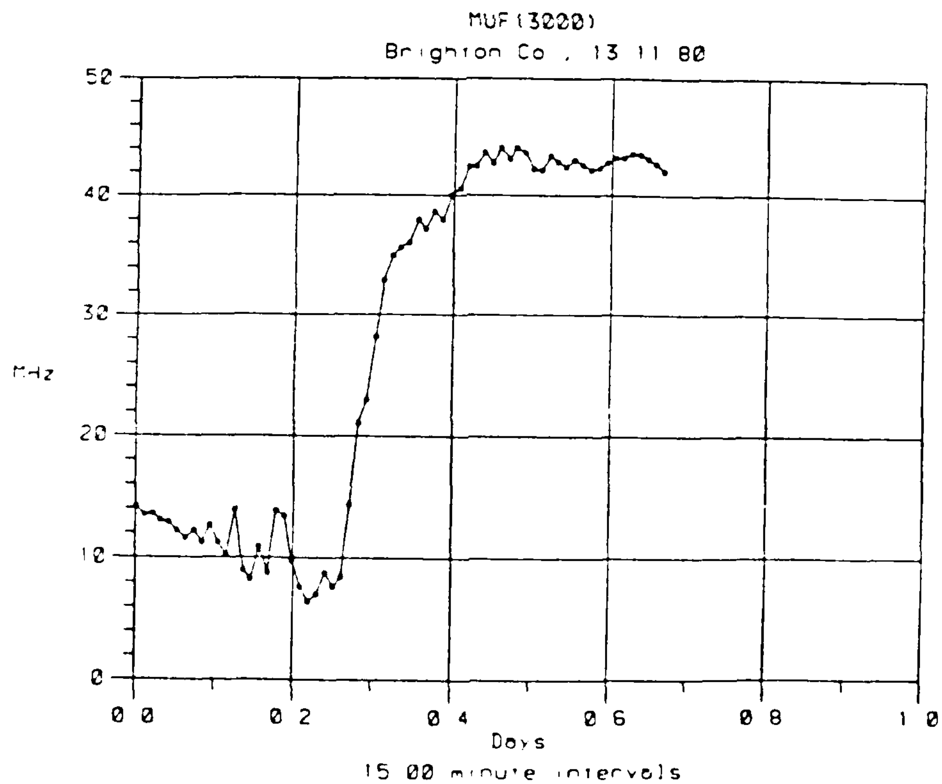
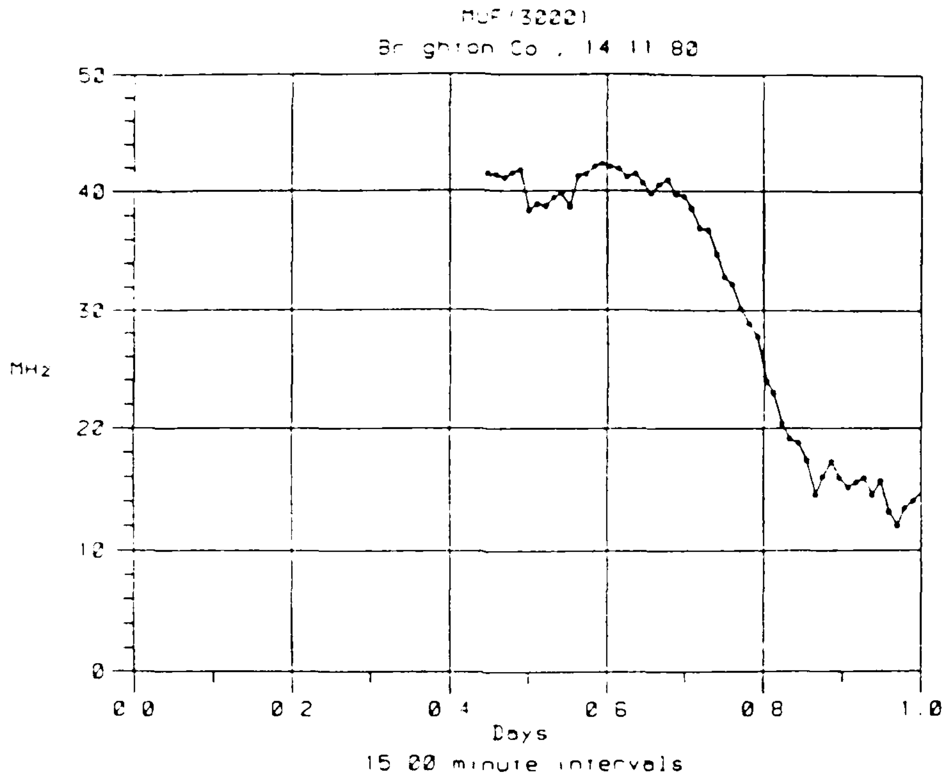
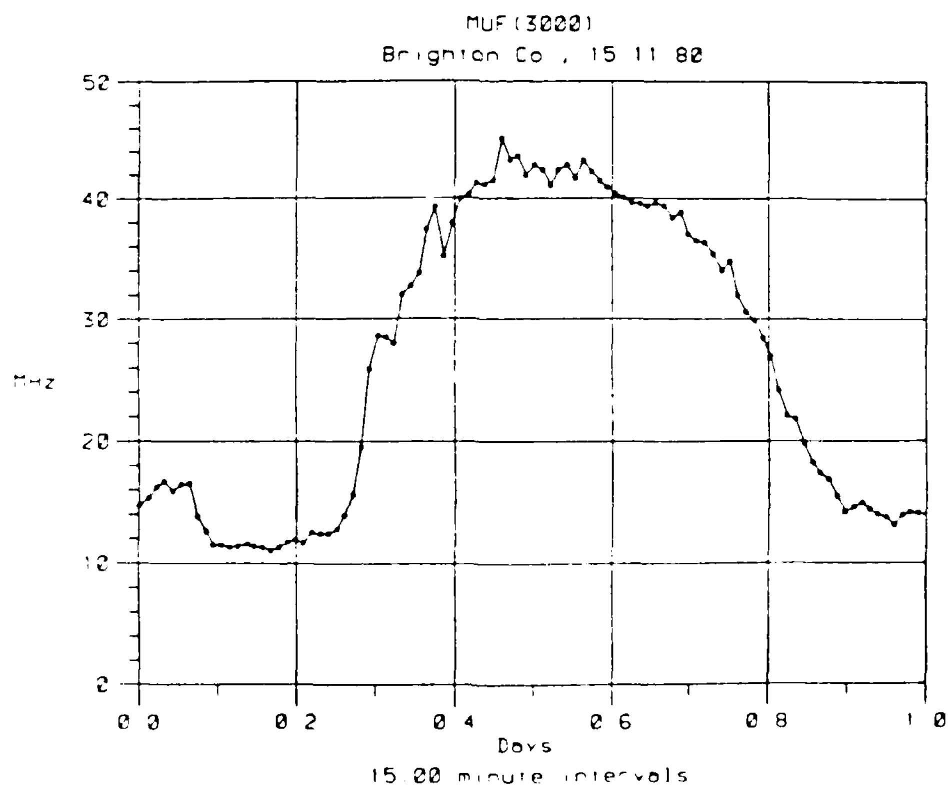
40
30
MHz
20
10
0
0 0
0 2
0 4
0 6
0 8
1 0
Days
15 00 minute intervals

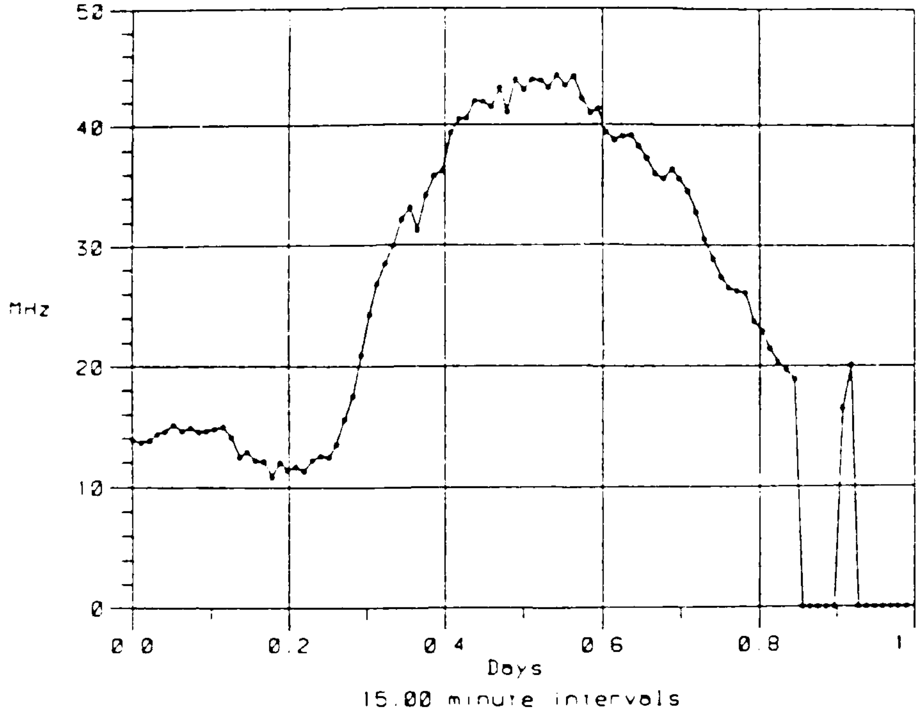

MUF(3220)
Brighton Co., 6 11 80
MHz
50
40
30
20
10
0
0 0
0 2
0 4
0 6
0 8
1 0
Days
15 00 minute intervals


MUF(3000)
Brighton Co., 13 11 80
MHz
50
40
30
20
10
0
0 0
0 2
0 4
0 6
0 8
1 0
Days
15 00 minute intervals

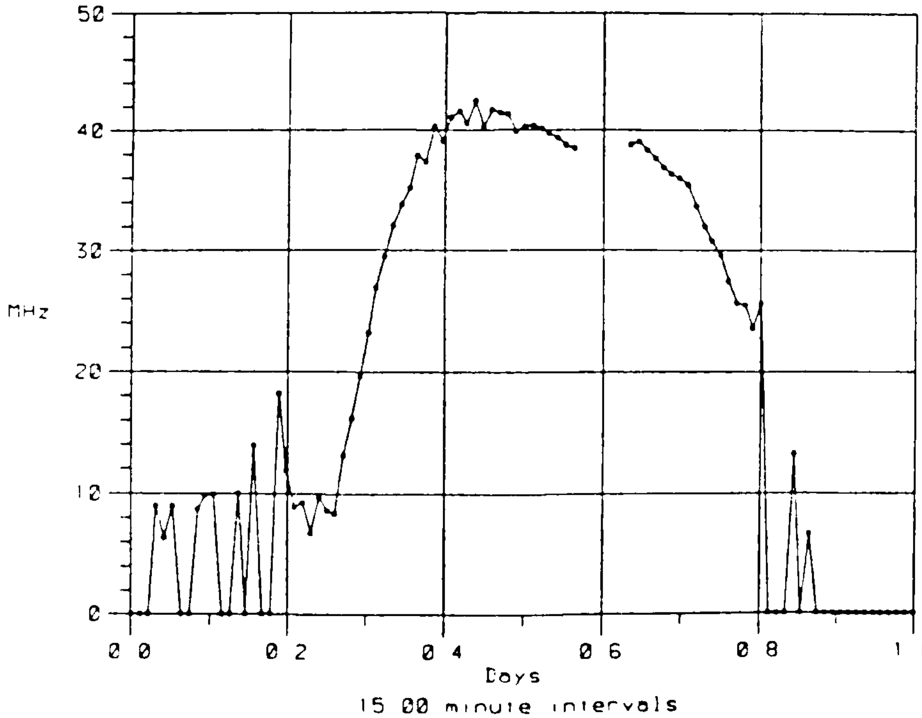

MUF(3000)
Brighton Co., 14 11 80
52
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 15 11 80
52
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals

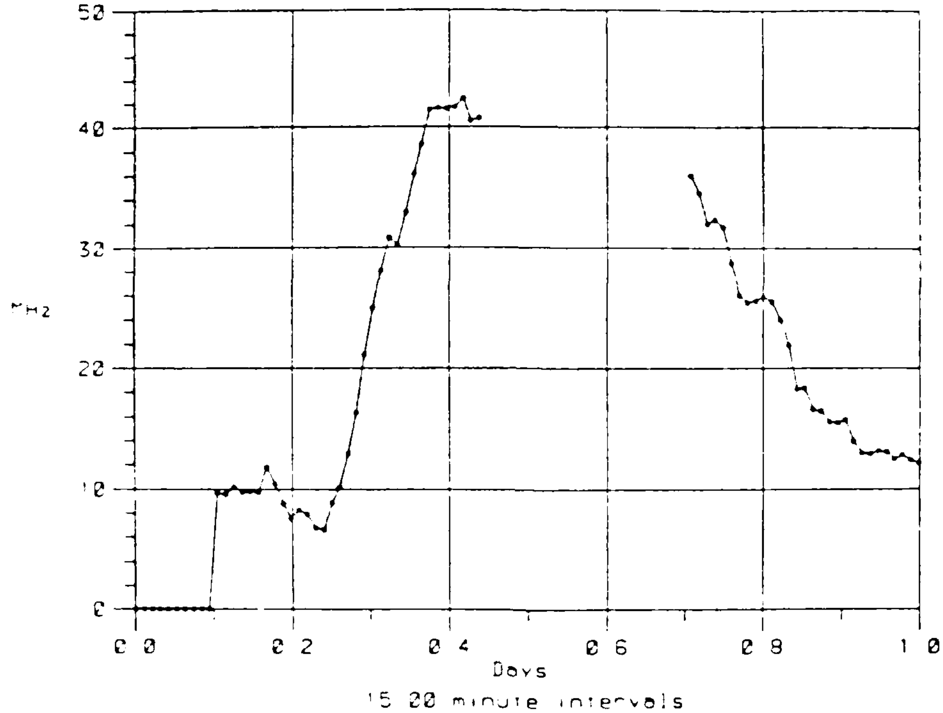
MUF(3000)
Brighton Co., 16 11 80



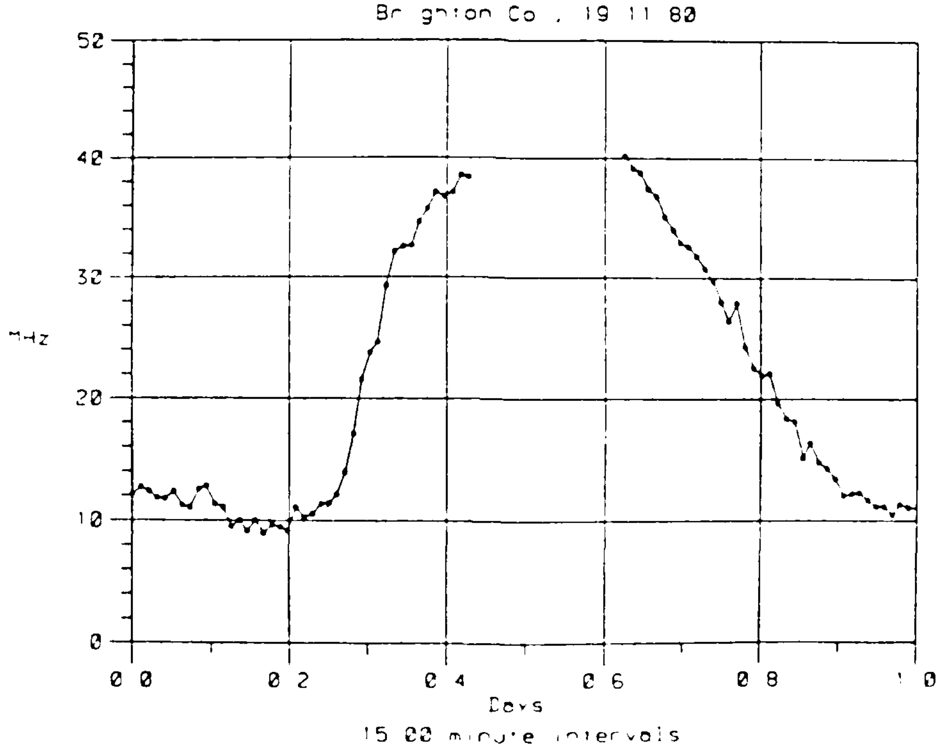
MUF(3000)
Brighton Co., 17 11 80

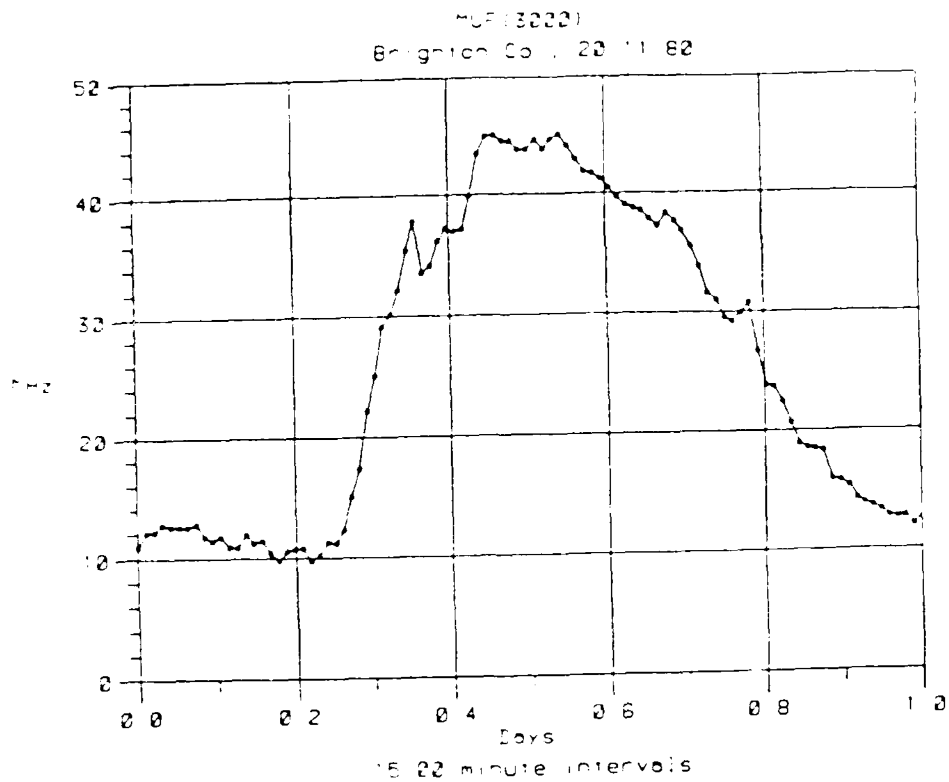


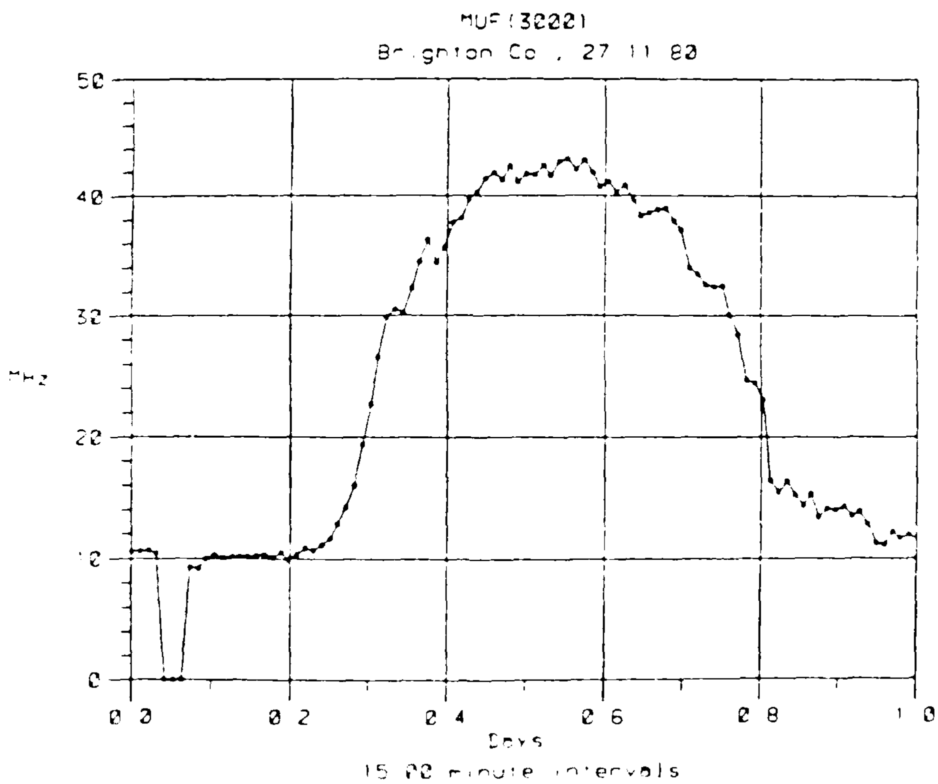
MUF(3222)
Brighton Co., 18 11 80

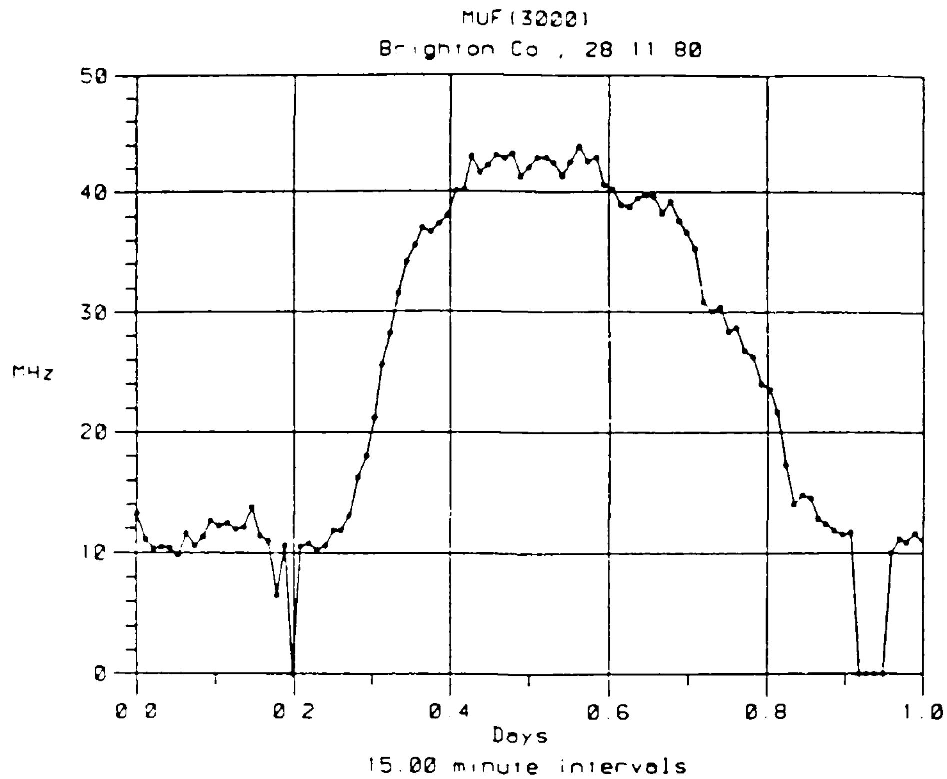


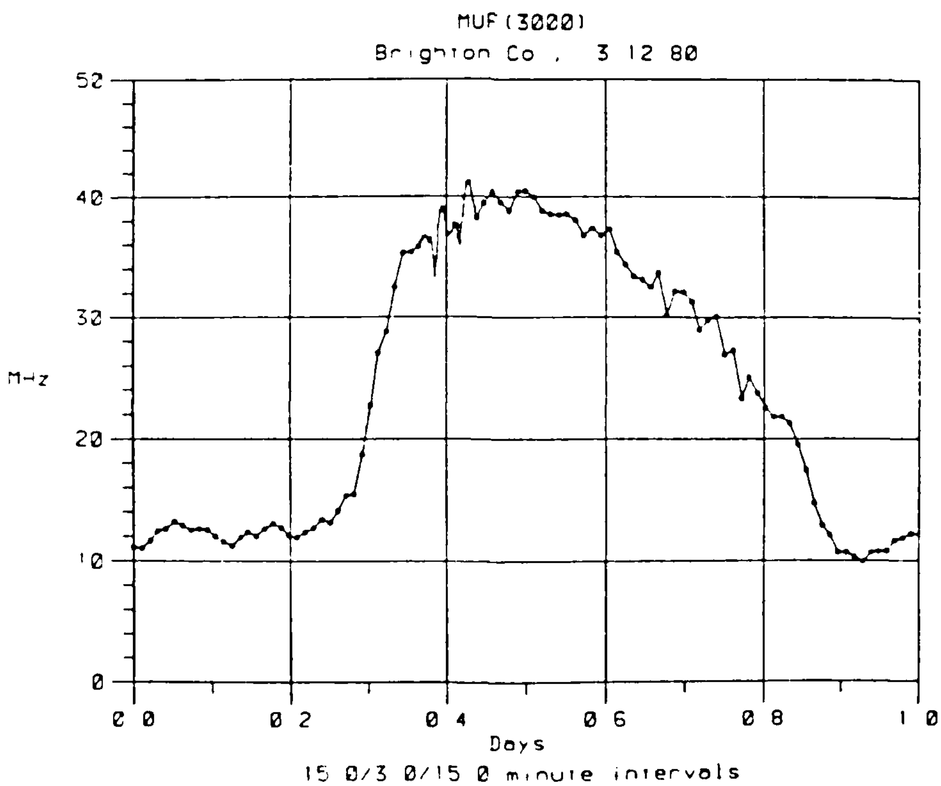
MUF(3222)
Brighton Co., 19 11 80




MUF(3000)
Brighton Co., 20 11 80
MHz
52
40
30
20
10
0
0 0
0 2
0 4
0 6
0 8
1 0
Days
15 00 minute intervals


MUF(3000)
Brighton Co., 27 11 80
MHz
50
40
30
20
10
0
0 0
0 2
0 4
0 6
0 8
1 0
Days
15 00 minute intervals


MUF(3000)
Brighton Co , 28 11 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co , 3 12 80
52
40
30
20
10
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MHz
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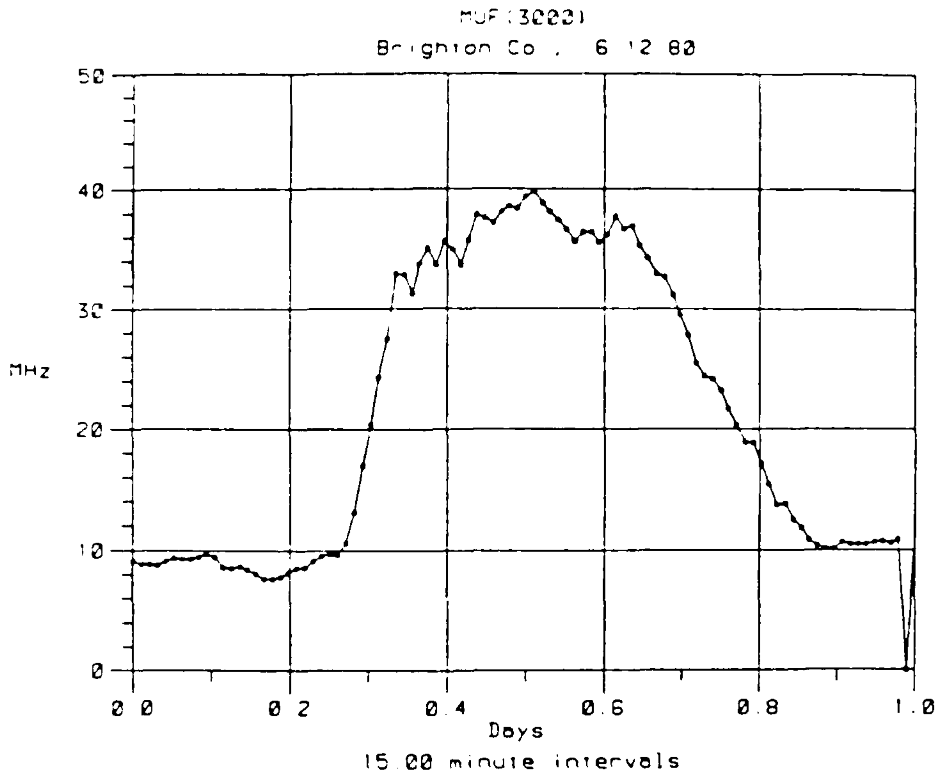
0.2
0.4
0.6
0.8
1.0
Days
15.0/3.0/15.0 minute intervals


MUF(3000)
Brighton Co , 6 12 80
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30
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10
0
MHz
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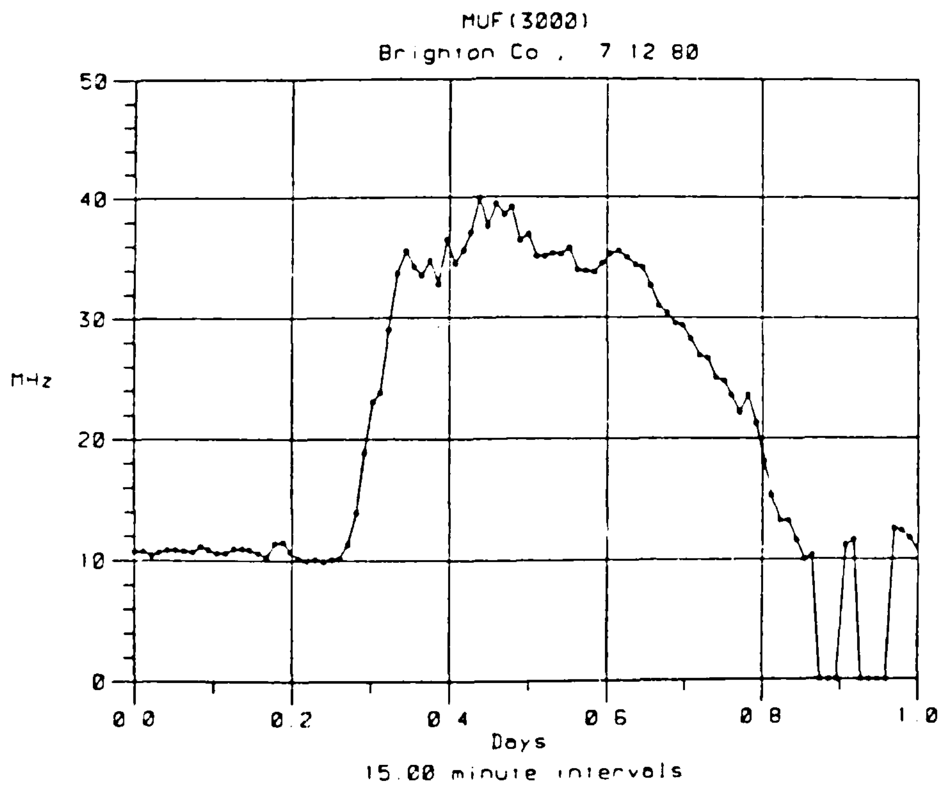
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
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MHz
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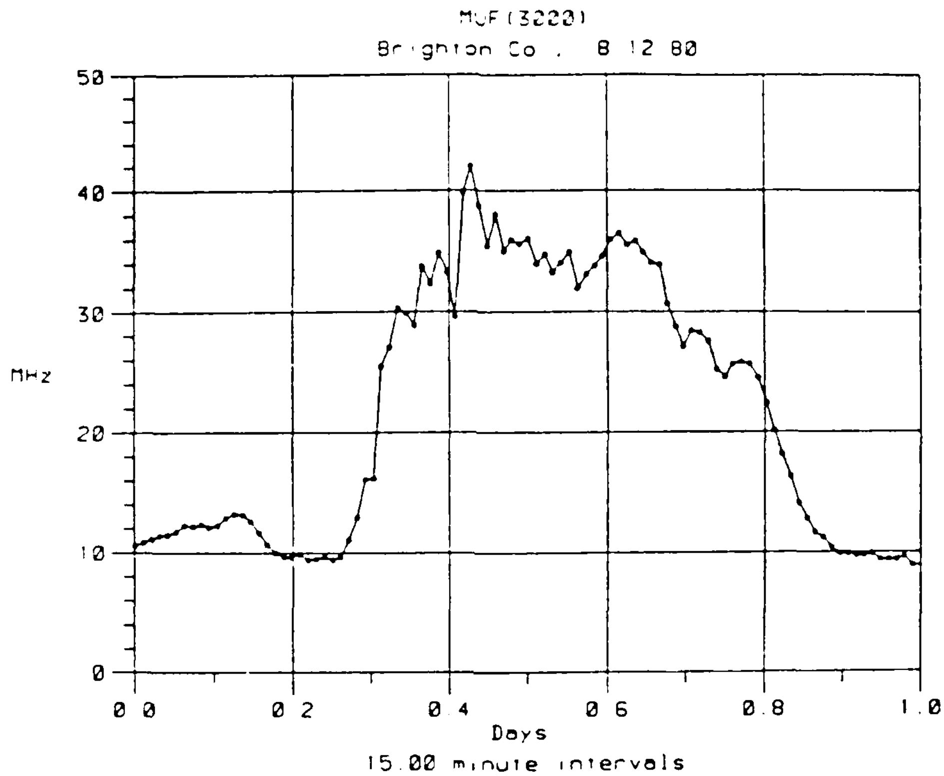
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3220)
Brighton Co., 8 12 80
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MHz
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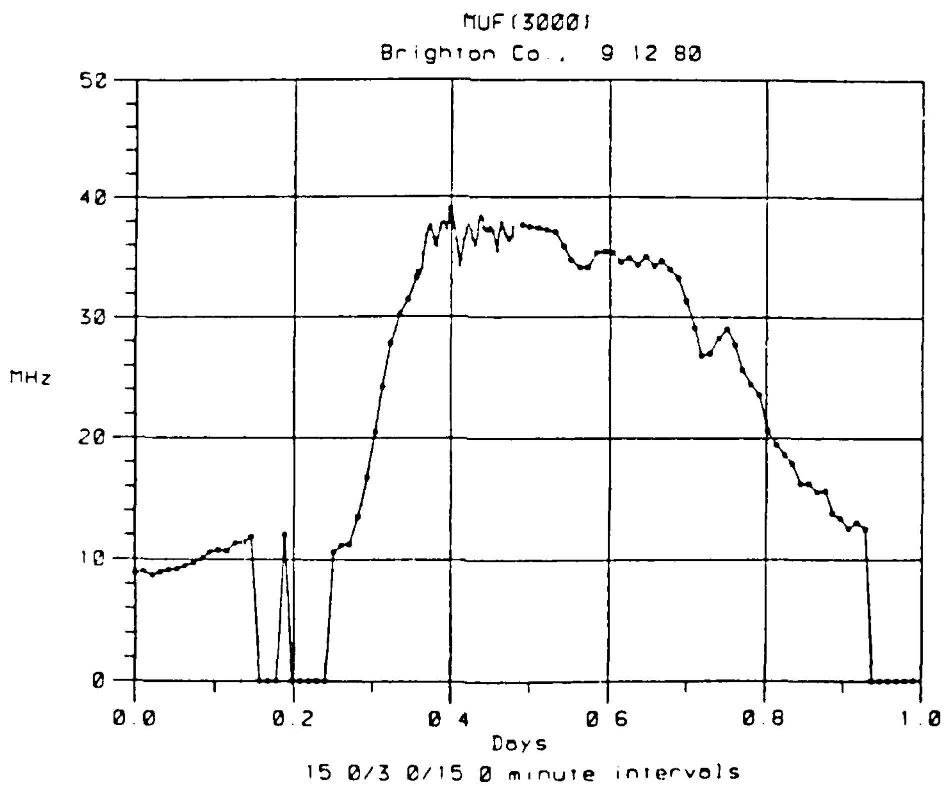
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 9 12 80
50
40
30
20
10
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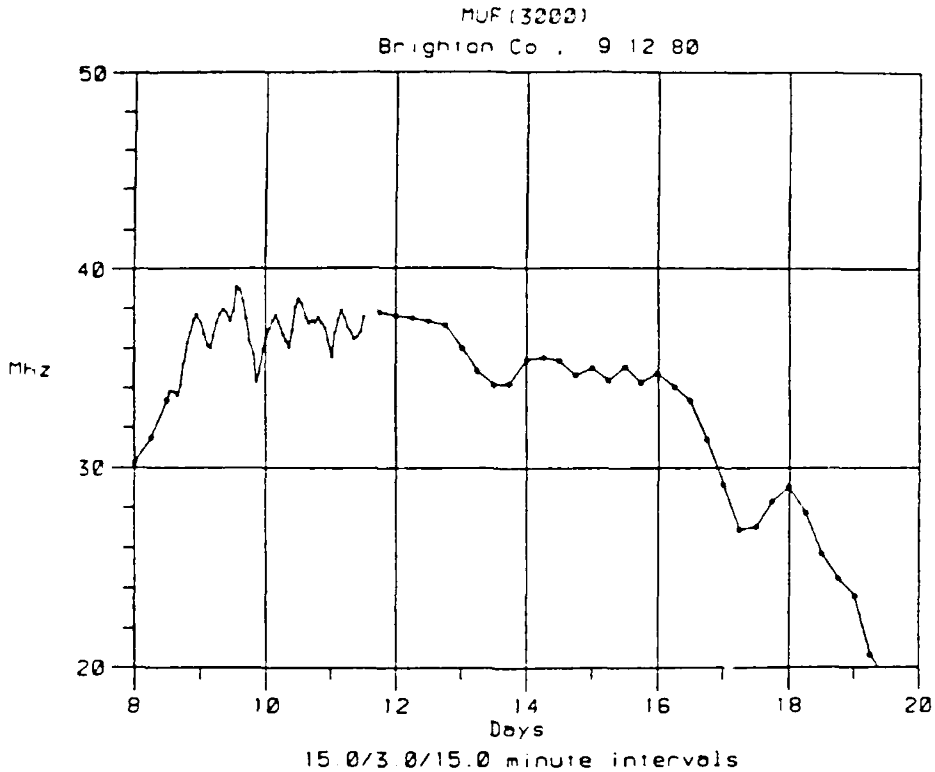
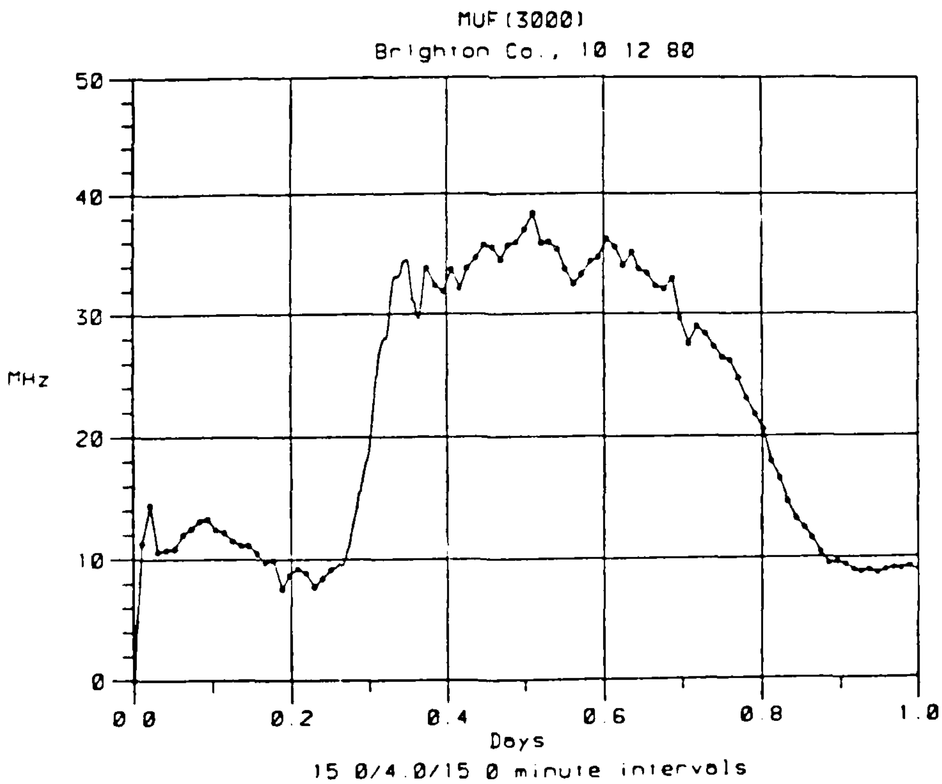
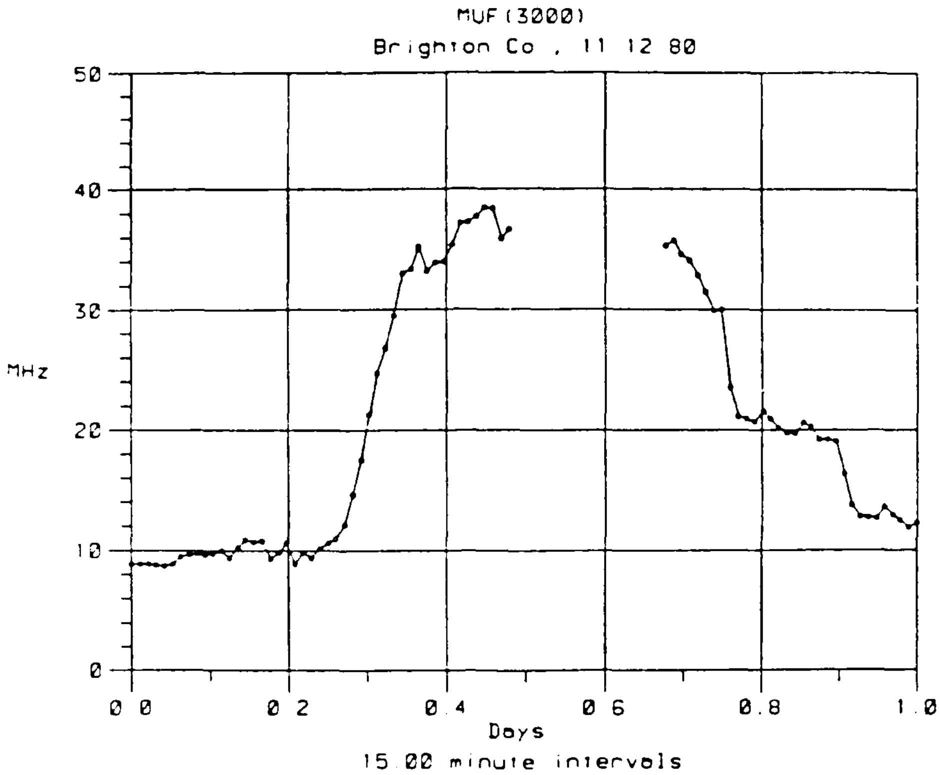
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.0/3.0/15.0 minute intervals


MUF(3000)
Brighton Co., 9 12 80
50
40
30
20
MHz
8
10
12
14
16
18
20
Days
15.0/3.0/15.0 minute intervals


MUF(3000)
Brighton Co., 10 12 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.0/4.0/15.0 minute intervals



MUF(3000)
Brighton Co., 11 12 80
MHz
50
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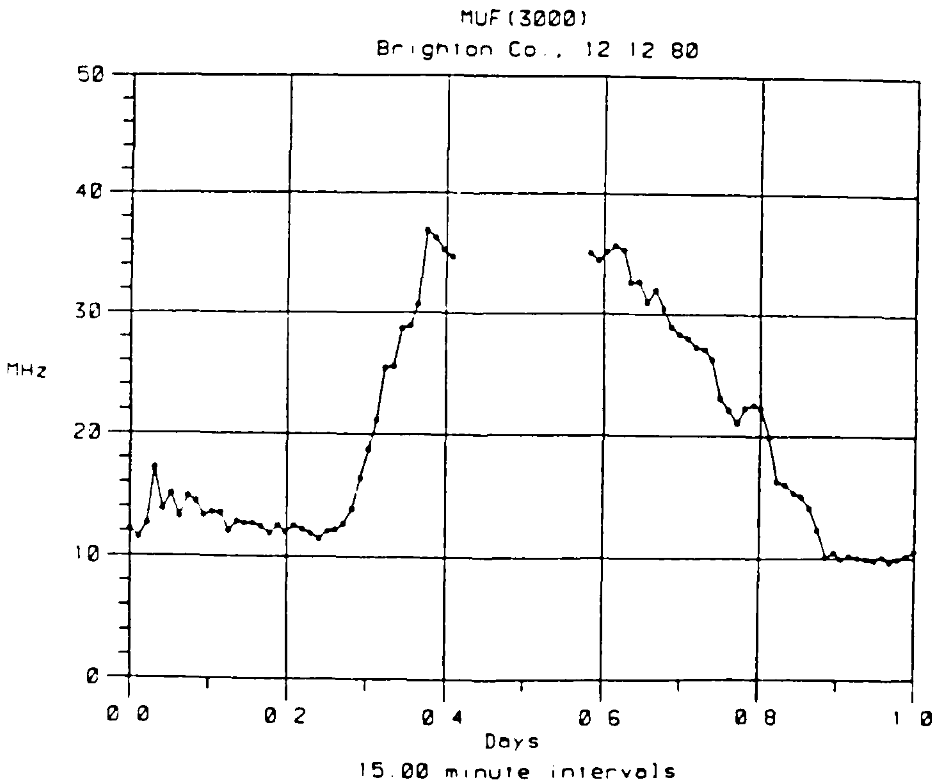
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals



MUF(3000)
Brighton Co., 12 12 80
MHz
50
40
30
20
10
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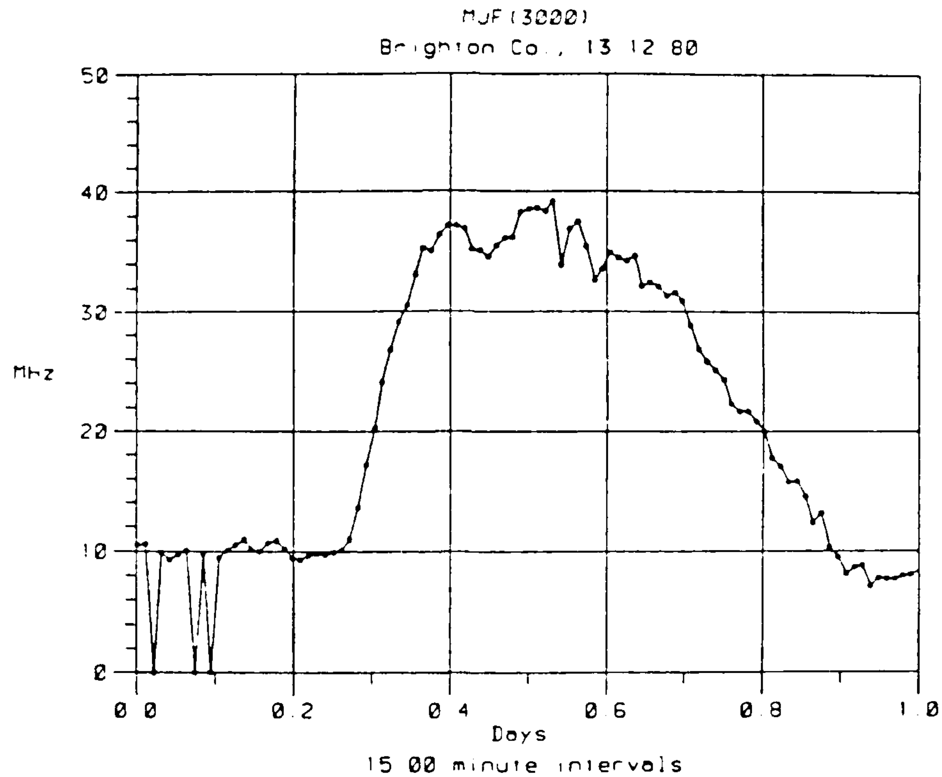
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 13 12 80
50
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10
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MHz
0.0
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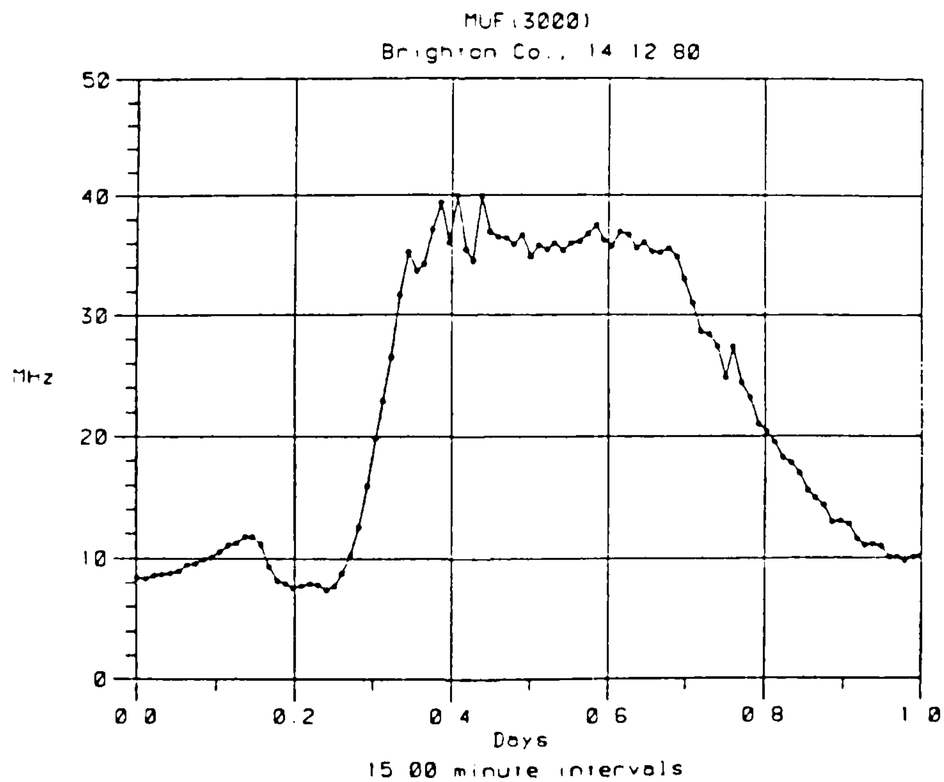
0.4
0.6
0.8
1.0
Days
15 00 minute intervals


MUF(3000)
Brighton Co., 14 12 80
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0
MHz
0.0
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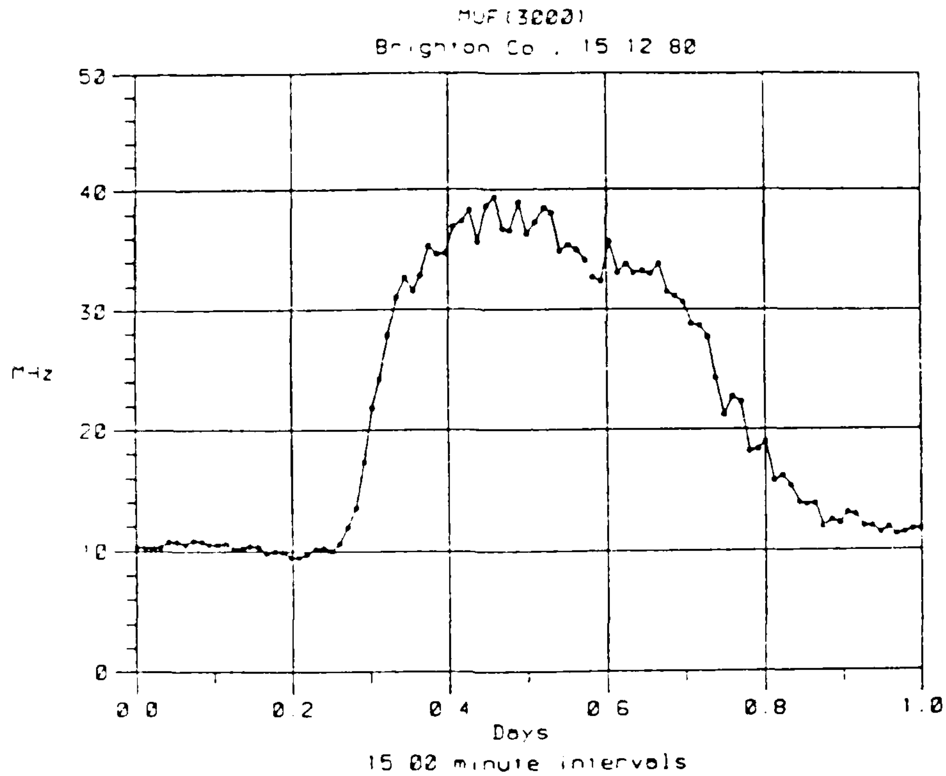
0.4
0.6
0.8
1.0
Days
15 00 minute intervals


MUF(3000)
Brighton Co , 15 12 80
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MHz
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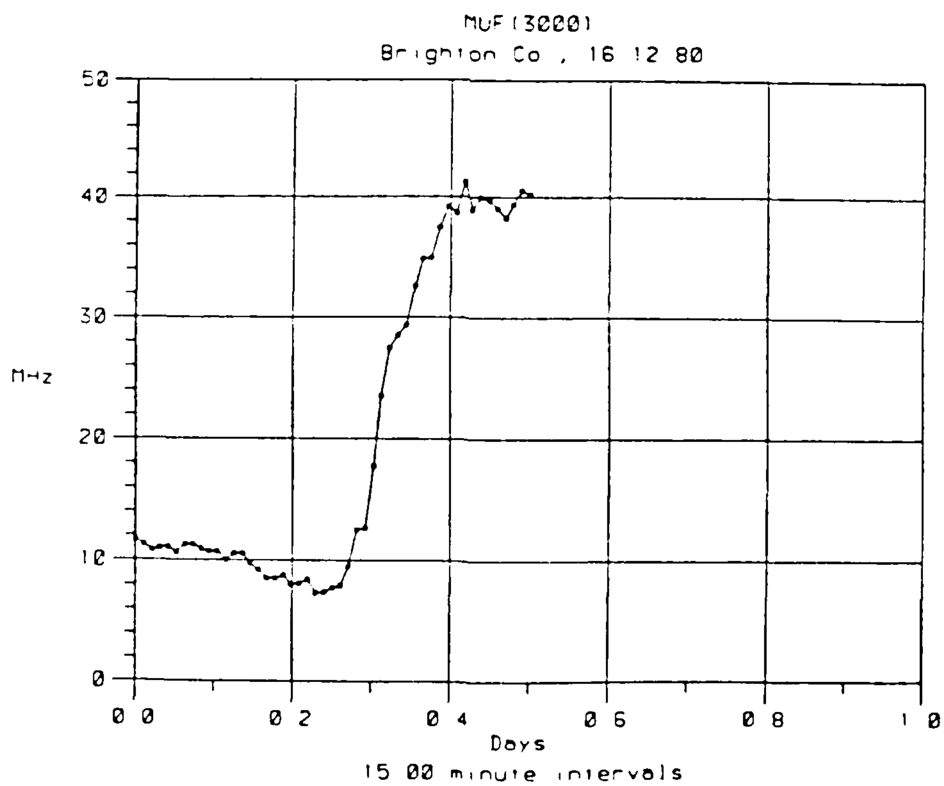
0.4
0.6
0.8
1.0
Days
15 00 minute intervals


MUF(3000)
Brighton Co , 16 12 80
50
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10
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MHz
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0.2
0.4
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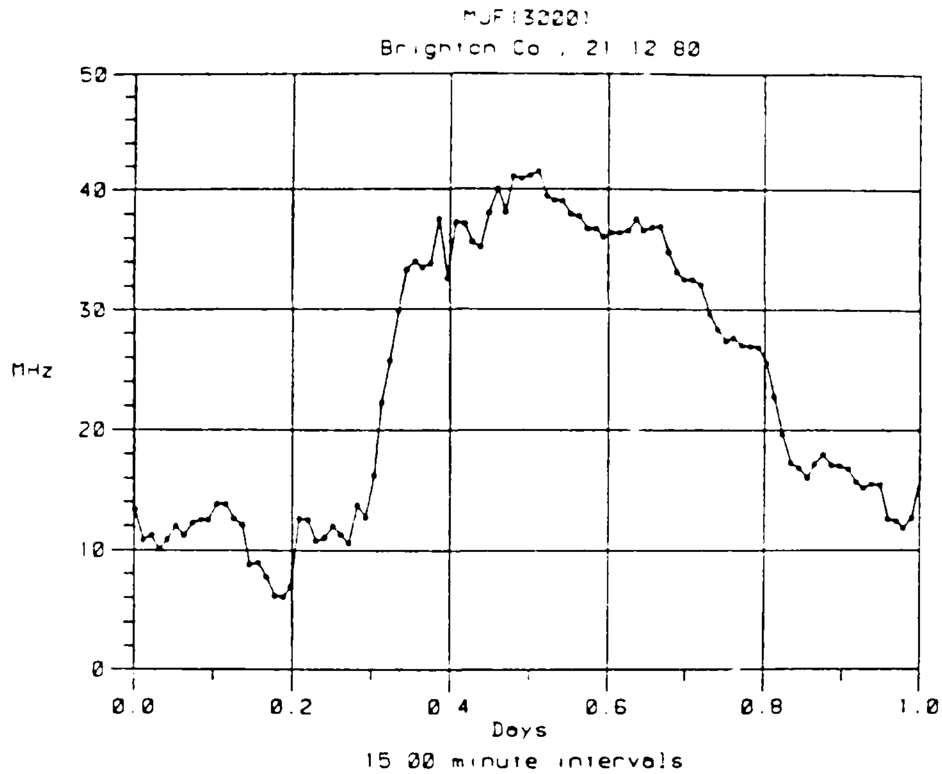
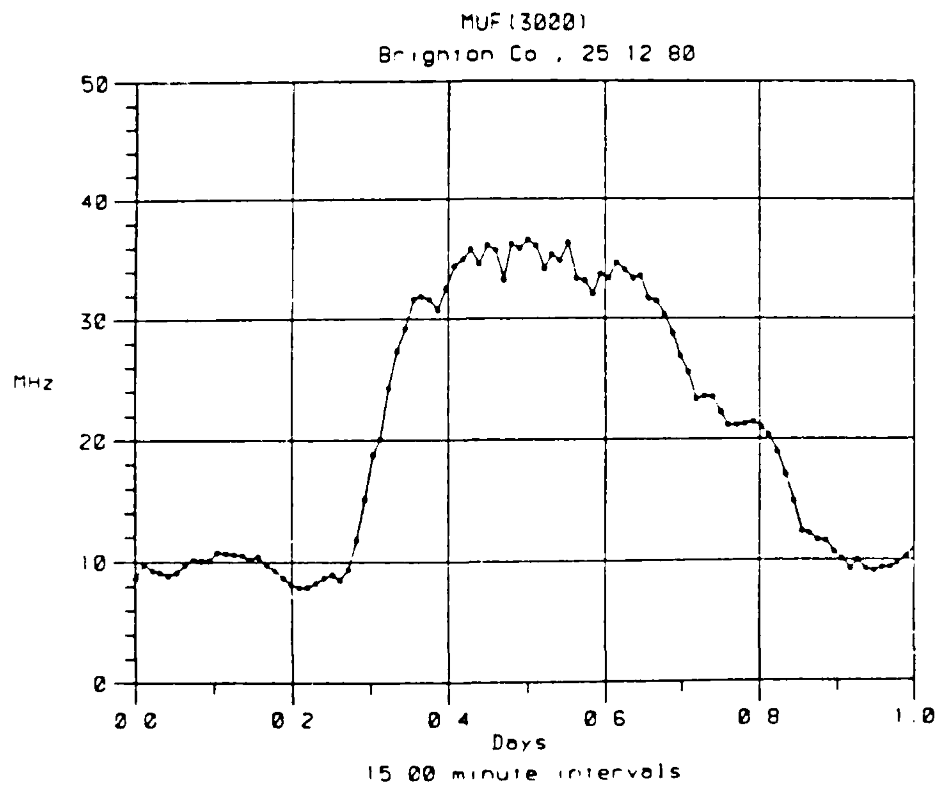
0.8
1.0
Days
15 00 minute intervals


MUF(3220)
Brighton Co , 21 12 80
50
40
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15 00 minute intervals


MUF(3020)
Brighton Co , 25 12 80
50
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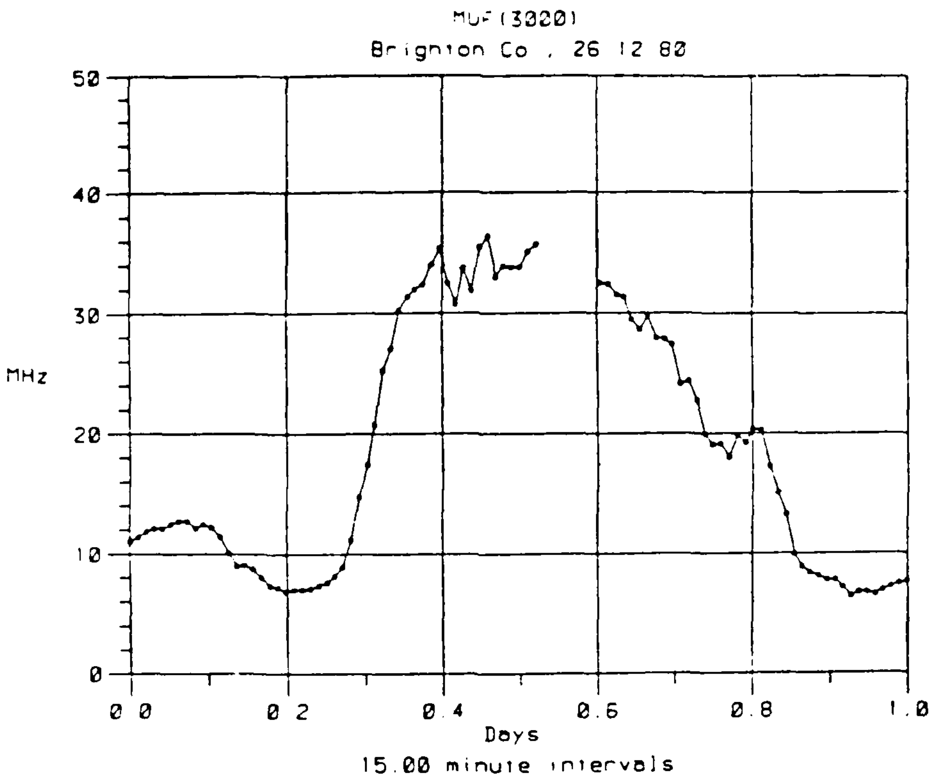
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15 00 minute intervals


MUF(3020)
Brighton Co., 26 12 80
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10
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MHz
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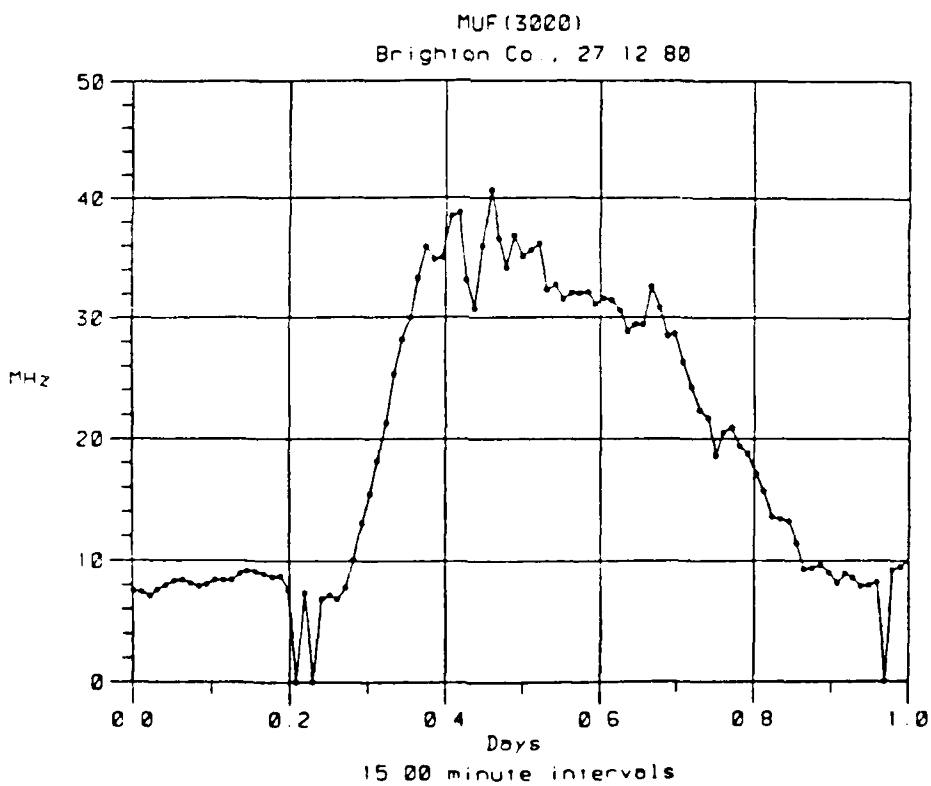
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 27 12 80
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10
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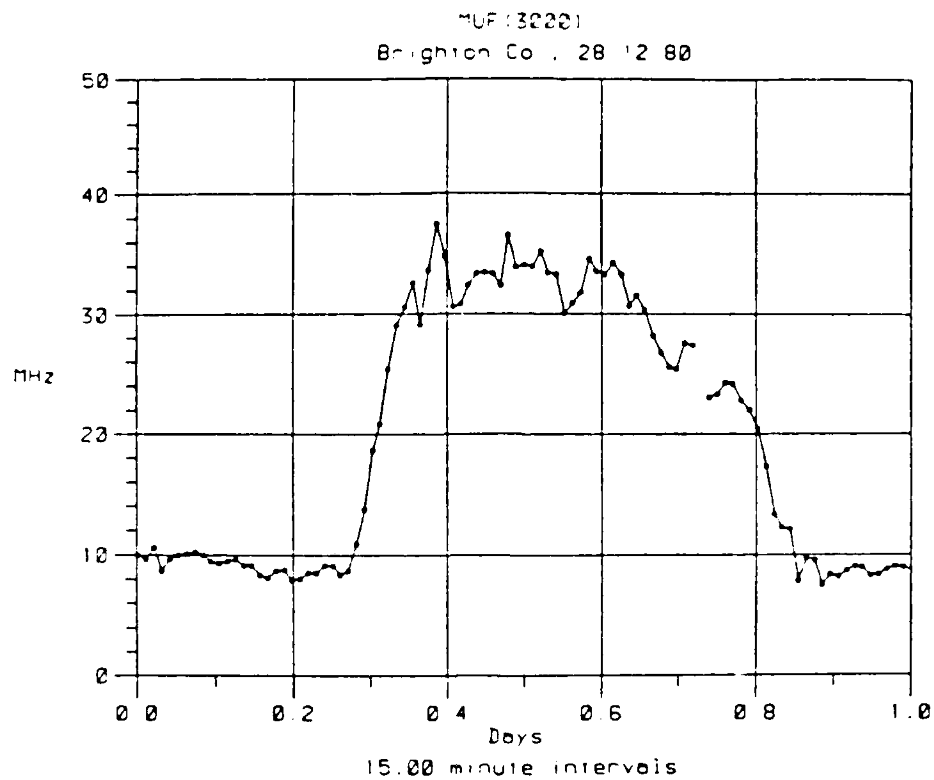
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 28 12 80
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20
10
0
MHz
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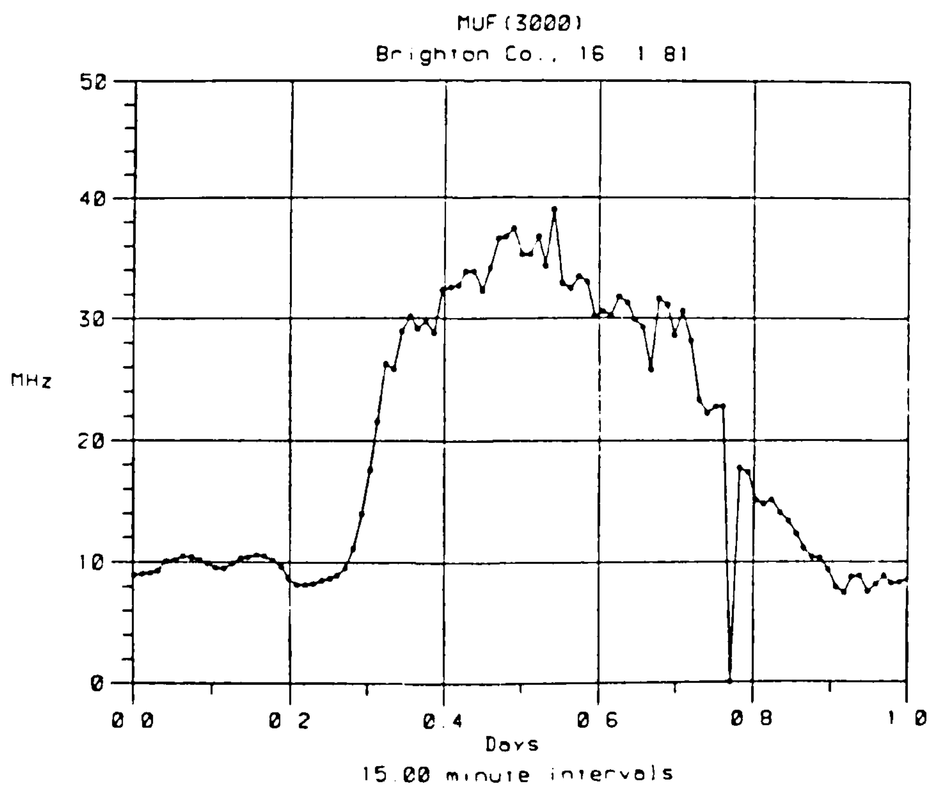
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 16 1 81
50
40
30
20
10
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MHz
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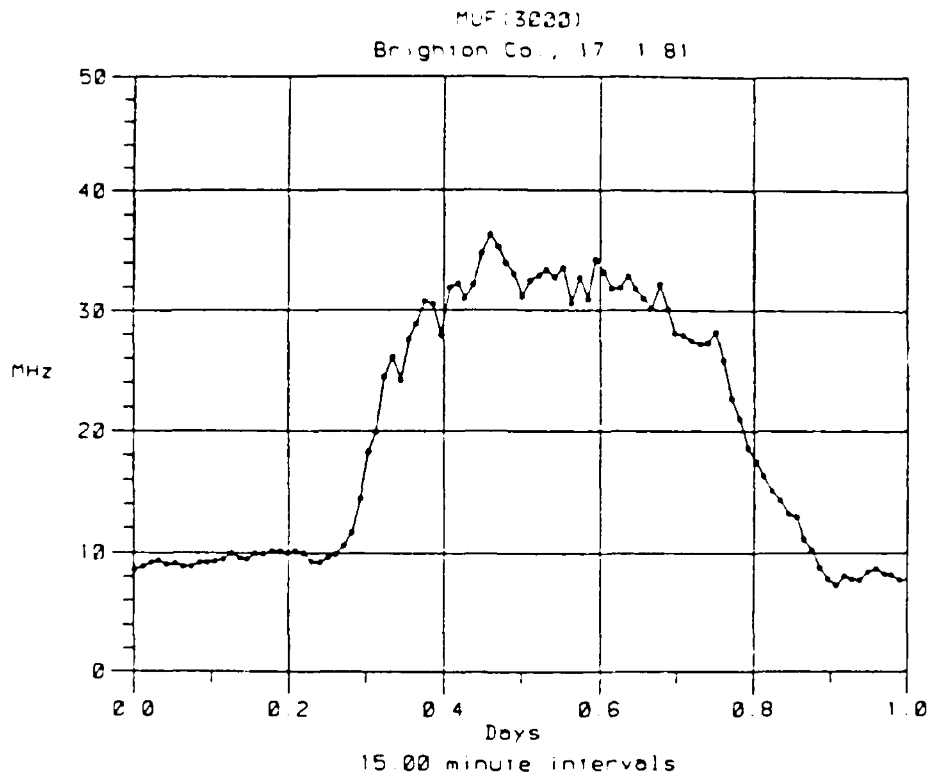
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 17 1 81
50
40
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20
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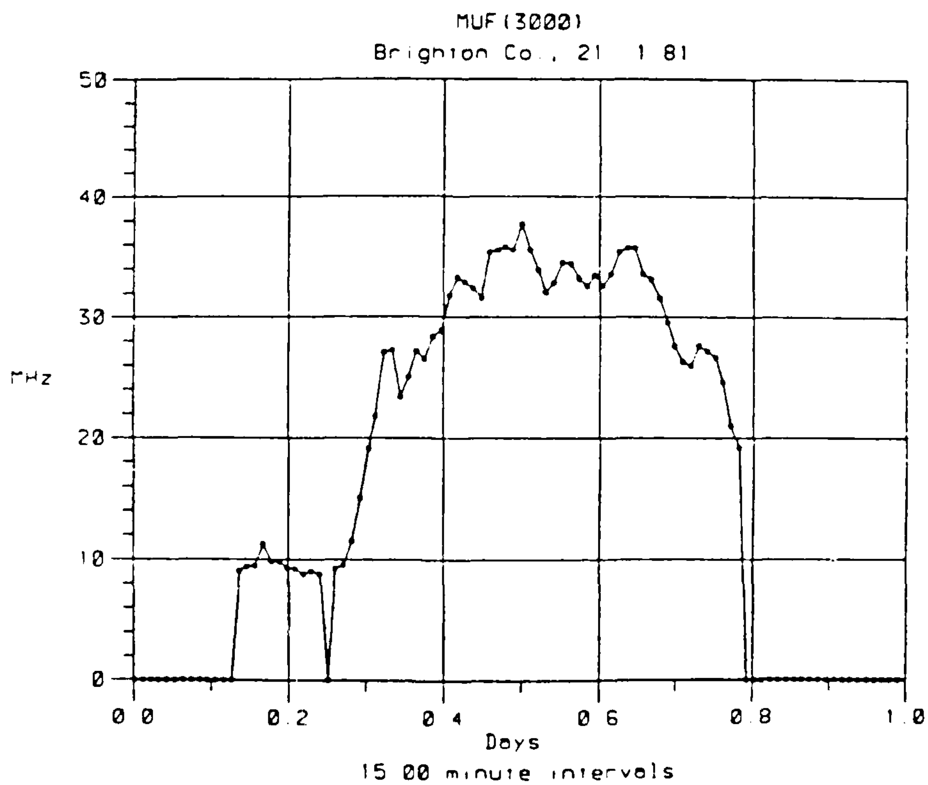
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 21 1 81
50
40
30
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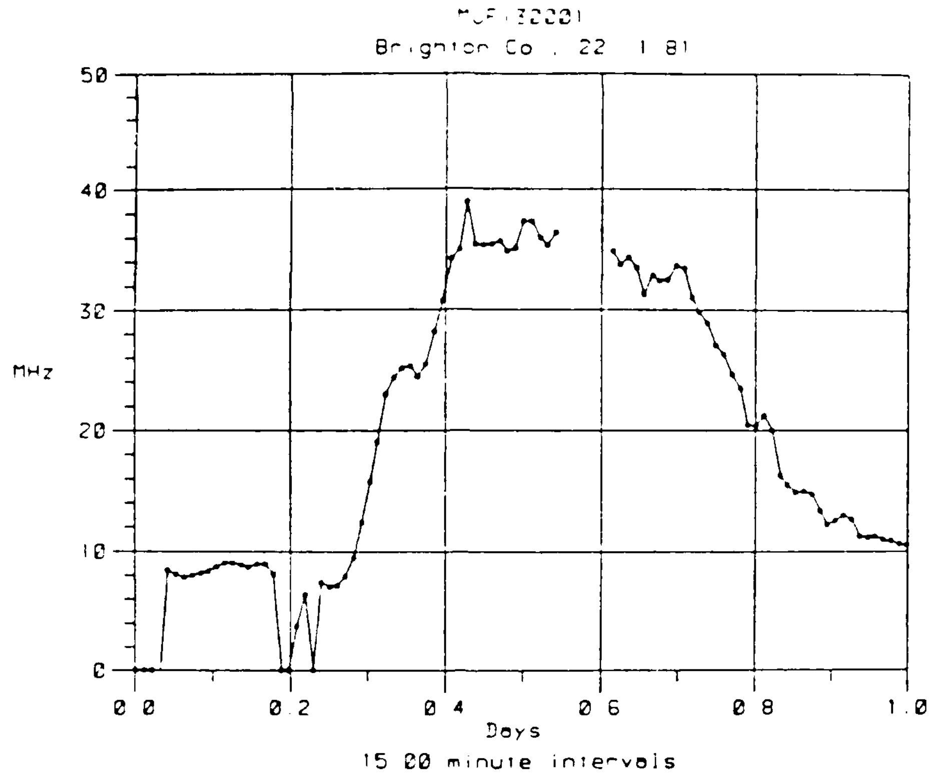
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals



MUF(3000)
Brighton Co., 22 1 81
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MHz
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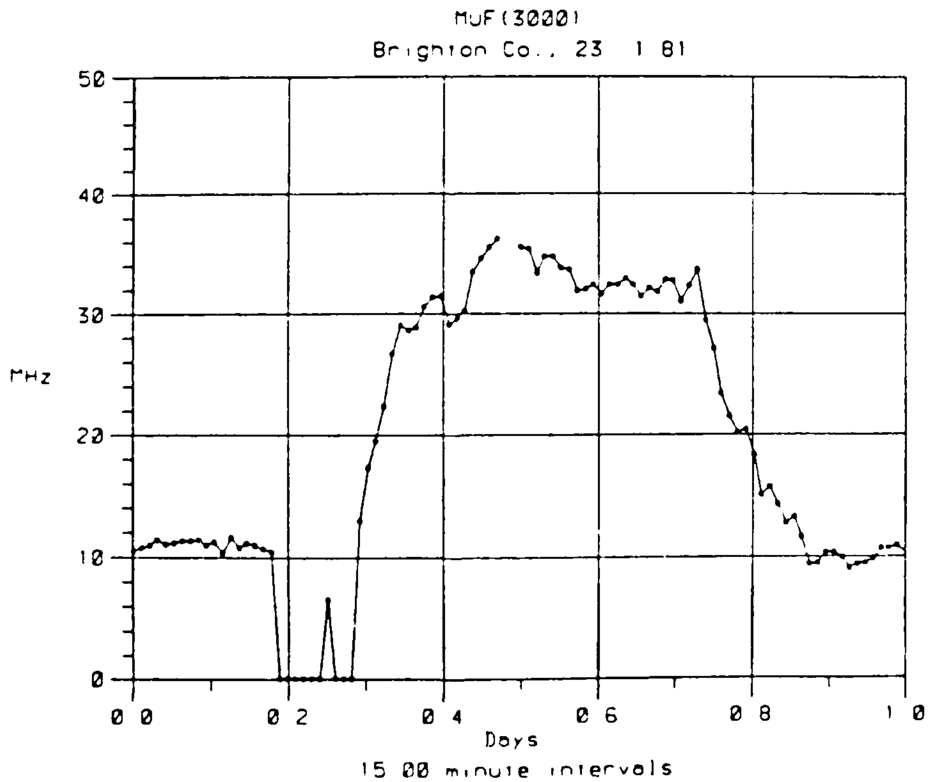
0.4
0.6
0.8
1.0
Days
15.00 minute intervals



MUF(3000)
Brighton Co., 23 1 81
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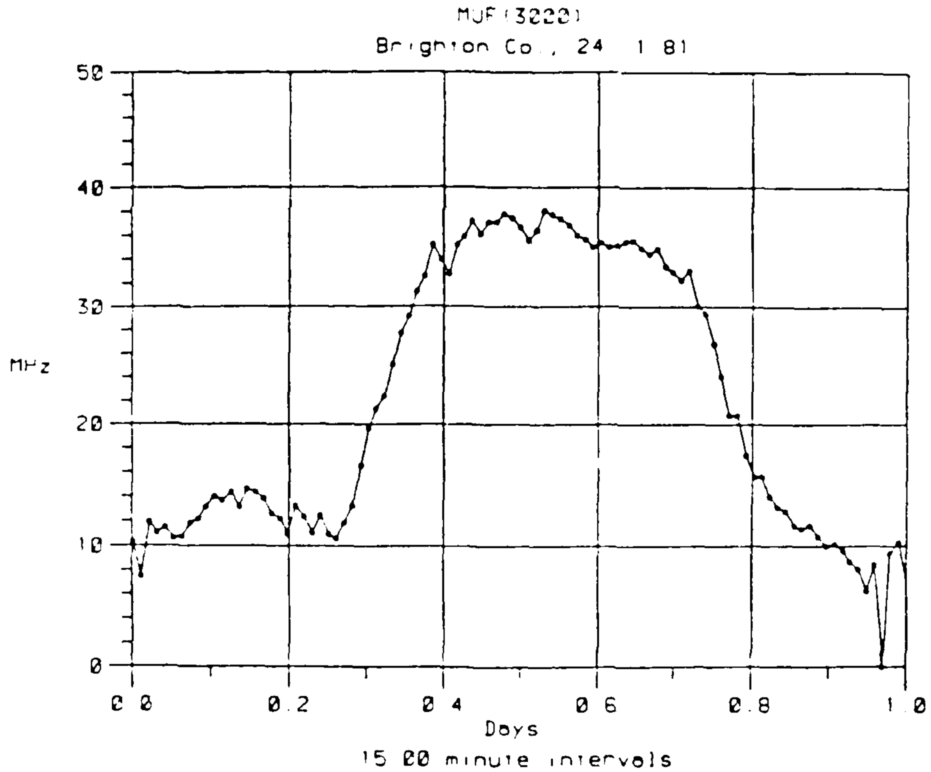
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 24 1 81
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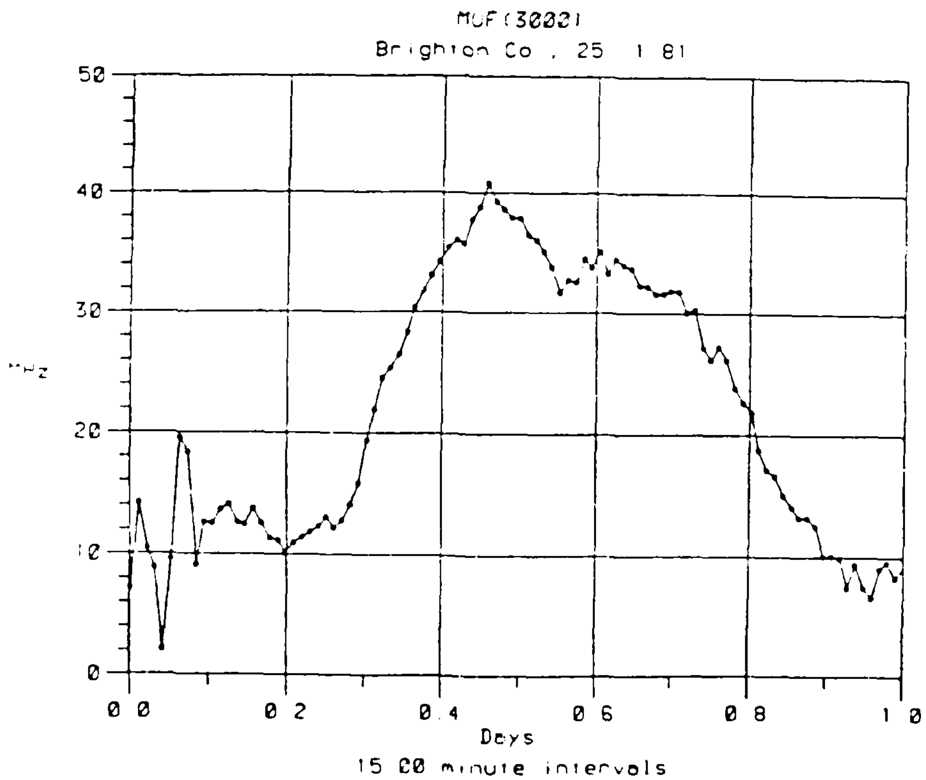
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 25 1 81
50
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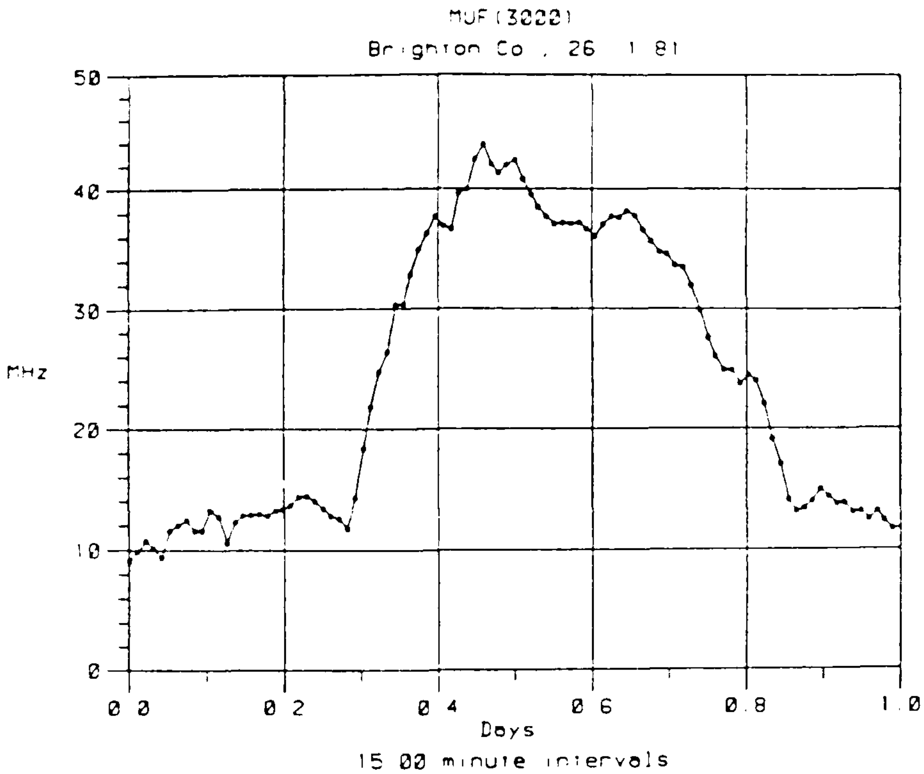
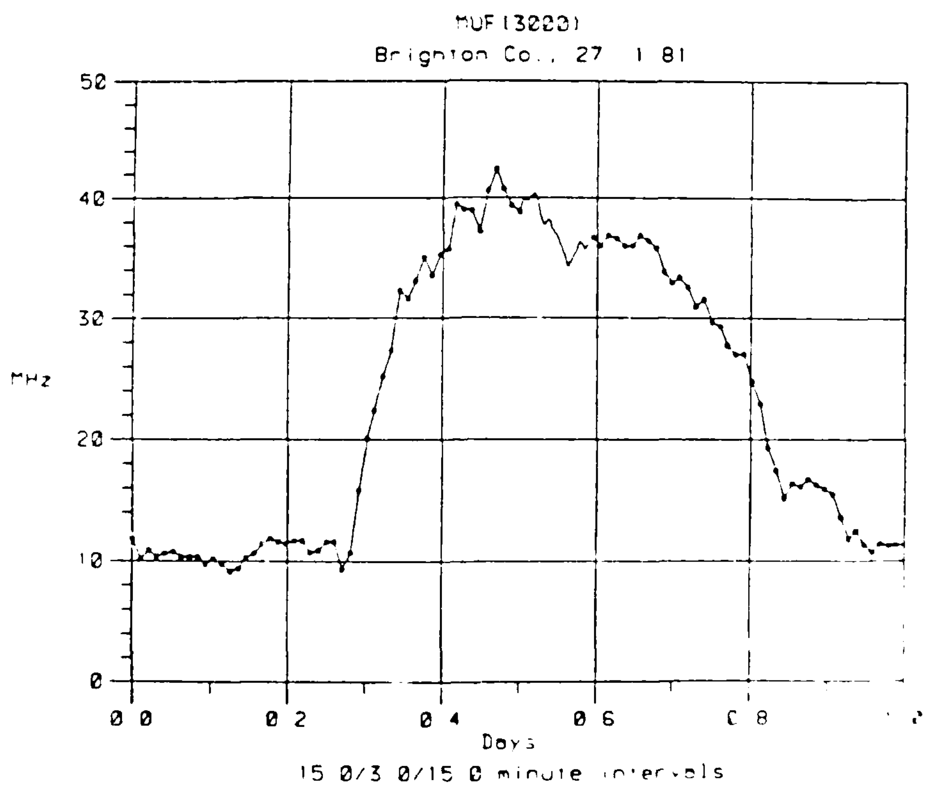
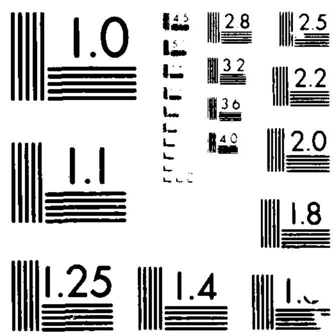
30
20
10
0
MHz
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 26 1 81
MHz
Days
15.00 minute intervals

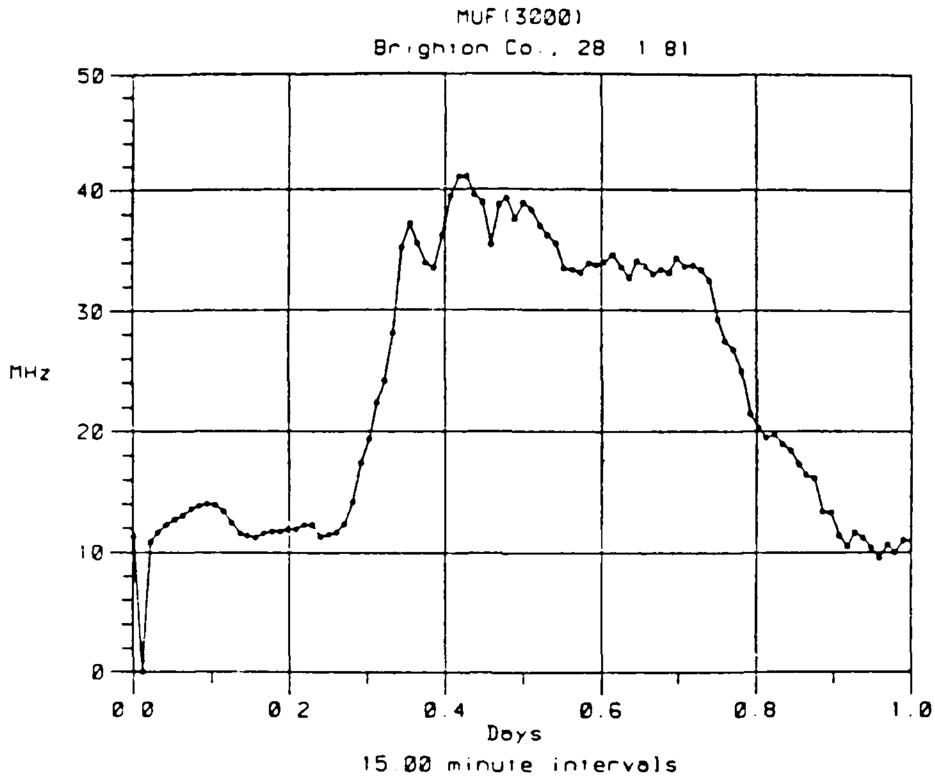

MUF(3000)
Brighton Co., 27 1 81
MHz
Days
15.0/3.0/15.0 minute intervals

AD-A191 655 THE MUF (MAXIMUM USABLE FREQUENCY) (3000) AS AN INDICATOR FOR F-REGION VARIATIONS(U) NAVAL OCEAN SYSTEMS CENTER SAN DIEGO CA A K PAUL JAN 88 2/2

UNCLASSIFIED NOSC/TR-1204 F/G 4/1 NL



MICROCOPY RESOLUTION TEST CHART


MUF(3000)
Brighton Co., 28 1 81
50
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20
10
0
MHz
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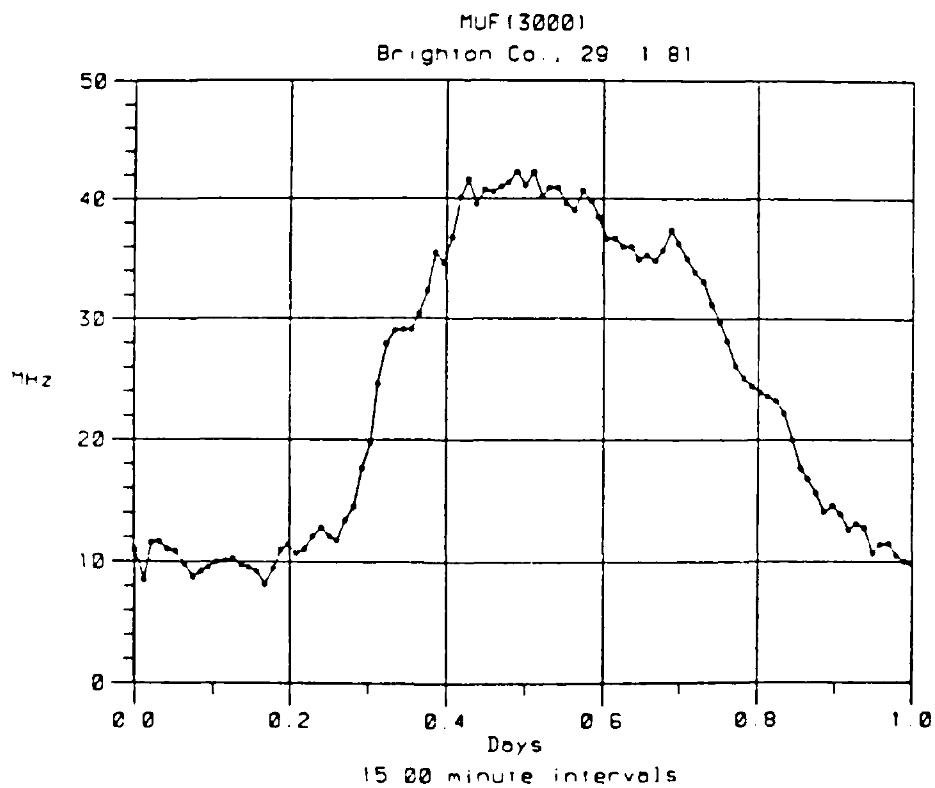
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 29 1 81
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MHz
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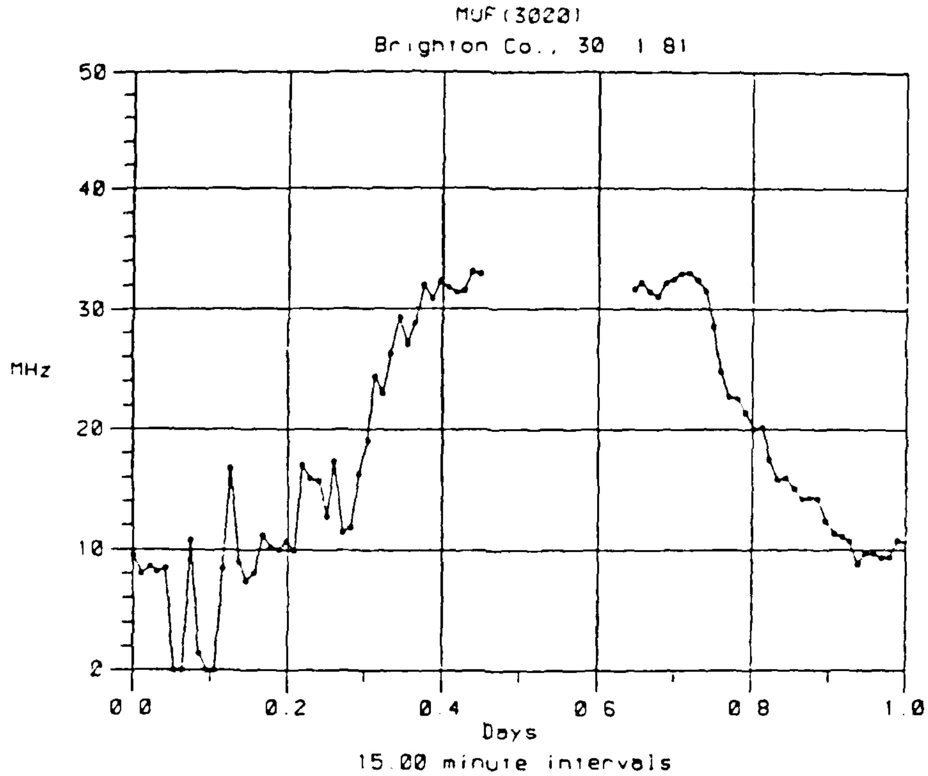
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals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Brighton Co., 30 1 81
MHz
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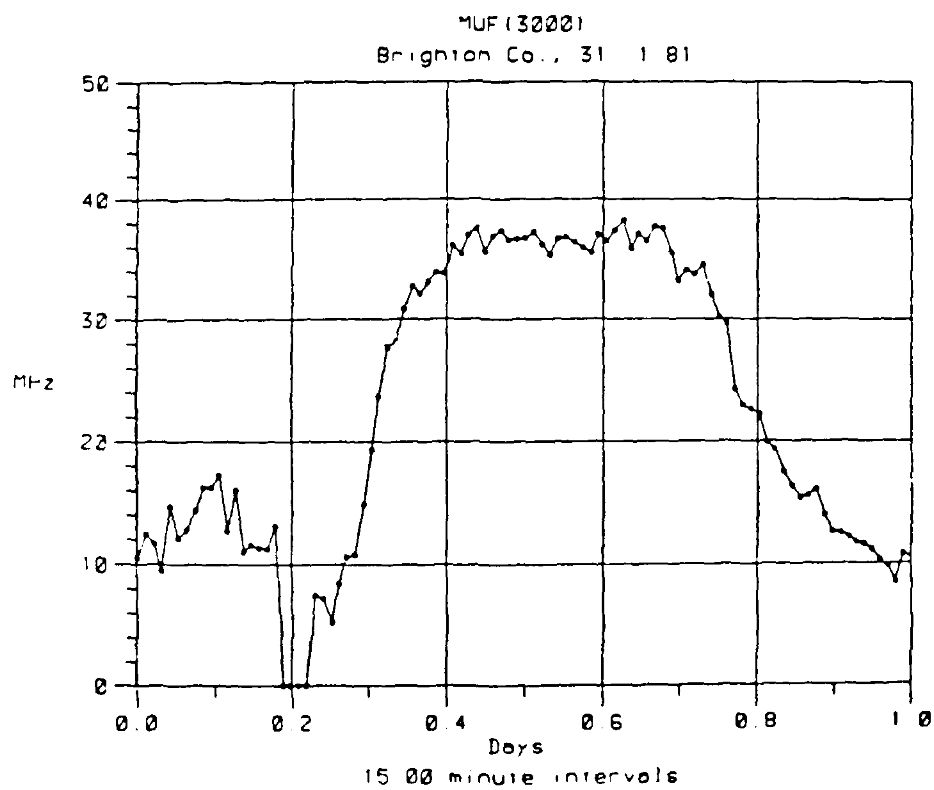
40
30
20
10
2
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 31 1 81
MHz
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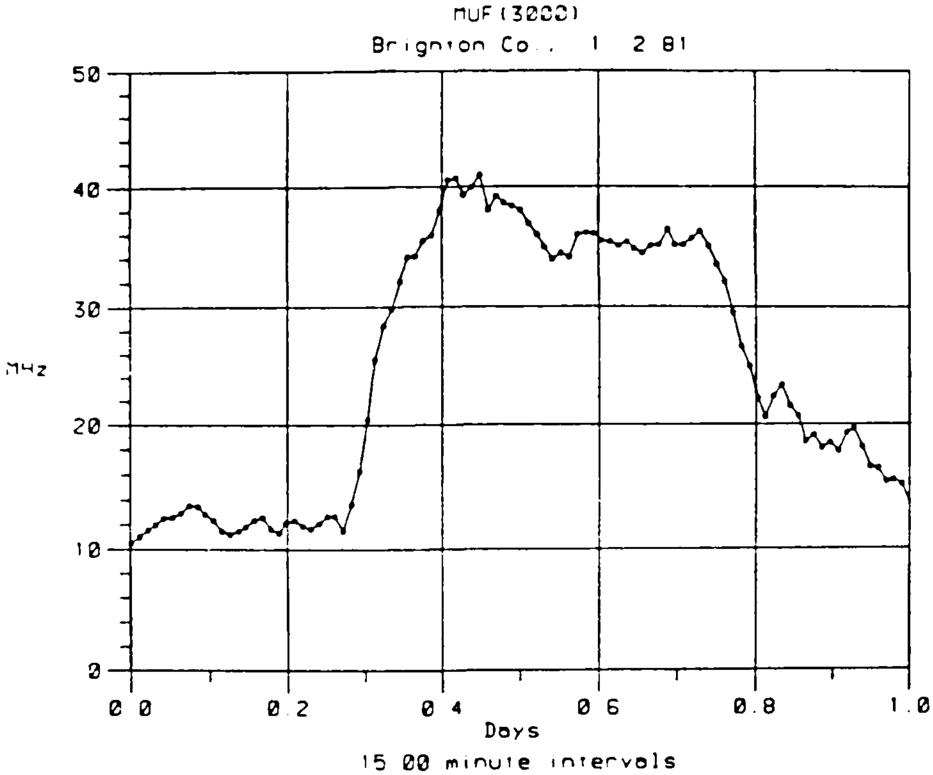
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF (3000)
Brighton Co., 1 2 81
MHz
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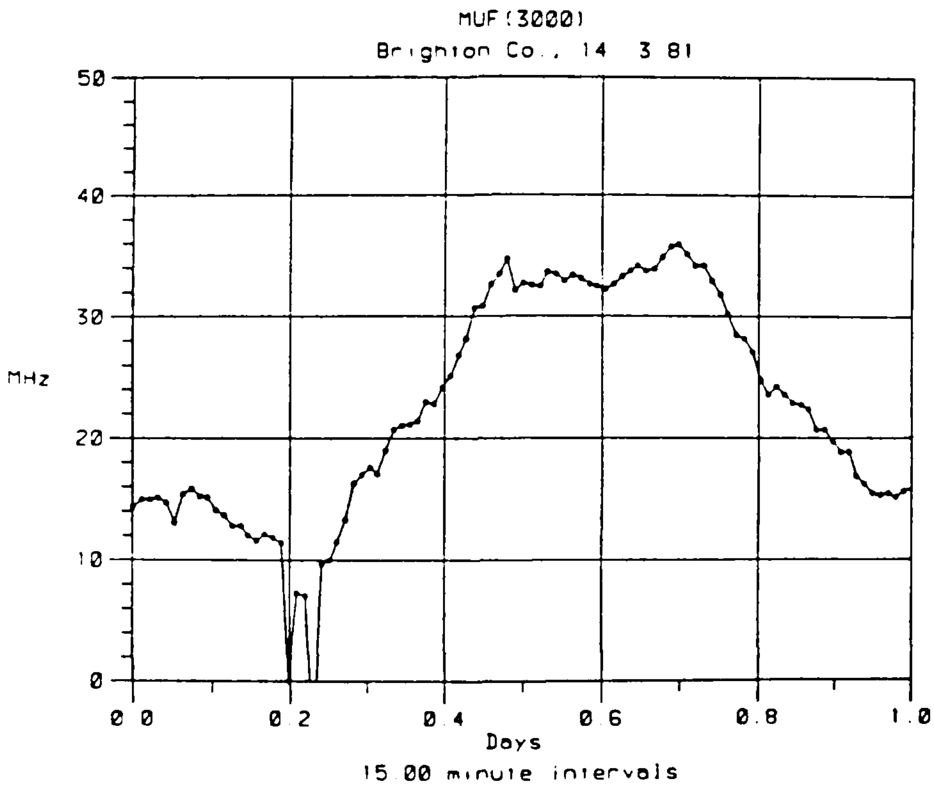
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF (3000)
Brighton Co., 14 3 81
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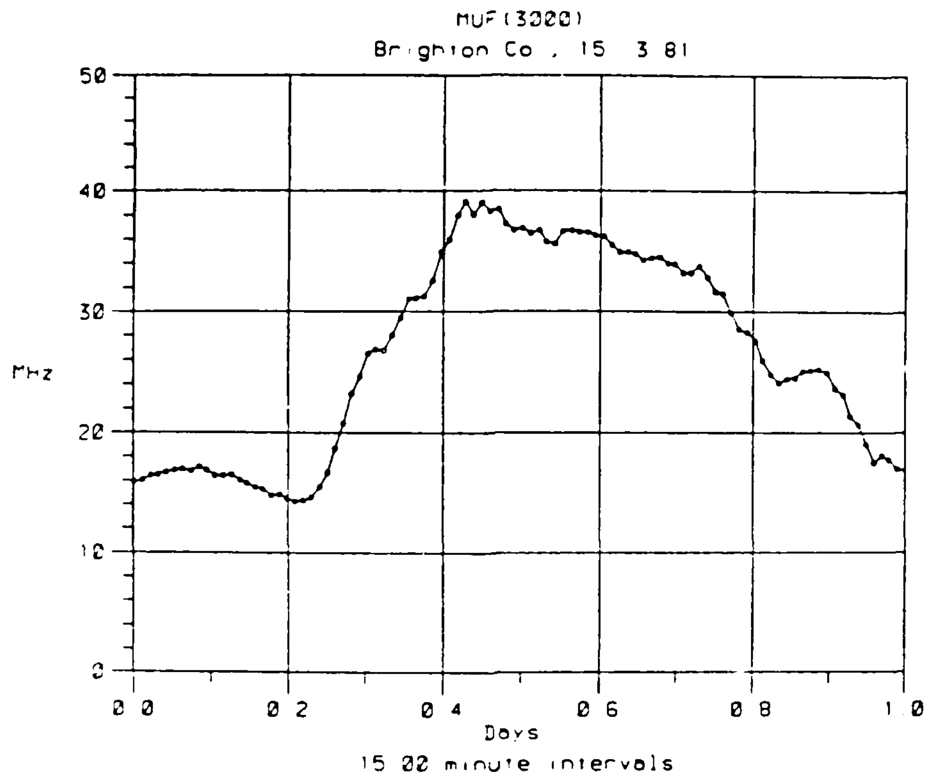
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co , 15 3 81
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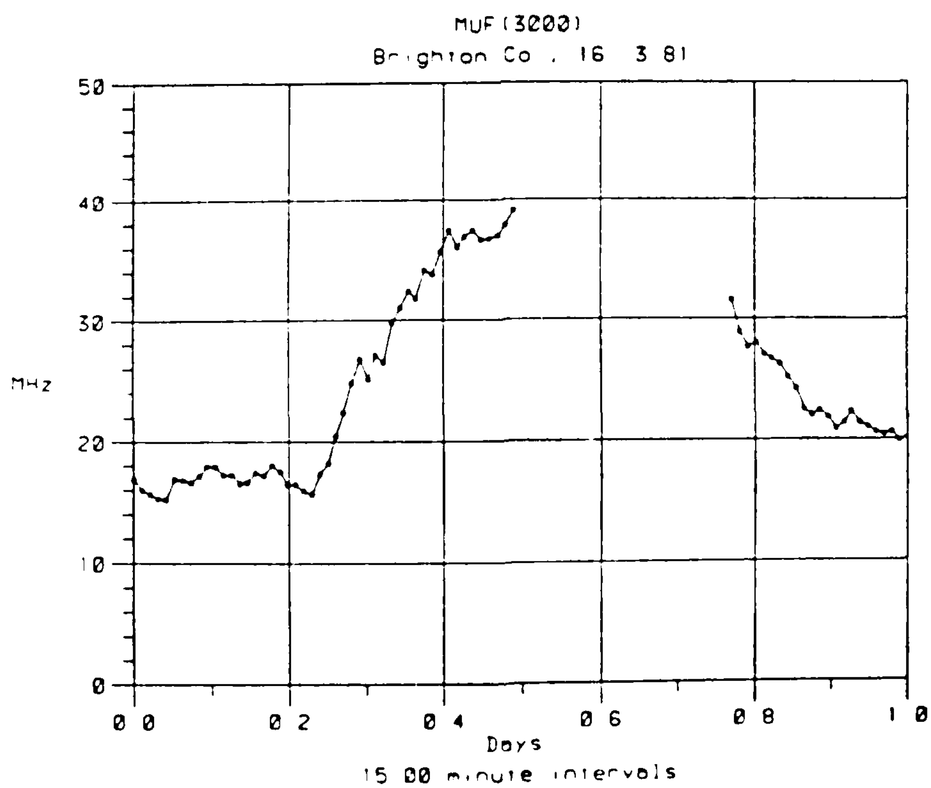
40
30
20
10
0
MHz
0 0
0 2
0 4
0 6
0 8
1 0
Days
15 00 minute intervals


MUF(3000)
Brighton Co , 16 3 81
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MHz
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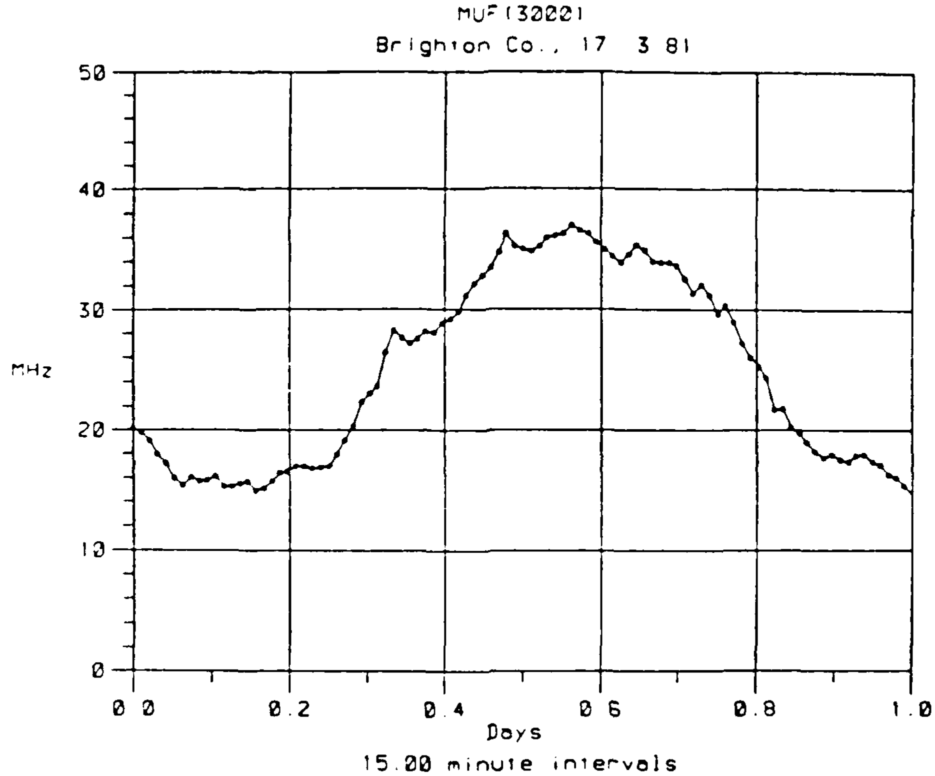
0 4
0 6
0 8
1 0
Days
15 00 minute intervals


MUF(3000)
Brighton Co., 17 3 81
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MHz
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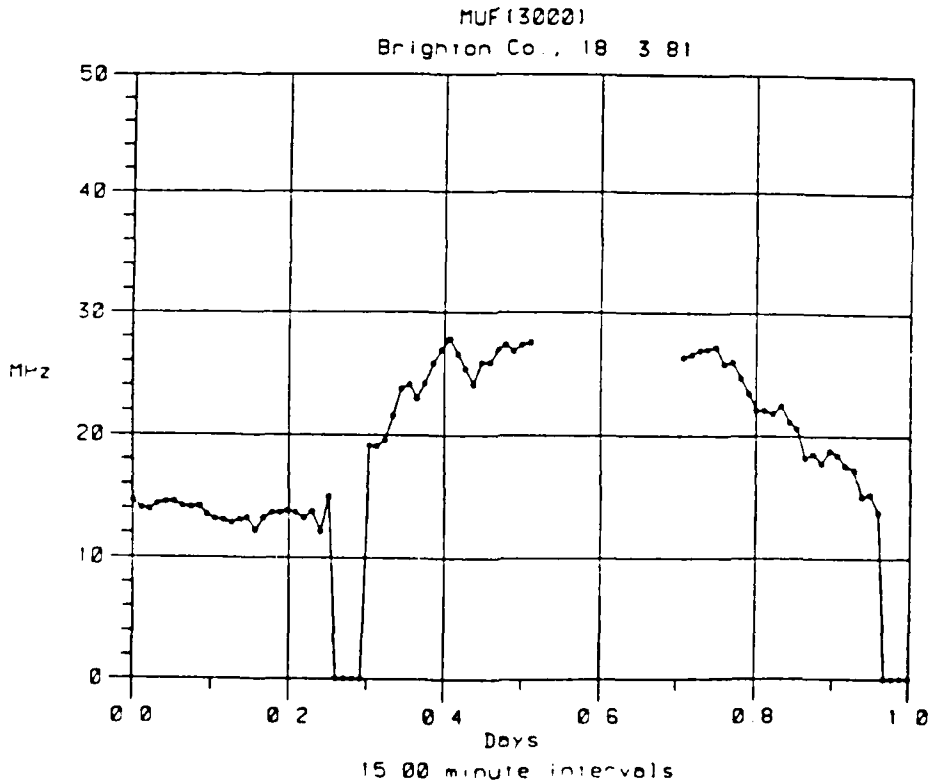
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 18 3 81
50
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MHz
0.0
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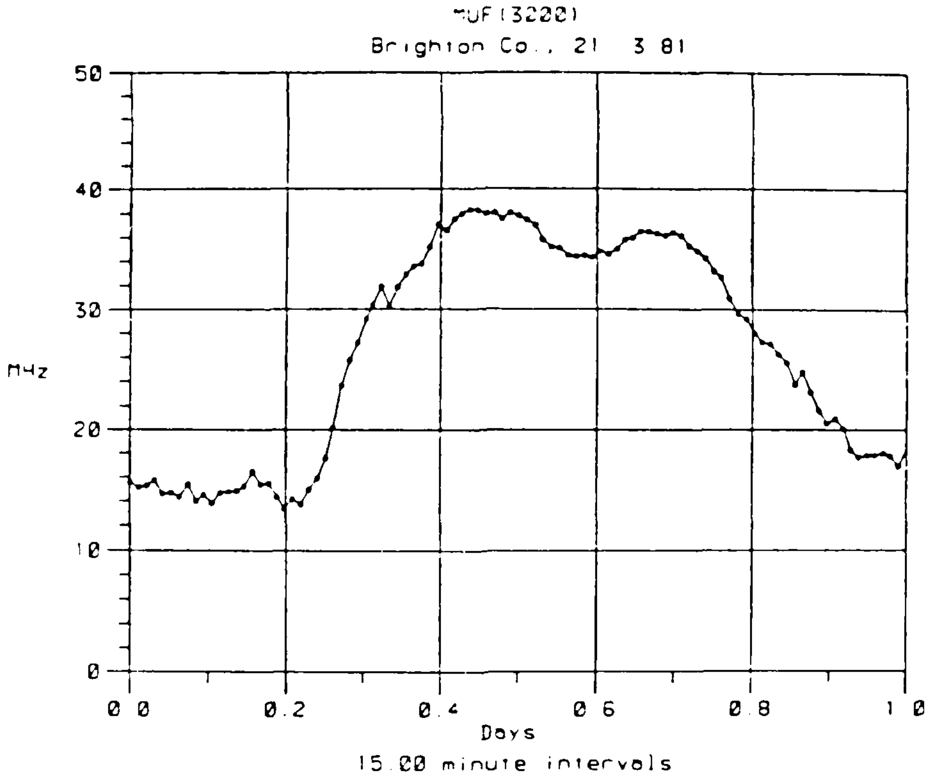
0.4
0.6
0.8
1.0
Days
15.00 minute intervals


MUF(3200)
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0.4
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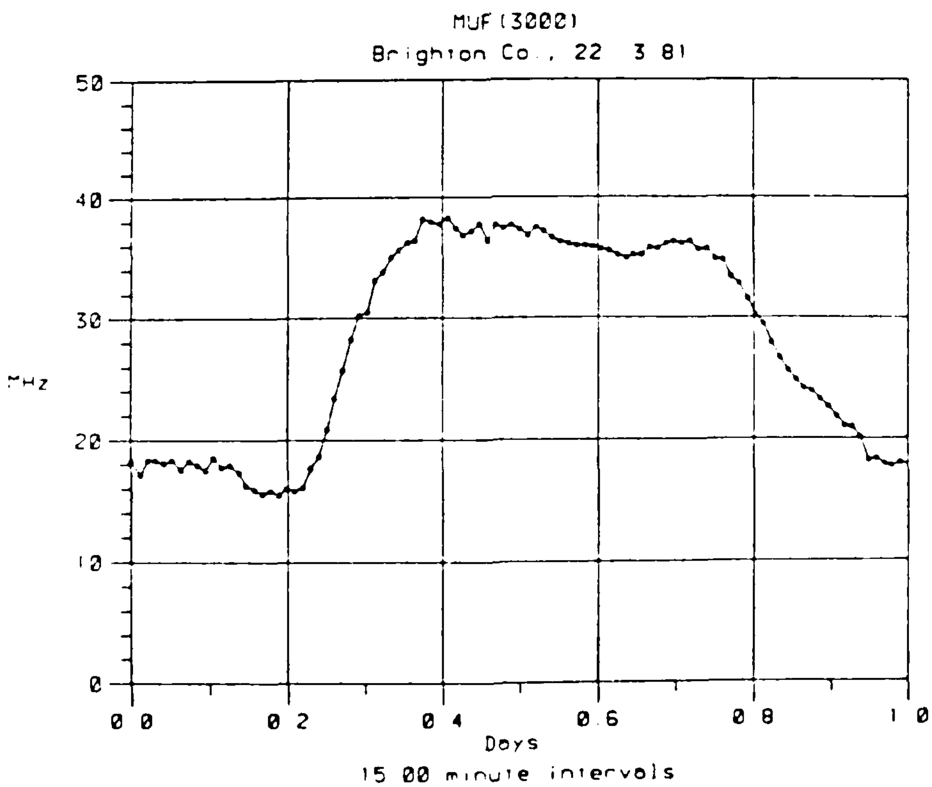
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co., 22 3 81
MHz
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0.4
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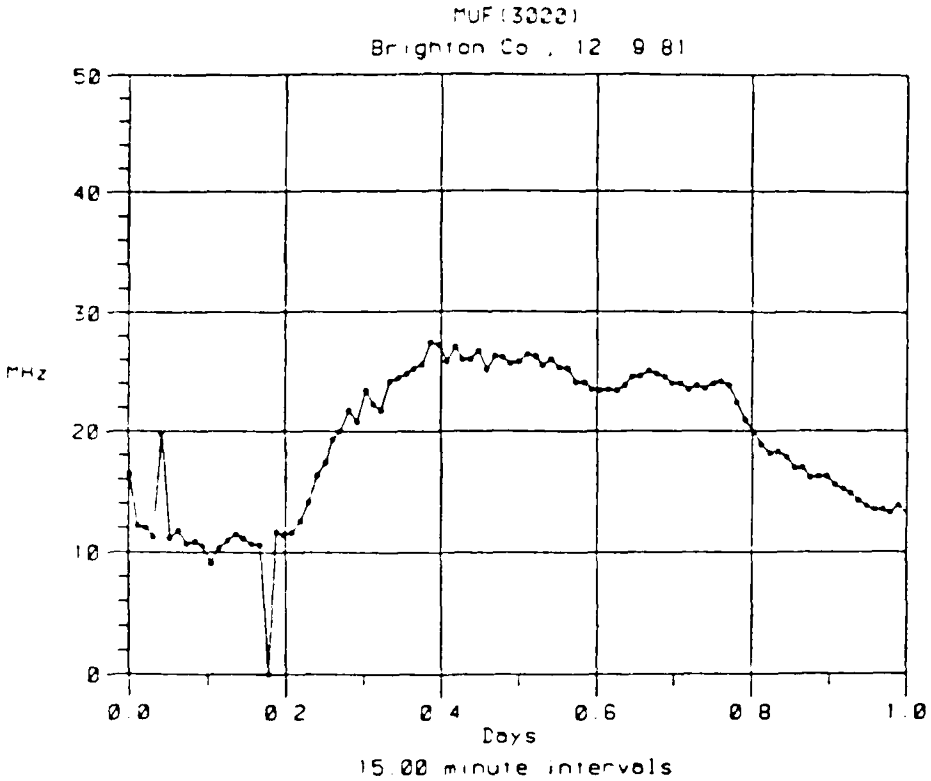
1.0
Days
15.00 minute intervals


MUF(3000)
Brighton Co , 12 9 81
MHz
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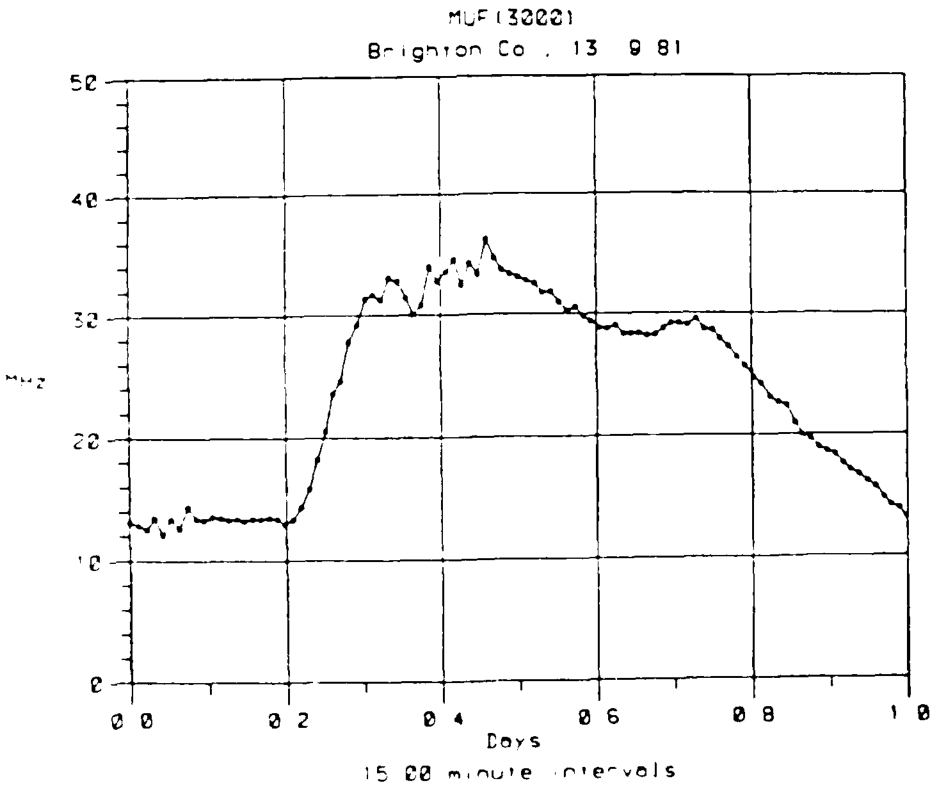
Days
15.00 minute intervals


MUF(3000)
Brighton Co , 13 9 81
MHz
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0 6
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Days
15 00 minute intervals

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