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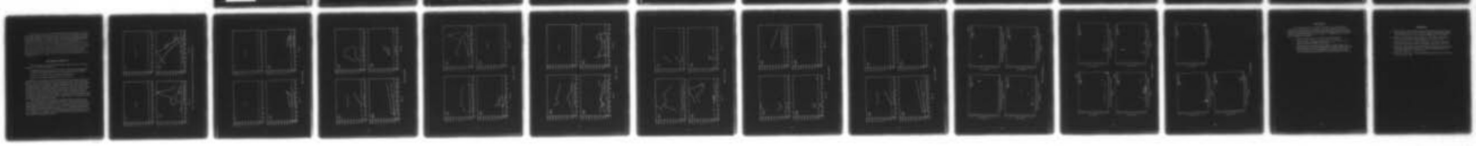

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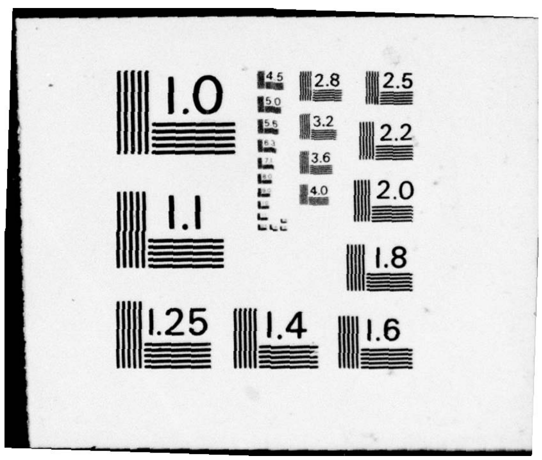
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SOLAR ACTIVE-REGION CHARACTERISTICS AT RADIO WAVELENGTHS AND THEIR RELATION TO PROTON EVENTS

30 July 1976

Research and Development, July 1975 to June 1976

Prepared for
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
LG Hanscom Field
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SOLAR ACTIVE-REGION CHARACTERISTICS AT RADIO WAVELENGTHS AND THEIR RELATION TO PROTON EVENTS

Max P Bleiweiss, Fred L Wefer, and Marshall D Hurst, 30 July 1976

LITERATURE CHANGE

1. On DD Form 1473, add to block 14: Naval Electronics Laboratory Center, San Diego, CA 92152 (Code 220)

2. On DD Form 1473, add to block 10: (NELC Z110)

3. On page i, change ADMINISTRATIVE INFORMATION to read: This work was performed by members of the NELC Propagation Technology Division between July 1975 and June 1976 under Program Element 62101F, Project AFCRL, Task Area O, and NELC Work Unit M403. Additional funding was provided by NELC under NELC Work Unit Z110 and was monitored by Code 220. This report was approved for publication on 30 July 1976.

4. On cover, after "30 July 1976," add "Changed 2 November 1976."

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Solar flares

Proton events

Electromagnetic propagation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The literature dealing with solar events and their effects upon electromagnetic propagation was surveyed and the data were compared with those taken by the La Posta Astrogeophysical Observatory of the Naval Electronics Laboratory Center. These latter data do not contain obvious "radio signatures" for identifying proton-producing active regions. Additional efforts are required.

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OBJECTIVE

Develop solar-flare prediction techniques based upon solar radiometry in order to circumvent the adverse effects of solar/ionosphere disturbances to Navy communications, navigation, and surveillance systems. The NELC mission is electromagnetic propagation.

RESULTS

The NELC La Posta Astrogeophysical Observatory obtained solar-flare data at wavelengths of 8 millimetres and 2 centimetres. No obvious "radio signatures" were found in the observed data which could be used to identify proton-producing active regions. Additional efforts are required.

RECOMMENDATIONS

1. Obtain data (8.6 mm and 2.0 cm) with better time resolution.

2. Perform regular observations of the polarization characteristics of active regions and their relationship to flare activity.

3. Broaden the efforts to understand the "physics" of active regions (the spectrum of the emissions, the mechanism of the emissions, and the polarization of the emissions at all radio wavelengths) and to understand how these relate to other non-radio observations and the proton-acceleration process.

ADMINISTRATIVE INFORMATION

This work was performed by members of the NELC Propagation Technology Division between July 1975 and June 1976 under Program Element 62101F, Project AFCRL, Task Area O and NELC Work Unit M403. This report was approved for publication on 30 July 1976.

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

The predictability of proton events falls essentially into two categories: the identification of the event by its radio emission characteristics during the proton flare but prior to the arrival of the particles on earth, and the identification of those active regions which have the potential to produce proton events. It is the second class of these prediction schemes which will be addressed in this report. A review of the available literature on the subject is presented and is followed by a description of the data used in the present analysis. Finally, the results of the analysis are given.

LITERATURE REVIEW

Although proton-producing active regions and their early identification are of interest to many researchers and organizations throughout the world, the results obtained to date are not conclusive. The radio part of the solar spectrum would seem to allow the establishment of an objective set of criteria whereby the active proton-producing regions could be identified on the basis of some "radio signature."

Investigations at radio wavelengths require either large antennas or large antenna arrays in order to obtain sufficient spatial resolution to gather unconfused data. Several past (and present) investigations have been initiated in the field of high-resolution solar astronomy. In this connection, the Japanese seem to have, by far, the greater capability at centimetre and millimetre wavelengths where, it is supposed, the clues for identifying proton-active regions are to be found. The Japanese are also the most published on this topic.

The first report of these efforts is that by Tanaka and Kakinuma (ref 1). Their study showed that a high flux ratio (3.2 cm/7.5 cm) and a large flux (3.2 cm) are favorable conditions for the production of proton events. Quantitatively, the ratios should be greater than unity and the 3.2-cm flux should be greater than 30 flux units ($10^{-22} W m^{-2} X Hz^{-1}$). The results of the Tanaka and Kakinuma effort are shown in table 1. In this table, the numbers in parentheses represent the number of regions not resolved by their observations; hence, the flux contains contributions from other regions as well.

It is seen that the conditions are not physical limits but are derived from the distribution of events. While the method yields statistically good results, false alarms and misses are often encountered. While statistical results can be interesting, it is those unique, necessary, and sufficient conditions which are the most important in allowing meaningful predictions to be made.

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[1] Research Institute of Atmospherics, Nagoya University, Report 18, *The Relation Between the Spectrum of Slowly Varying Component of Solar Radio Emission and Solar Proton Event*, by H Tanaka and T Kakinuma, p 32 - 44, 1964

TABLE 1. THE 3.2-cm INTENSITY DISTRIBUTION AND FLUX-RATIO DISTRIBUTION OF ACTIVE REGIONS (AR) AND POLAR-CAP ABSORPTION (PCA) ASSOCIATED ACTIVE REGIONS FOR THE PERIOD MAY 1959 THROUGH DECEMBER 1960 (REF 1).

	INTENSITY DISTRIBUTION			FLUX-RATIO DISTRIBUTION	
NUMBER OF:	$I<30$	$30<I<60$	$60<I$	$R<1.0$	$1.0<R$
AR	25 (4)	8	2	28 (3)	7 (1)
AR WITH PCA	8 (4)	3	1	7 (3)	5 (1)
PCA	10 (7)	12	5	8 (5)	19 (2)

Improvement in these techniques was presented in a cursory manner by Tanaka (ref 2) and, in more detail, by Tanaka and Enome (ref 3). It was shown that the magnetic field which polarizes the radio emission to produce a "P-configuration" can be seen in the difference between the right- and left-hand circularly polarized components. As shown in figure 1, there is a main peak with strong polarization surrounded by oppositely polarized and less intense subpeaks. These new results, obtained with higher-resolution instruments, change the flux and flux-ratio criteria to:

$F_{3\ cm} \geq 10$ and

$F_{3\ cm}/F_{8\ cm} \geq 0.8$

It should be noted that the scheme is still a statistical one which continues to give false alarms and misses. Some problems can be encountered due to insufficient time and spatial resolution which, if these were available, might define the necessary and sufficient conditions for the identification of proton-producing active regions.

A similar investigation was undertaken by Nakajima (ref 4) utilizing 1.8-cm and 3-cm data. The only results presented to date concern the series of August 1972 events. Nakajima states that the ratio of 3-cm flux to 1.8-cm flux was rapidly increasing each time a major event occurred. This was due primarily to the rapid decrease in the 1.8-cm flux and a slight increase in 3-cm flux. His interpretation is that an optically thick, 3-cm region and an optically thin, 1.8-cm region would undergo opposite temperature changes if plasma heating took place in the region. Figure 2 is from his paper and, indeed the 1.8-cm flux does decrease and the 3-cm does increase prior to each event. Unfortunately, this happens only for a few events in one active region; it remains to be seen whether or not this method has wide applicability.

[2] Tanaka, H, "Activity Report, Radio Astronomy," *Proceedings of the Research Institute of Atmospherics*, Nagoya University, v 20, p 43 - 46, 1973

[3] Tanaka, H, and S Enome, "The Microwave Structure of Coronal Condensations and Its Relation to Proton Flares," *Solar Physics*, v 40, p 123 - 131, 1975

[4] Nakajima, H, "Time Variation of a Slowly Varying Component Observed at Short Centimetre Wavelengths in August 1972," *Report of Ionosphere Research in Japan*, v 27, p 149 - 150, 1973

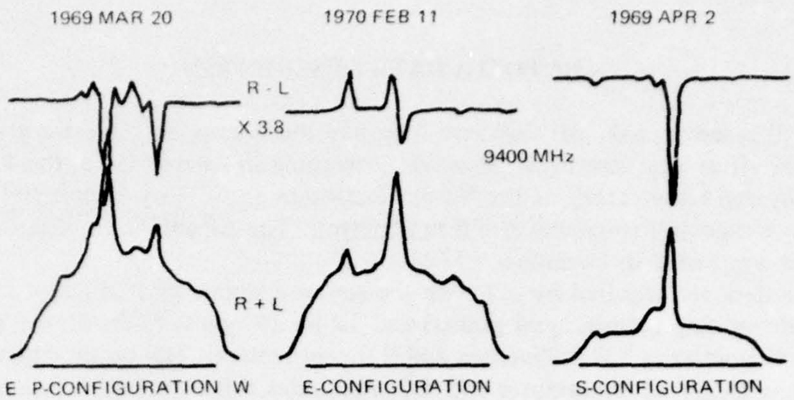

Figure 1. Strip-scan curves of the sun in intensity (R + L) and polarization (R - L) at a wavelength of 3 cm showing examples of P-, E-, and S-configurations (ref 3).

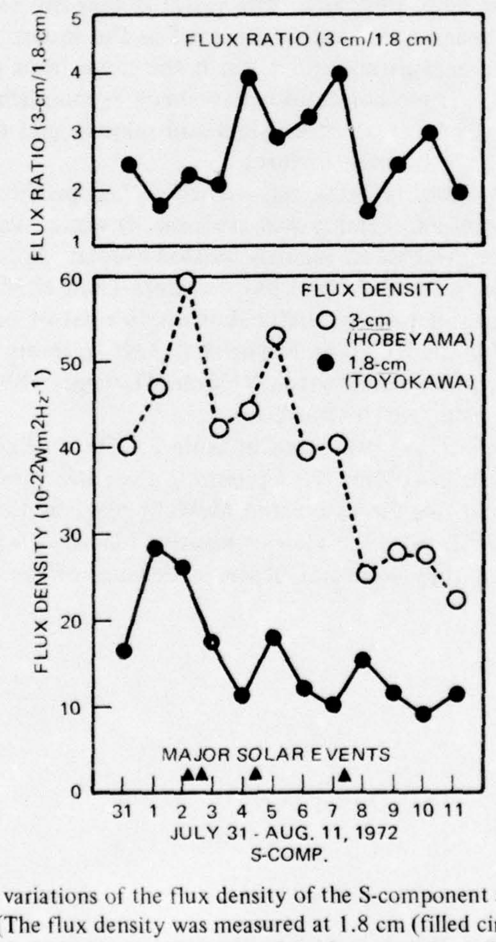

Figure 2. Time variations of the flux density of the S-component associated with McMath plage region 11976. (The flux density was measured at 1.8 cm (filled circles with solid line) and at 3 cm (open circles with dashed line). The ratio of the 3-cm to 1.8-cm flux density is shown in the upper part of the figure; major flares produced from the active region are indicated at the bottom of the figure (triangles) (ref 4).

LA POSTA DATA DESCRIPTION

Until recently, only the Japanese have had the instruments necessary to conduct the types of effort just described. However, beginning in August 1972, the La Posta Astrogeophysical Observatory of the Naval Electronics Laboratory Center (ref 5) began acquiring radiospectroheliograms at 8.6 millimetres. The capability to observe at 2.0 centimetres was added in December 1972.

The data are acquired by scanning the sun in a square grid which is 35 by 35 points (1-arcminute spacing between grid points) and 19 by 19 points (2-arcminute spacing between grid points) at 8.6 millimetres and 2.0 centimetres. The beamwidths at the respective wavelengths are 2.8 arcminutes and 4.0 arcminutes full-wave half maximum (FWHM). The 8.6-mm maps require approximately one hour for acquisition and 2.0-cm maps can be made in 25 minutes.

These data for the period August 1972 through December 1974 have recently undergone considerable reduction. The effects of antenna-pointing errors present during data acquisition, as well as the effects of day-to-day variations in atmospheric attenuation and receiver calibration, have been removed. The result is that the maps have been regularized with respect to grid spacing, the sun is centered in the square grid, and the maps are normalized such that the background quiet sun is the same from one map to the next to within about ±1 percent. These corrections have been accomplished to facilitate computer determination of the location of maxima and minima and to assign magnitudes and heliographic coordinates to the map features.

The next step was to identify those regions which had produced the proton events during the period. As no complete catalog was available, it was necessary to construct one. The following sources were consulted to identify proton events: Solar Geophysical Data (plots of data from Explorers 41 and 32 and plots of data from NOAA satellites 2 and 3); Geophysical and Space Data Bulletin, Appendix A (Castelli's list of outstanding solar geophysical events); Astrogeophysical Teletype Network (ATN) (primary and secondary reports from NOAA-SEL, Boulder); and Solar Physics, Volume 41, pages 189 to 223 (1975) (solar proton-energy spectra and size distribution).

The results of this search are presented in table 2. The date of the flare associated with the proton event is given in column 1. Column 2 gives the approximate time of the flare peak and column 3 identifies the associated McMath plage region. Table 3 is a list of significant gaps in the proton data which restrict positive identification; there may have been other proton events but they were not observed because of the lack of satellite coverage.

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[5] Bleiweiss, M, and F Wefer, "La Posta Astrogeophysical Observatory," *Solar Physics* v 43, p 253 - 259, 1975

TABLE 2. PROTON EVENT CATALOG FOR THE PERIOD AUGUST 1972 TO AUGUST 1975.

DATE	TIME	McMATH REGION	DATE	TIME	McMATH REGION
02 AUG 72	0400	11976	03 JUL 74	0835	13043
	2145	11976	04 JUL 74	0650	13043
04 AUG 72	0630	11976		1400	13043
07 AUG 72	1520	11976		1730	13043
29 OCT 72	1652	12094		2100	13043
30 OCT 72	0730	12094	10 SEP 74	2140	13225
25 NOV 72	0830	12115	13 SEP 74	1556	13224
16 DEC 72	0350	12136	19 SEP 74	2240	13225
11 APR 73	1849	12306	22 SEP 74	2340	?
29 APR 73	2100	12322	23 SEP 74	1200	?
29 JUL 73	1310	12461	11 OCT 74	0330	13280
07 SEP 73	1140	12507		1446	13280
03 NOV 73	0021	12584	15 OCT 74	1326	13280
02 JUN 74	0425	12977	05 NOV 74	1535	13310
30 JUN 74	2230	13043	21 AUG 75	1520	13811
02 JUL 74	0715	13043			

NOTES

1. Because some events occurred so close together that their proton events cannot be properly separated, the following time periods are not 100 percent certain in identification of flare to event:

   August 1972
   July 1974
   September 1974

2. Additional possible events:

   16 to 17 August 1972
   7 September 1972

   However, they cannot be associated with certainty with any particular event.

3. The event of 25 November 1972 is very small proton-wise; if it is a proton event at all.

4. The following four events cannot be confirmed due to data gaps:

   29 July 1973
   07 September 1973
   03 November 1973
   02 June 1974

5. The events of 22, 23 September 1974 cannot be associated with a particular region.

TABLE 3. PROTON DATA GAPS.

17 to 20 March 1973
07 to 10 April 1973
19 to 23 April 1973
23 to 26 May 1973
June 1973 to June 1974

The next step was to extract from the radio data the characteristics of the active regions which coincide with the proton events in table 2. The series of plots of enhancements above background for 8.6 mm and 2.0 cm as a function of heliographic longitude are presented in figure 3. In each part of figure 3, the lower panel presents the 8.6-mm data while the 2.0-cm data are shown in the upper panel. The upper left-hand scale is enhancement as a percent of central disc brightness temperature which is drawn with a box. The "X" in the active-region enhancement symbol (the box) denotes that a flare was present during the time the map was acquired. The upper left-hand scale is in arbitrary units for the flare index during the 24 hours following the map start time; the symbol is a diamond. The lower graph of each panel is a plot of the largest flare occurring during the same 24-hour period; the symbol is a triangle. The scale is on the lower left-hand side and is in units of flare class size.

DISCUSSION OF THE DATA

No clear relation can be derived from the plots of figures 3 and 4. The several "signatures" to look for in the plots are:

A heating prior to the event (to satisfy Tanaka's criterion that the region needs to be above some threshold level) if a very low enhancement exists initially;

Declines in the enhanced levels (according to Nakajima); and

Behavior of the flux-ratio characteristic prior to the event.

A careful perusal of the data does not reveal any rule that is not broken in at least one instance. It is also readily apparent that a lack of daily continuity of the active-region data precludes any firm conclusions. Tanaka and Kakinuma (ref 1) used the flux density as observed near the central meridian passage in their study. This is not an ideal situation when looking for precursors because the event may have taken place before the flux was measured. Also, this limits the types of changes under investigation to those that take place on the time scale of one solar rotation (27 days). The approach with the La Posta data, similar to that used by Nakajima, is more desirable as the changes, thought to differentiate proton-producing active regions, might take place over a period of minutes and hours to days, but likely not months.

The La Posta results do not confirm the Japanese findings but this may be because of the differences in the wavelengths of observation. In order that the Japanese observations be confirmed, it would be necessary to obtain data from at least one other longer wavelength. This can be done for events which took place prior to about August 1973 using data acquired by Stanford University at 9.1 cm. (Stanford ceased observations in August 1973). However, even if the Stanford data were to be used, our 8.6-mm and 2.0-cm data are so sporadic as to preclude a final solution. Improved observations in the future may provide better results.

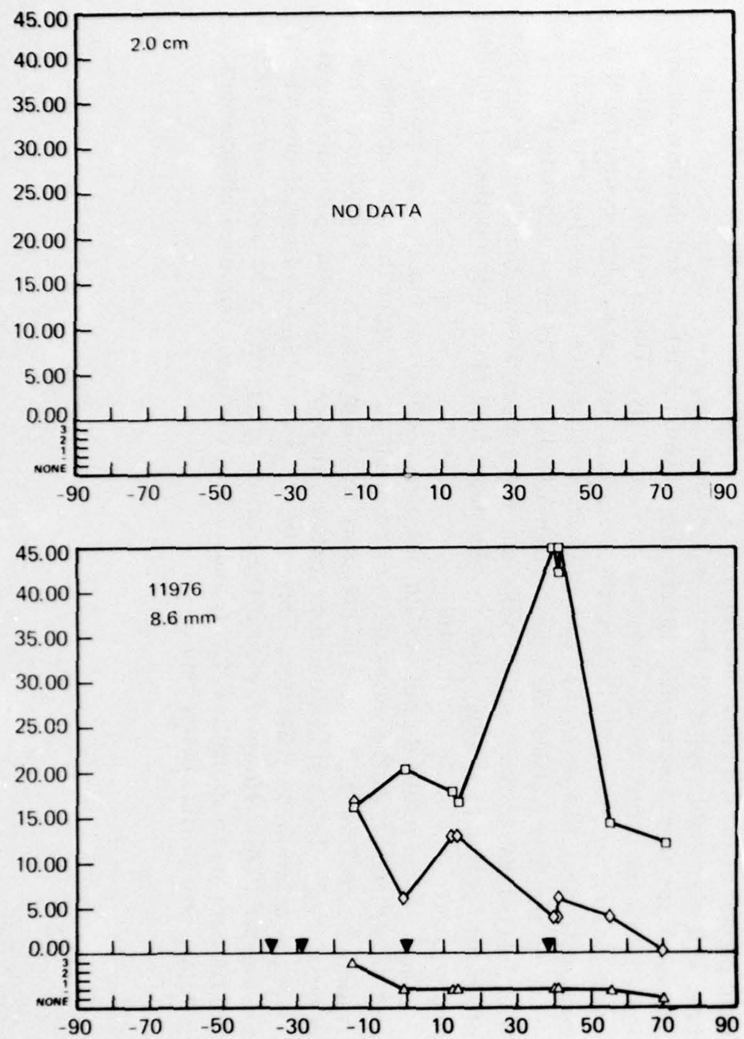


Figure 3a

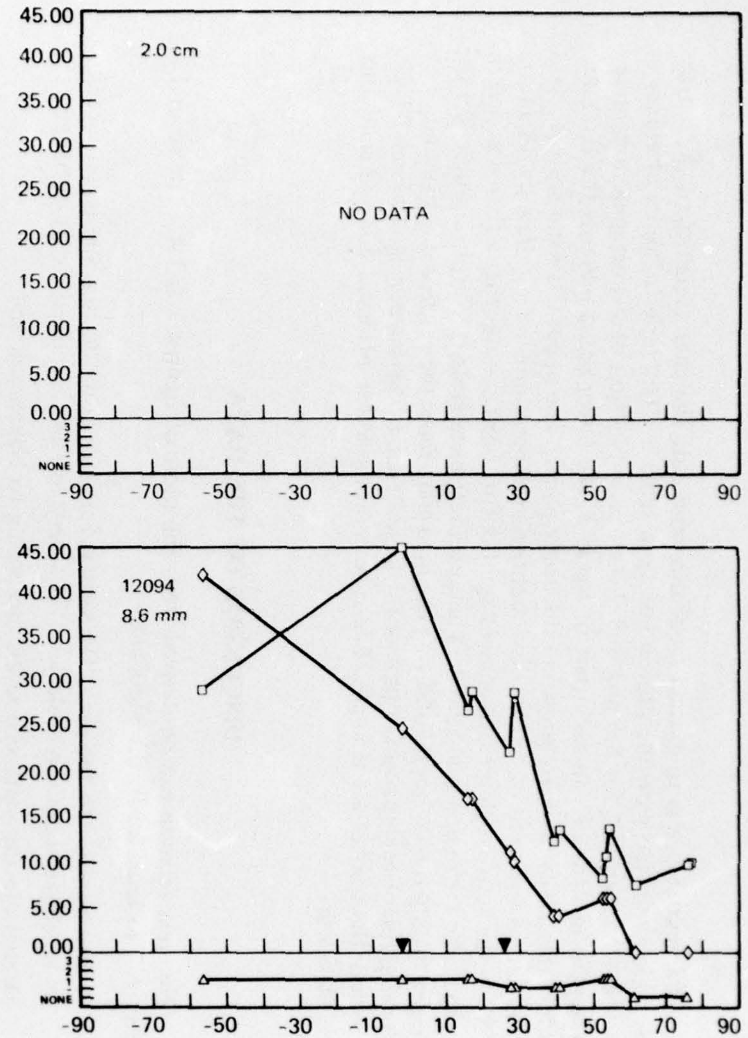
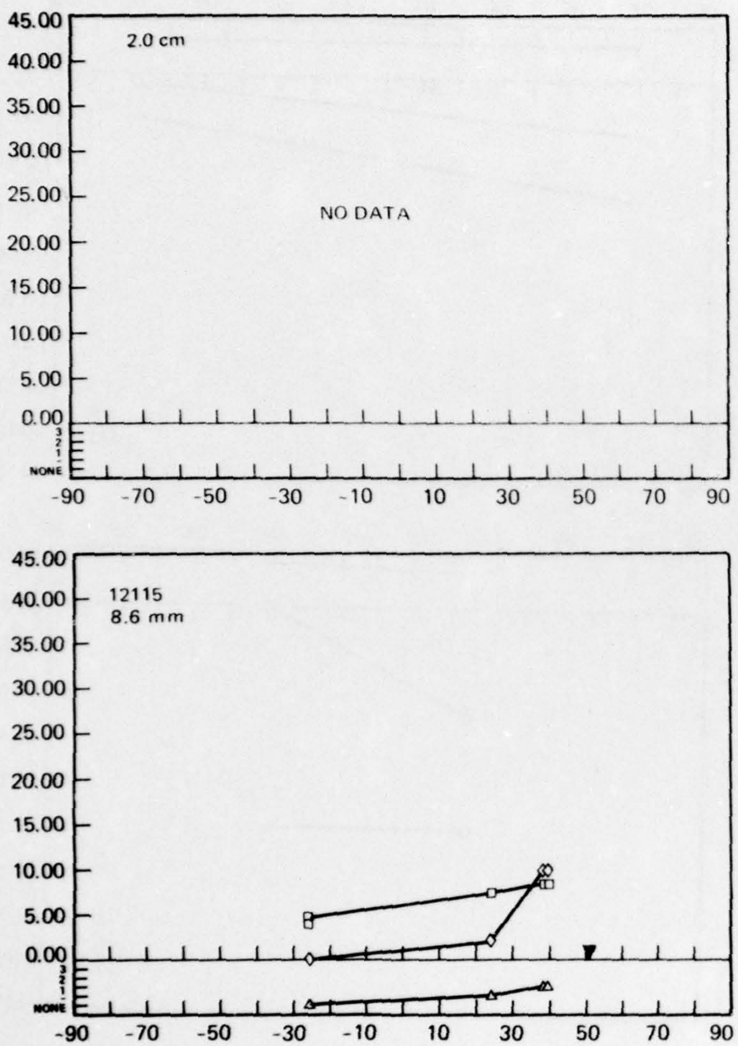


Figure 3b

Figure 3. Enhancement above background for 8.6 mm and 2.0 cm as a function of heliographic longitude.



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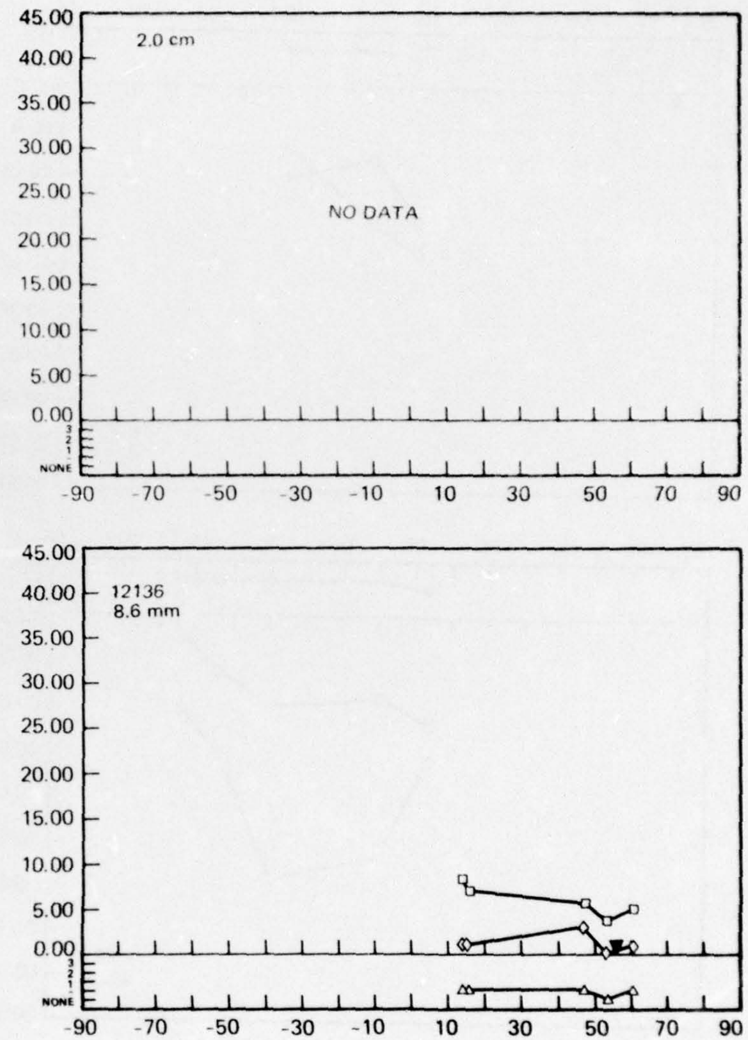

Figure 3d

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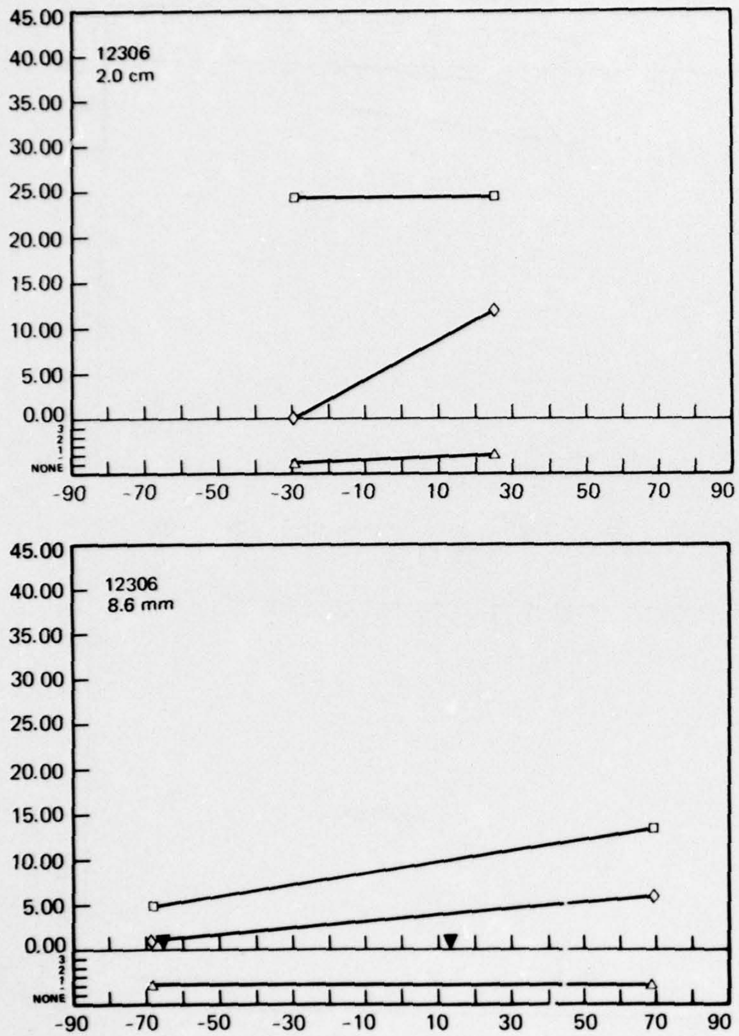

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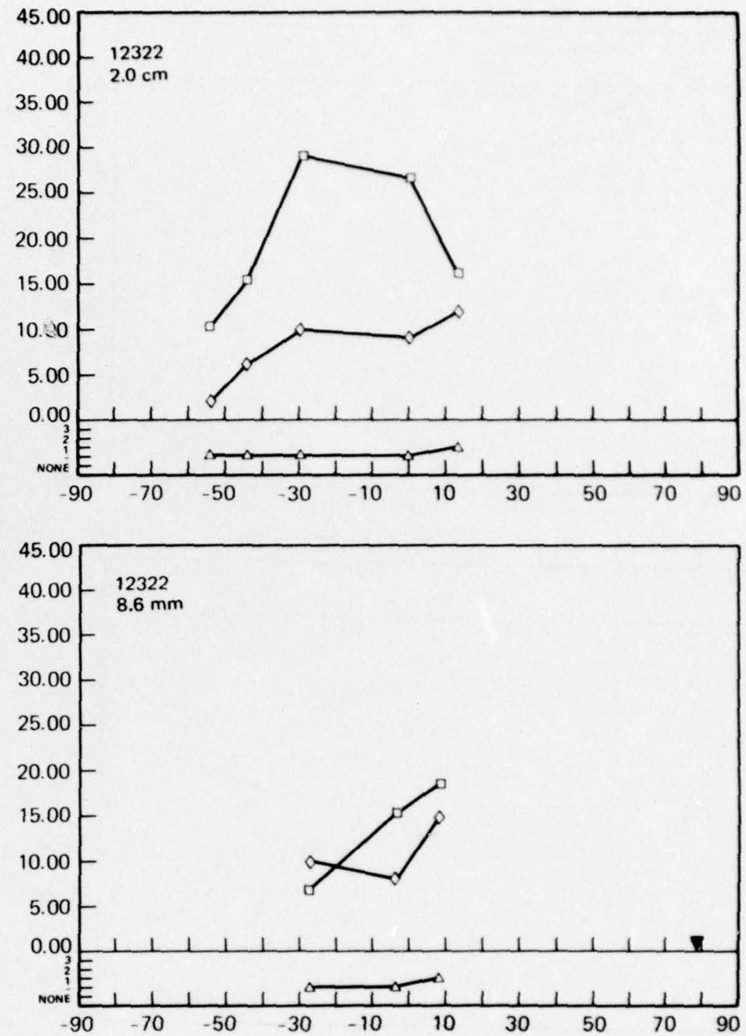

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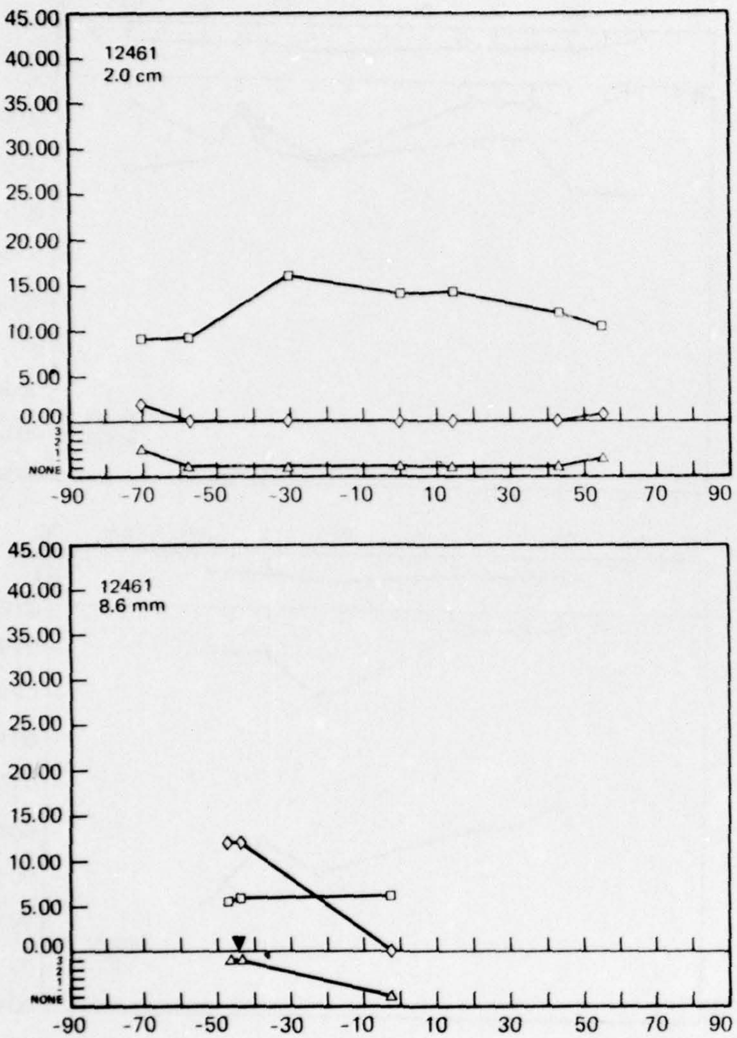

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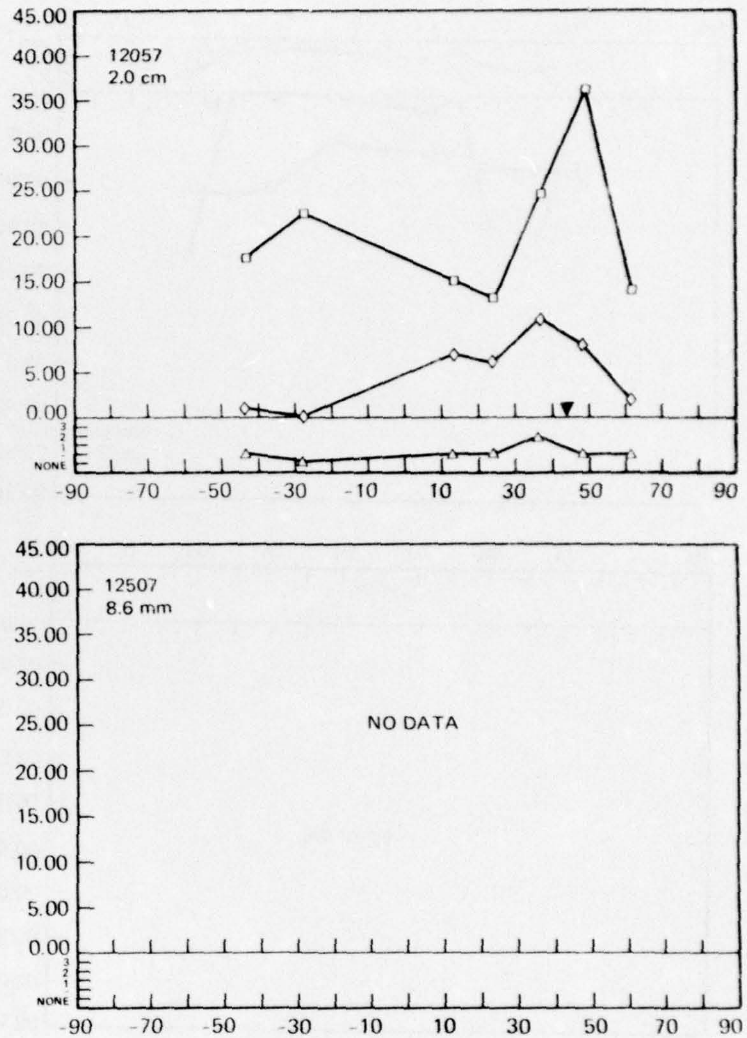

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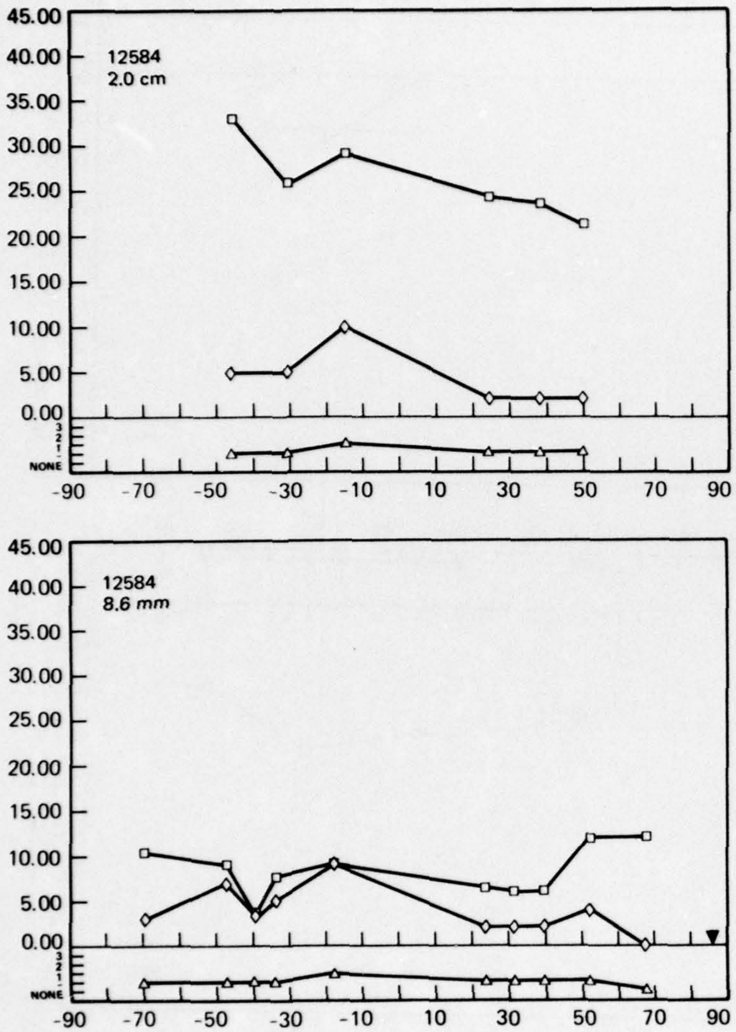

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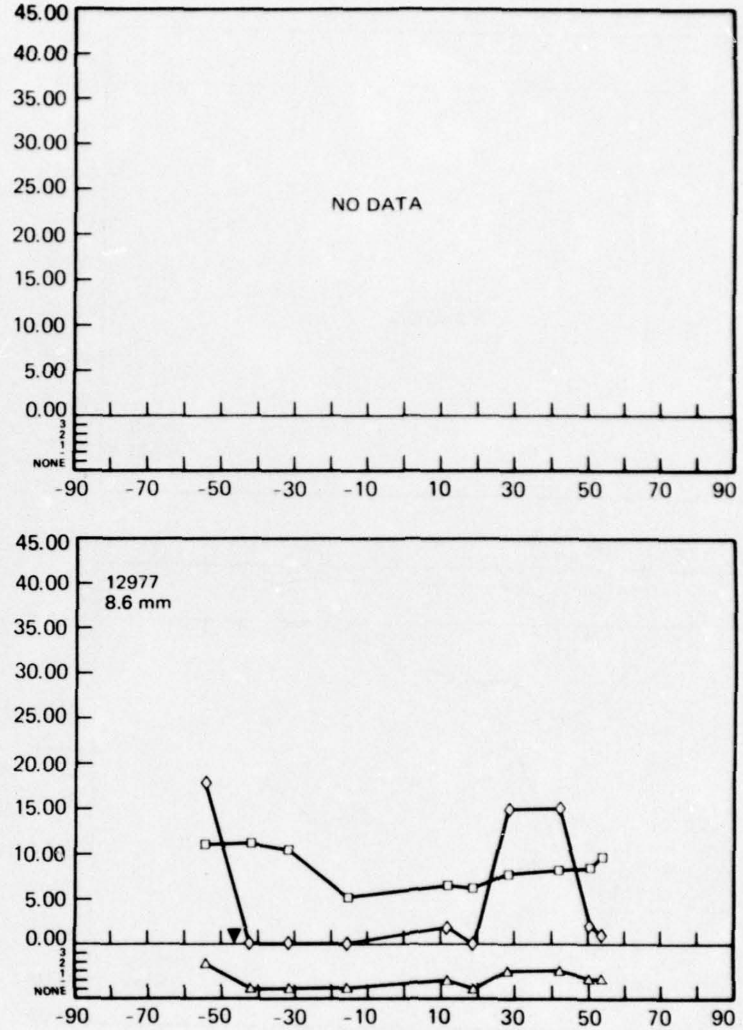

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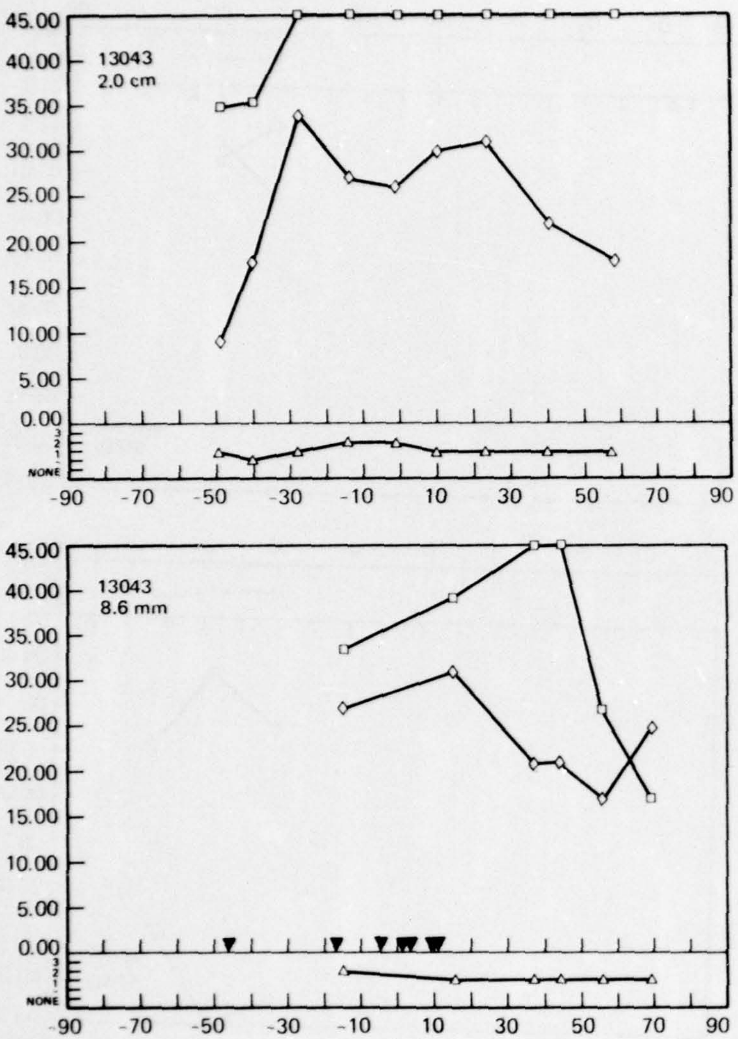

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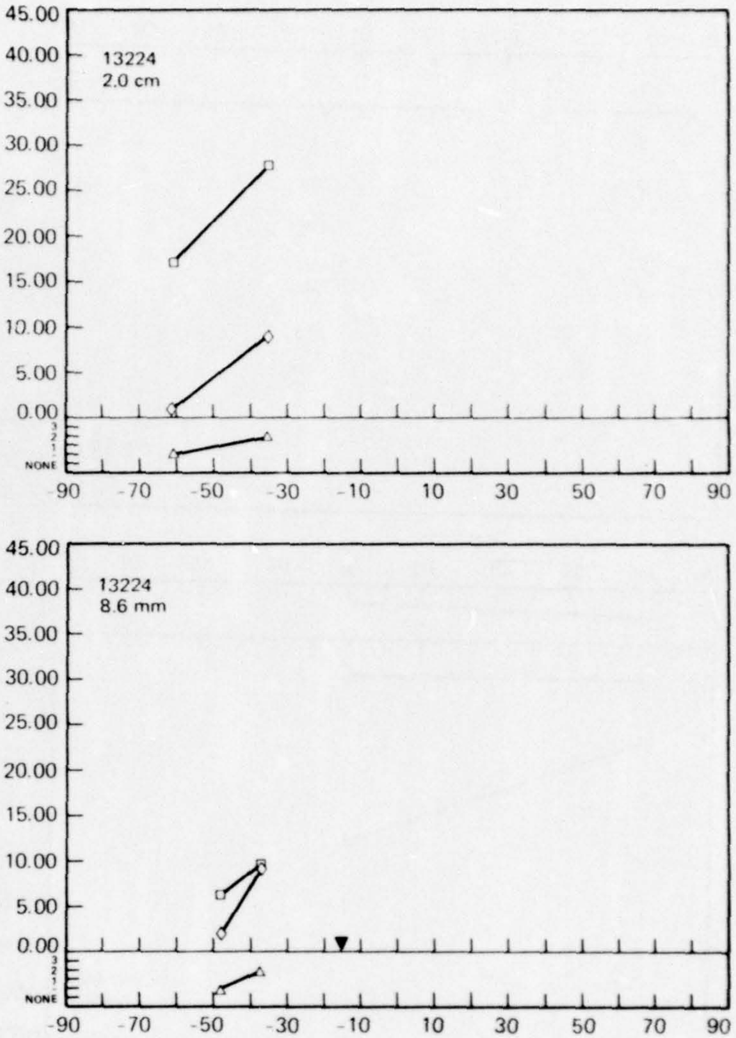

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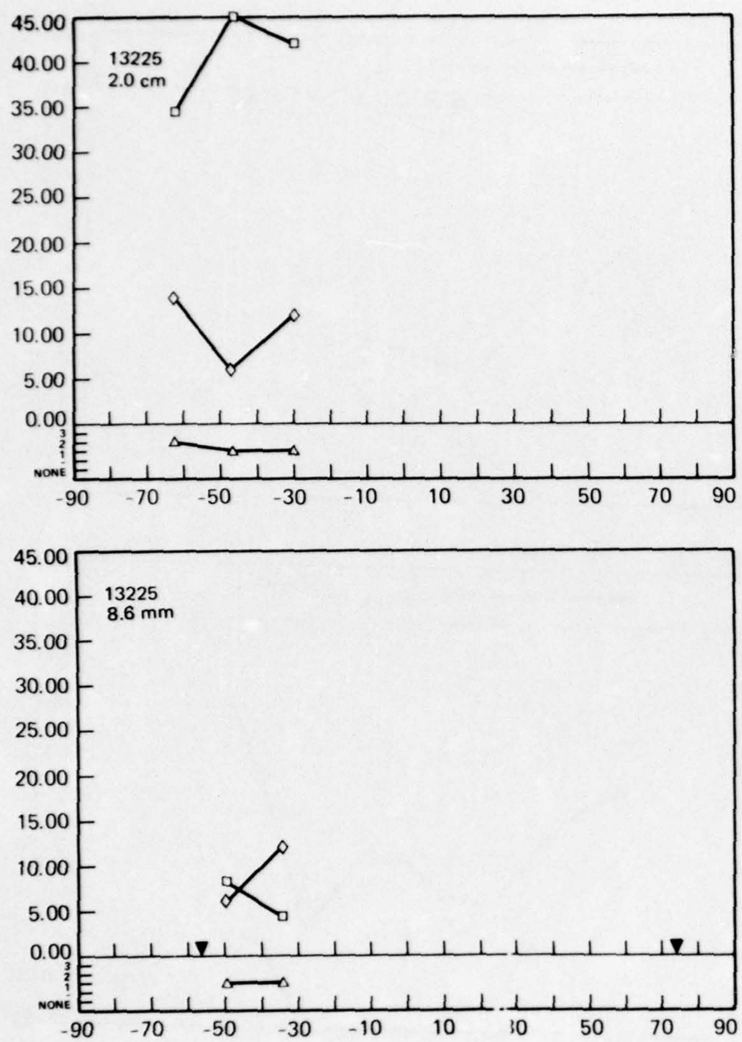

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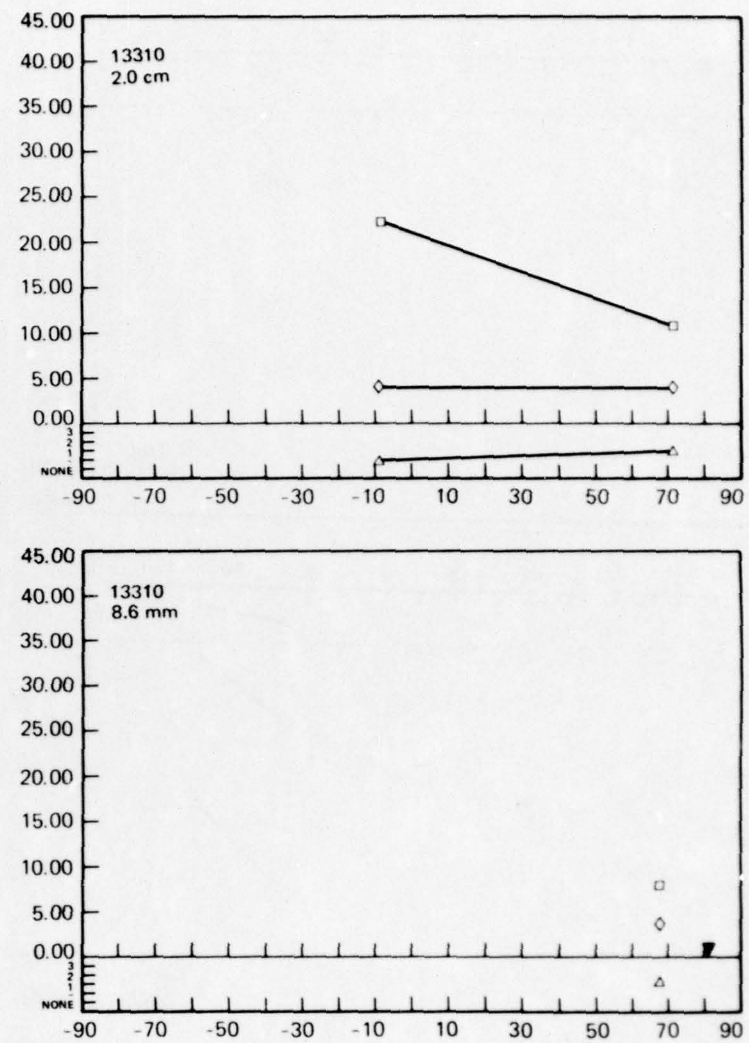

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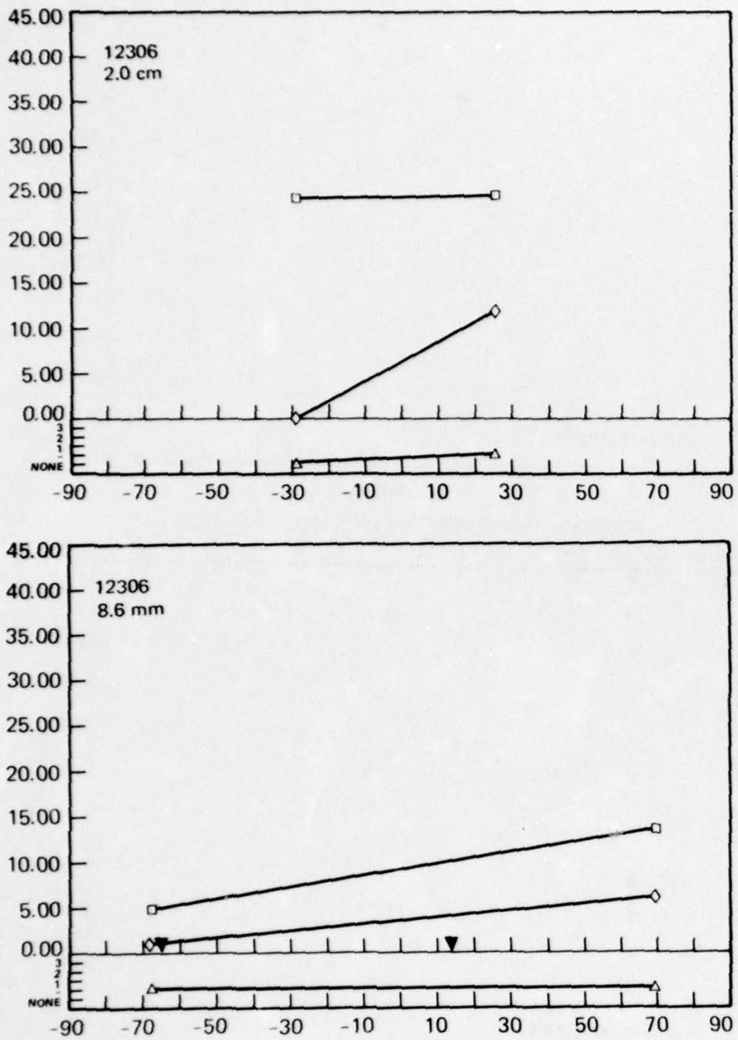

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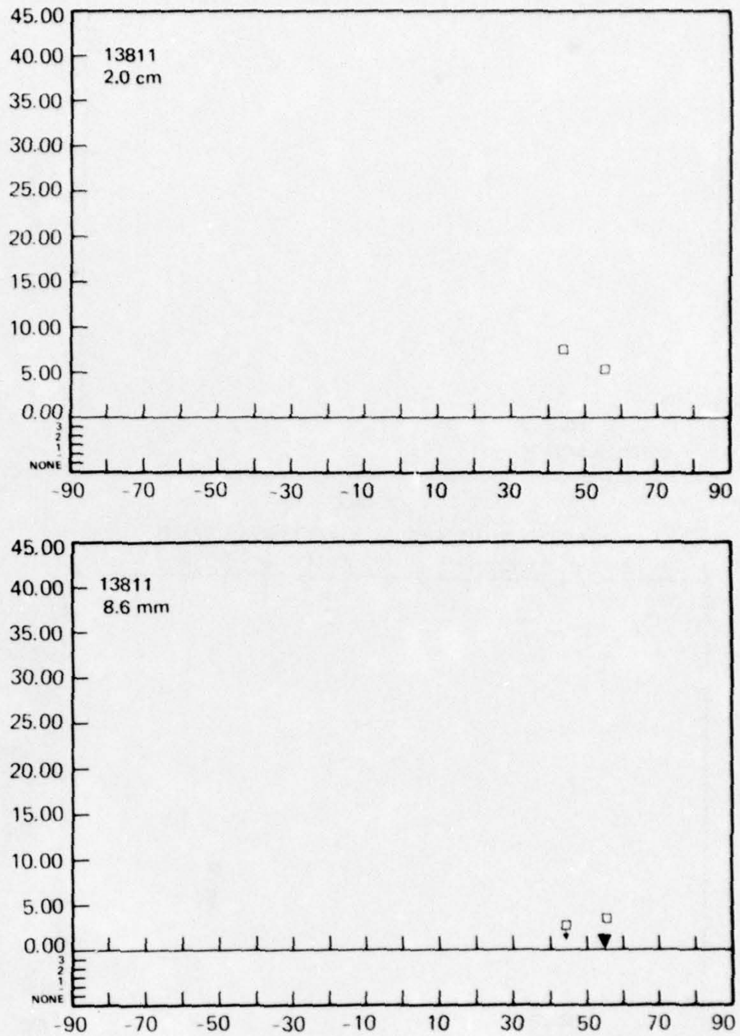

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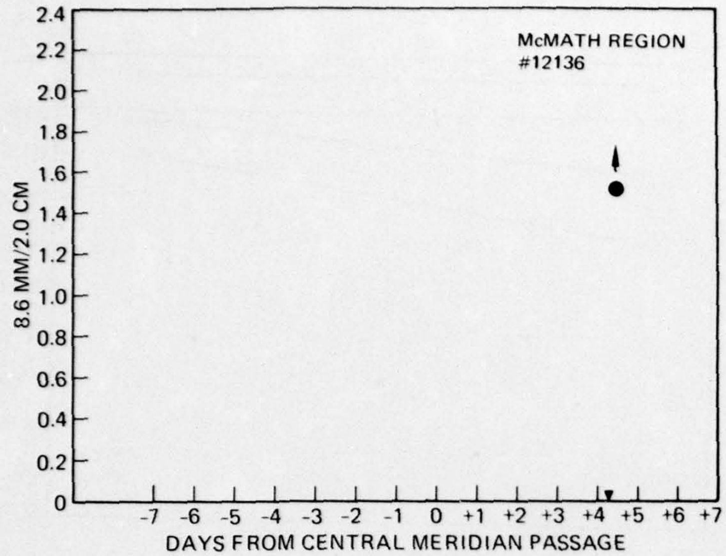

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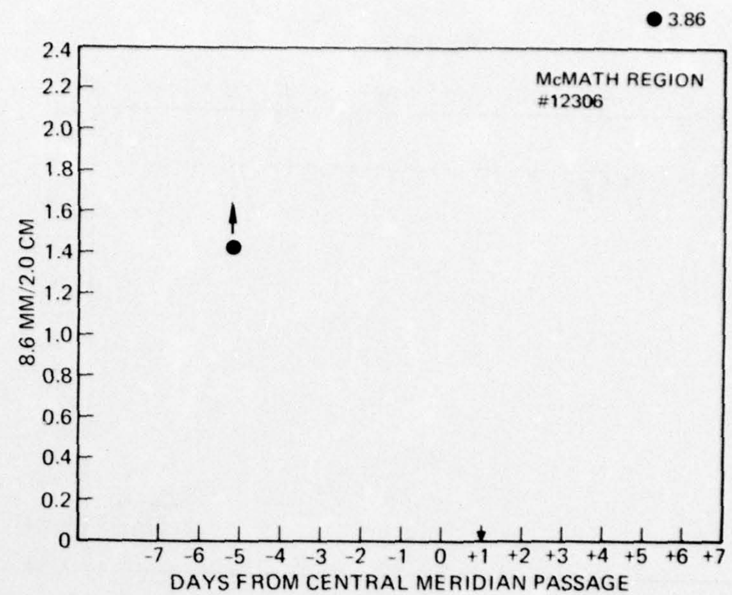

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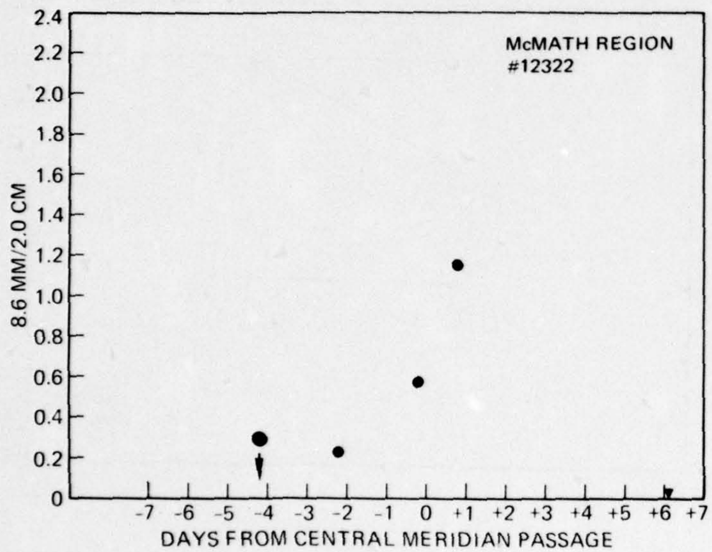

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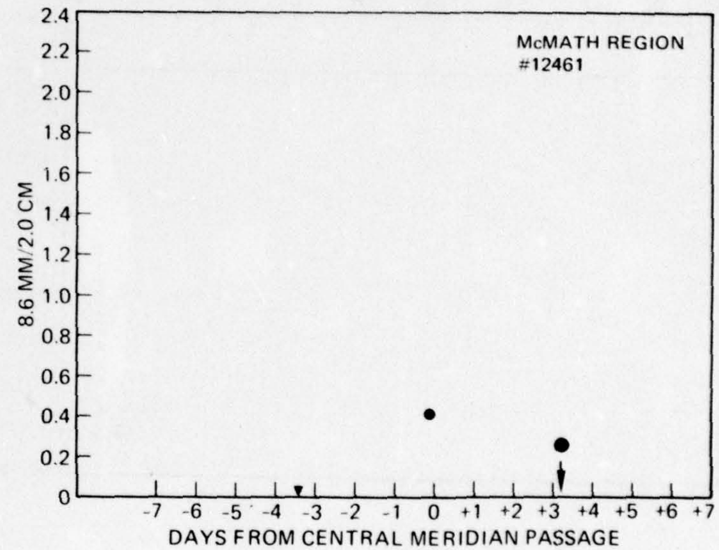
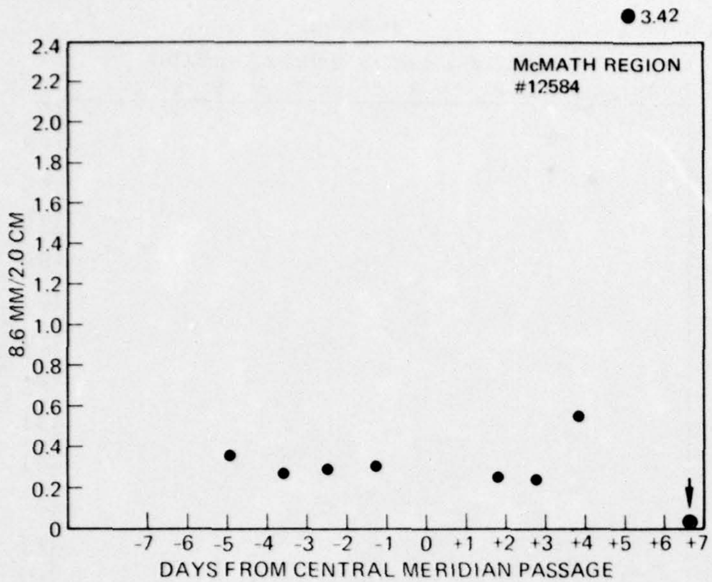


Figure 4d

Figure 4. Enhancement ratios.



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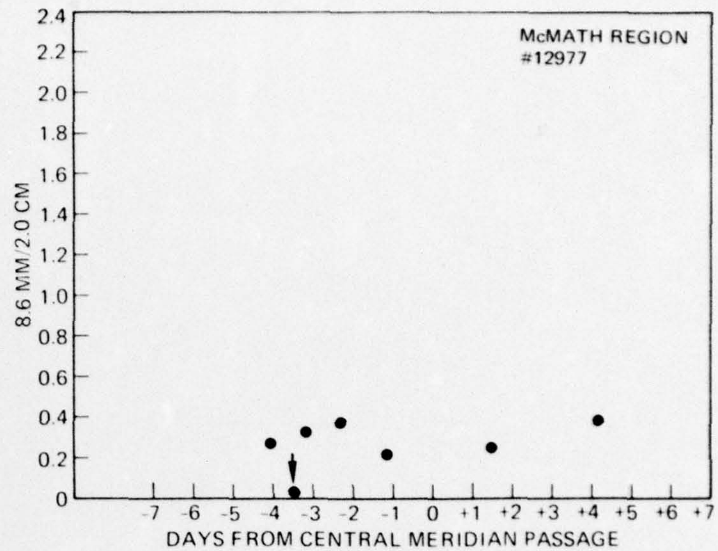

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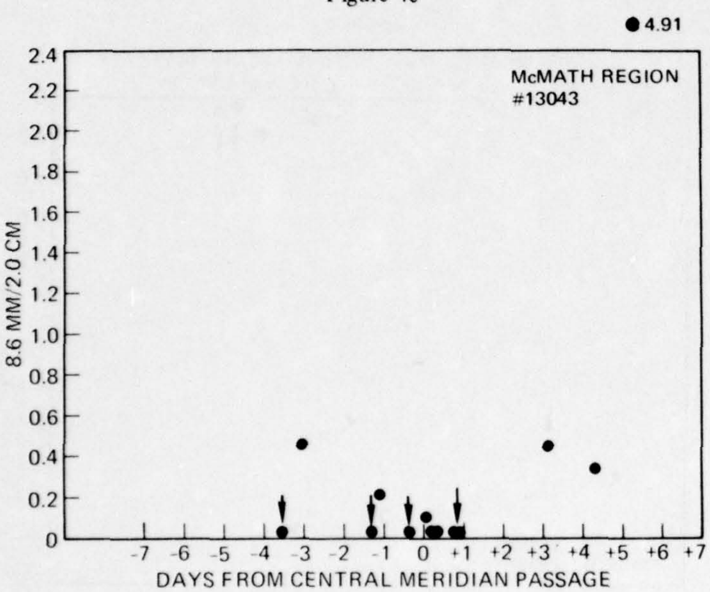

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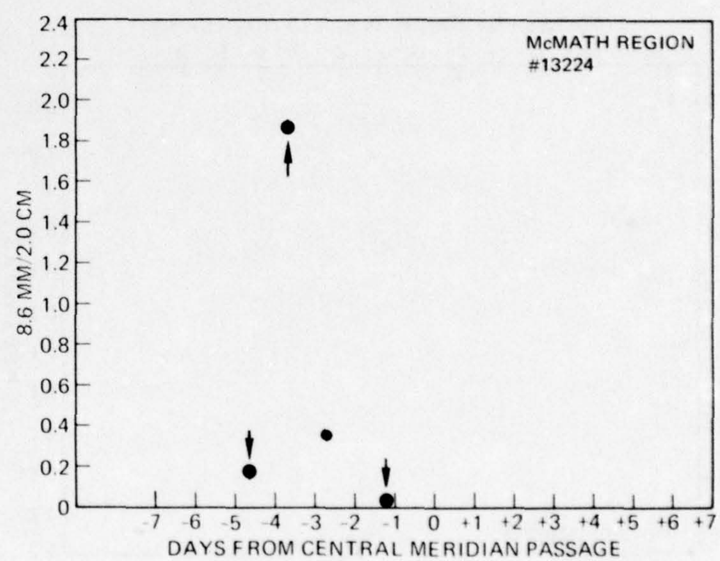

Figure 4h

Figure 4. (Continued)

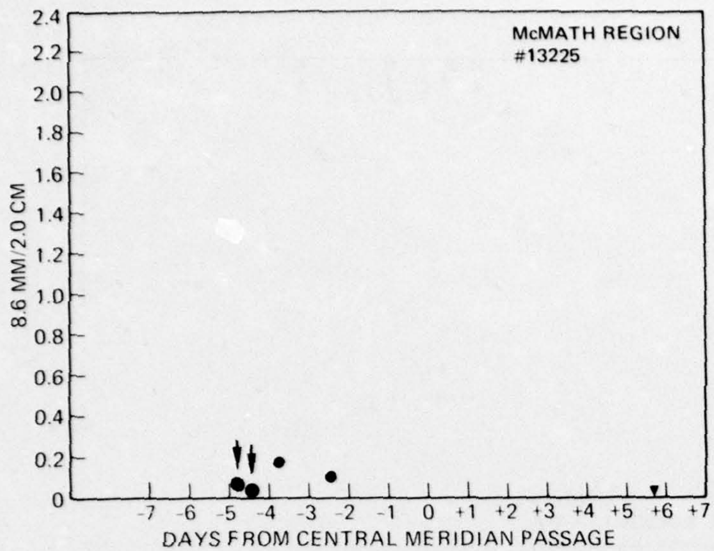

Figure 4i

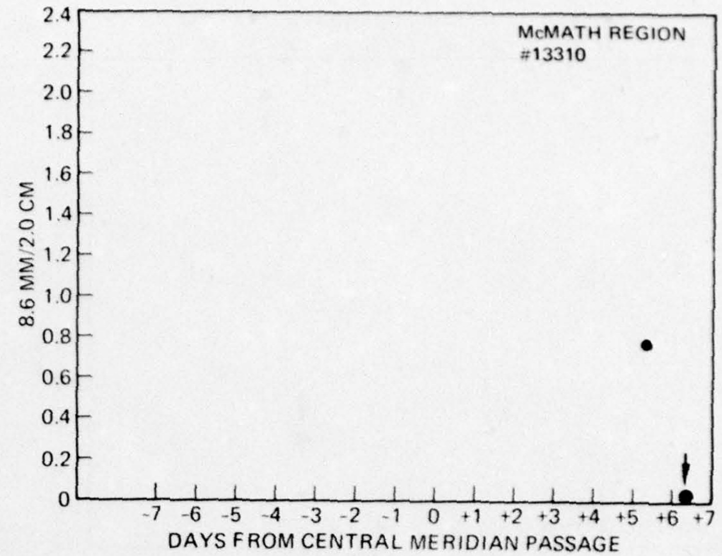

Figure 4j

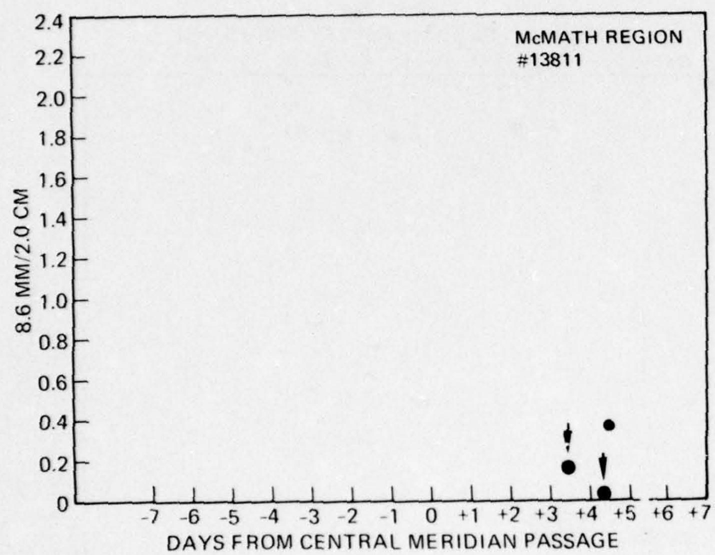

Figure 4k

Fi; re 4. (Continued)

CONCLUSIONS

The data obtained between 1972 and 1974 at LPAO do not contain obvious "signatures" for identifying proton-producing active regions. Neither do they appear to confirm the results of the Japanese. Further analysis utilizing the Stanford 9.1-cm data should be made before final conclusions are reached. It is suggested that the following avenues of approach be explored:

1. Obtain data (8.6 mm and 2.0 cm) with better time resolution.
2. Perform regular observations of the polarization characteristics of active regions and their relationship to flare activity.
3. Broaden the efforts to understand the "physics" of active regions (the spectrum of the emissions, the mechanisms of emissions, and the polarization of the emissions all at radio wavelengths) and to understand how these relate to other non-radio observations and the proton-acceleration process.

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