REPORT UAG-32

WORLD DATA CENTER A
for
Solar-Terrestrial Physics

SYNOPTIC RADIO MAPS OF THE SUN AT 3.3 mm FOR THE YEARS 1967-1969

APRIL 1974

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National Academy of Sciences

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by

Earle B. Mayfield and Kennon P. White III
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and
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El Segundo, California 90245

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The Aerospace Corporation millimeter radio telescope was completed in 1963 and has been used since then for various observations in planetary, solar and stellar research. It is located in El Segundo, California with coordinates 33° 54' 53" N and +7h 53m 30s (118° 22' 30" W) at a height of 38 m. Since 1966 radio maps of the whole solar disk have been obtained routinely at 90 GHz (3.3 mm wavelength). An effort has been made to make a map at least once a day, except when conditions of very dense clouds or rain prevail. Consequently, an extensive library of solar data exists which may be of considerable interest to others.

A difficulty in making these observations available is in developing an appropriate format for publication. The method adopted is based on our investigations of variations of the 3.3 mm emission and correlations with other solar phenomena which have established relationships with photospheric magnetic fields, faculae and centers of activity. Further, the regions of enhanced millimeter emission are well-defined and stable features which can be readily identified and followed during disk passage. Transient phenomena associated with flares which have been discussed by *Shimabukuro* [1968] are usually at the resolution limit of the antenna and are relatively infrequent. As a result, we consider synoptic maps as the most informative presentation and the most concise. For those who may require more detailed data or individual maps for specific dates, separate maps can be provided.

Although the instrument has been previously described by *Jacobs and King* [1965] and by *King et al.* [1966], a brief description is appropriate. The antenna is a Cassegrain design of 15-foot diameter (4.57 meters) in a polar mount. 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. The antenna is controlled by an on-line digital computer through a closed loop servo which permits a variety of tracking modes including a mapping mode which is used 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-ended gallium arsenide crystal mixer which provides for frequency conversion to a 3 GHz intermediate amplifier. The system sensitivity for a signal-to-noise ratio of one at the output is about 0.6°K for 1 second integration time.

For the results reported here, the antenna was programmed to obtain a matrix of emission temperatures centered on the solar disk. A 19x19 matrix was obtained by rastering the antenna between adjacent points. Four seconds settle time was allowed between readings and one second integration for temperature measurement. These individual values were normalized to an undisturbed region near the center of the disk to eliminate the requirement for absolute calibration of the data. This reference temperature used for normalization was selected by analysis of observations previously obtained of the mm radio emission together with the Fraunhofer Institut maps to select a quiet region free of plage or other disturbed emission. One limitation of the maps is that beyond 0.7 $R_{\odot}$ (normalized solar radius) the interpretation becomes difficult because of the finite beam width of the antenna at the solar limb. As a result, the isotherms are restricted to regions less than 0.7 $R_{\odot}$. Occasional pointing errors also occur in centering the temperature matrix on the disk. These errors are typically greater than 20 arc-sec but less than 1 arc-min. Occasional variations in cloud cover can also account for slight differences in the temperature matrix.

A typical map is shown in Figure 1 for 30 June 1971. This has been overlaid on an Hα picture and isotherms have been constructed on the temperature matrix at levels of 2% enhancement. The isotherms in Figure 1 indicate the presence of two regions of significant enhancement which can be identified with the Hα plage in centers of activity associated with magnetic fields in sunspot groups. The maximum enhancements of these mm regions usually occur near the neutral lines of primary bipolar magnetic regions and show daily variations associated with the changes in the magnetic fields. Previous analysis by *Mayfield et al.* [1970] has discussed these relationships of mm enhancement and magnetic fields in detail.

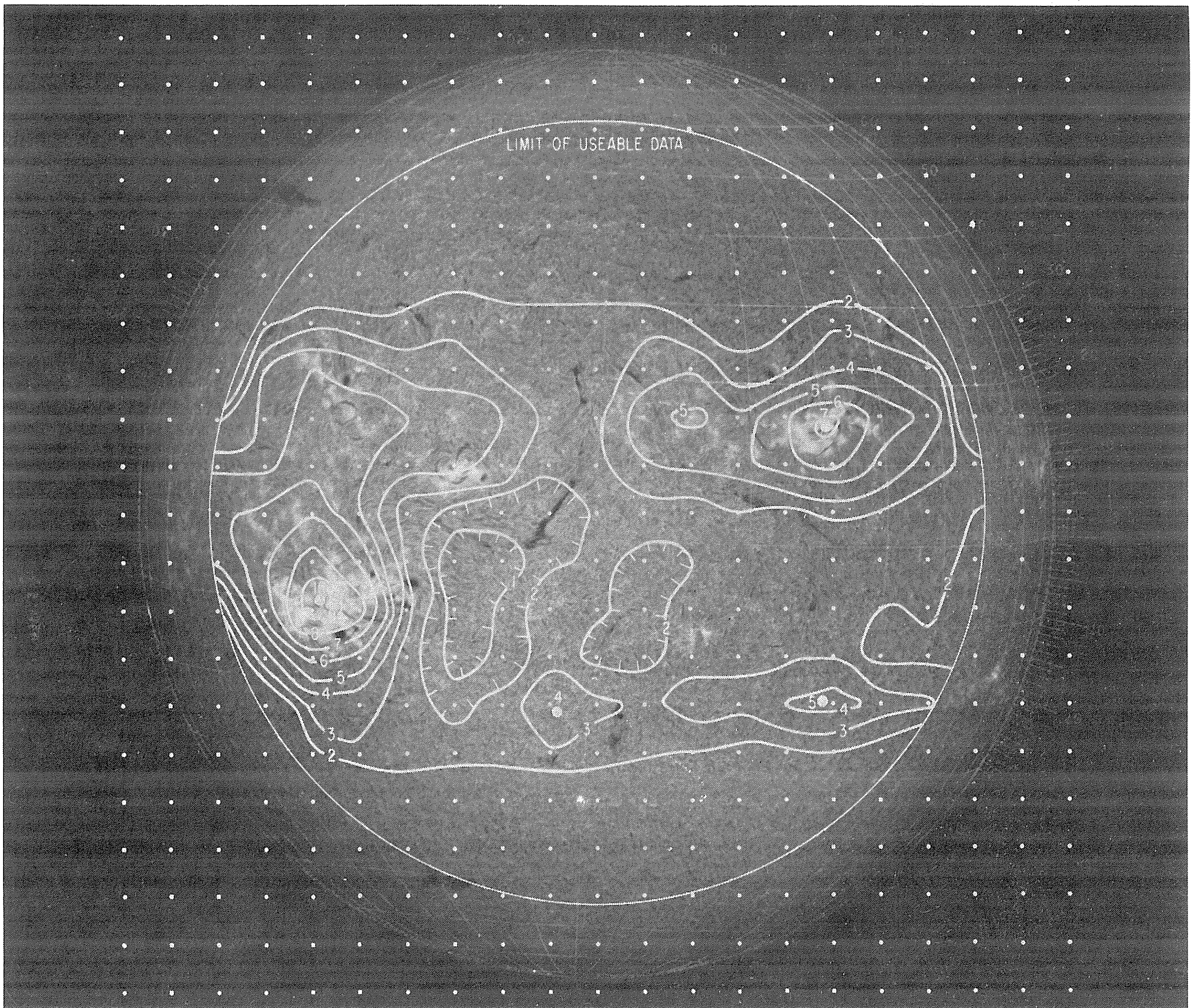

Fig. 1. The 3.3 mm solar radio temperature contour map made on 30 June 1971 superimposed on a concurrent Hα photograph. The contours are labeled in percent enhancement relative to the temperature of the undisturbed region denoted by the hatched contours.

To summarize the results of three years' observation from 1967 through 1969, a synoptic presentation was used based on the Zürich heliographic maps of the sun by *Waldmeier* [1968] and the magnetic field presentation of Mt. Wilson by Howard. These maps are arranged to present the 360° of the solar disk showing the mm 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 of the figure. The vertical scale is the solar longitude between ±50°. 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 from 4% enhancement up have been used. This is done to identify enhanced regions and to show the close correlation between the mm enhancement and white light faculae identified in the Zürich maps.

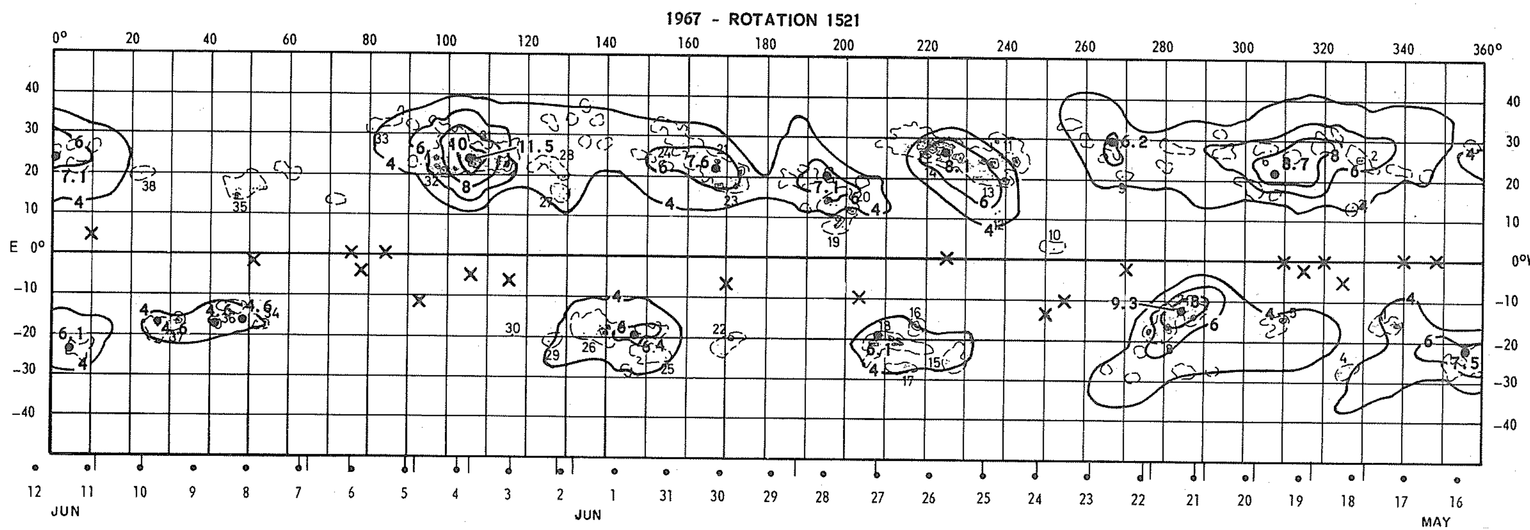

Fig. 2. Synoptic 3.3 mm radio temperature contour map for Carrington rotation 1521 superimposed on the corresponding heliographic map of the photosphere by Waldmeier. Carrington longitude appears at the top of the Figure and date of CMP is given at the bottom. Vertical scale is solar longitude. The contours 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 correspondence between the 4% contour levels and facular areas and between peak enhancements and sunspots.

Plotted in Figure 2 also 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 mm emission and the relation with white light faculae has been given by *Mayfield et al.* [1973] and will not be discussed here. Synoptic maps for the years 1967 through 1969 are given in the appendix. These have been plotted so that they can be readily compared with the Zürich photoheliographic maps and with the synoptic magnetic field maps published in the *Quarterly Bulletin of Solar Activity*.

The question of the longevity of active regions can be investigated by inspection of successive synoptic maps to note 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 at this level individual active regions are usually discernable, whereas a 3% contour usually will run nearly the whole length of the map providing very little information. Additionally, the repeatability of measurements made on different daily maps either on the same day or different days can be as large as ±0.5%, though the average is probably closer to ±0.3%, with some outstanding examples showing variations of no more than ±0.2% over a five- or six-day period. To maintain a precision of about 10% (e.g. 4 ±0.4%), we felt it was safest to display the 4% contour as the lowest level.

Therefore, the longevity of an active region is defined as the time from when it first exceeded 4% enhancement to when it first disappeared below the 4% level. Based on this criterion, some regions are found to last less than a full solar rotation, while others can persist and be followed over five or six rotations. As will be shown below, this result is entirely consistent with the result that the 4% contour level coincides in shape and location with the facular areas, which have lifetimes that can be as short as a few days or as long as a few solar rotations.

Another feature of the synoptic maps whose longevity can be gauged is the quiet regions, as indicated by the clustering of crosses. The nature of these regions is still in question, but certain examples of them can be followed over three or four rotations.

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 in Figure 2 shows each sunspot group at the time of its maximum evolution. Umbrae are given as black dots, penumbrae are shown by their outlines, and facular regions are shown by dashed lines on the maps.

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, which include: (1) slow, evolutionary changes in the active regions, since the photospheric maps pertain to the maximum development of the regions, while the millimeter maps reflect the appearance closest to central meridian passage; (2) rapid changes in the active regions, as caused by flares, whose residual effects can influence the radio contours (although, such has been allowed for and corrected when possible); (3) selection of an invalid normalization point for a particular daily radio map (e.g., a dark absorption filament), which would cause an apparent "growth" or "contraction" of the enhancement levels; and (4) the lack of a physical connection between the two phenomena.

We hope these results will be of benefit to other investigations of solar phenomena. Subsequent data will be published as they are reduced and analyzed. Individual maps of particular times, if available, may be obtained for the years 1970 to the present by communicating with the authors. Comments or recommendations for improving the format of the presentation are welcomed.

Acknowledgements

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MAYFIELD, E. B., J. HIGMAN and C. SAMSON | 1970 | *Solar Phys.*, *13*, 372.

MAYFIELD, E. B., K. P. WHITE III and F. I. SHIMABUKURO	1973	IAU Symposium 57 on Coronal Disturbances, Surfers Paradise, Australia.
SHIMABUKURO, F. I.	1968	*Solar Phys.*, *5*, 498.
WALDMEIER, M.	1968	*Publikationen der Eidgenossischen Sternwarte, Zürich 13*, Heft 2.

APPENDIX

Synoptic Radio Maps of the Sun at 3.3 mm Wavelength for the Years 1967-1969

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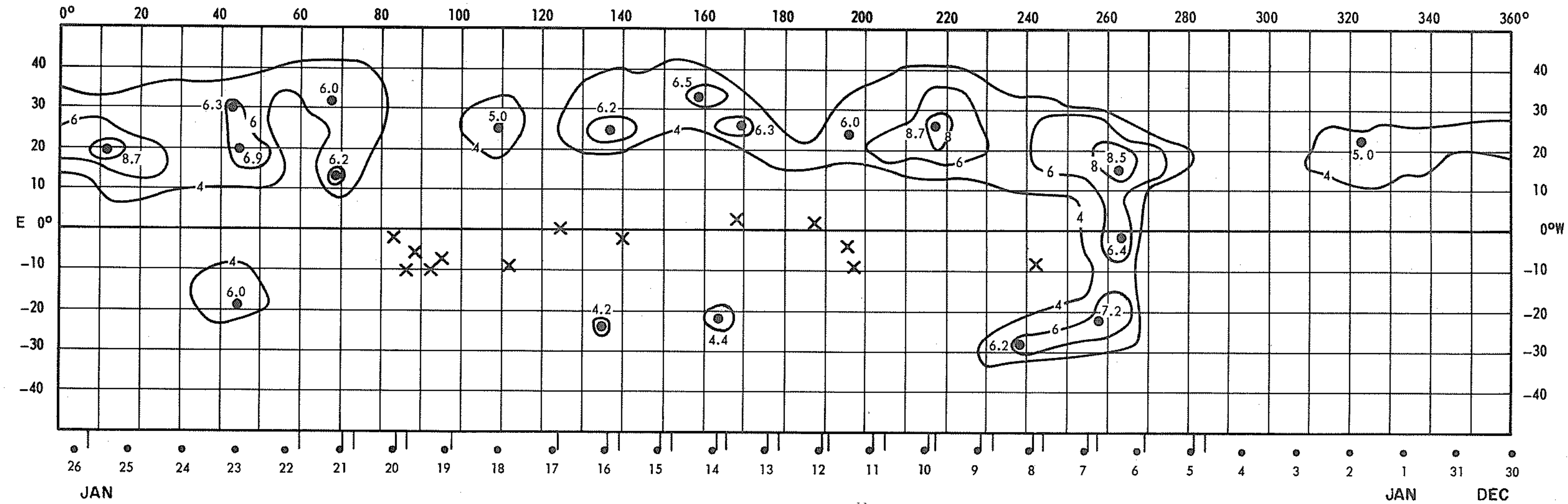

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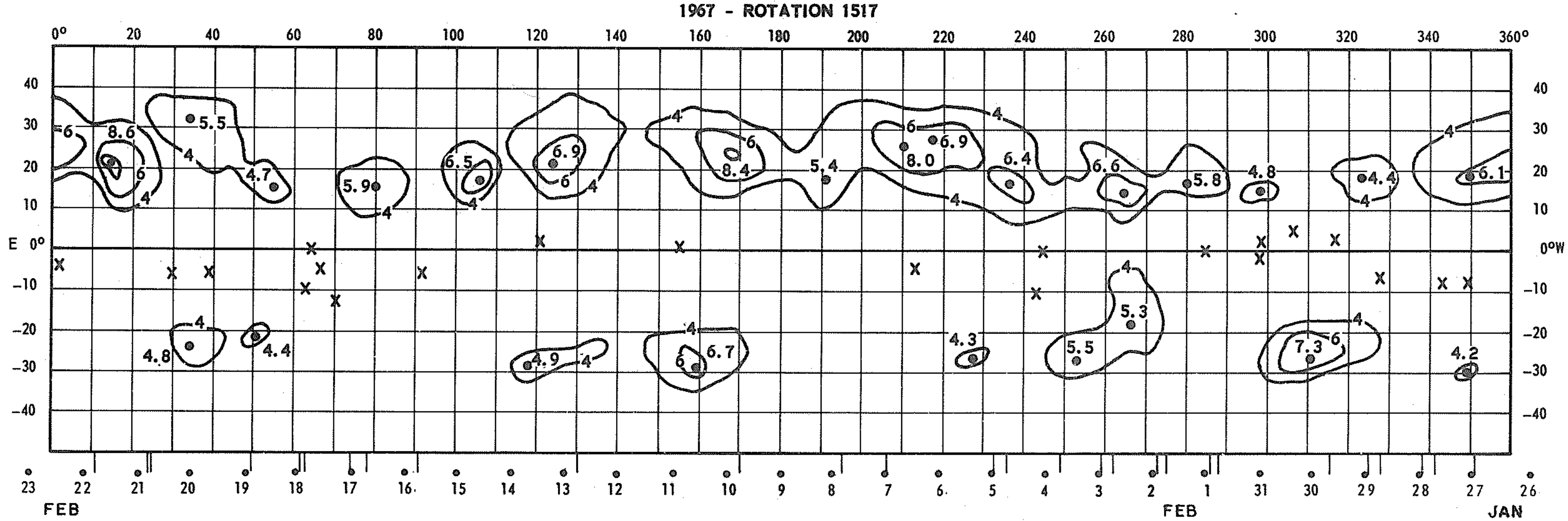

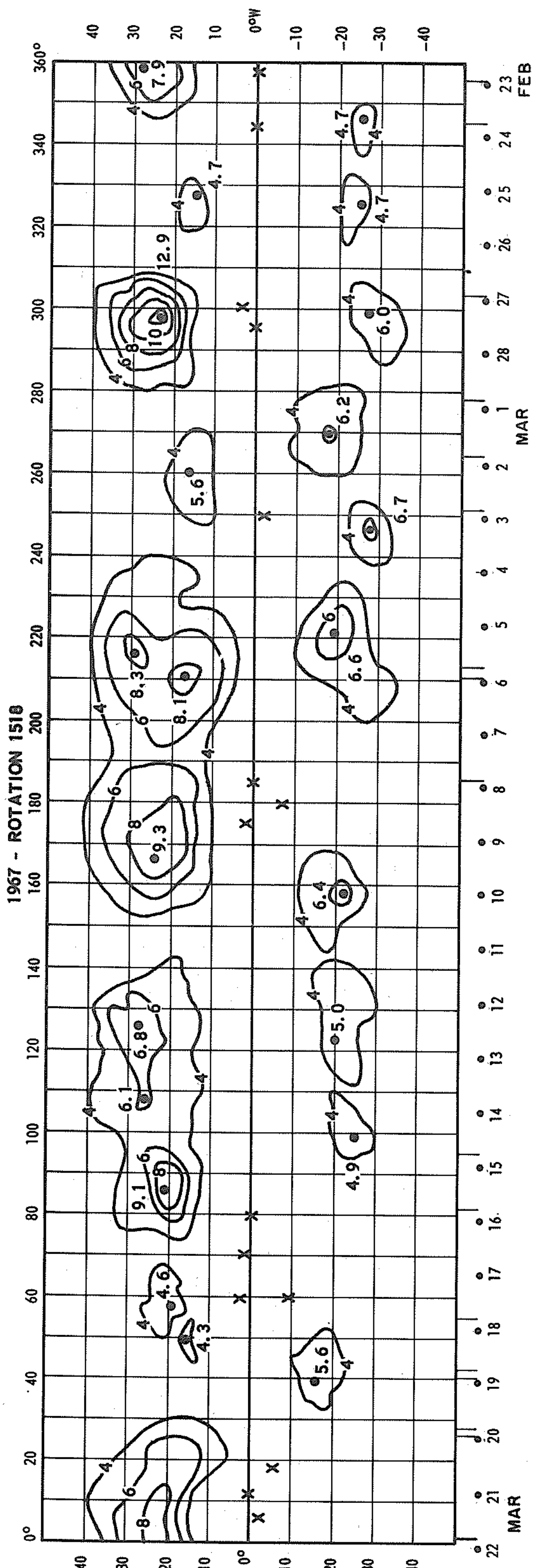
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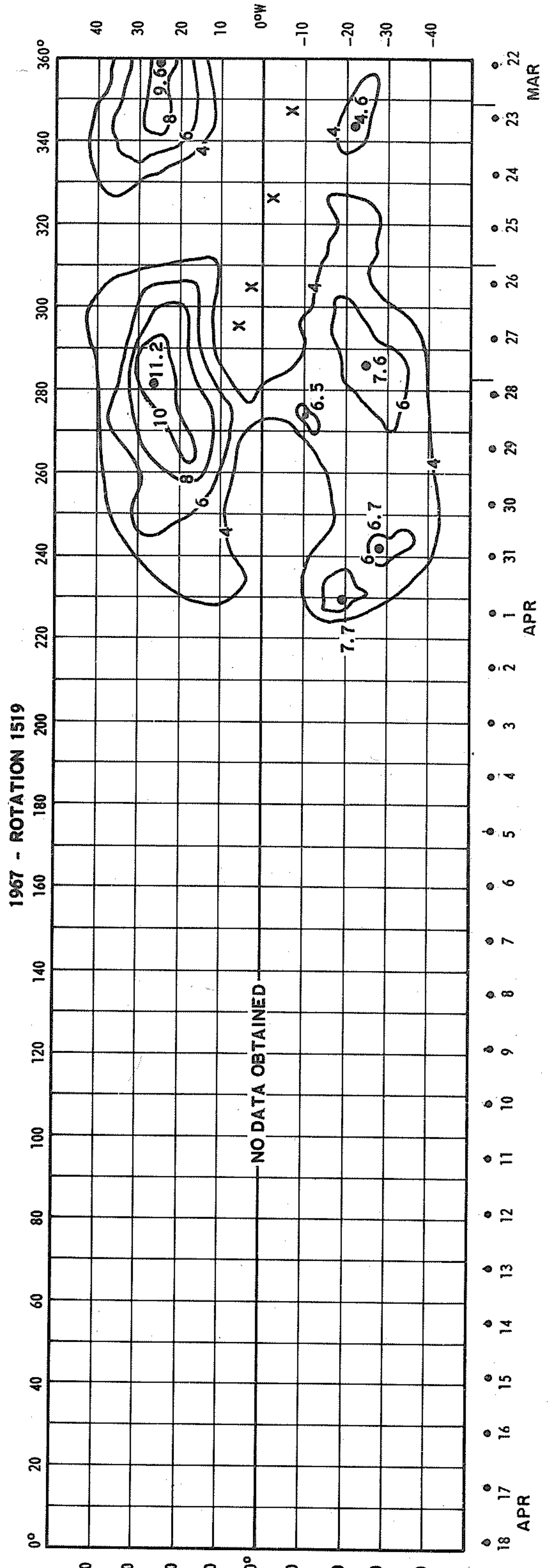
FEB
MAR
MAR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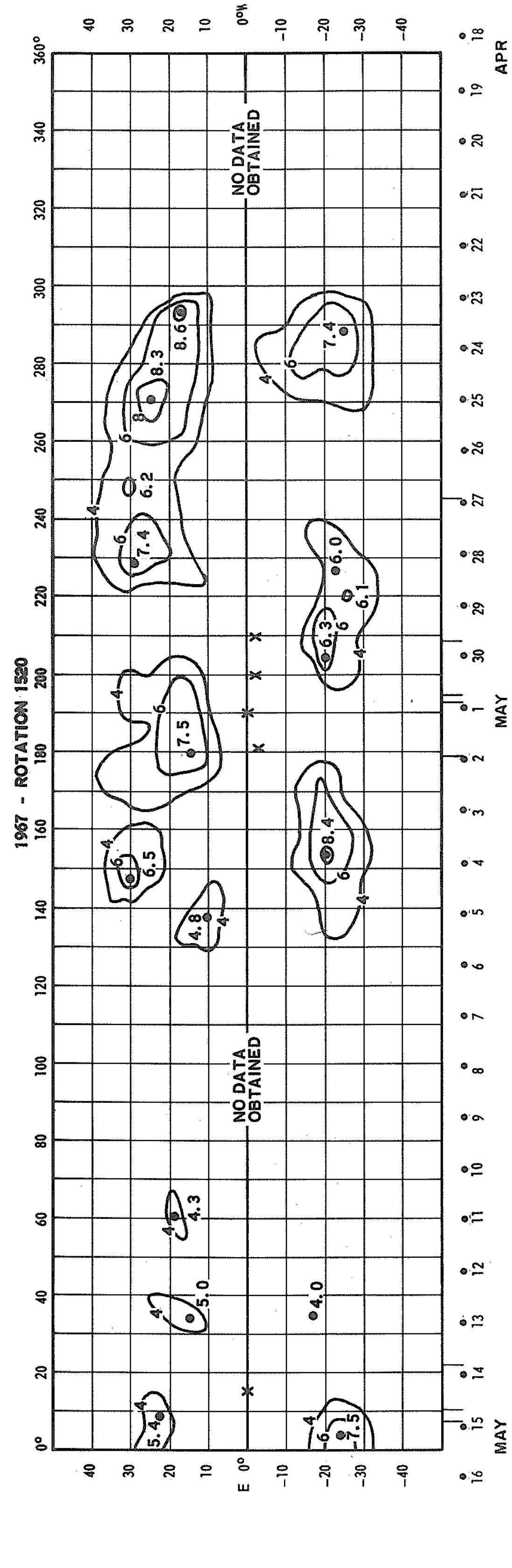
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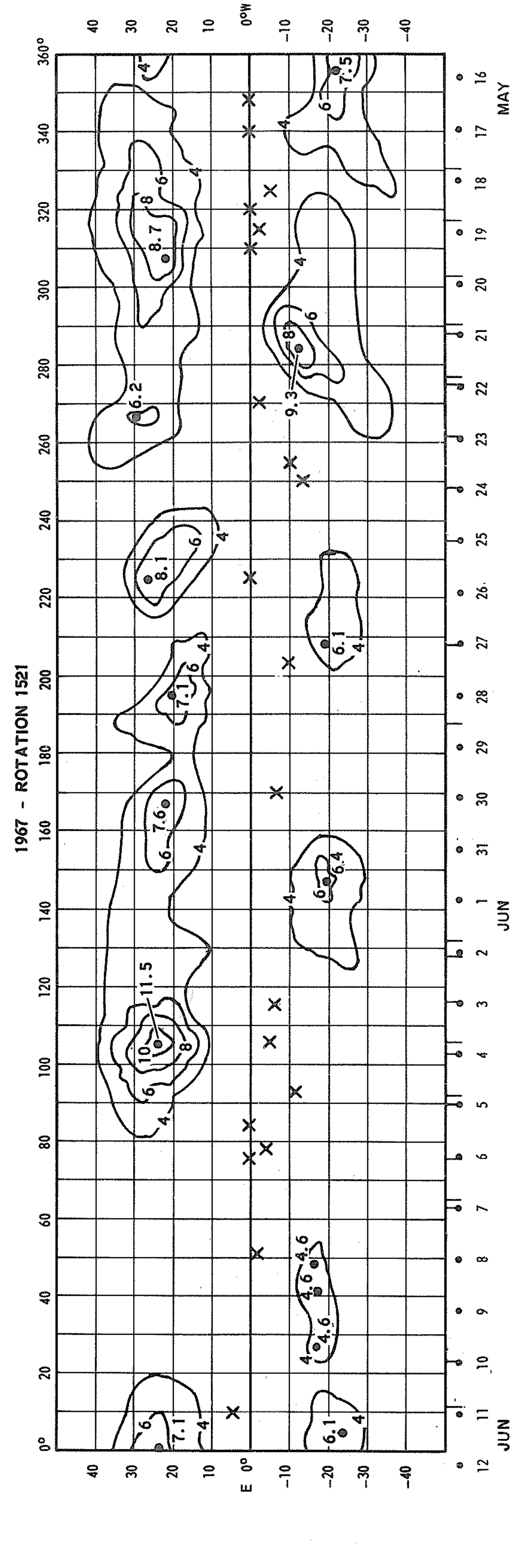
MAY
MAY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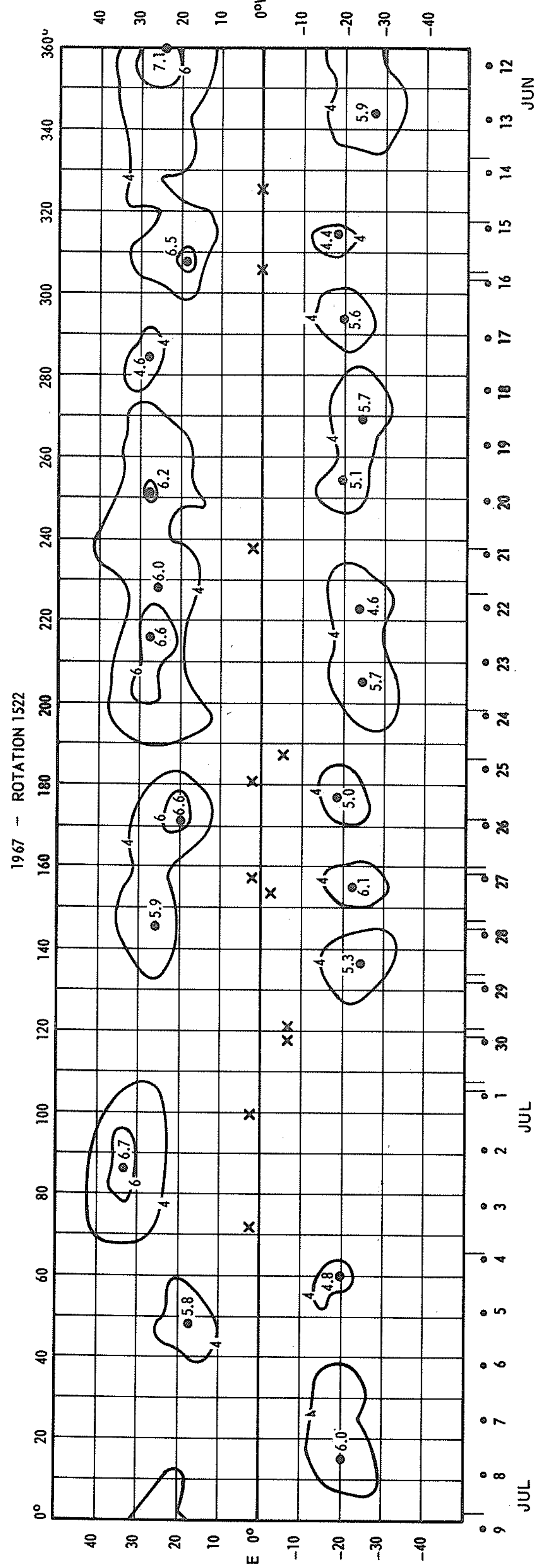
JUN
JUN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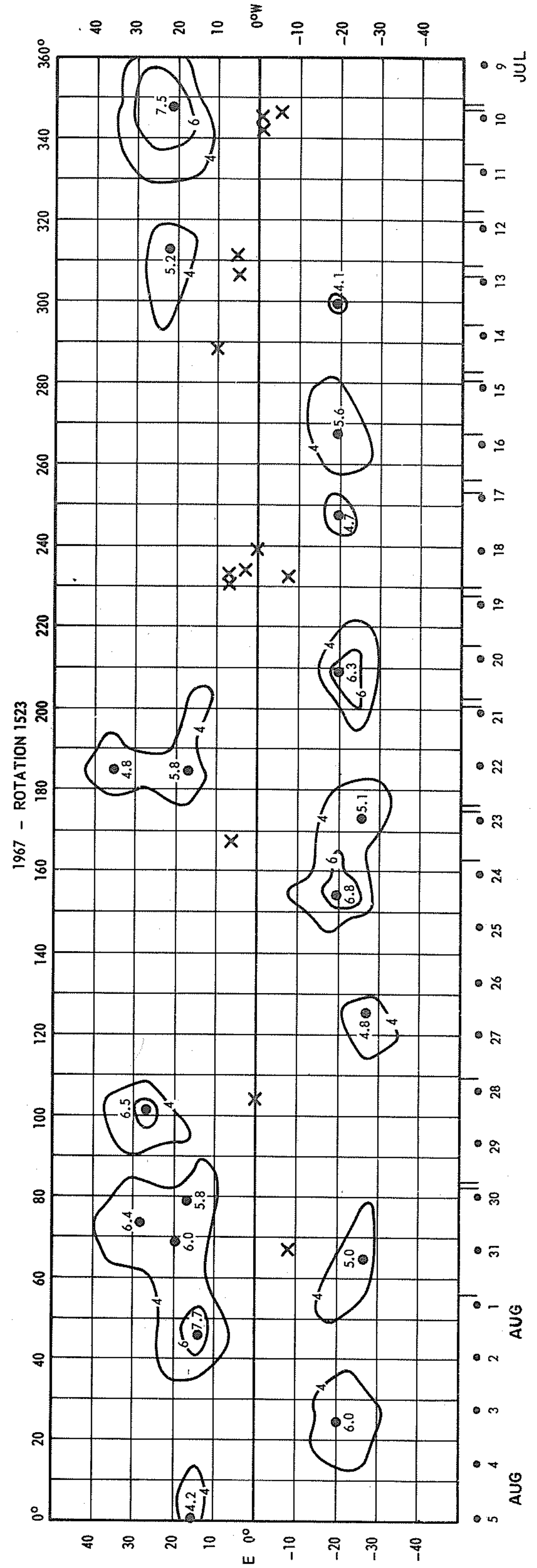
JUN
JUL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JUL
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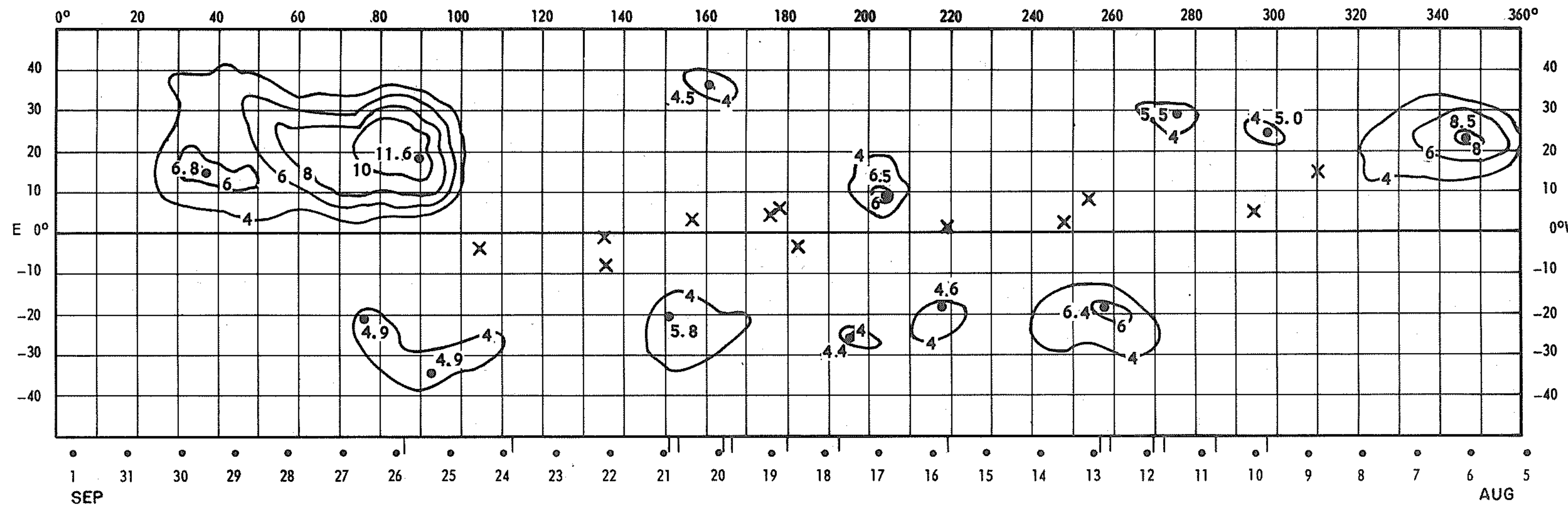
1967 - ROTATION 1524



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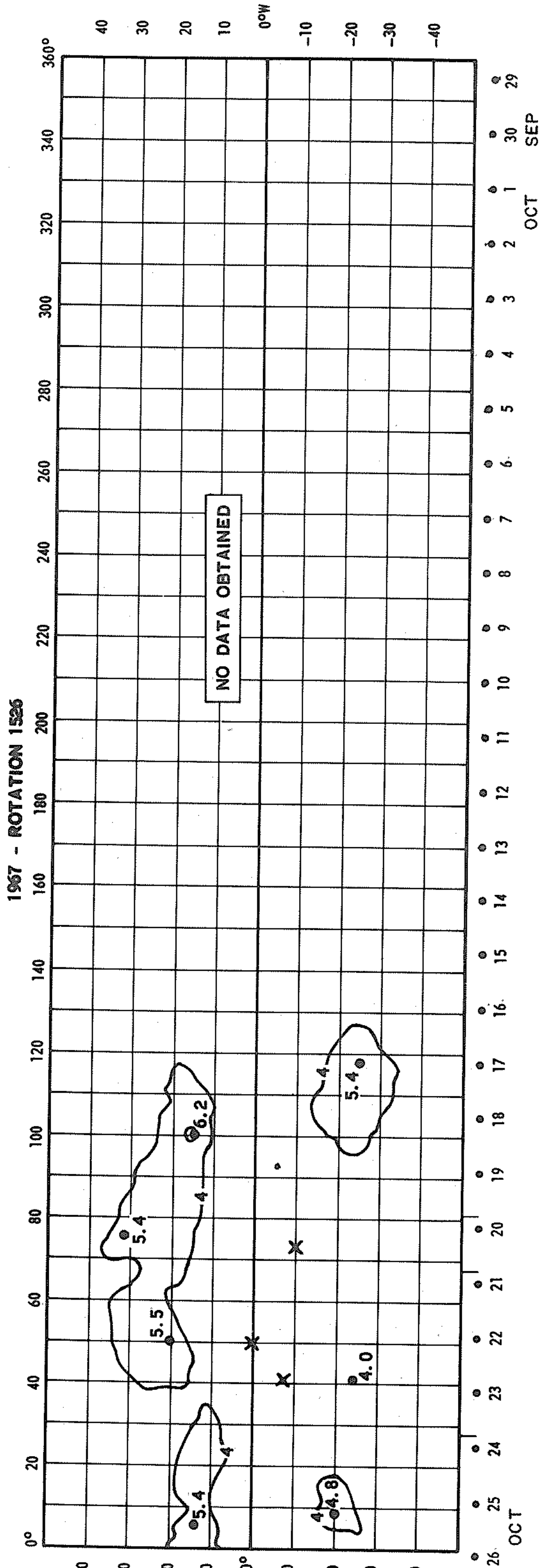
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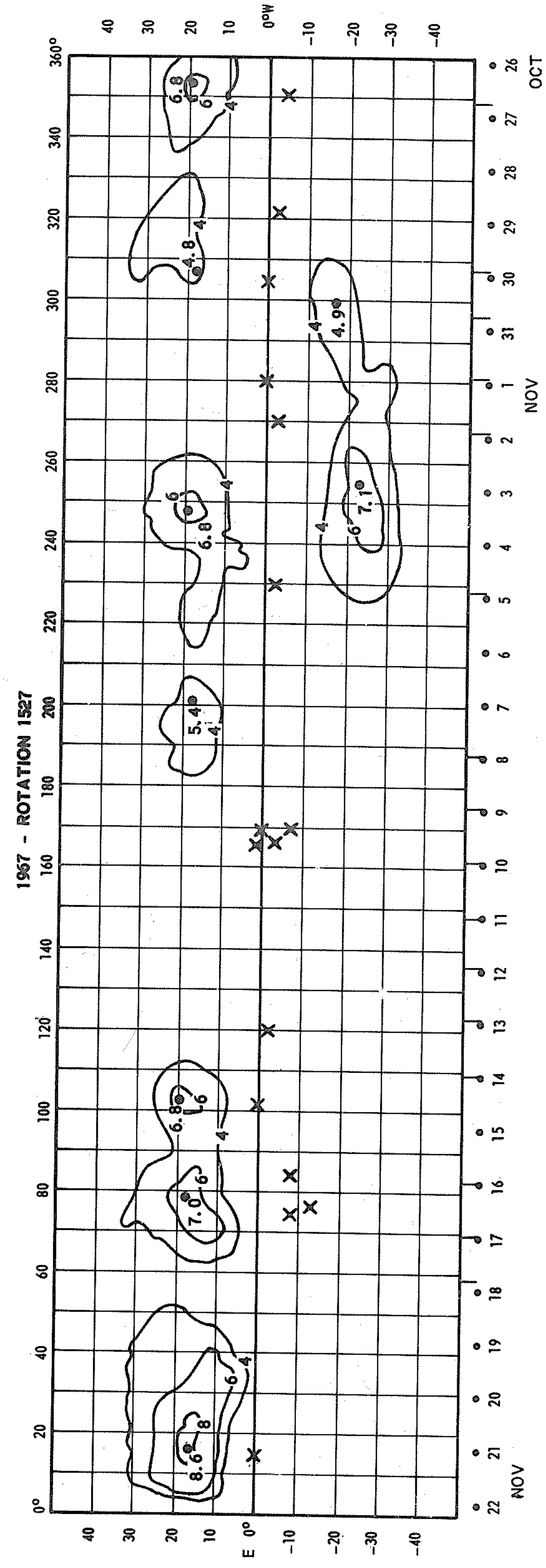
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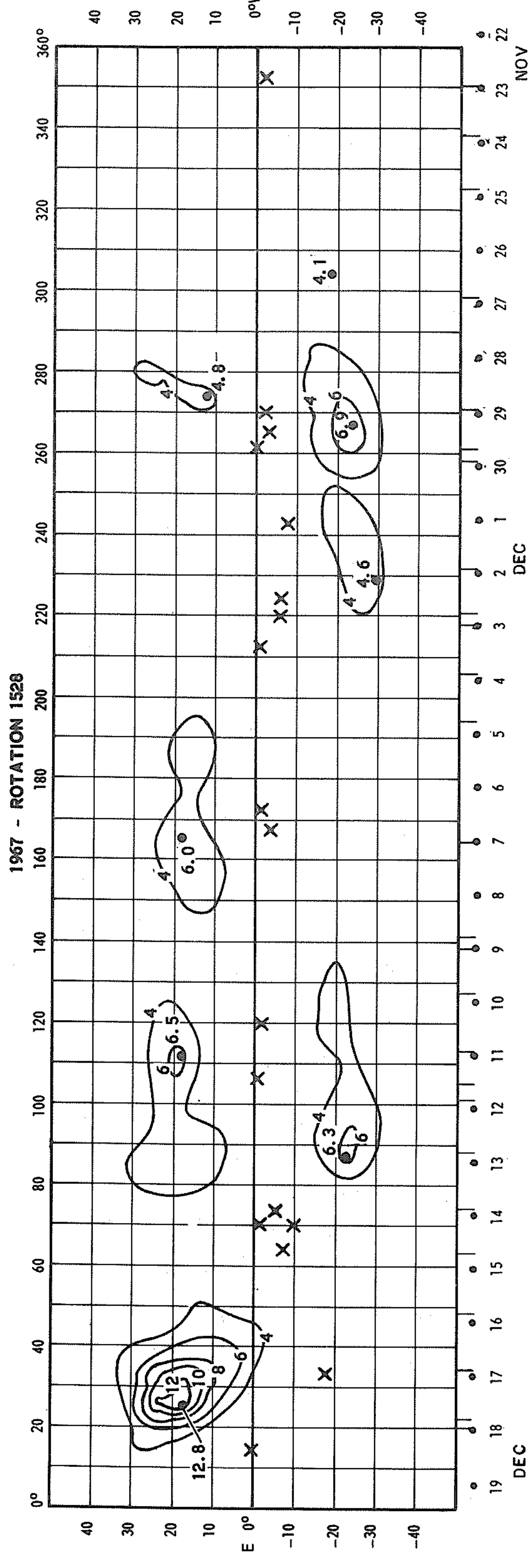
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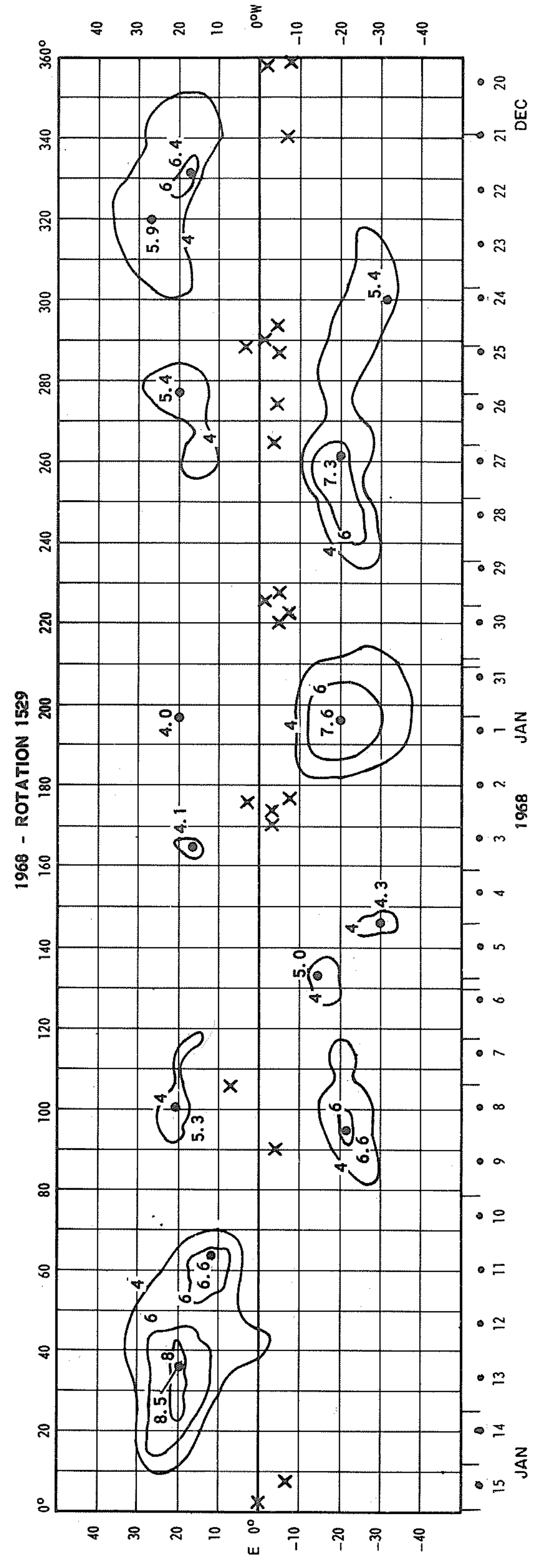
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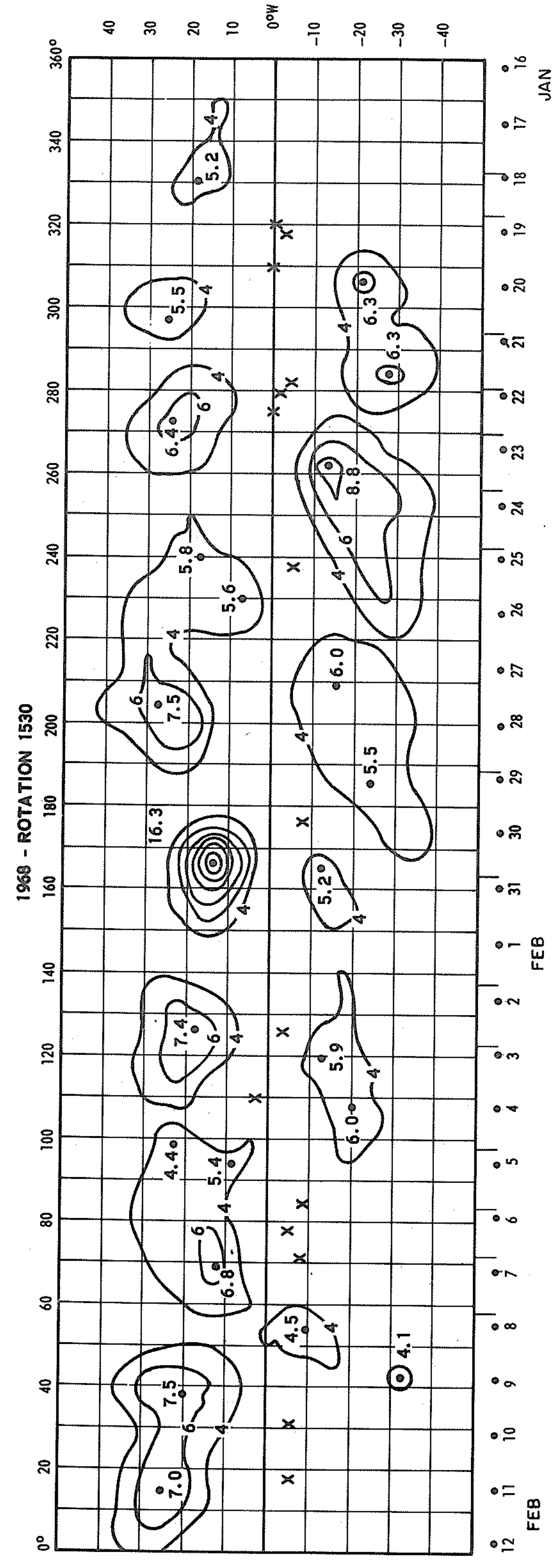
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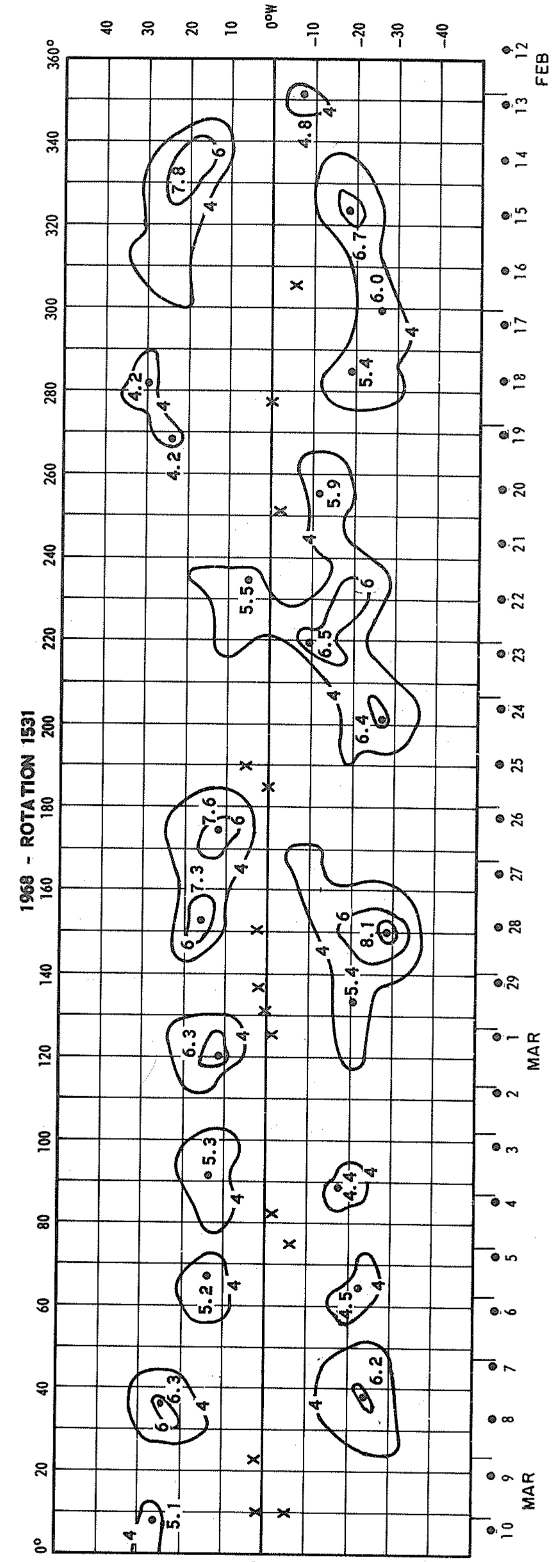
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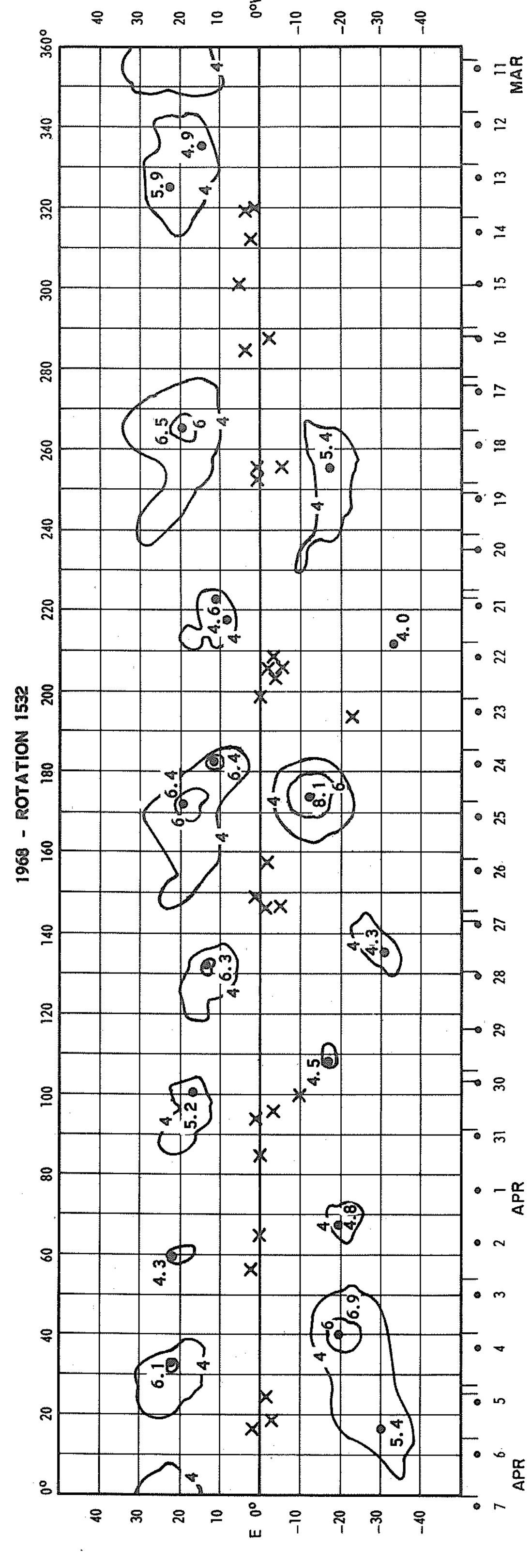
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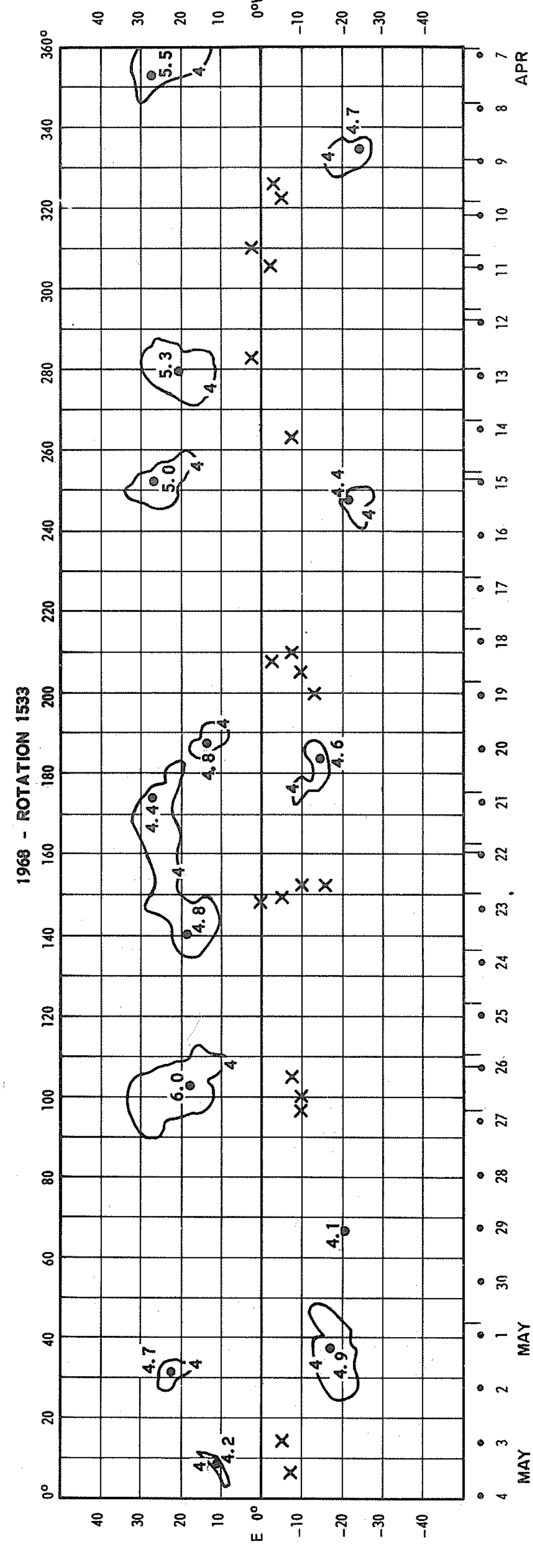
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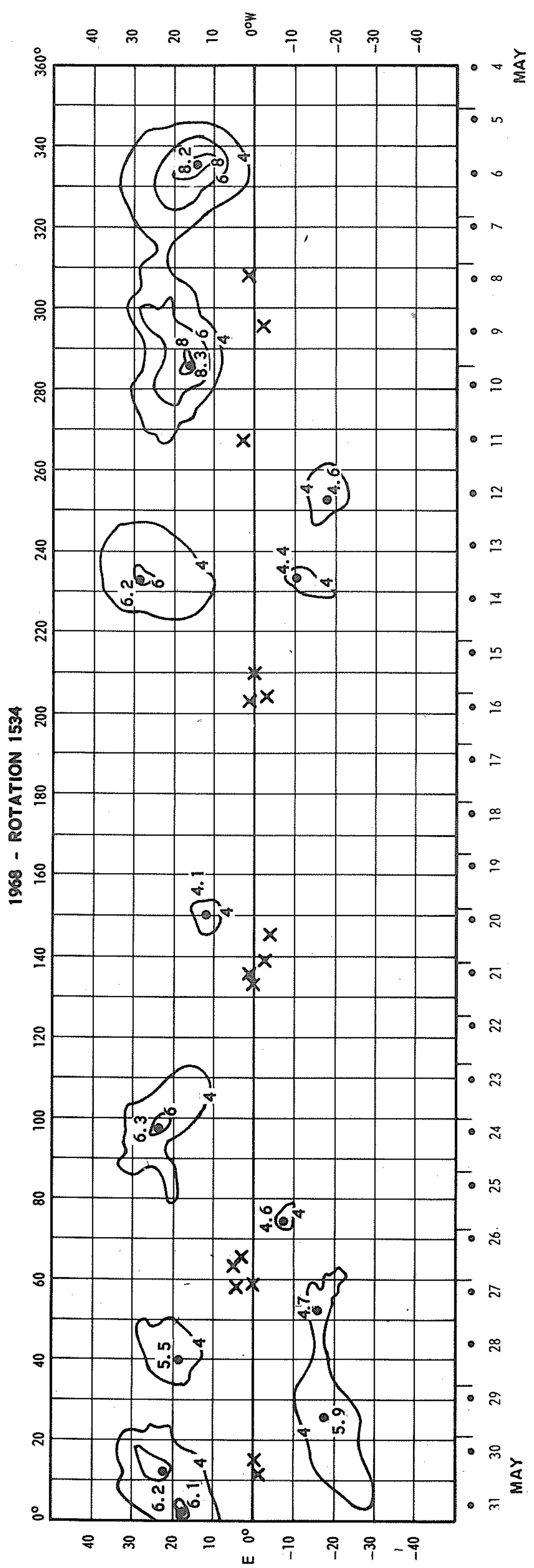
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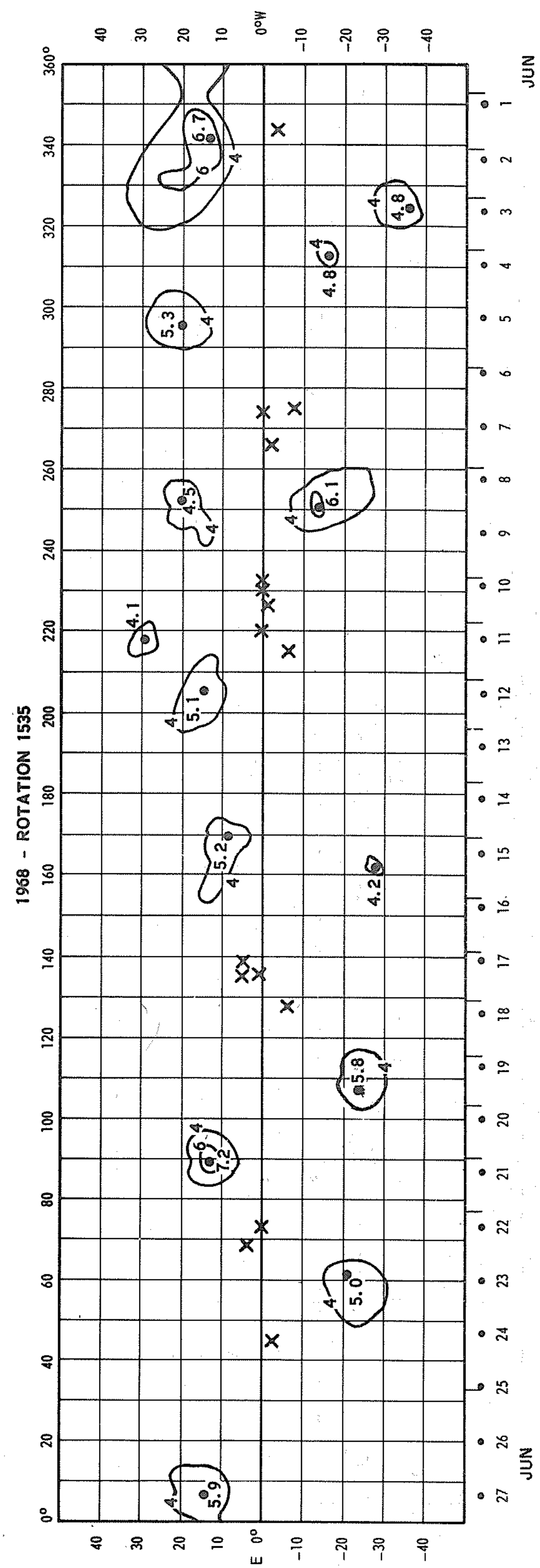
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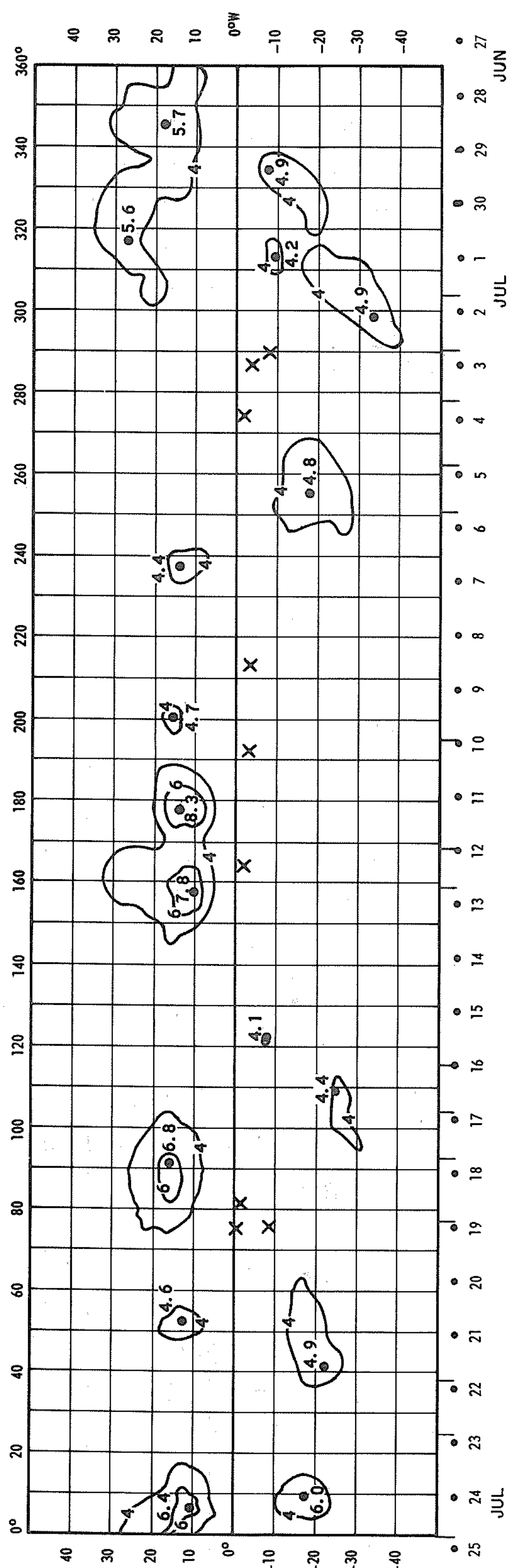
1968 ROTATION 1536



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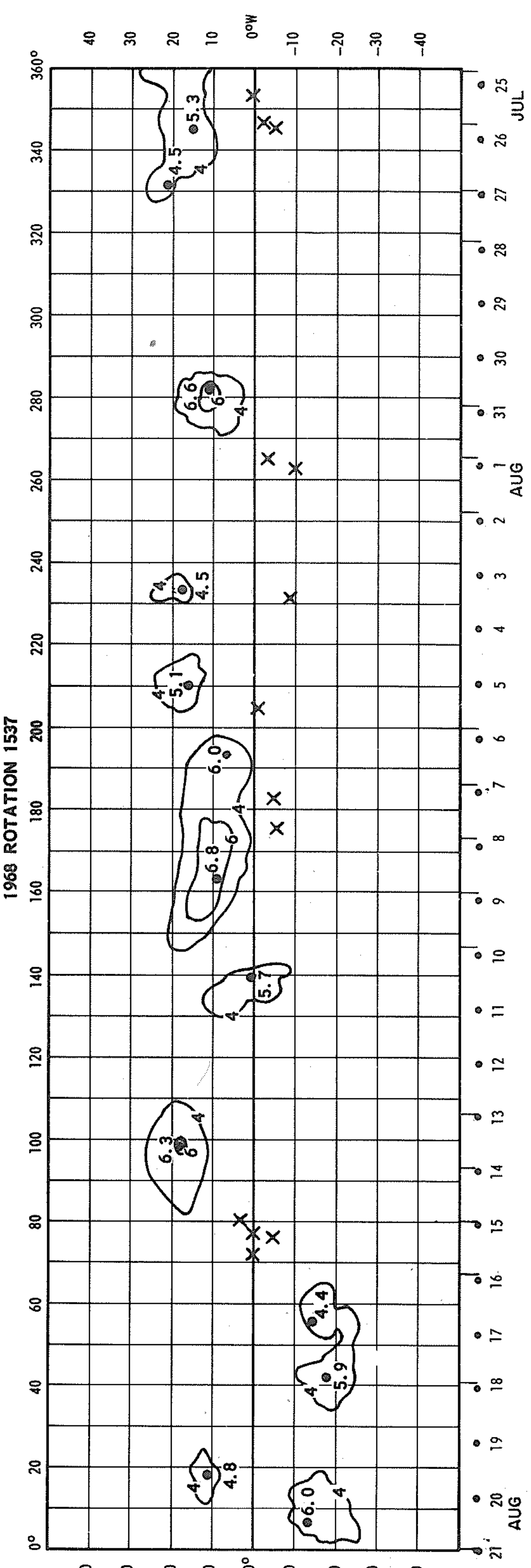

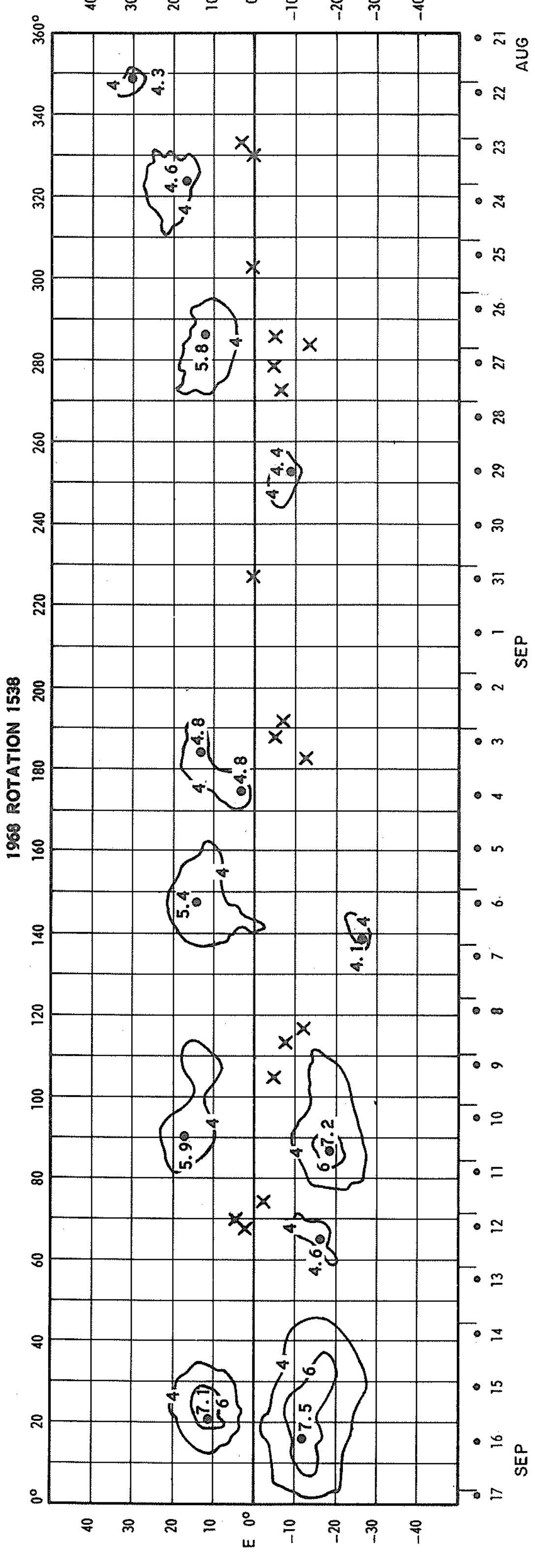
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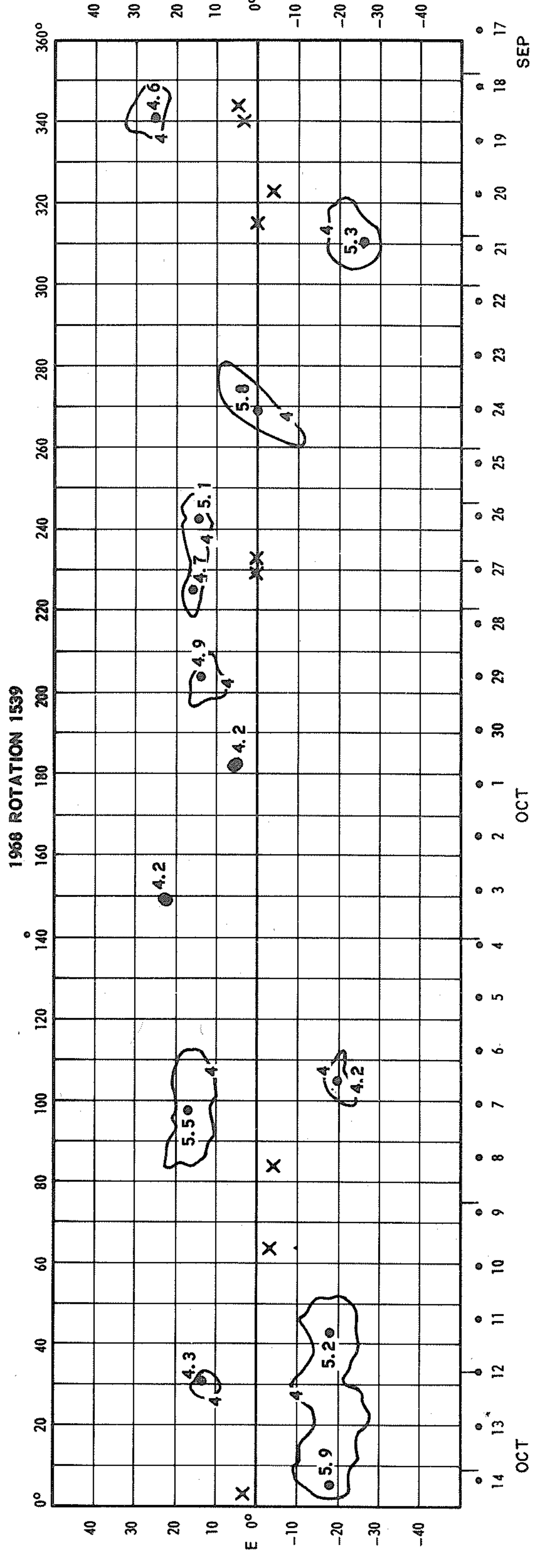
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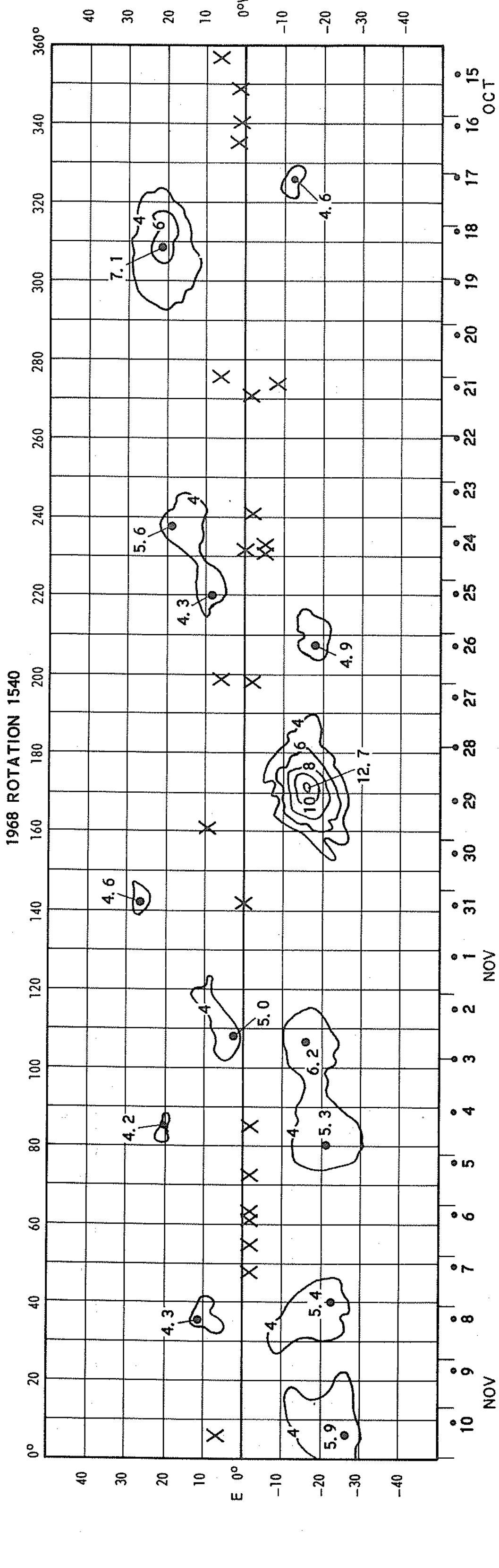
SEP
OCT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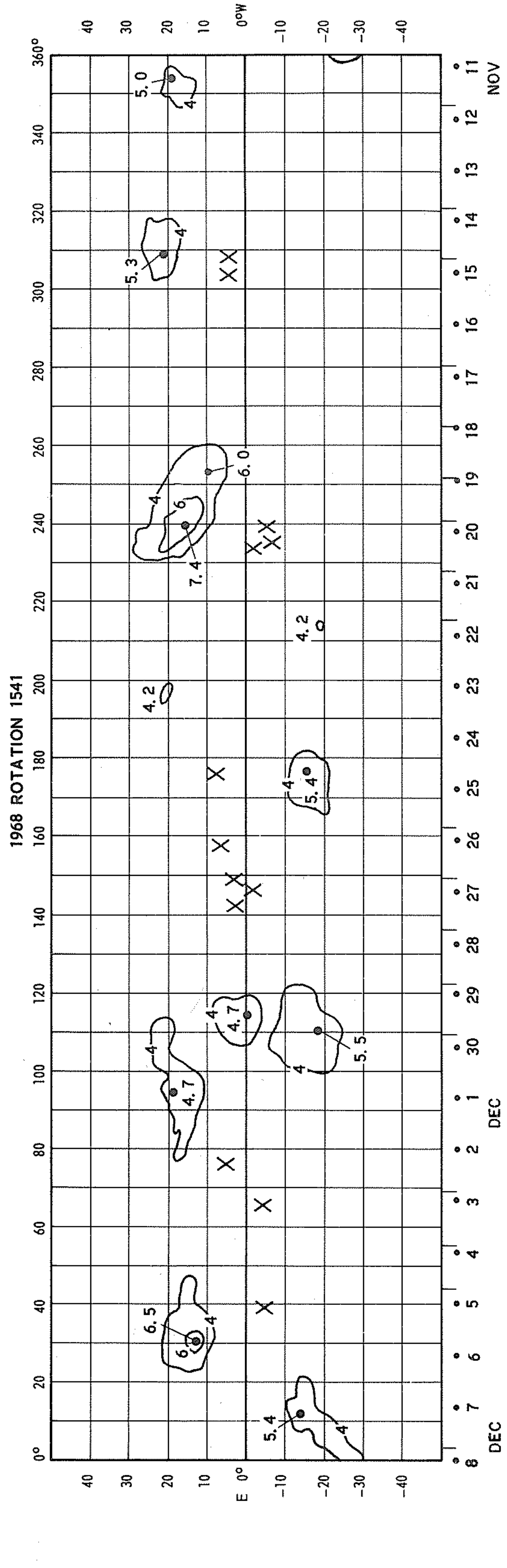
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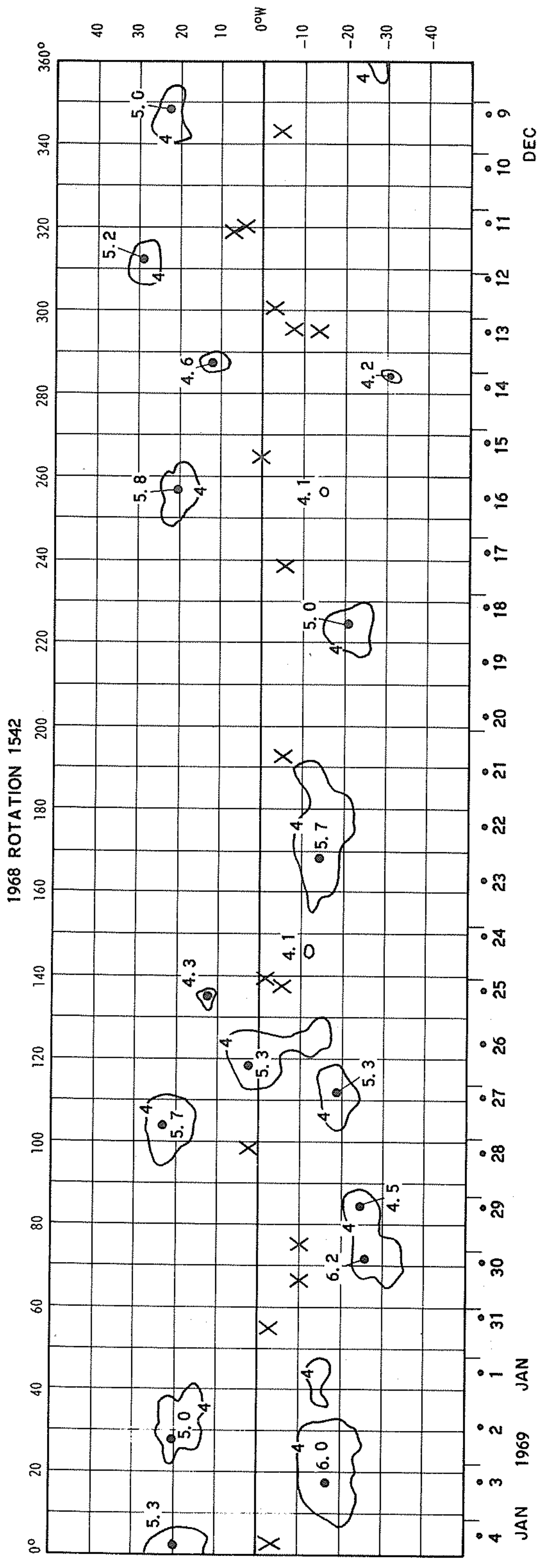
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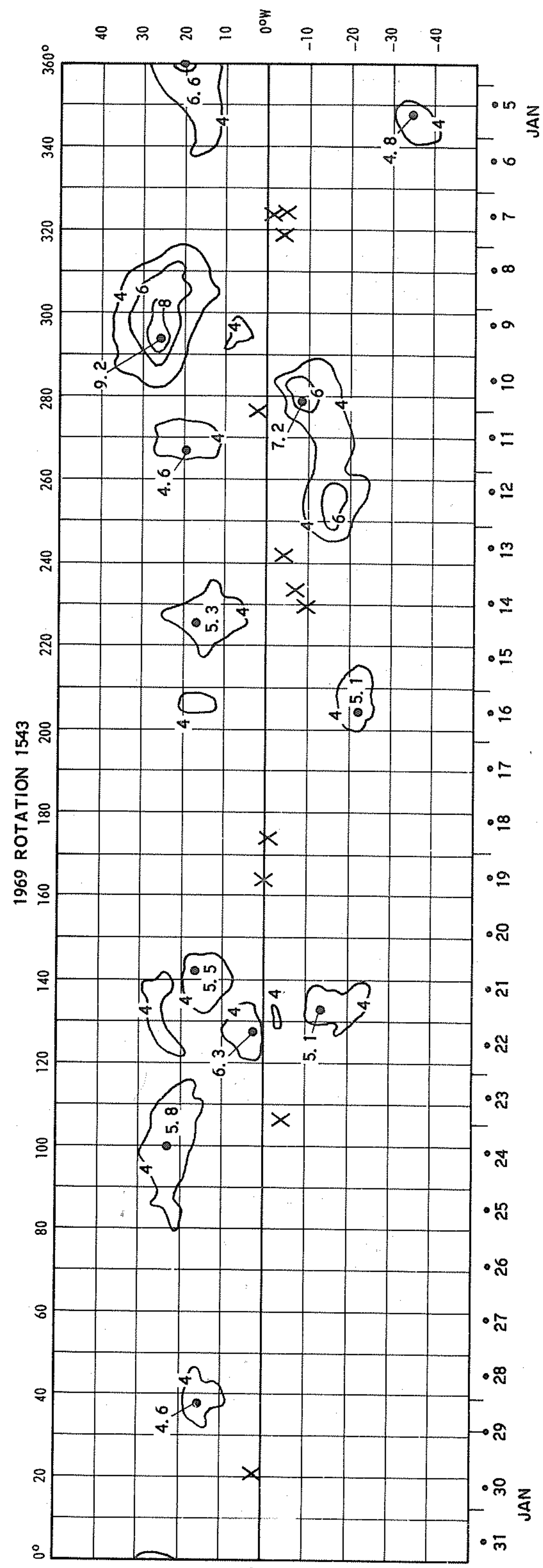
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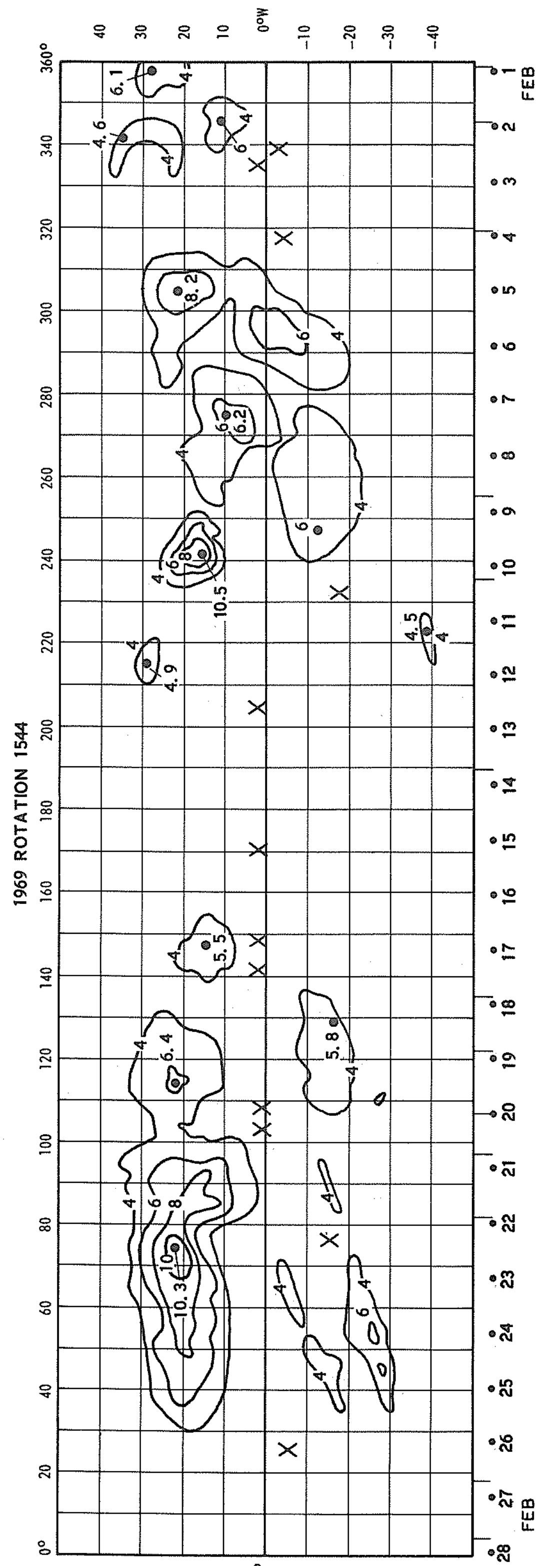
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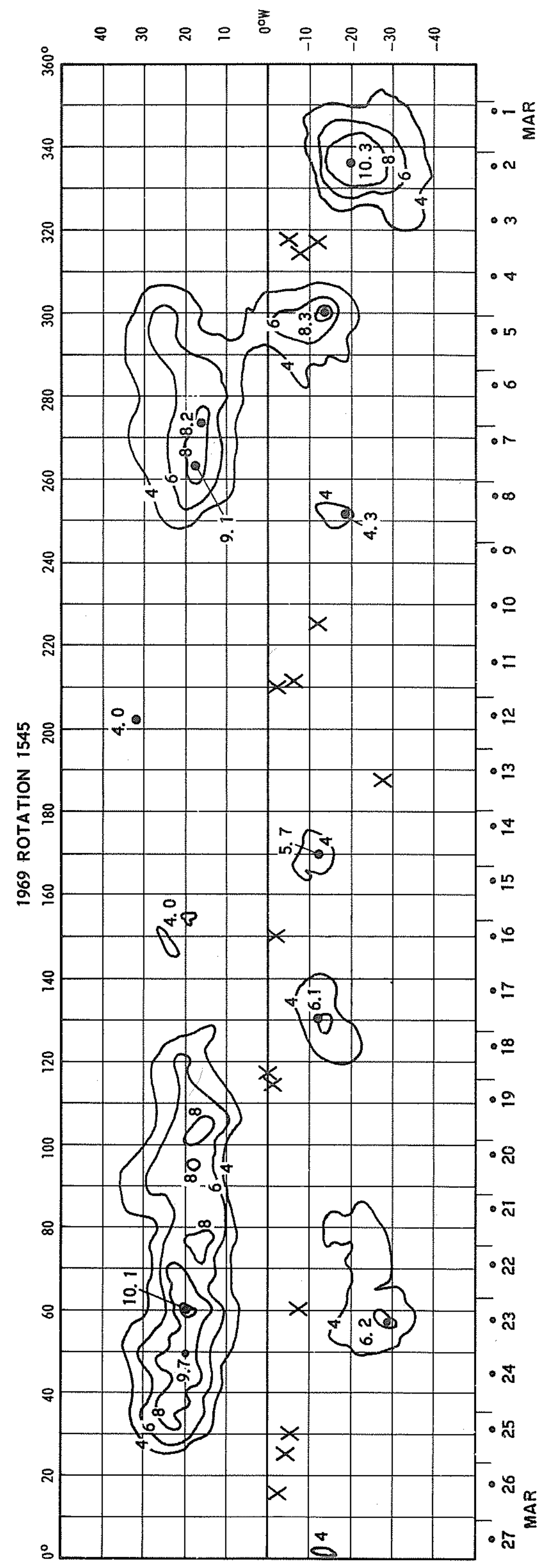
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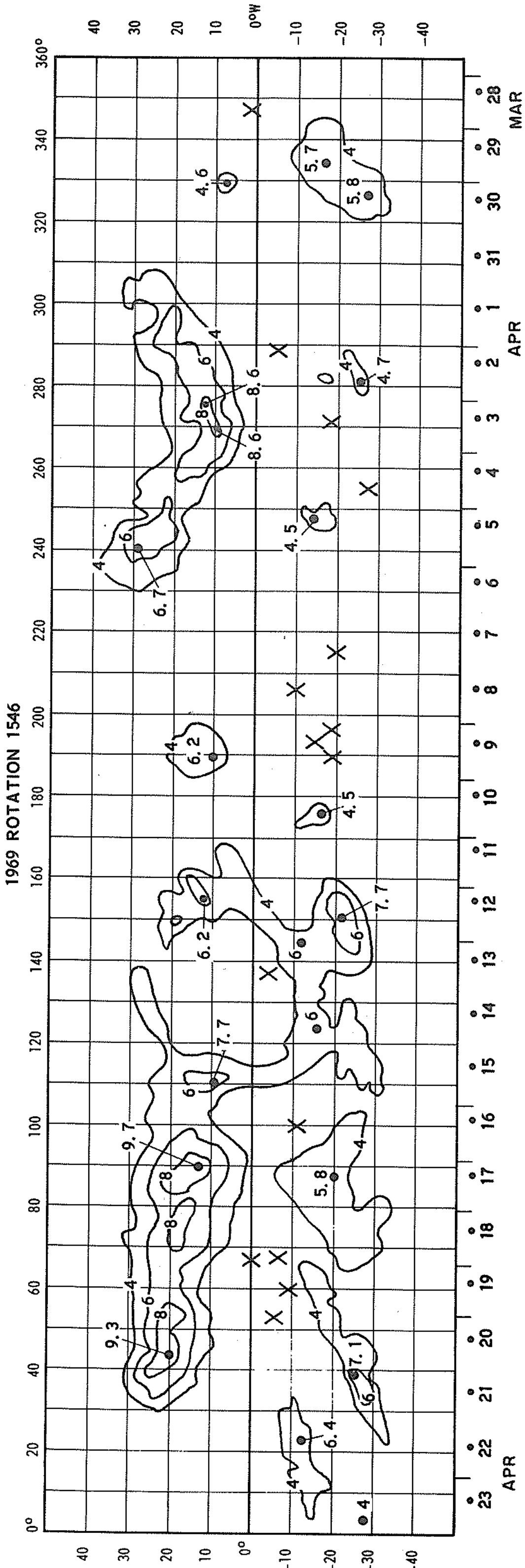
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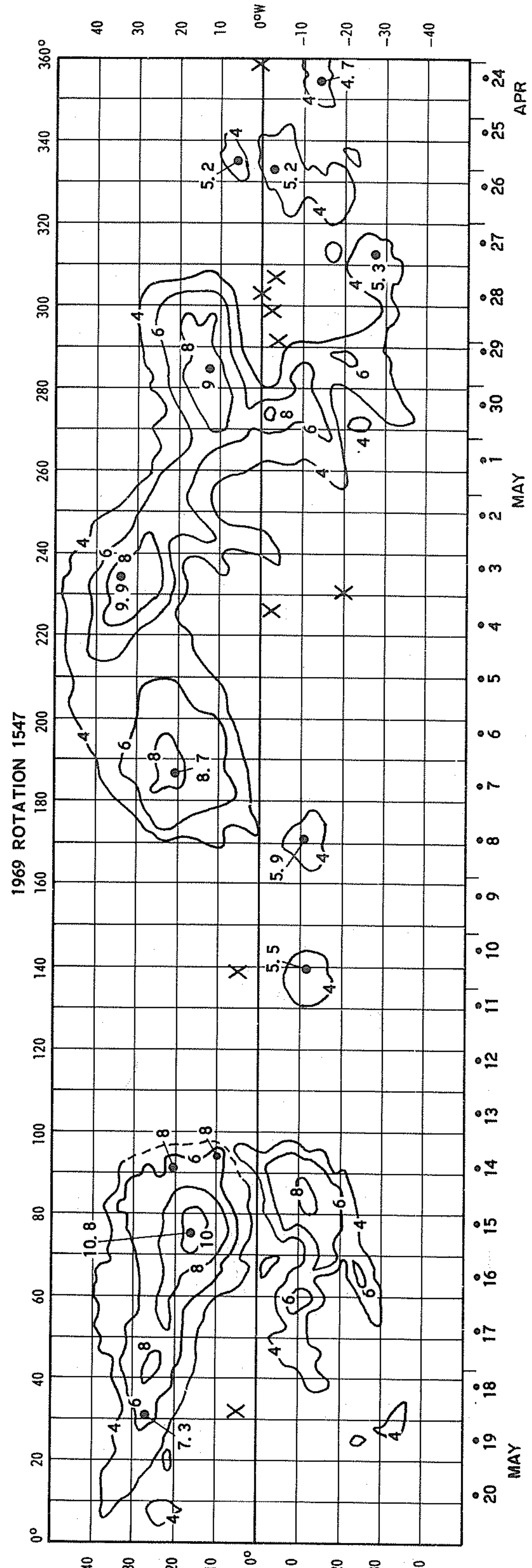
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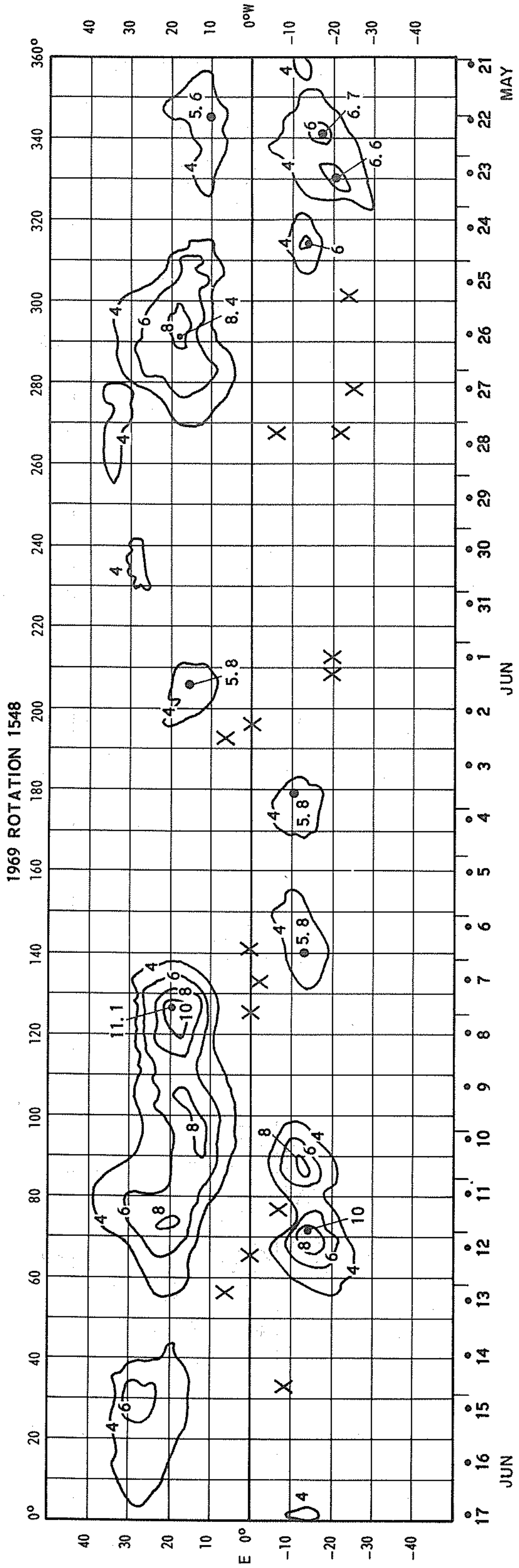
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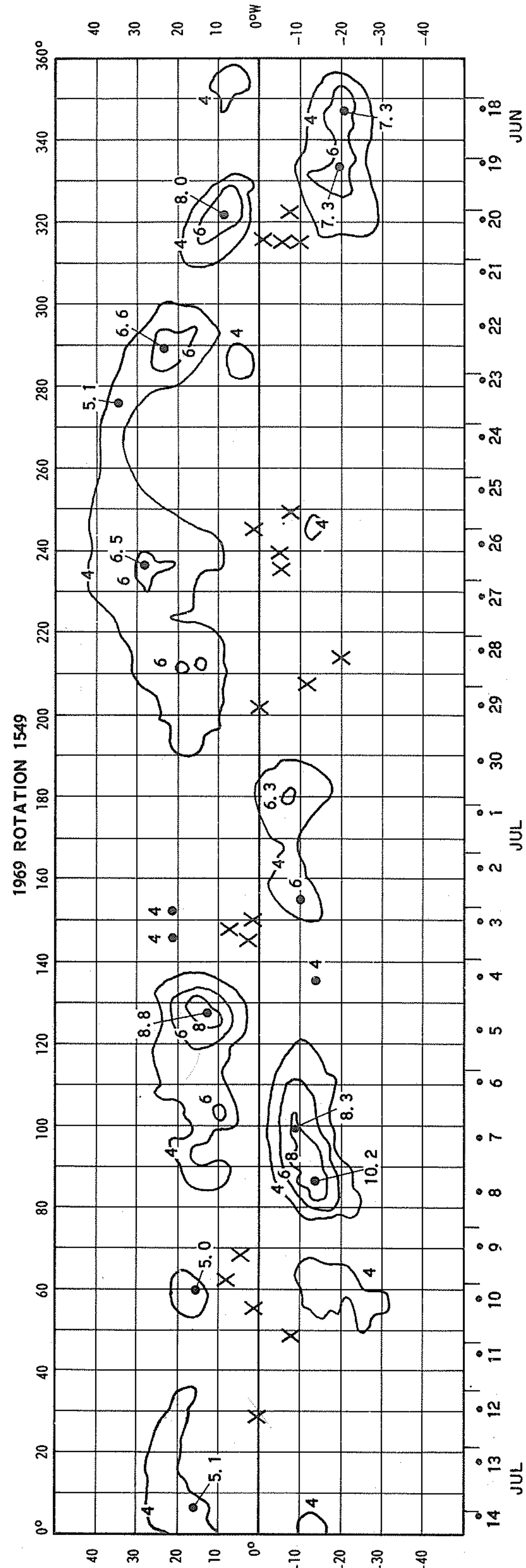
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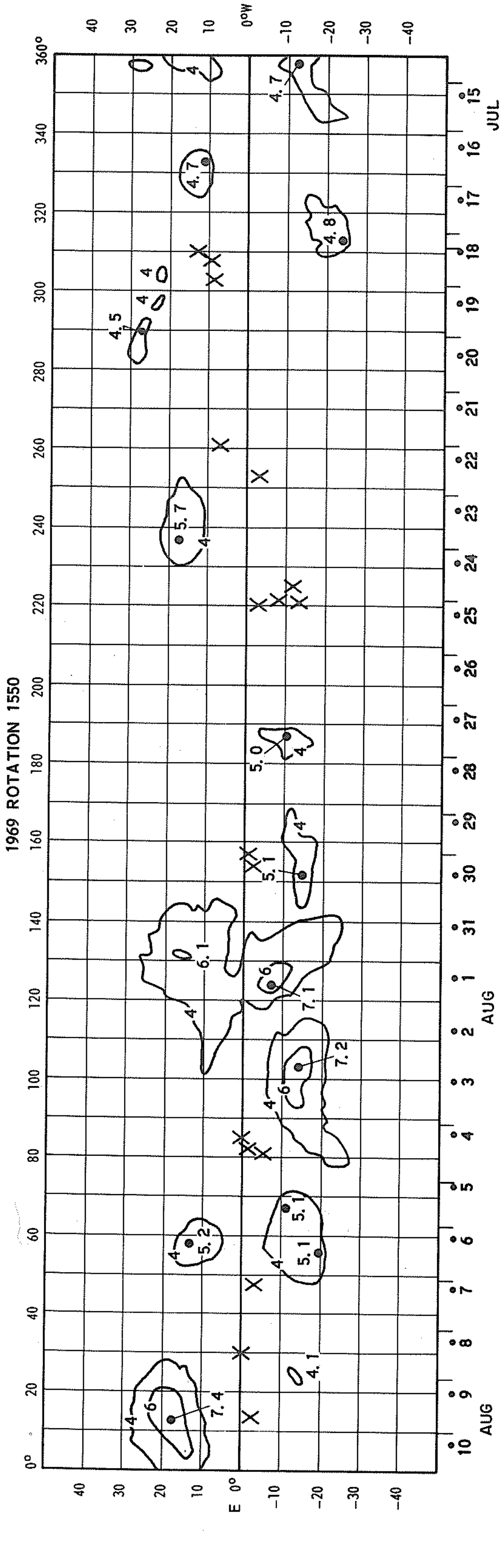
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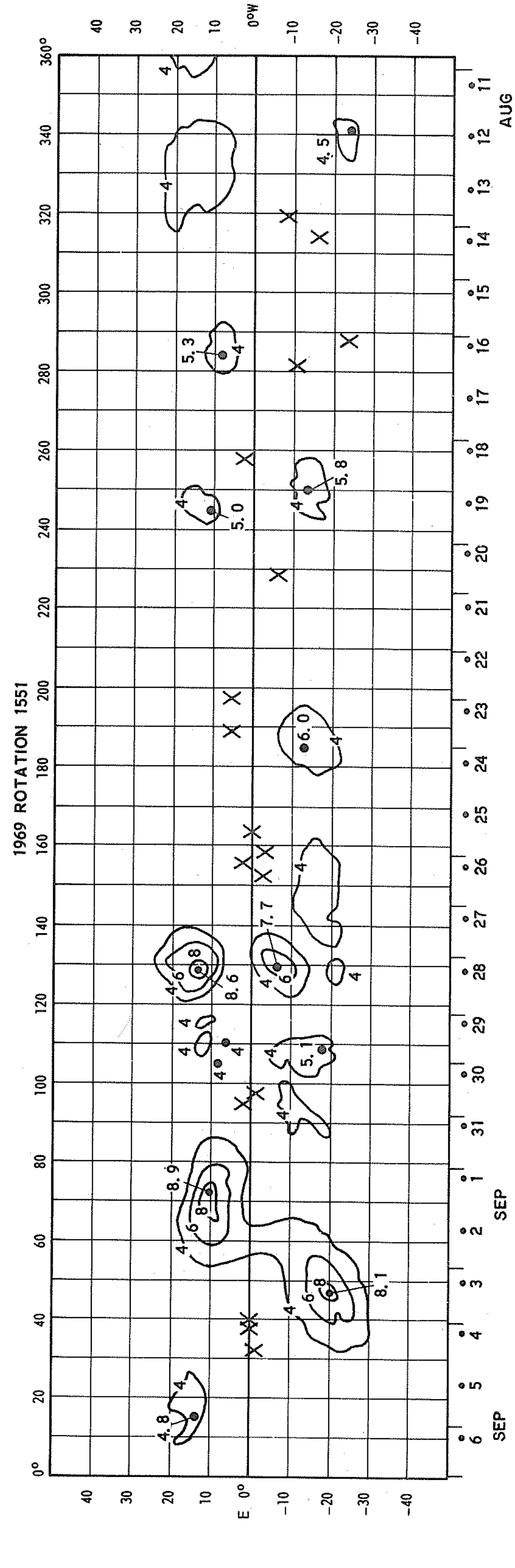
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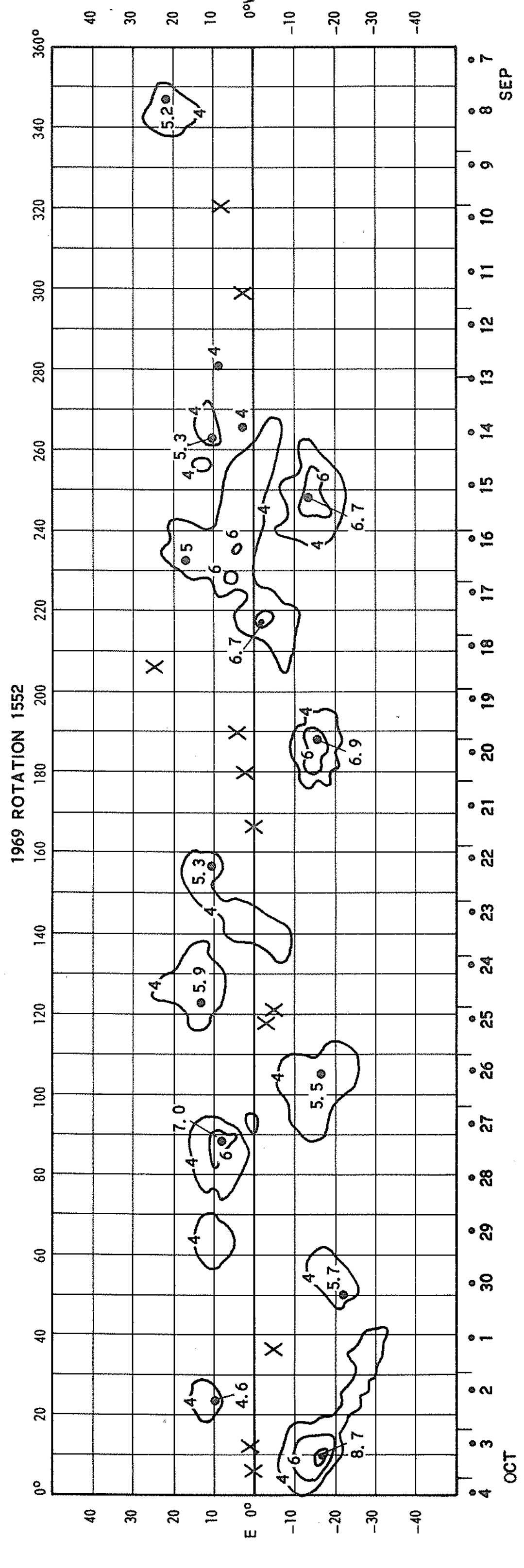
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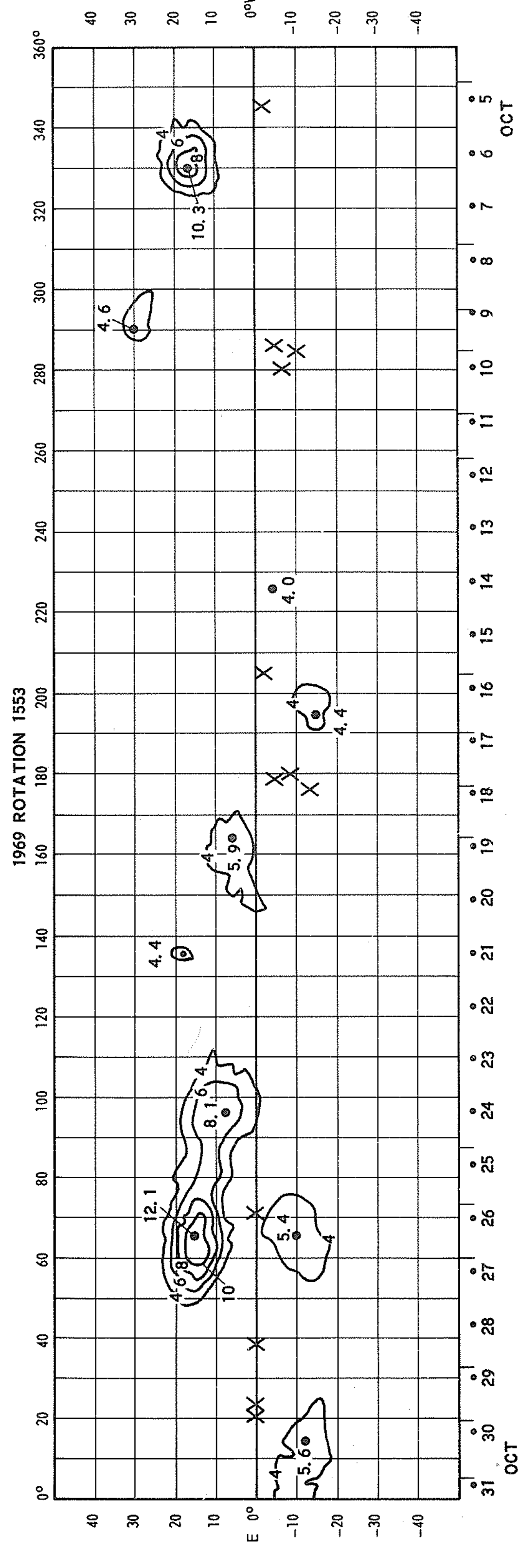
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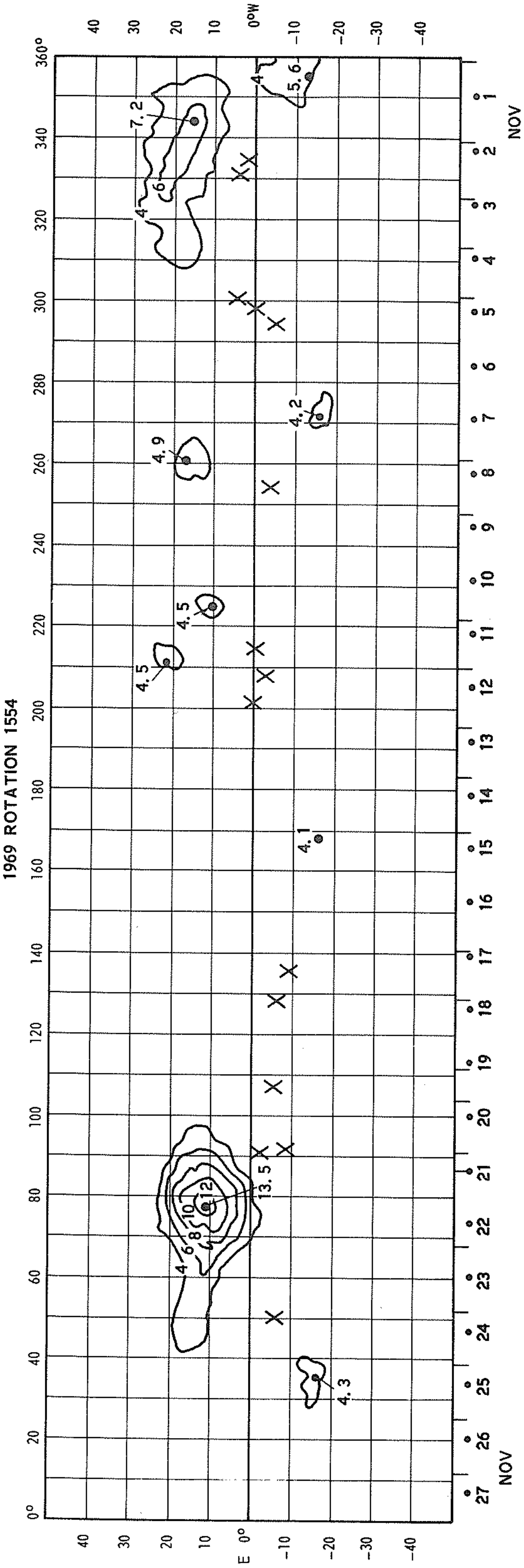
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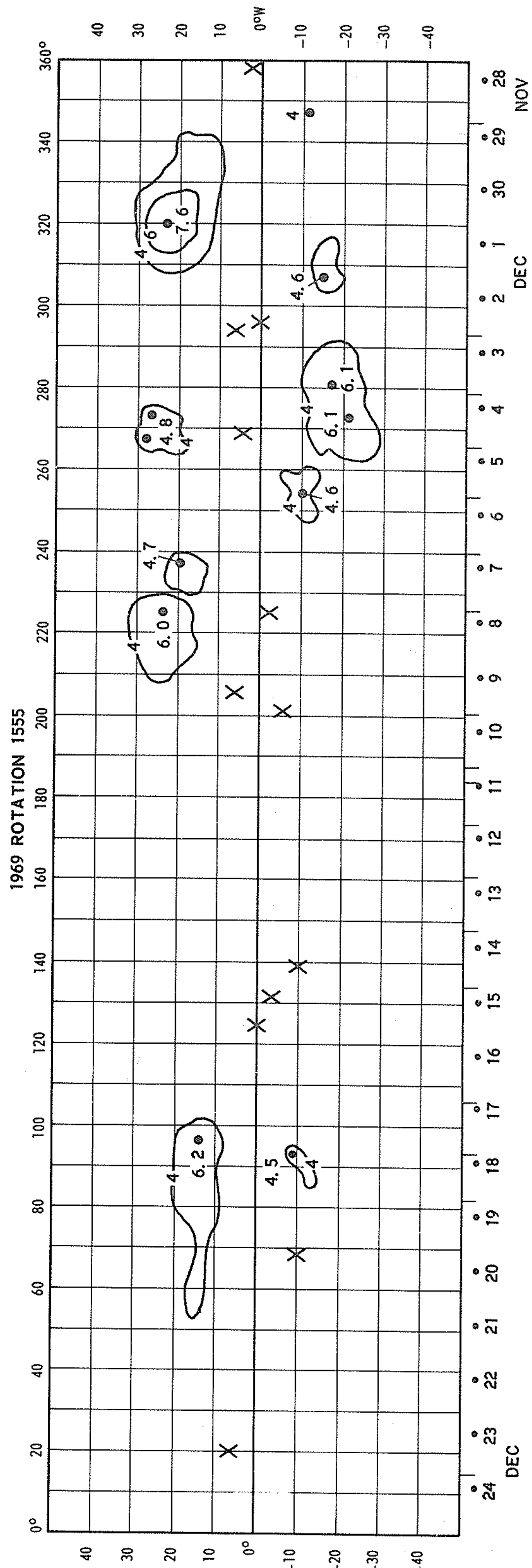
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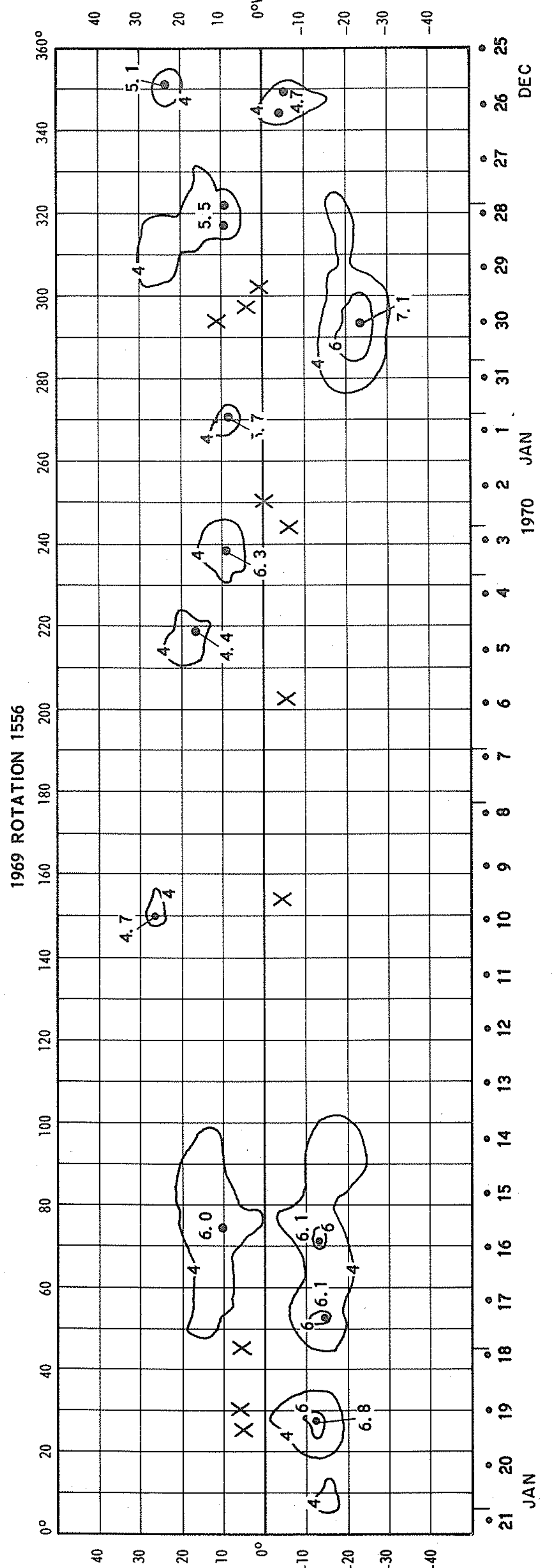
1969 ROTATION 1556
DEC
JAN
1970
JAN
E 0°
0°W

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