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RECENT MEASURES OF THE LATITUDE AND LONGITUDE OF JUPITER'S RED SPOT

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The latitude and longitude of Jupiter's Red Spot were measured from photographic plates obtained between June 1962 and May 1965 at the New Mexico State University Observatory. The longitudes measured from photographs have been found to be an order of magnitude more accurate than the longitudes obtained from visual estimates of central meridian transit times. The Red Spot was observed to increase irregularly in System II longitude from 10° in June 1962 to 24° in May 1965. The significantly improved accuracy of photographic observations made possible the detection of rapid, short term changes in longitude. The Red Spot slowly oscillated in latitude, remaining within 1°.4 of its mean latitude of 22°.4 for the reported interval.

author

INTRODUCTION

Throughout most of the history of Jovian observations, positional measurements of the Red Spot and other atmospheric features have been obtained by visual means: the longitudes of markings have been determined from estimates of central meridian transit times, and the latitudes have been measured with filar micrometers. In an effort to improve the accuracy of latitude and longitude determinations, the writers have measured the position of the Red Spot from photographic plates of Jupiter obtained at the New Mexico State University Observatory. The photographic method has proven to be definitely superior to visual transits in determining longitudes, and slightly superior to the filar micrometer in determining latitudes. A great advantage of the photographic method is that a photograph can be measured many times, if necessary, while a visual observation can be made only once for any given time. Accordingly, small changes in the longitude of the Red Spot which could not have been detected by visual transit observations were measured from the photographs.

METHOD

The photographs were made with the New Mexico State University's 12-inch reflector at the 66-foot Cassegrain focus. Nearly all of the photographs chosen for measurement were taken in blue light. Blue plates were selected for their superior definition of the Red Spot, and also of the planetary limb and terminator, as compared to plates taken in longer wavelengths. Compare Figures 1, 2, and 3 taken in blue light with Figure 4 taken in red light. In addition, however, a very few green and ultra-violet plates were measured.

Each plate normally contains 63 images. During the 1962-63 apparition, exposures were made at 30-second intervals. The longitude of the central meridian could thus be easily determined for each image. In 1963-64, however, exposures were made at the moments of best seeing with the time of only the first and last exposures being recorded. The probable error involved in interpolating the time of any random exposure has been found to be about ±0.3 minutes. During the 1964-65 apparition, a time recorder was employed to print the time to the nearest second on a paper tape whenever the shutter was opened.

The photographic plates were processed in full strength D-19 developer until October 1963. Since then UFG developer (diluted 1:1) has been used, with a corresponding improvement in plate quality; lessened contrast, smaller grain, and a sharper limb have increased the accuracy of the measures. The image quality

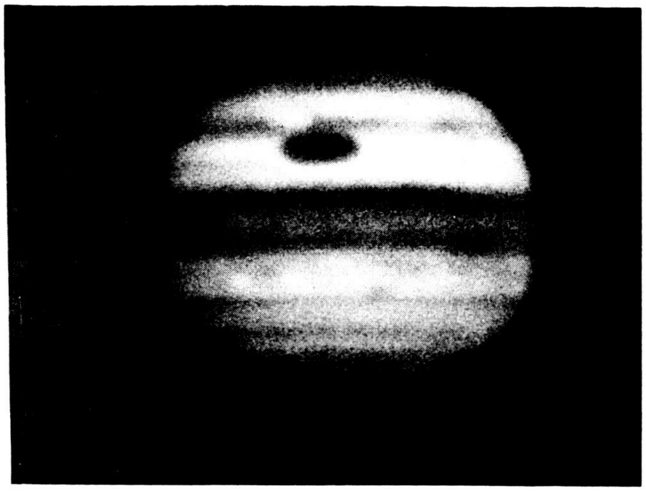

Fig. 1. Composite photograph of Jupiter in blue light showing the bright south temperate oval "FA" near conjunction with the Red Spot, 19 August 1964, 1036 U. T., ω_2 = 24°.

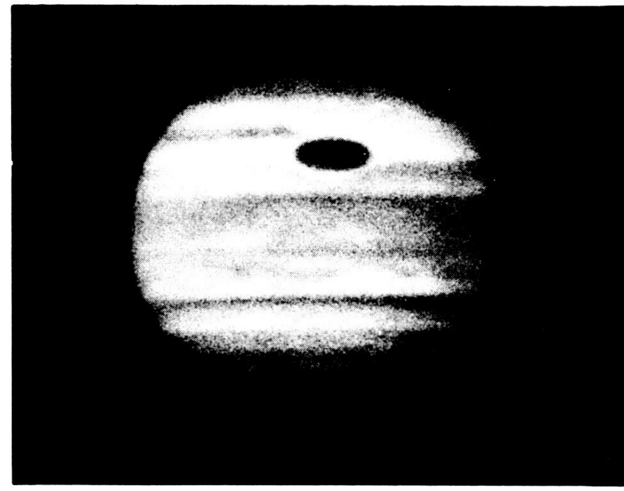

Fig. 2. Composite photograph of Jupiter in blue light showing the bright south temperate oval "BC" near conjunction with the Red Spot, 28 January 1965, 0407 U. T., ω_2 = 20°. Note the changes in relative intensity of many of the belts and zones (compare with Fig. 1).

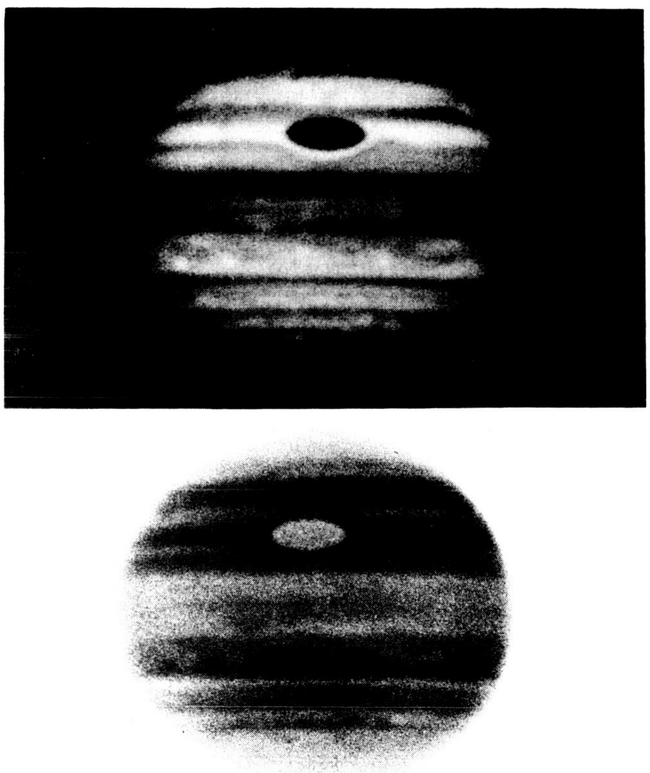

Fig. 3. Positive and negative prints of Jupiter in blue light, 23 October 1964, 0901 U. T., ω_2 = 19°. The positive print is a composite of three images. The negative print was made from a single image. In preparing the negative prints for this and the following figure, an attempt was made to reproduce the photographic image much as it appears on the original plate.

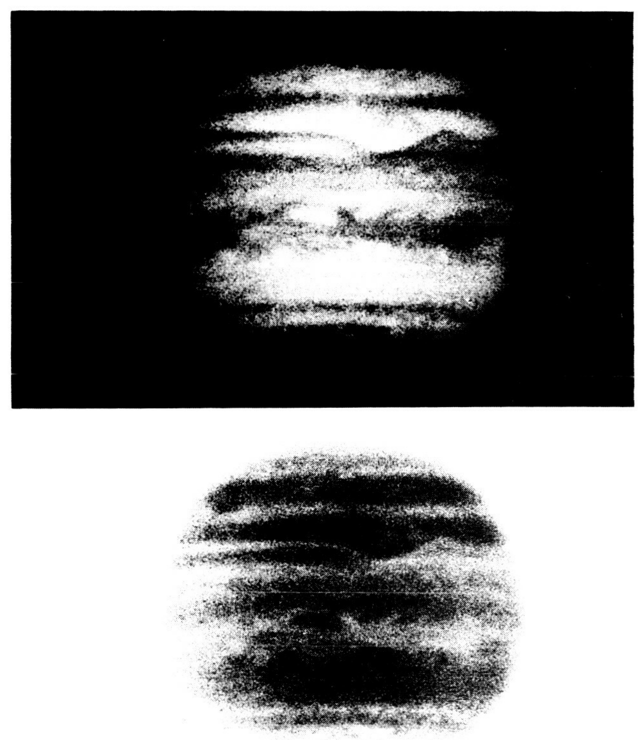

Fig. 4. Positive and negative prints of Jupiter in red light, 23 October 1964, 0840 U. T., ω_2 = 6°. The positive print is a composite of two images. The negative print was made from one image.

was improved again in June 1964, when the telescope was moved to its present location on 4750-foot Tortugas Mountain, where much better seeing prevails.

The better images on each plate were measured with a Mann measuring machine. When the longitude of the Red Spot is measured, the horizontal crosshair is set parallel to the planet's equator, and measures are made at the equatorial limbs, at the limbs at the latitude of the Red Spot, and at the preceding and following ends of the Red Spot itself. Four measures are made of each image, and four images are measured on each plate.

A similar procedure is used in recording the zenographic latitude of the Red Spot. Again, four measures are made of each image, and about three images are measured per plate. The horizontal crosshair is set parallel to the equator, and measures are made at the north and south limbs of the planet and at the north and south edges of the Red Spot.

MEASURING UNCERTAINTIES

During the 1964-65 apparition, the longitude of the Red Spot could be measured with a probable error of about $\pm 0\overset{\circ}{.}60$ per measure, as compared to a probable error of $\pm 1\overset{\circ}{.}2$ (Haas and Johnson, 1943; and Reese, 1962) for a longitude derived from a single visual transit. Since a total of 16 measures was usually made for each plate, the probable error of the longitude of the Red Spot was reduced to about $\pm 0\overset{\circ}{.}15$. The better plates could be measured with a probable error of approximately one-tenth of a degree or less.

A check is kept on the accuracy of the limb measures by comparing the measured diameter of the planet to the diameter computed from the ephemeris. The ratio of the measured diameter to the computed diameter is almost always very near 1.000. The probable error of this ratio for a single image is about ±0.010. A deviation this small indicates that the position of the limb can be measured with considerable precision. Furthermore, since the plate scale is known with great accuracy (Smith, 1964), the values of the polar radius and the radius of the parallel of latitude containing the center of the Red Spot are computed directly from the ephemeris and used in the reduction formulas.

CORRECTIONS

There exist systematic differences in the dimensions of the Red Spot as measured by the writers. On the average, measures by Reese make the Red Spot 1°.6 longer and 1°.2 wider than measures by Solberg. These differences have been minimized by applying an equal but opposite correction to the measures of each observer. Although the writers differed on the position of the ends of the Red Spot, they did agree to within 0°.1 on the location of the center of the Spot.

Longitudes obtained from the measurement of photographs are subject to a systematic error known as phase exaggeration. This phase effect, which is in excess of the geometric phase defect tabulated in the <u>American Ephemeris and Nautical Almanac</u>, is caused by faintness and loss of the geometric terminator and by irradiation at the bright limb. Phase exaggeration causes the measured longitudes to be too low before opposition, and too high after opposition. The error is largest at quadrature and diminishes to zero at opposition. A comparison of the rotation periods of both the Red Spot and the long-enduring bright ovals in the South Temperate Zone between successive quadratures and successive oppositions indicates that longitudes derived from visual transits are subject to a systematic error of about ±1°.2 at quadrature. This value is supported by discrepancies between the observed and computed central meridian transit times of satellites and their shadows at opposition and at quadrature. A comparison of the drift rates of the Red Spot during the last three apparitions, as determined from visual transits and from measures of photographs, indicates that the error caused by phase exaggeration is about ±0°.6 at quadrature for longitudes measured from the New Mexico State University Observatory photographs in blue light. A correction based on this maximum error at quadrature has been applied to all longitudes measured from the photographs. A more direct method of determining the error caused by phase exaggeration is being scheduled for the apparition of 1965-66.

RESULTS

The longitude of the Red Spot in System II from 20 June 1962 to 2 May 1965 is illustrated in Figure 5. During the 1962-63 apparition, the longitude of the Red Spot increased from 10° to nearly 18°. The drift during that apparition was characterized

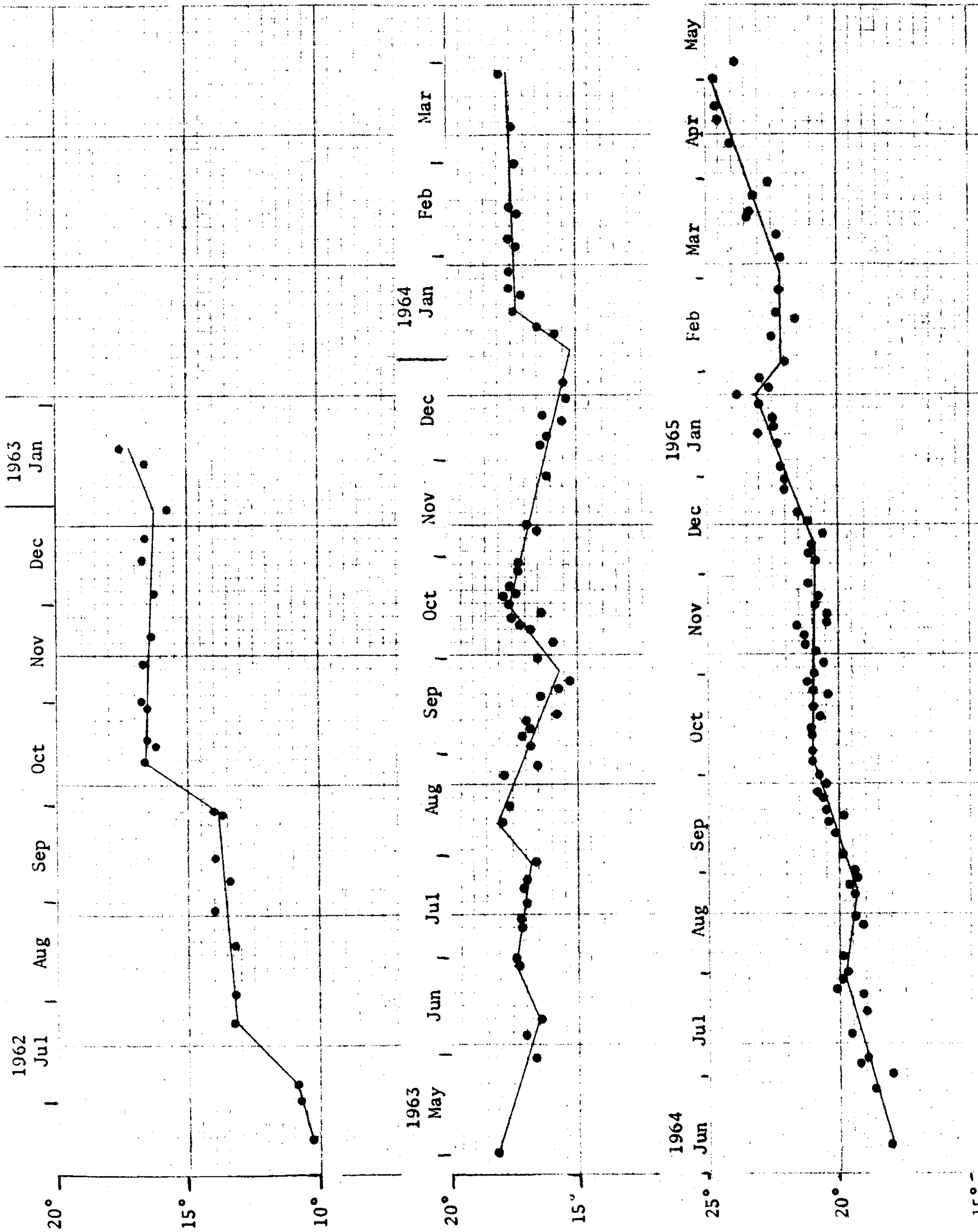

Fig. 5. Longitude of Jupiter's Red Spot in System II.

by sharp increases in System II longitude followed by long periods of little motion. These newly measured positions for the 1962-63 apparition, incidently, supersede the preliminary results reported earlier by Smith and Tombaugh (1963). During 1963-64, the Spot oscillated between 15° and 18°. Rapid increases in longitude were followed by gradual declines. During the 1964-65 apparition, the longitude gradually increased from 18° in June to 24° in April. Although there were definite irregularities in the drift of the Red Spot, the large, sharp jumps of the preceding years were absent during the apparition.

The length of the Spot decreased during the three apparitions from a mean of 24°.2 in longitude during 1962-63 to a mean of 23°.4 in 1964-65. The width also decreased from 13°.0 in latitude in 1962-63 to 12°.0 in 1964-65. During 1964-65, the mean length was about 27,200 km; the mean width was about 13,400 km.

The drift in latitude during all three apparitions was characterized by small gradual changes; the center of the Red Spot never varied more than 1°.4 from its mean latitude of 22°.4.

In Figure 6, notice the direct correlation between changes in width and variations in latitude of the center of the Red Spot. When the width decreases, the latitude of the center of the Spot decreases, and vice versa. This relationship between latitude and width has a correlation coefficient of 0.66. This effect is explained by the fact that the south edge of the Red Spot varied more in latitude than the north edge.

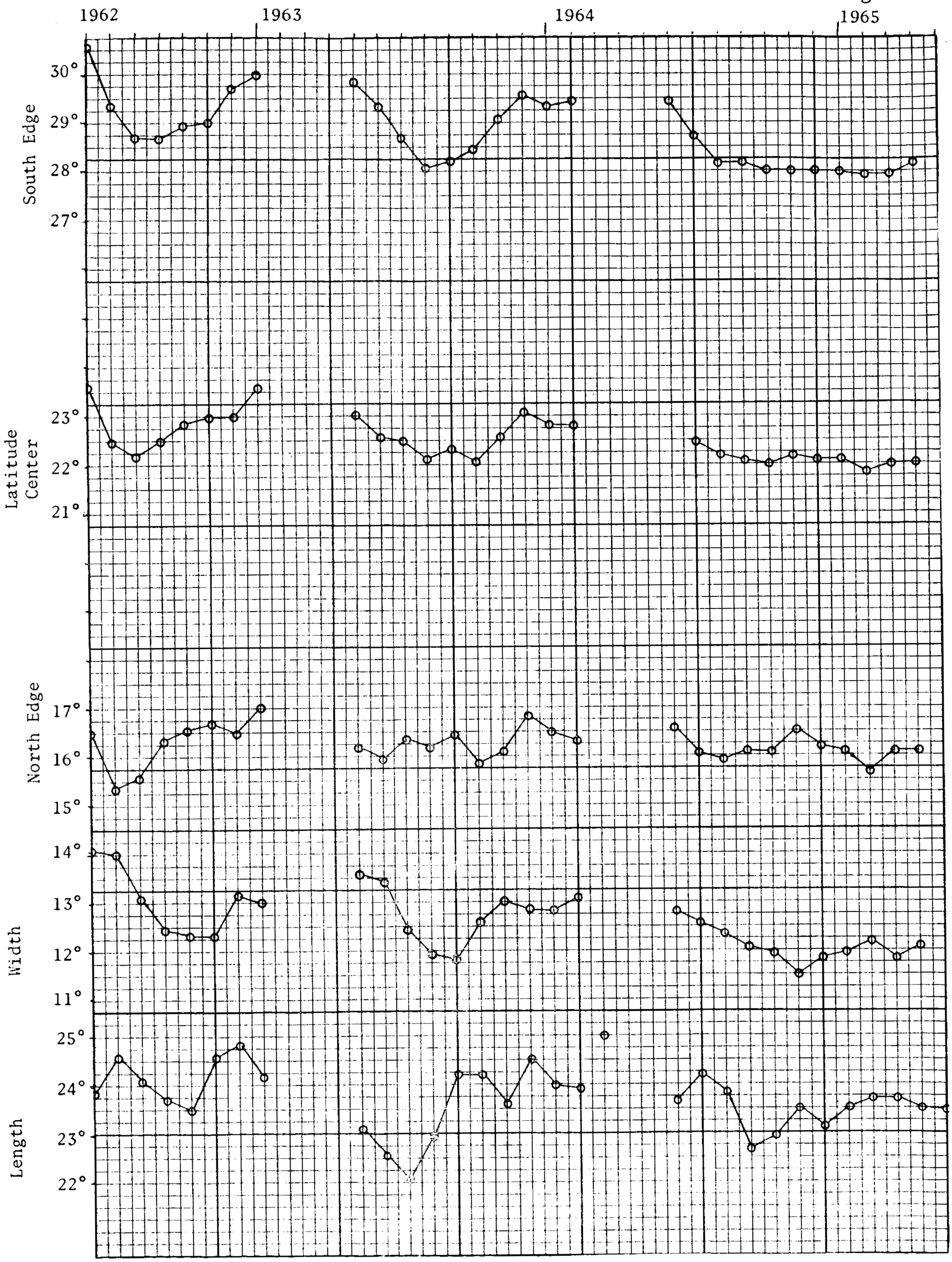

Figure 6: Latitude and Dimensions of the Red Spot
(monthly means)

The drift of the Red Spot in System II longitude during the interval covered by this paper is summarized in Table I. The longitude of the center of the Red Spot increased from 10°.3 on 20 June 1962 to 24°.8 on 2 May 1965 corresponding to an average rotation period of $9^h55^m41^s.2$. Thus the Red Spot has continued to drift in the direction of increasing longitude--a trend which began in 1937. The rotation periods for which probable errors are given were computed by the method of least squares. During each time interval covered by these periods the drift was essentially linear. As yet we have been unable to correlate the irregularities in the motion of the Red Spot with any other activity visible in the planet's atmosphere. A few possible relationships have been observed, but the numerous and erratic changes in the Red Spot's rate of drift preclude, at this time, the establishment of any definite correlations between the motion of the Red Spot and the motion of any other atmospheric feature.

CONCLUSIONS

Hide (1963), in explaining his model of the Red Spot, proposes that the atmospheric flow around the Spot is less turbulent on the north or equatorward side, as is evidenced by the presence of the Red Spot Hollow. This would imply that the south or poleward edge of the Spot would be buffeted more, and would therefore show greater variations in latitude. Such is apparently the case, as is shown by the correlation between latitude and width explained in the previous section. Obviously, many more than three apparitions will be needed to evaluate the validity of Hide's assumption.

During these past three apparitions, no correlation has been found between the longitude of the Red Spot and its length. A correlation would be expected if any of the observed irregularities in the longitudinal drift of the Red Spot were caused by a periodic build up and dissipation of dark material or obscuring material at either end of the Spot. No correlation has been found between its longitude and latitude, as might be expected if angular momentum were conserved within the Red Spot itself. The South Temperate Zone ovals seemed to have had no effect on the Spot as they passed by; however, the motion of the ovals, themselves, may have been affected by the proximity of the Red Spot.

It should not be construed that systematic and carefully executed central meridian transit observations are no longer needed. On the contrary, they remain a very useful and practical method of determining the longitudinal drift of a large number of markings in the various atmospheric currents. The time and labor involved in making precise measures of photographs are such that there is no immediate prospect of adequately following the drifts of more than a few selected objects.

ACKNOWLEDGEMENTS

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TABLE I

DRIFT OF RED SPOT IN SYSTEM II LONGITUDE

Drift During Successive Intervals

Limiting Dates	Limiting Longitudes	Drift degrees/day	Rotation Period
20 Jun 62 - 7 Jul 62	10°3 - 10°9	+0°030 ±0°001	9^h 55^m $41^s.9$ $\pm0^s.1$
7 Jul 62 - 26 Jul 62	10.9 - 13.2	+0.125	45.8
26 Jul 62 - 30 Sep 62	13.2 - 13.9	+0.010 ±0.003	41.0 ±0.1
30 Sep 62 - 15 Oct 62	13.9 - 16.6	+0.180	48.0
15 Oct 62 - 31 Dec 62	16.6 - 16.3	-0.004 ±0.003	40.4 ±0.1
31 Dec 62 - 19 Jan 63	16.3 - 17.2	+0.047	42.6
2 May 63 - 12 Jun 63	18.1 - 16.5	-0.038 ±0.005	39.1 ±0.2
12 Jun 63 - 29 Jun 63	16.5 - 17.4	+0.052	42.8
29 Jun 63 - 30 Jul 63	17.4 - 16.8	-0.019 ±0.003	39.8 ±0.2
30 Jul 63 - 11 Aug 63	16.8 - 18.1	+0.106	45.0
11 Aug 63 - 27 Sep 63	18.1 - 15.7	-0.051 ±0.007	38.5 ±0.3
27 Sep 63 - 17 Oct 63	15.7 - 17.6	+0.098	44.7
17 Oct 63 - 4 Jan 64	17.6 - 15.2	-0.031 ±0.002	39.3 ±0.1
4 Jan 64 - 16 Jan 64	15.2 - 17.3	+0.182	48.1
16 Jan 64 - 28 Mar 64	17.3 - 17.6	+0.004 ±0.002	40.8 ±0.1
10 Jun 64 - 2 Aug 64	18.0 - 19.8	+0.033 ±0.007	42.0 ±0.3
2 Aug 64 - 27 Aug 64	19.8 - 19.3	-0.020 ±0.005	39.8 ±0.2
27 Aug 64 - 6 Oct 64	19.3 - 21.0	+0.039 ±0.004	42.2 ±0.2
6 Oct 64 - 11 Dec 64	21.0 - 20.9	-0.002 ±0.003	40.6 ±0.1
11 Dec 64 - 26 Jan 65	20.9 - 23.1	+0.049 ±0.005	42.7 ±0.2
26 Jan 65 - 5 Feb 65	23.1 - 22.1	-0.097 ±0.032	36.7 ±1.3
5 Feb 65 - 3 Mar 65	22.1 - 22.2	+0.003 ±0.006	40.8 ±0.3
3 Mar 65 - 2 May 65	22.2 - 24.8	+0.044 ±0.005	42.4 ±0.2

Mean Drift During the Apparitions

20 Jun 62 - 19 Jan 63	10°3 - 17°2	+0°032	9^h 55^m $42^s.0$
2 May 63 - 28 Mar 64	18.1 - 17.6	-0.002	40.6
10 Jun 64 - 2 May 65	18.0 - 24.8	+0.021	41.5

Mean Drift Between Successive Oppositions

31 Aug 62 - 8 Oct 63	13°6 - 16°7	+0°008	9^h 55^m $41^s.0$
8 Oct 63 - 13 Nov 64	16.7 - 21.0	+0.011	41.1

TABLE II

MEAN LATITUDES, LONGITUDES, AND DIMENSIONS OF THE RED SPOT

		Zenographic Latitude			Width (lat)	No. of plates	Longitude II Center	Length (long)	No. of plates
		S. edge	Center	N. edge					
1962	Jun	-30°.6	-23°.6	-16°.5	14°.1	1	10°.3	23°.8	1
	Jul	29.3	22.4	15.3	14.0	3	11.8	24.6	3
	Aug	28.7	22.2	15.6	13.1	3	13.5	24.1	3
	Sep	28.7	22.5	16.3	12.4	4	13.8	23.7	4
	Oct	28.9	22.8	16.6	12.3	2	16.4	23.5	3
	Nov	29.0	22.9	16.7	12.3	2	16.6	24.6	3
	Dec	29.7	23.0	16.5	13.2	4	16.2	24.8	4
1963	Jan	30.0	23.6	17.0	13.0	2	17.7	24.2	2
1962-3	Mean	-29.2	-22.7	-16.2	13.0	21	13.6[a]	24.2	23
1963	May	-29.8	-23.0	-16.2	13.6	1	16.6	23.1	1
	Jun	29.3	22.6	15.9	13.4	2	16.8	22.6	3
	Jul	28.7	22.5	16.3	12.4	6	17.0	22.1	6
	Aug	28.1	22.1	16.2	11.9	2	17.2	22.9	2
	Sep	28.2	22.3	16.4	11.8	7	16.5	24.2	7
	Oct	28.4	22.1	15.8	12.6	11	17.1	24.2	12
	Nov	29.1	22.6	16.1	13.0	2	16.3	23.6	2
	Dec	29.6	23.1	16.8	12.8	5	15.8	24.5	5
1964	Jan	29.3	22.8	16.5	12.8	6	17.0	24.0	6
	Feb	29.4	22.8	16.3	13.1	5	17.4	23.9	5
	Mar	----	----	----	----	---	17.4	25.0	1
1963-4	Mean	-28.7	-22.5	-16.2	12.5	47	16.7[a]	23.7	50
1964	Jun	-29.4	-23.0	-16.6	12.8	1	18.6	23.7	1
	Jul	28.7	22.4	16.1	12.6	7	19.4	24.2	8
	Aug	28.2	22.2	15.9	12.3	5	19.5	23.8	7
	Sep	28.2	22.1	16.1	12.1	9	20.2	22.7	9
	Oct	28.0	22.0	16.1	11.9	9	21.0	22.9	10
	Nov	28.0	22.2	16.5	11.5	9	21.0	23.5	11
	Dec	28.0	22.1	16.2	11.8	6	21.4	23.1	8
1965	Jan	28.0	22.1	16.1	11.9	6	22.7	23.5	9
	Feb	27.9	21.8	15.7	12.2	4	22.1	23.7	5
	Mar	27.9	22.0	16.1	11.8	3	22.9	23.7	5
	Apr	28.2	22.0	16.1	12.1	2	23.8	23.5	4
	May	----	----	----	----	---	24.3	23.5	2
1964-5	Mean	-28.1	-22.1	-16.1	12.0	61	21.0[a]	23.4	79

[a] Longitude at opposition