Jupiter in 2019: Report no.6

John Rogers (2019 June 26)

Opposition was on June 10, and observers in the southern hemisphere and tropics have been producing superb images. I hope to include some images with satellite transits in a later report. Attention has mainly focussed on the Great Red Spot (GRS), where remarkable phenomena have continued, and that will be the main topic in this report. But first, here is a recent global map (Figure 1), and some examples of multispectral image sets covering infrared continuum, methane band, and ultraviolet, as well as visible colour (Figure 2). Reddish areas are dark in UV and this emphasises the great coloration of the Equatorial Zone as well as the GRS.

Juno's Perijove-20 was on May 29, over some of the less disturbed longitudes of the planet, and we have posted a report as usual on the 'Results from Juno' pages. The figures include amateur images: a gallery of images of the track in late May, a global map for May 28-29, and a series of maps of the NNTB, showing how a dark segment of the NNTB started to 'break up' within days of the fly-over.

Juno's Perijove-21 will be on July 21, and it will fly directly over the GRS and also over White Spot Z, the long-lived anticyclonic white oval in the N. Tropical Zone. Although the views will be oblique due to the orientation of the spacecraft's orbit, we hope for some images of both ovals.

Continuing disruption of the GRS

The 'shredding' of the GRS continues to be of great interest. It is now clear that the red, methane-bright 'flakes' or 'blades' are induced at the f.(W) end of the GRS by rings (vortices) from the SEBs jet that enter the Red Spot Hollow (RSH) at its p.(E) end. Sometimes the disturbance tracks round the S edge of the GRS to produce a flake at the p.(E) end as well. So far, as we can tell, the flakes appear simultaneously in RGB and the methane band. (This is shown in sets of images covering the origin of the flakes on April 16 (see Fig.10 from our Report no.4) and May 14-15 (Fig.1 from our Report no.5, plus methane images not yet posted). Often the methane image only shows a bright bulge where the flake is attached to the GRS, because of the limited resolution in that waveband, but it supports the view that this is material coming from the GRS, not emerging from elsewhere.

This activity was described in our 2019 reports nos.1-5, along with a summary of previous examples. It is now being documented thoroughly by Clyde Foster, Shinji Mizumoto, Marco Vedovato, Andy Casely, and Anthony Wesley, from images by themselves and other observers; and with measurements by the ALPO-Japan (Kuniaki Horikawa) and the JUPOS team. They will produce a full account in due course, and I thank them all for their contributions to this report. Meanwhile, the **Table** below summarises all the events from 2019 Jan. to May, with numbering by this team. Both Shinji and Marco have produced long animated series of maps which show these events. Their latest animations are at:
http://alpo-j.asahikawa-med.ac.jp/Latest/j_Cylindrical_Maps/j19_Maps_Animation_GRS.htm
http://pianeti.uai.it/index.php/Jupiter:_2019_Animated_gif

Despite the clear link with incoming SEBs rings, the size of the flakes produced has been unpredictable. They had modest sizes early in the year, then three large ones were produced in

April and May which later emerged at the p. end of the GRS as well; but a few incoming rings, notably the latest on June 2, produced little or no visible flaking.

The events are numbered in the **Table**. One event described in our Report no.4 has now been recognised as two, nos.4 & 5. The pair of SEBs rings that entered the Red Spot Hollow (RSH) on April 12 & 15 (event no.4) induced a flake at the f. end on April 15-17, accompanied by the very dark grey collar that spread round to the p. end by April 22. As this extended p. the GRS, a red streak was detectable within it on April 25, and we now suggest that this was part of event no.4. Meanwhile (event no.5), a small ring entered the RSH on April 24 and probably generated a feeble flake at the f. end on April 30 that was not well separated from the GRS; but this seems to have given rise to the notable flake p. the GRS on May 6. The next event (no.6) was the major one that developed from May 13-23, as described in our Report no.5. Then there was a similar large event from May 22-30 (no.7) (Figure 3), in which a SEBs ring again induced a major flake at the f. end which then propagated round and emerged impressively at the p. end. From May 22-30, the GRS looked quite extraordinary!

The huge flakes p. the GRS from May 22-25 onwards and from May 30-June 1 onwards have produced persistent red methane-bright features prograding in the dark S. Tropical Band, including streaks of various lengths, and at least two reddish rings that are likely to be anticyclonic vortices. Drift rates for these will be determined in due course.

GRS flaking events, 2019

	SEBs ring enters RSH	*(a) Flake appears at N/W = f.end*	*(b) Flake appears at E = p.end*	*Notes*
1	Jan.21&24	Jan.25	--	
2	Feb.8	Feb.9-12	--	Small event, imaged at PJ18.
3	Mar.23	Mar.27	Apr.1	
4	Apr.12&15	Apr.15-17	[Apr.22]*	Large event. *Very dark grey collar, emerging on p. side Apr.22, with red streak in it by Apr.25.
5	Apr.24	Apr.30	May 6	Small ring, small flake, but notable flake p. GRS from May 6.
6	May 13	May 17	May 21-23	Large event.
7	May 22	May 25-26	May 30	Large event; 7a connected to 6b.

After the end of May, things took an unexpected turn. The next ring entered the RSH on June 2, but it did not induce a flake; instead, it appeared to have been at least partly diverted northwards, through the white rift in SEB(N) that appeared at the northern point of the RSH on June 3 [see **Box 1**]. Observers (putting north up) have taken to calling this the 'chimney', and Shinji's animated maps suggest that the ring was partly diverted 'up the chimney'.

The very dark STropB emerged on the p. side of the GRS in mid-April, elongating rapidly as its p. end prograded, and is still prominent. On its S side, approximately in the latitude of the STBn jet, there have sometimes been striking chains of dark spots – looking like wave-trains – on May 5-6, May 22-23, June 3-4, and June 18-25 (Figure 4). On those dates, a red flake was appearing or had recently appeared at the p. edge of the GRS (**Table** column (b)). So I propose that the wave-trains, which extended ~12-36 deg. longitude p. the flake, were formed by instability on the prograding STBn jet, where the jet squeezed past the GRS and then opened out on the p. side. The constriction and instability of the jet could have been enhanced both by the flake disturbance moving around the periphery of the GRS, and by the presence of the STB Spectre alongside the GRS, which embodies a faster sector of the jet (Figure 5).

Box 1: The rift north of the GRS.

Sometimes the dark rim of the RSH is broken by a white 'rift' which curves NE into the northern SEB. (This rift also manifests itself during SEB Fades as an intermittent white spot [ref.1].) At ground-based resolution it is usually difficult to determine whether spots are drawn into it from the RSH, but the Bilbao group have reported that this happened with one large oval that had entered the RSH from the STropZ [ref.2].

An analysis of this white spot or rift N of the GRS, from ALPO-Japan records over many years, was presented by Kuniaki Horikawa at the RAS-Juno workshop in London in 2018 May [ref.3]. He showed that it only appears at a certain phase of the 90-day oscillation, when the GRS has more positive drift, up to the time when it has maximum longitude, then the w.s./rift disappears again.

Indeed, according to the charts by ALPO-Japan and JUPOS, the GRS adopted more positive drift around 2019 May 19 as expected within the 90-day oscillation, and the w.s./rift opened up on June 3. So the events were nicely consistent with previously reported behaviour.

The rift was also 'open' in late March, but did not prevent the formation of a flake then; but it is not surprising if there is a random element in the fate of these SEBs rings. Jupiter's atmosphere is always a balance between chaos and order, and apparently deterministic phenomena commonly arise from a series of random ones.

References:

1. Rogers JH (2017) 'Jupiter's South Equatorial Belt cycle in 2009-2011: I. The SEB Fade.' JBAA 127 (3), 146-158.

2. Sanchez-Lavega et al.(1998), Icarus 136, 14-26: 'Dynamics and Interaction between a Large-Scale Vortex and the Great Red Spot in Jupiter'.

3. Horikawa K (2018), 'On the Periodic Rifting in GRS Bay': https://www2.le.ac.uk/departments/physics/people/leighfletcher/ras-juno-europlanet-meeting-2018

The STB Spectre is currently passing the GRS, although indistinct (Figure 4). Its p. end is not clearly visible; I suspect it is at L2 ~ 280 (L3 ~ 253) (June 20), but this sector is confusing with the complex disturbances on the STBn/STropBand (prograding) and in the STZ (slow-moving in the 'tail' Sf. oval BA). Its probable f. end has become rather more visible, in RGB and methane, at L2 = 7 (L3 = 339) (June 20).

After June 2, there were no more rings on the SEBs for some distance; it would be three weeks before the next one arrived. So the GRS had an opportunity to settle down, and indeed it did resume its oval form and recovered slightly in size. However, unexpectedly, a new red, MB flake was recorded at the p.(E) end of the GRS on June 17 (Figure 4) --not initiated by anything we knew about! It was then followed travelling round the N side, becoming a flake on the NW side on June 20. I wonder if this indicates that residual disturbance from previous events is still travelling around the edge of the GRS.

The next SEBs ring should have arrived at the edge of the RSH on or around June 23, but had dwindled to a small size so may have dissipated. Another one has just arrived on June 25.

During all this 'unravelling', the GRS has been notably reduced in size. Its length has been measured by the JUPOS and ALPO-Japan teams (Figure 6)*. K. Horikawa said: "As result of flaking, GRS is shrinking more and more. It's amazingly small in Chris Go's images on June 1. I got 11.3 deg. for its size. It's the minimum record of GRS in not only my measurements since 2002 but also probably its life." According to Andy Casely it lost ~2000 km in length between

May 15 and June 1 – and also lost ~500 km in width. It reached a minimum in late May-early June with a mean length of only 12.1 deg (as low as 11.3 deg in a few images), but has recovered slightly to ~12.4 deg in mid-June. (1 deg.long. = 1165 km; 1 deg.lat. = 1122 km.) It has also been reduced in width (with no significant change in its central latitude) (Figure 7).

*The latest length charts by K. Horikawa and by M. Vedovato are at:
http://alpo-j.asahikawa-med.ac.jp/kk19/j190624r.htm
http://pianeti.uai.it/index.php/Jupiter:_2019_Animated_gif

Around the N edge of the GRS, on May 25-29, a thin red methane-bright line connected the large flake at the p. end (no.6b) to the new flake on the N side that grew into the large one at the f. end (no.7a) (Figure 3). This tenuous line, now greyish, has persisted ever since, running between the borders of the GRS and the RSH.
Around the same time, 'warm grey' shading developed in the RSH and in the STropZ just p. it, becoming notably darkened by mid-June. The nature of these shadings is unclear.

As the GRS has shrunk, we speculated that the thin line around the N side might mark its original outline; but this is not the case. Latitude measurements show that the thin line is further north than the original GRS north edge (Figure 7).

Nevertheless, it has still not been determined whether the GRS circulation has shrunk, or only the red/methane-bright cloud cover. It seems possible that some of the 'shredding' represents white clouds moving in rather than red clouds moving out (although, of course, considerable red clouds *are* moving out as they extend E and W out of the GRS). As the outline of the RSH marks the course of the SEBs jet around the GRS, the fact that it has not moved south is evidence that the circulation of the GRS has not changed dramatically (as Andy Casely and Clif Ashcraft have noted). It is possible that the circulation has not changed much but the red cloud cover has been disrupted, perhaps only at the surface.
This question will be best addressed by wind speed measurements from Hubble (which is due to take images on June 26 in the OPAL program), and perhaps from Juno (which will fly over the GRS at PJ21 on July 21, although the images will be taken obliquely).

It is worth bearing in mind that most of these events are invisible or unremarkable in images of modest resolution (e.g. by Paul Maxson – Figure 2b); they just show a dark collar forming around the GRS, and the S. Tropical Band or streaks emerging p. it, which are familiar phenomena from previous decades. Therefore, it is still possible that many such events have been missed in the past. Although no such feature was recorded in Hubble images from 2014 to 2016, we still need to check whether those images were taken at times when SEBs rings had entered the RSH. We have already noted a few previous examples of flaking from the GRS (see Report no.4), including one during the Voyager 1 flyby, and another has now been found during the Cassini flyby [see **Box 2**]. So such events were not as rare in the past as I thought. But also, it's satisfying to see that the flake in the hi-res Cassini sequence was induced exactly as proposed in the model in Figure 1 of Report no.5.

Box 2: A previous flake event in the Cassini data

Björn Jónsson has posted a series of images from the Cassini flyby in 2000, showing the origin of a 'flake' from the interaction of a SEBs ring with the GRS, exactly like the recent events. He says:

"I decided to check the Cassini images and found an interesting sequence of images that I processed and posted in a Cassini Jupiter PDS thread at the Unmanned Spaceflight forum:

http://www.unmannedspaceflight.com/index.php?showtopic=1222&pid=244961&mode=threaded&start=#entry244961 (In case this thread shows up with a strange/confusing layout, it's one of the most recent posts in the thread.)

"To me, the visual appearance of the GRS/RSH in the MT3 and enhanced color images strongly implies that in the Cassini images, orange/reddish material is flowing from the GRS. Visually this looks comparable to recent events - the effects look less pronounced though."

Figures (miniature copies):

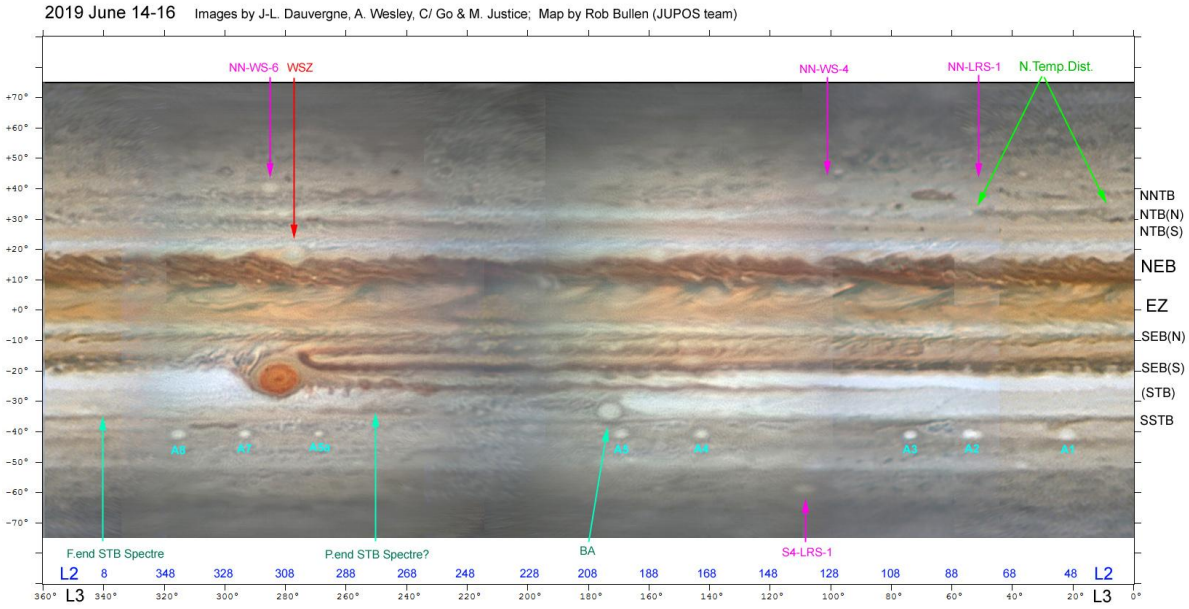


Figure 1. Map of the planet on 2019 June 14-16, with long-lived features labelled. North is up in all figures unless otherwise stated.

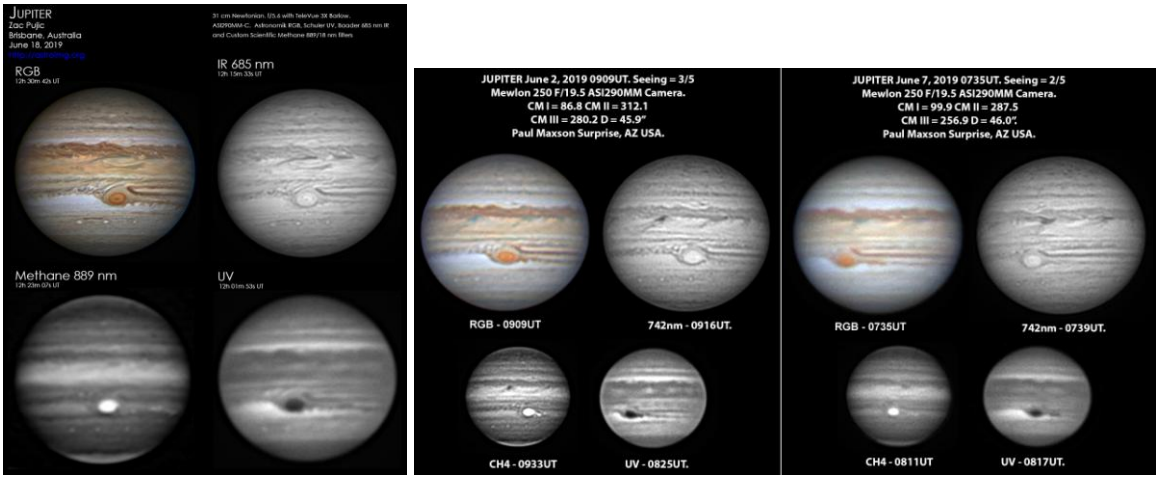


Figure 2. Examples of multispectral image sets: (a) from Zac Pujic; (b) from Paul Maxson.

Figure 3. Excerpt from the comprehensive series of maps made by Shinji Mizumoto and posted on the ALPO-Japan web site. *South is up in these maps.* These, on May 25-26, show a large red methane-bright flake being stretched out p. the GRS (red arrow: no.6b), while it is also connected by a thin line to a new flake that develops on the N edge (no.7a, on the trailing side of a SEBs ring that has travelled around the Red Spot Hollow to the f. end: blue arrow). The next SEBs ring is approaching (blue arrow).

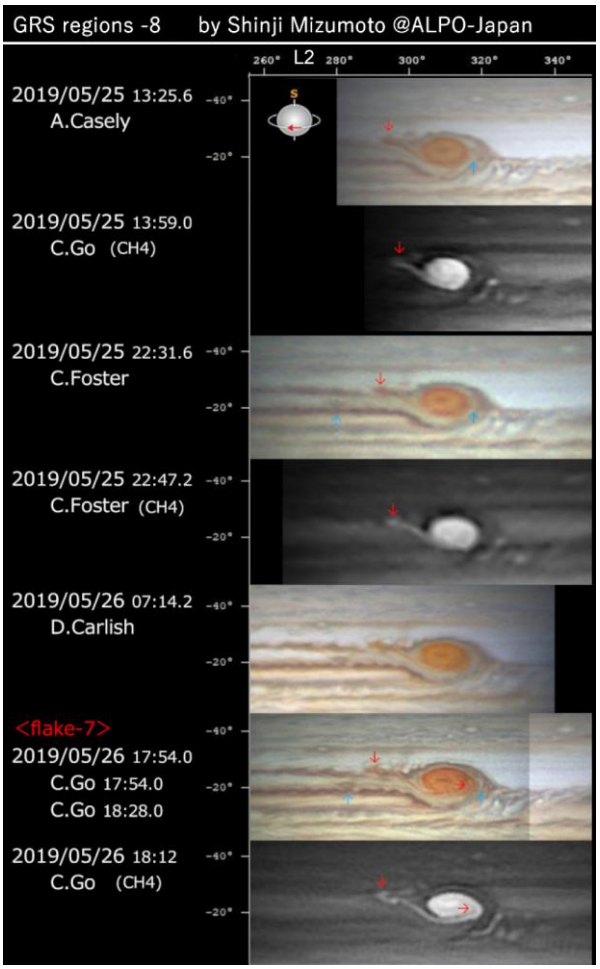
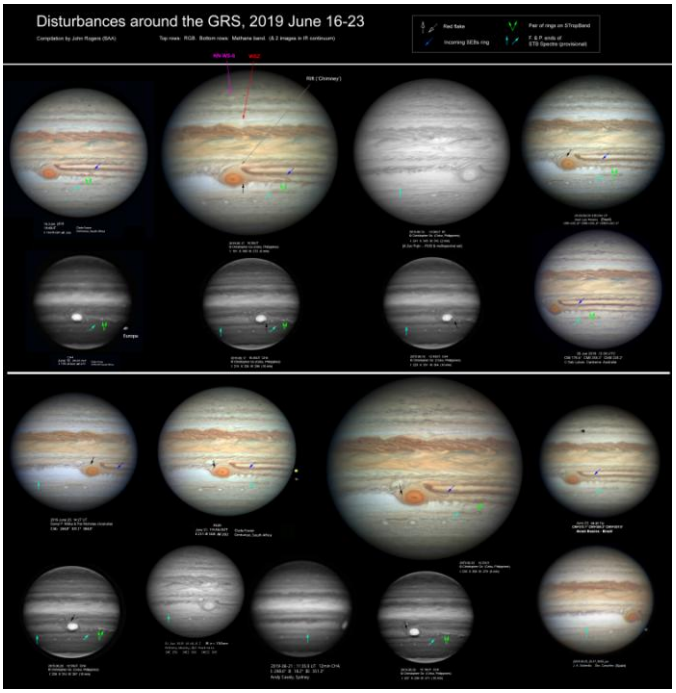


Figure 4. Set of images of the GRS region from June 16-23, in colour (top rows) and methane band (bottom rows) plus two IR continuum images. On June 17, a new red flake appears at the p. end of the GRS, then circulates round the north side to the f. end (black arrows). Meanwhile, a chain of dark spots (waves) develops on the S edge of the S. Tropical Band p. the GRS. The suspected ends of the STB Spectre are marked by bright cyan arrows.



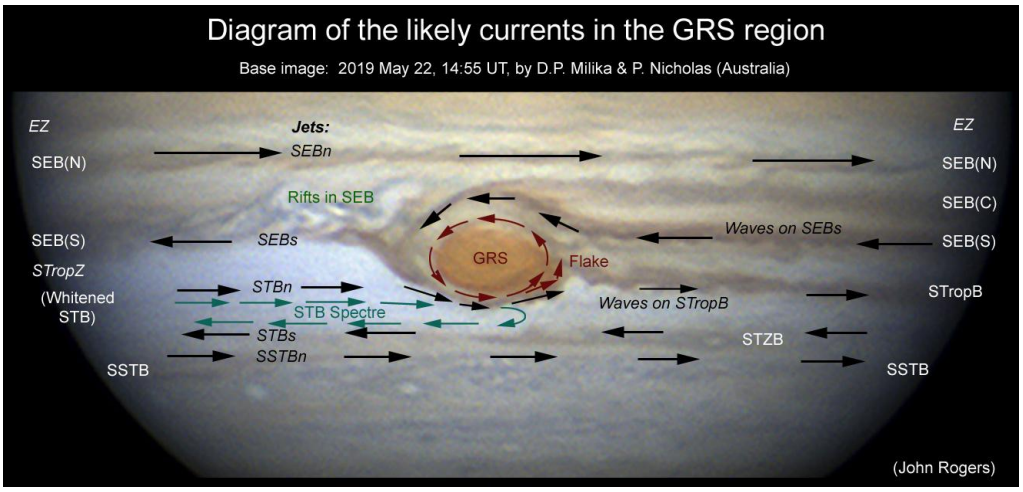


Figure 5. Diagram showing the likely arrangement of currents around the GRS. (Arrows are not scaled to wind speeds.) The base image from May 22 was shown in Fig.2 of Report no.5.

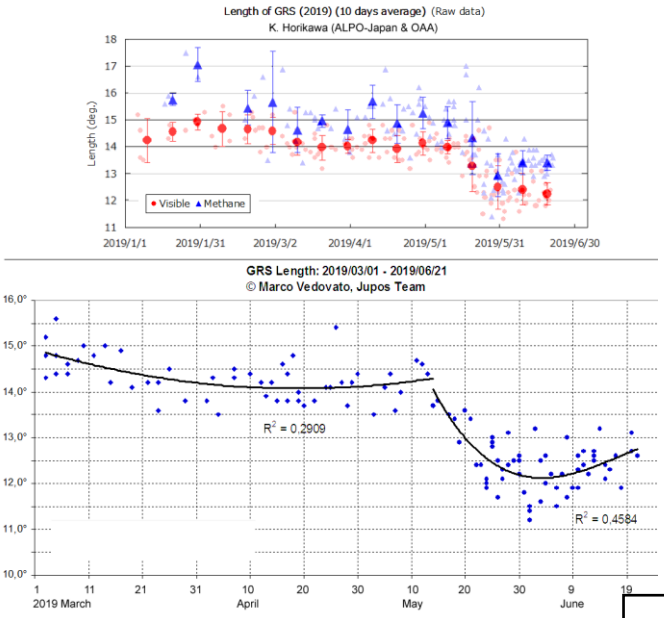


Figure 6. Charts of the length of the GRS, done independently by Kuniaki Horikawa (ALPO-Japan data) & Marco Vedovato (JUPOS data).

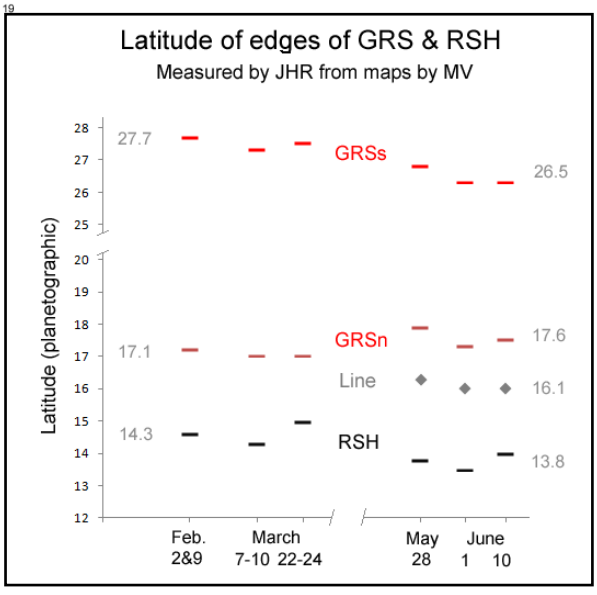


Figure 7. Chart of latitudes of the S and N edges of the GRS, and the lowest part of the RSH, and the thin line between them. *(South is up.)* Each measurement is the average from two maps. Numbers at the sides are averages for the Feb-March and May-June measurements respectively.