Jupiter in 2023/24: Report no.1

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[Updated version, 2023 Nov.27]

Summary

With Jupiter currently at opposition (2023 Nov.3), and many hi-res images being produced by observers in the northern hemisphere, it is timely to summarise the state of the main regions of the planet. Jupiter's atmosphere appears quite quiet and normal at present, with no large-scale dramatic activity, and only minor changes since 2022. The most obviously active region is the NEB, where typical disturbances have resumed, both within the belt and along its south edge. The GRS is notable for its record small size. Here we show images, maps and charts that illustrate these and many other phenomena.

Most of this report concludes in early November; the JUPOS charts date from early October. A preliminary version was posted in mid-November. This final version has been updated to include three relevant developments: (1) Another impact flash, on Nov.15; (2) Measurements of the speeds of the SEBs wave-trains; (3) Close encounter and probable merger of the the two S4 anticyclonic ovals, Nov.15-21.

Impact flashes

An impact flash was recorded on August 28 at 16:46 UT by several Japanese observers: T. Ishibashi, S. Ota, and T. Ohsugi (Figure 1). M. Morita visually witnessed it on the monitor between shootings. Thanks to Isshi Tabe and Marc Delcroix for spreading the word about it. It was at 45°N.

Another such flash was recorded on Nov.15 at 12:41 UT, again by Japanese observers: K. Suzuki, T. Arakawa, K. Yamada & O. Inouye. It was at 6°S. This was the eleventh such fireball recorded in 13 years. In all cases, there was no visible remnant.

Ricardo Hueso comments that Japanese amateur observers are being particularly efficient in finding these events, and if there was equally good coverage around the world, the rate of detections might be severalfold higher.

Introduction

This report is based on amateur images unless otherwise stated, and we are very grateful to all the observers who contributed images, including many in the international databases and in Facebook groups. Some of the many excellent images are shown in Figures 2-4.

Our reports on JunoCam images have already included brief comments and ground-based as well as JunoCam maps, at PJ52 (June 23), PJ53 (July 31), PJ54 (Sep.7), and PJ55 (Oct.15). More ground-based maps are posted here as Figures 5-7 [Aug.21-22; Oct.10-11; Oct.30-31; all by Rob Bullen]. These maps are produced every ten days or so by Rob Bullen, using some of the highest-resolution images, and including polar projections (not shown here).

> **Animation-1** shows a blink of part of Rob Bullen's Oct.10-11 map with Simon Labergere's map, from his own images 1 to 3 jovian rotations later (taken with an 80-cm telescope on the Mont d'Arbois in the French Alps); this shows the global wind patterns very clearly.

Maps are also produced every 1-3 days by Shinji Mizumoto and posted on the ALPO-Japan web site: https://alpo-j.sakura.ne.jp/Latest/j_Cylindrical_Maps/j_Cylindrical_Maps.htm Scanning through these maps is an easy way to follow rapid changes on the planet.

Charts from the JUPOS team are included here to show the drifts of features in the principal domains. A notable aspect is that the JUPOS charts all show numerous small dark spots that move more slowly than the main spots in the domain, retrograding in some domains. These are evidently influenced by the retrograding jet in the middle of each domain.

This item follows on from our 2022/23 reports nos.6 & 8. Our usual abbreviations and conventions are used. P. = preceding (east), f. = following (west). Longitudes are plotted in L3 unless otherwise stated, but drift rates are generally given in L2 (DL2, deg/30d). DL3 = DL2 + 8.0 deg/30d. Latitudes are planetographic. North is up in the figures unless otherwise stated.

N.N. Temperate (N2) domain & jet (Figure 8 = JUPOS chart)

The three long-lived ***anticylonic ovals*** have not drifted much in L3 this apparition, except that NN-LRS-1 accelerated at the end of August. NN-LRS-1 again has a distinctly reddish patch inside it. A dark ***NNTB*** currently exists around about half the planet; the other longitudes are largely occupied by FFRs. The JUPOS chart shows many small retrograding spots in the domain, as in 2022; now they are especially f. WS-4, and could be arising from the FFRs that exist both p. and f. it.

The long-term outbreak of ***NNTBs jet spots*** has continued, but now seems to be declining. JUPOS has still tracked many dark spots in the jet, but in images they appear sparser and smaller than before, especially since September.

N. Temperate (N1) domain & jet

The NTB is virtually absent. This state could lead to another spectacular NTBs jet outbreak with consequent NTB revival; the last was in 2020. They have historically occurred at 5-year intervals, but recently the interval has shortened to 3.9 years between 2016 and 2020 [ref.1]*. To predict whether there will be such an outbreak, in 2024 or 2025, or whether the series has stopped, it would be useful to know the present speed of the NTBs jet. It has been too featureless to measure from ground-based images recently, but a zonal drift profile from James Webb Space Telescope images in 2022 July has just been published [ref.2]*. Although this was derived from IR images, they were probably sensing the main cloud-tops. The peak speed of the NTBs jet was $u_3 \approx 143$ m/s, which suggests that it is indeed accelerating up to another NTBs jet outbreak, which could be in 2024 or 2025.

*1. Rogers J & Adamoli G (2021) 'Jupiter in 2020, Report no.9: Final report on northern hemisphere'. https://britastro.org/section_information_/jupiter-section-overview/jupiter-in-2020/
*2. Hueso R et 20 al.(2023) 'An intense narrow equatorial jet in Jupiter's lower stratosphere observed by JWST.' Nature Astronomy, https://doi.org/10.1038/s41550-023-02099-2.

North Tropical domain (Figure 9 = JUPOS chart)

The slow, undramatic revival of the NEB is essentially complete. There was only minor progress during solar conjunction (as illustrated by maps in our PJ52 report, Fig.3).

By July, the belt appeared fairly normal, except that the faded barges were mostly still lighter than the surrounding NEB. However the contrast was reduced as they have been very gradually darkening; 3 to 5 of them can still be discerned but they could be on the way to dissolving into the NEB. Also, one new dark barge (L3 = 215) had already formed at PJ52. Four the former 6 AWOs remain (white spots B, C, E & Z).

The JUPOS chart also displays many tracks for short-lived dark features running from L3 ≈ 280-->360-->20 in Aug. & Sep. The mean speed of the 6 best tracks was DL2 = +15 deg/30d (±4, SD; range +10 to +21). These were dark NEBn projections or waves retrograding f. WS-Z, which have often been seen before though in smaller numbers. They are also shown in the JunoCam image in Figure 12. As there were no turbulent sectors in the NEB, they probably resulted from instability of the retrograde NEBn jet downstream of WS-Z.

During the NEB's fade and revival in 2021-22, there was no rifting in the belt except in the dark NEB(S), until 2022 Dec. when a pair of bright outbreaks occurred within the belt [see our 2022/23 report no.5]. There was no further mid-NEB rift activity in 2023 June to Sep., then on Oct.8 a small bright white spot appeared at ~12.5°N on the Sp. corner of the longest faded barge (at L1=240), and intensified rapidly (although it was only modestly bright in the methane band). Its development is shown in Figures 10 & 11, and JunoCam approach images on Oct.15 (PJ55: Figure 12). It evolved into a classic rift, drifting at a rate intermediate between L1 and L2, and extending white streamers in the Sp. and Nf. directions, and sometimes renewing its very bright white core (e.g. Oct.22-23).

On Oct.12-13, a northerly streamer wrapped cyclonically around the N side of the faded barge, and its tip became an anticyclonic eddy as it extended into the NTropZ. This eddy or ring initially retrograded along the N side of the faded barge, then reversed its drift and prograded. On Oct.25, as the rift was passing the dark barge at L3 = 215, another streamer wrapped around that cyclonic feature. It looked remarkable in methane-band images around that time (Figures 10 & 11).

Small bright spots continue to appear in the NEB(S), esp. in a dramatically active sector of NEBs/EZn that has been notable at least since early Sep. (Figure 10). It exhibits many of these brilliant little outbreaks, and conspicuous, rapidly varying NEBs dark formations. This sector covered approx. L1 ≈ 50-130 (early Sep.), extending to L1 ≈ 50-150 (late Oct.).

Some of these small white eruptions in NEB(S) were noted as methane-bright, as in 2022 -- remarkably so as the surrounding southern NEB is itself still methane-bright, even though it is no longer strongly reddish. Two examples are shown in Figure 13. The second of these, which had started on Sep.18-20, was particularly impressive as it became exceptionally bright and methane-bright on Sep.26-27 [L1 ≈ 70] and then broke southwards through a blue NEBs dark formation. There are other examples in the ALPO-Japan maps, including one on Oct.13 in Figure 10.

Equatorial Region

NEB(S)/EZn: There are now typical NEBs dark formations all around the planet, mostly with drifts in L1 varying from near-zero to slightly prograding. They are especially prominent in the active sector noted above.

The EZ is now normal, off-white with many faint streaks, not very bright nor coloured.

SEBn jet: The JUPOS chart of the SEBn (not shown here) shows that most of the numerous chevrons have speeds of DL1 ≈ -34 to -54 deg/30d at all longitudes, similar to the range in the last two years. There is still a short gap, indicating that the putative S. Equatorial Disturbance (SED) is still present, with DL1 ≈ +30 deg/30d, as last year. However, in images

it has no distinctive structure apart from the lack of chevrons – except since Oct.28 when Miyazaki's images show a small but typical SED rift structure (Figure 14).

S. Tropical domain

The Great Red Spot (GRS) has continued to shrink and is now the smallest it has ever been (Figure 15A). The GRS was at L2 = 44 (L3 = 73) on Oct.1. Its drift rate has recently become more positive again (Figure 15B). In fact, this chart suggests that it is oscillating with an imprecise period near ~1 year, superimposed on the usual 90-day oscillation. The drift rate DL2 has been as follows, according to this chart in agreement with our previous reports:

2020 Jan-Dec.	+2.3 deg/30d	
2021 Mar-Sep.	+1.2	[previously given as +1.35]
2021 Sep - 2022 Dec.	+1.8	[previously given as +1.75]
2022 Dec - 2023 Aug.	+1.3	
2023 Sep-Oct.	(~ +2.0?)	

Some images show internal structure in the GRS. Figure 4 shows hi-res images of the GRS at intervals of ~20 hours; the internal structure is too variable to show the rotation reliably, but narrow dark grey streaks can be tracked passing along the deflected SEBs and STBn jets just outside the GRS. Images on Oct.30 from Enrico Enzmann's 80-cm telescope were processed by Damian Peach to give an animation which clearly showed the rotation of the GRS (not shown here). Some flaking events have been observed [e.g. Oct.8 (Casely, Casquinha, Peach) & 12 (Miyazaki)] , though there are none in Figure 4.

The SEB rifted sector just f. the GRS is quite active; white plumes are always present and often methane-bright. For instance, in August, strongly methane-bright plumes were recorded on Aug.7-8, 13-15, 20-22, and 29-30. In October, they were recorded on Oct.7-8 and 26-29, then on Nov.5-6 (on some of these dates there were pairs, e.g. Figure 4).

SEBs jet: There have been quite a lot of retrograding rings with DL2 ≈ +4 deg/day, especially a series of five that approached the GRS from mid-Sep. to mid-Oct.

There have been two examples of wave-trains on SEBs, similar to those we have reported in some previous apparitions with phase speeds less than the retrograding speed of the jet [ref.3]*. The first was visible in hi-res images in 2023 Sep. in the sector p. the GRS (e.g. Figure 2B), ahead of a SEBs ring, at the f. end of the dusky band in STropZ. These waves were entering the Red Spot Hollow around Sep.20. The second such wavetrain appeared from about Oct.4 onwards at lower longitudes, emerging around L2 ≈ 130 out of the turbulent region downstream of the SEB rifted region. It was unusual in its long extent (up to ~70° long.) and its high-contrast appearance (Figure 3 & 14). It was also conspicuous in 5-micron images from the NASA IRTF on Oct.16 (G. Bjoraker, personal communication). Its mean wavelength was 3.8° up to Oct.19, but longer (~5°) for waves emitted in late Oct.

*3. Rogers JH, Fletcher LN, Adamoli G, Jacquesson M, Vedovato M & Orton GS (2016). 'A dispersive wave pattern on Jupiter's fastest retrograde jet at 20ºS.' Icarus 277 (2016) 354–369. http://dx.doi.org/10.1016/j.icarus.2016.05.028

We have measured the wavelength and phase speed for parts of the wave-train in October, as listed below. These values lie fairly close to the relation established previously [ref.3], though slightly offset from it, and extending to shorter wavelengths.

No.	Wavelength (deg)	DL2 (deg/30d)	DL2 error	u_3 (m/s)	Dates
1	5.4	81	±7	-40.5	Oct.18-23
2	3.7	100	±1.5	-49.2	Oct.16-26
3	4.8	93	+20/-5	-46.0	Oct.23-30

The wave-train seems to have stopped emerging around Oct.26, but it has continued to retrograde on the SEBs, and has grown even longer. In late Nov. it is ~120º long (Figure 20) – still with a wavelength of ~3.7º in the leading (higher-longitude) part, and ~5º in the trailing (less regular) part – and the leading edge is almost at the Red Spot Hollow.

S. Temperate (S1) domain & jet (Figure 16 = JUPOS chart)

STBn (S1) jet: There are still many dark spots emerging p. STB segment G in the STBn jet; they continue past STB spot 8. There are also some alongside segment A, which may be arising there; these do not pass oval BA.

Oval BA was conspicuous, white with a dark rim, from June to early August, but then it became duller and lost its rim, so from late Sep. onwards it has had virtually no contrast. However, the reddish internal oval has again been faintly visible in v-hi-res images, esp. recently as it is passing the GRS (Figure 4B). Its drift decelerated during solar conjunction and from July 1 to Aug.31 it was moving more slowly than it has for several years, DL2 = -14.3 deg/30d; but then it suddenly accelerated to -20 deg/30d as it approached the GRS.

Spot 8 turned white during solar conjunction and is now a white oval in an oblique, pale bluish-grey sheath (e.g. Fig.2B), just like previous quiescent cyclonic circulations such as the STB Spectre. There is still a tiny cyclone ~20° p. it in JunoCam maps, but barely visible in amateur maps. Both spot 8 and this cyclone are methane-dark (e.g. Fig.3, & JunoCam maps).

There are two long ***dark STB segment***s: segment A, 105° long, and segment G (formerly DS7), 55°--> 60° long (Figures 5-7). Both are visibly turbulent for part of their length. The spaces between them have become clearer this apparition, although still bordered by small dark spots at ~27.5-->25.5°S (STBn) and 31-->33°S (STBs).

Mean drifts from late June to early Oct. were all similar, as follows (DL2):

Segment G, p. end:	-19 deg/30d
Segment G, f. end:	-16
Oval BA:	-14 then -20
Segment G, p. end:	-19
Spot 8	variable (-13 to -17)

There are many small dark spots or streaks with slow or retrograding drifts f. segment A, and some f. segment G (Figure 16), at 31-33°S. While some of these drifts clustered around DL2 = +5 deg/30d, others ranged from DL2 = -17 to +15, and a few even had DL2 = +24.

S.S. Temperate (S2) domain (Figure 17 = JUPOS chart)

The 7 AWOs (A1-A5, A7 & A8) are still the most prominent features of this domain. Their speeds are typical of the SSTC, ranging from DL2 -26 to -34 deg/30d (mean = -30.0 ±3.2).

There are cyclonic white oblongs (CWOs) in two sectors. The CWO between A4 & A5 persists but has not grown longer since last year. Between A1 & A2, there have been two

CWOs separated by a smaller cyclonic white oval, making the whole sector appear off-white. One of these, p. A2, dated from 2022, it was less bright in 2022 Sep-Nov., but this sector has still been largely off-white throughout 2023. The other, f. A1, developed this year; this sector was reddish on June 4 (Miyazaki), and has been a CWO from early July onwards.

There are slow-moving dark spots f. A8 (and a few elsewhere), as in 2022/23. Speeds range from DL2 -19 to -9 deg/30d. Among them is a tiny AWO or ring, with DL2 = -19 in Sep., possibly emitted from a FFR a short distance p. A1, and converging on A1. On Oct.10-11 (Figure 6) it was in contact with the rim of A1, possibly about to merge. There is evidence for a similar example in July.

S4 domain (Figure 18 = JUPOS chart)

The most conspicuous feature in high southern latitudes is the reddish anticyclonic oval, S4-LRS-1 (Figures 3,19,20). This apparition it has been at 59°S and drifting with only very gradual change in speed from +3 to +8 deg/30d, similar to the slow drift of most of the small dark spots in the domain (DL2 = +10.2, ±1.6; N=6). Conversely S4-AWO-2, which appeared last year, has been at ~60°S and oscillating between moderately slow (e.g. DL2 = -6) and fast (e.g. -35) speeds. Notably, the chart suggests that it switched to slow speeds when it encountered small slow-moving dark spots. We have noticed this before in high-latitude domains, and suggested that fast drift was impeded by disturbed regions; but the FFRs and spots shown in the JunoCam maps from PJ52 to PJ54 do not obviously correlate with the movements of S4-AWO-2.

AWO-2 and LRS-1 were rapidly converging at 28 deg/30d during Oct. & Nov., so we anticipated a merger. Indeed, with little or no change in speed, they came into contact on Nov.14, and AWO-2 quickly swept along the south edge of LRS-1 on Nov.15 (Figures 18-20). On reaching the p. end, it may have split into two: possibly a short-lived streak which prograded (although this may have been an unrelated feature in the S5 jet), and a small spot which circulated anticlockwise (anticyclonically) around the edge of LRS-1 until Nov.21, thus probably merging into it. A JunoCam outbound image from Nov.22 (PJ56) is awaited.

We likewise recorded an encounter between S4-LRS-1 and an earlier (different) S4-AWO-2 in 2018, also imaged by Juno at PJ15. That time, the ovals rebounded, but probably went on to merge during solar conjunction [refs.4 & 5]*.

*4. Rogers J & Casely A (2018), 'Jupiter in 2018, report no.7: The S4 ovals rebound' https://britastro.org/section_information_/jupiter-section-overview/jupiter-in-2017-18/jupiter-in-2018-report-no-7-the-s4-ovals-rebound
[also see: 'Jupiter in 2019, report no.3']

*5. Casely A, Foster C & Rogers JH (2019), 'Hungry Little Red Spot? The approach and probable merger of Jovian S4 storms AWO-2 and LRS-1 in 2018'. EPSC Abstracts Vol. 13, EPSC-DPS2019-1130.

Meanwhile, a third AWO has appeared elsewhere in the domain (Figures 6,7,18).

Figures

Figure 1: An impact flash observed on 2023 Aug.28 from Japan. (The point flash was blurred by unsteady seeing.)

Figure 2: Some recent images from the UK, France, and other places north of 45°N, showing what good resolution can be achieved now that the planet has moved into the northern sky.
(A) Two images on Oct.6 (upper right) show a grazing transit of Ganymede then a transit of Io with its shadow. (This set was also posted as a BAA on-line news item.)
(B) Two v-hi-res images by Enrico Enzmann (Germany) with Damian Peach (UK), including Ganymede with features including the white polar caps and the bright ray crater Tros.

Figure 3: Hi-res images in October including a bright plume that initiated a rift in the NEB at the p. end of a faded barge; a wavetrain on the SEBs jet, beginning to retrograde past a dark red-brown barge in the SEB; and numerous STBn jet spots streaming past STB Spot 8. (Also see Figures 10-14.)

Figure 4: (A) Hi-res images showing the GRS, and/or moons in transit with their shadows, Oct.29—Nov.1, just a few days before opposition on Nov.3. They show three transits of Io on the SEBs, and one of Europa on the SSTB (Oct.31). (Further images of the satellite transits with shadows at opposition, and hi-res views of the satellites, are posted in Report no.2.) Bright ovals in the methane-band images include the GRS with oval BA due S of it and NN-LRS-1 due N of it.
(B) Cropped versions showing details in and around the GRS. Note that the first two images are nearly simultaneous and demonstrate the reproducibility of the smallest details as imaged by different observers. Thereafter the images are at intervals of two jovian rotations, during which dark spots and streaks inside the GRS would be expected to rotate by ~90° in position angle, but they seem to be too variable to track them in these images. However, two narrow dark grey streaks can be tracked passing along the deflected jets just outside the GRS: one to the S (STBn jet) and one to the N (SEBs jet in the Red Spot Hollow). Note oval BA just S of the GRS; it has very low contrast but a pale reddish interior oval is discernible.

Figure 5. Map of Jupiter on 2023 Aug.21-22, by Rob Bullen.

Figure 6. Map of Jupiter on 2023 Oct.10-11, by Rob Bullen (also posted in BAA news item).

Figure 7. Map of Jupiter on 2023 Oct.30-31, by Rob Bullen.

Figure 8. JUPOS chart of the N.N. Temperate (N2) domain. For clarity, only spots belonging to distinct tracks are shown.

Figure 9. JUPOS chart of the N.Tropical domain. For clarity, only the main tracks are shown.

Figure 10. Maps of the equatorial region, Oct.6-26, aligned in L1, made by Shinji Mizumoto. Note the new plume in NEB(S) at L1 = 240 on Oct.8 (white mark) and its subsequent development as a rift, and the ring in NTropZ that it induced (white arrow). The active sector of NEB(S)/EZn is on the right at L1 ~ 50-150.

Figure 11. Hi-res images showing the new plume in NEB(S) (green arrow in first image) and its subsequent development as a rift, and the anticyclonic dark spot or ring that it induced in NTropZ (dark maroon arrow 'ADS').

Figure 12. JunoCam images at PJ55 (Oct.15), processed by Gerald Eichstädt, showing the same features as in Figure 11. Magenta arrows mark the NEBn retrograde jet; note the wave structure downstream of White Spot Z. (In the methane image, diagonal lines and bright pixels are artefacts.)

Figure 13. Two examples of white, methane-bright outbreaks in the NEB(S), spreading into the EZ. (A) Aug.18. (B) Sep.27-30: an exceptionally bright outbreak in the NEB(S) active sector. The new, brilliant plume is arrowed. In methane it is very bright on Sep.27 at 01:43 UT, even on the already methane-bright NEB(S), but by 20:49 it has faded. On Sep.29 it is surging S across a NEBs dark formation, and on Sep.30 it is complex and again very methane-bright. Also note an older, very methane-bright plume in the EZ(N) on Sep.27, ~25° f. the arrowed one, and other tiny white spots appearing in the NEB(S) over these 4 days.

Figure 14. The SEB in October, showing the long wavetrain on the SEBs jet (white arrow in some images), which is retrograding past a dark barge. Numerous STBn jet spots are streaming across the scene. The last 3 images show the putative S. Equatorial Disturbance (SED), which was visually obscure up until then, now appearing as a rift in the SEBn (green arrow).

Figure 15. Charts of the GRS, by Shinji Mizumoto. (A) Length. (B) Drift (p. & f. ends, and the 'Chimney' and 'Hook' when present), in a longitude system moving with DL2 = +1.71 deg/30d.

Figure 16. JUPOS chart of the S. Temperate (S1) domain.

Figure 17. JUPOS chart of the S.S. Temperate (S2) domain.

Figure 18. JUPOS chart of the S4 domain. (This chart has been updated to Nov.24.)

Figure 19. Maps of the southern domains showing the encounter and probable merger of S4 ovals LRS-1 & AWO-2, Nov.7-24, aligned in L3, made by Shinji Mizumoto.

Figure 20. Hi-res images of the probable merger of S4 ovals LRS-1 & AWO-2, Nov.15-20. Some are the originals for maps in Figure 19, others are confirmatory images.
