# The accelerating circulation of Jupiter's Great Red Spot

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*A report of the Jupiter Section (Director: John H. Rogers)*

Jupiter's Great Red Spot (GRS) has been evolving, with fluctuations, since it was first observed in the 19th century. It has shown trends of decreasing length, decelerating drift rate, and possibly accelerating internal circulation. This paper documents how these trends have progressed since the time of the *Voyager* encounters in 1979, up to 2006, from ground-based amateur observations.[1] The trends in length and drift rate have continued; the GRS is now smaller than ever before.[2] The internal circulation period was directly measured in 2006 for the first time since the *Voyager* flybys, and is now 4.5 days, which confirms that the period is shortening.[3] In contrast, the 90-day oscillation of the GRS in longitude continues unchanged, and may be accompanied by a very small oscillation in latitude.

## Introduction

The Great Red Spot (GRS) is a giant anticyclone in Jupiter's atmosphere, circulating anticlockwise, with winds that are among the most rapid in the solar system (see reference 1, pp.188-197). The circulation was already suspected in the early 20th century (ref.1, p.256), and the first tentative observation of it was by Elmer Reese from visual observations in 1949.[2,3] In 1966, Reese and Smith[4] demonstrated it clearly by tracking dark spots moving in and around the GRS on professional photographs. In 1979 the circulation was revealed most clearly and dramatically by time-lapse movies from the *Voyager* spacecraft.[5]

It is often said that the GRS has existed for more than 340 years, since Cassini and others first observed a similar spot in 1665. However that spot was never seen after 1713, and even though observations were infrequent during the subsequent century, it would be surprising if Schroeter, for instance, had missed it. Alternatively, it is possible that the present GRS is actually a new one that was never seen until the 1800s (ref.1 pp.188–196, 262–264). It was first observed as a long pale 'hollow' in 1831, and that was how it appeared until the 1850s. It became a dusky elliptical ring in 1857–'59, and again in 1870. It was first clearly seen to be reddish in 1873, with the great reflector of the Earl of Rosse, and only in the late 1870s did it become a striking Great Red Spot.

It has been shrinking in length and decelerating in drift rate (though with large fluctuations) ever since the late 1800s (Figure 1). I have therefore proposed that the present GRS arose inconspicuously in the 1700s, as a circulating current such as is sometimes created by a South Tropical Disturbance (STropD) (ref.6; ref.1 pp.262–264). It has been shrinking and decelerating, just as the homologous white ovals in the South Temperate domain did. According to this hypothesis, Cassini's spot in 1665–1713 was an old one, smaller and slower-moving than the present GRS has ever yet been, and it showed the condition towards which the present GRS is evolving (Figure 1).

As part of this evolution, there is likely to be an acceleration of the wind speeds within the GRS, from 44–51 m/s (DL2 =–110, +105°/month: the mean speed of the SEBs and STBn jets) through 63 m/s (DL2 = +130°/month: the mean speed of the SEBs jet when a STropD is present) to 110–140 m/s (the maximum internal wind speed recorded in the *Voyager* images: Table 1a). Images by the *Galileo Orbiter* in 2000 recorded a further acceleration to ~145–190 m/s.[11,12]

These wind speeds were derived by tracking small cloud tracers over short intervals in spacecraft images. The internal circulation can also be measured from the 'rotation period' of large spots or streaks within the GRS, on the infrequent occasions when they are visible (Table 1b). This was how Reese first suspected the internal circulation of the GRS[2,3] and first clearly demonstrated it.[4] However it has been uncommon for internal spots to be distinct enough to allow such measurements telescopically. In 2006, the improvement in amateur imaging has enabled such features to be measured much more distinctly, and I now report periods measured for dark streaks over up to three rotations of the GRS.

Another notable aspect of the GRS is its small oscillation in longitude with a period of 90 days (ref.1 p.194). In the final section of this paper, I summarise recent data showing that this oscillation is still present with remarkably constant period.

## Length and drift rate of the GRS

Figure 2 summarises how the longitudinal length and drift rate of the GRS have continued to evolve since the *Voyager* encounters.

The upper points in Figure 2 are measurements of the length of the GRS (in degrees longitude; 1° = 1160km), taken from BAA reports (including unpublished reports in preparation), continuing the series in Ref.1. Early values were largely from visual transits, but from the mid-1980s they were from photographs, and from the mid-1990s they

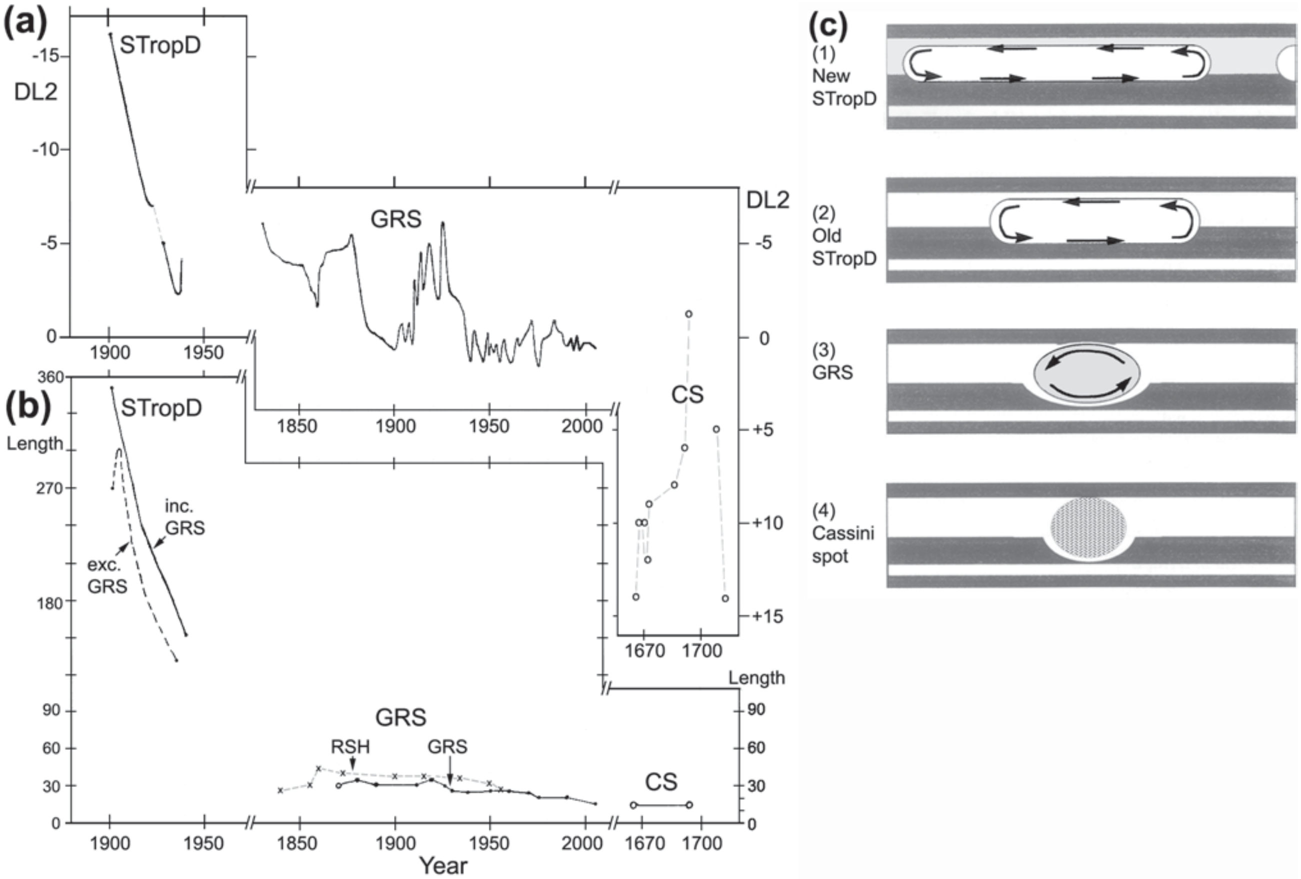


**Figure 1.** Hypothetical life cycle of the Great Red Spot, showing how it may have arisen as a sector with 'circulating current' excluded by a South Tropical Disturbance (STropD), and evolving to resemble Cassini's spot (CS). **(a,b)** Deceleration and shrinkage of the great circulations in the STropZ: Cassini's spot (1665–1713; right), the GRS (1831–2005; centre), and the 'circulating current' excluded by the great STropD (1901–1939; left). The charts are aligned to show that the GRS might have arisen (unseen) from a STropD in the 1700s, and is evolving towards a smaller slower condition like Cassini's spot. **(a)** Longitudinal drift rate (DL2, degrees/month). **(b)** Length (degrees longitude: 1° =1160km). **(c)** Diagram of these circulations in the STropZ. *(Adapted from Ref.1.)*

were from hi-res CCD images, measured using the *JUPOS* system by H–J. Mettig and colleagues. The measurements are the best estimate for the oval outline, whether it is the diameter of a reddish oval surrounded by other structures, or the internal diameter of a light oval, or (in 1989–'90 and 1992–'93) the external diameter of a distinct dark red oval when the SEB was faded (whitened). The general shrinkage of ~0.21°/year is evident, and the lengths of 16–17° measured since 2001 are the shortest values ever recorded for the GRS.

The lower points in Figure 2 are measurements of the mean drift rate of the GRS (in degrees per month in System II), from each opposition to the next. As in previous decades there are fluctuations, largely due to STropDs (which are accompanied by acceleration of the GRS, i.e. more negative DL2) and SEB Fades (with deceleration of the GRS, i.e. more positive DL2). The negative drifts in the 1980s and 1993–'94 were probably caused by STropDs, whereas the positive drifts in 1989–'90 and 1992–'93 were associated with fading of the SEB. However there have been no such events since 1993, and so no excuses for the strong positive drift rates seen in some years from 1995 onwards. Drifts as slow as +0.7°/mth have never previously been seen except during cycles of SEB fading, so these recent values probably represent the continuing long-term deceleration trend.

## Internal circulation period of the GRS

Since the 1960s, ground-based images have many times recorded small spots, which are vortices derived from SEBs jetstream spots, circulating part way around the periphery of the GRS in the Red Spot Hollow. However these do not reveal the faster internal winds. Only spacecraft images have tracked the GRS circulation, and they have shown the period to be shortening – largely due to the gradual shrinkage of the GRS, but also recently due to a real acceleration of the winds in 2000[11,12] (Table 1a,b).

Since 2000, amateur images have recorded features within the GRS that allow measurements of the internal circulation. The ALPO have measured such features over intervals of up to 40 hours and deduced a wind speed of 100 (±8) m/s for dark streaks on six separate occasions in 2001–'02,[13] and ~89 and ~97 m/s for two white spots in 2002–'03.[14]

In the last few years the 'webcam revolution' has produced a great improvement in the number and quality of amateur images, so that streaks within the GRS can be quite commonly resolved. In 2006, fairly distinct dark grey streaks were often recorded inside the GRS, and contributions from observers all around the world made it possible to follow them over several successive jovian rotations.

## Table 1. Reported wind speeds and circulation periods within the GRS.

### Table 1a. Wind speeds (measured from spacecraft images)

| Year | Spacecraft | $V_2$ | $V_1$ | Ref. |
|---|---|---|---|---|
| 1979 | *Voyager 1* | 110, **120** | 140 | 7,8 |
| | | 135 | **135** | 9 |
| 1979 | *Voyager 2* | 110 | 120 | 9 |
| 1996 | *Galileo* | **135** | **145** | 10 |
| | | 115 | 150 | 12 |
| 2000 | *Galileo* | **165** | **190** | 11 |
| | | 145 | 180 | 12 |

$V_2$: Mean maximum wind speed on minor axis.
$V_1$: Single-point maximum wind speeds (omitting outlying values).
Values are in m/s. These values were taken from the text and/or read off the charts in the cited references. The accuracy is typically ± 5–10 m/s.
**Bold:** Values selected to calculate circulation periods (Table 1b).

### Table 1b. Circulation periods (mean values for each year)

| Year | $P_4$ | $P_3$ | $P_2$ | $P_1$ | Ref. |
|---|---|---|---|---|---|
| 1949 | | 10.7 | | | Reese (visual) [2,3] |
| 1966 | 12 | 9 | | | Reese & Smith [4] |
| 1979 | 6 | 8 | 7.7 | 6.9 | *Voyager* (Table 1a) |
| 1996 | | | 5.3 | 5.0 | *Galileo* [10] |
| 2000 | | | 3.5 | 3.0 | *Galileo* [11] |
| 2006 | 4.5 | 5.2 | | | BAA (Table 1c) |

Values are in days, and are also shown in Figure 6.
$P_4$: Period directly observed over longest time-span.
$P_3$: Period directly observed over shorter time-span(s).
$P_2$: Period estimated from mean maximum wind speeds ($V_2$, above).
$P_1$: Period estimated from single-point maximum wind speeds ($V_1$, above).
$P_2$ and $P_1$ were calculated from the reported wind speeds by assuming that the elliptical circulation has the form of a projection of circular motion, thus: $P = 2\pi a/V$, where $a$ is the semimajor axis at the radius of maximum wind speed, and $V$ is maximum wind speed from Table 1a. This assumption was reasonably valid in *Voyager* data, but the speed was more uniform around the circumference in *Galileo* 2000 data, suggesting an even shorter period.[11]

### Table 1c. Circulation periods (2006, this paper)

| Month | $P_4$ | $P_3$ | N(rotn) | Radius |
|---|---|---|---|---|
| April | 4.4 | (5.0–5.5) | 2.8 | 43–69% |
| June | – | (4.2) | 0.2 | 70% |
| July | 4.5 | (4.8–5.2) | 2.9 | 72% |

These are the direct measurements of rotation periods reported in this paper.
$P_4$, $P_3$, as in Table 1b. *N(rotn):* number of rotations observed.
*Radius:* position of the measured streak as a fraction of the outer radius of the GRS, all ±5%. In April, while the main streak was at ~69%, the measured location was its interface with the central orange oval at ~43%.

## Methods

Images were obtained by amateur observers around the world using CCD cameras or webcams. The observers whose images were used for this analysis were: Stefan Buda (Australia), Fabio Carvalho (Brazil), Cristian Fattinanzi (Italy), Christopher Go (Philippines), Canon Lau (HongKong, China), Paolo Lazzarotti (Thailand), Jim Melka (Missouri, USA), Isao Miyazaki (Japan), Tiziano Olivetti (Thailand), Donald C. Parker (Florida, USA), Damian Peach (Barbados), David Pretorius (Australia), Brett Turner (Australia), Dave Tyler (Barbados), Maurice Valimberti (Australia), Anthony Wesley (Australia).

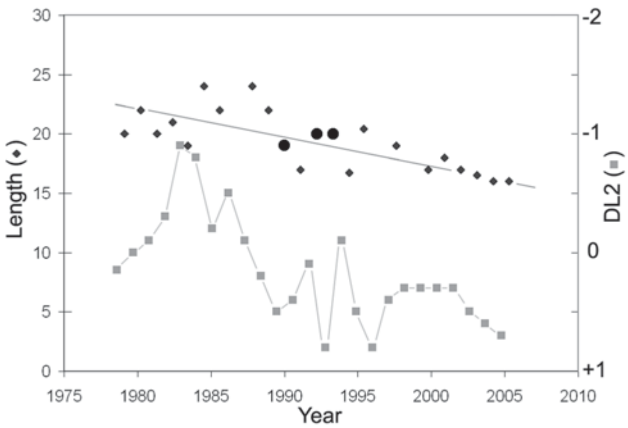


**Figure 2.** Deceleration and shrinkage of the GRS, 1979–2005. *Black diamonds:* length in degrees longitude. Most values are for the internal diameter of the 'hollow' and 'arch'. Large circles in 1989–'90 and 1992–'93 indicate the external diameter of a solid red oval. Smaller values in 1990–'91 and 1994 are the internal diameter of the pale ring after the SEB Revival.
*Grey squares:* drift rate between oppositions (DL2, degrees/month) (±0.1°/month). Rapid (negative) drift rates were associated with S. Tropical Disturbances, whereas the slowest (positive) drift rates were associated with fading of the SEB.
All data are from BAA reports, including some in preparation derived from *JUPOS* analysis (H.–J. Mettig, pers. com.)

Details of the observers and their equipment will be given in the final Jupiter Section report as usual. Most of these observers sent their images directly; others were made available through the Association of Lunar and Planetary Observers [**http://www.arksky.org/alpo/index.php**], and the ALPO-Japan [**http://www.kk-system.co.jp/Alpo/index.htm**], to whom we are grateful for making these observations available.

When a dark grey streak was visible within the GRS, the position angles (PA) of its leading and trailing ends were measured. The images were first stretched vertically to make the GRS approximately circular, then the PA was measured clockwise from north. The precision of these measurements is estimated as typically ±10° when the ends were reasonably well-defined. On many of the dates in 2006 April, the positions were measured from two or three independent and near-simultaneous images, which yielded a standard deviation of ±7°.

This procedure assumes the GRS to behave as a projection of circular motion (also assumed in deriving rotation periods in Table 1). If this formal assumption was wrong, it would not affect our rotation periods as they are measured over several complete rotations. It would however show up as a systematic variation in the angular velocity with half the rotation period, and no such variation is evident within the accuracy of the observations.

## Results

The GRS was well defined by a complete dark grey rim in 2006 April. Its dimensions, at the inner edge of the dark rim, were 10.3° (12400km) in latitude and 16–18° (~19800km) in longitude. In June and July the northern rim had faded and a light strip separated the GRS proper from the Red Spot Hollow.*

In each of these months, internal grey streaks were tracked, at ~70% (±5%) of the radius of the GRS (Table 1c). In April

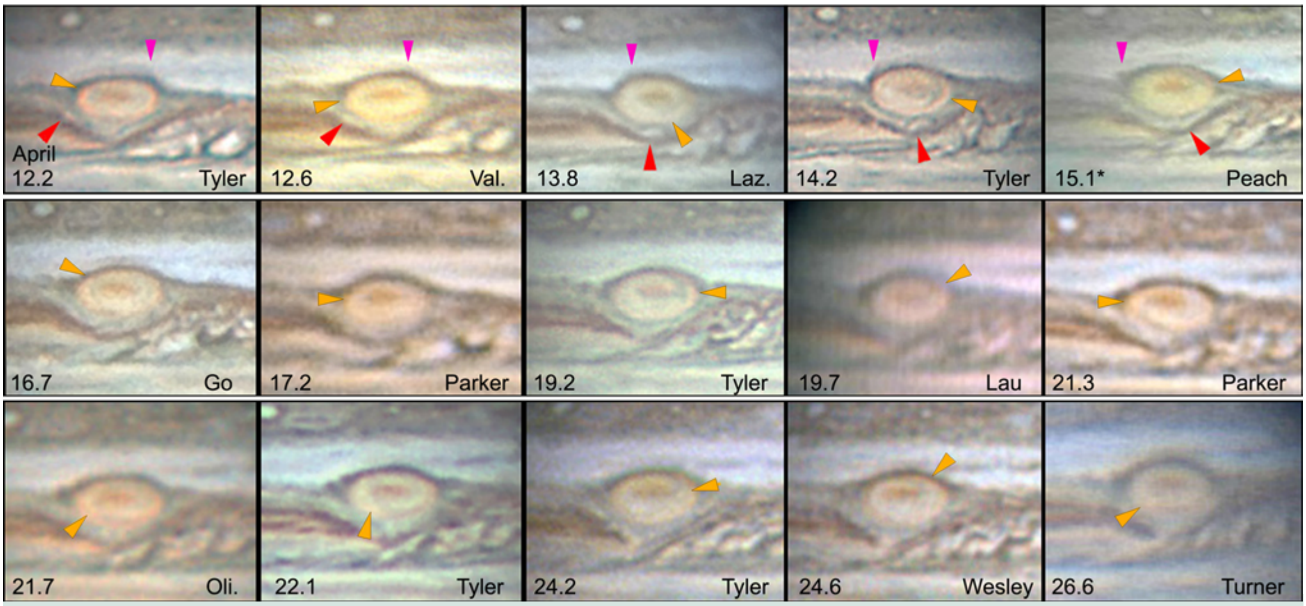


**Figure 3.** The GRS in 2006 April, showing a crescent-shaped blue-grey streak circulating within it. South is up. The yellow arrowhead points to its inner edge abutting the orange core of the GRS, which was measured. (Red and purple arrowheads point to other spots circulating around the outside of the GRS: a small dark spot on the south rim, and a small white spot in the Hollow. Also note the development of the rifted region of SEB f. the GRS: the very bright ringed spot on April 12 evolves into the long narrow streak on April 24.) Each image is labelled with the decimal date in 2006 April, and the name of the observer (abbreviations denote Valimberti, Lazzarotti, Olivetti; see text for details). The image at April 15.1 was rotated to place the GRS near the meridian. Contemporaneous images by Peach were also measured.

(Figure 3), there was a sickle-shaped streak: the arc tracked was its interface with the orange core of the GRS, at ~43% of the GRS radius; however the main extent of the streak was at ~69% radius. In June, a distinct dark spot was imaged on three successive rotations of the planet.[15] In July, there was a dark circumferential streak, and its leading and trailing ends were tracked (examples in Figure 4).

The PA measurements are plotted in Figure 5. This shows that, in each month, a single dark streak was tracked throughout the whole sequence of observations. The angular velocity appears to vary somewhat around the GRS, so the mean period measured over the longest intervals is most reliable, 4.5 (±0.1) days. Over some shorter intervals, Figure 5 indicates slower angular velocities (equivalent to rotation periods of 4.8 to 5.5 days). In most cases these variations could be compensated by more rapid circulation near PA ~180°, i.e. when the tracked streak was in the southern part of the GRS (when it was seldom observed, either by chance or because it was then ill-defined). Another explanation for the variations in angular velocity could be that a persistent disturbance with P = 4.5 days repeatedly generated transient streaks with slower angular velocity.

In retrospect, images from a year earlier showed a similar circulating streak in the GRS from 2005 May 10–26. Its appearance and circulation period were very similar to those in 2006 (data not shown).

*In 2006 August, the southern rim also largely faded; but a well-defined oval line developed at approximately the radius where the previous streaks had been, creating the impression of a GRS with a major axis of only ~12.5° (14500km). However, orange and methane-bright material did persist outside this oval so it was still an internal structure in the GRS.

### Discussion

Figure 6 shows all values obtained for the internal circulation period of the GRS, both as directly observed for more than one complete revolution of distinct spots or streaks, and as calculated from the internal wind field as observed by spacecraft. There is good agreement between the two types of measurement, and clear indication that the circulation period of the GRS is shortening with time.

The periods measured from the ground-based images may, of course, not represent the fastest wind speeds in the GRS. A visible streak may not be at the radius of the fastest winds, or it may entail a disturbance of the smooth circulation, or it could even be a wave propagating at a speed different from the physical wind circulation. Nevertheless, during the *Voyager* encounters in 1979, there was a distinct white spot or streak of similar scale to the features tracked here, (ref.1 pp. 194–196), and the directly measured rotation periods of 6–8 days agreed well with the values of 6.9 to 7.7 days calculated from the maximum local wind speeds (Table 1).

From 1979 to 1996, any change

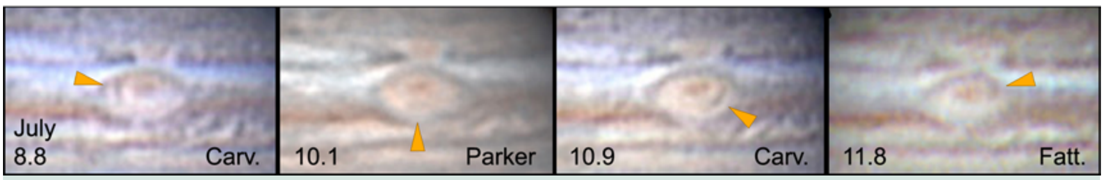


**Figure 4.** The GRS in 2006 July: a small selection of the images showing a crescent-shaped grey streak circulating within it (yellow arrow). South is up. (Oval BA, newly reddened, is on the south edge of the GRS.) Images by Carvalho, Parker, and Fattinnanzi (see text for details).

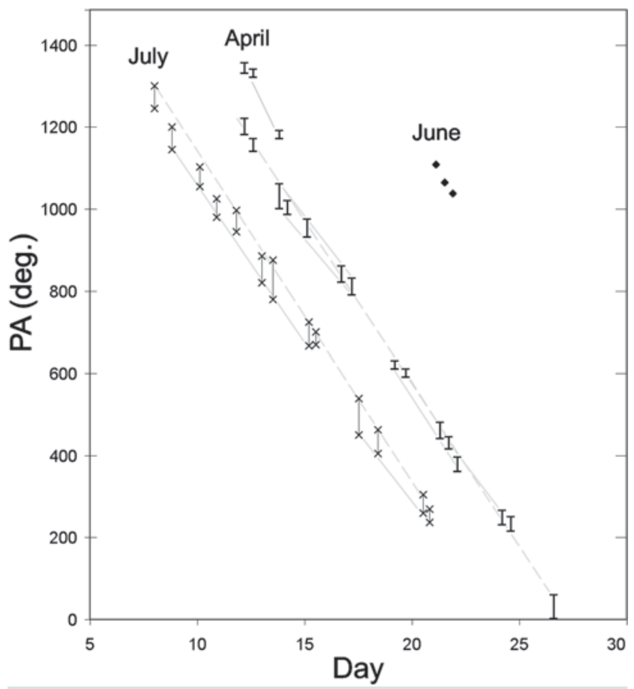


**Figure 5.** Measurements of the circulation of the GRS in 2006. Points represent the position angle of the leading and trailing ends of the dark streak in July (crosses), and of the base of the dark streak in April (bars), and the centre of the dark spot in June (diamonds).
Vertical lines indicate the extent of the feature. Solid lines indicate best fit over short intervals; dashed lines connect these segments such that the overall rotation period is 4.5 days.

in the wind speed or flow field did not reach statistical significance, although the later speed measurements were somewhat higher.[10] The shortened circulation period was mainly due to the shortened length of the GRS. However the *Galileo* images on 2000 May 22 indicated notably faster wind speeds.[11,12] As those images covered less than two days, it is possible that the acceleration was only a temporary fluctuation – just as the speeds were slower during the *Voyager 2* encounter than during that of *Voyager 1*.[9] However the 1979 deceleration could be accounted for by the development of a STropD between the two *Voyager* encounters, whereas there was no evident

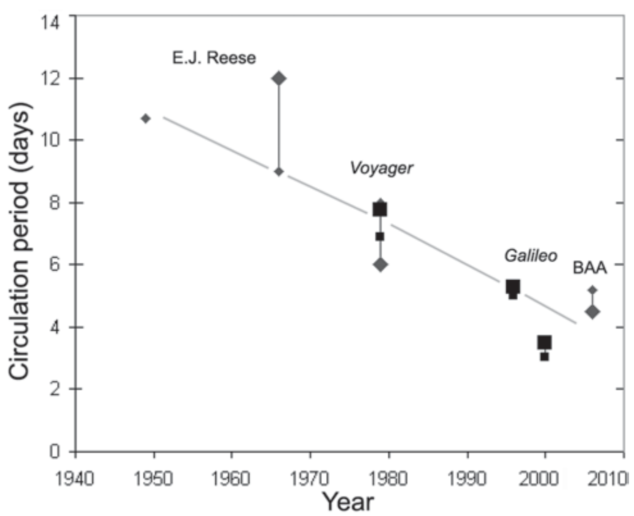


**Figure 6.** Chart of all measurements of the GRS circulation period, from Table 1b. Large diamonds, $P_4$; small diamonds, $P_3$; large squares, $P_2$; small squares, $P_1$. The line indicates shortening by 1.2 days every 10 years.

reason why the GRS should have been anomalous on 2000 May 22. (*Cassini* also imaged Jupiter, later in 2000, but the images had lower resolution than *Galileo*'s, and there was no coherent feature circulating within the GRS to give a rotation period.)

Our measurements in 2006 confirm that the period has shortened since 1979. However we cannot confirm that the wind speeds within the GRS have increased: our measurements imply a wind speed of ~112 m/s. This shortening of period could be entirely attributed to the physical shrinkage of the GRS and the contraction of its radius of maximum velocity. However, as noted above, it is still possible that even faster wind speeds prevail at a different radius within the GRS, as recorded in 2000.

## The 90-day oscillation of the GRS

Remarkably, one aspect of the GRS which has not changed in recent decades is its small oscillation in longitude with a period of 90 days (ref.1 p.194). This oscillation was first suspected by P. B. Molesworth in 1905,[16] and its existence from 1894–1905 has since been validated with P = 89–92 days.[17] The oscillation was first clearly demonstrated by G. Solberg and E. J. Reese at the New Mexico State University Observatory from 1963 to 1971, with P = 90 days.[18,19] It was also well documented in BAA visual data for 1973 to 1975.[20] Although the GRS, and consequently its oscillation, were less distinct after 1975, the oscillation did still continue. It was definite in *JUPOS* analysis of amateur transit data from 1975 to 1986, and probable from then to 1990, P = 89–91 days.[17] It has also been detected by measurements of CCD images in 1993–1999, P = 89.8 days;[21] and by *JUPOS* analysis of images in 2000–'01, with similar period.[22] Here we show that it is still present with the same period, and offer evidence for the first time that it may be coupled to an oscillation in latitude.

### *Methods*

Longitudes and latitudes for the centre of the GRS were measured on hi-res images by the *JUPOS* system, programmed by Grischa Hahn and coordinated by Hans–Joerg Mettig.[23] See **http://jupos.org**. The measurements were made by Hans–Joerg Mettig, Gianluigi Adamoli, Michel Jacquesson, Damian Peach, André Nikolai, and Marco Vedovato. To minimise scatter, measurements were selected from images by the most consistent hi-res observers (more than half of the total). Latitudes are zenographic.

### *Results*

*JUPOS* charts show clearly the 90-day oscillation of the longitude of the GRS in 2000–'01[22] and in all subsequent apparitions to 2006 (H–J. Mettig, personal communication;

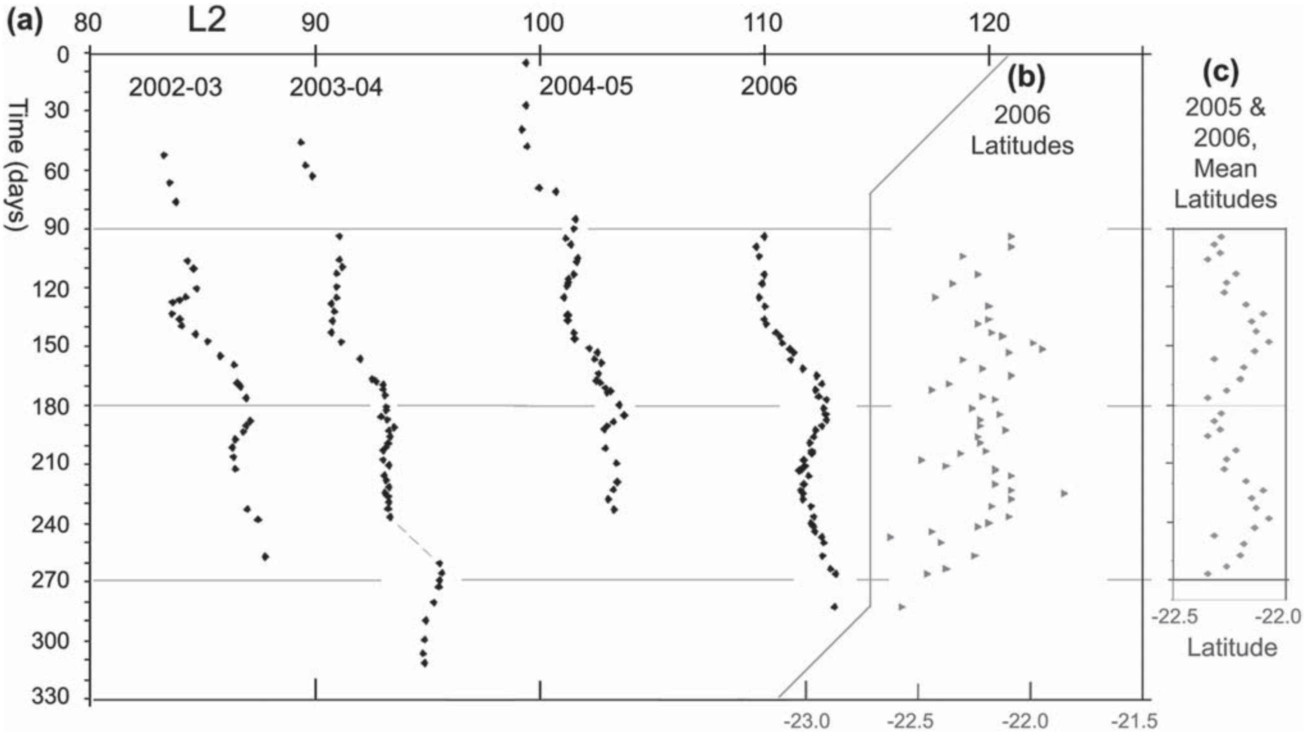


**Figure 7.** The 90-day oscillation of the GRS.
*(a)* Longitude of the GRS, 2002–2006: 8-point running means taken every 4 points. Horizontal grey lines indicate adopted times of maximum longitude at intervals of 89.5 days up to 2005, and 91.5 days from 2005 to 2006. The 90-day point corresponds to 2002 Dec.6, 2003 Nov.30, 2005 Feb.19, and 2006 Feb.19.
*(b)* Latitude of the GRS, 2006 only: 8-point running means taken every 4 points. The chart for 2004/'05 was similar (not shown). Note the scale (at bottom) is 10 times larger than the longitude scale.
*(c)* Mean of the latitudes for both 2004/'05 and 2006, folded with the 90-day period and shown twice. To construct this, starting with the 8-point means, 0.12° was added to the 2004/'05 values to correct for an apparent secular variation, then the values were ordered by phase relative to the 90-day period, and averaged in 5-day bins (n=4–6 values per bin).

Figure 7a). From 2000 Sep. to 2005 April, the times of maximum longitudes were fitted to within a few days by P = 89.4 days (±0.2d). However with this period the 2006 maxima occurred ~7 days late, suggesting that the period is not absolutely constant, with a genuine variation between 89 and 91 days. The amplitude of the oscillation is ~±0.5°, and the corresponding variation in drift rate (DL2) is ~±1.0°/mth.

The *JUPOS* data also enable us to enquire, for the first time, whether there is any synchronous oscillation in latitude. Any such variation may be uncertain, first because it could be influenced by changes in the visible outline of the GRS, and second because it is likely to be much smaller than the resolution of the images. Indeed, the GRS is one of several features whose latitude is sometimes assumed by the *JUPOS* measurers in order to optimise the fit of the measuring template to the limb. However it is not used for this purpose on its own, and variable latitude measurements for it are accepted, so true variations in latitude might be detected. In fact, the running mean latitudes in 2005 and 2006 suggest an oscillation of ~±0.1° in latitude, in phase with the longitudinal oscillation (Figure 7b), although there also seem to be longer-term variations. The oscillation is seen more clearly when the data from each apparition are further averaged and folded with a period of 90 days, as plotted in Figure 7c. When the rising and falling halves of the cycle are combined into a chart covering 45 days, the correlation coefficient for latitude versus phase is 0.72, which appears to be significant.

However, when the same analysis was done for the 2002–'03 and 2003–'04 apparitions, no such correlation was found (results not shown). (The data appear to be of equivalent quality: in each of the four apparitions, the mean standard deviation of latitude measurements over 20-day intervals was between 0.29 and 0.33°.) This could mean that the correlation in 2005 and 2006 was spurious. Alternatively, it could be because the data were better in 2005 and 2006 due to more very hi-res images, and less disturbance of the GRS by SEBs jetstream spots.

**Table 2. Mean latitudes of the centre of the GRS.**

| *Phase:* | *80–90–10d (max. L2)* | ± | *35–55d (min. L2)* | ± |
|---|---|---|---|---|
| *Apparition:* | | | | |
| 2005 | −22.49 | 0.18 | −22.24 | 0.08 |
| 2006 | −22.26 | 0.18 | −22.12 | 0.07 |

For each cycle of the 90-day oscillation in Figure 7, latitudes were averaged over 20-day intervals centred on phase 0 (maximum longitude) and phase 45 days (minimum longitude). Standard deviations ranged from 0.22 to 0.45; n = 7 to 30. Two or three such values in each apparition were then averaged to give the results in this table.

## Discussion

It is remarkable that the 90-day oscillation in longitude has continued for more than a century with a period that varies by no more than two days from year to year, and less than a day over longer periods. This constancy could indicate that the 90-day period is a property not of the GRS, but of the retrograding SEBs jet in which it is embedded. At its typical speed of DL2 = +120°/mth, 90 days is the period in which material would circle the planet once. However, the speed of the SEBs jet (at the observed cloud-top level) is much more variable than the 90-day period, so the stability of the 90-day period remains a mystery.

We present evidence suggesting a coupled oscillation of the GRS in latitude. If it is real, the GRS tends to have its highest longitude when at its highest latitude. This might be explained if the oscillations are primarily in latitude (of unknown cause), and the GRS is subject to longitudinal acceleration by the local zonal winds as a passive consequence of its latitude. The zonal winds are relatively more prograding at high latitude and more retrograding at low latitude. Hence, the GRS will experience maximum eastward acceleration at its highest latitude, and maximum westward acceleration at its lowest latitude, consistent with the observed relationship.

Anticyclonic ovals in other zones also show slight variations in speed correlated with latitude, ranging from the great South Temperate white ovals[24] to a long-lived oval at ~60°S.[25] *JUPOS* analysis in recent years shows that this behaviour is not uncommon. In all cases, the oval has its fastest prograding drift when it is at highest latitude, unlike the suspected relationship for the GRS. However, both relationships might be explained by the same mechanism proposed above, because of the different sizes of the ovals. The smaller ovals are accelerated to their steady-state velocity on a timescale much less than the interval over which they are measured, so their latitude correlates with their speed. In contrast the enormous GRS is accelerated much more slowly so its latitude correlates with its acceleration, not its speed. The amplitudes for the GRS are ~0.5 m/s in speed and ~0.1° in latitude, implying a similar latitude sensitivity to that shown by other ovals: values range from ~3.3 m/s per degree latitude for the South Temperate white ovals,[24] to ~8 m/s per degree latitude for the 60°S ovals.[25,26]

However the possible GRS oscillation in latitude needs to be confirmed by further measurements. In 2005 and 2006 it appeared to be significant, but it was not detected in 2002–'03 or 2003–'04, so we cannot be confident that it is real. As the GRS is becoming more isolated in 2007, it may be possible to settle the issue with new measurements of higher precision.

## Acknowledgments

I am grateful to all the observers who have contributed observations of the GRS to the Jupiter Section over the years. Thanks are especially due to those who provided hi-res images revealing of the internal circulation, and to the *JUPOS* team who showed the persistence of the 90-day oscillation, who are acknowledged by name in the text.

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***Note added in proof:***
More detailed analysis of the GRS circulation in the *Galileo* images has recently been published: Choi D. S. *et al., Icarus* **188**, 35–46 (2007).

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