JunoCam at PJ26: What the pictures show

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Perijove-26 (PJ26) was on 2020 April 10. Perijove altitude was 3501 km, at 24.1ºN, L3=50.5. Because of Jupiter's oblateness, minimum altitude came 1m 46s later and was 3354 km. Juno crossed the equator 9m 33s after perijove, at an altitude of 6239 km, at L1=17, L2=12, L3=63. The orbital inclination is currently 105º (i.e. 75º retrograde), and the solar latitude on Jupiter has decreased to 1.7º, proceeding towards equinox in 2021 April. At PJ26 the spacecraft was tilted to allow the Microwave Radiometer (and so also JunoCam) a better-than-usual view of the clouds below. So PJ26 produced what will probably be the last best images of the equatorial region, as future orbits will return to the Earth-pointing orientation and perijove will continue to drift northward.

Excellent ground-based images of the sub-spacecraft track were taken ~1 rotation before and 3-5 rotations after the perijove. Various maps have been made from them, including labelling and animation, and are posted separately in our BAA 2020 Report no.3 [ref.1].

This report, like all in this series, is due to the work of the NASA JunoCam team: Drs Candy Hansen (Principal Investigator), Glenn Orton, Tom Momary, and Mike Caplinger (of Malin Space Science Systems); and Gerald Eichstädt, who produces the complete sets of high-quality processed images and map projections. As usual, the JunoCam images have been presented (i) as initial versions posted by the JunoCam team ('v01', each projected as if from a point above Juno's track, but with reduced resolution); (ii) as full-scale, high-quality versions by Gerald Eichstädt (strips closer to Juno's actual perspective); and (iii) both cylindrical and polar map projections of all the images by Gerald, which I have combined into composite maps. Details were given in our PJ6 report. Also, Björn Jónsson has posted a seamless hi-res cylindrical map from the NEBs to the south pole, which we use for the S. Temperate domain.

Abbreviations and conventions are as in previous reports. P. = east, f. = west. AWO = anticyclonic white oval, FFR = (cyclonic) folded filamentary region. Latitudes are planetocentric.

Satellites

Juno's orbit now passes not far above the orbits of Europa and Io on its inbound leg, and images of both moons were taken (Figure 1). Io expert Jason Perry noted that no volcanic plumes were visible, but there could be a possible red ring (plume deposit) around the volcano Surt. Images 33 & 34 of the Equatorial Zone showed a diffuse oval dark spot which was the shadow Metis, one of Jupiter's small ring moons (Figure 1 & Animation-M). (Juno's perijove is well below all the moons' orbits. On two previous equator crossings, JunoCam fortuitously captured the shadow of Amalthea.)

North Polar Region

Composite north polar projection maps are presented in Figure 2 (down to 75ºN at the edges) and Figure 3 (down to the N. Temperate region, in both RGB and CH_4).

Circumpolar cyclones (CPCs) (Figure 2):

The view is similar to that at PJ24, again showing CPCs 8, 1, 2 & 3. They still fit into a regular ditetragonal arrangement, and their individual morphologies are largely unchanged.

The central North Polar Cyclone (NPC) is less clearly seen than at PJ24, despite the increasing illumination: the map shows only vague arcs of tiny white clouds around it, unlike the well-defined arcuate ridges seen at PJ24.

CPC-1 has, within its reddish central part, a small white oval with anticyclonic spiral arms, such as is commonly seen at the centre of these filled CPCs, but here it is off-centre.

CPC-2 has, on its outer edge, a very bright white caterpillar-shaped feature which is also methane-bright; it could be a new convective outbreak as it is not in a FFR nor other circulation.

Bland Zone and haze bands (Figure 3):

The Bland Zone is mostly well-defined but one sector (L3 ~ 20-70) is disrupted by chaos and ovals. The usual linear haze bands are visible near the terminator, and faintly as a dark band across the afternoon sector, though not as conspicuously as at PJ25. They can also be traced on the methane-band map.

Some haze bands are seen near the terminator further south, in the N5 domain, including a typical 'rainbow band' (Figure 4).

The low perijove altitude gave the opportunity to look for haze layers on the horizon, and one such can be found in image 26 (Figure 6C), in a narrow sector over the N3 or N4 domain.

High and mid-latitude northern domains

The north polar projection map from JunoCam (Figure 3) can be compared with one from amateur images taken over the following day (in our Report no.3: ref.1). In the ground-based map, all the substantial FFRs are visible up to the N5 domain, where they show up as a light belt. North of that, the largest N5-AWO is clearly recorded (appearing orange), and the Bland Zone and the largest FFR just north of it are dimly visible

The JunoCam images show particularly grand FFRs, in the NPR and N5 and N4 and N2 domains (Figures 5 & 6).

N2 (N.N. Temperate) domain (Figures 3 & 7):

NN-LRS-1, the long-lived, sometimes reddish oval that has recently regained red colour in ground-based images, was just captured at the edge of image 24. (It should not be confused with a similar-looking cyclonic orange oval in the N4 domain, in images 20 & 21.) Just west of NN-LRS-1, a band of FFR-type chaotic cloudscape interrupts the NNTZ, connecting the FFRs in the N2 and N4 domains.

The NNTB FFR (Figure 6) appears spectacular, as in similar views at earlier perijoves, with multiple cloud layers, and large cyclonic eddies with orange centres.

The JunoCam team again obtained a good-quality *methane image* at these mid-latitudes (image 25: Figure 6A). As at PJ25, the features coincide with those in the RGB image; the methane image does not reveal any otherwise invisible haze bands. In the FFR, the visibly white strips are very methane-bright, and so are some orange strips, while other orange strips are moderately methane-bright, as are the orange cores of the eddies. So here, the orange material is higher than the surrounding grey areas.

Figure 6 also gives a closeup view of a pair of NNTBs jet spots (at right), whose anticyclonic pattern is clearly visible.

Bright popup clouds are clearly seen in lines on some FFR white strips (in N5 and N4 as well as N2, thanks to the low altitude), and in the NTZ, but not in the NTB.

Low latitudes

Figure 7 is a global cylindrical map, made by our usual procedure. The inset (Figure 7B) is from a ground-based map of the NEB & EZ, longitude-shifted to match the time of perijove. This is adapted from our Report no.3 [ref.1], which also contains a set of ground-based images aligned in System I longitude to show the evolution of the NEBs features. Figure 8 is a set of the 'version 01' images posted by the JunoCam team, covering the NEB.

North Equatorial Belt (NEB) (Figure 8):

As usual, all the cloud features in the NEB are slightly diffuse, with no popup clouds, although there are a few popup clouds on the edge of the NTropZ.

The NTropZ/NEBn interface is currently very irregular in ground-based images, with white bays and dark projections. One of each is shown in the closeup images. The bay (labelled A in Figures 7 & 8) is a large white patch with enigmatic, largely amorphous cloud texture, not showing an anticyclonic pattern as might be expected. The adjacent projection (labelled B) shows complex streak patterns.

In the southern NEB, we see part of an extensive rift system, but without active white plumes at present.

Equatorial Zone (EZ) (Figures 8-10):

Juno's view included a small NEBs dark formation (labelled D in Figures 7-9); it had been larger two weeks earlier but was rapidly shrinking (see Report no.3). The festoons associated with it (labelled F in Figures 8 & 9) show diverse details that have also been seen in a few previous perijoves, including a very sharp edge to the festoon, and an anticyclonic gyre S of the dark formation (labelled E), consisting of dark blue-grey areas overlaid by rafts of white clouds patterned by mesoscale waves.

Elsewhere in the EZ, there is still an intricate mixture of pale ochre, white and blue-grey streaks. Images 32 & 33 (Figures 9 & 10) reveal mesoscale waves over much of it. This is the most extensive area of these waves that JunoCam has yet seen.

South Equatorial Belt (SEB):

This is a quiet sector of the SEB, although the JunoCam images show that it is all made up of beautiful streaks and swirls, the most prominent being the turbulence in the south component downstream of the GRS.

South Tropical Zone (STropZ):

There were closeup views of a prominent dark anticyclonic ring (Figure 11), which has been slowly retrograding in the STropZ since it appeared shortly west of the GRS around Feb.27 [data from the JUPOS and ALPO-Japan teams].

S. Temperate domain (Figure 12)

The images give an excellent view of a very interesting sector of the S. Temperate domain, in which two long-lived structured sectors have just collided and initiated some transformation following (f. = west of) oval BA, while a new structured sector may be arising preceding (p. = east of) oval BA. These events were explained and described up to the time of PJ26 in our BAA 2020 Report no.2 [ref.2]: direct link: https://www.britastro.org/node/21651

To summarise briefly: Oval BA is the only large anticyclonic oval in this domain, and always has a dark segment of STB f. it, called STB segment A; recently this has been short but turbulent. The STB Spectre

-- a long, low-contrast cyclonic circulation – has been the only other structured sector of the STB, and its p. end caught up with segment A at or shortly before PJ25. Ground-based images have not shown any change in this part of the STB Spectre, and we need to know whether its circulation has survived or shown any change. But since the collision, segment A has expanded and remained turbulent, and has emitted dark spots Np. it on the STBn jet and Sf. it on the STBs jet. Meanwhile, a new STB structured sector is expected to arise some distance p. oval BA, and ground-based images have recently revealed several candidate features. One, a streak now passing the GRS, was out of range of JunoCam, but another, a very dark spot, was in the closeup images at PJ26 (here labelled 'STB d.s.'). We are looking for any evidence that might suggest the initiation of a new structured sector, in particular, strong cyclonic circulation.

The PJ26 images cover most of the region of interest, and maps of them can be animated to show the wind patterns. Gerald has made hi-res maps of the individual images, and four pairs of these are blinked in Animations A to D, which overlap to cover the region of interest. Björn Jónsson has converted the images into a seamless hi-res map, which is used in Figure 12 (at reduced scale) to identify the features and to diagrammatically map the winds that are visualised in the animations.

In the animated maps, I especially looked for any signs of recirculation, i.e. flow in the N-S ('meridional') direction between the jets, indicating old or new structured sectors. I find them only in association with three visually prominent features: the STB dark spot; oval BA; and STB segment A. The p. end of the Spectre does not show any recirculation, so it may have dissipated since its collision with segment A.

In more detail: In Figure12, suspected sites of recirculation are marked with blue arrowheads – solid blue if confirmed by the animations, light-centred if not. In order of increasing longitude: (1) I had suspected cyclonic recirculation here (from ground-based images), but the animation shows there is none. (2) However, here we see evidence for anticyclonic recirculation; and the retrograde STBs jet curves around the STB dark spot and, from (3), it runs along an oblique boundary which shows rapid extension between the retrograde STBs jet and the prograde SSTBn jet. This is the same pattern that used to be seen south of the STB Ghost and Spectre where it bounded the anticyclonic 'recirculation loop'. Ground-based images show this boundary has stayed in the same relation to the dark spot throughout April [April 2-27, not shown]. (4) Here, at another oblique boundary, there is no evident deflection of the jets. **Oval BA** has rapid anticyclonic circulation internally, and it obviously deflects both the STBs and the SSTBn jets. On its f. side, Segment A is a FFR, and shows circulation at its p. end (5) and probably, weakly, at its f. end (6), although the winds in it appear to be weaker than in BA. Finally: (7) The p. end of the STB Spectre had arrived here, but there is no evidence for continuing recirculation in it, neither from the cloud textures nor from the animation. (Moreover: the Spectre has always been dark in methane images; the PJ26 methane map does show it still slightly dark at this end, but the latest ground-based methane images do not [April 17, M. Wong; April 24, A. Casely].)

The animations show clear internal circulation in the three principal features -- the STB dark spot, oval BA, and STB segment A – and will enable the wind speeds to be measured. (Our previous measurements of the rotation of oval BA were given in an Appendix to our report on PJ17.)

The STB dark spot has a distinctive appearance (Figure 11), although it has some similarity to dark brown cyclones seen in the northern mid-latitudes, e.g. in the N4 domain at PJ18 and PJ20. Its inner part consists of a lobed red-brown patch without spiral structure, surrounded by an incomplete oval outline of extremely dark streaks. Possibly the reddish cloud may be floating above a very dark deep oval. Outside this is a light collar, around which narrow spiral arms are tightly wound. The animation shows it rotating cyclonically, but is too short to reveal any relative motions internally. The wind speed appears to be comparable to the neighbouring jets.

To summarise, this dark spot is distinctive for the S. Temperate domain, and distorts the adjacent jets in the same way that the STB Ghost and Spectre did, with a potential recirculation loop on its S side. It could be an unusually deep circulation that will evolve into such a structured sector. However, it is too early to be sure of such an outcome.

High and mid-latitude southern domains

The images gave good views of S2-AWOs A7 and A8, and of S4-LRS-1 (Figure13).

S2 (S.S. Temperate) domain

The same maps (Figure 12) and animations (A-D) show fine details of structures in the S2 domain, including AWOs A7 and A8. The SSTB between them is a pale, closed cyclonic circulation (similar to the former STB Spectre). The retrograding jet along its S side traces out substantial waves.

South of STB segment A there is a small, very bright spot which looks like a new convective outbreak; will this develop into a FFR?* Almost due S of that, in the S4 domain, there is another such outbreak but bigger and brighter.

S4 domain

The very bright white, fish-shaped outbreak, at L3 ~ 134-141, is within a long pale fawn-coloured oblong (Figure 14), which seems likely to be a faded cyclonic circulation. This is confirmed in two ways:

i) Alignment of the maps from PJ24, PJ25 & PJ26 (Figure 14) shows that this oblong matches the position of a pair of 'barges' which were very dark at PJ24 and dark reddish at PJ25, so they probably merged and faded before PJ26. (Another single barge, at L3 = 246-257 at PJ24, also disappeared between PJ25 and PJ26, and a light red blur may mark its demise. Dark cyclonic features commonly turn reddish before fading away.)

ii) Animation of the PJ26 maps (Animation E) confirms that the fawn-coloured oblong is a cyclonic circulation. The bright white outbreak is near its f. end and shares the wind motions. Actually, the whole arrangement appears exactly like the STB Ghost on 2018 Feb.7 when a similar expanding convective outbreak was imaged by JunoCam at PJ11 and by amateur observers [refs.3 & 4]. At the p. end of the S4 oblong, there is also a smaller outbreak which also traces out the winds. As Gerald suggested, these outbreaks could well initiate the conversion of this oblong into a FFR (but see below)*.

Animation E also shows other interesting wind motions, including the anticyclonic circulation of S4-LRS-1 (at bottom right in the maps), and of a smaller AWO. The jets are obvious: the S4 jet is straight but the S5 jet is notably wavy.

**The bright outbreaks in S2 and S4 domains: ground-based follow-up:*

Despite their small size, the bright outbreaks in the S2 and S4 domains could both be followed in amateur images, but up to April 26, neither had produced any notable structure. A compilation of the best images from April 14 to 26 is in our Report no.3 [ref.1].

The S2 outbreak was followed by expanding small-scale bluish-grey granularity, perhaps an FFR but much smaller than some that are detected in this domain.

The S4 outbreak was apparently recorded as narrow white methane-bright streaks on April 14 (C. Go), but these did not evolve much thereafter – and did not differ much from the aspect previously. The reddish oblong was clearly visible as a bright reddish streak in all the south polar maps in Andy Casely's animation from April 7 to 14, [Report no.3 = ref.1], and was not notably brighter nor whiter after PJ26. Perhaps from the ground-based perspective it appeared brighter anyway than from Juno's more vertical perspective.

South Polar Region (SPR)

Figure 15(A-E) presents composite south polar projection maps made in our usual way. (Full-size, unlabelled versions of (A) and (D) can be provided on request.) An animation of three of the individual maps (Animation F) reveals the typical wind patterns very clearly; the most obvious are diagrammed in Figure 15(B). They include the S5 and S6 jets, and circulations in FFRs and in the CPCs.

60-75ºS:

The motions of the S5 and S6 jets are especially interesting, in relation to a high-amplitude wave at the edge of the South Polar Hood (SPH) that is visible in methane images both from JunoCam and from amateur observer Andy Casely, who pointed it out. [Report no.3= ref.1]

In our animated south polar maps (Animation F), the S5 jet is (as usual) not well shown, but where visible it runs exactly along the outer edge of the methane-dark South Polar Band at ~58ºS, although this does not coincide with a boundary in visible light. It is modestly deflected by an AWO.

The S6 jet is much better displayed, and (as usual) it has a wavy course which approximately, though not exactly, coincides with the waves on the edge of the methane-bright SPH. Around 2/3 of the circumference in the PJ26 map, the SPH edge has a mean wavelength of 26.6º longitude (Figure 15(D)). Between L3 ~ 100-140, the S6 jet traces waves of high amplitude (~4º latitude) which coincide with the largest waves in the SPH edge (Figure 15(B&C)). The latter were observed at even higher amplitude (~6º latitude) in Casely's ground-based methane images on April 12 and 14 [Report no.3 = ref.1].

The waves on the SPH edge have been characterised from Hubble and Cassini images [refs.5 & 6]. Those authors interpreted them as Rossby waves. They reported mean wavelengths of 26º-31º (i.e., wavenumber = 12-14), and phase speeds in the range 0 to +10 m/s [-50 deg/30d] relative to L3, the most reliable values being 2.3 (±1) m/s [-12 (±5) deg/30d]. Casely's alignment of maps from April 10-14 indicates a negative drift of ~1-2 deg/day, which is within the previously reported range. The high and increasing amplitude and the shape of the wave in the JunoCam maps suggests that it may be behaving as described from Hubble (1994) images [ref.5]: "When the meridional amplitude is large enough (≥4º), the wave seems to 'break' and bright material moves northward, resembling 'breaking episodes' seen in the Earth's planetary waves."

Two large AWOs are seen (Figure 15(A)). One has been tracked since 2015, and since PJ21 it has always been between ~71.5 and 73ºS, retrograding fairly steadily in L3. The other has been tracked since PJ20, and is brighter; since PJ21 it has been between 73 and 76ºS, and only retrogrades when at <74ºS. At PJ26 it is at 74ºS and has slightly prograded since PJ25.

Haze bands:

Few haze bands are visible in the SPR, although the usual series of images was taken and compiled into a map of near-terminator regions. Figure 15(E) is a diagram of the haze bands detected, whether bright or dark, regardless of their intensity. Most of them are faint narrow ones in the S5 domain, angled towards the powerful S6 jet as usual. Among these, two pairs of bright bands at dusk (in the lower right corner of the map) were the only conspicuous ones. South of the S6 jet, there were no substantial bands, although faint striations could represent ripples in the SPH.

Circumpolar cyclones (CPCs):

The composite south polar map (Figure 16, at full resolution) shows the central SPC (dimly) and four CPCs around it. The fifth CPC could be present but undetected because of the low contrast and resolution of the last images as the spacecraft receded. Although it seemed possible at PJ23 that the pentagon was turning into a hexagon, this did not last and the appearance now is similar to its usual state, despite some drift of individual cyclones. The CPCs seen include no.4, which is is still the largest and oval in shape, and nos.1 & 2, which have parted since PJ25 to reopen the gap in its original position opposite CPC-4.

The SPC was not visible at all in the earliest PJ26 images, because it was on the far side of the pole. The Sun now illuminates only 1.7º latitude beyond the pole, and the SPC is now centred 2.8º from the pole, as seen in outbound images. It has drifted further from the pole than ever before (Figure 17), though maintaining its usual oscillation in longitude.

References

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4. Iñurrigarro et al.(2020) 'Observations and numerical modelling of a convective disturbance in a large-scale cyclone in Jupiter's South Temperate Belt.' Icarus 336 no.113475.
5. Sanchez-Lavega A, Hueso R & Acarreta JR (1998) 'A system of circumpolar waves in Jupiter's stratosphere'. GRL 25, 4043-4046.
6. Barradi-Izagirre N, Sanchez-Lavega A, Perez-Hoyos S & Hueso R (2008) 'Jupiter's polar clouds and waves from Cassini and HST images: 1993-2006.' Icarus 194, 173-185.

Animations

All are made from maps produced by Gerald Eichstädt and animated by JHR. Some maps were slightly rescaled to minimise residual distortions.

A, B, C, D: Animations of four overlapping pairs of cylindrical maps centred on the South Temperate domain. (A) images 36 &40, 21.2 minutes apart (including the STB dark spot). (B) images 39 & 42, 23.6 minutes. (C) images 41 & 44, 30.2 minutes (including oval BA). (D) images 42 & 45, 30.2 minutes (including STB Segment A).

E: Animation of two cylindrical maps covering features in the S4 domain: the pale fawn-coloured oblong with white outbreaks, and S4-LRS-1. Images 42 & 45, 30.2 mins.

F: Animation of three south polar maps, down to 60ºS at the edges. Images 42 & 49, 60.3 minutes; images 49 & 56, 60.2 mins.

M: Shadow of Metis on the EZ: images 33 & 34, 2.5 minutes.

Figure legends

Figure 1. Images of the Galilean moons and the shadow of Metis.

Figure 2. Composite north polar projection map (down to 75ºN at the edges), showing the circumpolar cyclones.

Figure 3. Composite north polar projection maps, in both RGB and CH_4. (BZ = Bland Zone.)

Figure 4. Part of image 15, enhanced to show haze bands near terminator.

Figure 5. View of extensive FFRs in the N5 & N4 domains (north up)

Figure 6. Views of the NNTB FFR, in various projections by Gerald Eichstädt (with south up to maintain perspective). (A) Methane image 25, 'cleaned' of artefactual noise. (B) RGB images 24 & 26, reprojected and combined. (C) RGB image 26, adapted from draft version, with part of the limb enhanced and enlarged at left to show a bright haze layer.

Figure 7. Global cylindrical map. For further labelling of the S2 and S4 domains, see Figures 12 & 14. The inset (Figure 7B) is from a ground-based map of the NEB & EZ, longitude-shifted to match the time of perijove, adapted from our Report no.3 [ref.1].

Figure 8. Index images covering the NEB (from the 'version 01' images posted by the JunoCam team).

Figure 9. Part of image 32, showing the NEBs dark projection (D) and associated anticyclonic gyre (E) and festoons (F1, F2). There are mesoscale waves across large parts of the EZ. See main text for further description.

Figure 10. Part of image 33, showing mesoscale waves across most of the EZ.

Figure 11. Excerpt from a map showing the STropZ ring (upper) and the STB dark spot (lower).

Figure 12. Cylindrical map of the South Temperate domain (by Björn Jónsson, reproduced at reduced scale). Features are identified, and candidate sites of recirculation are marked with numbered blue arrowheads – solid blue if confirmed by animations, light-centred if not. Black arrows show diagrammatically the major jets and circulations displayed by animations A to D. Blue brackets at bottom indicate the sectors blinked in those animations. See main text for full details.

Figure 13. Part of image 40 showing three large anticyclonic ovals.

Figure 14. JunoCam maps of the S2 to S4 domains at PJ24, PJ25 and PJ26 (from our reports), aligned with a shift of -17º per perijove, showing possible evolution of features in the S4 domain.

Figure 15. Composite south polar projection maps.

Figure 16. Composite south polar projection map: the polygon of cyclones at full resolution.

Figure 17. Position of the centre of the South Polar Cyclone at PJ21 to PJ26, relative to the south pole.