REPORT UAG-66

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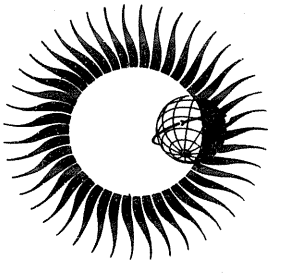
SYNOPTIC RADIO MAPS OF THE SUN AT 3.3mm 1970-1973



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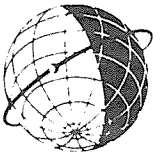

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SYNOPTIC RADIO MAPS OF THE SUN AT 3.3mm 1970-1973

by

Earle B. Mayfield
Space Sciences Laboratory

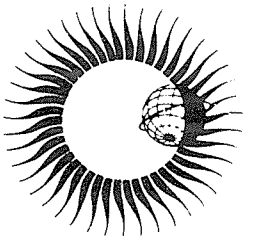
and

Fred I. Shimabukuro
Electronics Research Laboratory

The Ivan A. Getting Laboratories
The Aerospace Corporation
El Segundo, California, USA 90245

May 1978

Published by World Data Center A for
Solar-Terrestrial Physics, NOAA, Boulder, Colorado
and printed by
U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ENVIRONMENTAL DATA SERVICE
Asheville, North Carolina, USA 28801



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INTRODUCTION

The Aerospace Corporation millimeter radio telescope, which was completed in 1963, has been used extensively for investigations in planetary, solar, and stellar research. It is located in El Segundo, California, at 30°54'53"N and 118°22'30"W (7h 53m 30s) at a height of 38 m. Maps of the whole solar disk at 90 GHz (3.3-mm wavelength) were obtained routinely on a near daily basis from 1966 through 1973. In October 1973, loss of funding resulted in the discontinuation of the solar program. Since then, only infrequent observations of the Sun have been made to calibrate the radiometer.

The format used in presenting millimeter radio observations is the same as that employed for previous results [Mayfield et al., 1974] and is based on investigations of variations in the 3.3-mm emission and its correlation with photospheric magnetic fields, faculae, and centers of activity. Furthermore, the regions of enhanced millimeter emission are well-defined, stable features that can be readily identified and followed during their disk passage. The relatively infrequent, transient phenomena associated with flares, which have been discussed by Shimabukuro [1968], usually lie at the resolution limit of the antenna. As a result, synoptic maps are considered not only the most informative presentation but the most concise. The authors can provide separate maps for those individuals who require more detailed data or individual maps for specific days.

INSTRUMENT DESCRIPTION

The polar-mounted antenna is Cassegrain in design and 4.57 m (15 ft) in diameter [Jacobs and King, 1965; King et al., 1966]. Although the surface has been finished for operation at 400 GHz (1 mm), it is usually operated at 90 GHz (3.3 mm). At this wavelength the beamwidth at the half-power points is about 2.8 arc-min. Pointing accuracy and stability for the instrument is about 20 arc-sec. An on-line digital computer controls the antenna through a closed loop servo that permits a variety of tracking modes, including a mapping mode for solar studies. The radiometer is of the Dicke type in which switching is done at 465 Hz between the on-axis beam and a wide-beam sky temperature reference horn. The first stage of the radiometer is a single-end gallium arsenide crystal mixer that provides for frequency conversion to a 3-GHz intermediate amplifier. The system sensitivity for a signal-to-noise ratio of 1 at the output is about 0.6 K for a 1-second integration time.

For the results reported here, the computer-controlled antenna was programmed to obtain a square array of emission temperatures centered on the solar disk. A 19 x 19 matrix was obtained by rastering the antenna between adjacent points. A 4-second settle time was allowed between readings with a 1-second integration time for temperature measurement. These individual values were normalized to an undisturbed region near the center of the disk to eliminate the requirement of absolute data calibration. This reference temperature used for normalization was selected by analyzing millimeter observations previously obtained and by using the Fraunhofer Institute maps to select a quiet region free of plage or other disturbed emission. The finite beamwidth of the antenna at the solar limb restricts interpretation and thus the isotherms to regions less than $0.7R_{\odot}$ (normalized solar radius). The maps contain this limitation. Others include occasional pointing errors, typically greater than 20 arc-sec but less than 1 arc-min, that occur in centering the temperature matrix on the disk and slight differences in the emission temperatures owing to variations in cloud cover.

Figure 1 shows a typical map dated 30 June 1971 that has been superposed on an Hα picture. Isotherms have been constructed on the temperature matrix at levels of 2% enhancement, and they indicate in this case the presence of two regions of significant enhancement--ones that can be identified with Hα plage in centers of activity associated with spot group magnetic fields. The maximum enhancement in these millimeter regions usually occurs near the neutral line of a primary bipolar magnetic feature and shows daily variations associated with changes in the magnetic fields. In a previous analysis, Mayfield et al. [1970] have discussed in detail the relation between millimeter enhancement and magnetic fields.

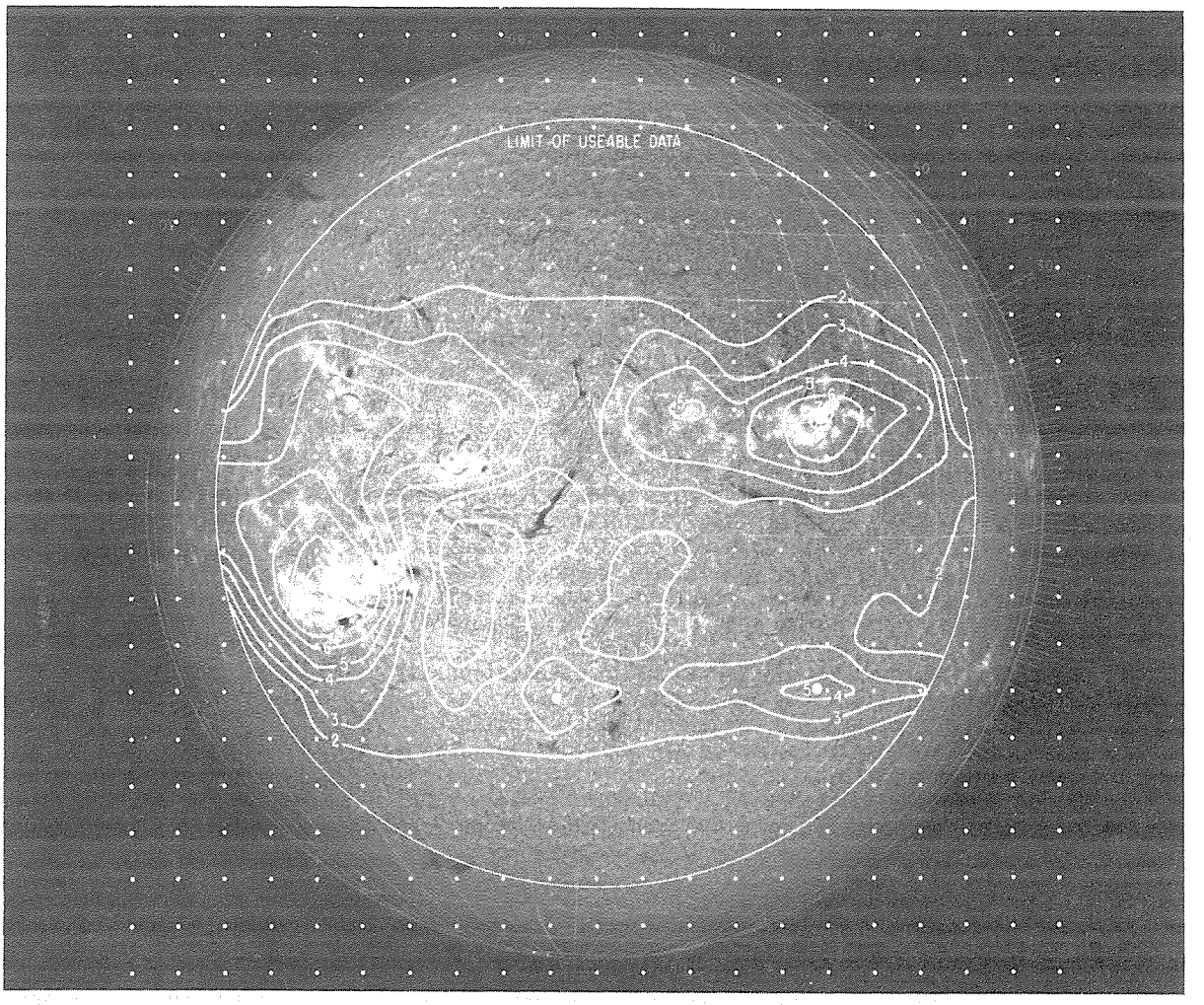

Figure 1. The 3.3-mm solar radio temperature contour map made on 30 June 1971 superposed on a concurrent Hα photograph. The contours are labeled in percent enhancement relative to the temperature of the undisturbed regions denoted by the hatched contours.

SUMMARY OF RESULTS

During the 4 years of observations (from 1970 through 1973) a synoptic presentation was used based on the Zürich heliographic maps of the Sun by Waldmeier [1968] and on the magnetic field presentation of Mt. Wilson by Howard. These maps are arranged to present the 360° of solar longitude, showing the millimeter isotherms on a day near central meridian passage. A typical synoptic map is shown in Figure 2 for Carrington rotation 1521. The Carrington longitude is given at the top of the figure, and the date of central meridian passage is located by the filled circle and day number at the bottom. Solar latitude between ±50° forms the vertical scale. Maps used in the synoptic presentation have been normalized to the quiet regions indicated by the crosses in the figure; times at which the maps were obtained are indicated with tic marks at the bottom of the figure. For presentation in this synoptic format, only isotherms representing 4% or more enhancement have been used, because they identify enhanced regions and show the close correlation between the millimeter enhancement and white light faculae evident in the Zürich maps.

Also plotted in Figure 2 is an overlay of sunspots and faculae taken from the Zürich map for rotation 1521. This shows a close correlation between the 4% isotherm contour and areas of faculae in sunspot regions. An interpretation of millimeter emission and its relation to white light faculae has been given by Mayfield et al. [1973] and will not be discussed here. Synoptic maps for 1970 through 1973 are given in the appendix.

Synoptic maps for 1970 through 1973 are given in the appendix. They have been plotted to facilitate comparison with the Zürich photoheliographic maps and with the synoptic magnetic field maps published in the IAU's *Quarterly Bulletin of Solar Activity*.

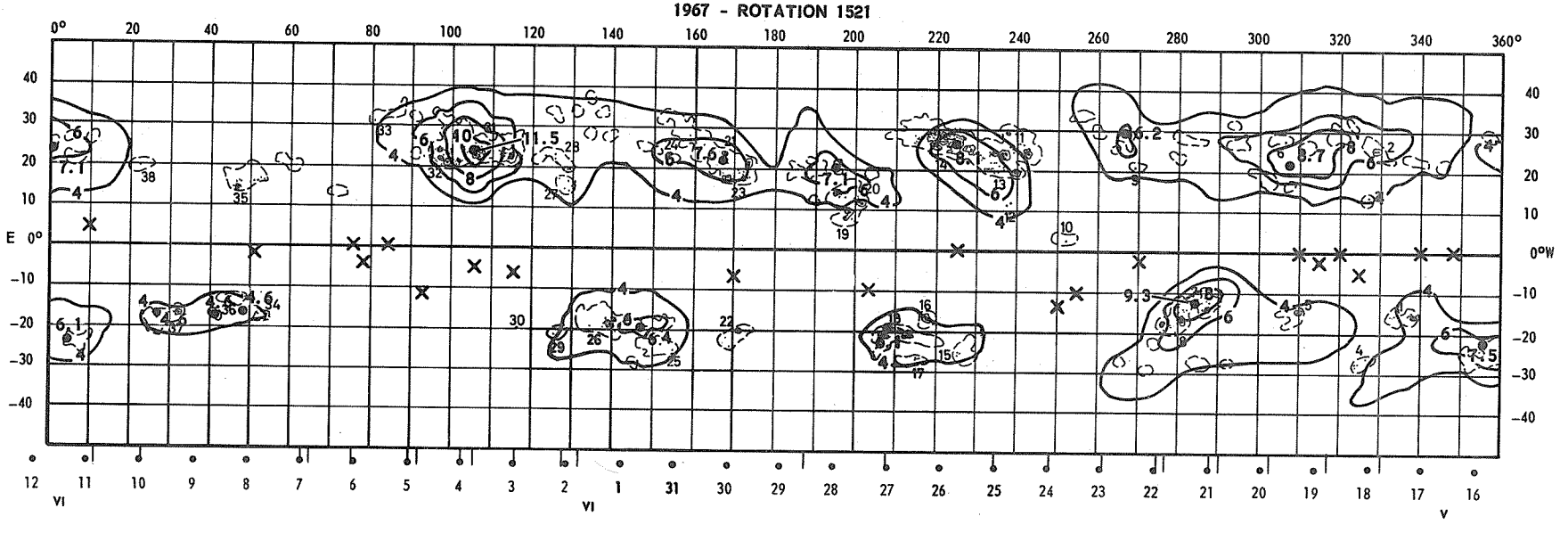

Figure 2. Synoptic 3.3-mm radio temperature contour map for Carrington rotation 1521 superposed on the corresponding heliographic map of the photosphere by Waldmeier [1968]. Carrington longitude appears at the top of the figure and date of CMP is given at the bottom. The tic marks along the bottom margin of the rectangular grid indicate times at which the maps were taken. Vertical scale is solar latitude. The contours are at levels of 4, 6, 8%, etc. enhancement above the quiet regions indicated by crosses. Peak enhancements are shown by the filled circles. Note the close correlation between the 4% contour levels and facular areas and between peak enhancements and sunspots.

The longevity of active regions can be investigated by inspecting successive synoptic maps and noting the recurrence of active regions. In this respect it is important to point out the sensitivity and precision of the data contained in the synoptic maps, because these parameters influence the visibility of the enhancements. The lowest contour level plotted corresponds to a 4% enhancement, so chosen because individual active regions at this level are usually discernible. A 3% contour, on the other hand, typically runs nearly the length of the map, providing very little information. Additionally, measurements made on different daily maps, either on the same day or on different days, can vary as much as ±0.5%. The average, though, probably lies closer to ±0.3%; some outstanding examples show variations of no more than ±0.2% over a 5- or 6-day period. To maintain a precision of about 10% (e.g., 4 ±0.4%), it was safest to display the 4% contour as the lowest level.

Therefore, the longevity of an active region is defined as the time it first exceeds the 4% enhancement level to the time it first drops below that level. Based on this criterion, some regions are found to last less than a full solar rotation; others can persist and be followed over 5 or 6 rotations. As will be shown below, this result is entirely consistent with the strong correlation between the shapes and locations of the 4% contour levels and the outlines of the facular areas--areas that can have lifetimes as short as a few days or as long as a few solar rotations.

As indicated by the clustering of crosses, quiet regions represent another feature of the synoptic maps, the longevity of which can be gauged. Certain examples of these regions can be followed over 3 or 4 rotations even though their nature remains in question.

Daily observations of sunspots and photospheric faculae have been presented in synoptic form by Waldmeier [1968] in *Heliographic Maps of the Photosphere*. An example of these maps (Figure 2) shows each sunspot group at the time of its maximum evolution. In the maps umbrae are depicted by black dots, penumbrae by their outlines, and faculae by dashed lines.

Comparison of the radio synoptic map with the heliographic map in Figure 2 shows how well the 4% enhancement contours correspond to the extensions of the facular regions. Differences in shape and extent can be attributed to a number of causes that include (1) slow, evolutionary changes in the active regions occurring between the maximum phase captured in the photospheric maps and the stage nearest central meridian passage reflected in the millimeter maps; (2) flare-induced rapid changes in the active regions, the residual effects of which can influence the radio contours (although, such effects have been allowed for and corrected whenever possible); (3) selection of an invalid normalization point for a particular daily radio map such as a point containing a dark absorption filament, which would cause an apparent "growth" or "contraction" of the enhancement levels; and (4) lack of a physical connection between the millimeter emission and the white light faculae and sunspots.

ACKNOWLEDGMENTS

This research was supported in part by company funds of The Aerospace Corporation.

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APPENDIX

Synoptic Radio Maps of the Sun at 3.3 mm, 1970-73

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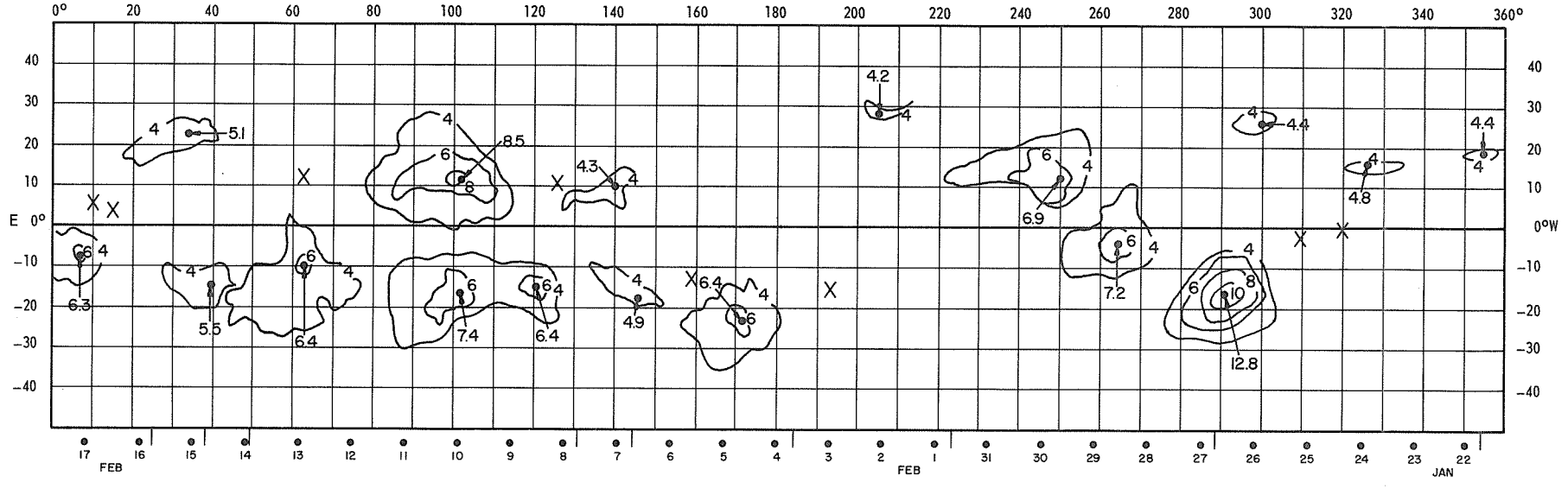

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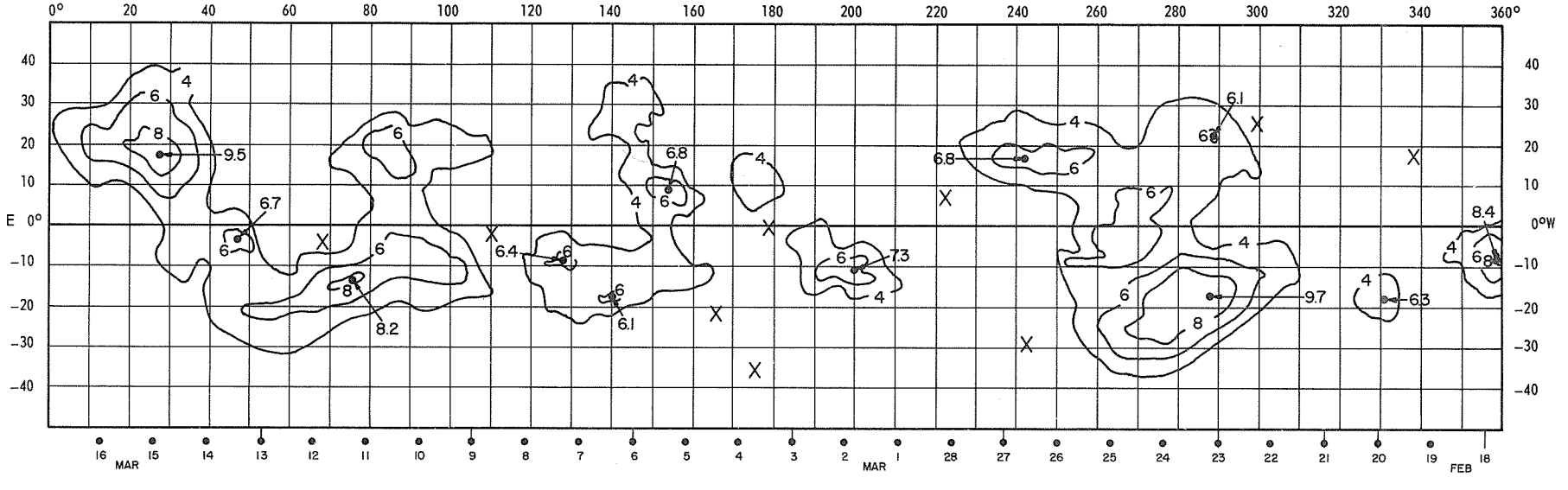

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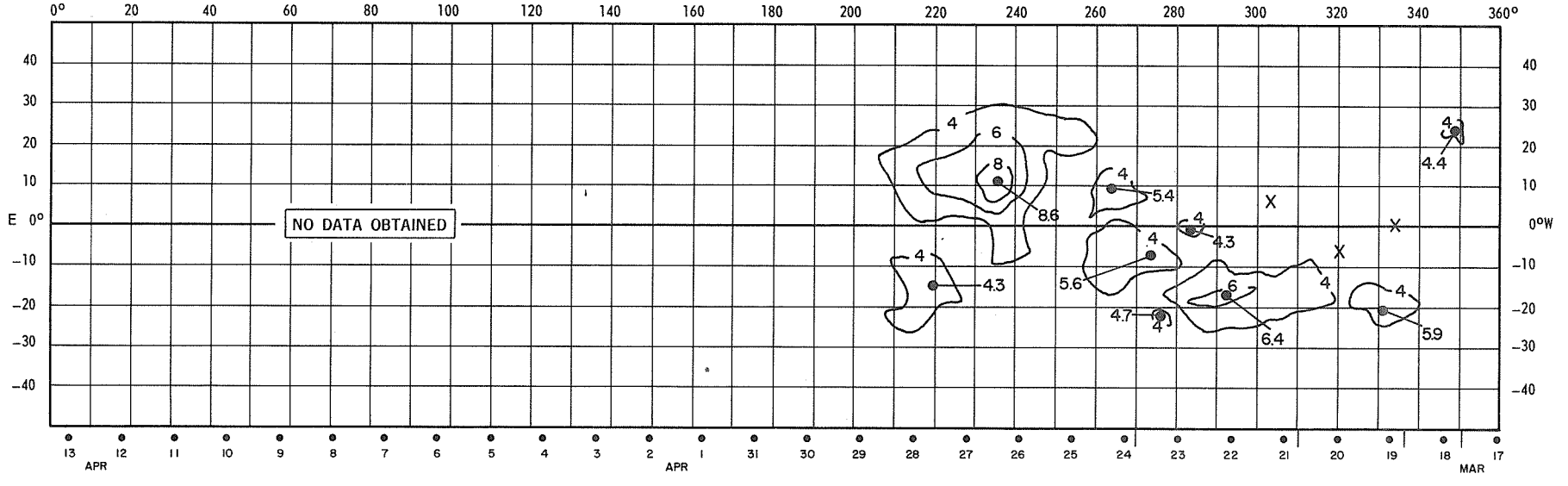

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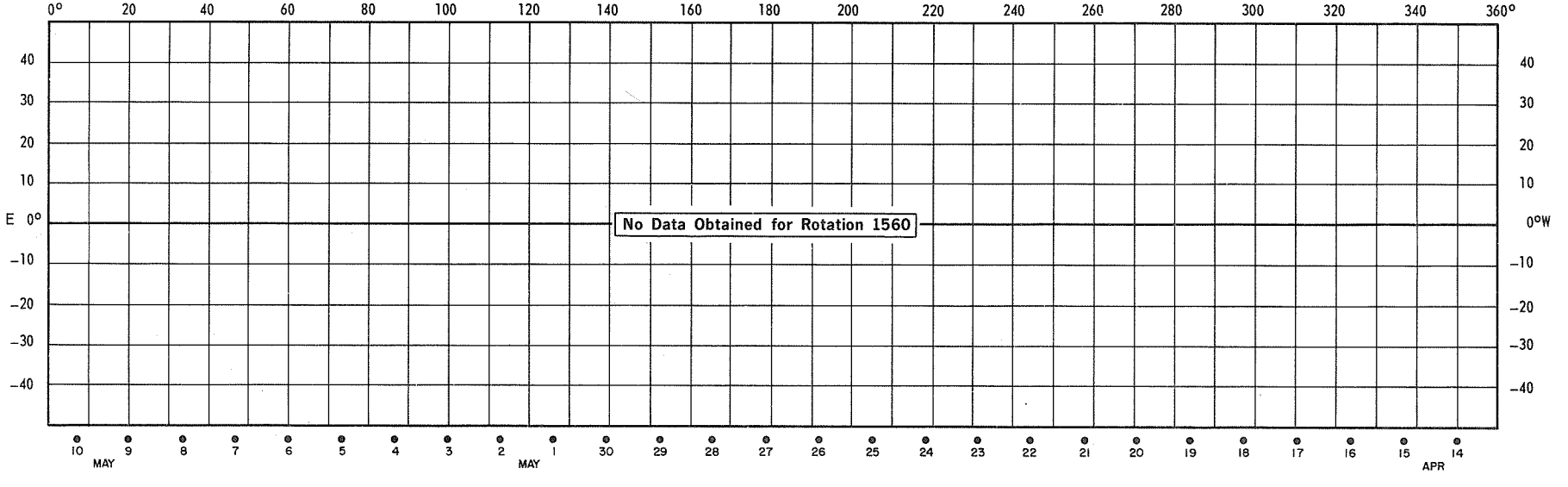

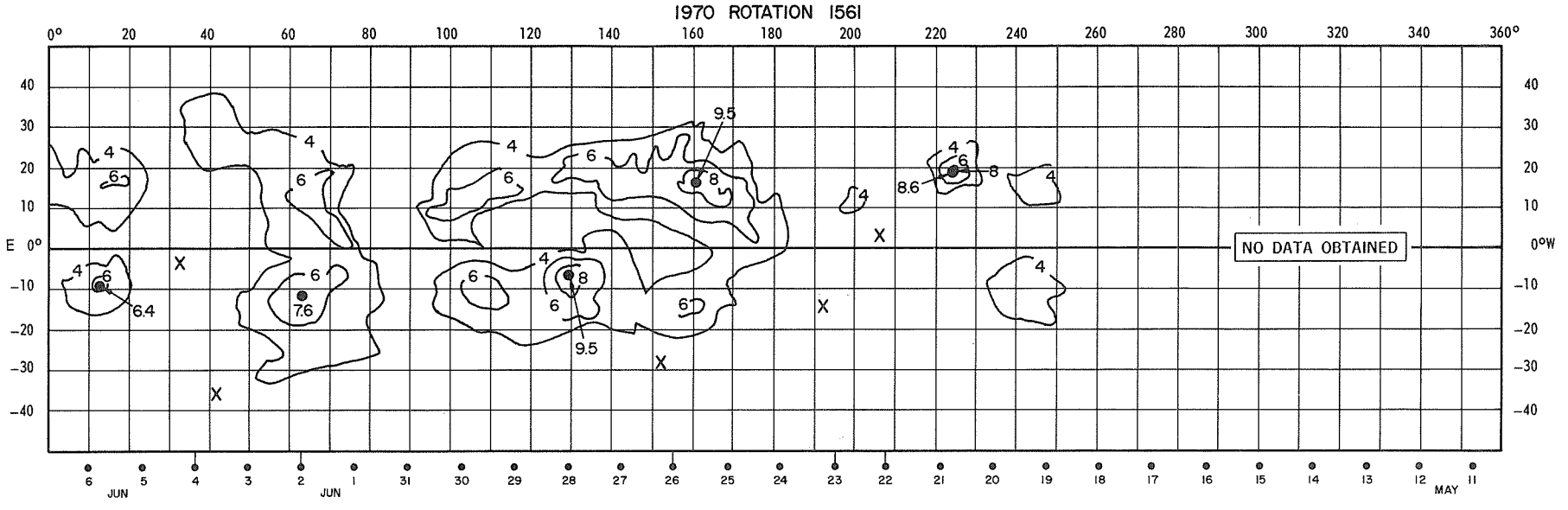
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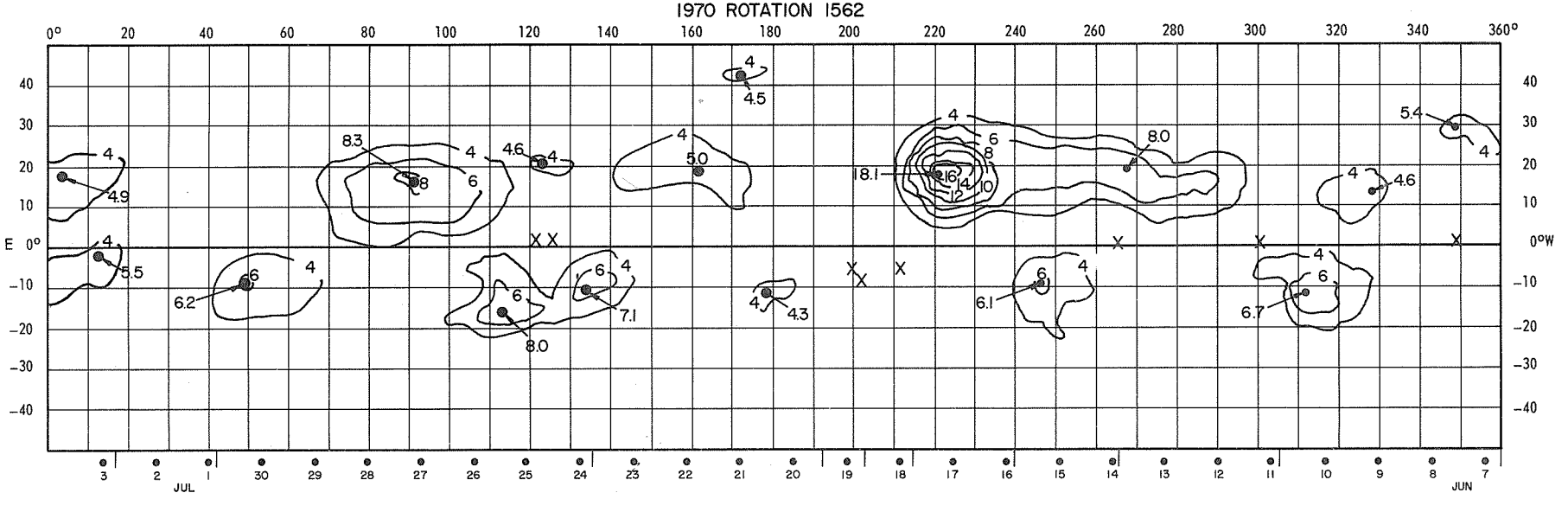
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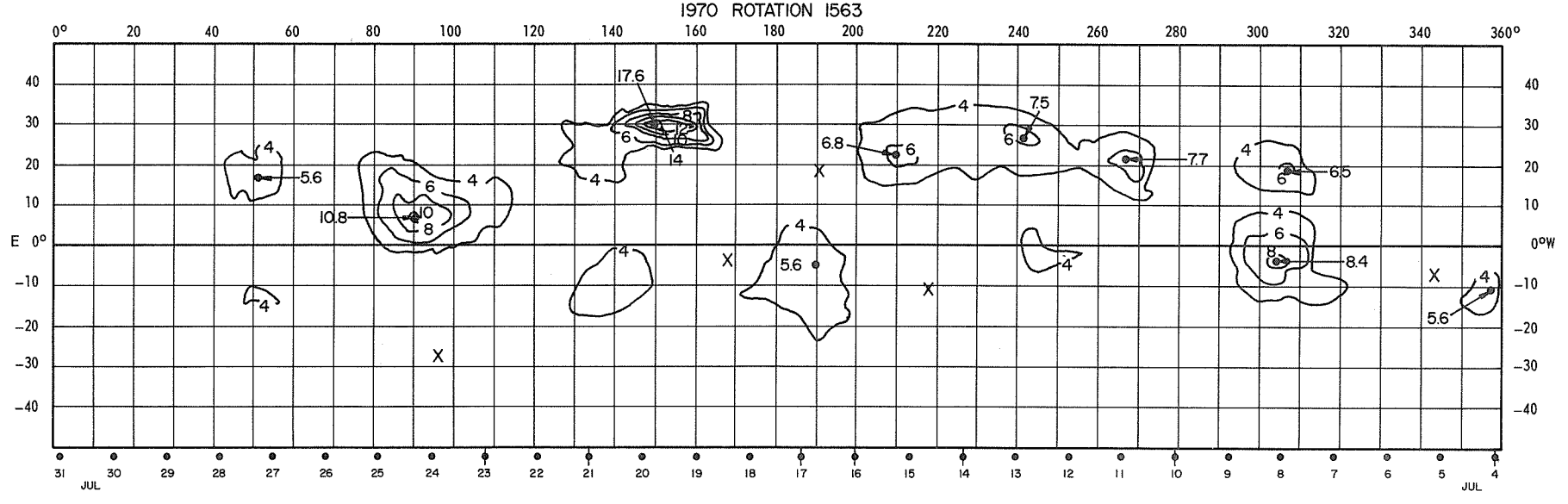
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6.8
7.7
6.5
10.8
5.6
8.4
5.6
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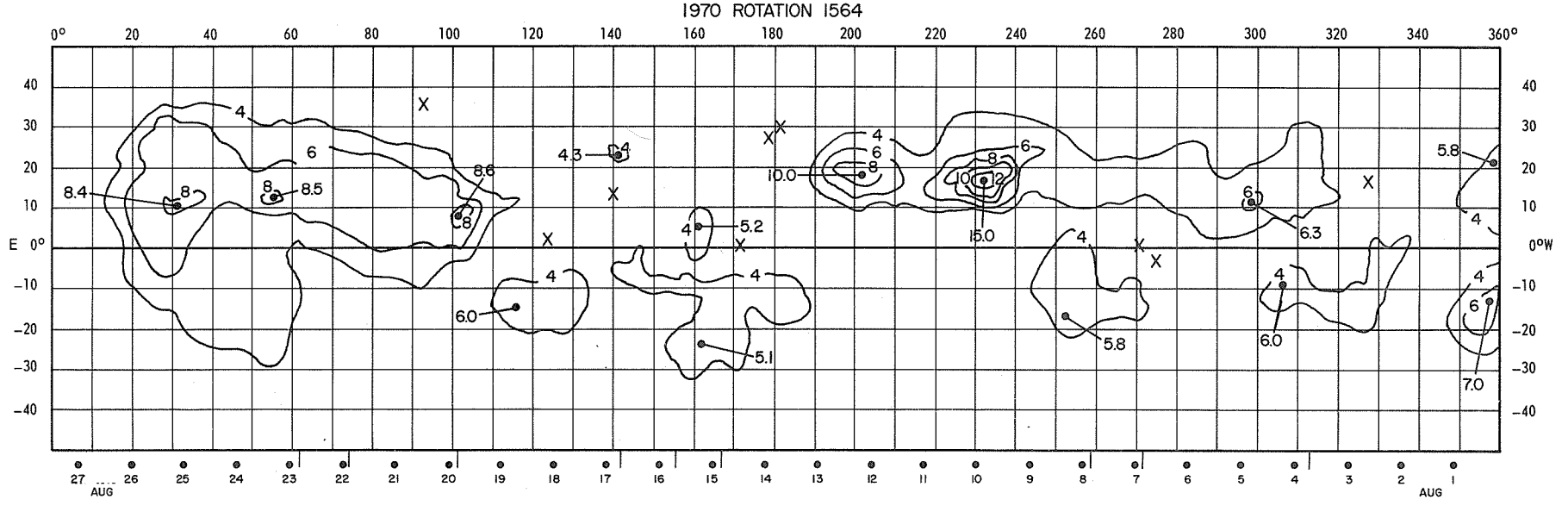
JUL
JUL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5.2
6.3
5.8
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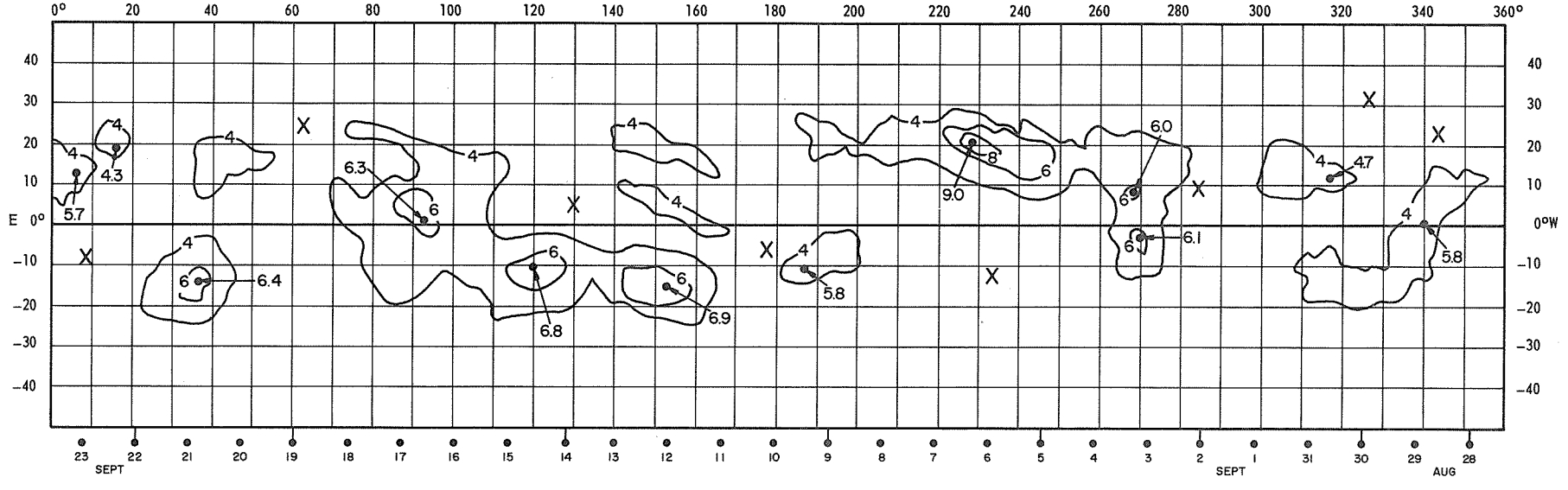

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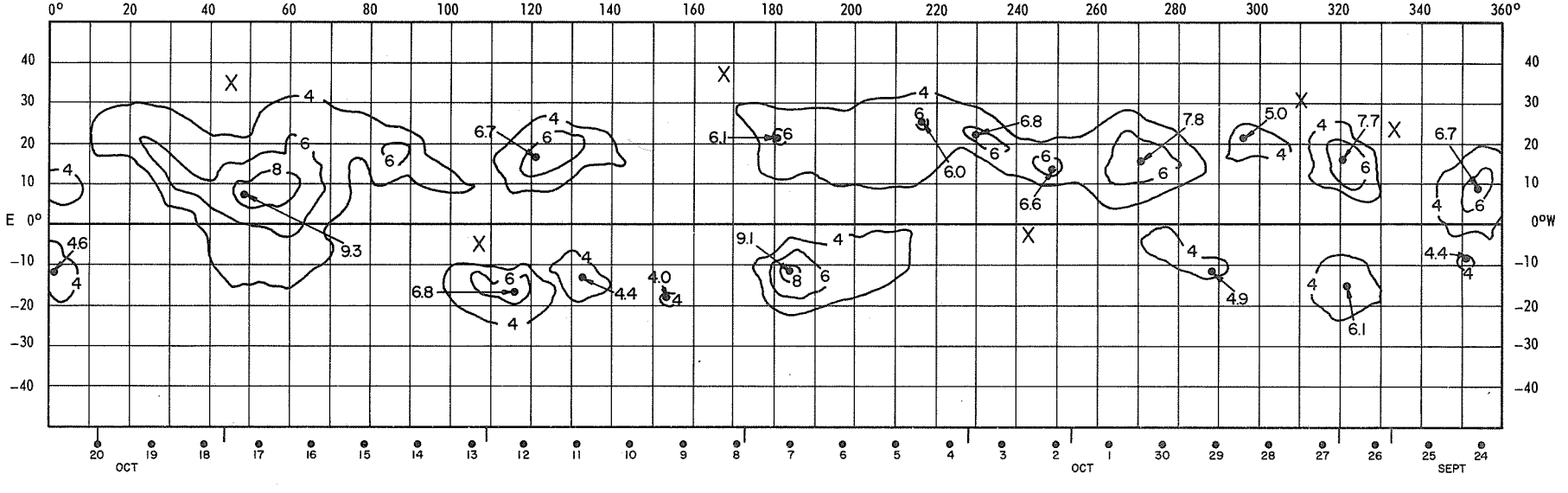

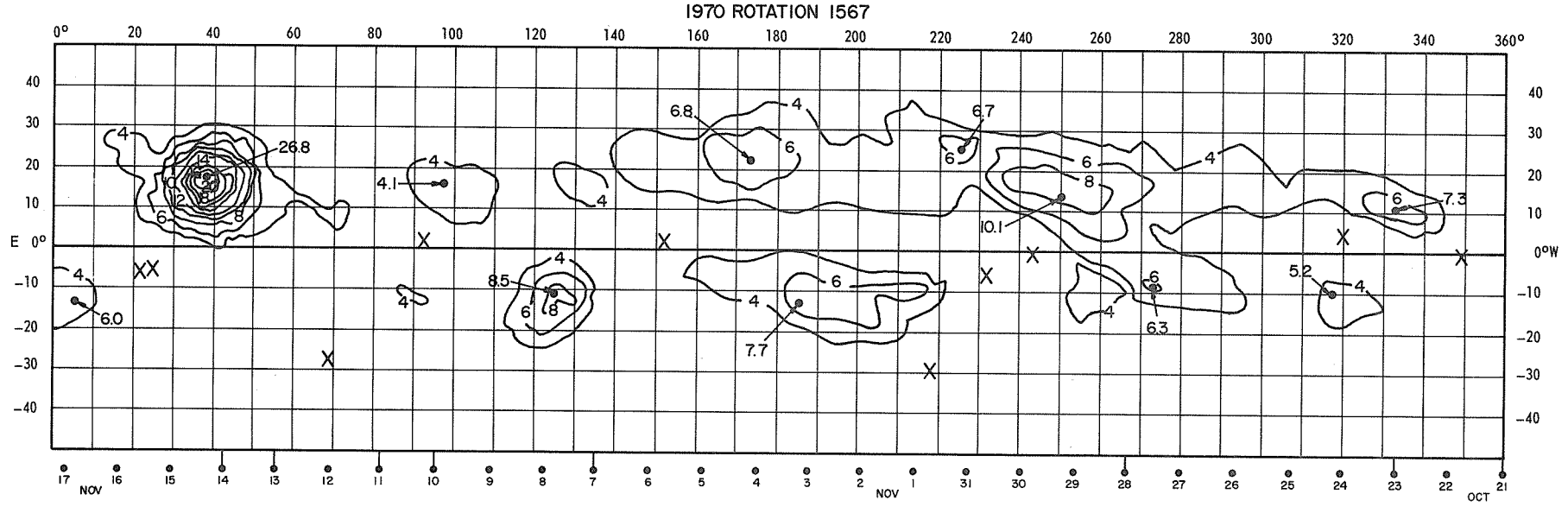
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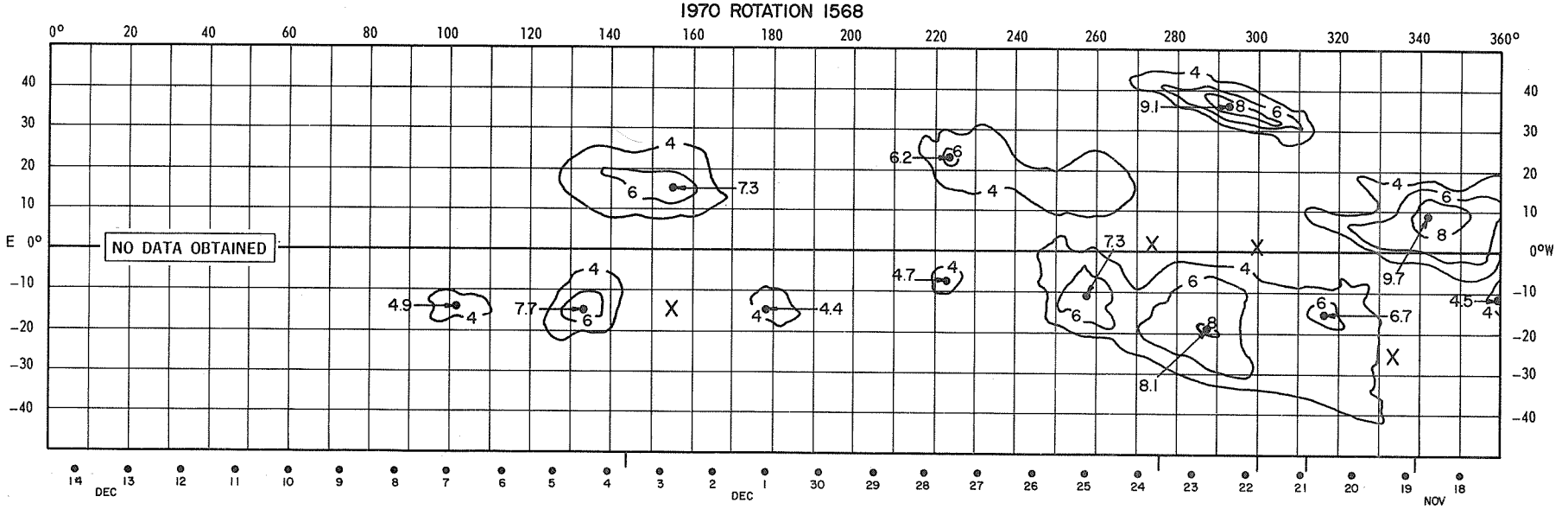
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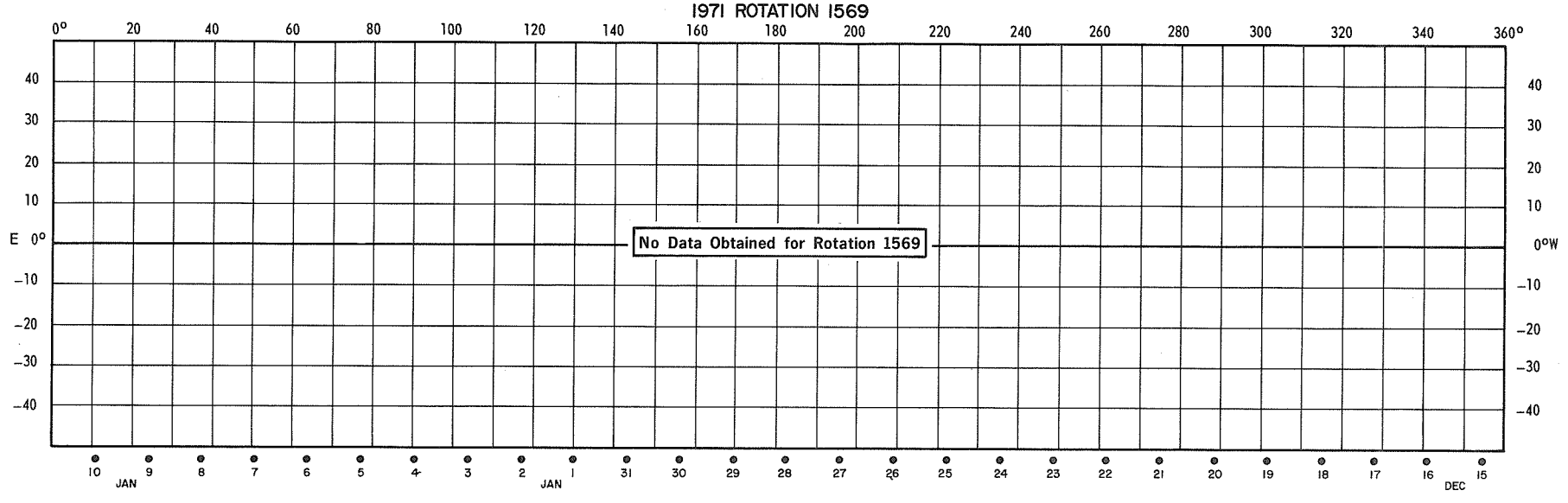
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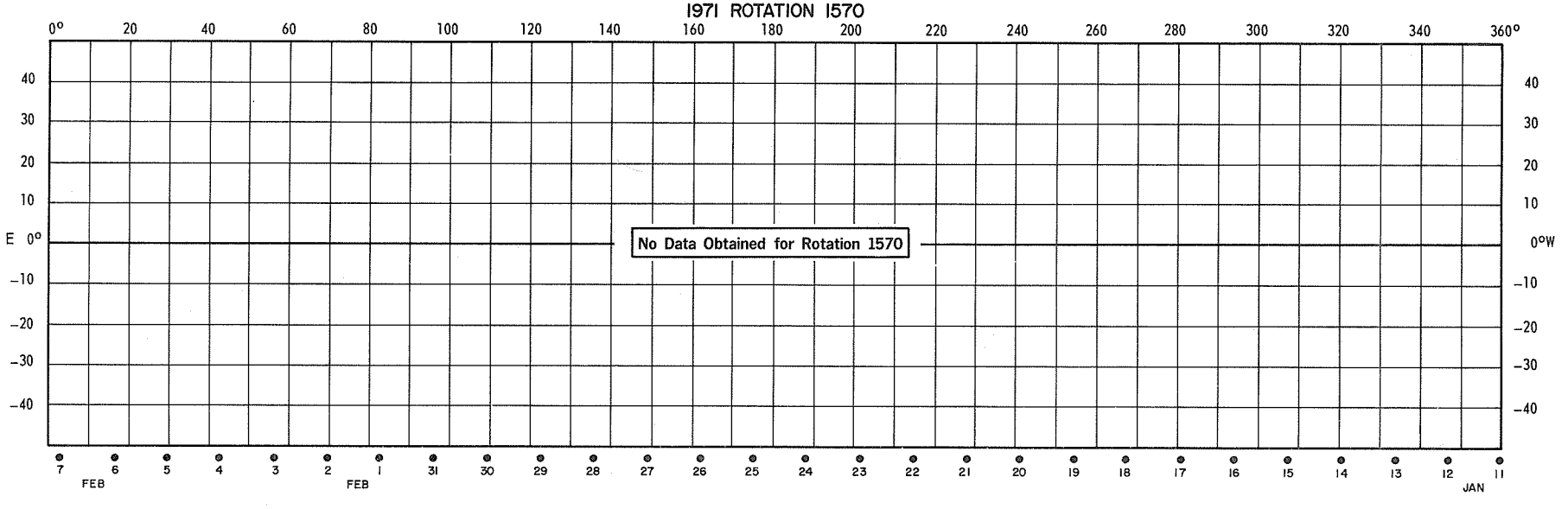
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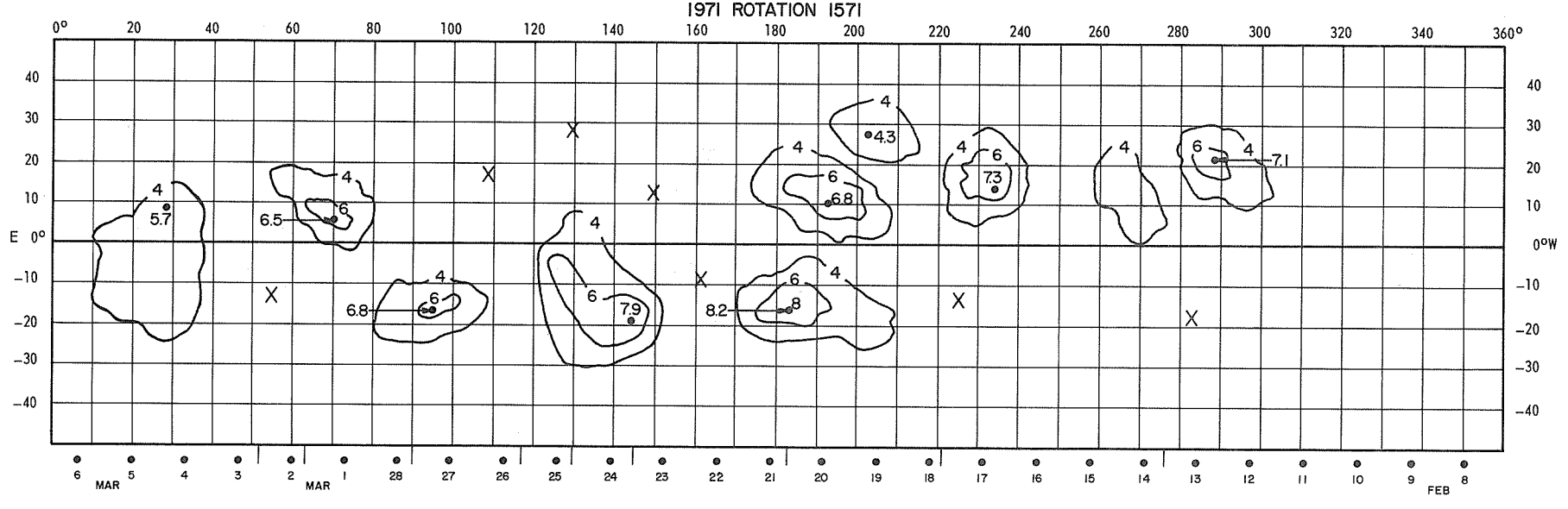
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4 6.8 6
4 6 7.9
4 4.3
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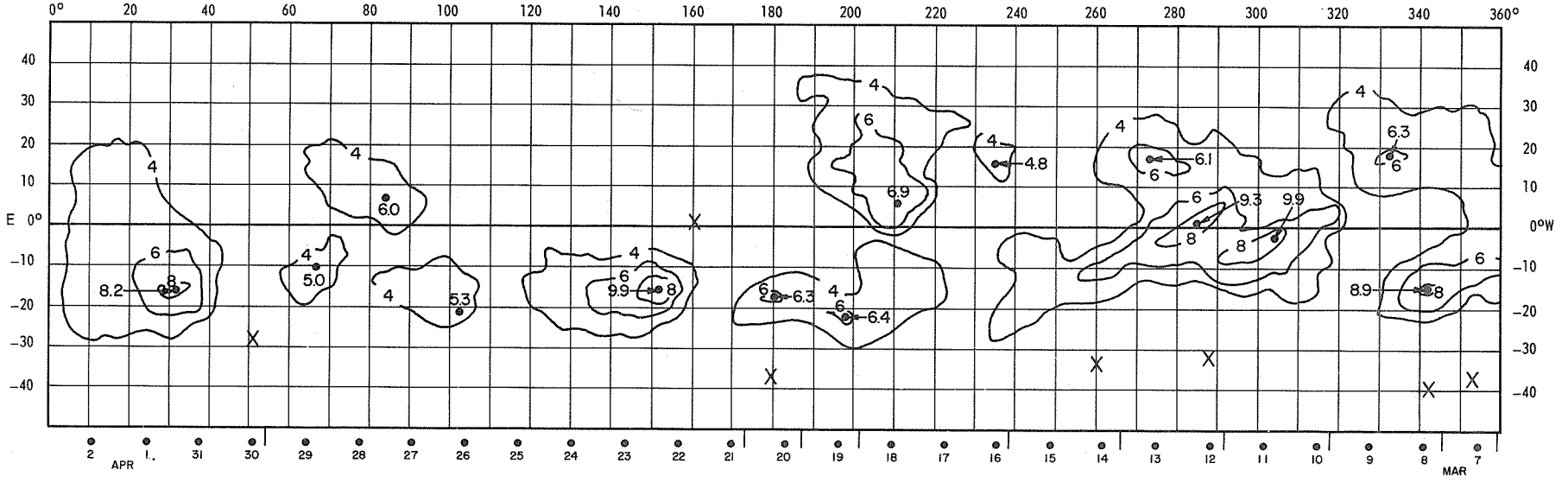
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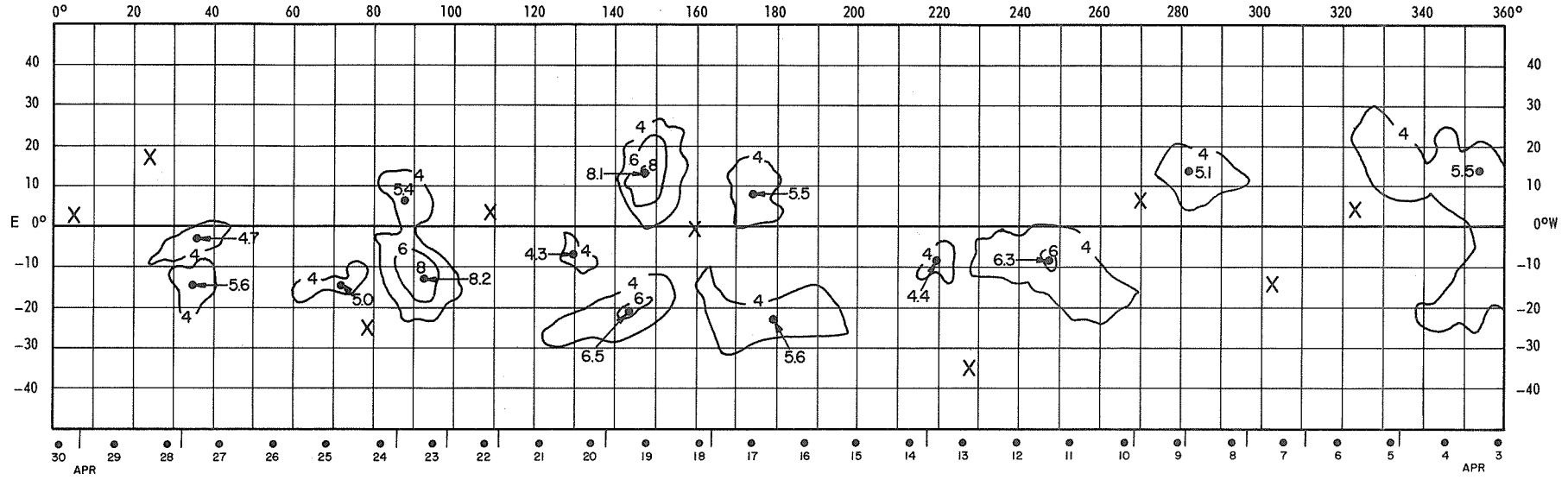
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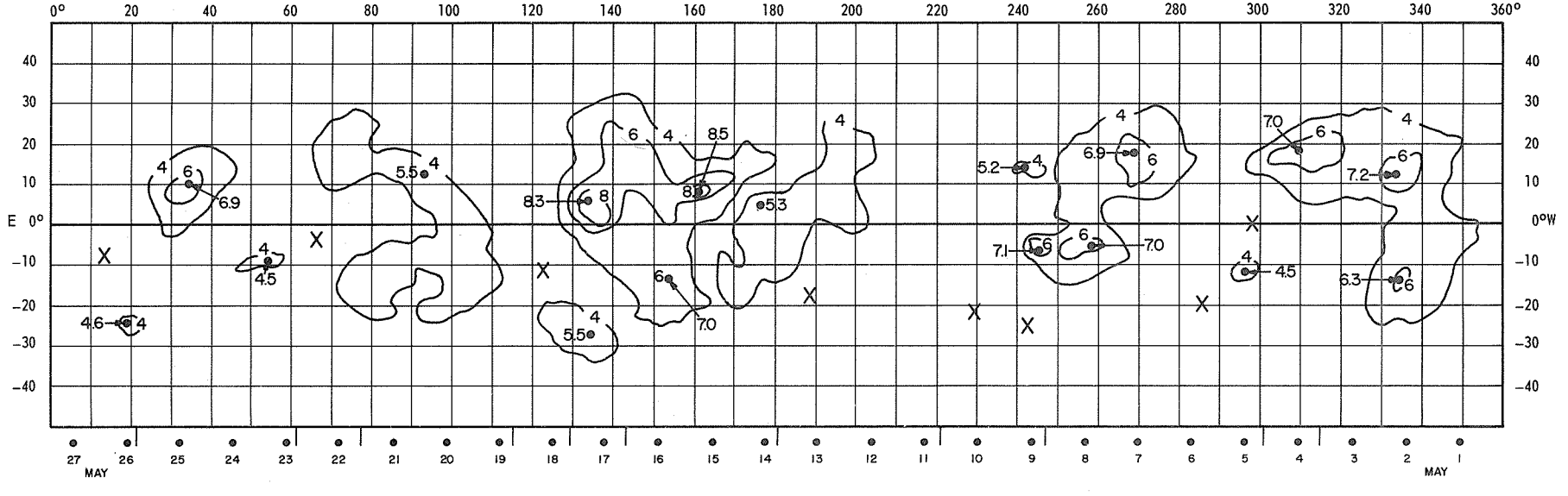
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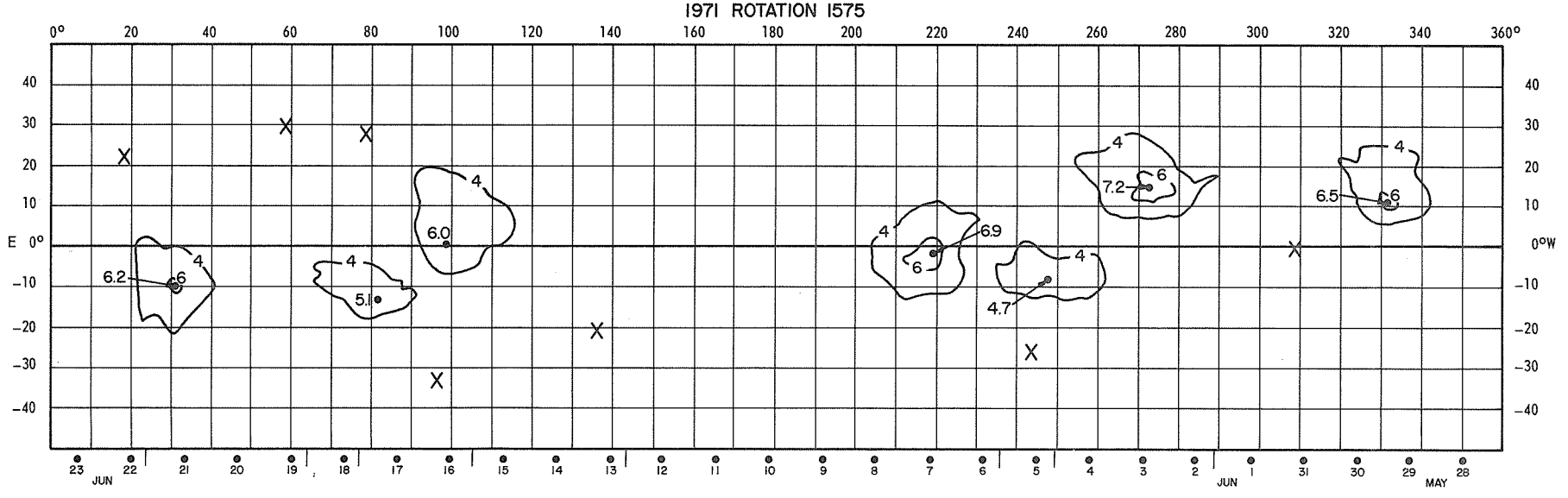
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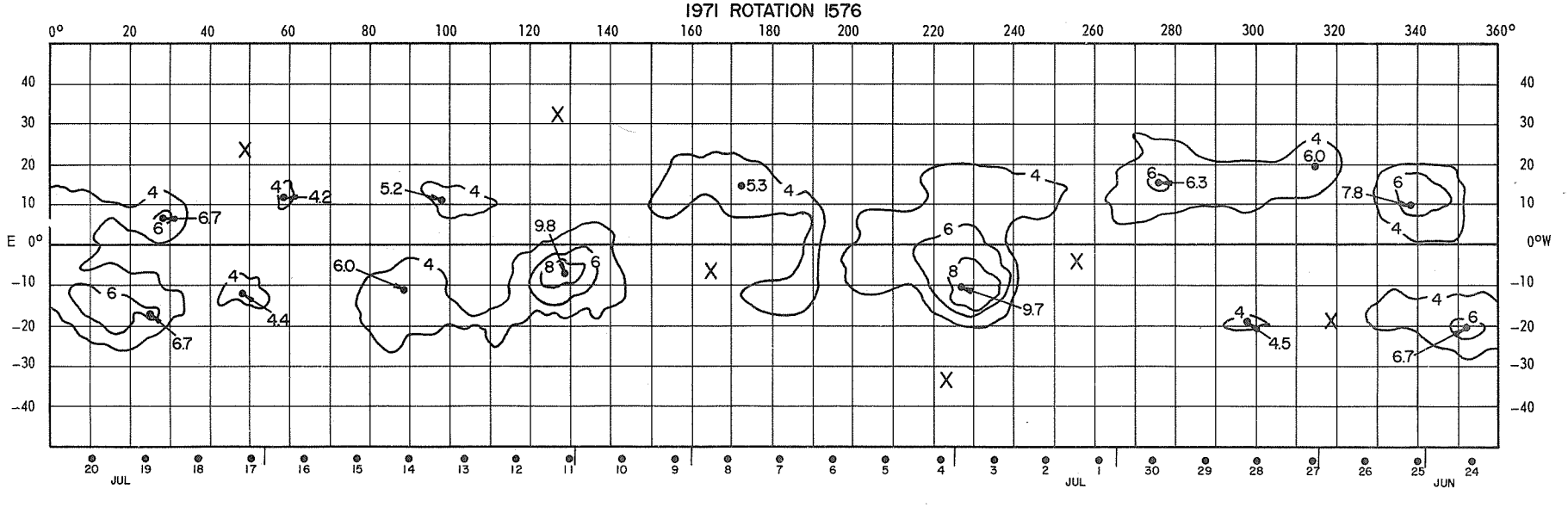
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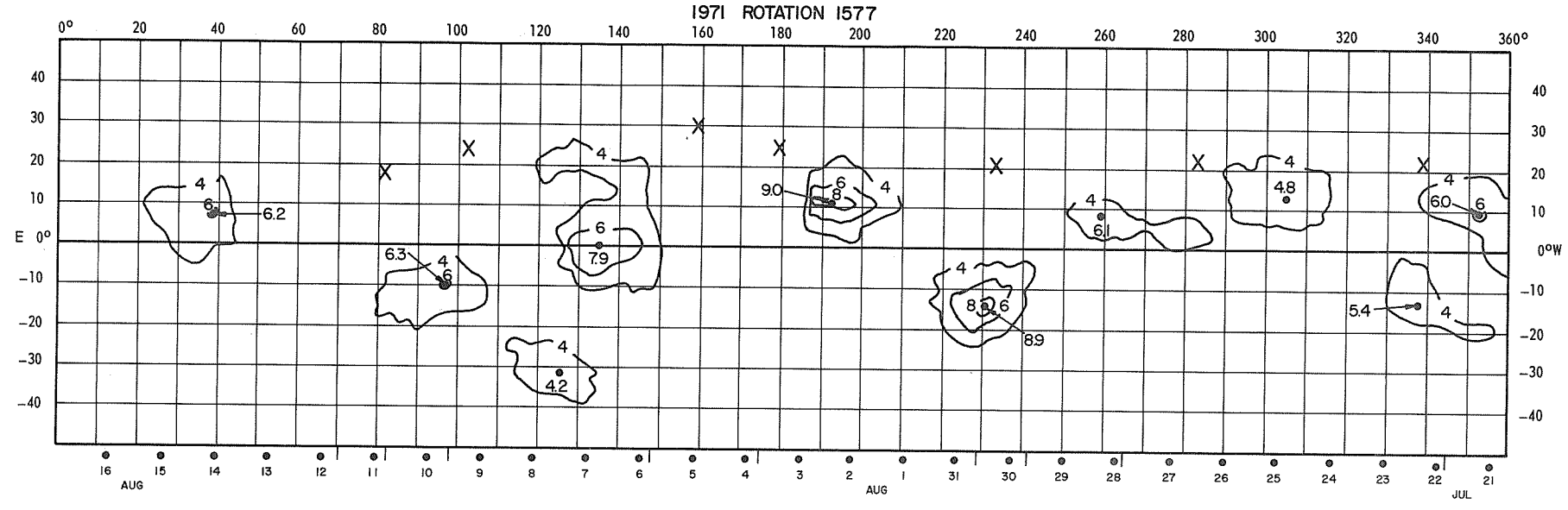
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AUG
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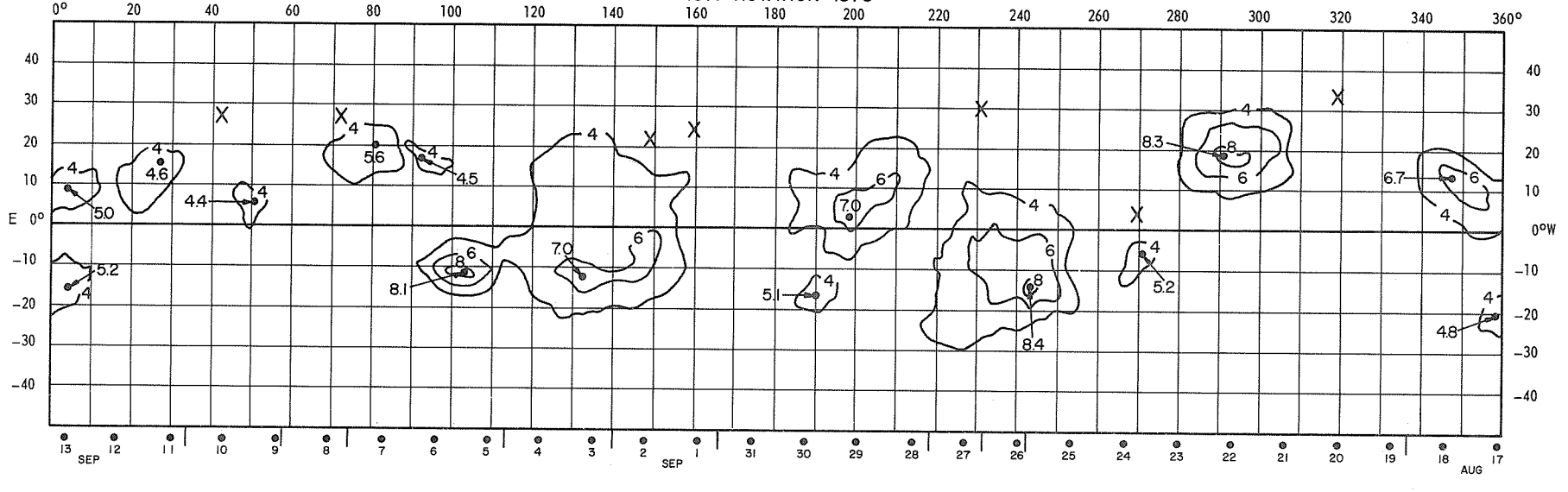
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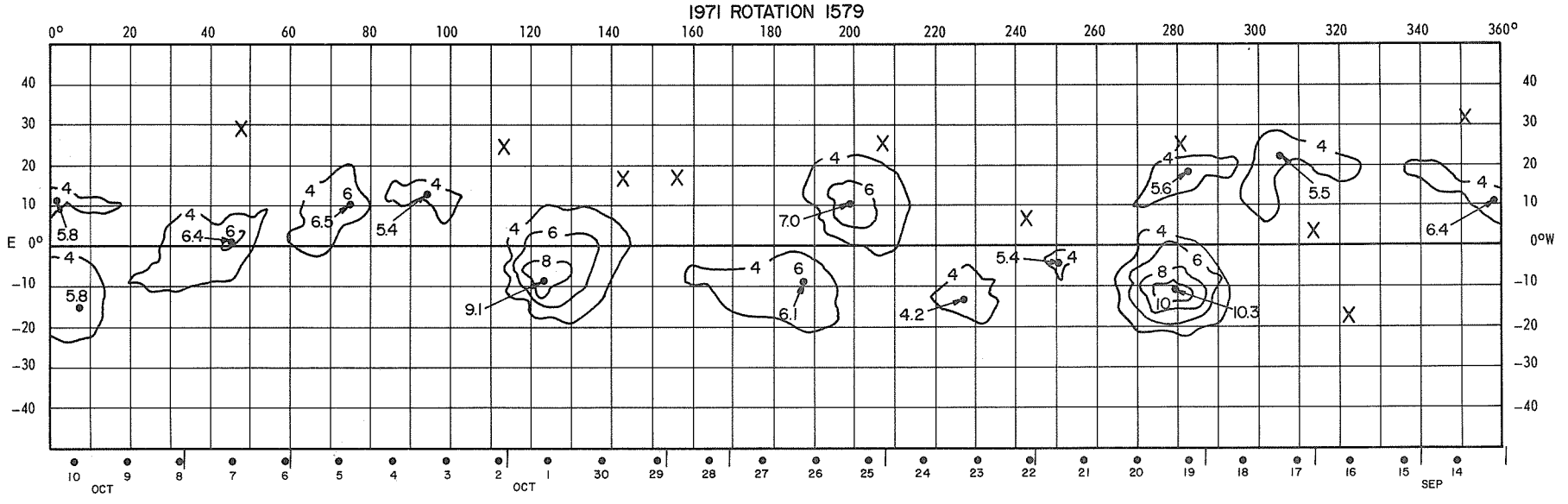
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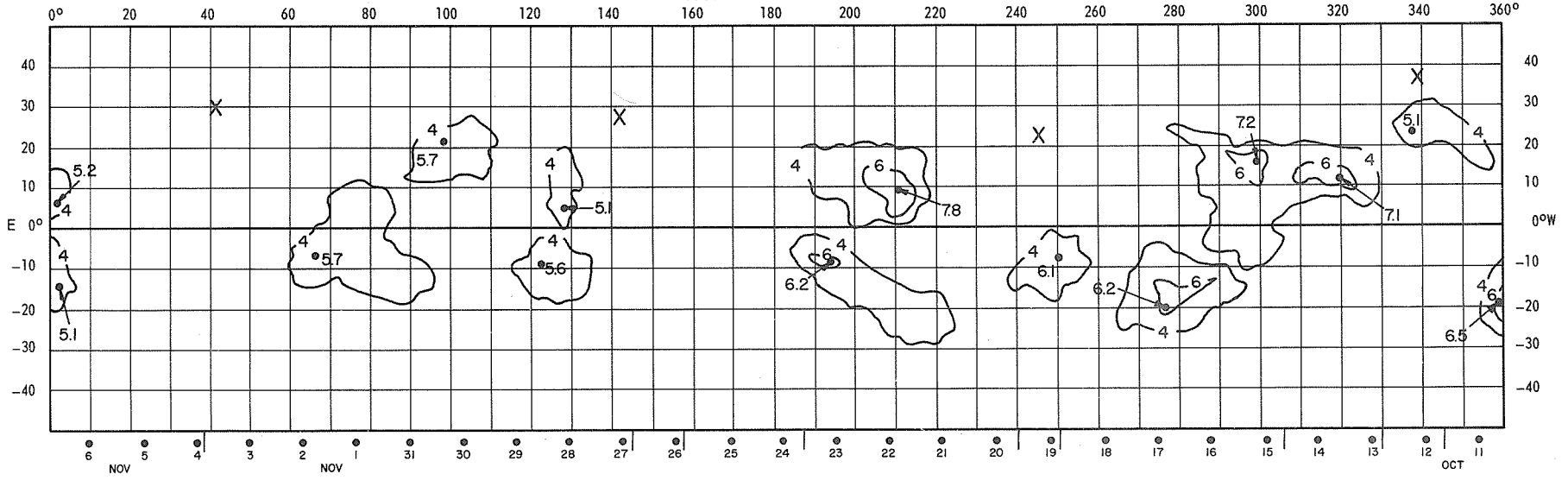
OCT
SEP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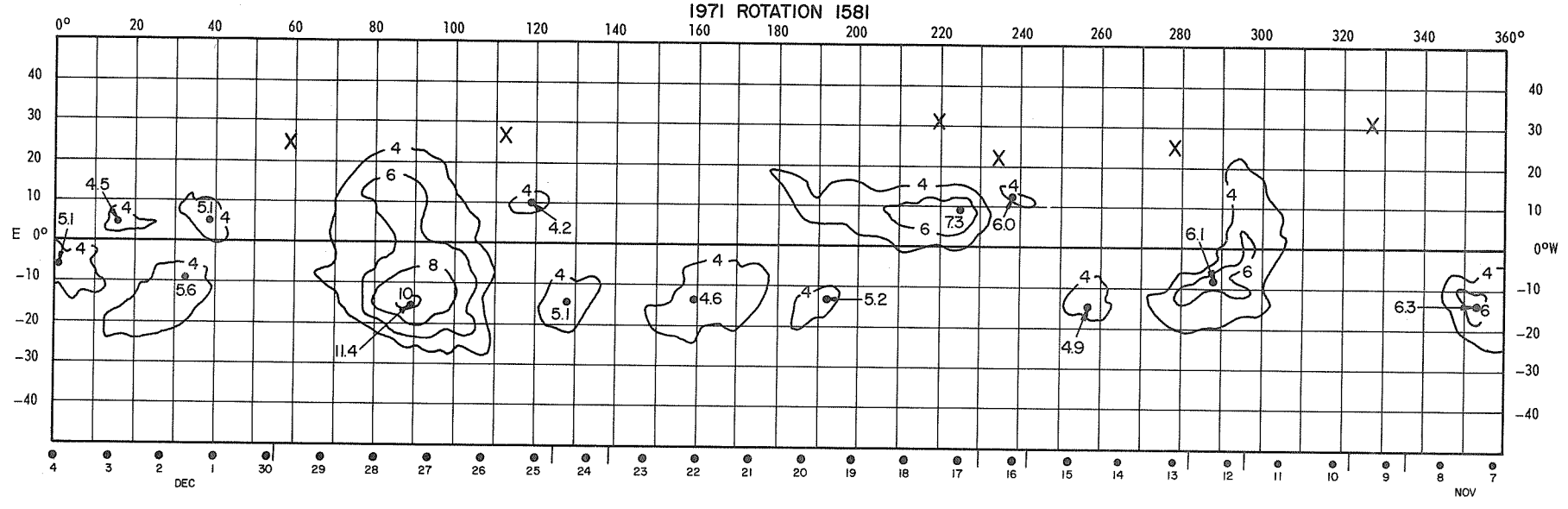
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NOV
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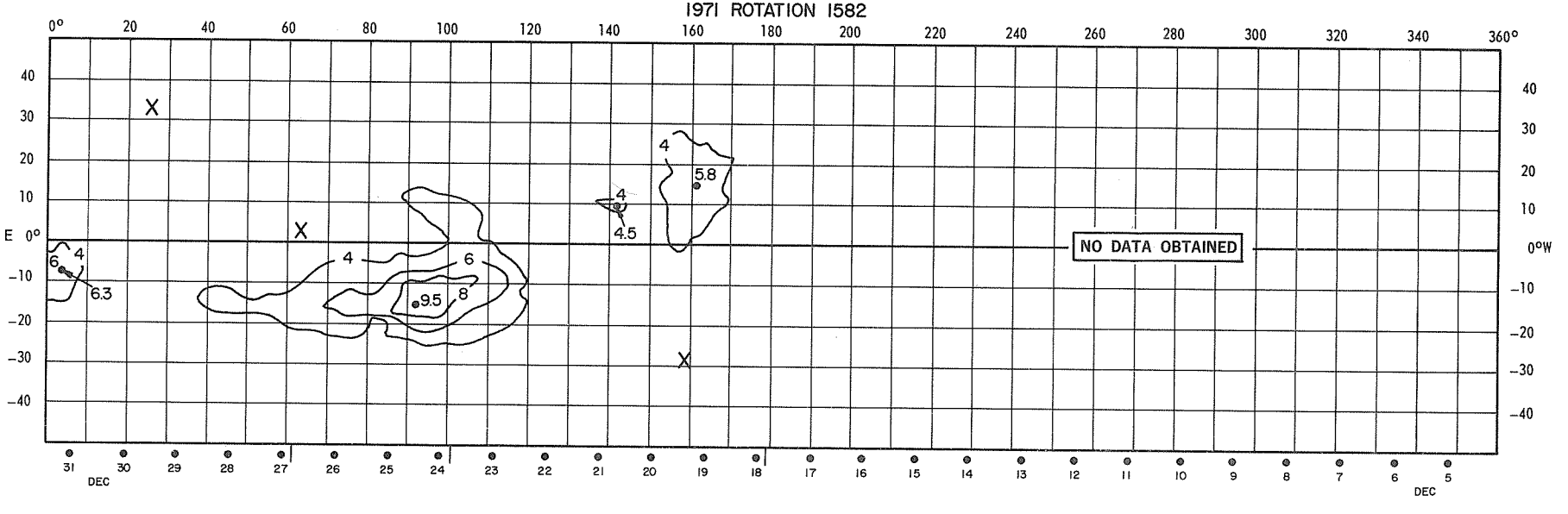
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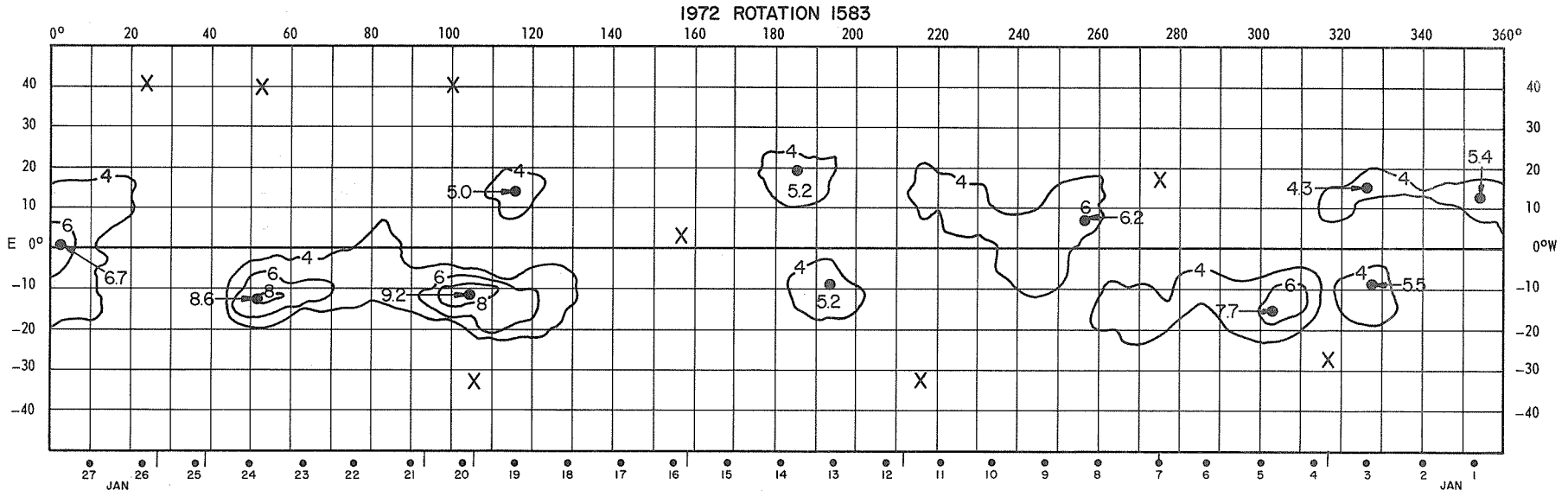
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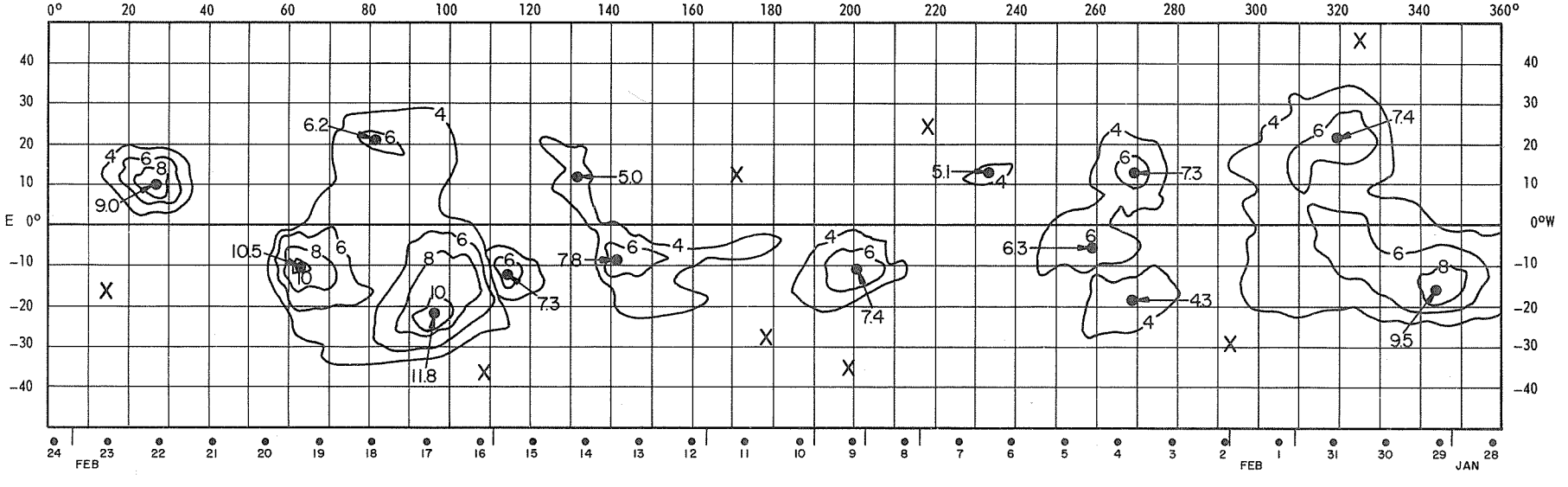
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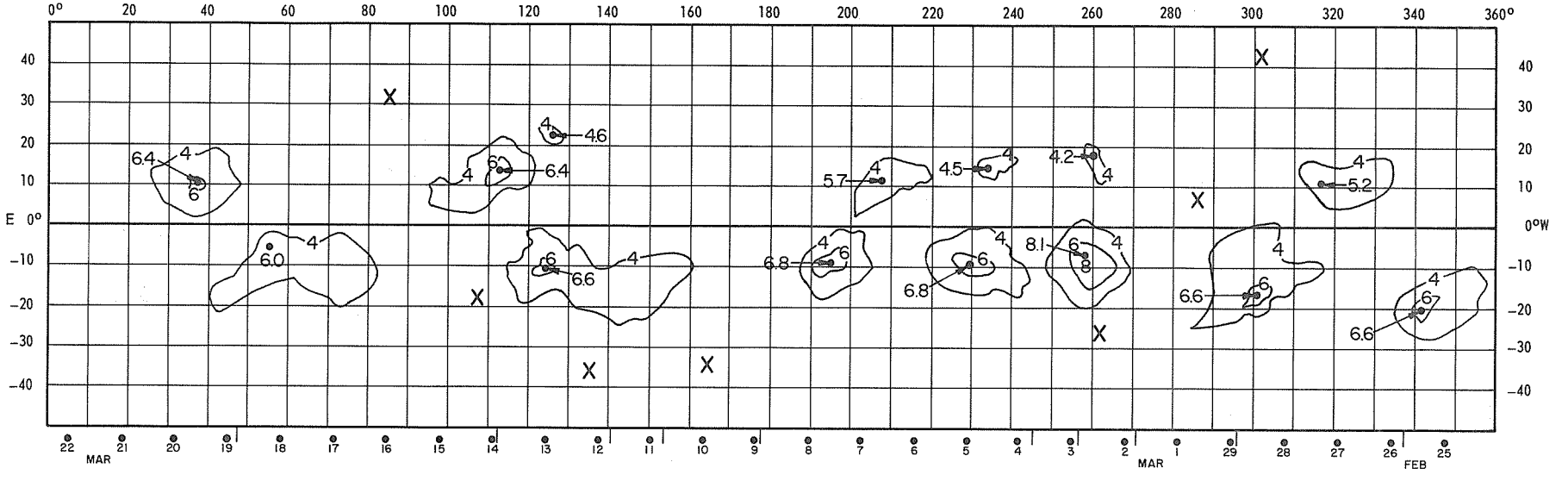

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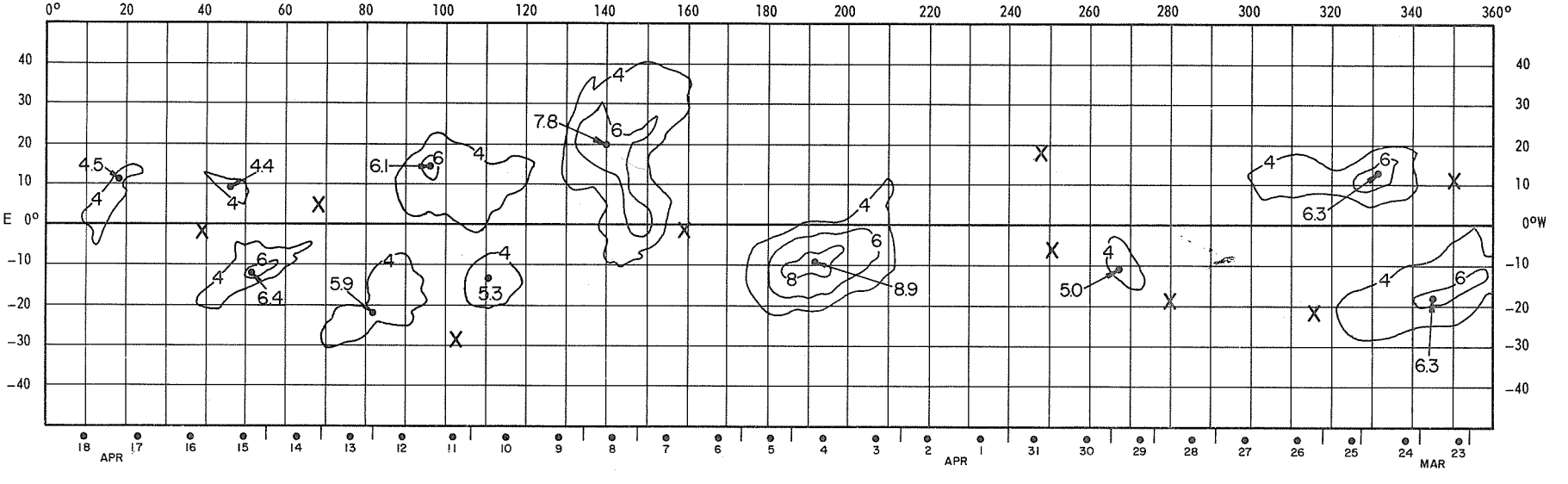

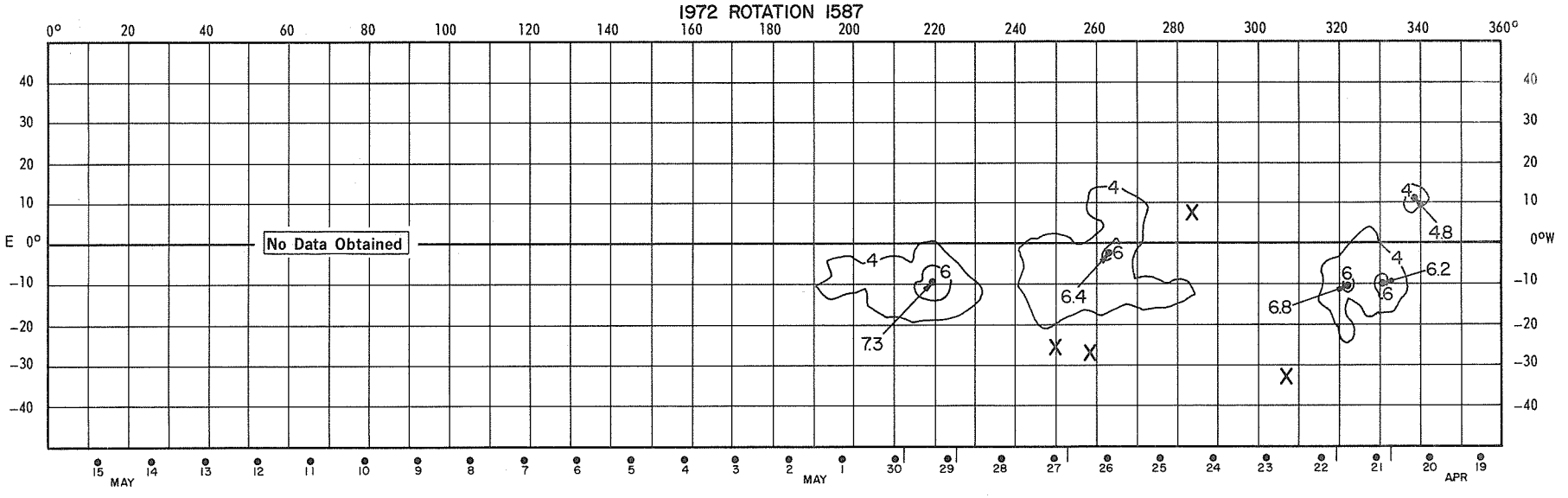
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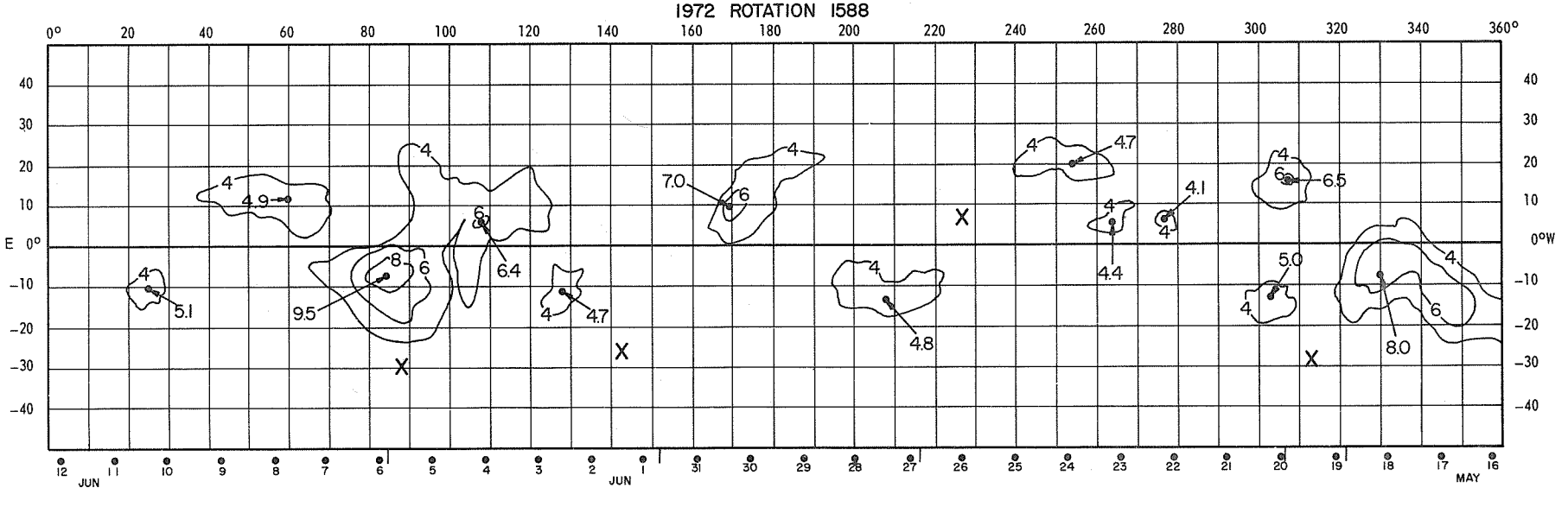
E 0°
0°W
MAY
APR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E 0°
0°W
JUN
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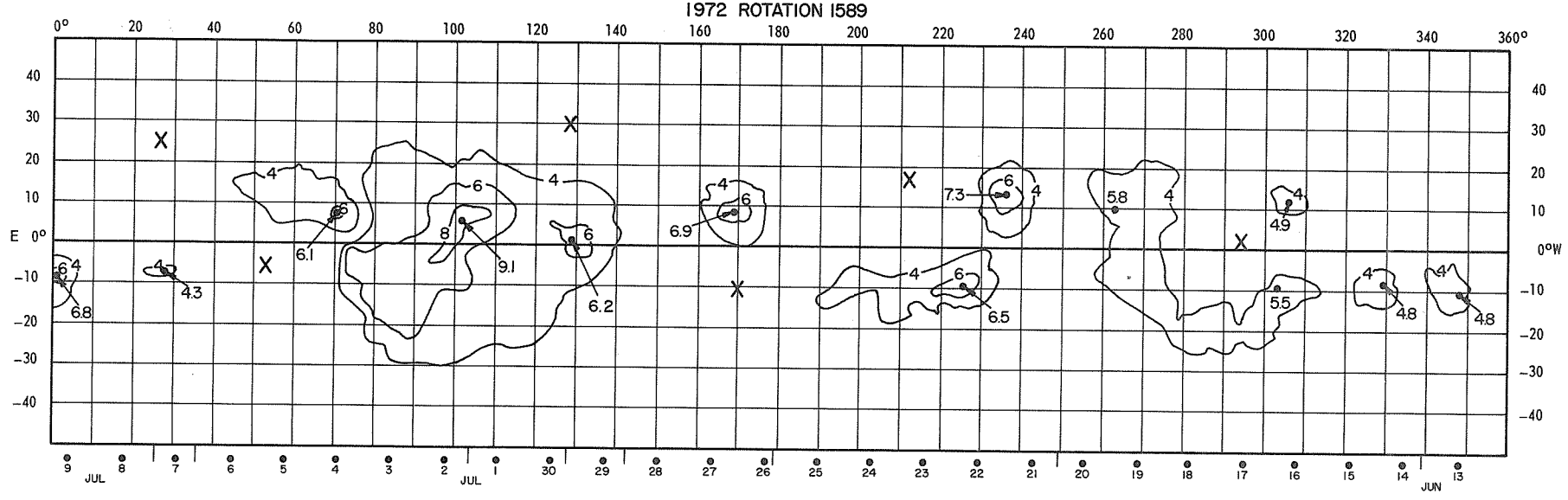
1972 ROTATION 1589



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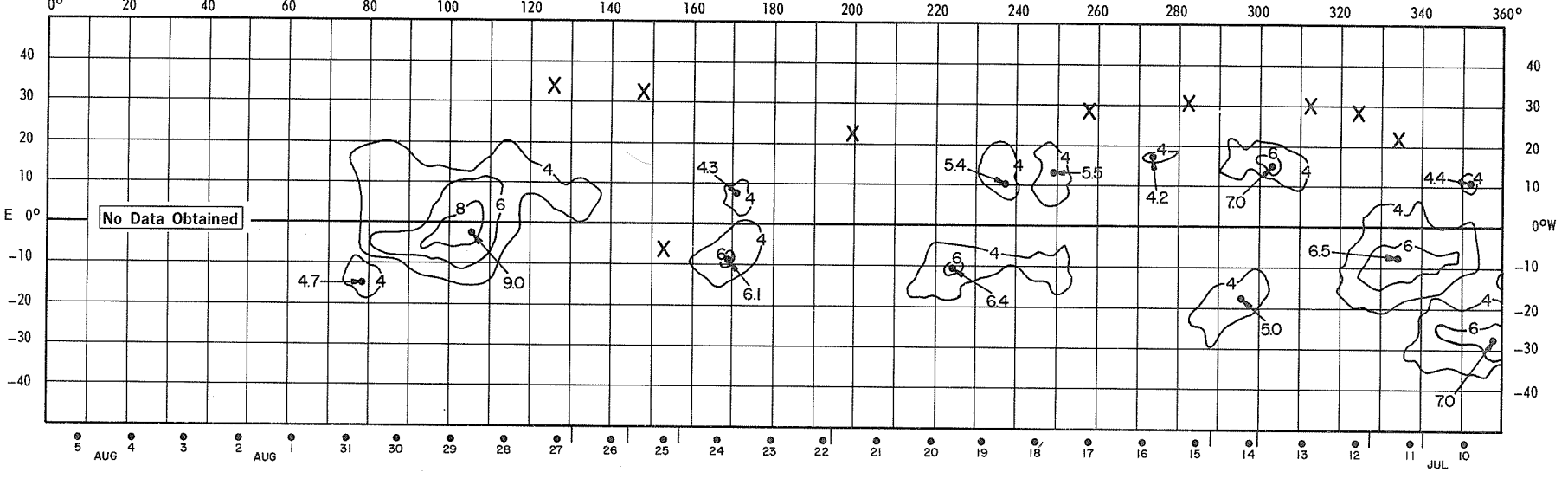

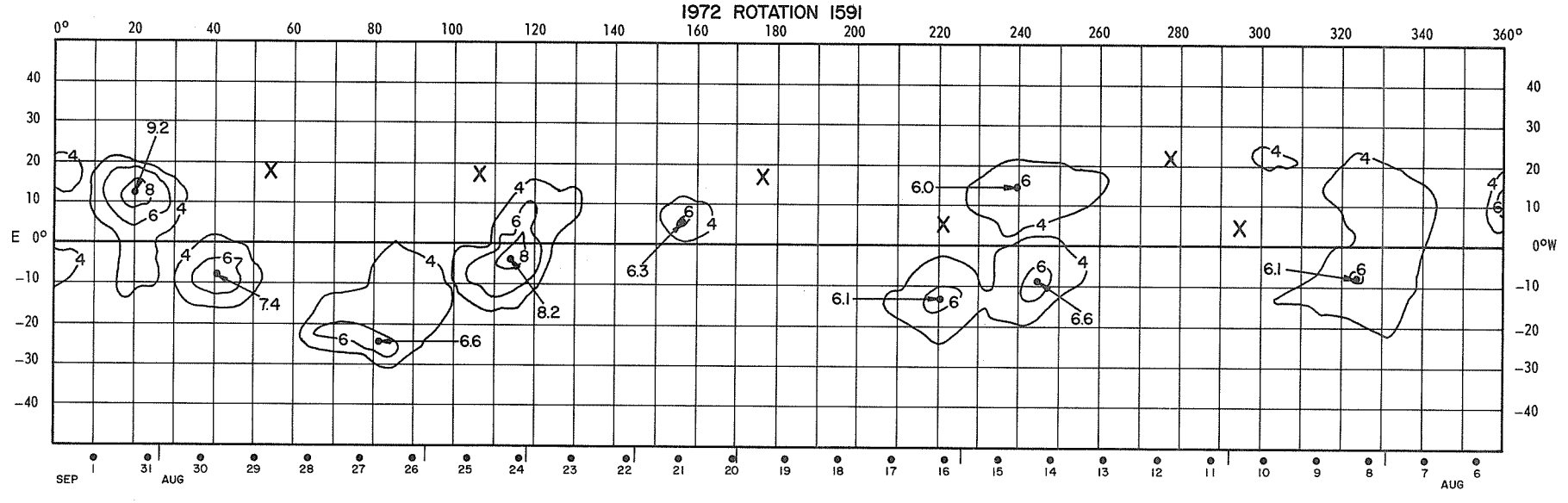
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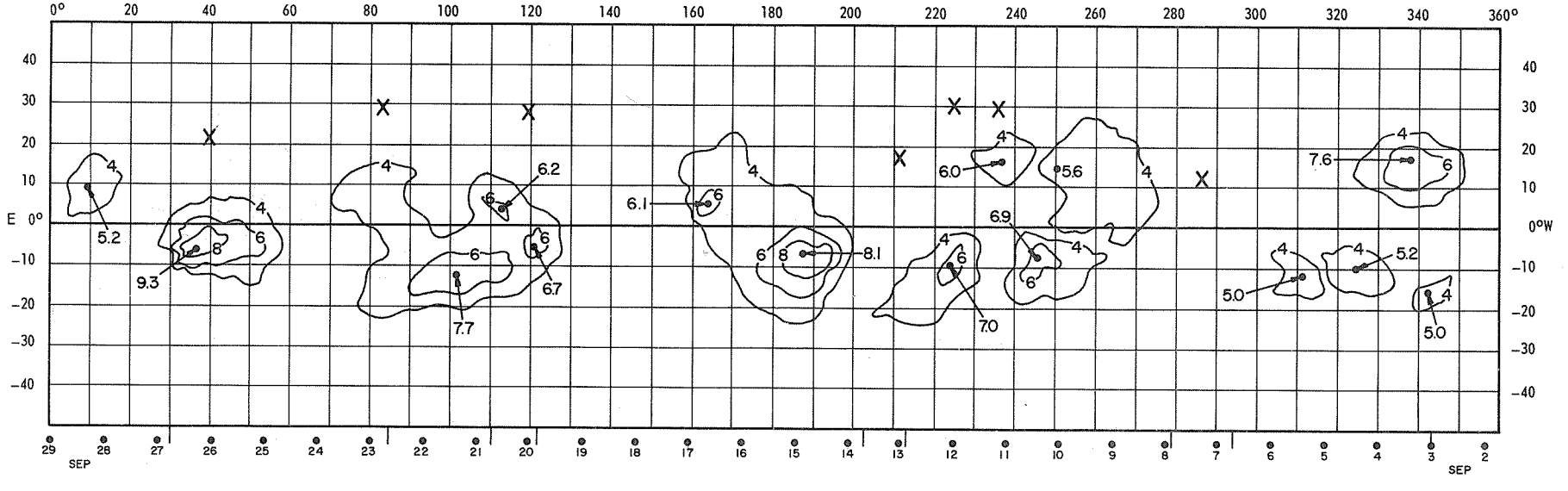
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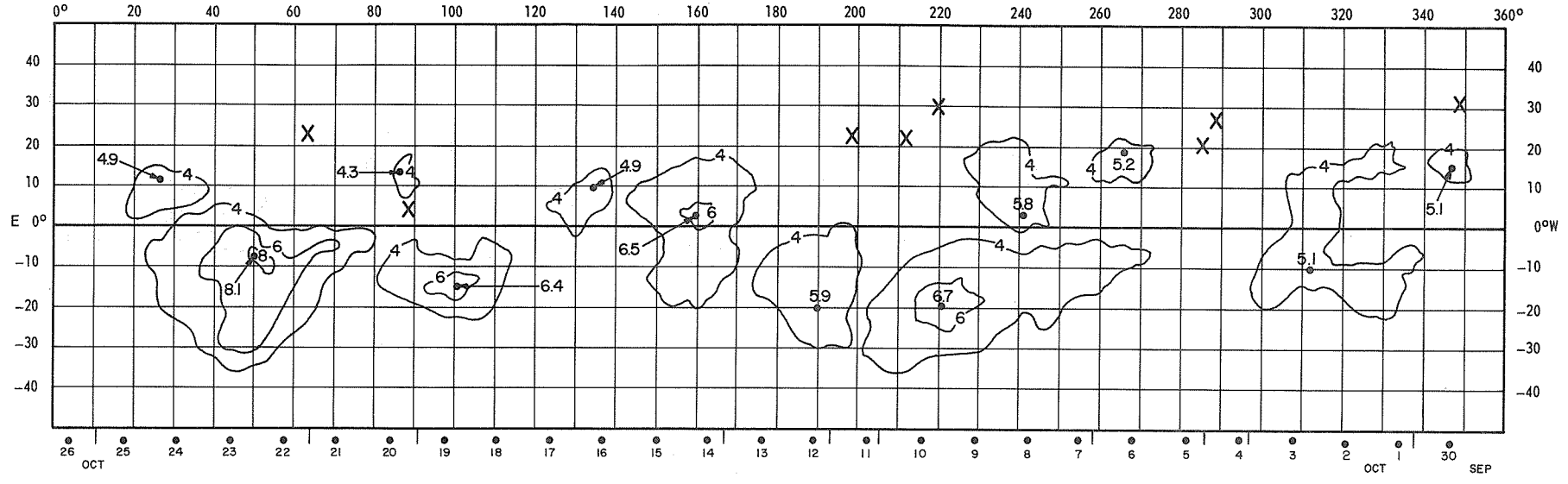

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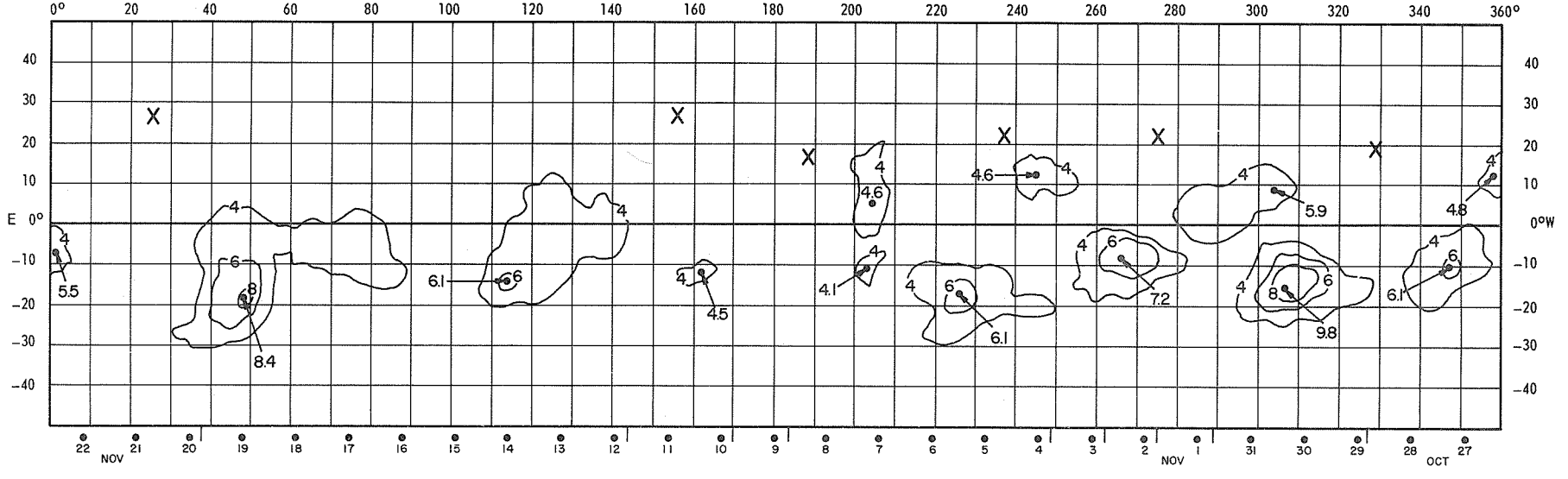

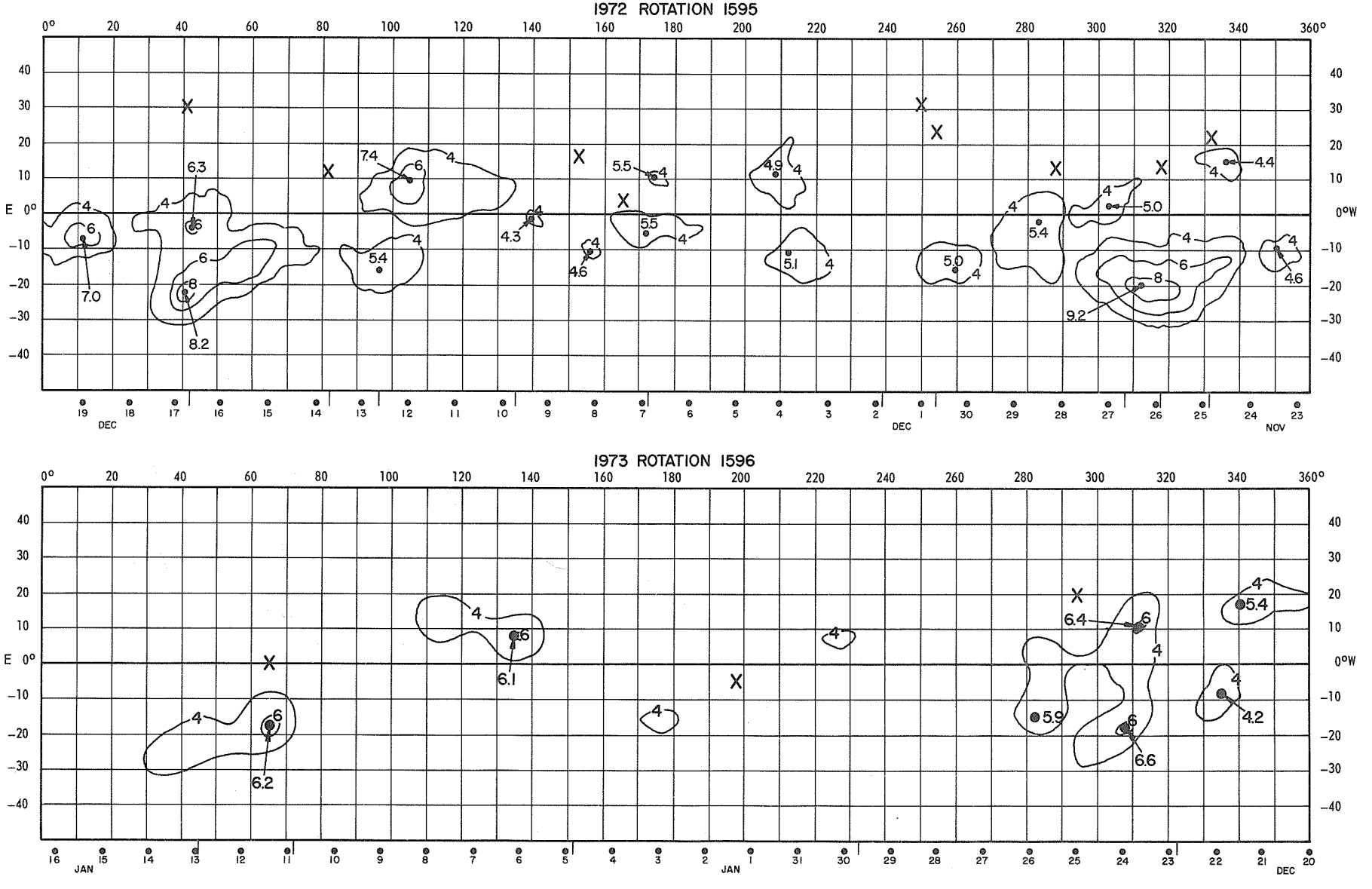
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DEC DEC NOV
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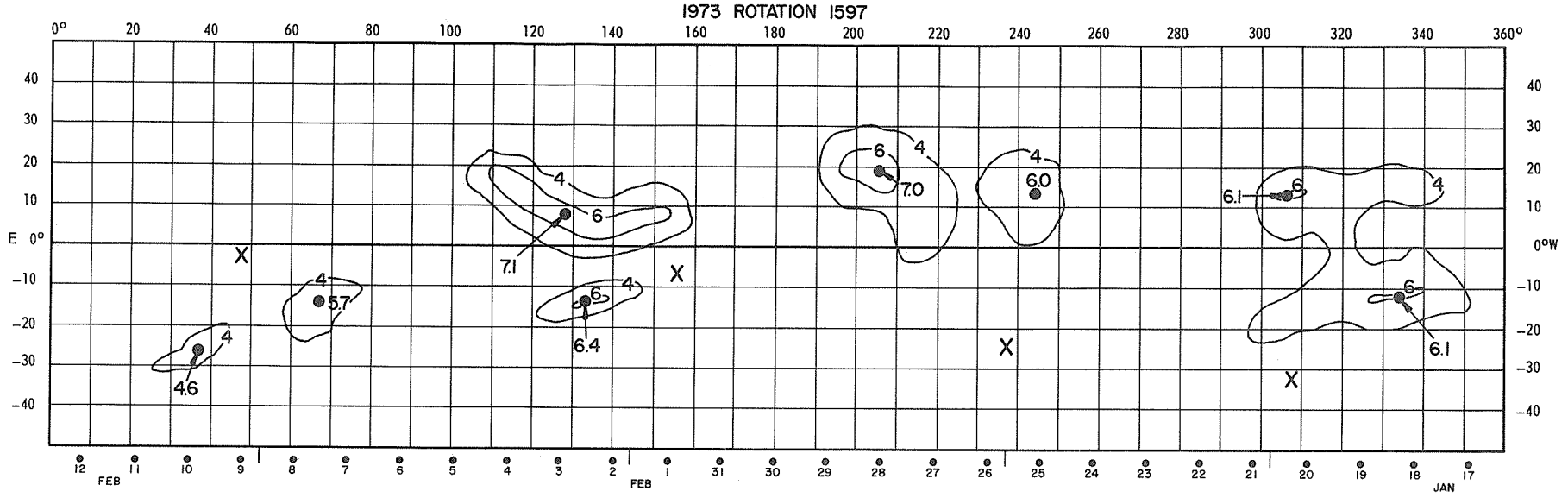
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6 4 7.0
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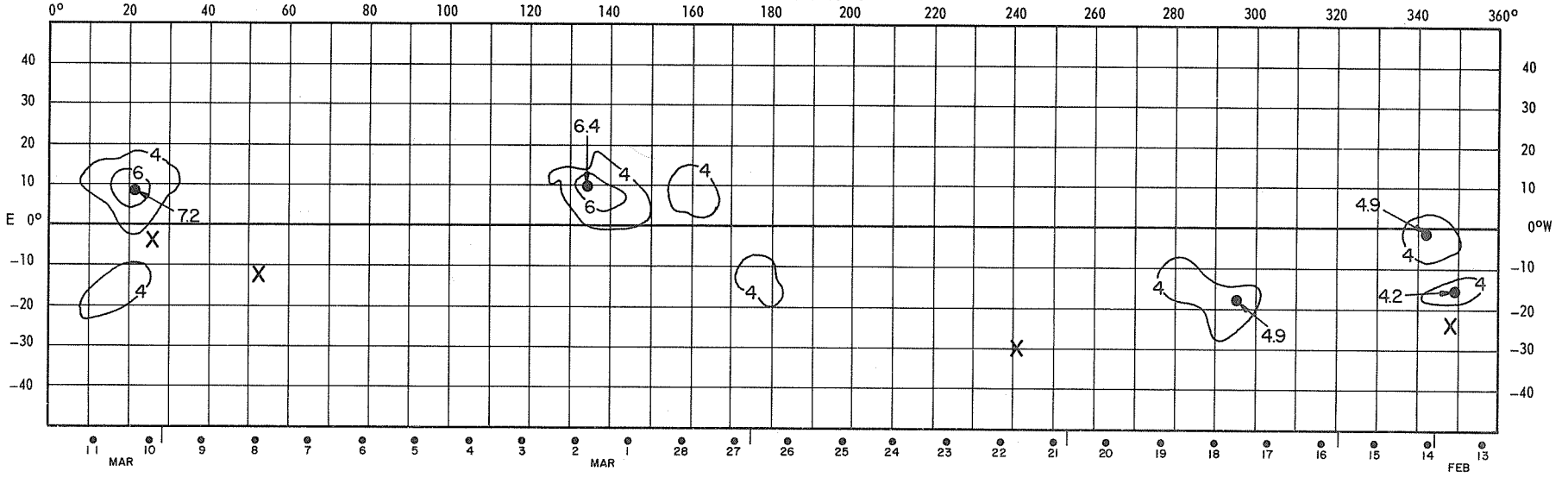
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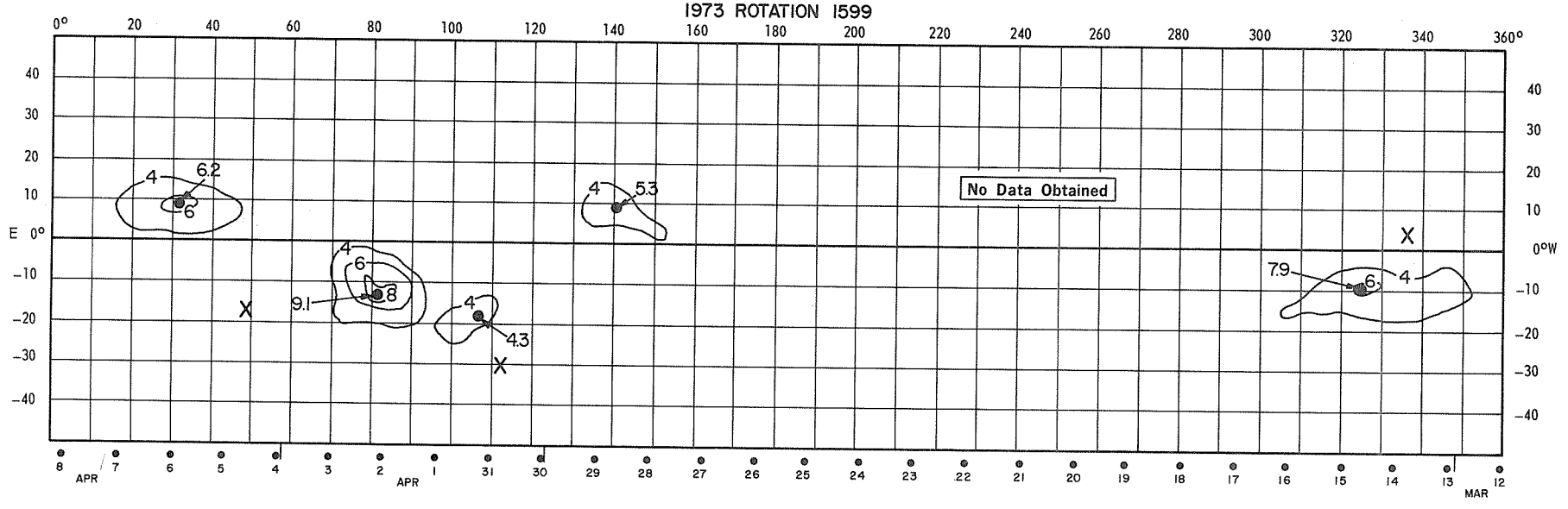
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APR
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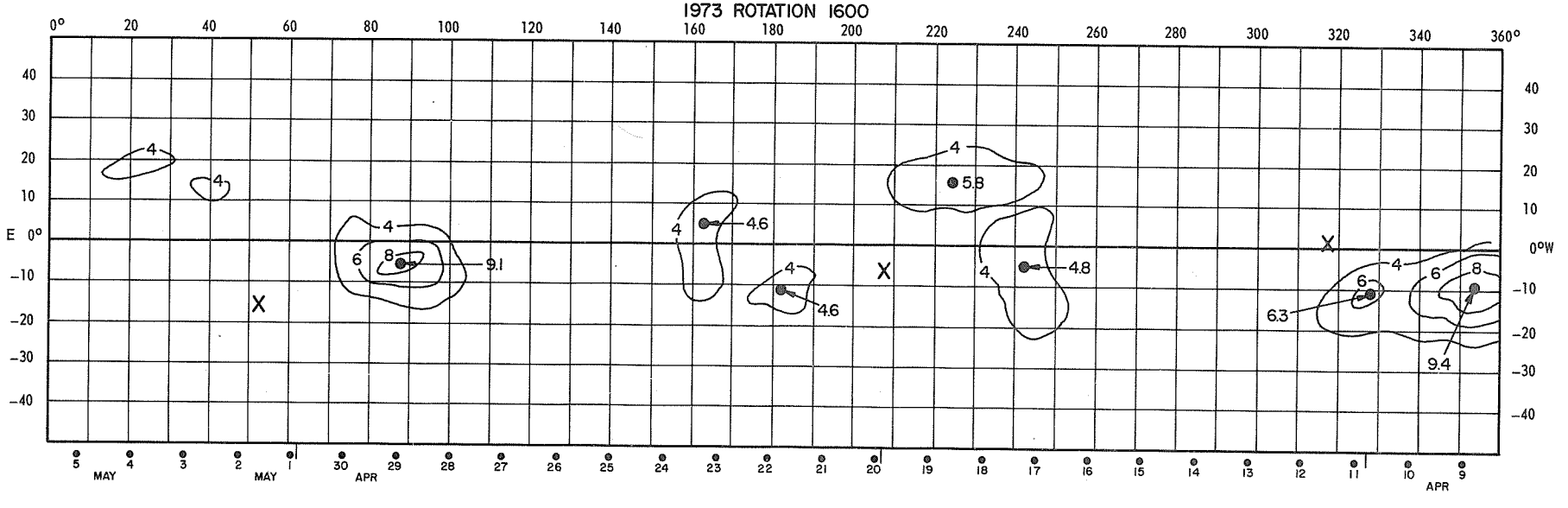
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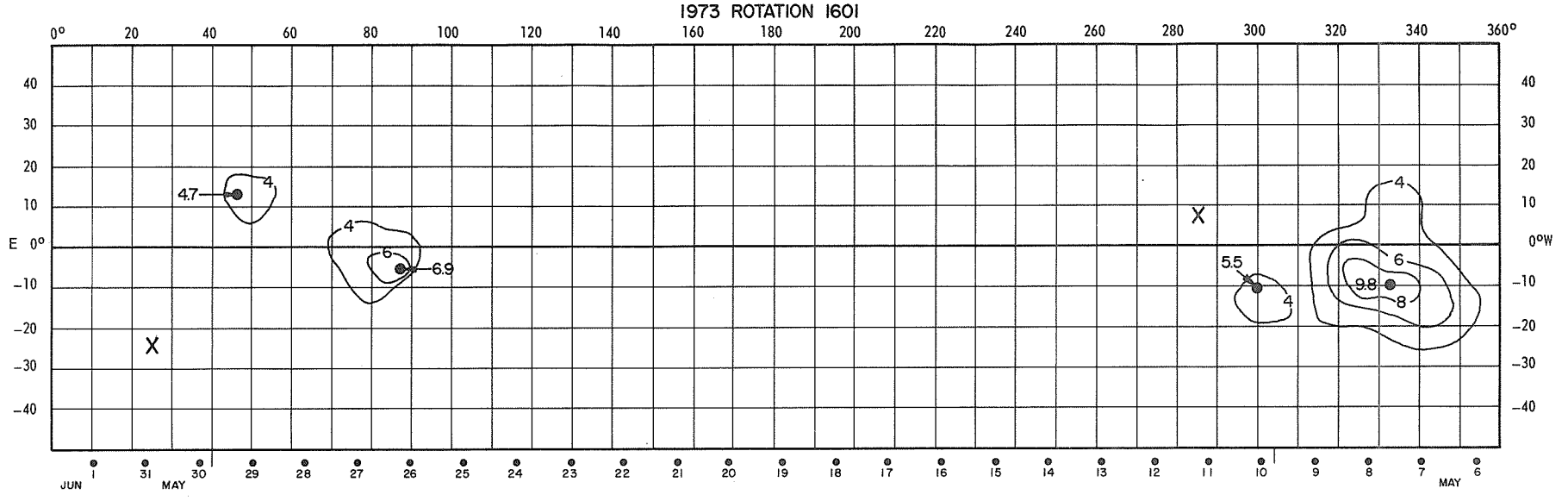
MAY
APR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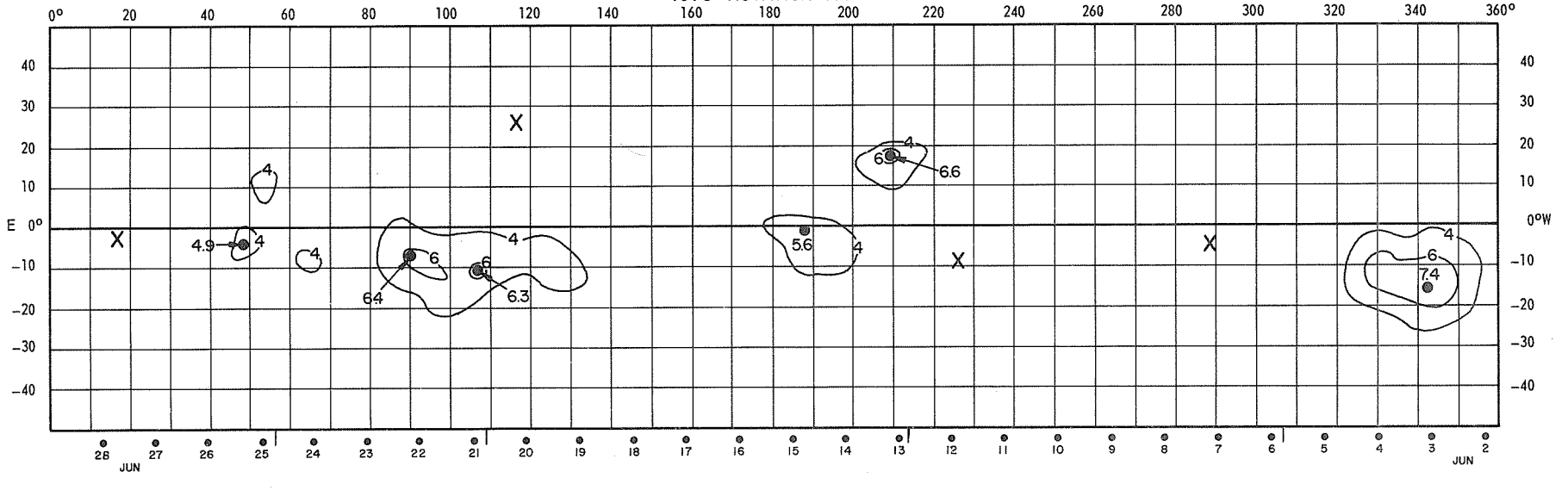
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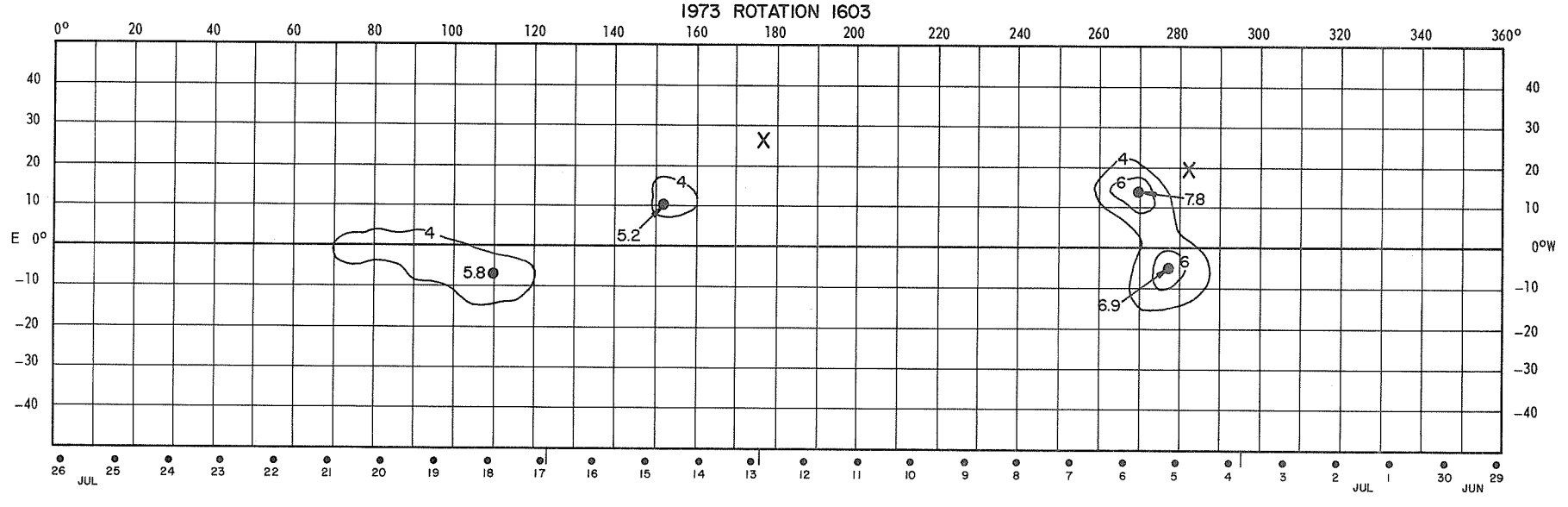
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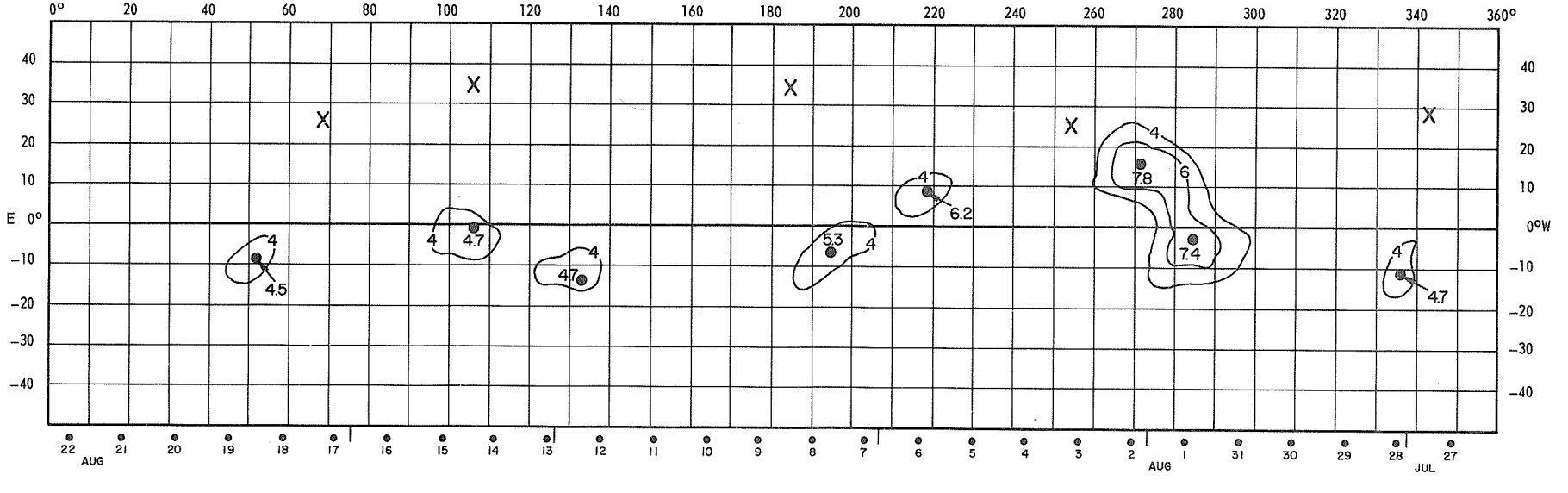
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4.5
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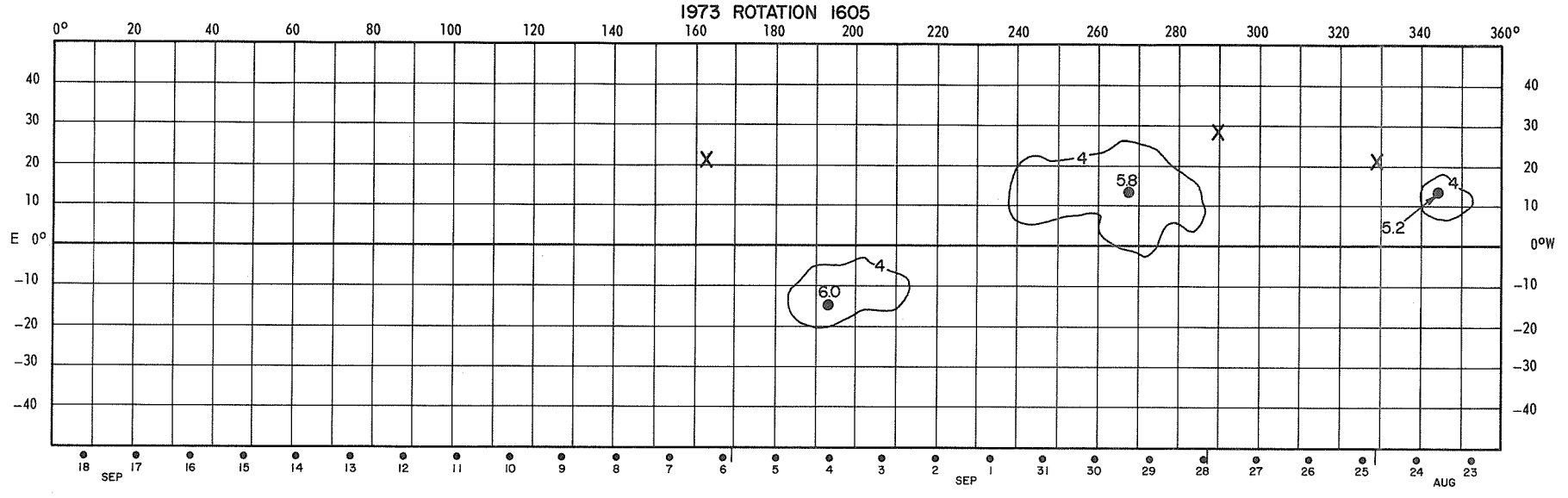
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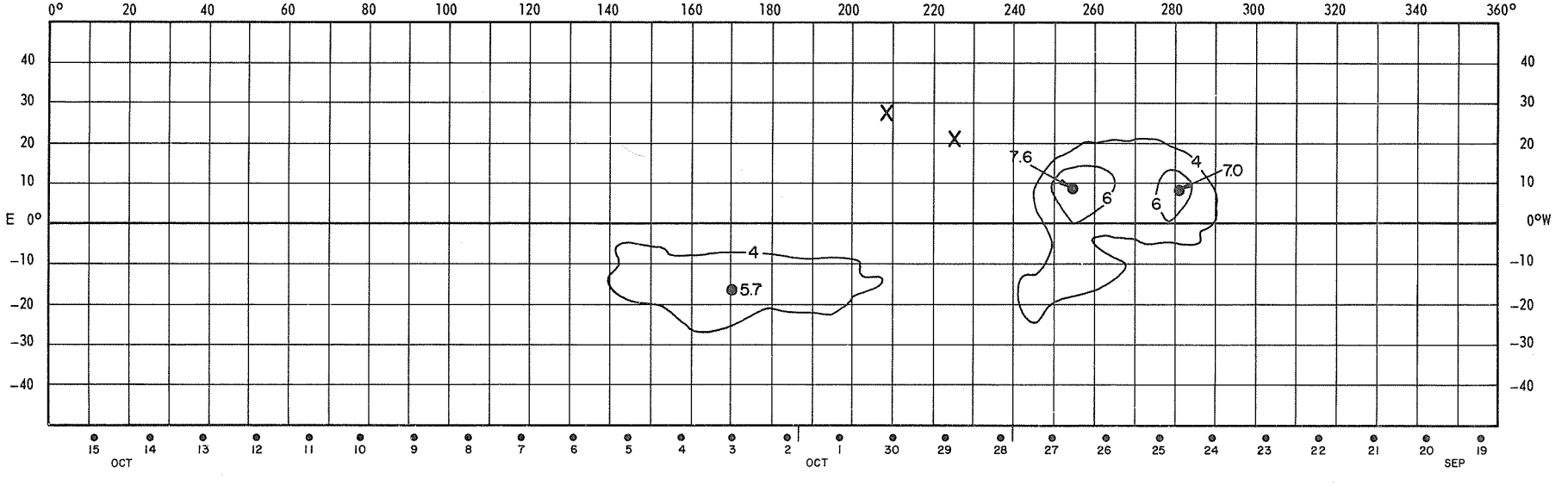
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7.6
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7.0
6
6
4
5.7
15 OCT 14 13 12 11 10 9 8 7 6 5 4 3 2 OCT 1 30 29 28 27 26 25 24 23 22 21 20 SEP 19

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