Jupiter in 2019, Report no.3

--John Rogers (2019 March 29)

This report goes up to mid-March, and includes the first set of JUPOS charts with substantial data from 2019. Juno's PJ17 was on 2018 Dec.21, and PJ18 on 2019 Feb.12.
Our last detailed report was 2018 Report no.6. Earlier in this apparition, 2019 reports nos.1 & 2 described and illustrated the region around the PJ18 track, including the GRS and oval BA.

As usual, this report mostly uses System II longitude (L2), although L3 scales are given on some maps, 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. Latitudes are planetographic. North is up in illustrations unless otherwise indicated.

The 4 Figures are shown in miniature at the end of this report. In addition, a ZIP file contains three large sets of supplementary figures:
i) Five image **sets** ('Fig-Set-A to –E'). All have north up.
ii) Five cylindrical **maps**. All have north up, and both L2 and L3 scales.
(Cylindrical maps are made every few days by Shinji Mizumoto and posted on ALPO-Japan [http://alpo-j.asahikawa-med.ac.jp/Latest/j_Cylindrical_Maps/j_Cylindrical_Maps.htm]. For the JUPOS team, Michel Jacquesson has made several recent maps and Marco Vedovato has now resumed mapping again.)
iii) **JUPOS charts** (labelled by domain: N2, N0 [N.Tropical], S1, S2, and GRS).
These are in L2 with longitude increasing to the right, and are aligned with maps with south up.

I am very grateful to all the observers, including Clyde Foster, Anthony Wesley, Phil Miles, Trevor Barry, Michael Wong, David Carlish and Chris Go who have contributed the most of the high-quality images.

N2 (N.N. Temperate) domain

NNTZ ovals: The JUPOS chart shows that all 3 long-lived anticyclonic ovals have maintained fairly steady prograding drifts since summer 2018. I have supplemented it with measurements on methane-band images in 2019. **LRS-1** is invisible in most RGB and I-band images, but is still very bright in methane images (Figure 2A & Set A). **WS-4,** ~40 deg. f. LRS-1, is weakly methane-bright. **WS-6** converged with another AWO in Jan., both being small and bright white (it is not clear which of the two was WS-6), and they apparently merged in mid-Feb.
The best images of the event are in Set B. Clyde Foster pointed out the two ovals very close on Feb.9; they can just be seen on Feb.10 although the f. one was then very faint; and they may be merging on Feb.12, although not well resolved. (This was the day of PJ18 but unfortunately these ovals were outside JunoCam's field of view.) From Feb.18 onwards, there was just one, larger and paler white oval. Before and during the merger, these ovals were very weak or invisible in methane images, but from March 1 onwards it had similar methane-brightness to WS-4.
NNTB: There are two conspicuous dark segments of NNTB, one reddish-brown (imaged by Juno at PJ15), and one dark grey (imaged by Juno at PJ18).

The NNTBs (N2) jet again has a substantial outbreak of dark spots.

N1 (N. Temperate) domain

The NTB(S) is now a very pale pinkish band, but there are long stretches of NTB(N) which are narrow and dark grey. The darkest of these, at L2 = 295-330 on Feb.7-9 (Map, & Set B), broke up rapidly in the first week of March. It was adjacent to the short rifted region (FFR) (L2 ~ 270-310 in early March, due N of the GRS, and imaged by JunoCam at PJ18). Following this rifted sector there is still a dark segment in the NTZ (the N. Temperate Disturbance); these are the same features that existed throughout 2018.

N. Tropical domain

The NTropZ consists of a clear white N half, and a S half still containing some fawn-coloured streaks left over from the formerly expanded NEBn. But the NEBn has largely receded to normal latitude, albeit with a conspicuously wavy edge at all longitudes. The structure of the NEB is much the same as in summer 2018. The JUPOS chart (with aligned maps) can be compared with the equivalent figure posted with our 2018 Report no.6. Three or four AWOs have persisted from 2017 (including White Spot Z: WSZ), and several more probable AWOs have appeared; conversely only one barge has survived. New barges and other features are appearing f. WSZ, near-stationary in L2, while WSZ has DL2 = -5.6 deg/mth (and WS-a and WS-b have DL2 ~ -4 to -5 deg/mth).

In the NEB, rifts are still sparse and short.

Equatorial region

The most distinctive feature of Jupiter this year is the intense ochre (or orange) shading of the EZ. It developed in spring, 2018, and now covers not only the central latitudes but also the northern part of the EZ. Even the bright areas following NEBs dark formations (NEDFs) are now ochre rather than white.

There is a prominent array of dark grey NEDFs all around the NEBs, with dark festoons extending to the equator. Although the NEDFs look bluish by contrast as usual, the festoons rapidly become dark brown and merge into a dark brown EB as one follows them into the ochre EZ. The mixture of orange, grey, and brown is typical of these coloration events.

Recently, Antuñano et al.(2018) have defined these events independently as brightenings of the EZ in thermal infrared images at 5 microns wavelength. At this wavelength, they are detecting clearance of the main clouds, which likely occurs below the visually orange haze, and so corresponds to the greyer or browner parts of the complex visual picture. The visible colour and the 5-micron cloud clearance largely coincide in time but not completely; they are different aspects of the same large-scale phenomenon. Antuñano et al. propose an approximate periodicity of ~6-8 years for the 5-micron clearance events, which seem to be more clearly defined than the rather variable visible coloration, and the 2018-19 phenomenon fits in with this pattern. This is the most intense EZ coloration event since 1989-1992; events in 1999-2000 and 2006-2007 began with brown colour but then became largely dark grey, and one in 2012 was limited and short-lived.

The drifts of the NEDFs are not yet well characterised this year, but appear to range from DL1 ~ 0 to +12 deg/mth. Slower, i.e. more westward or positive drifts (DL1 ~ +25 deg/mth?) are seen within a particularly complex structure at L1 ~ 320-360, where a large dark formation in EZ(N) is separated from the NEB by a series of white spots or plumes, separated by dark blue-grey columns or spots. This complex is shown in Set C & Figs.2 & 3. Following the major dark 'projection' (thick white lines), the smaller features are indeed moving westwards away from it (thin white lines for dark features, blue lines for bright plume cores), probably because of their latitude of 9-10 deg, which is further north than the usual NEBs edge. But the changes are more complex than this, and inspired by the findings from Galileo and Cassini that winds in festoons blow Np.(NE) towards the 'projection', I speculate that some dark features on the N edge of the festoon may be moving in this direction (green lines). Juno imaged this complex near the horizon at PJ18.

EZ(S)/SEBn:
The only remaining white part of the EZ is the narrow southern strip, and even this is not as bright as it was. Nevertheless, two sectors have been distinctive:
1) A very disturbed sector of SEBn, L1 ~ 100-150 or 160 (mid-Jan. to early Feb.), then L1 ~ 130-210 (late Feb.), and L1 ~150-200 having just passed the GRS in mid-March.
2) A short brown sector, L1 ~ 300, first seen as a bulge adjacent to a dark grey-brown segment of EB (Foster, Feb.20; Olivarez, Feb.22; Go, Feb.25; Camarena, Feb.26; first reported by Foster, Feb.27 & March 1), then as a coloured sector spanning the EZ(S). (Figure 2C & Set C)

S. Tropical domain

The GRS is still small and very red. In the last two years its periphery has become ragged, as if red strips were being shed outwards, although this small-scale phenomenon is best seen in spacecraft images. The GRS, and the SEB rifted region f. it, were the subject of our 2019 Reports nos. 1 & 2, as Juno flew just 3 deg f. the f. end of the GRS at PJ18 on 2019 Feb.12 (& see our report on PJ18, posted concurrently with this report). A set of ground-based images was posted in our 2019 Report no.2 (https://britastro.org/node/17341), some of them shown again here (in Sets B & C).

Drift rate of the GRS: The JUPOS chart confirms that the GRS has decisively decelerated again, as expected, after the STropD cleared it last summer (i.e., it has more positive drift in L2). The mean drift rate since then is DL2 = +1.7 deg/mth, and there is nothing to suggest that it will change substantially in the coming months. On Feb.12 (at PJ18) it was at L2 = 302.7, L3 = 241.6 (±0.5 deg). For PJ21 on 2019 July 21, it is very likely that Juno will fly over the GRS.

The SEB sector f. the GRS had minimal activity, with just one or two bright spots, until Feb.9-18, when the bright spots proliferated; Juno's images captured this upturn in convective activity [see Report no.2]. The enhanced activity has been maintained since (Fig.2B & Sets B & E). It is odd that the northern half of the SEB is largely white, as though it was entering a SEB Fade, whereas the southern half is still dark, with resumed convective activity f. the GRS. Moreover, there are now several distinct vortices on the SEBs jet retrograding at typical jet speed (DL2 = +116 deg/mth) (Fig.2D & Set D), which have not been seen for some time.

There is a single barge in the SEB at ~16.3°S, presently stationary at L2 = 224 (Fig.2D & Set D). It is merely light brown, with a light-coloured halo. It has probably existed since 2013; its history is described in the **Appendix** below.

S1 (S. Temperate) domain

We recently posted a detailed account of the S. Temperate domain from 2015 to 2018, including a complete report of the STB Ghost and its transformation in 2018 into a dark turbulent segment of STB f. oval BA (https://www.britastro.org/node/17283). There are only two structured sectors of the domain: one that includes oval BA, and the STB Spectre.

Oval BA passed the GRS during solar conjunction, in 2018 Dec. (see our PJ17 report), and was well imaged by JunoCam at PJ17 on Dec.21, enabling us to measure its internal rotation. Its orange colour had faded during 2018 and virtually disappeared during solar conjunction, leaving it looking white. Images and description of BA and its surroundings in Jan-Feb. were given in our reports for 2019 nos.1 & 2 (https://www.britastro.org/node/17157). Oval BA is still almost white (Figures 2E & 4, & Sets D & E), although the improving resolution of images does reveal a slight residual fawn tint.

Oval BA has accelerated considerably since the arrival of the STB Ghost in 2018 Feb. An initial but short-lived acceleration in 2018 June resumed in September and increased during solar conjunction, so the speed in 2019 Jan-Feb. was DL2 = -17.3 (±0.3) deg/mth, even faster than usual in these circumstances.

The dark STB segment f. it is less turbulent now (Figures 2E & 4, & Set E). Accordingly, it appears that no more dark material is being emitted p. and f. it. The very dark grey band or 'tail' in the STZ Sf. it broke up into dark streaks late in 2018, and these are now well separated from the STB segment. The outbreak of dark material Np. BA on the STBn jet has almost completely died away.

The STB Spectre elongated rapidly during solar conjunction and is now ~50 deg long, almost invisible in RGB, but well defined as a dark band in methane images (Fig.2B & Set B & Map [2019mar6-8]). Measurements have been added to the JUPOS chart. It can also be traced in the RGB map made from JunoCam PJ18 images on Feb.12, from L3 ~ 309-366 (L2 ~ 10-67) [Set B, copied from my PJ18 report].

However, a new structured sector may be appearing in the region where it is predicted, tens of degrees p. BA. A faint oblique streak is present there across the whitened S. Temp. domain, spanning 28-33 deg.S, methane-dark and stable (Figure 2D & Set D). It was first noticed by Chris Go on March 4, but was visible in images from mid-Feb. It may be the same as a pair of small vortices recorded in the JunoCam images on Dec.21 [boxed in Fig.10 of my PJ17 report], with DL2 ~ -20 deg/mth until mid-Feb., although DL2 ~ -14 (±1) deg/mth in Feb.-March. This may be the start of the next STB structured segment: watch this space! However it still could be ephemeral: there are other similar streaks though even fainter: one ~20 deg p. it, and another further p. We will have to wait and see whether it develops further or just fades away.

Higher southern domains

S2 (S.S. Temperate) domain
All 8 AWOs are still present as in summer 2018 (JUPOS chart), though A5a is very small. The whitened cyclonic cell still exists between A8 and A1, and another has developed in the adjacent interval, between A1 and A2.

S3 domain
S3-AWO-1, the largest and longest-lived AWO in this domain, was tracked throughout 2018 largely from JunoCam images up to PJ16, with a rather steady mean speed of DL2 = -19 deg/mth. It was a large, bright white, but rimless oval, having virtually no contrast with its surroundings. In 2019 Feb., after solar conjunction, it can be identified in the PJ18 images, now having a dark rim; and also in JUPOS data, but with DL2 = +7 deg/mth! This drastic change of speed is quite possible given its historical behaviour, but must have occurred immediately before imaging began in 2019 Jan or Feb. On Feb.12 it was at L2=73 (L3=12).

S4 domain
S4-LRS-1, the largest and longest-lived AWO in this domain, appears to have merged with S4-AWO-2 during solar conjunction, after their close approach in 2018 Sep. (at PJ15) (see our 2018 report no.7: https://www.britastro.org/node/15856). Only S4-LRS-1 remains, large and reddish as usual (Figure 2D & Set D). It has had a mean speed of DL2 = -18.5 deg/mth since Sep. On Feb.12 it was at L2=178 (L3=117).

Appendix: History of the present barge in the SEB, 2013-2019

This spot, always at 16-17°S, has been a dark 'barge' since spring 2017. Before then it had been an inconspicuous light-coloured spot since 2014. This in turn was plausibly identified with a dark barge that first appeared in 2013 Sep.

The feature in 2013 Sep. was a dark brown barge at L2 ~ 350 --> 360, forming in the wake of the post-GRS rifted region of SEB. (There was another one 50 deg. f. it, and others formed later p. it as 'ours' drifted to higher longitude with DL2 ~+7 deg/mth.) In the 2014/15 apparition, the barge had been replaced by an unusual inconspicuous light-coloured spot at 16.3°S, on the same track.* This persisted, still with modest but variable drift in L2, until 2016 Dec., when a similar 'white barge' p. our spot had approached it until they were only 12 deg. apart.** Hubble images on 2016 Dec.11 showed the pair of them, both well-defined white ovals embedded in the cyclonic shear of the SEB; likewise on 2017 Feb.2, for 'our' barge only.

In 2017 March-April, 'our white barge' turned into a brown barge again, as described in our 2016/17 report no.10: "Meanwhile, p. the GRS, there was a diffuse white spot at L2 = 217 --> 232, a twin of the former one in which the mid-SEB outbreak erupted. In Feb.-March, white and brown filaments extending f.(W.) from the mid-SEB outbreak encroached on its S edge, and it became progressively enveloped in brown material, so in April it appears as a dark brown barge with a pale core, at 16ºS (Fig.8). This confirms that both white and brown spots in this latitude are cyclonic circulations. It is very methane-dark (Figs.7&8)." In 2017 April it also reversed its drift in L2: it had increased to L2 = 233, only 27 deg. p. the Red Spot Hollow, but then moved to lower longitude again. In 2018, it was an isolated brown barge, at first nearly stationary at L2 = 184, then increasing again. Now in 2019 Feb-March, it is nearly stationary at L2 = 224.

JunoCam imaged this barge at PJ14 (2018 July 16), when it was deep red-brown. As described in my PJ14 report: "JunoCam obtained excellent closeup views of the longest-lived SEB barge (Figure 6C). It has a well-defined oval shape and cyclonic circulation pattern. The images support what we'd deduced from ground-based imaging: that the 'white spot' on its N edge, which is often the most conspicuous part of such features, is a diffuse, irregular band of white cloud lining the N edge of the circulation, not a coherent structure in itself."
JunoCam also imaged similar but different red-brown barges at PJ5 (2017 March 27) and PJ15 (2018 Sep.27). The PJ15 images were as spectacular as those at PJ14, showing the cyclonic morphology of the barge and revealing mesoscale waves on its periphery.

*A similar 'white barge' existed from 2011 July to 2015 April, with similar drift close to System II. It was described in our reports for 2012/13 nos.9 & 11, and 2013/14 no.4. When last seen in 2015 it was stretching out as a very long pale strip p. the GRS, while 'our' barge, then an indistinct pale spot, converged on it from lower longitude.

**In the second 'white barge', just 12 deg. p, 'ours', a bright convective plume erupted on 2016 Dec.29, initiating a vigorous 'mid-SEB outbreak' from that location which dominated the region fof several months. See my reports on this in 2016/17, esp. the final report which is 2016/17 no.17.

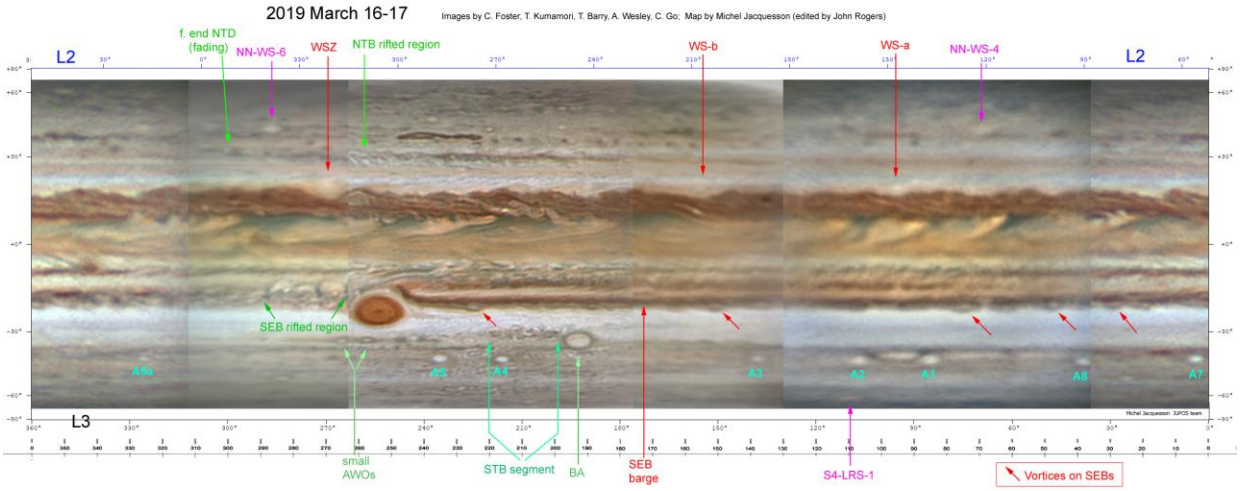

Figure 1. Map of the planet on 2019 March 16-17. For other maps, unlabelled, see Supplementary Figures.

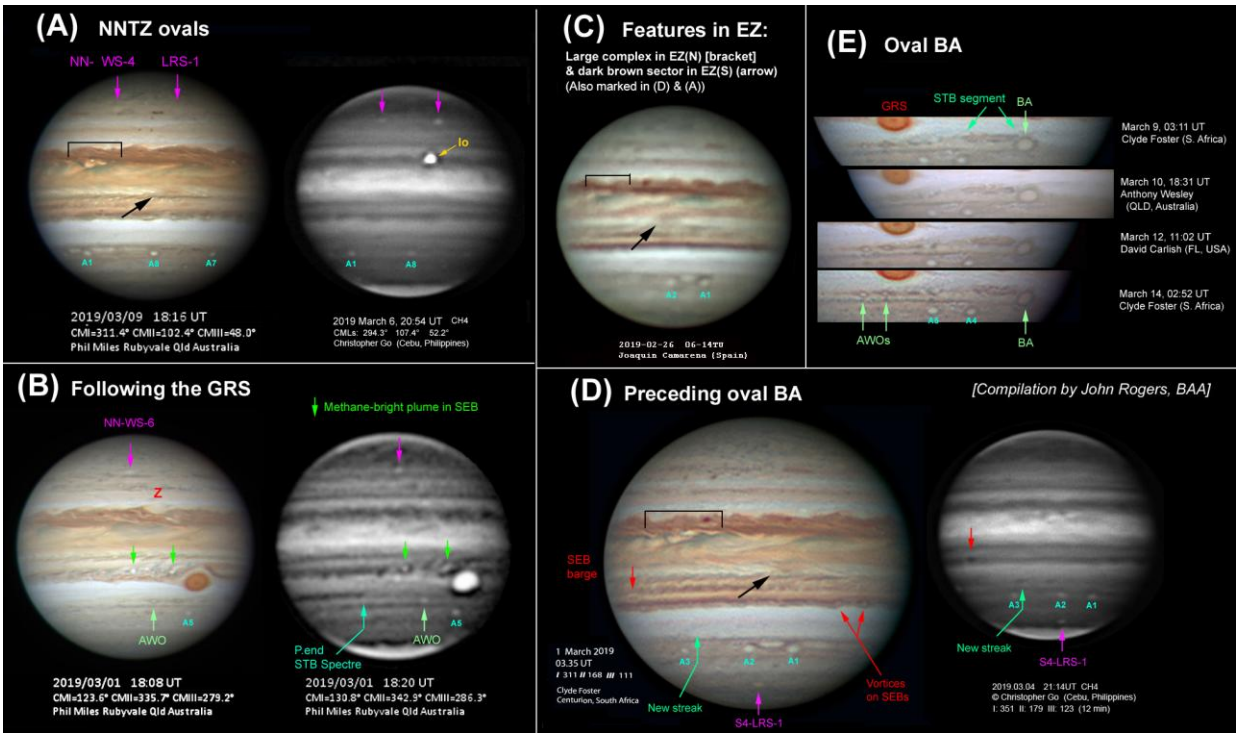

Figure 2. Images with key features marked. Each panel A to E shows one or two images from the larger sets A to E in the Supplementary Figures.

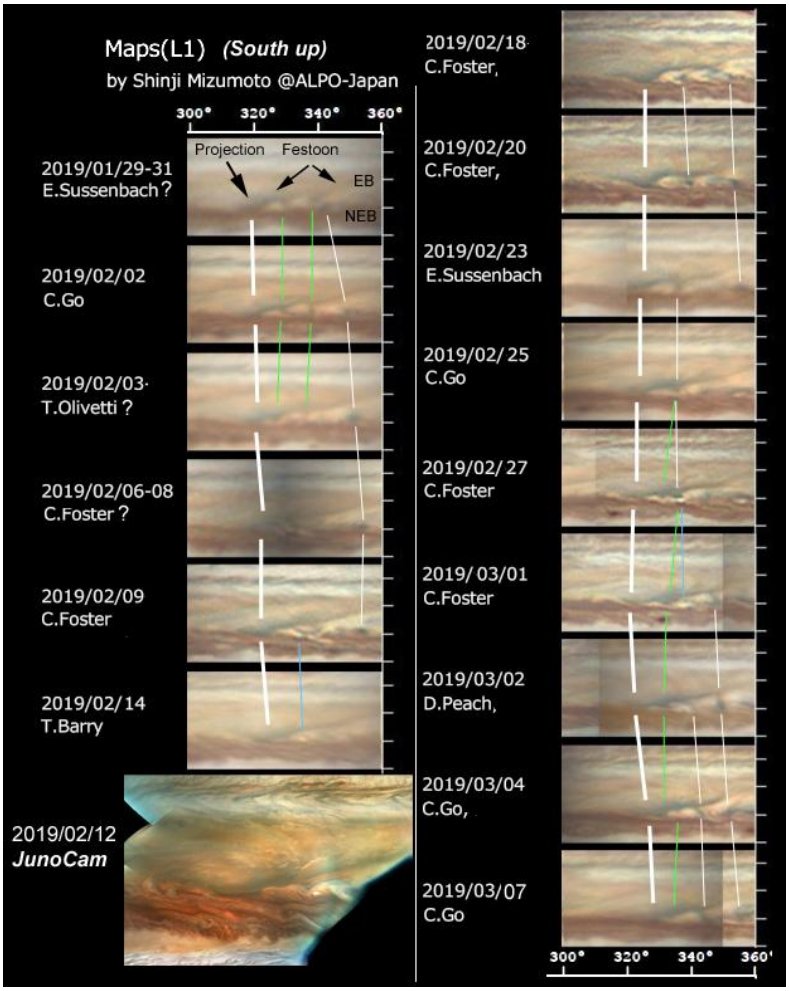

Figure 3. A labelled series of Mizumoto's maps (*South up*), showing the complex structure in EZ(N) at L1 ~ 320-360. Following the major dark 'projection' (thick white lines), the smaller features are indeed moving westwards away from it (thin white lines for dark features, blue lines for bright plume cores), probably because of their latitude of 9-10 deg, which is further north than the usual NEBs edge. Also, I speculate that some dark features on the N edge of the festoon may be moving NE towards the 'projection' (green lines). See **Set C** for a series of full-scale images of this complex structure. (Clyde Foster particularly followed this and on March 1 he called it the "puffing billy outbreak".)

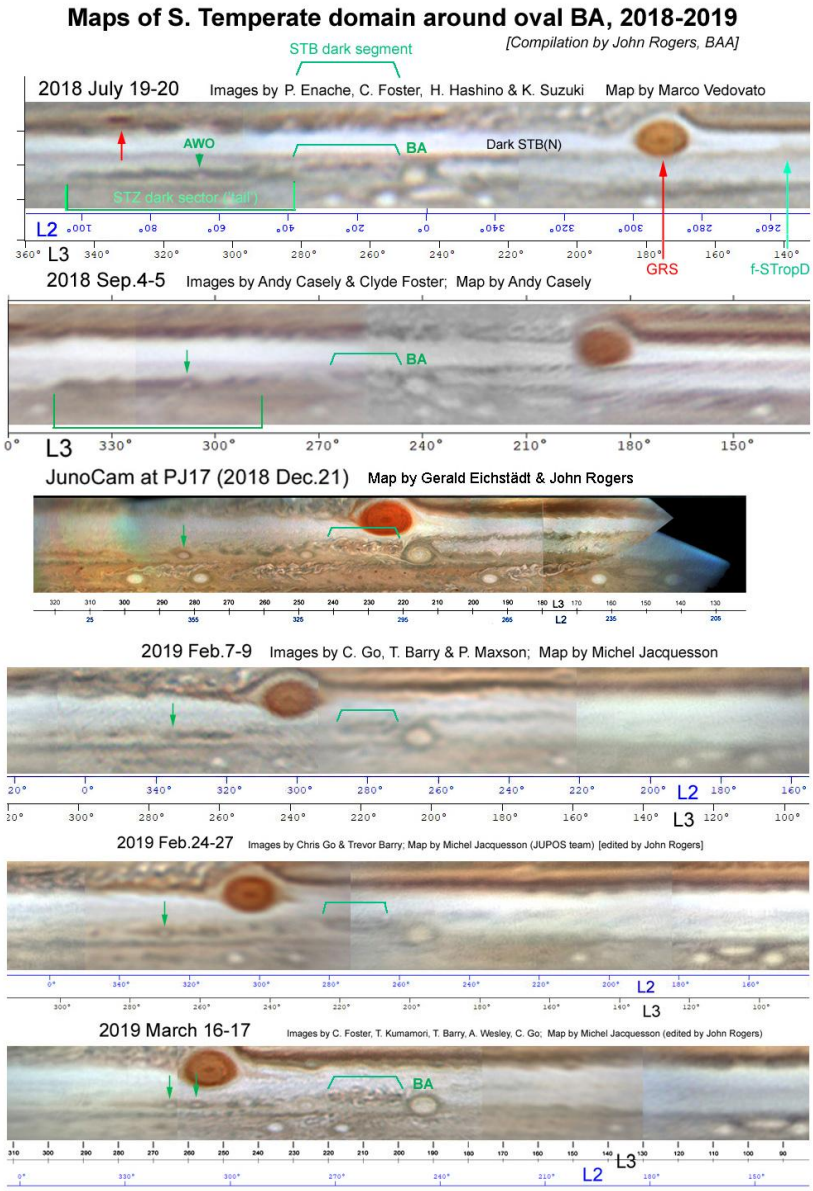

Figure 4. Maps of the South Temperate domain centred on oval BA, showing its evolution since summer 2018.