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SYNOPTIC MAPS OF SOLAR CORONAL HOLE BOUNDARIES DERIVED FROM HE II 304 A SPECTROHELIOGRAMS FROM THE MANNED SKY-LAB MISSIONS

J. D. Bohlin, et al

World Data Center A for Solar-Terrestrial Physics

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Report UAG-51

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by

J. D. Bohlin and D. M. Rubenstein

E.O. Hulburt Center for Space Research
Naval Research Laboratory
Washington, D. C. 20375 U.S.A.

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24 May - 23 June 1973

2 August - 24 September 1973

21 November 1973 - 2 February 1974

by

J. D. Bohlin and D. M. Rubenstein
E. O. Hulburt Center for Space Research
Naval Research Laboratory
Washington, D. C. 20375 U.S.A.

ABSTRACT

The disk boundaries of coronal holes have been determined from He II 304 Å spectroheliograms which were taken with the Naval Research Laboratory (NRL) slitless XUV spectrograph during the manned Skylab missions. These boundaries are plotted by Carrington rotation as synoptic charts in both the standard rectangular as well as polar-view projections. The polar-view projections emphasize that the major areas occupied by coronal holes during this period were in the polar caps at latitudes >60° North and South. The periods of time for which boundaries were determined are 24 May through 23 June 1973 (first manned Skylab mission), 2 August through 24 September 1973 (second manned mission), and 21 November 1973 through 2 February 1974 (third manned mission); the Carrington rotations covered (in part or totally) are 1601 and 02; 1604, 05 and 06; and 1608, 09 and 10, respectively. These charts are presented for use in the study of Skylab and corroborating space/ground-based data taken during the manned mission periods.

One of the earliest and most surprising discoveries from the NRL Skylab data was that the resonance line of singly ionized helium, He II 304 Å, reveals the presence of a coronal hole as a region of decreased emission and loss of definition of the chromospheric network [Tousey *et al.*, 1973; Brueckner and Bartoe, 1974; Bohlin *et al.*, 1975 a,b,c]. It is not obvious why this emission line of helium, which theoretically forms in the upper chromosphere at 6-10 x 10^4K, should reflect large-scale temperature and density depressions in the overlying corona, especially since other XUV chromospheric lines show a much less pronounced effect [Brueckner and Bartoe, 1974; Huber *et al.*, 1974]. Several theories have been advanced to account for this apparent anomaly, but it is outside the scope of this atlas to discuss them here. For our purposes it is sufficient only to note that usually a distinct and unambiguous He II 304 Å signature of the coronal holes does exist and can be used to determine their boundaries, subject to the limitations discussed below.

These data are presented here without interpretation or comparison to other observations. However, several papers have discussed the XUV phenomena of coronal holes (see references above), and these particular maps have been used to derive a number of general conclusions concerning the evolution of coronal holes and their relationship to large-scale magnetic fields [Bohlin *et al.*, 1975c]; a more detailed paper is currently in preparation.

These He II coronal hole maps were generated from a standard series of exposures made daily (typically 1200 to 1600 UT) throughout the manned Skylab missions under the general heading of the synoptic program [Reeves *et al.*, 1972]. High-contrast transparency enlargements were used to determine, by visual inspection, the coronal hole boundaries. Their heliocentric coordinates were digitized directly using overlay projections of spherical coordinates (i.e., Stonyhurst disk grids) and then plotted by computer in rectangular and polar projections. The elements of this program are considered in detail in the following paragraphs:

i) Validity of He II 304 Å as an Indicator of Coronal Holes

The question is not whether He II 304 Å spectroheliograms exhibit regions of abnormally low intensity and lack of chromospheric network, but whether these regions reliably outline coronal holes. With only a few exceptions, it has been found [Bohlin *et al.*, 1975c] that this resonance line of helium does reveal the large-scale coronal hole boundaries to a high degree of accuracy when compared to the soft X-ray coronal images obtained by the American Science and Engineering (AS&E) experiment on board Skylab [Timothy *et al.*, 1975; A. S. Krieger, private communication]. The major difference occurs in coronal holes which are undergoing rapid evolution on a time scale of a few days, as opposed to the more usual scale of weeks. In these instances the overlying corona and He II chromospheric patterns can be 'out of phase'; i.e., the X-ray corona can show a small hole or a fine-scale detail in a larger coronal hole while the heliogram does not, or vice-versa. The other major difference concerns the presence of holes in close proximity to complex active regions. Pictures which show the corona projected on the disk, e.g., AS&E X-ray data or NRL spectroheliograms in the coronal line Fe XV 284 Å [Sheeley *et al.*, 1975], often show small-scale regions of open field lines and reduced coronal intensity in complexes of disk activity that are difficult to reliably recognize and measure from He II 304 Å images. Therefore these small active region coronal holes are not included in this atlas.

ii) Frequency of Observation

Although daily observations were available, we soon discovered that the usually slow evolution of the coronal hole boundaries permitted their complete documentation using frames taken at three day intervals. This three-day cadence greatly reduced the amount of data to be digitized, at a negligible loss in information for all but a few cases where rapid evolution was taking place. (Those particular situations are being studied with finer time resolution for separate publication.) The boundaries were determined from limb-to-limb (± 60-70° about central meridian), so that any one feature was determined at least three times during its disk passage.

iii) Visual Determination of Coronal Hole Boundaries from He II 304 Å

After some experimentation it was found that first-generation, high-contrast transparencies (Kodak Super Neg) seemed to be optimum for visual measurements. These enlargements (18 cm solar diameter; ~11 arc sec/mm) were examined on a light table and the boundaries of all coronal holes were traced onto clear acetate overlay sheets using a fine-tip felt pen. The boundary lines were determined independently for each image, without any effort to project the boundaries from a previous image forward with time. However, images three days on either side of the one being traced were examined as an aid in those cases where evolution had changed the visibility of a hole. Corresponding Hα observations (provided by NOAA during Skylab) were used to discriminate long narrow coronal holes from filaments and/or filament channels, which can be remarkably similar to coronal holes in He II 304 Å.

In spite of these aids, however, determination of coronal holes by this visual method was fundamentally a problem of subjective pattern recognition, and thus liable to personal bias. We guarded against bias by two techniques: First, the original sketching of the boundaries was done by one of us alone. Then working as a team, we re-evaluated each image and its overlay tracing to arrive at a mutually agreed-upon decision. This process was greatly facilitated by flipping the clear overlay tracing against the spectroheliogram, a process we found to permit discrimination of many otherwise doubtful or subtle cases. Second, to insure that our level of visual sensitivity to the boundaries did not change over the five weeks involved in processing all the images, we reexamined every image a second time, thereby picking up several small coronal holes and/or complexities in boundaries overlooked the first time.

However, some portions of a few boundaries remained simply too ambiguous or obscure to determine with a reasonable level of certainty. In these cases (perhaps 25 in all) the boundaries were not drawn. However, in every one of these instances, the boundary was sufficiently defined sometime during its disk passage so that no break occurs when the multiple patterns are finally plotted.

iv) Transformation to Heliocentric Coordinates and Digitization of Data

These data did not warrant mathematical transformation from projected orthogonal (x, y) into spherical heliographic coordinates, so Stonyhurst disk grids were used instead. The heliographic latitude and longitude were read point-by-point at sufficiently fine intervals (minimum of 1°) to specify completely the convolutions of the boundaries. In no case was the maximum interval between two points allowed to exceed 5° in either latitude or longitude. The 38 separate spectroheliograms required 3550 points in all to specify the boundaries.

The various uncertainties (peak-to-peak, heliocentric) for any one point in the central portion of the disk (i.e., $r < 3/4\ R_S$) can be estimated as follows:

a) The inherent uncertainty in determining a reasonably distinct boundary was typically ~1°;
b) A slight eccentricity in the He II solar images caused a mismatch to the circular Stonyhurst grids of ~1°;
c) The Stonyhurst grids discriminated between values of the tilt of the solar axis, B, by 1° increments, so a maximum error of ~1/2° could result;

d) The fine-tip pen used for tracing made a line typically 1/2° wide; and
e) The visual reading of the boundary was no more accurate than a degree and rounded to whole degrees.

Thus, for the central disk portions, assuming a random addition of errors, each boundary point has a possible rms error of the order of 2° peak-to-peak. As a general rule this level of uncertainty is completely dominated by the uncertainty of the boundary itself (see paragraph (iii) above) combined with the inherent small-scale evolutionary changes in the boundaries over the three-day intervals between observations; this latter effect alone has typical peak-to-peak values of 4 to 8°.

v) Plotting of the Data

The data have been plotted by computer to allow the option of easily displaying the same material in different ways. In particular we have plotted the data in three formats, all by Carrington rotation: a) Rectangular disk projections (±90° latitude in width and 360° longitude in length, plus 30° overlap at each end) with both latitude and longitude in equal linear scales; b) Polar-view projections (radius = cosine of heliographic latitude) for both north and south poles; and c) Equal-area rectangular projections (similar to (a) except the vertical scale follows the sine of the latitude). Plots (a) and (b) are contained in this atlas; plots (c) were generated for in-house study of the areas covered by coronal holes; copies can be made available upon request. In all cases a Carrington rotation rate of 13.2° per day was used. To avoid cumulative errors, each rotation was independently registered to start with the day (to two decimal places) as listed in the *American Ephemeris and Nautical Almanac*. The date scales on both the rectangular and polar plots are referenced to central meridian passage in the usual way, and are supplemented with a day-of-year (DOY) index just inside the boundary of the rectangular disk projection plots. The rectangular plots have been scaled to duplicate in size the Hα synoptic charts contained in an earlier UAG Report [McIntosh, 1975].

These coronal hole charts differ from usual synoptic maps of solar activity and magnetic fields in the fundamental respect that the data are taken from the entire disk (to typically 0.1 R_S of the limb) on three-day centers instead of from a restricted longitude zone near central meridian every day. The chosen three-day cadence combined with the ability to determine the boundaries to within 25° of the limb (somewhat less for the polar holes) means that any one coronal hole feature is plotted as many as four times during a given disk passage.

The resulting multiplicity of overlapping lines may appear confusing, but retention of all the data on these charts does have several significant advantages. First, since the coronal hole boundaries in certain areas occasionally could not be determined, observations three days on either side fill in the gap. Thus the continuity of the averaged boundary is preserved. Second, since the data were plotted independently for each day by computer, the degree to which they overlap confirms that our original subjective determination was reasonably self-consistent and valid. Well-defined and temporally stable boundaries frequently superpose to within a few degrees (e.g., the south polar coronal hole in rotations 1604 and 1605). Third, failure of the boundaries to overlap is an indication that either small-scale evolution has occurred over the time scale of 3 to 12 days, or that the boundaries themselves were initially poorly defined. In order to differentiate between the two cases, the original transparencies were re-examined, and cross-hatching added within the peak-to-peak envelope of boundaries in those areas where the identification of the coronal holes was uncertain (e.g., the north polar hole in rotation 1601 shown on the rectangular plot).

Of course, this evaluation itself is highly subjective and should be used only as an indication that the exact boundary from He II for a given area and day could not be determined better than 3-5° heliocentric. As a rule of thumb, a mean boundary drawn through the average of such shaded zones will give an accurate (± 2-4°) measure of the coronal hole.

One last point should be noted: the anomalous break in the boundaries from 4 to 7 June (rotation 1602) was caused by a camera malfunction in the first manned Skylab mission, and no He II images were exposed from 31 May through 3 June 1973.

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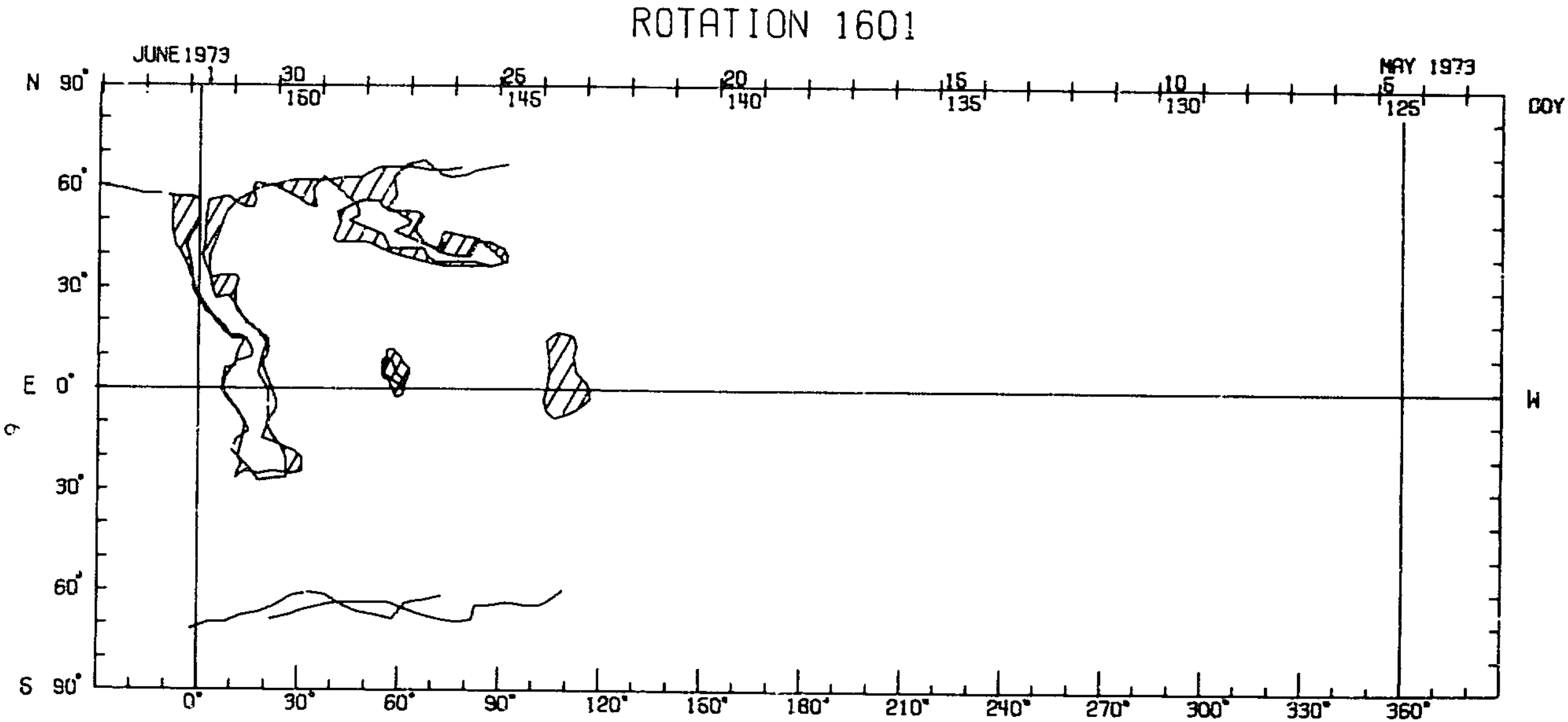

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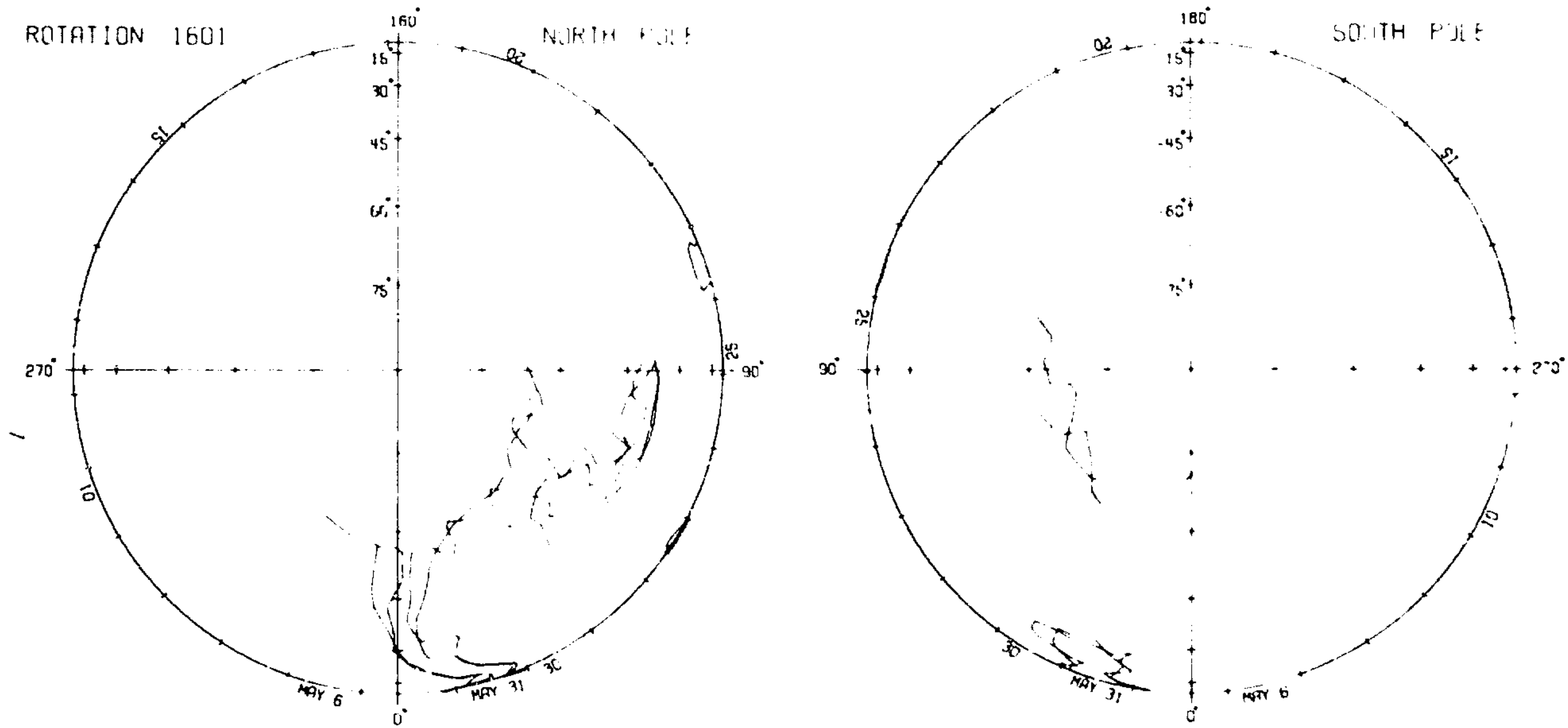
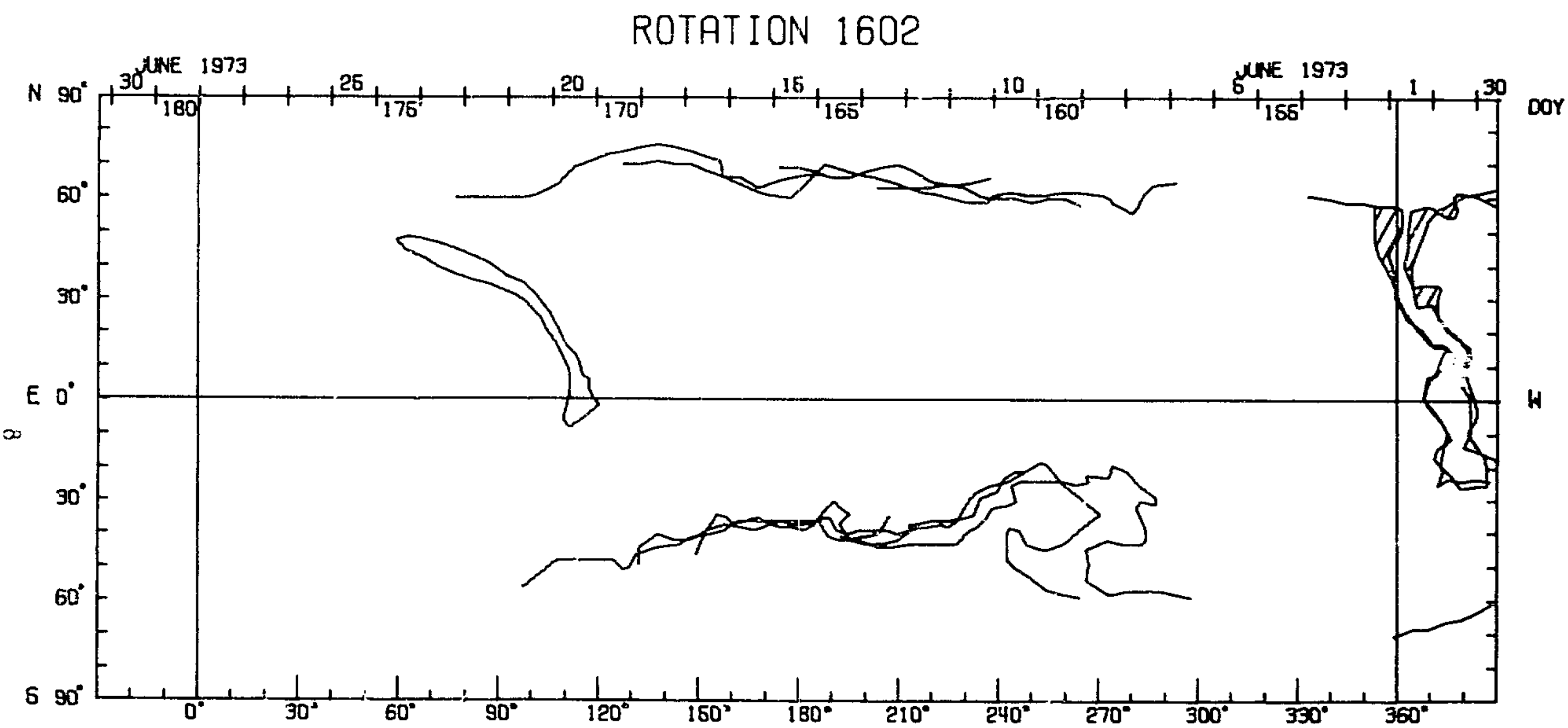
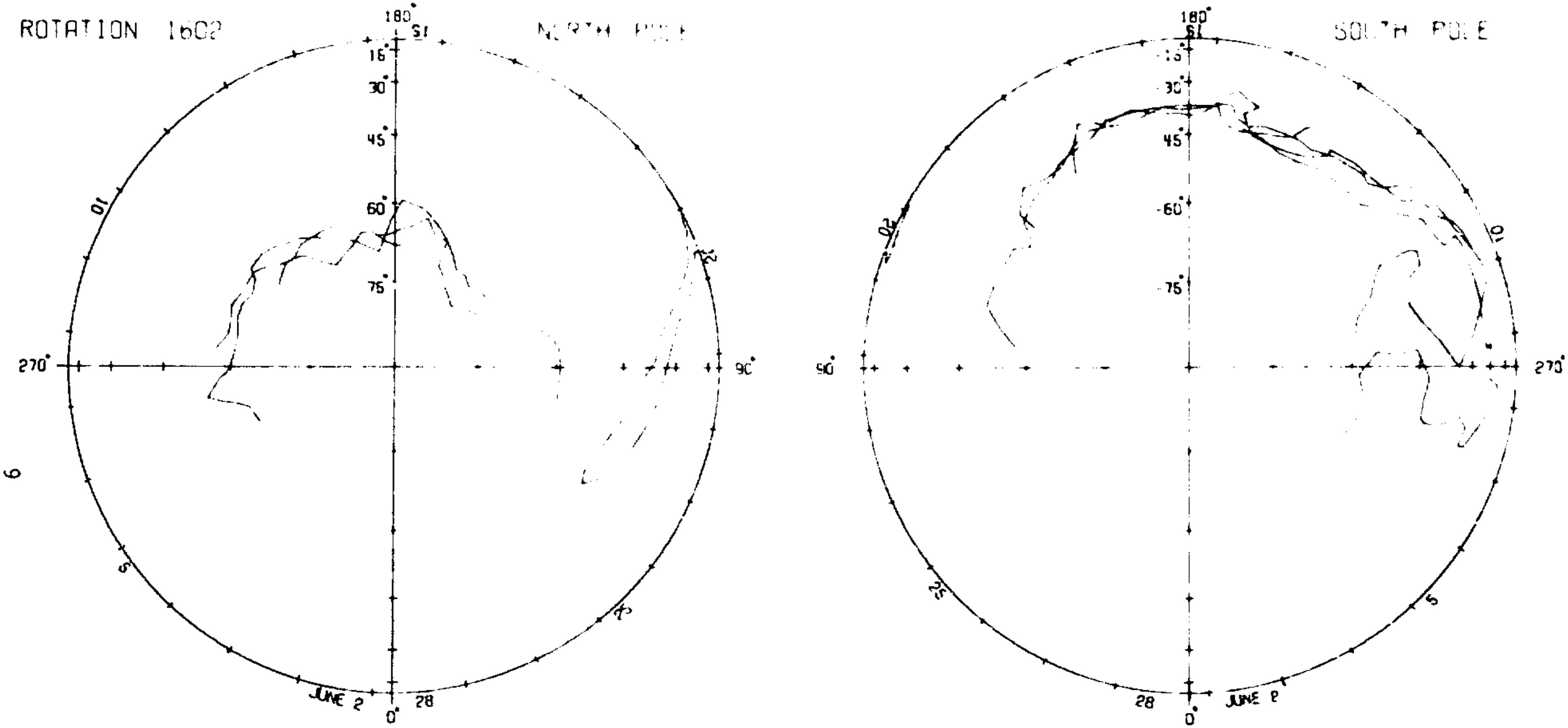




ROTATION 1602
JUNE 1973
30
180
25
175
20
170
15
165
10
160
5
JUNE 1973
155
1
30
DOY
N 90°
60°
30°
E 0°
30°
60°
S 90°
W
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
360°

ROTATION 1602



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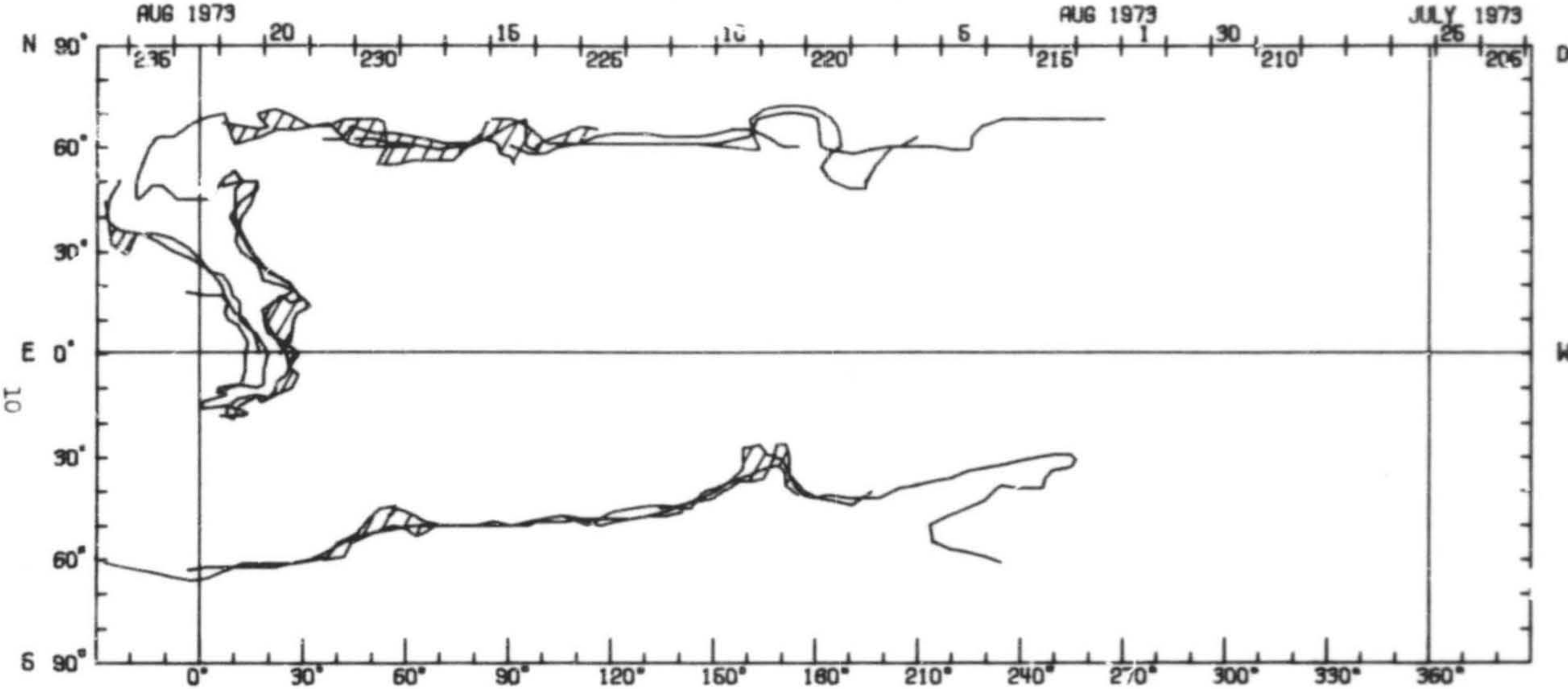

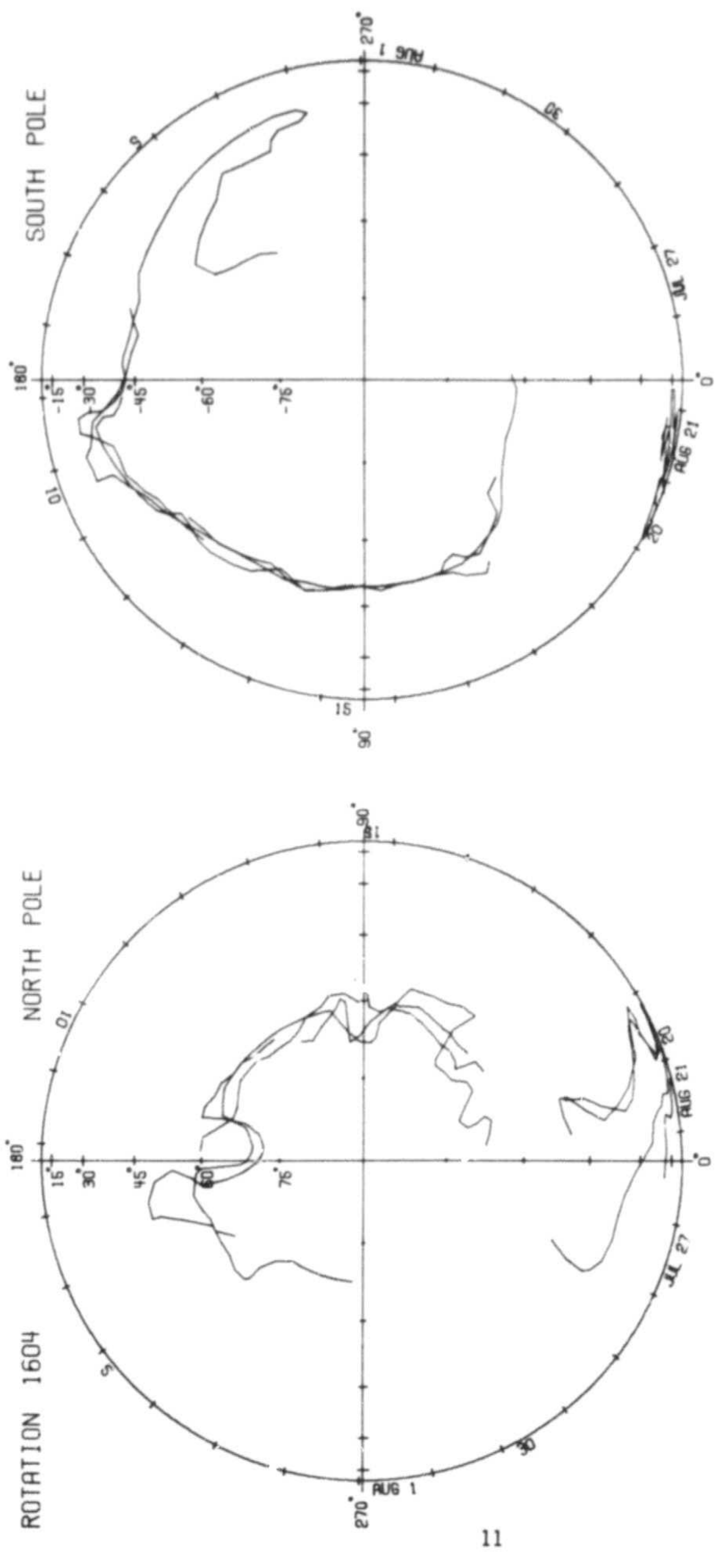
ROTATION 1604
NORTH POLE
SOUTH POLE
180°
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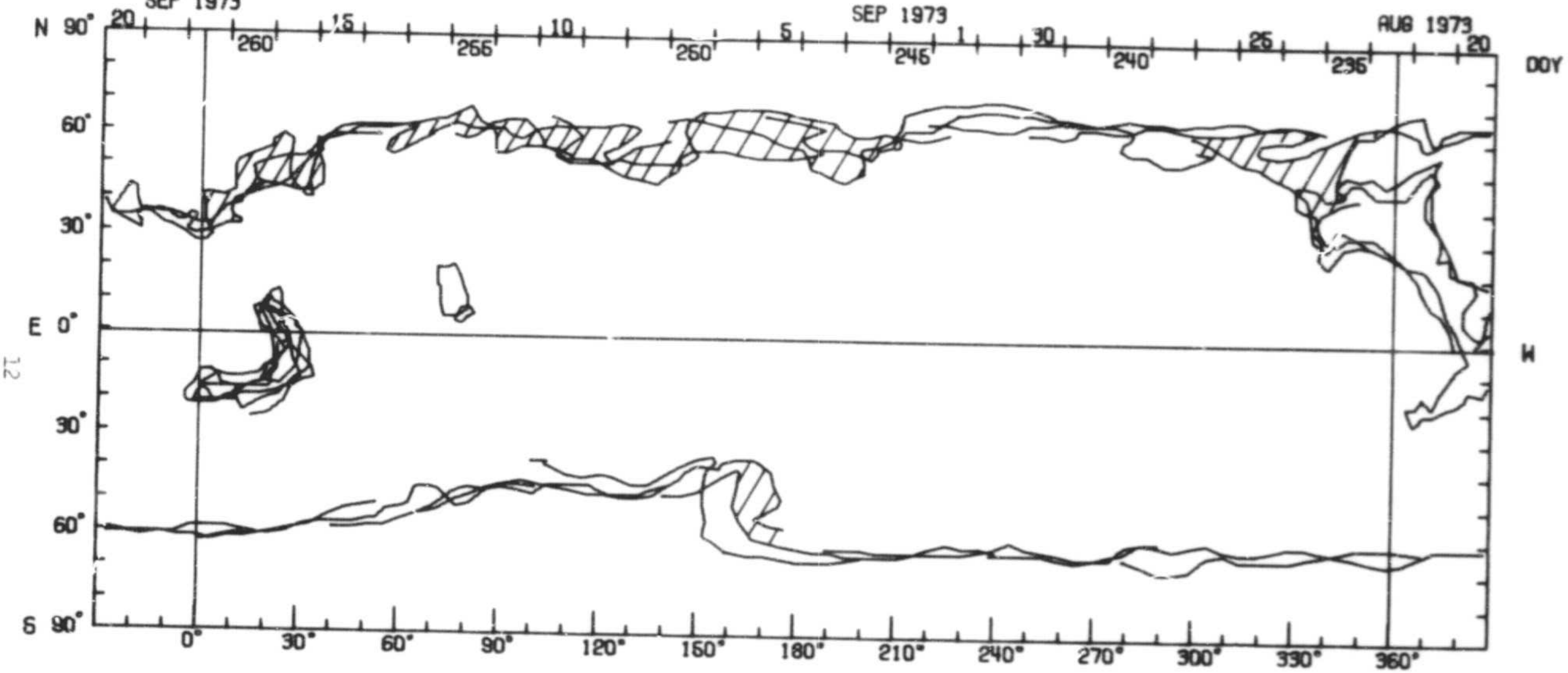
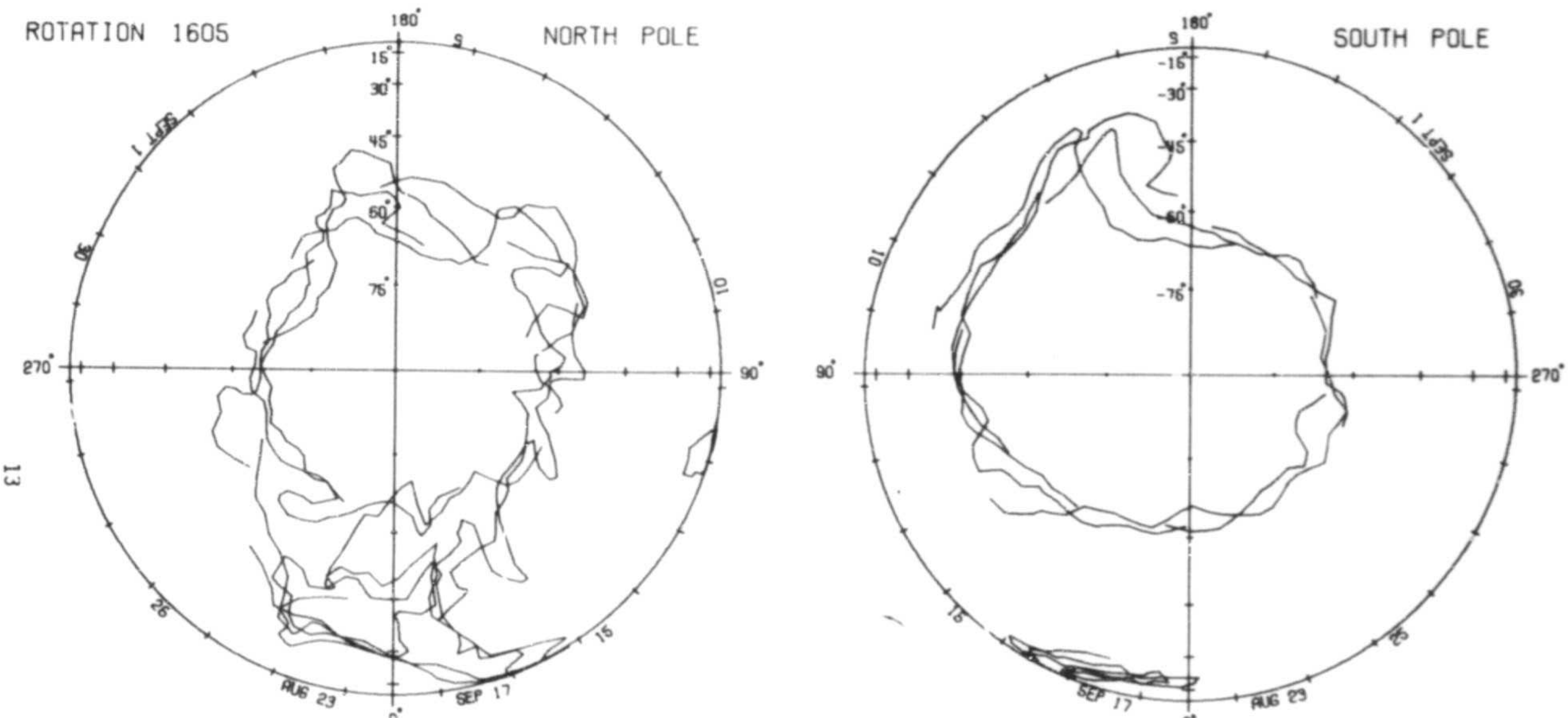
90°
0°
15°
30°
45°
60
75
-15°
-30°
-45°
-60°
-75°
AUG 1
AUG 21
JUL 27
5
10
15
20
30

ROTATION 1605

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60°
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270°
90°
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SEPT 1
30
26
AUG 23
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15
10
5
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-15°
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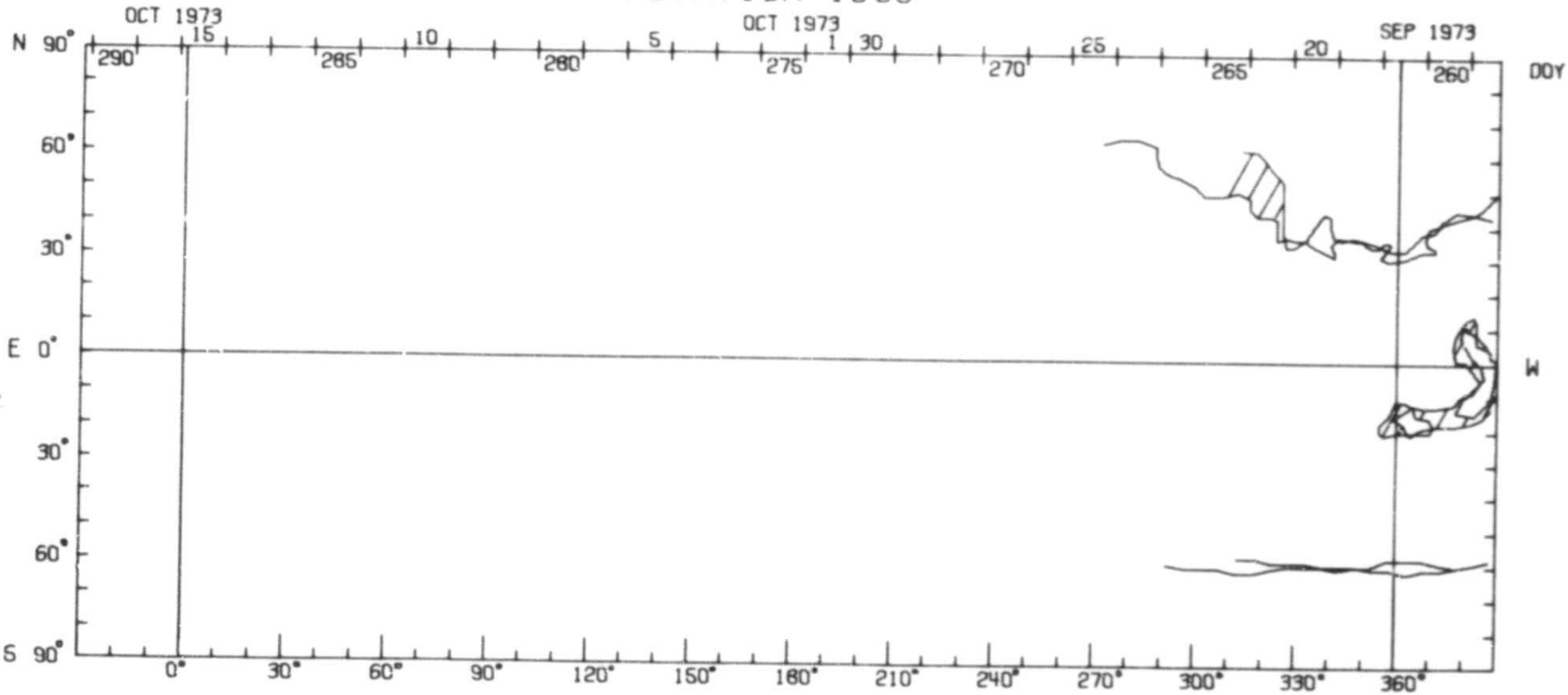
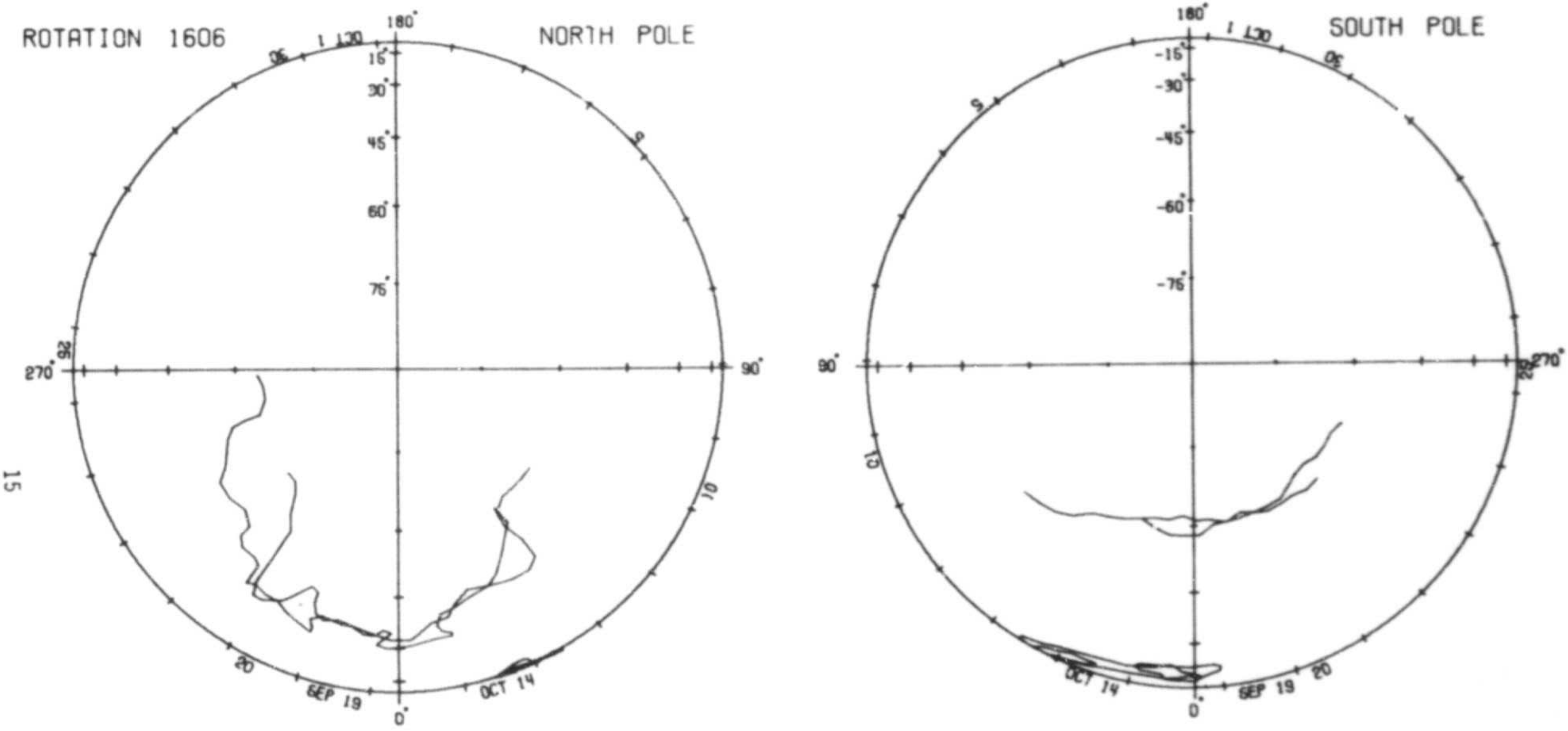
-45°
-60°
-76°

ROTATION 1606

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SEP 19
OCT 14
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OCT 1
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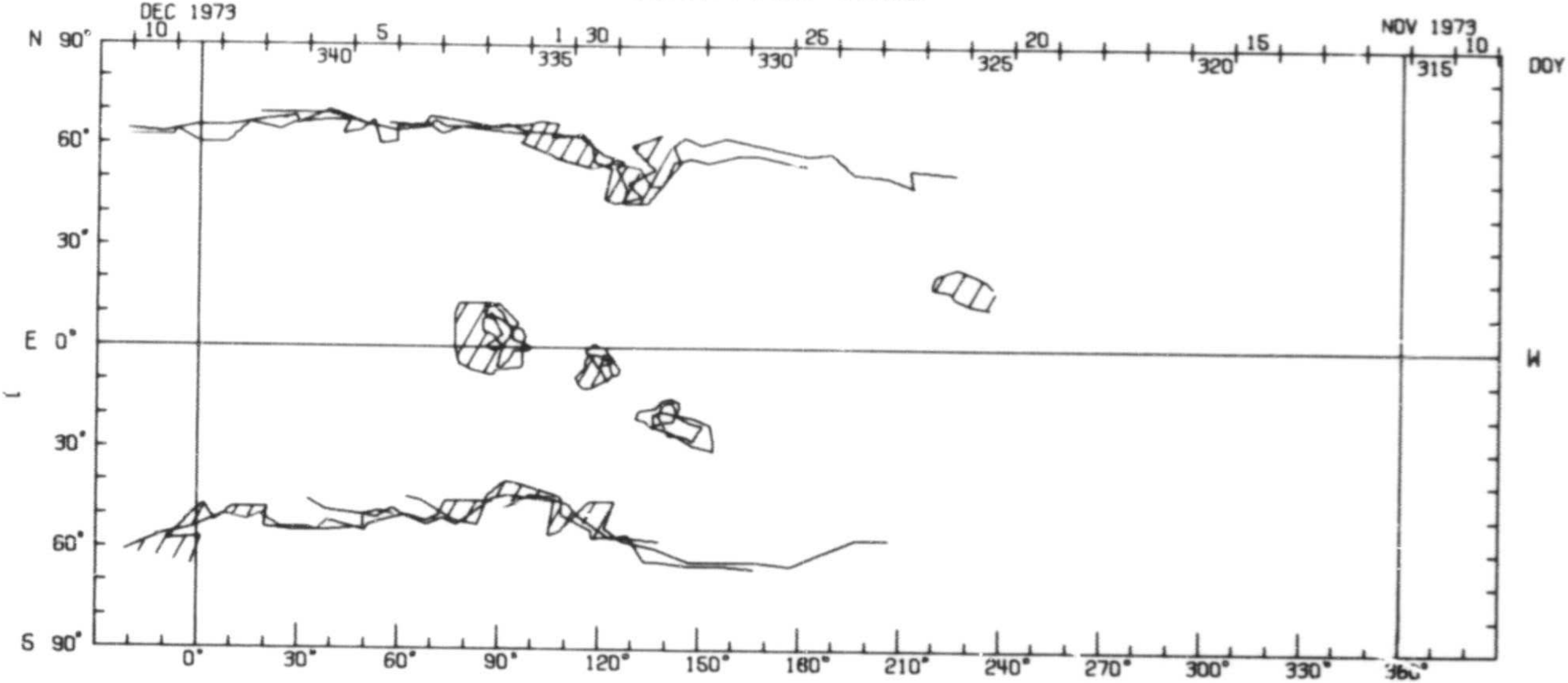

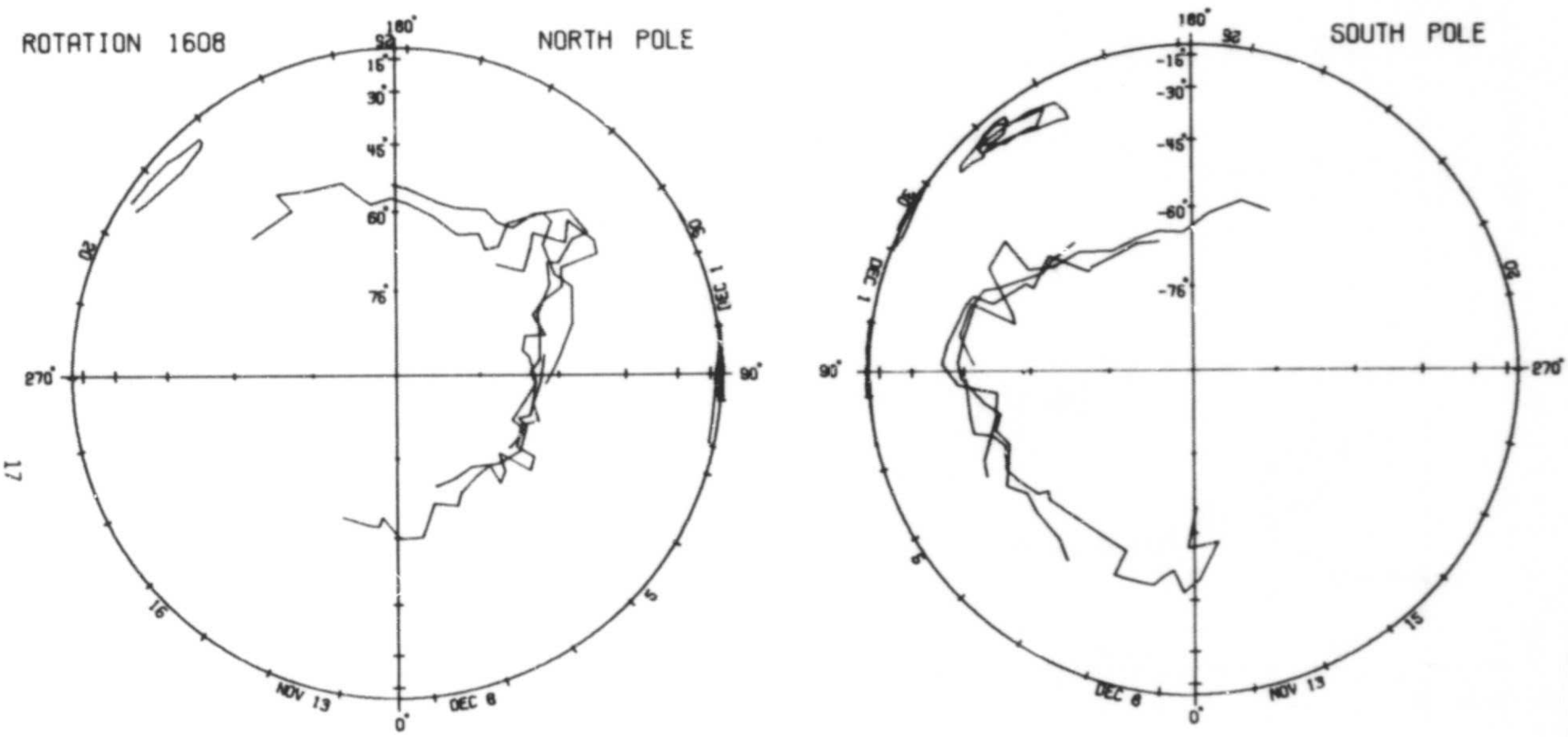
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SOUTH POLE
180°
270°
90°
0°
92
15°
30°
45°
60°
75°
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-45°
-60°
-76°
20
16
NOV 13
DEC 8
5
DEC 1
30
15

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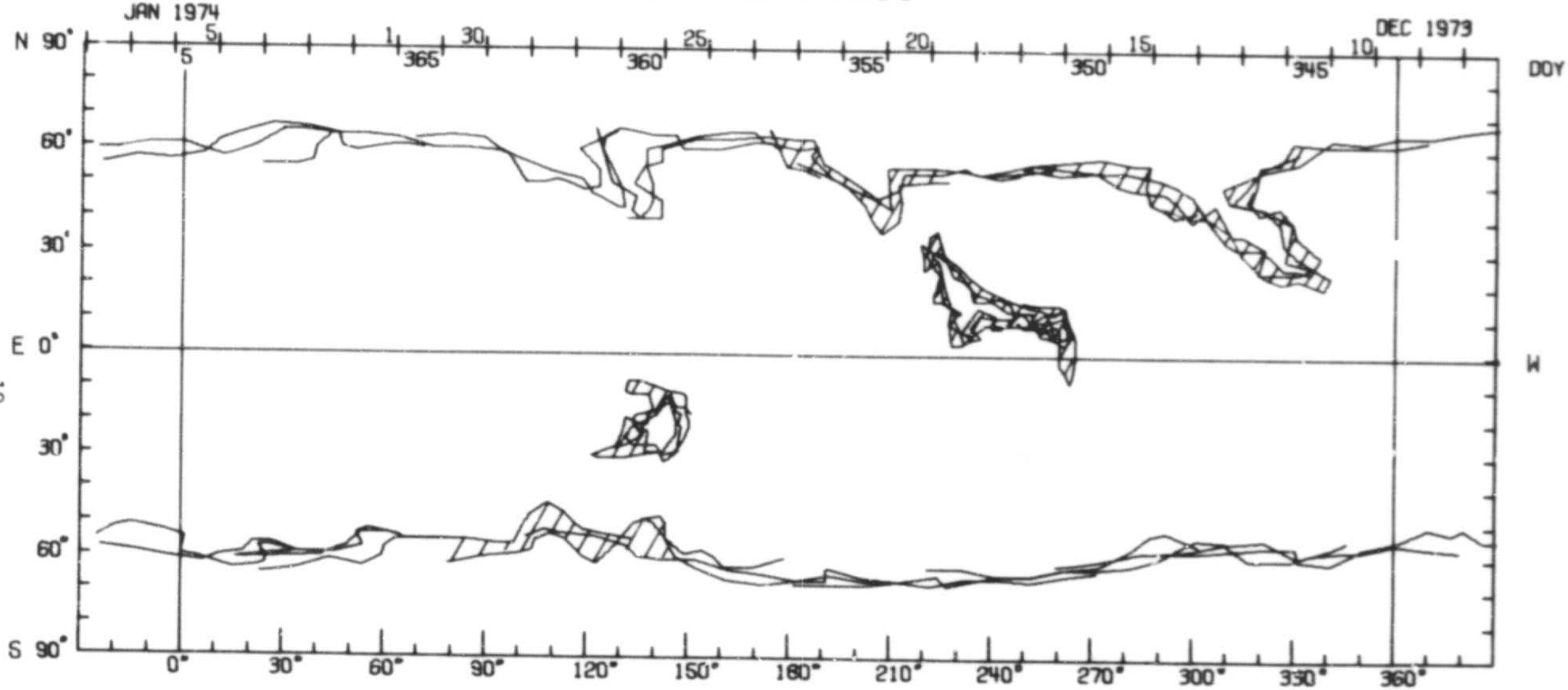

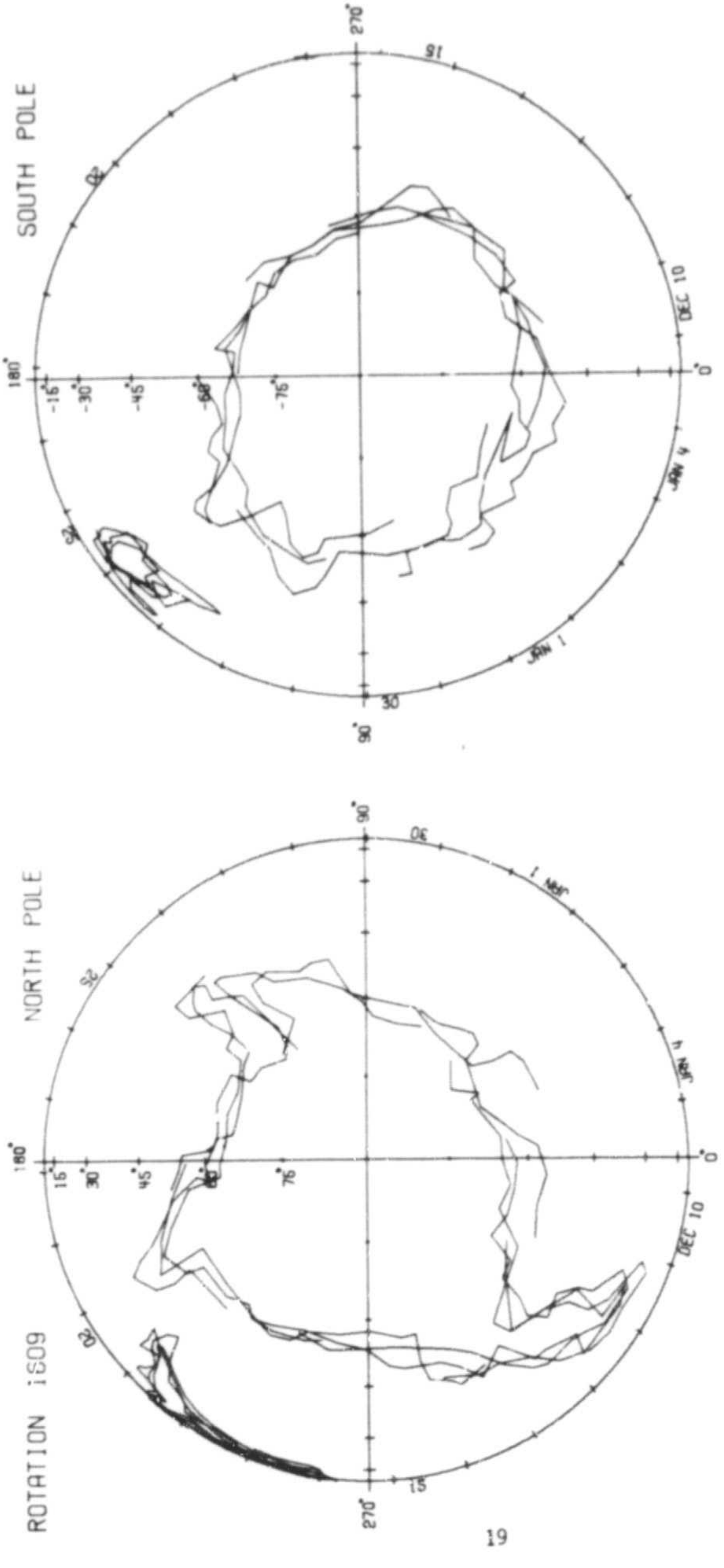
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SOUTH POLE
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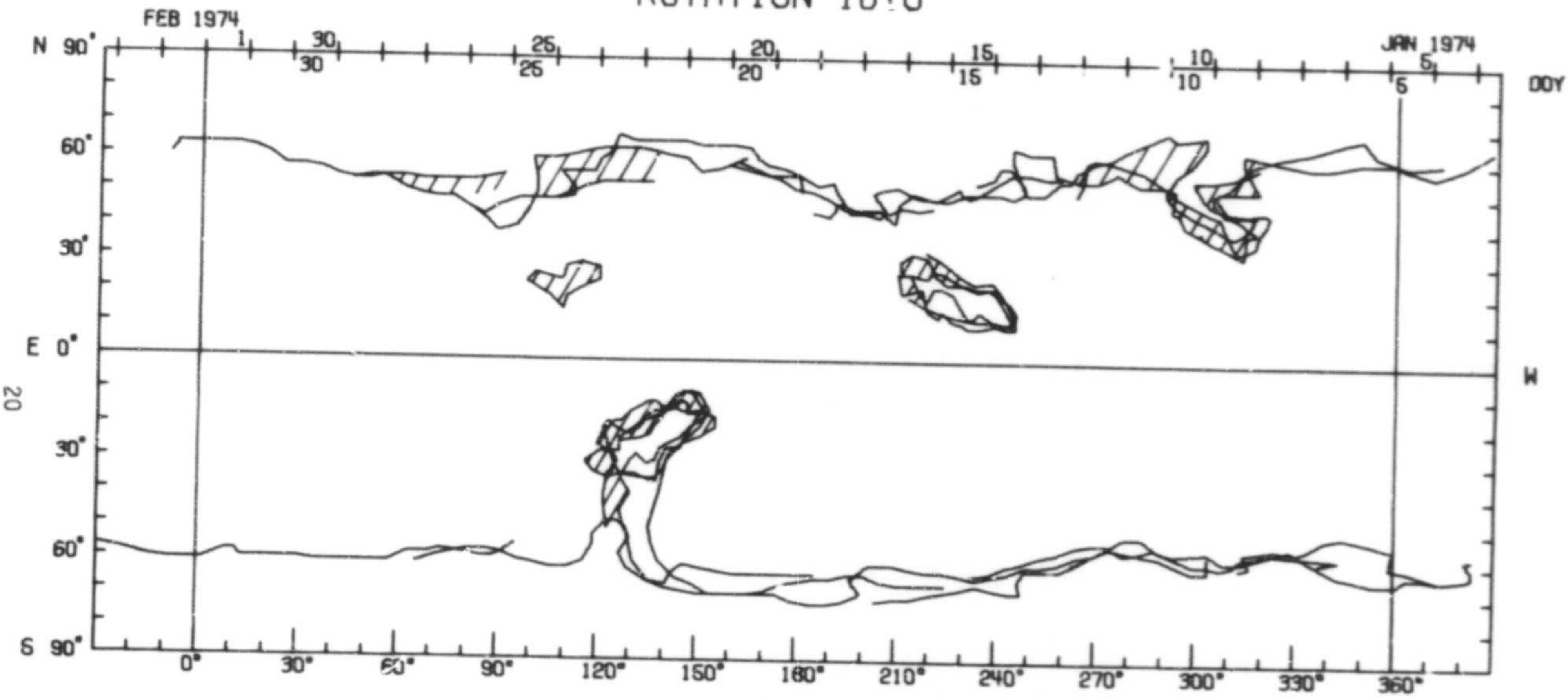
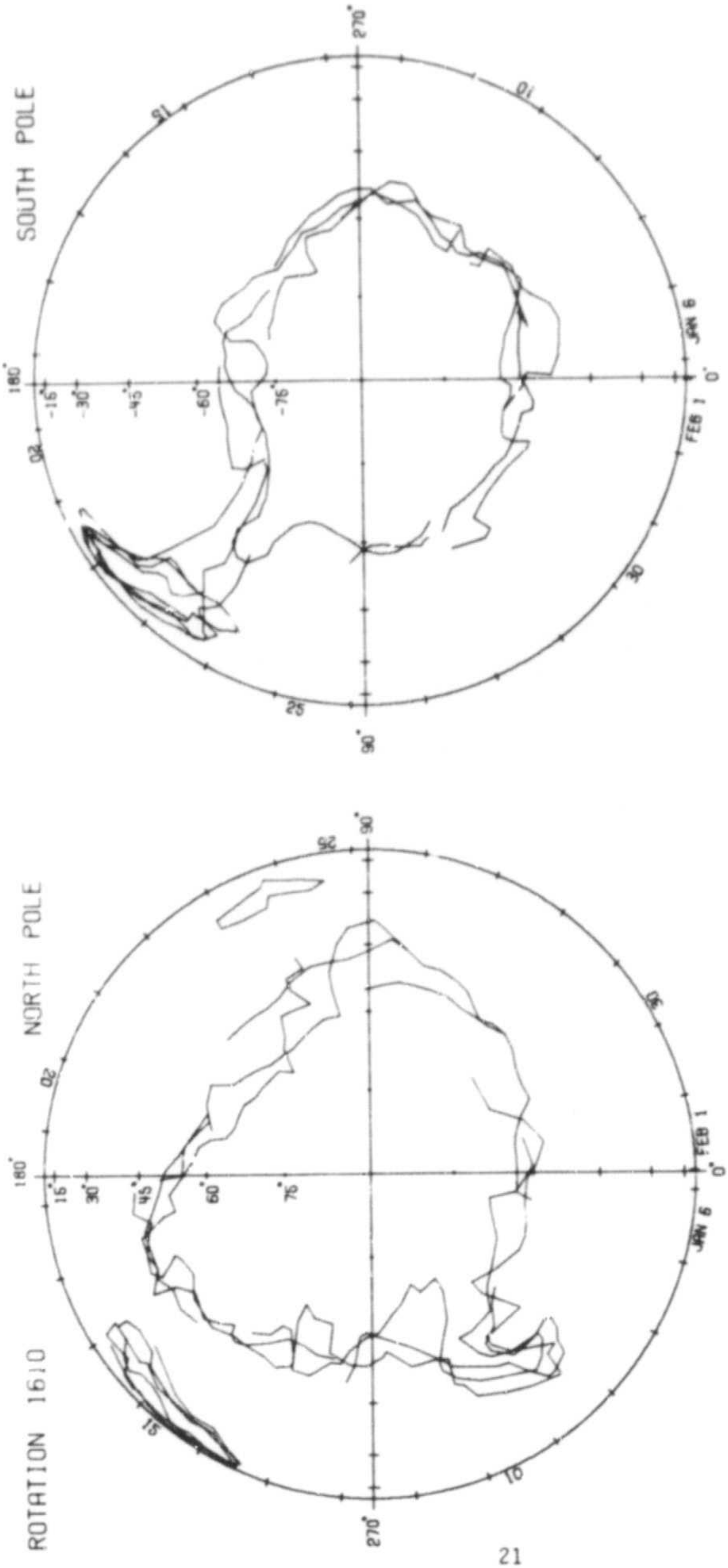
270°
90°
0°
15°
30°
45°
60°
75°
-15°
-30°
-45°
-60°
-75°
DEC 10
JAN 4
JAN 1
30
15
02
32

ROTATION 1610





ROTATION 1610
NORTH POLE
SOUTH POLE
270°
180°
90°
0°
15°
30°
45°
60°
75°
-15°
-30°
-45°
-60°
-75°
JAN 6
FEB 1
10
15
20
25
30

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Prepared by World Data Center A for Solar-Terrestrial Physics, NOAA, Boulder, Colorado, U.S.A.

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