RESULTS OF CURRENT MARS STUDIES AT THE IAU PLANETARY RESEARCH CENTER

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The purpose of this paper is to give an updated report on several recent findings concerning Mars obtained from studies now in progress at the Planetary Research Center of Lowell Observatory. In this work, extensive use has been made of ground-based images obtained almost hourly by seven observatories cooperating under the International Planetary Patrol Program (Baum, 1973).

L. J. Martin has recently completed a detailed hour-by-hour mapping of the first twenty days of the 1971 global dust storm, and Figure 1 shows an interesting behavior that we were not so much aware of at the time of Capen and Martin's (1971, 1972a) original reports a little over a year ago. In Figure 1 you see, for illustration, the outline of storm-brightened areas at two-hour intervals on the 11th day of the storm. Each small map represents approximately the area visible from Earth at that hour, with the morning terminator at the left-hand edge and the afternoon limb at the right-hand edge. The solid line identifies the central meridian, while the dashed line represents where it is noon on the planet.

If the dust storm were associated mainly with particular regions on Mars where the dust has been stirred up, evolving gradually in the course of weeks, its shape on the map would appear to change only a

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little in the course of one day. Figure 1 clearly shows that it does not behave that way. Nor could the apparent changes of shape and position be easily explained as some kind of optical scattering effect. The degree of activity of the dust storm depends both on the region and on the time of day.

We find, in fact, that the dust storm seems to be locally regenerated in this manner about midday each day during its developing stages. These maps for two-hour intervals can be superimposed upon one another to produce a single map describing the day's progress of the storm, and this can be done for each day of the storm. Figure 2 shows ten such maps representing the first ten days of the storm. The contours show outlines of the active areas at two-hour intervals, and the numbers labelled on them indicate the time of day at 0° longitude. In other words, the numbers are approximately a Martian equivalent of Greenwich Mean Time. A very similar set of maps has been made for days 11 through 20. After the 20th day, the accumulated general haze had become so dense that the daily pattern of regional dust generation became too difficult to map. This kind of hour-to-hour history of the storm would have been totally impossible without a complete network of observatories participating full time in the Patrol Program.

Figure 3 sums up the regions that were active during the developing stages of the storm. The main core and the secondary core include the great bowls of Hellas and Argyre, and extend westward from them. Of the five regions identified as recurring bright spots, the one at the right is centered on the great depression just east of Syrtis Major, the one near the center of the map also lies in a region of [redacted] low elevation, and the small one at about 70° longitude in the vicinity of Melas Lacus straddles the enormous equatorial canyon discovered by Mariner 9. However, the remaining two recurring bright spots do not seem to be associated with unusual topography.

Neither does the initial cloud, but as Figure 4 by Capen and Martin (1972b) shows, the three best recorded dust storms of the Martian perihelion season have all started at about the same place. In addition to the remarkable coincidence of position of these three initial clouds, they share another unusual trait, namely, the suddenness and intensity of their onset. In September 1971, for example, there was no visible evidence of any unusual activity on September 21st, but early the following morning as Noachis emerged from the morning terminator, it was brighter and whiter than any features of the storm during the days that followed. What would trigger such a vigorous onset? And why so early in the day, possibly even before dawn? If condensates play a role in making it rather white, why only at the site of the initial cloud?

There is an entirely different kind of observation that may be evidence for persistent dust activity throughout the Martian year. Figure 5 shows data obtained by Thompson (1973) from the statistical analysis of regional contrast variations on our Patrol photographs. Historically, this is the old "blue clearing" phenomenon, which we find is not limited to blue and which we do not believe has anything to do with dilution of contrast by a widespread overcast. Thompson has measured the contrast of four selected features in blue light on about 6,000 image sets from 1969 and 1971. In Figure 5 the ordinate represents the brightness of neighboring light areas divided by the brightness of the dark feature indicated, and the data are plotted against the planetocentric longitude of the Sun, L_S. This diagram spans about one-third of a Martian year, starting with Martian "September" and extending through Martian "December." Data for 1971 considerably overlap those for 1969 and seem to show some degree of qualitative agreement, so we think that the contrasts of these features have at least some dependence on the Martian season. Residual differences may be due to a phase angle dependence.

The most interesting feature of Thompson's analysis is illustrated in Figure 6. These data pertain to the Nilokeras region during a particular time interval. Similar diagrams exist for other time intervals and also for the Syrtis Major region. These diagrams confirm our earlier finding that there is a systematic trend of regional contrast with time of the Martian day and that the afternoon is not symmetric with the morning.

If we assume that the contribution of the surface can be represented by a symmetric Minnaert function having slightly different coefficients for light and dark areas, we are then left with the non-symmetric residual contribution shown in Figure 7. We think it is reasonable to assume that this contribution is due to the atmosphere. The three curves in Figure 7 represent three different time intervals--early, middle, and late--during the 1971 Mars apparition. The agreement of the three curves shows that the apparent difference between morning and afternoon has nothing to do with any phase angle effect. It is really due to something going on on Mars.

The afternoon upturn illustrated here is an order of magnitude greater than statistical uncertainties in the data. It amounts to a daily rise of 8% between noon and 4 p.m. local Martian time, and it is occurring when Mars is supposedly "normal" and no actual dust storm is in progress. We interpret this as mainly a rise in the brightness of the light areas, with less change (perhaps none) taking place in the dark areas. If this phenomenon is due to a ground haze that is regenerated each afternoon, one can show that it may limit the horizontal visibility range of Mars landers if they are put down in light areas.

The third finding (Baum and Martin, 1973) to mention in this paper concerns the Martian polar caps and is illustrated in Figure 8. We have plotted the mean latitude of the north polar cap boundary against the Martian season, expressed in terms of L_s. This diagram spans two-thirds of a Martian year, but the data were obtained from the Lowell plate collection covering more than 60 years (Fischbacher, Martin, and Baum, 1969), plus more recent data from Patrol films; and the solid dots represent means for different years. Since the scatter of the dots is not significantly greater than the estimated errors, the regression of the surface cap evidently runs on a very predictable schedule.

Now, what does this diagram say? Until a few weeks after the vernal equinox (until a bit past $L_S = 0°$), the boundary is vague, rapidly variable, and visible mainly on blue or ultraviolet images. It commonly reaches down to latitudes as low as 40° north. We identify this as the north polar hood, and we use the crosses here to represent approximate long-term means. As the hood clears away soon after the vernal equinox, a new and different looking boundary becomes visible much further north. It is sharp, it is seen in all colors, and its mean latitude is 65 to 66 degrees north. We identify it as the surface cap, and we suspect that it never extends much below 65°, because it is not initially receding. In fact, it does not start receding rapidly until 80 days later. The boundary again becomes almost tationary when it reaches the edge of the permanent cap at 82 to 83 degrees north. About 150 days after that, a new polar hood starts to obscure the cap.

In Figure 9, our result is again represented schematically by the bent solid line. For comparison, the three dashed lines show north cap regression curves published previously by others. These dashed curves do not give any clear indication of the approximate stillstand that we find near 65° latitude, and the overall disagreement amongst the curves is large. We believe that the differences arise from the method of measurement. We superimpose images optically onto an orthographic grid and read the latitude of the boundary of the cap near the central meridian of the image. Others have instead measured the apparent angular width of the cap near the polar limb, where the hood would be harder to distinguish from a surface cap and where any atmospheric haziness would bias the readings.

The situation in the southern hemisphere shown in Figure 10 is much the same, except that the cap is more eccentric with respect to the pole. When the south surface cap first becomes visible, its boundary runs from about 56°S latitude on one side to 60°S on the other. Like the north cap, it appears to have been at a stillstand, but it starts receding sooner. It reaches the eccentric permanent cap when L_s is about 280°. There is no evidence to support the widely held belief that the south cap dissipates completely.

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Capen, C. F., and Martin, L. J. (1972b). "Survey of Martian Yellow Storms." Bull. Amer. Astron. Soc. **4**, 374.

Fischbacher, G. E., Martin, L. J., and Baum, W. A. (1969). "Mars Polar Cap Boundaries." Report under JPL Contract No. 951547, May 1969.

Thompson, D. T. (1973). "Time Variation of Martian Regional Contrasts." Icarus, in press.

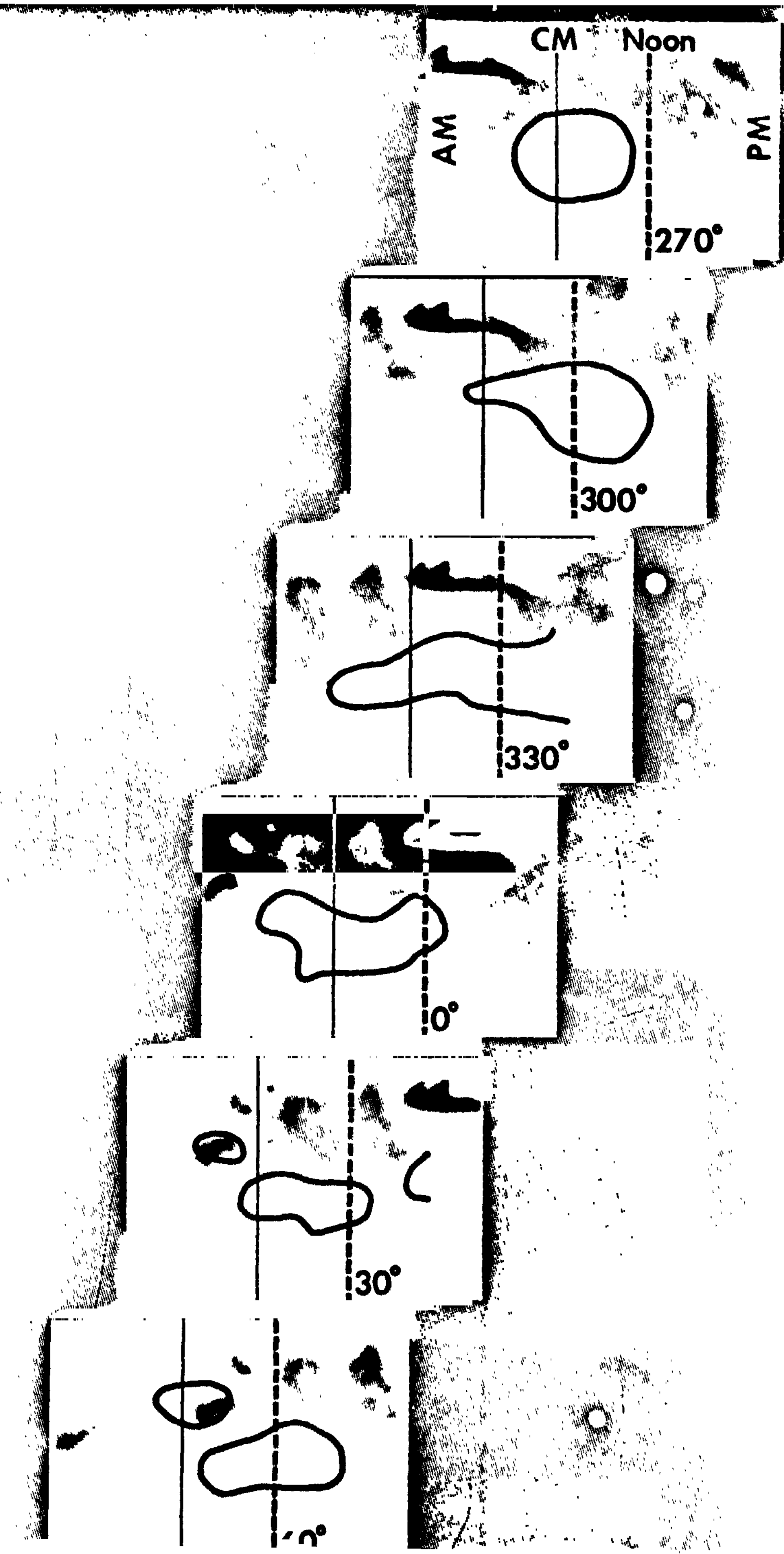
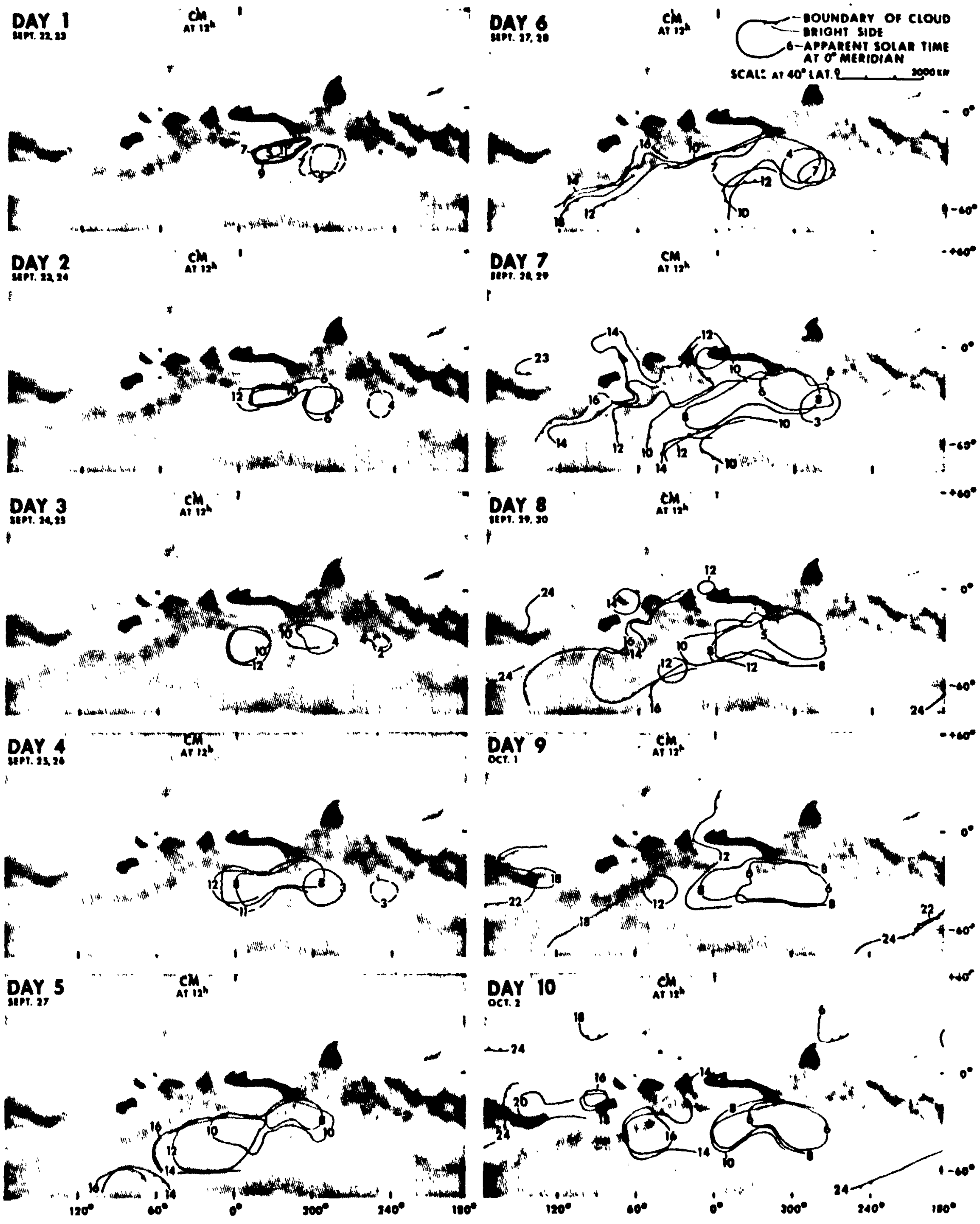


FIGURE 1.



DAY 1
SEPT. 22, 23
DAY 2
SEPT. 23, 24
DAY 3
SEPT. 24, 25
DAY 4
SEPT. 25, 26
DAY 5
SEPT. 27
DAY 6
SEPT. 27, 28
DAY 7
SEPT. 28, 29
DAY 8
SEPT. 29, 30
DAY 9
OCT. 1
DAY 10
OCT. 2
CM
AT 12h
BOUNDARY OF CLOUD
BRIGHT SIDE
APPARENT SOLAR TIME AT 0° MERIDIAN
SCALE AT 40° LAT.
3000 KM
+60°
0°
-60°
120°
60°
0°
300°
240°
180°

FIGURE 2.

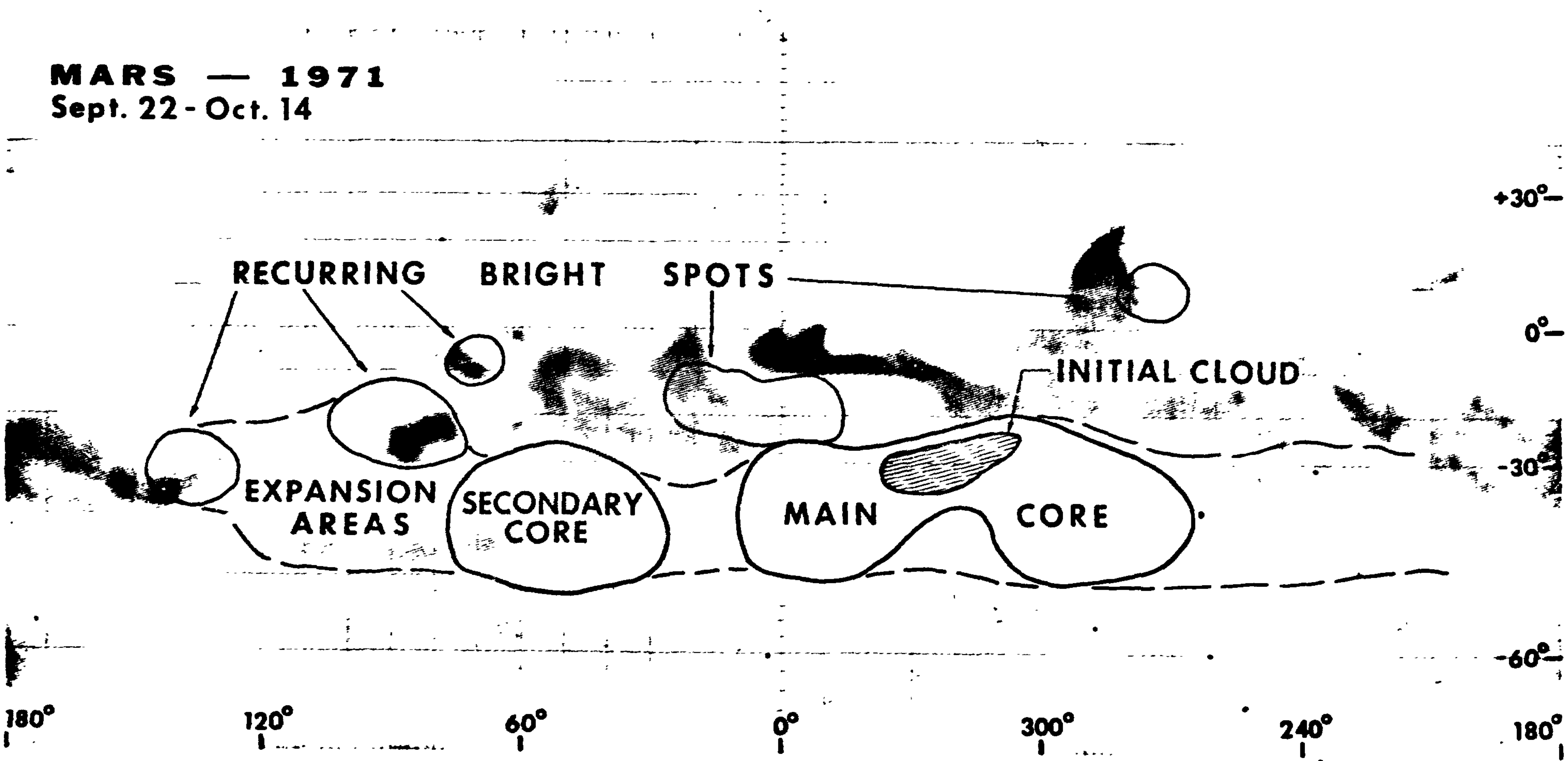

MARS — 1971
Sept. 22 - Oct. 14
RECURRING BRIGHT SPOTS
INITIAL CLOUD
EXPANSION AREAS
SECONDARY CORE
MAIN CORE
+30°
0°
-30°
-60°
180°
120°
60°
0°
300°
240°
180°

FIGURE 3.

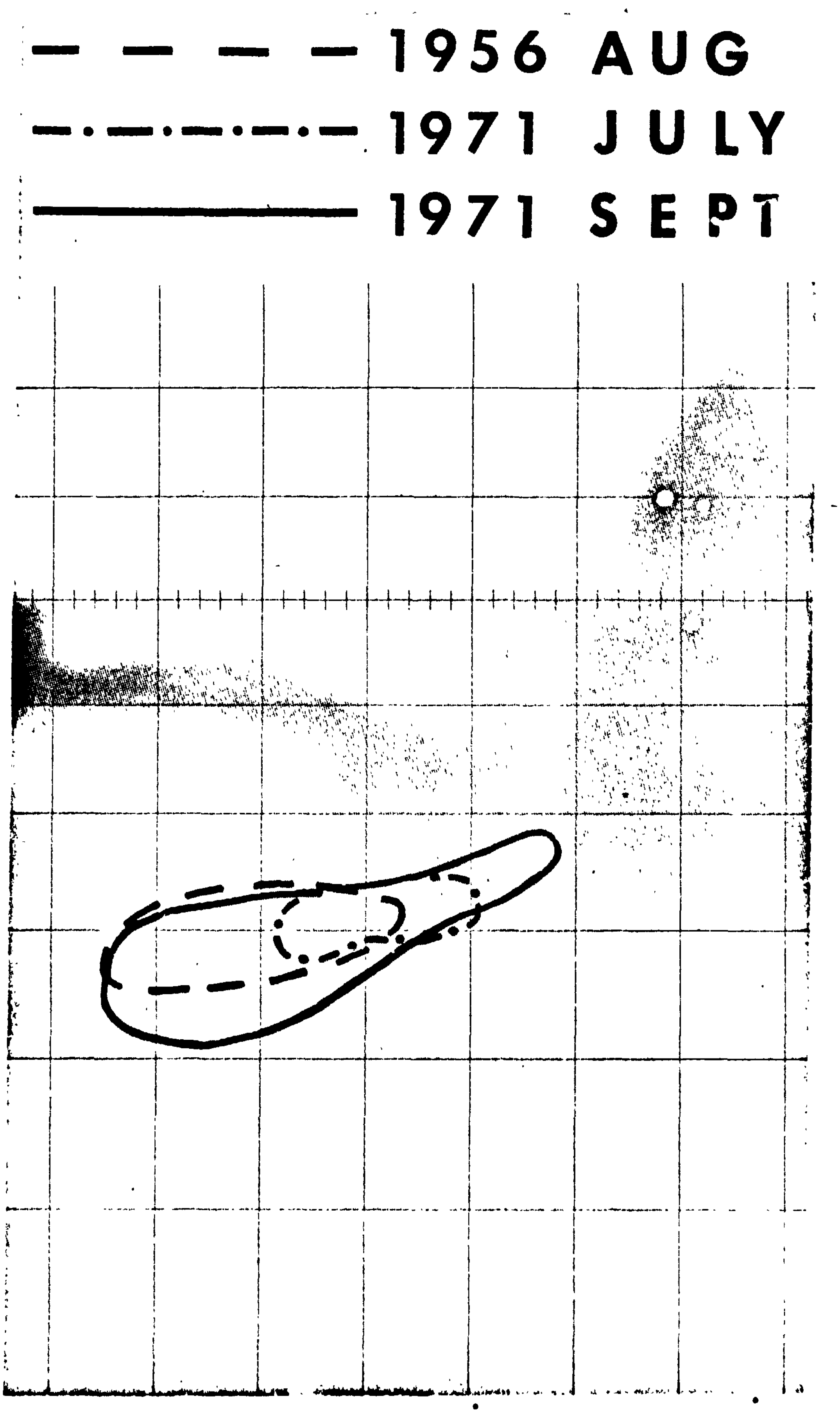


FIGURE 4.

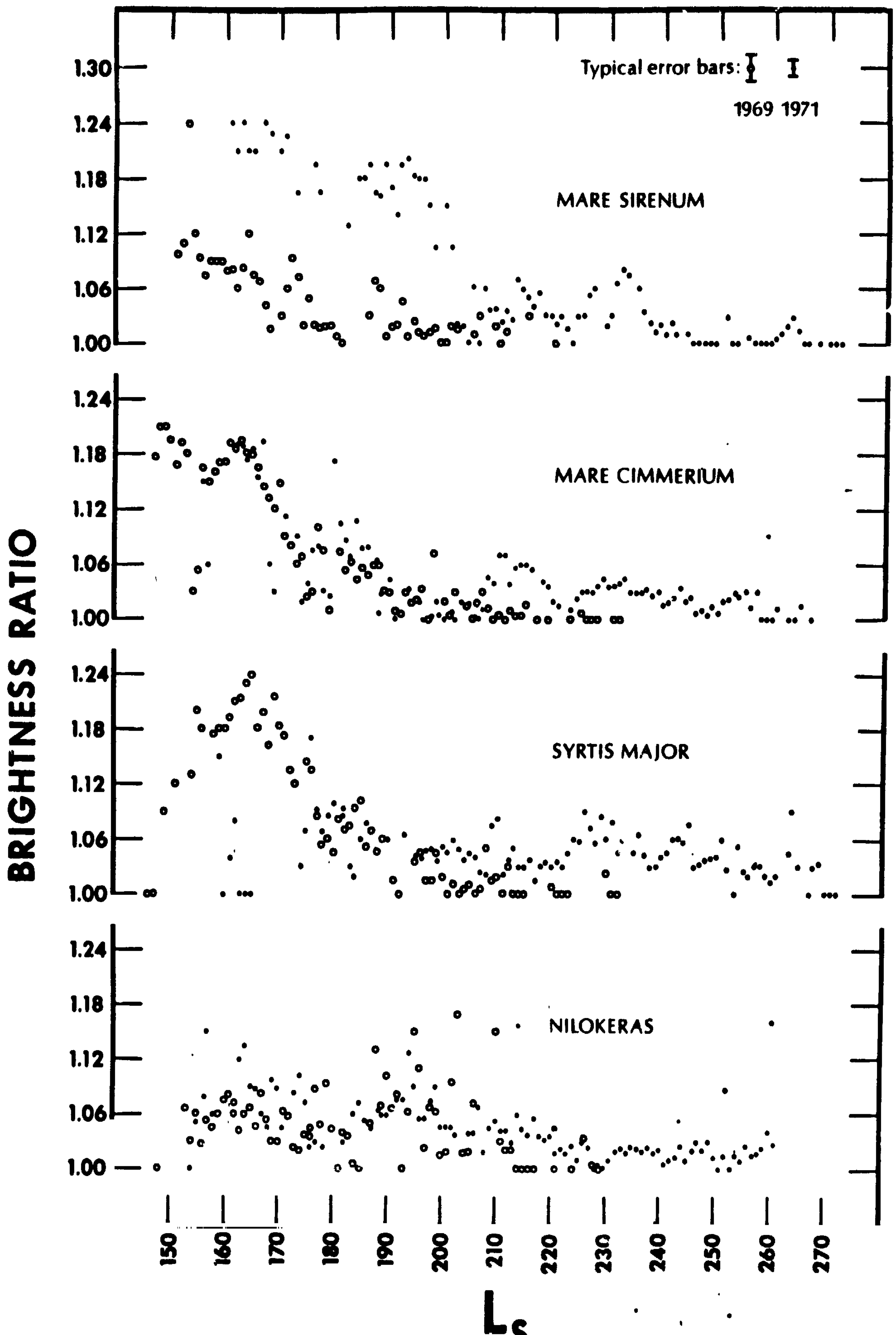

Typical error bars:
1969 1971
MARE SIRENUM
MARE CIMMERIUM
SYRTIS MAJOR
NILOKERAS
BRIGHTNESS RATIO
1.30
1.24
1.18
1.12
1.06
1.00
150
160
170
180
190
200
210
220
230
240
250
260
270
L_S

FIGURE 5.

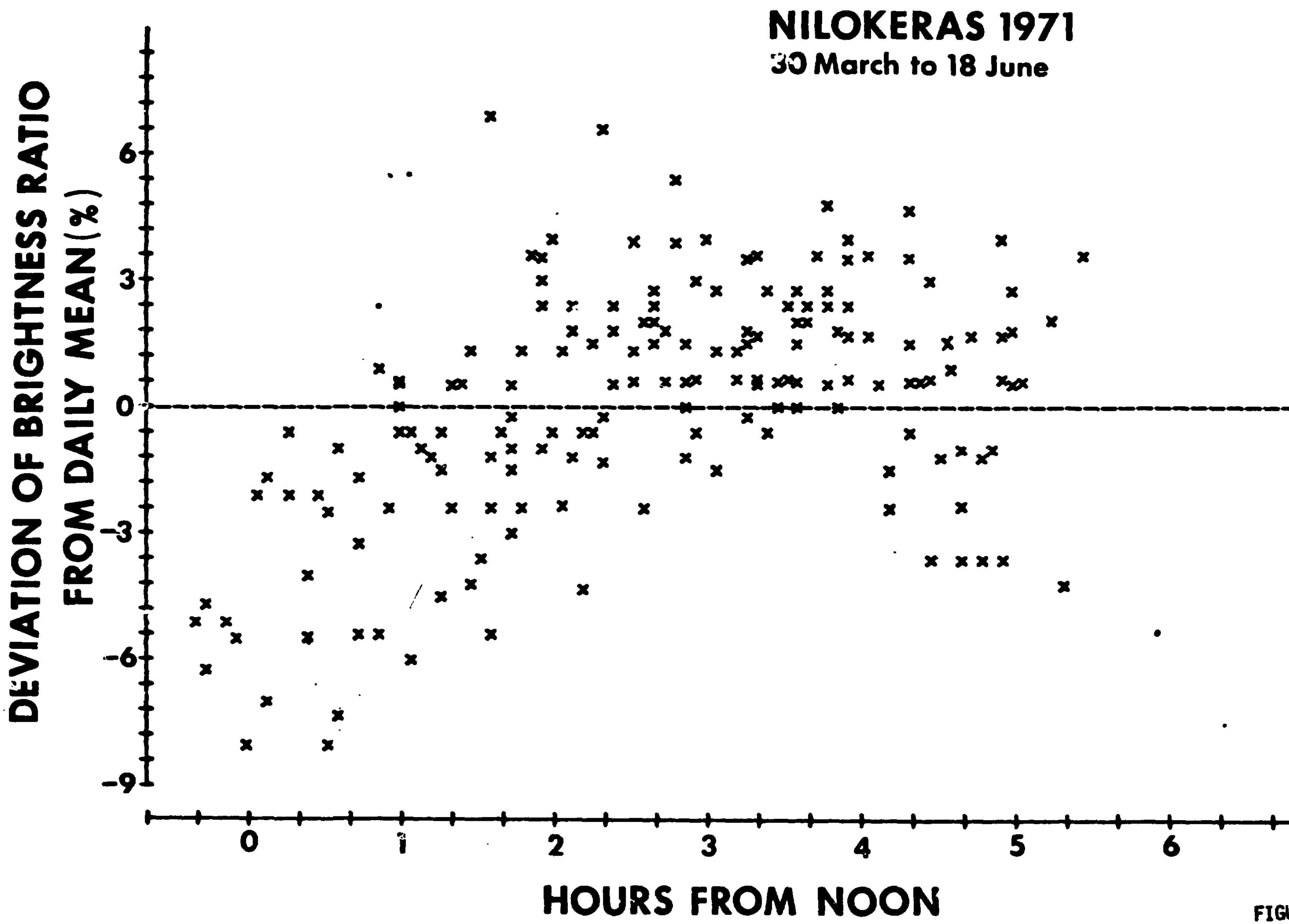

NILOKERAS 1971
30 March to 18 June
DEVIATION OF BRIGHTNESS RATIO
FROM DAILY MEAN(%)
6
3
0
-3
-6
-9
0
1
2
3
4
5
6
HOURS FROM NOON

FIGURE 6.

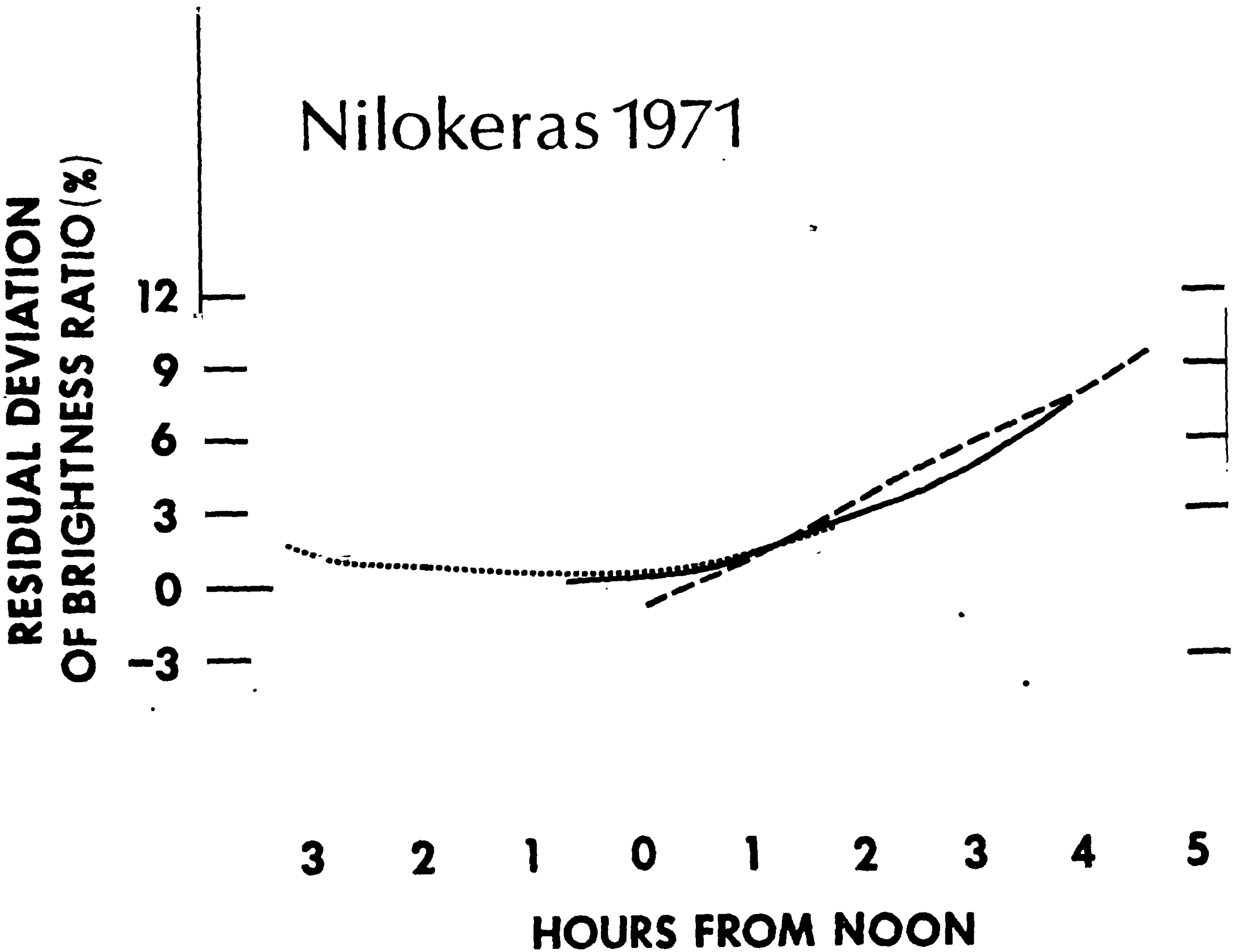

Nilokeras 1971
RESIDUAL DEVIATION
OF BRIGHTNESS RATIO (%)
12
9
6
3
0
−3
3
2
1
0
1
2
3
4
5
HOURS FROM NOON

FIGURE 7.

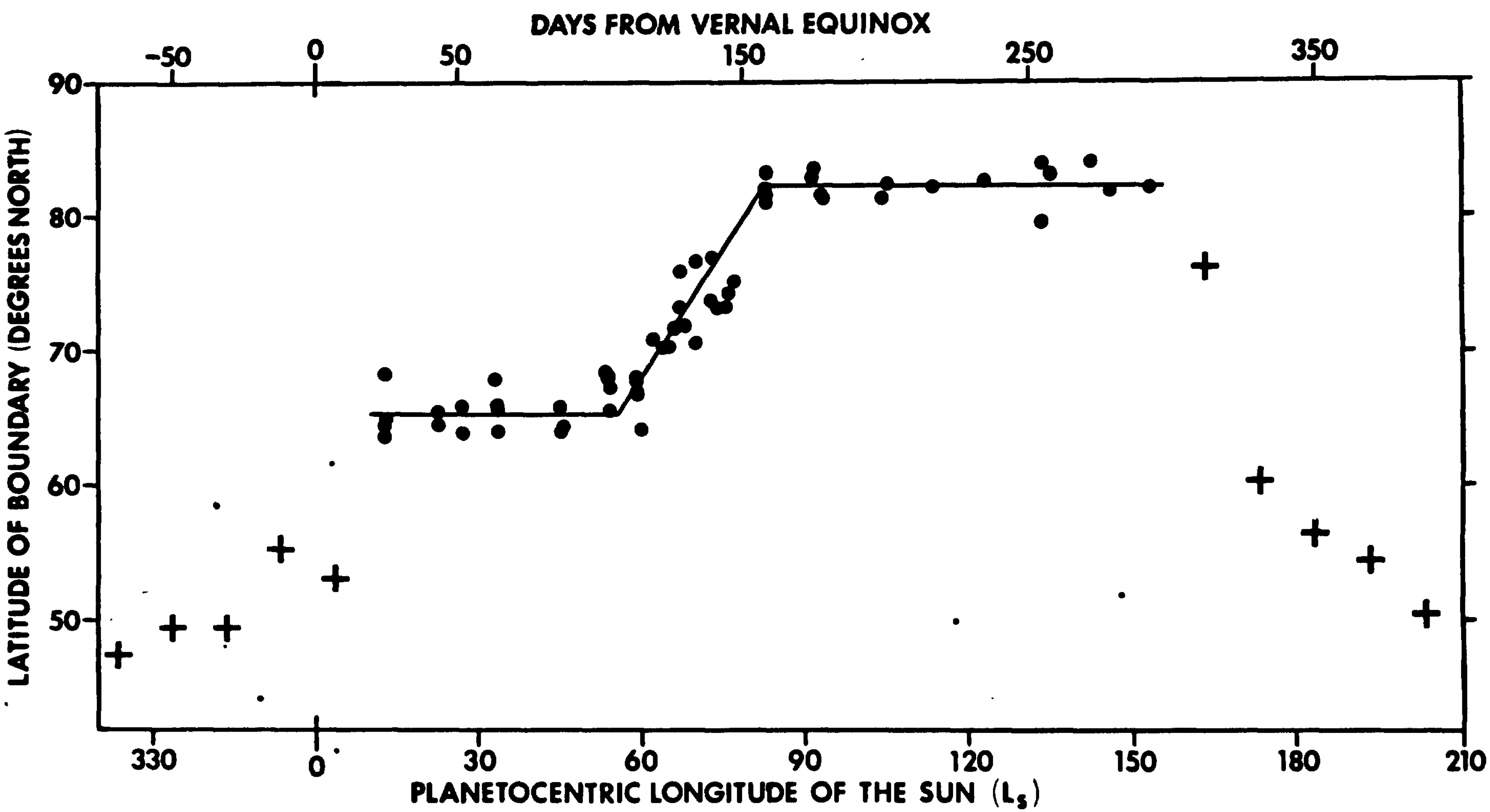

DAYS FROM VERNAL EQUINOX
-50
0
50
150
250
350
90
80
70
60
50
LATITUDE OF BOUNDARY (DEGREES NORTH)
330
0
30
60
90
120
150
180
210
PLANETOCENTRIC LONGITUDE OF THE SUN (L_s)

FIGURE 8.

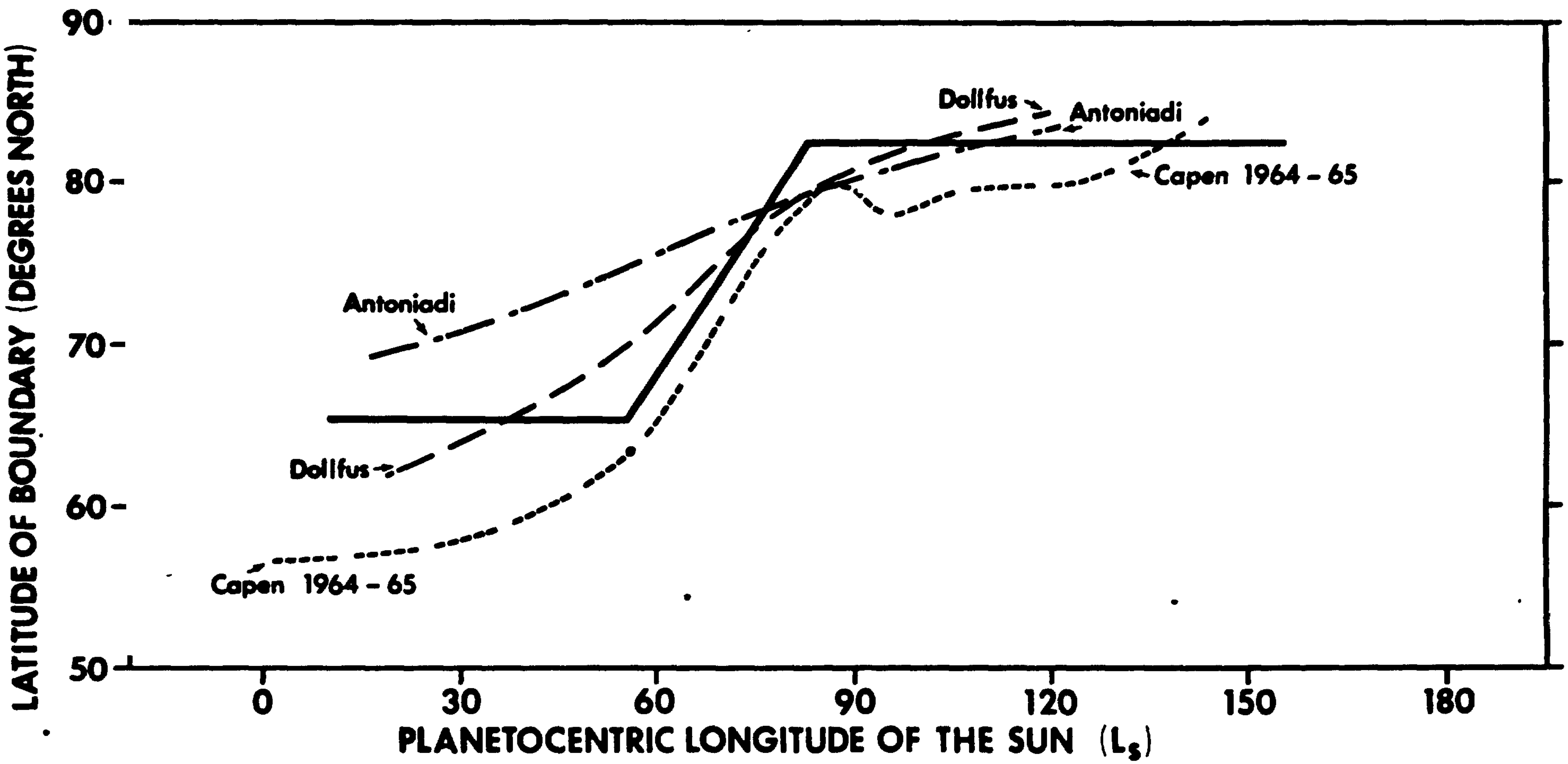

LATITUDE OF BOUNDARY (DEGREES NORTH)
90
80
70
60
50
0
30
60
90
120
150
180
PLANETOCENTRIC LONGITUDE OF THE SUN (L_s)
Dollfus
Antoniadi
Capen 1964 - 65
Antoniadi
Dollfus
Capen 1964 - 65

FIGURE 9.

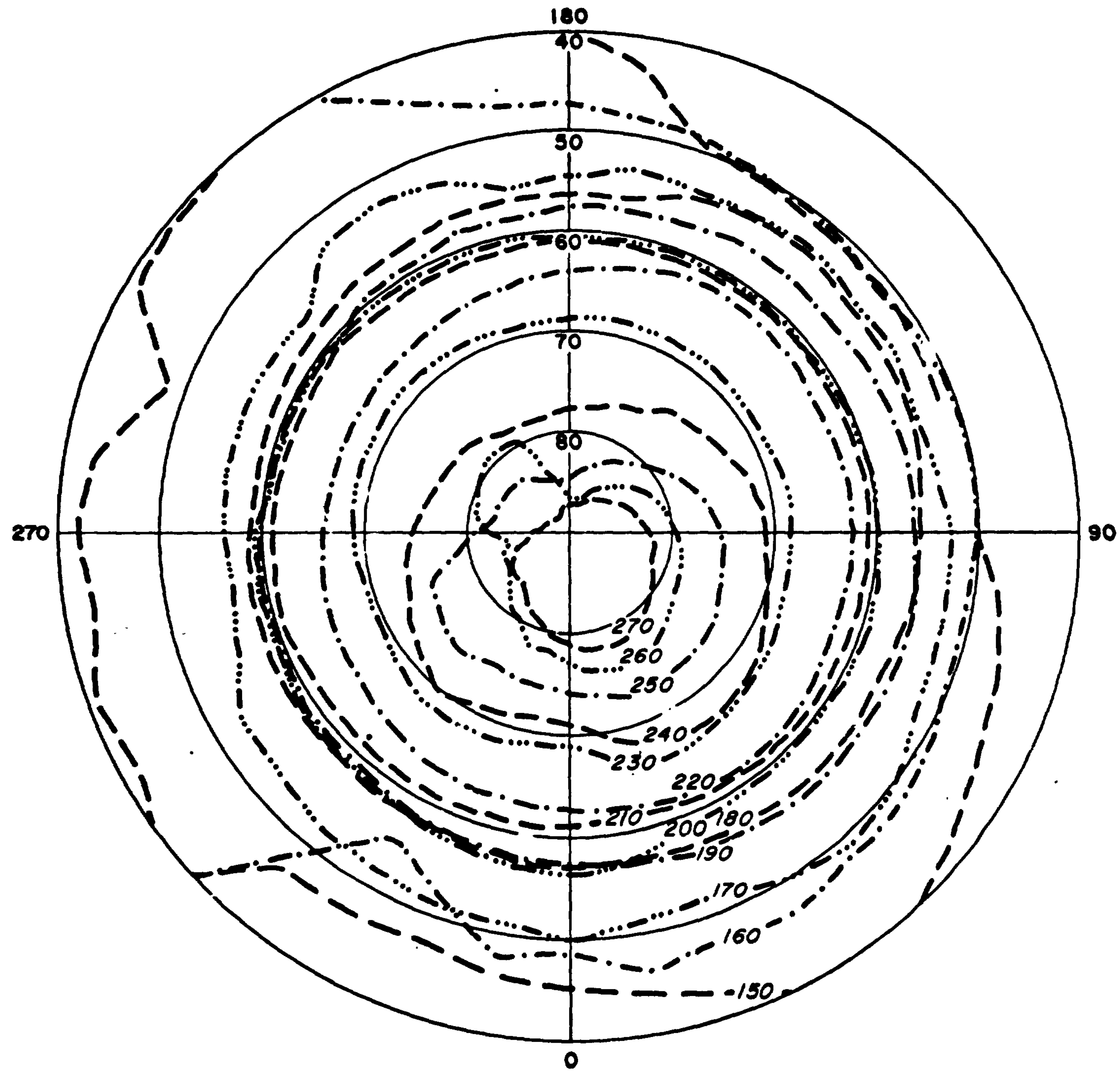

180
40
50
60
70
80
270
90
0
270
260
250
240
230
220
210
200
180
190
170
160
150

FIGURE 10.