Jupiter in 2020: Report no.4: Part II

John Rogers (BAA), including results from the JUPOS team. (2020 July 29)

Part I (Extended Summary) was posted separately.

Introduction & Acknowledgements

This report was largely completed by early July, and some additions have been made up to July 25, where indicated in italics.

This report covers Jupiter's atmospheric activity from 2020 February to June. It follows on from our report no.2 (about the S. Temperate domain) and no.3 (about the NEB and with a general overview of the planet). As usual, it is based entirely on amateur ground-based images apart from specific references to JunoCam images. More detail on the JunoCam images is in our reports on each perijove (PJ), on this site at: https://www.britastro.org/node/17650. This period included PJ25 (Feb.17), PJ26 (April 30), and PJ27 (June 2).

Results are included from the JUPOS team (Gianluigi Adamoli, Rob Bullen, Michel Jacquesson, José Luis Pereira, Marco Vedovato & Hans-Jörg Mettig), who produced a comprehensive set of charts up to June 21. Annotated copies of these charts are attached as **Appendix 1**. Note that they are oriented with longitudes increasing to the right, for alignment with maps with south up, and thus inverted relative to the illustrations in the main report, which all have north up.

As usual, this report mostly uses System II longitude (L2), although L3 scales are given on maps for compatability with spacecraft data, and L1 is used for the equatorial region. Drift rates in L1 or L2 (DL1, DL2) are given in degrees per 30 days (deg/mth). DL3 = DL2 + 8.0 deg/mth. P. = preceding (east), f. = following (west). Latitudes are planetographic.

I'm very grateful to all the observers who contributed images, whether they are shown here or not; and especially to the observers in the southern hemisphere and the tropics (Australia, Brazil, the Philippines and South Africa), whose assiduous imaging was essential.

Animations-A & B are blinks of pairs of images 20 hours apart, showing the jetstreams.
Figure 1 is a map of the planet on June 21-22 (already posted with the Extended Summary).
Figure 2 is a map on July 19-20.
Figure 3 presents maps on July 3-4 in colour (RGB), methane (CH4), near-IR continuum, and false colour with methane and UV.

Images in the methane absorption band at 0.89 μm have been particularly interesting recently; some were shown in Report no.3, and galleries of them are provided in **Supplementary Figures A & B**. More methane images are presented in **Part III**, covering the remarkable new wave system in the EZ, and **Animation-D** compares them with RGB images.

North Polar Region

N5 domain: One white oval has been tracked exceptionally far north, at 62-64ºN, and it may be the same N5-AWO that was tracked during 2019 near 60°N. It was tracked from 2019 March to Sep. DL2 changing gradually from +15 to +9 deg/mth. (See our 2019 report no.9, & see Juno images at PJ20 and PJ23, & JUPOS chart.) It has continued to accelerate and drift northwards, being imaged at PJ25 (2020 Feb.17), and then in amateur images: at ~62-63ºN, DL2 = -10 (March-May), then at ~64ºN, DL2 ~ -31 (May-June).

In the ***N4 & N3 domains,*** various spots were tracked with typical speeds, not itemised here.

N2 (N.N. Temperate) domain

NNTZ ovals:

NN-LRS-1 was strongly red from Feb. to April but lost some of its colour during May. *In July it is white, with a dark rim.*

NN-WS-4 had been quite reddish in 2019, but was white in Feb., then almost or completely invisible thereafter due to low contrast with its surroundings. JunoCam got a good view of it at PJ25 (Feb.17), finding that its central region was slightly reddish and also the most methane-bright. *In July it is visible as a white oval.*

NN-WS-6 had apparently merged with a smaller AWO in 2019 Nov. [2019 report no.9, & JUPOS chart], but in 2020 there are two similar AWOs near the extrapolated track, so it is not certain which of them is the long-lived WS-6. I have labelled them arbitrarily *WS-6 & WS-7*. Both are rather small and bright white.

In methane images, LRS-1 is large and strongly methane-bright as usual. WS-4, WS-6 & WS-7 appear small and weakly methane-bright. The methane images allow WS-4 to be tracked [added to the JUPOS chart], although presumably only the central region is visible, as at PJ25.

Drifts (DL2):

NN-LRS-1: mean -11 (Feb-June), oscillating with period ~2 months.
NN-WS-4: mean -11 (Feb-June), largely tracked using methane images.
NN-WS-6: varying, mostly DL2 = -1 (April & May).
NN-WS-7: mean -4 (Feb-June), with irregular oscillations.

NNTB:

At least four dark sectors of NNTB have faded away in the past year, usually reddening as they did so, but can still be made out as pale oblongs.

F. NN-WS-4: In 2019 there was a dark segment at L2~90-105, which reddened then faded away in 2019 Sep. [2019 Report no.9]. This was very likely the same as the pale sector of NNTB imaged by JunoCam at PJ25 (Feb.17), spanning L2 = 86-103, alongside WS-4; it appeared to be a closed cyclonic circulation. This same pale sector was still present in 2020 May, e.g. Figure 4, at L2 = 75-104.

Immediately f. this, a long dark NNTB in Feb. contracted to become a well-defined dark bar from March to May. In late May it split in two, and both parts faded away in June.

F. this, a FFR can be seen from April onwards (if not earlier).

F. NN-WS-6: In Feb. there was a red-brown sector of NNTB alongside WS-6, which faded in March and disappeared in April. Immediately f. it was a very dark sector of NNTB; this was red-brown in April & May, becoming lighter in June; *it persists as a pale reddish sector f. WS-6 in July.*

F. NN-LRS-1: This is a remarkable sector as the disturbance spans the NNTZ. In April, a large complex of dark streaks and light spots filled the NNTZ for ~60º f. LRS-1. (This was seen by JunoCam at PJ26 on April 30, as we reported: "A band of FFR-type chaotic cloudscape interrupts the NNTZ, connecting the FFRs in the N2 and N4 domains. The NNTB FFR appears spectacular, as in similar views at earlier perijoves, with multiple cloud layers, and large cyclonic eddies with orange centres.") It changed over subsequent weeks: in late May and early June it included an unusually large FFR, and a very dark structure occupying the NNTZ f. the FFR and up to NN-WS-4.

NNTBs (N2) jet: The outbreak of dark spots continues at all longitudes, with a uniform DL2 = -80 (±2) deg/mth.

N. Temperate domain

The rifted sector of NTB from 2019 still existed throughout this period, consisting of tiny white spots (Figure 4) but it was becoming weak and southerly, with the narrow dark NTB(N) extending along its N edge. The dark band in NTZ f. the rifted sector, known as the N. Temperate Disturbance (NTD), still existed until March, but it contracted to a short streak which disappeared in mid-April. As of late June, there is still a dark narrow NTB(N) spanning ~150º longitude with the narrow rifted sector on its S edge, following which there is again a dark sector of this NTB(N).

The approx. positions of the rifted sector and NTD have been added to the JUPOS chart. The chart shows that features had a range of retrograding speeds within the N. Temperate Current A (NTC-A) as usual. A white spot in the NTZ near the f. end of the rifted sector had DL2 = +9 in March-April and +18 in May-June. F. the rifted sector, dusky streaks had various motions within NTC-A (two of them probably oscillating), up to the f. end of the NTD which had DL2 ~ +30 deg/mth.

P. the rifted sector, there is a rather narrow variable NTB(N), which is sometimes a long very dark segment and sometimes merely streaks with variable intensity.

NTC-B: Small dark spots at ~28ºN were still arising just p. the rifted region and prograding rapidly with the NTC-B, but after April they were only tracked for short distances. The speed is well documented on the JUPOS chart, with DL2 ranging from -74 to -56. Images from June 16-21 show a long line of them just p. the residual rifted region (Figures 1 & 5): *these have emerged further p. in July (Figure 2).*

NTBs jet: There are no substantial features to track in this very bland pale latitude, but one small dark spot was recorded from May 13-18 (Figure 6), with a mean speed of DL1 ~ -4 deg/day, similar to last year.

North Tropical domain

The NEB is still impressively disturbed; it looks as though a NEB Expansion Event (NEE) is taking place*. As described in Report no.3, this started in mid-February when a bright spot at ~14ºN initiated a complex rift system. This is illustrated in Figure 7A. The initial white spot (green arrow, up to Feb.17) was inconspicuous; by Feb.26-29, multiple tiny bright spots and streaks had appeared p. WSZ; by March 9, the rift system had mostly low contrast but was expanding rapidly. Hi-res images showed that it developed into a very turbulent sector throughout March. Figure 7B shows the development in a set of maps from Feb. to June. In late March, some sectors of NEB p. White Spot Z (WSZ) were inflated northward to 20ºN with this turbulence, and stabilised as expanded sectors of NEB while new ones were appearing further p.

In May and June, the NEE made some progress, but also appeared to be fading in parts. The big rifted region (which spans the full width of the belt) has come round to its original longitude again and appears to be disrupting the expanded sector. We wait to see whether the belt will stabilise in the fully expanded state. *Nevertheless, the maps from late June (Figure 1) and July (Figure 2) show that the belt has expanded to 20ºN at most longitudes.*

*Background information on NEEs can be found in the following accounts that we have published, as well as more detailed interim reports on this web site:
For all from 1987 to 2009: Ref.1; for the 2012 event: Ref.2; for the 2015-2017 events: Ref.3.

Features on the NEBn:

The rift system initiated at White Spot Z (WSZ) (Fig.7A), which still divides distinct sectors of the NEB (Fig.6). WSZ decelerated suddenly around April 21, from DL2 = -8 to -4.

F. WSZ, the NEBn is irregular but features have been transient. The JUPOS chart shows tracks for several white ovals (AWOs or just bays), retrograding with DL2 = +9 (±4), but not lasting more than a month. (JunoCam viewed one such area at PJ26 on April 10, at L3 ~50 (L2 ~0), finding it surprisingly amorphous, without any distinct anticyclonic pattern.) Dark features have a similar speed to these white ovals.

The rifted region traversed this sector from late April to mid June, occupying the whole width of the NEB.

P. WSZ, there are several other white ovals which appear to be fairly stable AWOs, all with DL2 in the range ~0 to -3 deg/mth. One (WS-a) has persisted since 2017, but others have appeared more recently. As of mid-June there are three pairs of them, which I here designate as follows (see Figures 1 & 7B): WSZ & WS-n; WS-a & WS-o; & two new ones. But WS-o has shrunk to a tiny spot, embedded in a large dark brown patch of expanded NEB. Unusual large *cyclonic* white ovals have also developed along this sector (blue points & arrows on the JUPOS chart & Figures 1 & 7B). We can't tell whether they have coherent circulations, but Juno imaged one at PJ25 (Feb.17; between WS-a and WS-o; Figure 7B), and showed it to be a well-formed cyclone, rarely seen in the NEB. Figures 4&5&8 show some of the best images of this sector.

Methane images are shown in Figures 8 & 9, with a larger set in **Suppl. Figure A**. The cyclonic 'ovals' in the NEB appear dark (Figure 8), though mostly less so than the N half of the NEB itself. The AWOs are not methane-bright, though they are generally lighter than the adjacent NEB; this is typical for NEBn AWOs.

The rather narrow, strongly red-brown NEB(S) component was still present in May and still methane-bright (Figures 4 & 8). In methane images (e.g. Figures 8 & 9), the NEB and EZ presented a bizarre picture, with various methane-specific features as described below, and variation depending on the methane filter used, the resolution, and perhaps other factors.

Methane-dark waves:

In May, a series of large diffuse methane-dark waves developed in the expanded sector of NEB, reminiscent of those observed during NEEs in 2000 and 2015-2017. There were five such waves from L2 ~ 80-190 (L3 ~ 140-250), with a spacing of ~25-30º (Figure 9; compare Figure 5). They were overlying the retrograding NEBn jet, and just north of the methane-bright reddish NEB(S) where it was present.

Wave no.2 was especially large and coincided with the dark brown block around the tiny WS-o. Other waves were flanking AWOs, incuding no.4 over a transient cyclonic mini-barge, and no.5 over the cyclonic bulge between WS-n and WSZ. Other cyclonic ovals were not strongly methane-dark. These methane-dark waves were short-lived, only appearing in mid-May and fading in mid-June as the rifted region began to disrupt this sector.

NEB Rifts:

The large rift system has continued to expand, its p. end having DL2 ~ -130 deg/mth (-4.3 deg/day), and the f. end DL2 ~ -80 deg/mth (-2.7 deg/day). Individual white spots have been tracked at both these speeds and a range in between.

Equatorial Zone (EZ)

NEBs dark formations:

There is still an array of prominent NEBs dark formations all around the planet, with complex festoons and whitish areas in the northern EZ. Up to late June, the dark formations are drifting at DL1 = +5 to +8 deg/mth, as is typical. A set of maps in System I longitude (Figure 10) shows the persistence and the variablity of the NEDFs. Typically during this period, about six of the NEDFs were large and prominent, others were smaller. Most have changed their appearance considerably, possibly due to the passing rift system enhancing or disrupting them. But the overall appearance of the EZ and the NEBs has not changed during this period.

EZ colour:
As noted in Report no.3, there is still significant pale ochre colour in the EZ, esp. the central part which is also very methane-bright (see below). The ochre colour varies between images, and this may depend largely on the camera and filters used by individual observers. The southern strip of EZ is white but methane-dark.

Methane images: a novel pattern of stationary waves:
The methane images reveal an astonishing new phenomenon: a series of waves within the EZ that are not moving with System I (the great equatorial current) but are stationary in System III – unlike anything previously seen in the EZ. These waves are latitudinal undulations of the boundary at ~3ºS between the methane-bright, visibly ochre EB and the methane-dark, visibly white EZ(S). They do not correspond to any distinct features in visible light. They were first noticed in May (Figure 8 & Anim-D), but they can be recognised in images from Feb. to July, always in a restricted longitude sector. A full account of these waves is given in **Part III** of this report.

South Tropical domain

SEB:

The SEB is generally similar to last year [2019 Report no.9]. Maps (Figures 1 & 2) and charts show the following minor variations.

SEB(C): This dark belt component at ~12ºS had a tapered p. end ~160º p. the GRS, up to April, with smallscale disturbance in the northern SEBZ just N of it. In April, this disturbance seems to have become more vigorous, and interrupted the SEB(C), so that a dark segment of the SEB(C) broke off and prograded with DL2 = -85 deg/mth. It faded as it approached the GRS in early June.

Post-GRS rifted region: There is still a short sector of convective disturbance here (e.g. Figures 11 & 12), which repeatedly dwindles to almost nothing then revives. In May and June it is usually very short (Suppl. Figure B), but a methane-bright plume occasionally erupts immediately Nf. the GRS (May 27-29, June 6-8), or a little further f. (May 24-31) (Figure 11). The series continues with Figure 13, in which the activity increases to three methane-bright plumes on June 16.

Two white barges are still present in the southern SEB p. the GRS, though indistinct. One was closely imaged by JunoCam at PJ23 and the other at PJ27, showing evidence for partial cyclonic circulation.

The SEBs appears messy along much of its length and there are few features travelling with full jet speed. Instead, there are many dark streaks in northern STropZ with more modest retrograding speeds.

The SEBs and GRS are being studied thoroughly by Shinji Mizumoto and Kuniaki Horikawa for the ALPO-Japan [http://alpo-j.sakura.ne.jp/Latest/j_Cylindrical_Maps/j_Cylindrical_Maps.htm], and the following is adapted from Mizumoto's preliminary account. Figure 14 is his drift chart for features near the GRS *(updated to July 20)*. He notes that the activity status of the SEBs has changed. Up to mid-March, there were still retrograding rings on SEBs (20-21ºS) as in 2019, with DL2 ranging up to +109 deg/mth [no.4]; the last of these [no.6] entered the Red Spot Hollow (RSH) around March 10 (see below). After that, there were no more rings approaching the RSH until April, and even then, few actually entered the RSH. Instead of rings, there were dark spots or streaks at 22-24ºS, with modest retrograding drifts of ~+60 to +90 deg/mth. It seems that they were repeatedly appearing and disappearing. One dark streak on SEBs, with DL2 = +31 deg/mth, drifted south and slowed down just as a faster-retrograding spot [no.10] interacted with it and passed it in late April; the dark streak then became stationary at L2 = 252 throughout May and has remained prominent, while the other spot continued as a rare example of a full-speed SEBs ring [no.10] with DL2 = +113. This ring then entered the RSH on May 17. *Since then, two other similar dark streaks have also ceased retrograding and drifted south in the STropZ. In July, all three of them have become dark spots in mid-STropZ at 22-23ºS with prograding drifts.*

Great Red Spot

Interactions with SEBs spots & GRS flaking events:

In 2019, many SEBs rings entered the RSH and induced red, methane-bright flakes to split off the f. end of the GRS, and sometimes also at the p. end. [Our full report on this phenomenon is Ref.4.] JunoCam images showed evidence that similar events were continuing during solar conjunction. However, in 2020 there have only been infrequent flaking events, & no large ones. This may be attributable to the reduced number of SEBs rings, the failure of some of them to enter the RSH, and the regular openings of the rift in the N side of the RSH (the 'chimney'). From the images received and the maps and charts from them posted by Shinji Mizumoto [URL above], the following interactions have been recorded, including 5 flaking events:

1) A SEBs ring [no.1 in Figure 14] entered the RSH on Feb.17. Its distorted remains apparently passed through the RSH and out the f. end on the SEBs jet; it formed a prominent ring in the STropZ with DL2 ~ +23 throughout March, which then became almost stationary at L2~20 from about April 10 to May 10.
2) That was the first of four quite large retrograding rings that arrived at the RSH between Feb.17 and 27 (Figure 14). Only one rather small flake was recorded -- a narrow flake on the north edge of the GRS on Feb.27 (image by Foster), which may have emerged at the f. end around **March 1** -- but images at that early stage were insufficient for full coverage.
3) Although no more rings were seen to enter the RSH, a small white spot was recorded proceeding slowly through the RSH on March 28-30 (Wesley, Foster, Go). A small methane-bright flake was then imaged at the f. end on **April 2** (Miles) and one at the p. end on April 6 (Go).
4) Another ring [no.7] entered the RSH on April 25, and a medium-sized, short-lived flake appeared at the f. end on **April 30**, followed by one at the p. end on May 5.
5) Two rings with different speeds [nos.8&9] converged and entered the RSH on May 9 and 13. A flake appeared at the f. end on **May 14**.
6) The next ring [no.10] was the largest and fastest, with DL2 = +113. It entered the RSH on May 17, and a flake appeared at the f. end on **May 21** (Figure 11 & Animations-B & C). This flake grew larger than the others, red and methane-bright, expanding west and retrograding along the SEB(S), along with the remnant of the SEBs ring that had survived though the RSH. Remnants of both the flake (a small methane-bright spot on SEBs) and the ring (a tiny light spot, not methane-bright) survived up to May 29.

In the last week of May, a dark grey-brown 'bridge' connected the retrograding remnant of SEBs ring no.10 with the S rim of the GRS and a very dark patch at its p. end. *During June, this elongated to form a dark* ***S. Tropical Band*** *p. the GRS, but it faded at the end of June and had almost disappeared by mid-July.*

JunoCam at PJ27 (June 2) showed the GRS wrapped in lightly reddish and methane-bright loops that were likely the remains of these flaking events. These are part of a pale brownish halo that surrounds the GRS, which may be derived from flake material mixed and diluted into the background clouds. Hi-res images showed signs of continuing disturbance around the periphery of the GRS, but there were no other flakes and no more incoming SEBs rings up to late June. *Since this hiatus:*

7) On June 29, a large SEBs ring[no.11] entered the RSH, and although the 'chimney' was open, the ring passed it intact, and produced a flake at the f. end of the GRS on ***July 4-5****.*

8) On July 19, the next SEBs ring [no.12] entered the RSH , and substantial flake began developing towards the f. end on ***July 22.***

GRS dimensions and drift rate:

The GRS remains small and dark red. Its mean drift rate is unchanged at DL2 = +1.9 deg/mth (JUPOS data).

Remarkably, it has been shrinking since Feb., despite the lack of large flakes. By mid-June it was only 12.3 deg long, the same as its minimum in 2019 June (Mizumoto's data: Figure 15). We wait to see whether this is a renewal of its long-term shrinkage.

South Temperate domain

This domain is undergoing some interesting transitions as part of its long-term cycles of STB structured sectors. We gave a full account of the situation up to April in Report no.2 and in our PJ26 report, so here we will continue from Report no.2, and include a brief summary of JunoCam's findings at PJ26. Figure 16 is a set of maps of the domain from 2020 March to June; also see Figures 1 & 2.

F. oval BA: The p. end of the STB Spectre had arrived at STB Segment A (the dark patch f. oval BA) in mid-Feb. or slightly earlier, and Juno Cam images at PJ25 (Feb.17) and PJ26 (April 30) showed that it had lost its circulating current. There was no other evident transformation in the Spectre. But Segment A was reinvigorated with increased size and turbulence, accompanied by the usual signs of these encounters: dark spots emitted Sf. Segment A in the STZ, and Np. BA on the STBn jet, a dark rim around BA, and acceleration of BA.

Since then, Segment A continued to grow longer, reaching a maximum of ~25º around mid-May, while BA and the smaller AWO (which are close to the p. and f. ends of Segment A) drifted apart. There seems to have been more vigorous small-scale turbulence on Segment A from May 15-30. Then the length decreased again, being around 20º during June.

F. Segment A and the AWO, dark spots and streaks have extended west in an expanding 'Sf. tail' which by early June had reached the f. end of the STB Spectre, forming a dark band all along the STBs retrograding jet. One of these spots had the remarkable speed of DL2 ~ +67, which could be typical of the westward spread of this dark material.

Oval BA: Oval BA underwent a sudden acceleration when the STB Spectre arrived, and this very fast speed has been maintained (DL2 = -17.4), with slight oscillation with a period of ~2 months.
BA is still white with a dark rim. However, there have been no significant dark streaks on the STB(N) p. BA since March.

The f. end of the STB Spectre:
This was described in Report no.2, and since April it has not changed much. There is still a concave outline of the presumed cyclonic recirculation at the f. end of the Spectre (last imaged by JunoCam at PJ21 and PJ22: Figure 17), and in April and May there was a dark mass adjacent, suspected of being an anticyclonic recirculation loop. From late April to early May, images trace the motions of tiny spots there (Figure 18), which are consistent with this picture although recirculation has not been directly observed: details are given on the figure. The dark complex includes a stationary ring, probably anticyclonic, and a small AWO was in this position at PJ21 and PJ22 (Figure 17); this may be the core of the recirculation loop.

Drift rates in S. Temperate domain:

	DL2 (deg/mth)	
Oval BA	-17.4 (±0.3)	(March-June), with oscil'n of P ~ 2 months.
Small AWO f. BA	-12	(mean, March-June), varying.
Fastest-retrograding d.s.	-67	(April)
F.end STB Spectre	~-10.6	(Feb-June)
Clyde's spot	~-10 (±0.5)	
STB v.d.s.	-13	(May-June)

These drifts are notable. Oval BA has undergone a massive acceleration since the Spectre arrived. Conversely, other features have drifts slower than usual for features not in contact with BA.

P. oval BA: New cyclonic spots.

As noted in Report no.2, we have been expecting a new STB cyclonic structured sector to arise p. oval BA, and there were two candidates in early 2020: a very dark spot ~42° p. BA, and a pale oblique streak with a tiny white spot embedded in it, ~80° p. BA [Report no.3].

The first feature persists as a compact dark spot, roughly oval, sometimes with a lighter interior; it passed the GRS in early July. (PJ26 close-ups confirmed that it is a cyclonic dark oval, with lighter red clouds in its central region.)

The main development has been the eruption of a methane-bright plume within the second feature (Figure 12 & Suppl.Fig.B). This was known as ***'Clyde's spot'***, as it was discovered by Clyde Foster on May 31, and by great good fortune, it was imaged close-up by JunoCam on June 2 at PJ27, showing that it was a methane-bright cloud with evidence of expansion, within a strong cyclonic vortex. Clyde's spot is described in **Appendix 2**, and also in a NASA press release [https://www.nasa.gov/image-feature/jpl/clyde-s-spot-on-jupiter]. Although the methane-bright plume was was short-lived, and was never conspicuous in visible light, images continued to show one or more variable tiny spots at the original site, increasingly dominated by a dark spot which has grown more conspicuous until at the end of June it was a dark spot rivalling the first one,, although less compact, with continuing signs of small-scale disturbance. *The appearance has remained the same up to late July.*

We conclude that this single plume eruption initiated turbulence in the pre-existing cyclonic vortex which is now turning into a dark spot. There are also streaks connecting the two dark spots which suggest that a longer cyclonic circulation might yet develop between them, although no such circulation existed at PJ26 & PJ27.

These features will need names, so I provisionally suggest some in accordance with our previous records of such features (as in Report no.2). The previous two STB structured sectors were sector E (the STB Ghost) which began with a dark spot labelled DS4, and sector F (the STB Spectre) which began with a dark spot labelled (circumstantially and coincidentally) as DS5. So I suggest that the first dark spot in 2020 should be called DS6, while the second (derived from Clyde's spot) should be called DS7. When a longer structured sector develops, it will be structured sector G; and if it is a pale one like the former STB Ghost and Spectre, I suggest it could be called the STB Phantom.

We should not expect this evolution to be fast; DS4 and DS5 both existed as very dark spots for 9-10 months until they faded and turned into expanding pale sectors.

S2 domain

Figure 16 is a set of maps which include the S2 domain from 2020 March to June. There are still seven AWOs, as described in our 2020 Report no.1:
"The SSTB is marked by the usual array of AWOs on its S edge. They are numbered A1 to A8, but lacking A6. A6 merged with A7 in 2018 May, then A5a, the small AWO that had replaced it, was fortuitously imaged merging likewise with A7 at PJ24 (2019 Dec.26)."

There are no white oblongs now. Two were present in 2019 Sep-Oct. (an old one between AWOs A1-A2, and a new one between A2-A3). But in 2020, in the PJ25 map (Feb.17) and subsequent ground-based maps (Figure 16), those sectors are very short and appear to be FFRs. FFRs have also been recorded in some other sectors. The long sector between A8-A1 (part of which has been alongside STB Segment A) was mostly white up to early June apart from a narrow SSTB(N); *but in June and July it is more shaded*.

S3 domain

In 2020 two AWOs have been tracked. One is S3-AWO-1, definitely tracked from 2019 in JunoCam maps as it was always the largest and maintained a fairly steady mean drift of DL2 = -22 during solar conjunction. The other may be AWO-2 from 2019.
Both of them were prograding until April, then each suddenly halted in L2 (as had also happened several times in 2019). From then until early June, AWO-1 had DL2 ~ 0 --> -10, and AWO-2 had DL2 = +8; then both started prograding rapidly again. It is curious how AWOs in a domain sometimes undergo parallel changes of speed within weeks of each other, even when far apart in longitude (also see S4 domain, below). We have also noted that such sudden halts sometimes happen when the prograding AWO meets a slow-moving FFR or (esp. in the S3 domain) a much smaller retrograding dark spot. However, this was not the case for S3-AWO-1 on 2020 April 10: the PJ26 map, on that date, shows it at the p. end of a FFR which it had probably just passed, and it had not yet encountered the next group of slow-moving dark spots, so its deceleration is unexplained.

S4 domain

There are two AWOs. The long-lived one, S4-LRS-1, prograded during solar conjunction but was stationary at L2 = 42 from March to June 3. Since then, it seems to have started prograding again. Another AWO, here dubbed S4-AWO-2 although it is new, prograded in March, then was stationary at L2=160 from March 28 to June 3, and is prograding again since then.

South Polar Region

In JunoCam maps, we have been tracking two quite large AWOs at >70ºS, as follows:
PJ25 (Feb.17): W1, 73ºS, L2=299; W2, 77ºS, L2=219.
PJ26 (Apr.10): W1, 73ºS, L2=328; W2, 76ºS, L2=188.
Each of these is represented by several points from amateur images on the JUPOS chart.

References

Background information on NEB Expansion Events:

1. Rogers JH (2019) JBAA 129 (no.1), 13-26. 'Jupiter's North Equatorial Belt and Jet: I. Cyclic expansions and planetary waves.' https://britastro.org/node/9140

2. Rogers JH & Adamoli G (2019) JBAA 129 (no.3), 158-169. 'Jupiter's North Equatorial Belt and Jet: III. The 'great northern upheaval' in 2012.' https://britastro.org/node/15629

3. Rogers JH et al.(2019) EPSC Abstracts Vol. 13, EPSC-DPS2019-302.

'The cyclic expansions of Jupiter's North Equatorial Belt in 2015-2017.'
https://www.britastro.org/node/19341

Full account of the 2019 GRS flaking phenomena:

4. Foster C. et al. (2020). Jupiter in 2019, Report no.10: 'The GRS in 2019 and its interaction with retrograding vortices as monitored by the amateur planetary imaging community.'
https://britastro.org/node/22552

List of components of this report:

Part I: Extended summary (inc. mini-figure)

Part II: Main report (text);

Part II: Main report (mini-figures).

Part III: 'Stationary waves revealed by methane images of the EZ' (inc. mini-figures).

Figures 1-22, for all 3 parts.

Supplementary Figures A & B (galleries of methane images).

Animations A,B,C,D *[list below]*.

Appendix 1 = JUPOS charts (annotated).

Appendix 2 = 'A rare methane-bright outbreak in Jupiter's South Temperate domain' by C. Foster et al. (Abstract for EPSC 2020 describing 'Clyde's spot').

Figures:

Figure 1. Map of the planet on 2020 June 21-22.

Figure 2. Map of the planet on 2020 July 19-20.

Figure 3. Maps on 2020 July 3-4 in RGB, methane, near-IR continuum, and false colour (methane, near-IR and UV).

Figure 4. Some of the best images of the disturbed, expanded sector of the NEB in early May. showing the AWOs (red arrows) and cyclonic ovals (cyan arrows). Also includes the NTB rifted region.

Figure 5. Some of the best images of the disturbed, expanded sector of the NEB in June, also the NTB rifted region. These images match the 4 methane images in lower left of Figure 9.

Figure 6. A series of images of the N. Tropical domain around White Spot Z, 2020 May 12-18. The bracket indicates a wave-train that develops on the NEBn f. WSZ on May 16.

Figure 7A. Images of the region around WSZ in 2020 Feb., showing the origin of the NEB rifted region that generated the NEB expansion, as described in the main text.

Figure 7B. Maps of the NEB and EZ, aligned in L3, Feb. to June. Red arrows indicate AWOs.

Figure 8. CH4 & RGB images in early May, showing the partly expanded sector of NEB, and the stationary waves in the EZ. All images by Chris Go. *Top:* Methane-band images. Cyan dots mark waves in southern EZ, stationary in L3; blue arrow marks a methane-bright spot, stationary in L1. (This was before the methane-dark waves on the NEB appeared.) *Bottom:* Colour images, similar to Figure 4. Also see **Animation-D** (blink of the CH4 and RGB images).

Figure 9. Set of CH4 images all around the planet, 2020 May & early June, showing the methane-dark waves that developed over a sector of NEB. Cyan numbers indicate the waves; red letters indicate the positions of the AWOs (not clearly shown in methane images). (The four images at lower left, in June, match the IR and RGB images in Figure 4.) Also see **Supplementary Figure A** for a more extensive set of these images.

Figure 10. Maps of the Equatorial Region, 2020 March to July, in L1. Tracks of the major NEBs dark formations are marked.

Figure 11. GRS region, 2020 May 21-24, in RGB and CH4, showing a plume outbreak in the SEB (green arrow) and a flake emerging from the GRS (yellow arrow). Images & annotations mostly by Clyde Foster. Also see **Animations B & C**.

Figure 12. GRS region, 2020 May 31 to June 13, in RGB and CH4, showing the appearance and evolution of Clyde's spot. Also see **Supplementary Figure B** for a more extensive set of these images.

Figure 13. GRS region, 2020 June 15-18, in RGB & CH4, showing bright plumes erupting in SEB f. the GRS.

Figure 14. Longitude-vs-time chart of the features around the GRS, 2020 Jan.-July.

Figure 15. Length of the GRS, 2019 Jan. to 2020 July.

Figure 16. Set of maps from ~13 to 53ºS, covering the STropZ & S.Temperate & S.S. Temperate domains, 2020 March-June, aligned in L3. (Also see Figures 1 & 2.)

Figure 17. Closeup view of the f. end of the STB Spectre from JunoCam at PJ21 (2019 July 21), showing its cyclonic circulation.

Figure 18. The f. end of the STB Spectre in 2020. Coloured arrows track various small spots in and around the complex, as described in the legend at top right.

Figures 19-22: In **Part III.**

Animations (GIF's):

Anim-A. Blink of two images 20 hours apart on May 12-13 (E.Sussenbach & C.Foster, animated by JHR). This is the quiet side of Jupiter, though it includes WSZ and the f. end of the STB Spectre.

Anim-B. Blink of two images 20 hours apart on May 21 (C. Foster). This includes the GRS with a developing flake and convective activity in the SEB f. it. Also shown in **Anim-C**:

Anim-C. The images from Figure 11, map-projected and animated by Andy Casely, showing the origin of a flake at the f. end of the GRS.

Anim-D. Blinking of RGB images with CH4 images that have been rotated in Photoshop for approximate alignment. All images by Chris Go, aligned by JHR. Note that the dark red-brown strip in the NEB and the pale ochre strip in the EZ are methane-bright. In RGB, arrows indicate AWOs and cyclonic 'ovals' in the NEB. In CH4, in the southern EZ, the dark blue arrow indicates a methane-bright spot fixed in L1, and cyan dots indicate the waves stationary in L3.
