NAGW-742

IN-91

59538-CR

P-21

Interannual Variability of Mars' South Polar Cap

Philip B. James
and
Klaus M. Malolepszy
Physics Department
University of Missouri - St. Louis
St. Louis, Missouri 63121

and

Leonard J. Martin
Lowell Observatory
Flagstaff, Arizona

(NASA-CR-180207) INTERANNUAL VARIABILITY OF MARS SOUTH POLAR CAP (Missouri Univ.) 21 p CSCL 03B

N87-19323

Unclas

G3/91 43634

Variability of Mars' South Cap

Send correspondence to:

Philip B. James
Physics Department
University of Missouri-St. Louis
St. Louis, MO 63121

Abstract

Telescopic data on the twentieth century regressions of Mars' south polar cap have been reexamined for evidence of interannual variability. Several regressions, particularly that of 1956, are found to differ significantly from the mean. The possibility of correlations with major duststorms is explored.

INTRODUCTION

William Herschel (1784) was the first astronomer to seriously consider the seasonal changes of the martian polar caps; he used the periodic growth and recession of these condensate deposits to locate the planet's rotation axis relative to its orbital plane. Since that time numerous observers have recorded the seasonal cycles of the polar caps, particularly the cap regressions which are most easily observed from Earth. The question of interannual variability in the seasonal cap cycle has been vigorously debated over the years. Despite the fact that it is more difficult to observe, the north cap has been the subject of most attention regarding variability. Antoniadi (1930) considered polar cap drawings by himself and others spanning the period from 1856 to 1930; he noted variations, particularly in the north polar cap, which, he suggested, were correlated with the solar activity cycle. More recently, Parker, Capen, and Beish (1983) have also noted variations in the north cap's regression since 1963; and Iwasaki, Saito, and Akabane (1982) have reported more subtle differences between the north cap regressions of 1977-78 and 1980. Differences also appear in data based upon Viking orbiter images (James, 1979 and 1982), although the incomplete longitudinal coverage in those data rendered such a conclusion weak. On the other hand, Dollfus (1973) found very precise repititions in the north cap's behavior based on his observations in 1946, 1948, and 1950.

The south polar cap regressions could be a more sensitive measure of interannual climate variability than those in the north because Mars is substantially closer to Earth and has a larger angular diameter during south cap regressions, it is larger at its maximum extent, insolation is maximum during its recession and it therefore sublimes more rapidly, and there is less confusion due to circumpolar clouds and hazes during the southern spring season than the corresponding season in the north. Slipher (1962), comparing data on the size of the south cap at summer solstice, remarked that "agreement among various observers ... is remarkable" and used photographic evidence to refute earlier reports of variations based on visual observations. Orbiting spacecraft have made accurate comparisons of different regressions possible, although constraints on temporal and spatial coverage have not permitted the ideal comparison of two complete regressions. James et al. (1979) used Mariner 9 and Viking orbiter data to establish that the late phases of the 1979 and 1971 recessions of the south cap were significantly different. However, a comparison of the complete 1977 regression curve obtained by Viking and the 1971 curve obtained by the International Planetary Patrol suggested that these differences did not appear until around $L_s = 260°$, when the major 1971 duststorm prevented the use of subsequent images (James and Lumme, 1982, subsequently referred to as I.). Comparison of the 1977 curve with the large body of earlier telescopic data reported by Sipher suggested that the 1977 regression (and by implication that of 1971) was retarded relative to the mean of previous recessions during the period near summer solstice (James et al., 1979). Planetary Patrol data for 1973 suggested that the south cap might have retreated more rapidly during that year than during 1977, but there were not enough data to make a valid conclusion. Iwasaki et al. (1986) used their temporally more extensive data set for 1973 to show that the 1973 retreat was faster than 1977 or 1971. These studies confirm that some interannual variations do occur, but the extent of these differences and whether they can be revealed by telescopic observations is still somewhat uncertain.

Any hope of realistic comparisons between cap regressions must rely on using consistent data sets so as to eliminate systematic errors. The measurements reported by Fischbacher et al. (1969) and by James and Lumme

(1982) were obtained using the same method (devised by W. Baum) and equipment. Because variations between results obtained by different researchers using different techniques often exceed the apparent interannual variations, we have limited the current analysis to the self consistent data reduced as described by Baum and Martin (1973).

SOUTH CAP DATA

Since the same Martian season can be observed from Earth just once in fifteen years, there are only five different photographic data sets obtained during oppositions or pairs of oppositions suitable for intercomparison from this century. Fortunately, the south cap recession occurs during favorable apparitions and therefore yields larger scale images and is more heavily observed. Our most recent data from earth-based observations is International Planetary Patrol photography from 1971 and 1973, measured and analyzed in I. We have reexamined the data from the study of the historical plate collection conducted by Fischbacher et al. (1969) specifically looking for variations in the south cap recession through comparisons with the more recent 1971, 1973, and 1977 data. Because the south cap does not recede symmetrically, we have plotted regression curves for four different areographic longitudes, 30° longitude, the approximate location of the slowest recession, 120°, 210°, and 300°. The data were binned in 10° bins centered on every 10° of L_s (areocentric longitude of the Sun) to obtain the median curves shown in Figure 1; the 1977 curves are also shown for comparison. This diagram clearly demonstrates that the asymmetry of the cap becomes most pronounced within the interval between L_s 240° and 260°, which is also the period of most rapid regression at all areographic longitudes and is the time of perihelion for Mars in its orbit about the sun.

The median recession curves shown in Figure 1 were used as standards to compare with the recession curves from each apparition covered by the study. The only years which had variations from the medians which were consistently positive or negative were 1939 and 1954, which were slower, and 1956, which was faster. The 1977 recession appears to be somewhat slower than the median during the period around summer solstice; this is apparent on Figure 1 for the longitude where the cap is largest, 30° (James et al., 1979). The 1971 recession is very similar to the median and to 1977 until roughly $L_s = 260°$ when a suggestion of acceleration of 1971 relative to 1977 occurs; this is consistent with the later summer behavior. The 1973 data after $L_s = 250°$ suggest a more rapid than average recession that year; this was supported by the observations of Iwasaki et al. before $L_s = 250°$.

1956 Data

Because the qualitative look at the south cap recession data discussed above suggests that the 1956 recession is advanced relative to the mean and because the 1956 data are by far the most extensive of the historical Lowell data set, a more detailed comparison of the 1956 data with those of 1971, 1973, and 1977 has been undertaken. Because the 10° L_s bins used by Fischbacher et al. may smear over periods of significant changes in the south polar cap, the data were rebinned in 2° L_s intervals. The comparison was made in two different ways. First, the radius of the cap on a polar sterographic projection and the displacement of the center of the geographic pole were determined as described in I. These values were determined only for L_s intervals for which at least ten data points existed in three of the four longitude quadrants. The results of this analysis are listed in Table I which records the areocentric solar longitude, L_s, the number of data points measured, the cap radius, the standard deviation of the data points (not of the mean), and the x and y displacements of the cap center; notation is as in I. The resulting regression curves are shown in Figure 2.

The second method of comparison involved the behavior of cap radii in two confined ranges of longitude. For these purposes the longitude ranges chosen were 20°-40°, where the cap radius is maximum, and 180°-200°, where the cap radius is minimum. The resulting regression curves for the four data sets for these limited longitude ranges are shown in Figures 3 and 4.

It can be seen from Figure 2 that the average cap radius for 1956 is substantially less than that of 1971 or 1977 from L_s = 230° to L_s = 270°; the post perihelion cap regression in 1956 appears to have also been more rapid than 1973. The standard deviation of the means for the 1956 data points in Table I are given by the quotient of the standard deviations, σ, and the square roots of the number of measurements, n; this is typically less than 0.002 or 0.2°. Therefore, the deviations of the 1956 data points from the 1977 and 1971 curves are all at least five standard deviations between L_s = 230° and L_s = 275°, and the radii are consistenly smaller. This strongly supports the tentative conclusion, voiced in I, that the 1956 regression was "fast".

The accelerated regression in 1956 can also be seen by comparing the asymmetry parameters, x_o and y_o, from 1971 and 1956. There is much more scatter in these numbers from both years because they are much more sensitive to asymmetrically distributed data points. However, the behaviors of x_o and y_o also suggest that the 1956 jump (see Figure 9 of I) occurred roughly 7° of L_s earlier than in 1971.

The recession curves for fixed longitude ranges shown in Figures 3 and 4 also show that the 1956 recession was accelerated relative to the 1971-1977 standard. A comparison of the two figures also leads to several interesting conclusions. The rapid divergence of the 30° and 190° curves between L_s = 225° and L_s = 245° is indicative of the asymmetry in the south cap sublimation which is also reflected in the growth of x_0 and y_0 at the same time. The accelerated 1956 recession is first signaled in the 190° curve; there is no noticable difference in the 30° regression curve until near perihelion when it, too, supports a more rapid 1956 recession. This could be a hint that it is CO_2 deposition in the cap interior during winter which is variable rather than the surface heating at the periphrey during spring.

DUST STORM DATA

Can variations in the recessions of Mars' south polar cap be attributed to major dust storms? Martin (1984) pointed out that major dust storms do not occur regularly and that they have starting dates spanning at least a third of a Martian year. Since these large storms can begin at different points on the cap's recession curve, the question of a correlation is nontrivial. Because we are only dealing with favorable, well-observed apparitions, it is reasonable to assume that any storms that might have been large enough to influence the cap's recession rate would have been observed. Localized dust storms could have remained undetected, but any large storms of a week or more duration would have been recorded. Table II is a complete list of all large dust storms that have been photographically documented. No large storms were observed in 1939 or 1954, when the south cap recessions were slower than the median. Both of these apparitions were intensely observed, including observations by Lowell Observatory expeditions to South Africa. It is unlikely that large storms occurred during the intervals covered by our polar cap recession measurements. The storms of 1922 and 1969 probably were not large enough to have an effect upon the south cap, although data on the 1969 storm are sparse.

In 1956 there was a substantial planet-encircling storm commencing at $L_s = 250°$; thus the cap was subliming faster than the median before the dust storm began. There were two planet-encircling storms in 1977. The first 1977 storm began much earlier in the season than the 1956 storm, occurring shortly after the cap had begun its recession. Although the early 1977 recession phases were near median, or even somewhat ahead, during the period between storms, the recession rate eventually slowed to a rate somewhat below the median. Finally, after the second storm began, the recession rate again was seen to be near the median. The two 1977 storms were far from identical and probably produced different effects. In 1971, a very intense global storm eliminated the possibility of earth-based observations of the polar cap shortly after the storm began at $L_s = 260°$. The last two 1971 data points suggest an increase in the recession rate at that time. After the global storm cleared, Mariner 9 images showed the recession rate was ahead of that seen in the Viking pictures taken in 1977 (James et al., 1979). This is not surprising since, although two storm years were being compared, the 1971 storm was much larger than either of the 1977 storms. Both years had early storms, so the similarity of regression curves is not surprising. The 1973 planet-encircling storm began too late in the season to have much impact on the cap recession. Nevertheless, Figure 2 suggests a possible pre-storm effect similar, but less pronounced than observed in 1956.

The data on the 1956, 1971, 1973, and 1977 storms and regressions are consistent with the proposition that regressions associated with early spring storms (1971, 1977) are slow compared to those that aren't (1956, 1973). However, the observations of the latter oppositions did not include the necessary early dates, and there are therefore no hard data to rule out early storms in those years. Also, the 1939 and 1954 regressions appear qualitatively to be slower than either 1971 or 1977; but those years did not have any well documented storms. Thus, the data are consistent with but do not require this proposition.

The proposition that post perihelion storms accelerate cap recession does not seem to be particularly supported by the data. 1971 is possibly consistent with that assumption, although the data are only suggestive. The deviation from mean in 1956 precedes the 1956 storm by almost 20° in L_s. And the effect of the late 1977 storm seems to be in the opposite direction. The 1973 storm did not occur until the cap sublimation was almost complete and would not, therfore, be expected to have had a large effect.

One must temper any such attempt to correlate dust storm activity with cap recessions with the realization that these major storms are unique entities with different geographical evolution, different opacities, and perhaps even different dust composition or size distribution. Thus, attempts to correlate only with the date of first observation is a great oversimplification. Also, in high latitudes the large and variable incidence angles for insolation make the effects of aerosols on surface heating very sensitive to variations in physical parameters even if the geographical distribution of dust opacity is known. The general background opacity during 1977 seems to have been greater than during years lacking storms, suggesting that the influence of the temporal history of the major storms may be diminished. And the temporal/geographical distribution of the localized dust storms near the south polar cap is unknown as is its interannual variation. Thus the lack of more positive correlations is likely to represent our lack of data on the entire range of dust phenomena in the years in question rather than a refutation of the general idea that dust can effect the CO_2 cycle. On the other hand, the strong simularity between the seasonal pressure variations observed by Viking landers during three years with very different dust histories would also imply such a lack of correlation. These questions can be answered only with better models and more data.

This work was partially supported by NASA grants NAGW-742 and NAGW-638.

References

Antoniadi, E. M. (1930). La Planete Mars. Herman, Paris.

Baum, W. A., and L. J. Martin (1973). Behavior of the Martian polar cap since 1905. Bull. Am. Astron. Soc. 5, 296.

Dollfus, A. (1973). New optical measurements of planetary diameters. IV. Size of the north polar cap of Mars. Icarus 18, 142-155.

Fischbacher, G. E., L. J. Martin, and W. A. Baum (1960). Martin polar cap boundaries. Final report under JPL Contract 951547. Lowell Observatory, Flagstaff.

Herschel, William (1784). On the remarkable appearences of the polar regions of the Planet Mars, the inclination of its axis, the position of its poles, and its spheroidical figure; with a few hints relating to its real diameter and atmosphere. Phil. Trans. lxxiv, 233-273.

Iwaskaki, K., V. Saito, and T. Akabane (1979). Behavior of Martian north polar cap, 1975-1978. J. Geophys. Res. 84, 8311-8316.

Iwasaki, K., Y. Saito, and T. Akabane (1982). Martian North Polar Cap 1979-1980. J. Geophys. Res. 87, 10,265-10,269.

Iwasaki, K., Y. Saito, and T. Akabane (1986). Martian south polar cap 1973. Publications Astronomical Society of Japan (in press).

James, P. B., G. Briggs, J. Barnes, and A. Spruck (1979). Seasonal recession of Mars' south polar cap as seen by Viking. J. Geophys. Res. 84, 2889-2922.

James, P. B. (1979). Recession of Martian north polar cap: 1977-78 Viking observations. J. Geophys. Res. 84, 8332-8334.

James, P. B. and K. Lumme (1982). Martian south polar cap boundary: 1971 and 1973 data. Icarus 50, 368-380 (1982).

James, P. B. (1982). Recession of Martian north polar cap: 1979-1980 Viking observations. Icarus 52, 565-569 (1982).

Martin, L. J. (1984). Clearing of the martian air: The troubled history of dust storms. Icarus 57, 317-321.

Parker, D. C., C. F. Capen, and J. D. Beish (1983). Exploring the martian arctic. Sky and Telescope 65, 218-220.

Slipher, E. C. (1962). Mars: The Photographic Story, Northland Press, Flagstaff.

FIGURE CAPTIONS

Figure 1: Median regression curves for four different longitudes are shown offset from each other by 10° on the ordinate scale. The 1977 curves (solid lines) are remarkably similar even though they were derived from Viking imaging. Some of the straight sections in 1977 are due to a lack of Viking observations at some longitudes and L_s periods.

Figure 2: The radius of the south polar cap relative to its center, which is displaced from the geographic pole, is presented as a function of areocentric polar longitude, L_s. The cap radius is given both in terms of degrees and as a dimensionless radius measure on a polar sterographic projection, as in I. Data are presented for 1956 (solid circles), 1971 (x's), 1973 (+'s), and 1977 (open circles).

Figure 3: The latitude of the south polar cap edge is plotted as a function of L_s for longitudes between 20° and 40°, the portion of the cap which recedes most slowly. Notation is the same as in Figure 2.

Figure 4: The latitude of the south polar cap edge for longitudes between 180° and 200° where the recession is most rapid, is shown as a function of L_s. The notation is the same as in Figure 2.

Table I

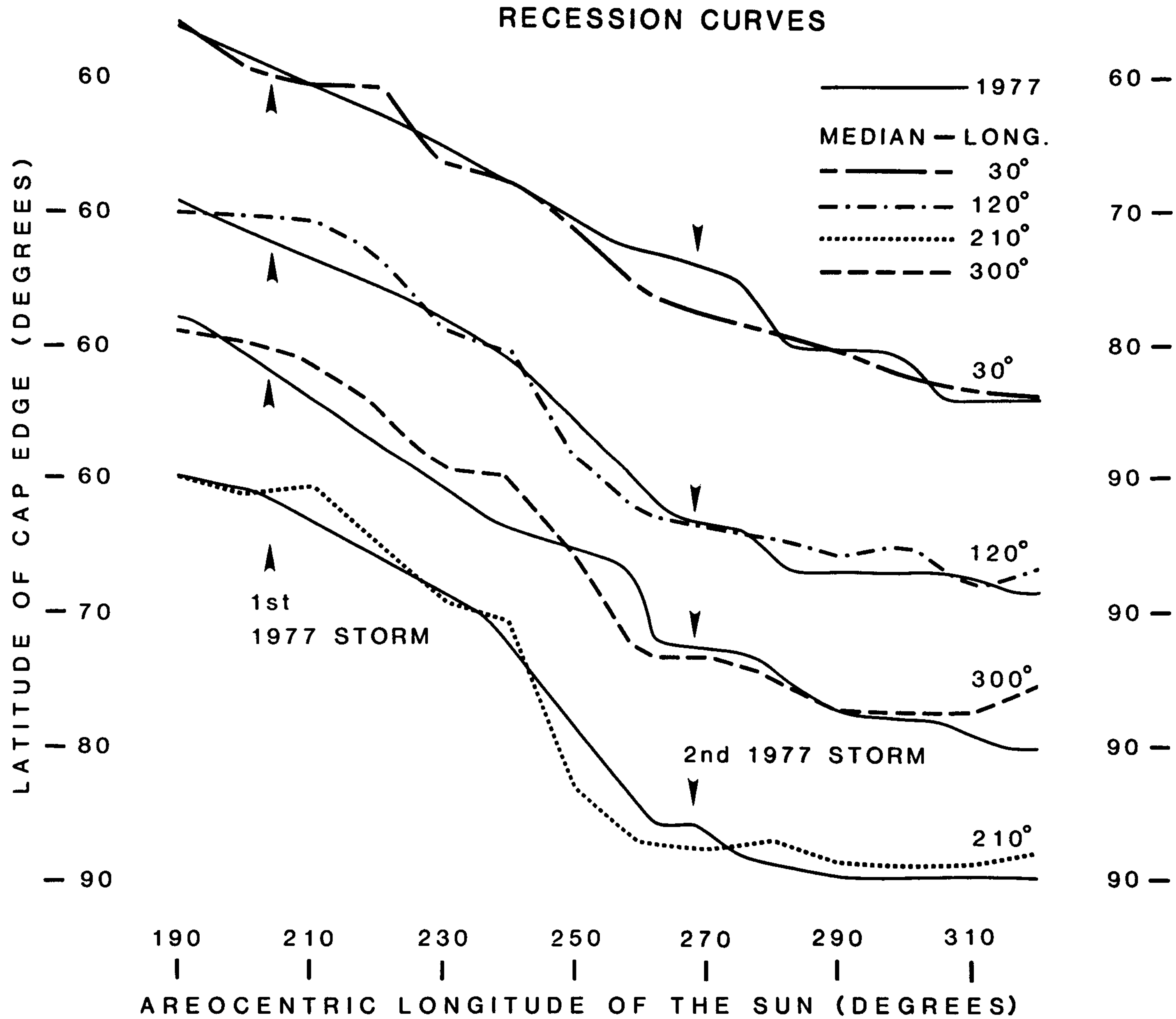
L_s	n	r	σ	x_o	y_o
228	63	.201	.008	-.002	.015
232	138	.170	.015	-.020	.015
234	82	.170	.015	-.012	.008
236	100	.155	.014	-.017	.039
238	139	.152	.013	-.018	.042
240	107	.154	.019	-.054	.015
244	111	.125	.011	-.025	.053
248	131	.103	.012	-.026	.034
250	115	.079	.018	-.041	.009
270	168	.040	.011	-.017	.016
272	97	.046	.012	-.035	.011
280	78	.056	.012	-.015	.052

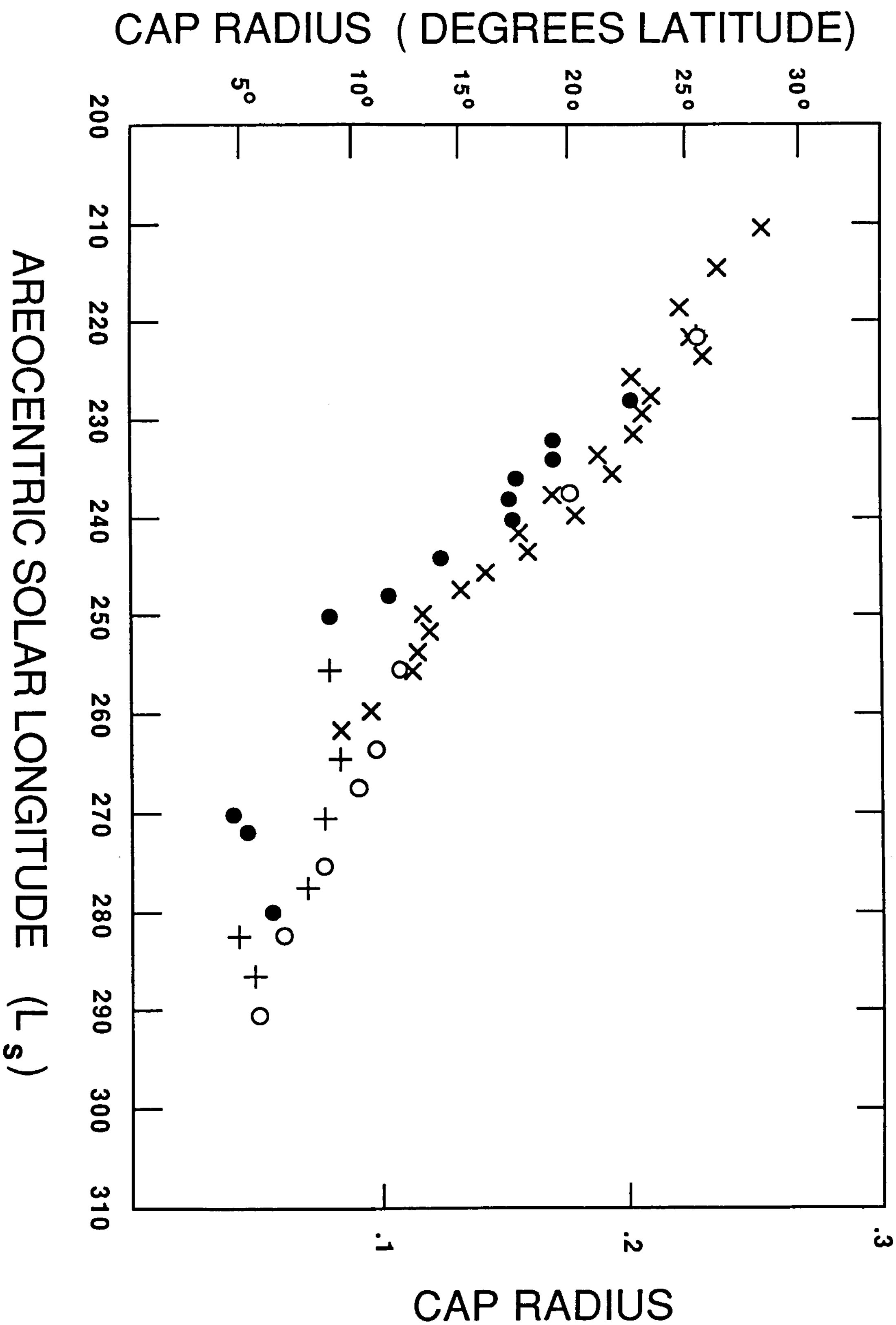
PHOTOGRAPHICALLY DOCUMENTED STORMS THAT EXPANDED

BEGINNING DATE	L_S	APPARENT DIAMETER	INITIAL LOCATION	COMMENTS
10 July 1922	192°	19″	Margaritifer Sinus	Observed for 4 days only
19 Aug 1956	250°	23″	Hellespontis	Planet encircling
29 May 1969*	163°*	19″	Hellespontis*	Size unknown
10 July 1971	213°	21″	Hellespontis	Two weeks duration
22 Sept 1971	260°	19″	Hellespontis	PLANETWIDE
13 Oct 1973	300°	22″	Solis Planum	Planet encircling
VIKING ORBITER IMAGING				
15 Feb 1977*	204°*		Solis Planum*	Planet encircling
27 May 1977*	268°*		Solis Planum*	Planet encircling

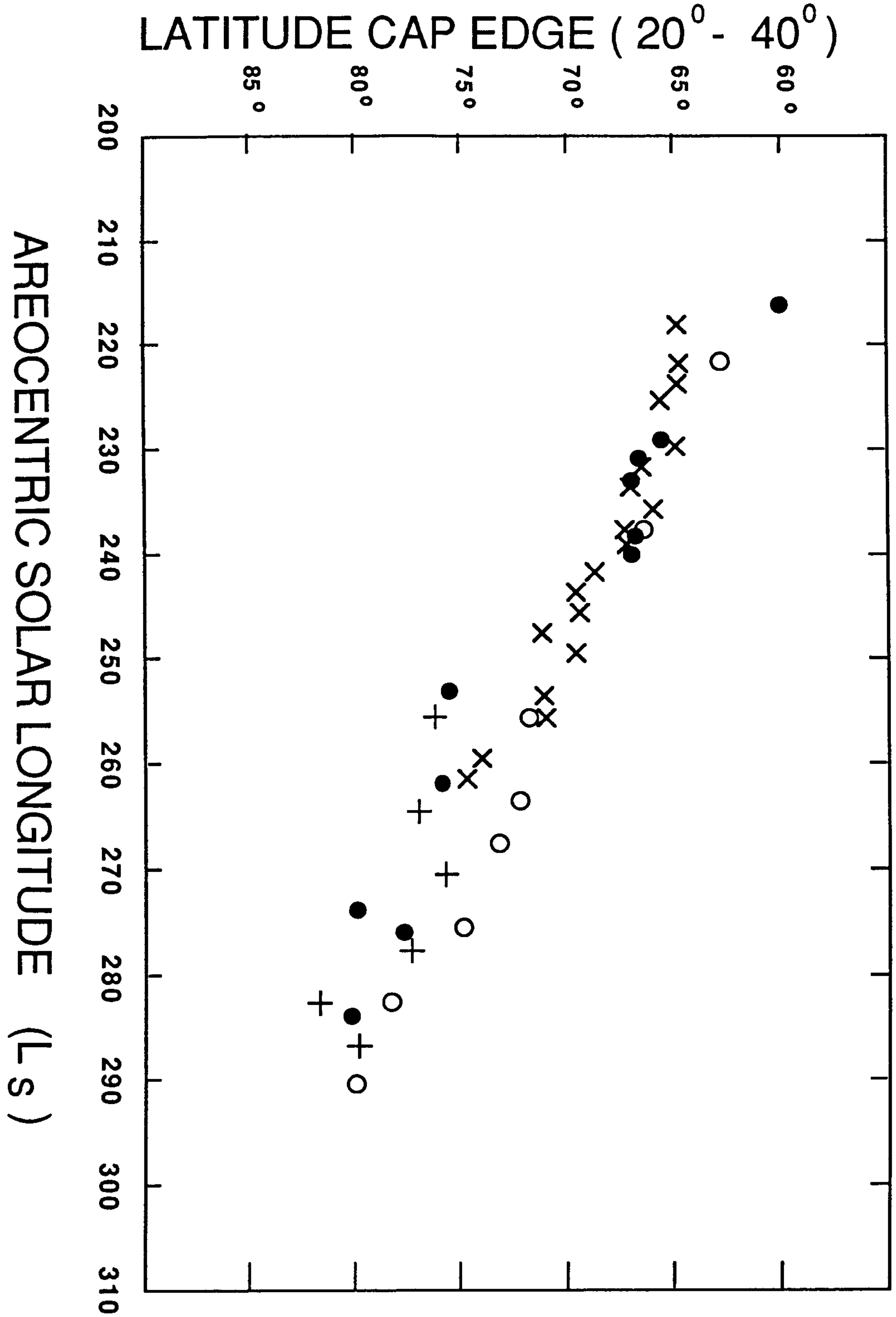
*Estimated; earliest clouds may not have been observed.

Table II

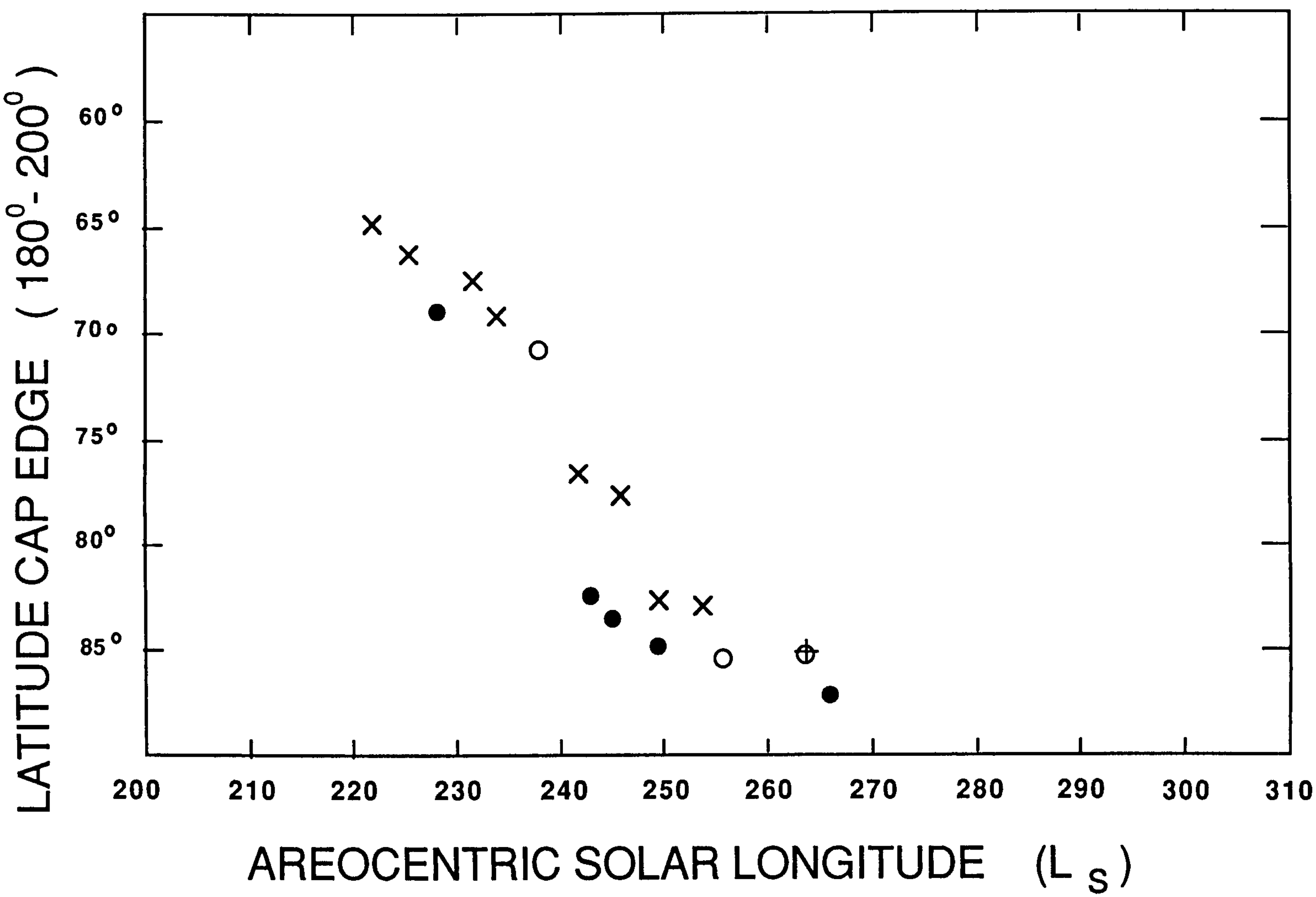

RECESSION CURVES
1977
MEDIAN — LONG.
30°
120°
210°
300°
1st
1977 STORM
2nd 1977 STORM
30°
120°
300°
210°
60
60
60
60
70
80
90
60
70
80
90
90
90
90
190
210
230
250
270
290
310
AREOCENTRIC LONGITUDE OF THE SUN (DEGREES)
LATITUDE OF CAP EDGE (DEGREES)



CAP RADIUS (DEGREES LATITUDE)
5°
10°
15°
20°
25°
30°
200
210
220
230
240
250
260
270
280
290
300
310
AREOCENTRIC SOLAR LONGITUDE (L s)
.1
.2
.3
CAP RADIUS



LATITUDE CAP EDGE (20° - 40°)
85°
80°
75°
70°
65°
60°
200
210
220
230
240
250
260
270
280
290
300
310
AREOCENTRIC SOLAR LONGITUDE (L s)



LATITUDE CAP EDGE (180°- 200°)
60°
65°
70°
75°
80°
85°
200
210
220
230
240
250
260
270
280
290
300
310
AREOCENTRIC SOLAR LONGITUDE (L S)