Jupiter in 2013/14 Report no.9. (*This report was produced on 2014 July 8 but not posted; it has now undergone minor revisions for publication (2015 July). Material changes are indicated as 'Additional note'.)*

The GRS and adjacent jets: Further analysis of amateur images, 2013/14

John Rogers, Gianluigi Adamoli, Michel Jacquesson

Summary

1. Shrinkage of the GRS

The GRS has shrunk in latitude as well as longitude – slightly over many years, and considerably in 2013/14, in parallel with the shrinkage in longitude. This is the first definite change recorded in latitudes for the GRS. The centre latitude did not change significantly until 2013/14, when it is ~0.2º further south.

These recent changes in the GRS are not due to the incoming STBn spots, because detailed study of the STBn outbreak shows that the spots did not reach the GRS until 2013 Dec., long after the GRS had shrunk.

2. Circulation of the GRS

Measurements of hi-res images in 2014 Feb., tracking a dark grey streak round nearly 3 circuits inside the GRS, show a slightly varying rotation period of 3.6 to 3.8 days, confirming our measurement in Jan. The hi-res images in 2014 Feb. have been compiled into (i) a series of maps, (ii) measurements of the internal rotation of the GRS, (iii) an animation of the maps showing the interactions with STBn jet spots.

The images in 2014 April, spanning the time of the HST imaging, have also been compiled but there were no persistent trackable features within the GRS.

3. The STBn jet outbreak

3.1. We present a full JUPOS analysis of the STBn jet outbreak in 2013/14. The jet spots appeared on the STB(N) just p. oval BA; they initially moved comparatively slowly [DL2 ~ -75 to -86 deg/mth], but speeded up to the usual jet speed [DL2 ~ -94 deg/mth] within months; their zonal drift profile (ZDP) followed a shallow cyclonic gradient from ~28.5ºS to 27ºS, shifting to higher speed as the outbreak developed; many of the spots drifted north through this range during their lifetimes without change of speed. In all these respects, the outbreak behaved exactly like previous ones in 2004-2005 and 2010-2011.

3.2. Interactions with the GRS: Hi-res image sets are provided for 2014 Feb. and April, showing in detail how the jet spots were distorted and disrupted as they passed the GRS. They were strongly accelerated and deflected south for the duration of the passage. In some cases, remnants survived, reverting to approx. their original speed and latitude.

3.3. Interactions with the STB Ghost: A few STBn jet spots survived to pass the STB Ghost, when they drastically decelerated. (The same was recorded in 2005.)

4. The SEBs jet

The SEBs jet carries sparse, small white spots. In 2013/14 they appear to be vortices with peak jet speed running slightly south of the nominal jet peak, as in most other years. Although there was anomalous behaviour in autumn, 2012, with exceptionally rapid retrograde speeds, there has been no long-term change in the behaviour of this jet.

Background

This report describes the GRS and STBn jet up to 2014 April, when they were viewed by the Hubble Space Telescope on April 21 [Ref.1]. This report is entirely based on amateur images and the JUPOS measurements of them, except where stated otherwise.
It follows on from our 2013/14 Reports nos.4 and 6 (including the STBn jet outbreak) and no.7 (the GRS), both posted on-line [Ref.2]; and our previous results cited in Report no.7.

1. Shrinkage of the GRS in latitude

The GRS has shrunk in latitude as well as longitude – slightly over many years, and considerably in 2013/14, in parallel with the shrinkage in longitude (**Figures 1 & 2**). This is the first definite change recorded in latitudes for the GRS.

Michel Jacquesson measured the latitudes of the N and S edges on some of the best amateur images from 2006-2014, making no assumption about the centre latitude, and in some cases using satellites or their shadows to establish the precise position of Jupiter's limb. (JHR has independently confirmed a small selection of these results, to within 0.1°.) The GRS was a distinct oval in all these images except for some in late 2012: usually an orange oval against white surroundings, but in 2006 and 2011, a light oval contrasted with a dark grey collar.

Table 1. Latitudes and width of the GRS, 2006-2014: Apparition means.

	Appar'n	Centre	Mean			SD			N
		Lat.	Lat N	Lat S	Diff	Lat N	Lat S	Diff	
	2006	-22,11	-17,10	-27,12	10,02	0,27	0,27	0,27	20
	2007	-22,25	-16,86	-27,63	10,77	0,25	0,18	0,23	13
	2008	-22,30	-17,13	-27,46	10,33	0,37	0,39	0,34	24
	2009	-22,37	-17,31	-27,44	10,13	0,28	0,25	0,30	19
	2010	-22,21	-17,10	-27,32	10,22	0,25	0,27	0,28	21
	2011	-22,11	-17,11	-27,12	10,01	0,20	0,27	0,35	19
	2012/13	-22,21	-17,13	-27,29	10,16	0,26	0,25	0,29	27
	2013/14	-22,47	-17,79	-27,14	9,36	0,25	0,23	0,35	18
						(Note: SEM is ~0.06 deg. in each case.)			
Mean,	2008-2012	-22,24	-17,16	-27,33	10,17				5
	(SD)	0,10	0,09	0,14	0,12				
Historical mean	**1952-1990**	**-22,3**	**-16,5**	**-28,4**	**11,9**				13-19
(from photos: book p.400)		0,3	0,4	0,5					

The GRS width in latitude was only 9.4° in 2013/14 (**Table 1**), compared with 10.2° from 2008-2012, 10.0° in 2006, 10.8° in 2007 (a temporary expansion), and 11.9° historical average (1952-1990, from Appendix 2 in Ref.3). This is the first definite report of variations in the GRS width (although there may be a slight trend in the historical data in that Appendix). The centre latitude (22.2°S) has not changed significantly, until the present apparition, when it seems to be slightly higher (22.5°S), as the N edge has contracted more than the S edge.

The width has declined along with the length, which was also static from 2008-2012 and higher in 2007. The one apparition where they were dissociated was 2012/13, when the width was unchanged, but the length was rapidly declining.

Large-scale atmospheric events which could have affected the GRS in these years are listed in **Table 2**. Comparison with **Fig. 2** suggests that the GRS length and width were not influenced by any of the above factors, except possibly for the South Tropical Disturbances of 2007, which could be associated with the temporary enlargement of the GRS in that year. (This enlargement was probably not due to the SEB Fade in 2007, as it was not repeated during the SEB Fade in 2009-10. The merger with the 'Baby Red Spot' in the STropZ in 2008 July may have been responsible for the increased length in the following 2 months, but no change in width.)

This shrinkage may of course affect the GRS interaction with the flanking SEBs and STBn jets. However, the GRS still deflects both jets around it, as of this year. This interaction is investigated in detail below.

Table 2:
Large-scale atmospheric events which could have affected the GRS, 2000-2014.

2004	STBn jet outbreak
2007	South Tropical Disturbances; SEB Fade and Revival
2008	Merger with 'Baby Red Spot' (oval in STropZ)
2009-10	SEB Fade
2010-11	STBn jet outbreak; SEB Revival
2013-14	STBn jet outbreak

The 90-day oscillation of the GRS is still obvious in the JUPOS chart (**Figure 3**), and its mean period in 2013/14 is 91.5 (±1.5) days, not significantly different from the period that it has shown since 1895 [Ref.4] -- in spite of the huge reduction in the size of the GRS. This period is more invariant than anything else that we can measure on the surface.

The drift rate of the GRS in 2013/14 is DL2 = +1.5 (±0.06) deg/mth [u_3 = -4.26 (±0.03) m/s], which is slower than ever before with the SEB in its normal state.
The GRS appears to be evolving towards the state of Cassini's spot [Ref.3 pp.262-3]. That spot was as small as or smaller than the present GRS (subject to the resolution of telescopes of the time), and had a drift rate of u_3 ~-6 to -10 m/s. Thus the GRS still has some way to go reach that state, but at the recent rate of shrinkage, it could be achieved within only a few decades, becoming circular by 2030-2040, or even earlier if this year's shrinkage is sustained.

2. Circulation of the GRS

The internal rotation period of the GRS in 2014 Jan. was measured as 3.6 (±0.2) days [Ref.2, Report no.7].

The internal rotation has now been measured in 2014 Feb. as well. We used the best set of images from 2014 Feb.13-24, as shown in Reports no.6 & 7, and in **Figure 8**. In the GRS, these images show one or more dark grey streaks circulating just within the perimeter. These images have been map-projected by Michel Jacquesson to study these phenomena. To measure the circulation of the GRS, each map was stretched to make the GRS approx. circular (**Figure 4**), and the position angle of the dark streak was measured, as previously [Report no.7 & refs. therein]. To a first approximation, a single dark grey streak could be traced round 2.9 circuits in 11.2 days, giving a rotation period of 3.86 d (±0.04 d). However, the track appears to have a slight discontinuity around Feb.17, with P = 3.59 d before and P = 3.76 d after. On Feb.17, the small dark streak was embedded in a much longer one and indeed appeared double on Brian

Combs' image; then on Feb.19 it was involved with a transient white rift in the perimeter. We therefore think that on Feb.17-18 the first dark feature was replaced by a similar one adjacent but just behind it, all within a complex longer streak. The image set also shows another, longer dark streak tracking the GRS rotation on Feb.22-23 only.
Taking the Jan. and Feb. results together, we report a slightly variable GRS rotation period of 3.6 to 3.8 days.

We have also compiled hi-res images in 2014 April, spanning April 21 when the HST imaging was done. These do not show any persistent trackable features in the GRS, but STBn spot interactions are well shown (**Figure 8**).

3. The STBn jet outbreak

This report presents analysis of the JUPOS data on this outbreak (by G. Adamoli), and is continued from the previous, more qualitative description in our 2013/14 reports nos. 6 & 7 [Ref.2]. The background to the phenomena is given in our long-term report on the S. Temperate domain [Ref.5]. The STBn jet (or S1 jet, to use our alternative simplified nomenclature) is undergoing an intense outbreak of dark spots, which began during solar conjunction in 2013, triggered by the collision of a dark STB segment with oval BA. Similar outbreaks occurred after previous STB segments collided with oval BA in 2003/04 and 2010. Here we present a full JUPOS analysis of the STBn jet outbreak in 2013/14. In a separate long-term report on the STB [Ref.6], we compare these results with analysis of the outbreaks in 2004-2005 and 2010-2011. This shows that the present outbreak is essentially identical to those previous examples.

3.1. The outbreak from oval BA to the GRS

The following characteristics are essentially identical to those of previous outbreaks [Ref.5], and F**igures 6 & 7** are presented in the same format as Figs.16 and 17 in Ref.5. Further details are in **Supplementary Figures S1-S5.**

The spots early in the outbreak had low speeds
(DL2 = -83 deg/mth, u_3 = +32.5 m/s; 2013 Sep-Nov),
but the mean speed quickly increased and has been normal for this jet since 2013 Dec.
(DL2 = -94 deg/mth, u_3 = +37 m/s, Dec-Mar.;
DL2 = -97 deg/mth, u_3 = +38.3 m/s, 2014 April). (**Table 3**, below.)

Their Zonal Drift Profile (ZDP) followed a shallow cyclonic gradient from ~28.5 to 27ºS (**Figure 6 & Fig.S1**). When the mean speed increased, the ZDP shifted to higher speeds. On these charts, a typical spacecraft ZWP is shown for comparison, suggesting that the spots lie between the two sub-peaks of the jet, but no ZWP has ever been established in a sector undergoing an outbreak, until now. [*Additional note, 2015:* This has now been done by Grischa Hahn from amateur images in 2014 Feb. and HST images in 2014 April [Ref.7]. He finds that the mean ZWP in this sector matches the ZDP, and the southerly side of the jet at ~29.5ºS becomes weaker with decreasing longitude as the spots move northwards.]

Many individual spots in this range drifted northwards without change of speed (which accounts for some of the scatter in the ZDP). Tracks for some of the best-established are shown together in **Figure 7**, and separately in **Fig.S2:** these examples were well-observed spots which were also tracked while passing the GRS. The northward-drifting spots all started in a narrow latitude range, 28.4 (±0.3) °S; their final latitudes were more diverse. Their speeds were typical of spots in this outbreak.

Table 3

STBn jetstream dark spots 2013-14					
(JUPOS data - GA's analysis)					
spot	ΔL2(°/30d)	U3(m/s)	lat.	N(a)	N(b)
Spots transiting from BA to GRS/Ghost in Sep-Nov					
mean	**-83,3**	**32,5**	**-28,3**	5	8
SD	8,2	3,6	0,29		
Spots transiting from BA to GRS/Ghost in Nov-Dec					
mean	**-90,1**	**35,5**	**-27,8**	9	9
SD	4,7	2,1	0,42		
Spots transiting from BA to GRS in Dec-Jan					
mean	**-94,8**	**37,5**	**-27,9**	12	12
SD	1,6	0,8	0,20		
Spots transiting from BA to GRS in Jan-Feb					
mean	**-94,0**	**37,1**	**-27,9**	13	11
SD	4,7	2,1	0,37		
Spots transiting from BA to GRS in Feb-Mar					
mean	**-93,7**	**37,0**	**-27,8**	16	16
SD	4,9	2,2	0,37		
Spots transiting from BA to GRS in Mar-Apr					
mean	**-96,8**	**38,3**	**-27,9**	7	9
SD	2,5	1,1	0,33		
Spots transiting from BA to GRS in Dec-Apr					
mean	**-94,3**	**37,2**	**-27,9**	49	48
SD	4,0	1,8	0,36		
Spot remnants transiting from GRS to STB Ghost (Jan-Mar)					
mean	**-95,0**	**37,7**	**-27,3**	7	10
SD	7,6	3,3	0,41		
Spots remnants followed beyond STB Ghost (Feb-Mar)					
mean	**-88,1**	**34,8**	**-27,2**	3	5
SD	5,3	2,3	0,42		
N(a) = number of well-determined tracks (>6 obs'ns), as used for latitude determ'ns.					
N(b) = number of spots, sometimes with several track segments, as used for speed determ'ns.					

3.2. Interactions with the GRS

The outbreak was still in its early stages at the start of the apparition, and the darkening of the STB(N) p. BA was not entirely resolved into spots [see figures in our 2013/14 Report no.4]. It had a diffuse p. end near L2 ~ 280 in 2013 August, which reached the STB Ghost (just f. the GRS) in Sep. Distinct jet spots did not pass the STB Ghost, and did not reach the GRS until early Dec., when the STB Ghost had moved alongside the GRS.

From Dec. onwards, the images showed that the spots were dramatically disrupted while passing the GRS, typically being drawn into long streaks. Most of these probably dissipated chaotically p. the GRS; sometimes an irregular bright white area expanded p. the GRS like a ‘splash’ between the streaks derived from two successive spots. A few of the spots did re-emerge (with less coherent aspect) so as to be tracked after passing the GRS (see below). Examples of these passages are illustrated for Jan. [Fig.3 in Report no.7], Feb. [Fig.4 in Report no.7, revised here as **Fig.8**], and April [**Fig.9** herein]; and more examples in **Figs.S4 & S5**. Similar behaviour was recorded in our reports for 2010.

As the spots were stretched alongside the GRS, they also accelerated massively for the duration of the passage, reaching DL2 between -3.9 and -5.2 deg/day (**Table 4 in Fig.S3**). The speeds in this table are inversely correlated with the time interval over which they were measured, implying that the maximum speed was typically DL2 ~ -5.0 deg/day (u_3 ~ 61 m/s) for only a few days during the passage. At the same time, the spots all moved south while passing the GRS **(Fig.7, Figs.S2 & S3).** Each spot’s latitude increased suddenly as it began to pass the GRS, reaching a maximum of 28.7 (±0.3) ºS (0.8 to 1.9º higher than before; mean increase = 1.2º (±0.34º): **Table 4 in Fig.S3**). If the spot survived, its latitude declined just as rapidly as it ended its passage.

3.3. Spots tracked after passing the GRS

> *G. Adamoli described the process thus:*
> But some features managed to pass the GRS, usually in the form of faint, irregular streaks and wisps, that appeared as their ephemeral dying form. A few definite, longer tracks appear in charts p. the GRS, and I wondered if they could be linked to spots previously followed f. it. Identification were quite hard: I had to resort to images (generally, from the ALPO-Japan archive). Through almost day-by-day compilations (see examples in attached JPEGs), I came to realize that spots, when passing along the S. edge of the GRS, were usually torn apart in streaks and abruptly accelerated; if a remnant survived, definite enough to be measured, this tended to decelerate again, more or less to its previous drift. It was also at a rather lower latitude.

The fate of the jet spots may also have been affected by the STB Ghost, which was passing the GRS in Dec., and was just p. it in Jan.; no spots were tracked p. the GRS at this time. From late Jan. onwards, when a gap had opened up between the STB Ghost and the GRS, several spots survived to be tracked p. the GRS; the best examples are plotted in **Fig.7**. Image alignments for five of these spots are in **Fig.8 & Figs.S4 & S5**.

Their speeds averaged DL2 = -95 deg/mth (u_3 = 38 m/s), the same as before the GRS passage, and their latitudes were mostly similar to before the GRS passage and consistent with the same descending trend, although some were higher or lower. The mean latitudes p. the GRS were mostly between 27.2-27.6ºS, although two spots descended to 26.4ºS. Some latitude values appeared to be more scattered or even oscillating after the GRS passage, perhaps due to the disordered motion and/or shape of the features.

A few of these spots even persisted after passing the STB Ghost (**Fig.7 & Fig.S2**). All three slowed drastically as they passed it, thereafter showing speeds of only DL2 = -86 (±2.2) deg/mth (u_3 = 34 m/s). Their latitudes did not show a consistent trend. Similar decelerations occurred when spots passed the STB Remnant in 2005 (Refs.6&8).

The speeds and latitudes of these post-GRS spots are plotted in **Fig.6 & Fig.S1(d).** Most of them do not fall near the pre-GRS ZDP, nor do they form a well-defined ZDP of their own. However, the divergence from Hahn's 2014 ZWPs (with the northerly jet sub-peak at ~37 m/s and ~27ºS [Ref.7]) is much less than from the Cassini ZWP as shown in **Fig.6**. These scattered values may be attributable to turbulence after passing the GRS, and possibly local distortion of the jet adjacent to the STB Ghost.

4. The SEBs jet in 2012-2014

(In this section only, 'fast' means rapidly retrograding.)

The SEBs jet is the fastest retrograde jet on the planet, and vortices on it interact with the GRS, possibly transferring vorticity into the GRS. Therefore, changes in the GRS might have causes from, or effects on, this jet. Spacecraft ZWPs have a mean peak speed of +120.6 deg/mth (-58.6 m/s) for this jet, the fastest being from New Horizons with +133.4 deg/mth (-64.5 m/s). J. Rogers has argued that +120 deg/mth is the typical speed of vortices on the S edge of the jet peak, while +133 deg/mth is the true peak jet speed [Ref.9]

Here we summarise our data on the SEBs jet and its interaction with the GRS in 2012-2014. Trackable spots have been sparse in these apparitions, mostly small white spots embedded in the dark grey fringe of the SEBs. The resulting speeds and latitudes are shown in **Figure 10F**, in a ZDP chart which is compared with the ZDPs for other recent apparitions, from our final reports posted on-line.

In autumn 2012, most of the spots were retrograding remarkably fast (mean DL2 = +150.8 deg/mth, u_3 = -72.3 m/s; max. +165 deg/mth, u = -79 m/s). Details are posted separately in [Ref.10]. This very rapid speed has not been detected in any other apparition since 1993, and seems to indicate an abnormal condition of the SEBs jet in late 2012 only, although there was no visible anomaly to account for it. As some or most of these rapidly-moving spots were embedded in wave-trains, it is possible that the speeds were actually phase speeds for waves that were faster than the jet wind speed.

In 2013/14, SEBs spots were sparse but had a more typical speed (mean DL2 = +122 deg/mth, u_3 = -59 m/s; max. +129.5 deg/mth, u = -62 m/s) **(Table 5)**. They were further south, south of the peak of the spacecraft ZWP. This is typical: we have recorded such spots in this position in almost all recent apparitions (**Fig.10**). They are usually vortices on the south flank of the jet, as in the Cassini data (**Fig.10A**) – although the spots in the 2010 SEB Revival, following a similar ZDP south of the spacecraft ZWP, were not vortices (**Fig.10D**). The reason for this ZDP-ZWP difference is still unclear. Nevertheless, the speed and latitude of the SEBs jet spots in 2013/14 [and also 2014/15, report in preparation] were the same as in many years since 1999, showing that the SEBs jet has not undergone any long-term change.

Table 5: SEBs jet spots, 2013/14 (white spots)

spot	*time interval*	*ΔL2(°/30d)*	*U3(m/s)*	*Lat.*	*SD*	*N*	*notes*
W20	Nov 18 - Dec 13	129,5	-62,3	-21,1	0,16	9	
W21	Dec 4 - 23	114,9	-55,7	-20,9	0,40	11	
W22	Jan 4-22	119,7	-57,9	-20,6	0,37	14	See figure.**
W23	Feb 17 - Mar 1	119,8	-58,0	-20,8	0,41	10	See figure.
W24	Feb 7 - 24	125,2	-60,5	-20,7	0,35	9	See figure.
	Mean	121,8	-58,9	-20,8			
	SD	5,6	2,6	0,19			

See **Fig.S6.

Interactions with the GRS in 2013/14

Some of these white spots in the SEBs jet reached the GRS, and we have studied the images of these encounters (**Fig.S6**). In well-observed cases, the spot accelerated on entering the Red Spot Hollow, but decelerated as it reached the northernmost point. In all cases the white spot travelled along the dark rim of the RSH towards its f. end, not making contact with the GRS. For example, spot w24 took ~49 hours to traverse the first quadrant (10º long., ~5 deg/day), and a little over 71 hours to traverse the second quadrant, remaining distinct.

Despite the lack of visible contact, we do not think these observations provide evidence of any change in the interaction of SEBs jet vortices with the GRS. Even in the Voyager 1 movie, which first showed these interactions so dramatically, SEBs vortices did not merge with the GRS directly as they squeezed round the Red Spot Hollow (RSH); only a vortex returning along the GRS south edge (with the STBn jet) merged with it. Passages of SEBs jet spots into the RSH are sometimes recorded in amateur images; the best examples are probably from 2003-2006*, as the SEB Fade/Revival cycles precluded such interactions in subsequent years. As in the Voyager 1 movie and the 2006 April example, spot w22 in 2014 moved around the RSH but did not visibly interact with the GRS (**Fig. S6**). Other spots tracked around the RSH in 2012-2014 were smaller, so it is not surprising that they remained separated from the GRS by a clear white arc. [*Additional note:* In 2015, we have again recorded vortices which visibly interact with the GRS despite its shrunken state [report in preparation]]. So within the resolution of ground-based imaging, we have not seen any qualitative change in these interactions.

*[We recorded good examples in 2003 April and 2004 April, which were rather large, less-rapidly-retrograding vortices, and they did contact the GRS directly. The best-observed was in 2006 April [Ref.11], which moved around the RSH but did not visibly interact with the GRS.]

References

1. Simon AA, Wong MH, Rogers JH, Orton GS, de Pater I, Asay-Davis X, Carlson RW & Marcus PS. 'Dramatic Change In Jupiter's Great Red Spot From Spacecraft Observations' *Astrophysical Journal Letters*, 797:L31-L34 (2014 Dec.20) doi:10.1088/2041-8205/797/2/L31.

2. Jupiter in 2013/14: Interim report no.4, http://www.britastro.org/jupiter/2013_14report04.htm
   & Jupiter in 2013/14: Interim report no.6, http://alpo-j.asahikawa-med.ac.jp/kk14/j140406r.htm
   & Interim report no.7: The Great Red Spot in 2013/14, http://alpo-j.asahikawa-med.ac.jp/kk14/j140406s.htm

3. Rogers JH (1995). *The Giant Planet Jupiter*. Cambridge Univ. Press.

4. Hahn G., 'The 90-day oscillation of the jovian GRS.' *J.Brit.Astron.Assoc.* 106, 40-43 (1996).

5. Rogers J, Adamoli G, Hahn G, Jacquesson M, Vedovato M, & Mettig H-J (2013). 'Jupiter's South Temperate domain: Behaviour of long-lived features and jets, 2001-2012.' http://www.britastro.org/jupiter/stemp2013.htm

6. Rogers JH (2015) 'Jupiter's South Temperate Domain, 2012-2015'. http://www.britastro.org/jupiter/2014_15report08.htm *[Posted with this report.]*

7. Hahn G & Rogers J (2015) 'Zonal wind profiles from ground-based and Hubble images, 2014 February and April.' http://www.britastro.org/jupiter/2013_14report10.htm *[Posted with this report]*

8. Rogers J & Adamoli G (2015), 'Jupiter in 2005 and 2006: Final report.' http://www.britastro.org/jupiter/2006report13.htm

9. Rogers J (2011), Jupiter in 2010, Report no.22: 'Jupiter's SEB Revival in 2010/11: Analysis of the early stages of the southern branch.' http://www.britastro.org/jupiter/2010report22.htm

10. Rogers J, Adamoli G & Vedovato M (2015 July) Jupiter in 2012/13: Report no.12. 'The SEBs jet in 2012/13.' http://www.britastro.org/jupiter/2012_13report10.htm *[Posted with this report.]*

11. Rogers JH (2008) 'The accelerating circulation of the Great Red Spot.' JBAA 118, 14-20.

Figure legends.

Figure 1. Chart showing length of the GRS, 2003-2014 (updated version of the chart in our Report no.7.)

Figure 2. Charts showing latitudes and width of the GRS, 2006-2014. Top & middle: Individual measurements on selected hi-res images. Bottom: Apparition means. Data from Table 1.

Figure 3. JUPOS chart of the GRS, showing the 90-day oscillation.

Figure 4. Circulation of the GRS, 2014 Feb.
(Left) Set of reprojected GRS images with measurements of position angle (PA).
(Right) Chart of PA measurements, showing P = 3.6 to 3.8 days.
South is up in all figures unless otherwise stated. (Also see **Supplementary Movie**.)

Figure 5. STBn jet spots, 2013/14: JUPOS chart, plotted by G. Adamoli, highlighting points belonging to measured tracks, plotted in a longitude system moving at DL2 = -90 deg/month.

Figure 6. STBn jet spots, 2013/14: ZDP. For early spots (blue), the mean speed and the ZDP were slower than for later spots (red). Trend lines have been drawn by eye. Spots which passed the GRS (open diamonds) had lower latitudes and a range of speeds; spots which then survived beyond the STB Ghost (open triangles) had much slower speeds. For charts broken down by month, see **Suppl. Fig. S1**.

Figure 7. STBn jet spots, 2013/14: Tracks for 11 individual spots, plotted as longitude (L2) vs latitude. Positions of the GRS and the STB Ghost are indicated schematically. The spots move from right to left; trend-lines (fitted by Microsoft Excel) show the decline in latitude down to the GRS. Note the marked increase in latitude as each spot passed the GRS, and for those which survived, return to an approximate extrapolation of the previous track.
These were selected spots which were well tracked, showed a progressive decline in latitude, and reached conjunction with the GRS. For separate tracks of longitude and latitude vs time, and derived parameters, see **Suppl. Fig. S2.**

Figure 8. Images of the GRS region, 2014 Feb.12-24, showing STBn jet spots passing the GRS. *The same set of images was shown in Report no.6 [Fig.6] and Report no.7 [Fig.4], and they have now been reprojected as maps by M. Jacquesson, some of which are used in this figure where the GRS was near the limb. The set of maps is also shown in **Fig.4** (circularised to measure the GRS circulation) and in an animation (**Supplementary Movie**). The series of images is continued in **Fig.S6.***

Figure 9. Images of the GRS region in 2014 April, spanning the time of HST imaging on April 21, with STBn spots tracked. Chris Go's image coincided with the first HST image set. (South is up. For lat. & long. charts of these spots, see Fig.S2B.)

Figure 10. ZDPs for spots in the SEBs and STropZ, 1999-2014, with the Cassini ZWP [Porco et al., 2003] for comparison. Reproduced from our final reports posted for these apparitions (inc. Fig.8 of our 2010 Report no.22). In general, red colours denote white spots and blue or black denote dark spots; green denotes certain anomalous dark spots. For full colour keys see the original reports.

Although most spots lie close to the Cassini ZWP, some groups of SEBs jet spots between ~20.5 and 22 S lie above and right of the ZWP: i.e., they lie further south or retrograde faster than expected from the ZWP). Usually these are oval vortices (the oval in (A) indicates the typical latitudinal extent in Cassini images); also the first SEBs spots in the 2007 SEB Revival; and, most egregiously, the dark spots in the 2010 SEB Revival. (In 2010 and 2011/12 there were also wave-trains on the SEBs, which had much slower retrograding speeds of ~+70 deg/mth and +39 deg/mth respectively.)

Supplementary Figures

Fig. S1. STBn jet spots, 2013/14: ZDPs broken down by months.

Fig. S2. STBn jet spots, 2013/14: Tracks for individual spots, in longitude and latitude. (Similar analysis was performed for all 66 spots in the outbreak.)
(A) Tracks for 4 well-tracked spots. These are examples in which the latitude decreased steadily, then increased suddenly as the spot passed the GRS; the first two also showed deceleration as the spot passed the STB Ghost.
(b) Tracks for 4 later spots, which were near the GRS at the time of the HST imaging on April 21. (See **Fig.9** for the images. These spots were late in the apparition so were not tracked as thoroughly as earlier spots; they are included in **Table 3** but not in other charts. Tracks for d62 and d63 were not well enough determined to include.) Like the earlier spots, most of this group had latitude decreasing steadily, then, if tracked to the GRS, increasing sharply.

Fig. S3 = Table 4. STBn jet spots, 2013/14: Table of conjunctions of STBn jet spots with the GRS, showing the temporary increase in latitude and speed during the passage.

Fig. S4. Images showing STBn spot d19 passing the GRS.

Fig. S5. Images showing STBn spot d41 passing the GRS.

Fig. S6. SEBs jet spots in 2014, approaching and encountering the Red Spot Hollow.